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Expert Consensus on Buffer Zone Governance: Interface Concepts, Ecosystem Service Priorities, and Territorial Strategies Around Cerro Castillo National Park, Chile

Trace Gale [1,2,*], Emilia Astorga [1,3], Andrés Adiego [1,4] and Andrea Báez-Montenegro [1,5]

[1] Centro de Investigación en Ecosistemas de la Patagonia (CIEP), Coyhaique 5951601, Chile; astorgem@oregonstate.edu (E.A.); andres.adiego@ciep.cl (A.A.); abaez@uach.cl (A.B.-M.)
[2] Cape Horn International Center (CHIC), O'Higgins 310, Cabo de Hornos 6350000, Chile
[3] Fisheries, Wildlife and Conservation Science, Human Dimensions Lab, Oregon State University, 2820 SW Campus Way, Corvallis, OR 97331, USA
[4] Department of Geography and Territorial Planning, Universidad de Zaragoza, Calle Pedro Cerbuna 12, 50009 Zaragoza, Spain
[5] Institute of Statistics, Los Laureles 35 Interior, Universidad Austral de Chile (UACh), Campus Isla Teja, Valdivia 5110027, Chile
* Correspondence: tracegale@ciep.cl; Tel.: +56-09-8955-6032

Abstract

Buffer zones around protected areas (PA) face complex governance challenges as territorial transitions accelerate globally, yet limited consensus exists on their definition, ecosystem service (ES) priorities, and management strategies. This study employed a three-round Delphi methodology with 23 transdisciplinary experts to build consensus on buffer zone governance around Cerro Castillo National Park in Chilean Patagonia, using the IPBES ecosystem services framework to structure the analysis. Round 1 employed open-ended questions to explore expert perspectives, Round 2 evaluated 56 statements and 15 strategic components using structured questionnaires, and Round 3 refined non-consensus items. Experts achieved 76.7% overall consensus across three thematic areas: PA interface conceptualization (79.2% consensus on 24 statements), ES assessment (91.2% consensus on 34 statements), and territorial transition strategies (15 components evaluated). Water-related services achieved unanimous agreement across multiple IPBES categories, revealing their potential as boundary objects bridging conservation and development perspectives. Educational approaches and voluntary compliance emerged as high-feasibility strategic components, while regulatory frameworks showed high importance but implementation uncertainty. The study demonstrates that structured expert consultation can identify collaborative pathways for buffer zone governance, with water services providing concrete entry points for multi-stakeholder cooperation and education-based strategies offering promising implementation pathways for sustainable territorial transitions.

Keywords: buffer zones; ecosystem services; IPBES framework; Delphi method; protected areas; territorial transition; conservation governance; Chile; Patagonia

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1. Introduction

The Kunming-Montreal Global Biodiversity Framework (GBF) represents a paradigm shift in conservation thinking, recognizing that effective biodiversity protection must extend beyond protected area (PA) boundaries to encompass surrounding landscapes [1]. Target 3 of the GBF calls for conserving 30% of terrestrial and marine areas by 2030,

explicitly acknowledging that traditional PA models alone cannot achieve global conservation goals [1,2]. Recognition of these limitations has intensified focus on buffer zones—transitional areas between strictly protected cores and human-dominated landscapes—as critical components of landscape-scale conservation strategies [2,3].

Buffer zones serve multiple functions that align closely with the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) conceptual framework: they provide habitat connectivity for wildlife movement (supporting services), filter external threats to PA (regulating services), offer opportunities for sustainable resource use by local communities (provisioning services), and maintain cultural values and recreational opportunities (cultural services) [4–6]. The IPBES framework provides a comprehensive structure for understanding these multiple functions and their interconnections, facilitating evidence-based decision-making in complex socio-ecological systems [7].

However, the conceptualization, delimitation, and governance of buffer zones remain contentious issues that intersect conservation science, land use planning, and socioeconomic development [1,8]. The challenge is particularly acute in regions experiencing rapid land use transitions, where amenity migration, tourism development, and changing agricultural practices create complex pressures on both PA and surrounding landscapes [1]. Understanding these dynamics through the IPBES framework can help identify priority ecosystem services (ESs) and develop targeted governance strategies [7].

Chile's PA system faces these challenges acutely, particularly in Patagonian regions, where rural land transitions have accelerated over the past decade [9,10]. With over 50% of the Aysén Region under some form of protection, the interface between protected and private lands represents a critical frontier for conservation innovation [11,12]. Cerro Castillo National Park (CCNP), established as a reserve in 1970 and redesignated as a national park in 2018, exemplifies these dynamics. From the time leading up to redesignation to the present day, the area surrounding CCNP has experienced accelerated land subdivision, with research indicating that 37.5% of private properties within a 10 km radius have undergone division between 2011 and 2023 [13].

Rapid territorial transition has generated what conservation scientists term "wicked problems"—complex, multi-dimensional challenges that resist simple solutions and involve multiple stakeholders with divergent values and interests [14–16]. Traditional approaches to buffer zone management, often imposed through top-down regulatory frameworks, have proven inadequate for addressing these complex socio-ecological dynamics [17,18]. Instead, researchers increasingly advocate for collaborative governance approaches that integrate diverse forms of knowledge and build consensus among stakeholders, particularly as studies suggest that local contextual factors and unequal participation patterns can significantly affect PA governance decisions [19–21].

Despite growing recognition of the importance of buffer zones, three critical knowledge gaps persist. First, limited consensus exists on how buffer zones should be defined and delimited, with various international frameworks proposing different criteria [22,23]. Second, while the IPBES framework provides a comprehensive structure for linking conservation and development objectives, consensus on priority services in buffer zone contexts remains unclear [24,25]. Third, effective strategies for managing territorial transitions in buffer zones lack empirical validation and stakeholder endorsement [26,27].

The Delphi method offers a valuable approach for addressing these knowledge gaps by systematically building consensus among experts while preserving space for divergent perspectives [28]. Originally developed for technological forecasting, the Delphi method has proven effective for addressing complex environmental governance challenges where traditional research methods may be insufficient [29,30]. Its iterative structure allows for

the refinement of ideas through multiple rounds while maintaining participant anonymity, reducing the influence of dominant voices, and encouraging open dialogue [31,32].

We employed a three-round Delphi methodology to investigate expert perspectives on buffer zone governance around CCNP, using the IPBES framework to structure ES analysis and interpretation. Three core research questions guide the investigation:

1. How did the expert community conceptualize PA–landscape interfaces, and what patterns of agreement emerged across different dimensions of this conceptualization?
2. What are the critical ES that PA and their buffer zones must protect, as categorized by the IPBES framework?
3. What constitutes an effective territorial transition strategy for sustainable development around PA?

Findings contribute to both theoretical understanding of buffer zone governance and practical policy frameworks for managing PA interfaces in rapidly changing landscapes.

2. Materials and Methods

2.1. Study Area

CCNP is located in the Aysén Region of Chilean Patagonia, covering 143,502 hectares of subantarctic ecosystems, including glaciers, mountains, forests, and wetlands (Figure 1). The park protects critical habitat for endangered species, such as the huemul (*Hippocamelus bisulcus*), and serves as the headwater for two major regional watersheds: the Baker and Aysén Rivers [33].

The Aysén Region represents one of Chile's most sparsely populated areas, with demographic patterns characteristic of remote Patagonian settlements [34]. According to the 2017 Chilean Census, the region around CCNP exhibits a classic center–periphery settlement structure, with the regional capital of Coyhaique serving as the primary urban hub for a constellation of small rural communities scattered throughout the surrounding landscape [34,35].

Coyhaique, situated 57 km from CCNP, is the largest settlement in the area, with a population of 49,667 residents (24,166 men and 25,501 women) distributed across 18,848 households according to the 2017 census. The city functions as the administrative, commercial, and service center for the broader region [34,35]. In contrast, smaller settlements directly adjacent to the park demonstrate the rural character typical of Patagonian communities. Villa Cerro Castillo, positioned just 5 km from the park and serving as the primary gateway community, maintains a population of approximately 500 residents and represents the heart of the park's "frontside", the easily accessible eastern sector reachable from the main Carretera Austral highway [35,36]. Other nearby communities include Puerto Ingeniero Ibáñez (30 km from CCNP, population 757), Balmaceda (35 km, population 456), El Blanco (20 km, population 305), and dispersed rural populations near Lago Monreal, Lago La Paloma, and Villa Frei [35].

The birth sex distribution across these communities generally reflects a demographic balance, with minor variations that may indicate local economic specializations [34]. The settlement hierarchy and population distribution reflect an economy increasingly influenced by tourism development, alongside traditional activities. The area surrounding CCNP has traditionally supported extensive livestock grazing, forestry, and small-scale agriculture. However, recent decades have witnessed significant land use transitions driven by property fragmentation resulting from inheritance, changing economic conditions, tourism growth, and amenity migration [35–37].

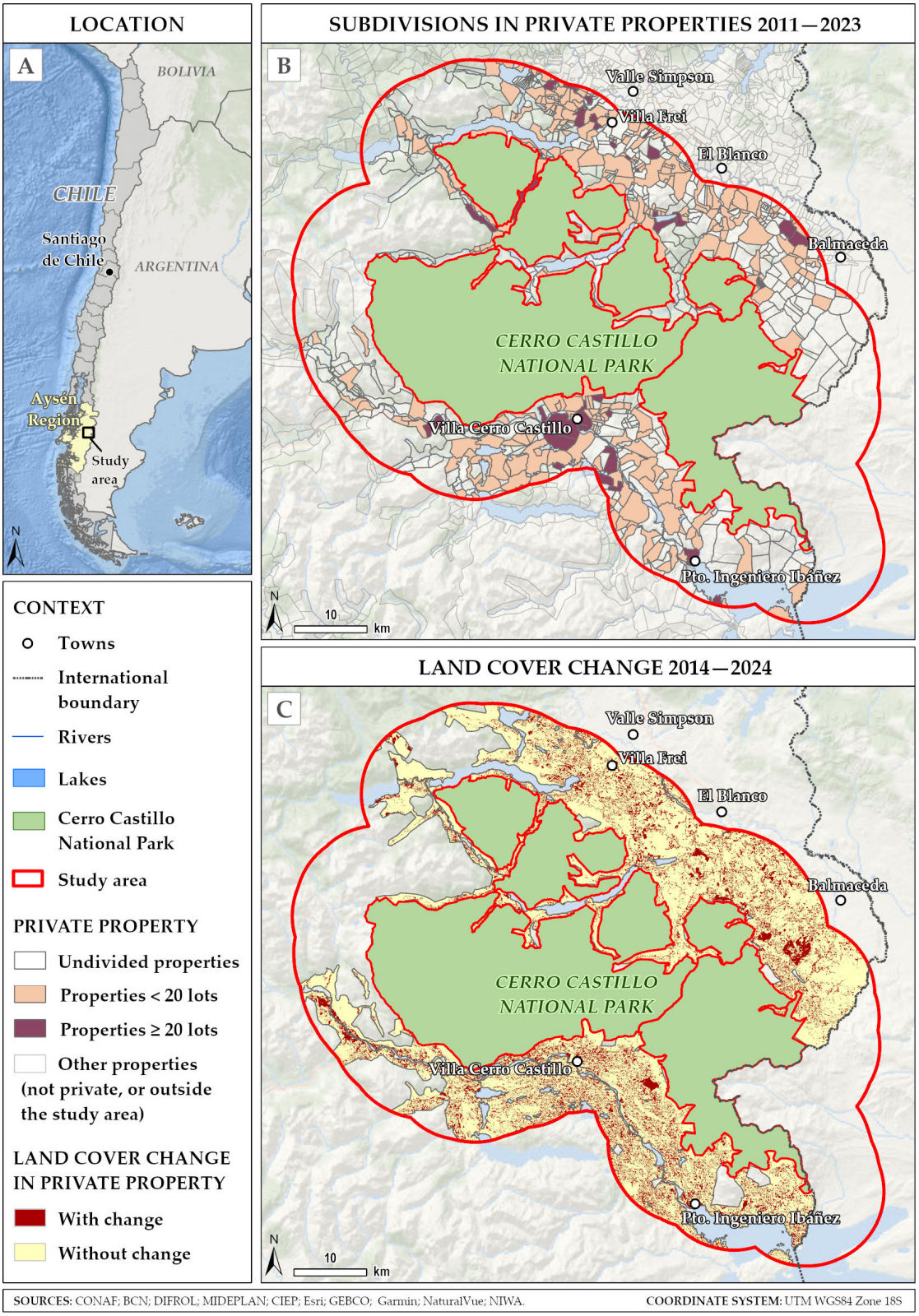

Figure 1. (**A**): Study area location. (**B**): Subdivisions in private properties during 2011–2023. (**C**): Land cover change during 2014–2024.

Primary livelihood activities in the gateway community of Villa Cerro Castillo include ranching, tourism, commerce, and public services, while the park's "backside"—the western sector accessed by rough dirt roads—supports isolated rural farms and tourism lodges in the Monreal, Paloma, and Desierto lake sectors [35]. The dramatic growth in park visitation, though modest in absolute terms, increased by 733% between 2007 and 2016 (from 613 to 5149 annual visitors), indicating the region's transition toward a tourism-based economy that complements traditional rural livelihoods [35].

This economic transformation is paralleled by accelerated land subdivision within the study area. Between 2011 and 2023, subdivision activity intensified dramatically within a 10 km radius of CCNP, with 304 of the original 810 private properties (37.5%) undergoing division, resulting in 3237 new land parcels. The subdivided properties encompass 68,267 hectares, representing 43.7% of the total private property area within the buffer zone. The intensity of fragmentation varies considerably, with subdivision patterns ranging from 2 to 207 divisions per original property, averaging 21.7 divisions per subdivided property [13].

Concurrent with land subdivision, the study area has experienced significant land cover changes between 2014 and 2024. Satellite image analysis reveals substantial transformations within private properties, with native forest coverage expanding from 51,320 to 56,480 hectares (a 10.1% increase), urban areas growing dramatically from 63.3 to 159.6 hectares (a 152.2% increase), and exotic forest plantations experiencing explosive growth from 978.1 to 3370.8 hectares (a 244.6% increase) [13].

These observed land cover transitions reflect the cumulative effects of historical environmental disturbances, economic transitions, and evolving conservation policies spanning several decades [38–42]. Extensive anthropogenic fires throughout the 20th century, driven by land-clearing practices encouraged by early colonization laws, such as the "Austral Property Constitution Law," devastated approximately 3 million hectares across the Aysén Region, transforming contiguous old-growth Nothofagus pumilio forests into a mosaic of land cover types [38–40]. The 1991 Hudson Volcano eruption further contributed to environmental disruption and the decline of traditional livestock ranching in the region [42,43].

Contemporary forest patterns reflect complex interactions between natural recovery processes and policy-driven restoration initiatives within a transformed regulatory framework [44,45]. Native forest regrowth can be attributed to natural succession following volcanic and fire disturbances, abandonment of agricultural or grazing lands, and recent native species reforestation efforts associated with conservation and sustainable tourism [37,41,42,45]. The dramatic increase in exotic plantations results from multiple post-disturbance interventions, including commercial forestry companies acquiring damaged lands at reduced prices following the volcanic eruption and government erosion prevention programs in the 1960s–1970s that promoted afforestation using fast-growing non-native coniferous species, including *Pinus contorta*, *P. sylvestris*, and *P. ponderosa*, which are now reaching maturity [41–43].

Parallel to environmental disturbances, significant shifts in economic and conservation priorities have fundamentally altered the region's development trajectory, further impacting land use patterns [35,37,38,46]. Chile's National Tourism Law No. 20.423 [47] recognized tourism as a strategic pillar for economic development in rural communities, prioritizing tourism concessions within protected areas and transferring decision-making authority from forest management agencies to tourism-focused ministries [35,37]. The 2014 Special Development Plan for Extreme Zones (PEDZE) allocated over USD 700 million to Aysén for tourism infrastructure development, while the elevation of the Cerro Castillo protected area from National Reserve to National Park status in 2017 created the highest level of protection and significantly increased national attention as a tourism

destination. These policy changes, combined with the 2017 creation of the Network of National Parks of Chilean Patagonia through the Tompkins Conservation donation, fundamentally repositioned the region from extractive resource use toward conservation-based development, including tourism development, amenity-based migration, and property investment [35–37,46,48]. Consequently, the observed urban expansion likely corresponds with recent amenity migration and tourism development pressures facilitated by these policy transformations [10,17].

Accelerated subdivision trends and parallel land cover changes have created complex governance challenges involving multiple stakeholders, including Chile's Ministry of the Environment, the Chilean National Forestry Corporation (CONAF), as administrators of Chile's public PA, municipal and regional governments, private landowners, tourism operators, real estate developers, and conservation organizations, amongst others [44,46]. The diversity of actors and interests makes the CCNP interface an ideal setting for investigating consensus-building approaches to buffer zone governance using the IPBES framework [49].

2.2. Research Design

A three-round Delphi methodology was conducted between October 2023 and March 2024. The Delphi method is a structured communication technique designed to build consensus among experts through iterative questionnaires with controlled feedback [30]. Ethics approval was obtained from the Chilean certified university ethics committee associated with the co-researchers' affiliations (I.R.I. No 11-2023).

2.2.1. Expert Panel Selection

The expert panel comprised 23 participants selected through purposive and snowball sampling to ensure transdisciplinary representation across conservation science, policy, and practice domains [50]. Our sampling strategy prioritized expertise and regional knowledge rather than demographic representation, following established Delphi methodology guidelines [27,29,50,51]. Inclusion criteria required a minimum of five years of experience in conservation within the Aysén Region, interpreted broadly to encompass ecological or nature conservation (biodiversity protection, ecosystem management, and environmental restoration), cultural or heritage conservation (historical preservation, traditional knowledge systems, and community identity maintenance), and biocultural conservation (integrated approaches linking cultural practices with ecosystem stewardship). Participants demonstrated expertise in one or more relevant domains: PA management, ecological research, community engagement, local knowledge and practices, policy development, or tourism planning (see Appendix A.1).

Panel composition included 14 males and 9 females across four age groups: 30–39 years (n = 3), 40–49 years (n = 10), 50–59 years (n = 6), and 60–70 years (n = 4). Geographic representation was primarily regional, with 19 participants from the Aysén Region and additional experts from the Chilean regions of Los Lagos (n = 1), Biobío (n = 1), and Magallanes (n = 2), ensuring both local knowledge and external perspective integration. Our 23-expert panel size aligns with established Delphi methodology guidelines, suggesting optimal sizes of 10–50 participants for heterogeneous expert groups, with 20–30 experts providing sufficient diversity for complex environmental governance topics while maintaining manageable consensus-building processes [29–31,49,51].

For analytical purposes, we organized the 23 experts into four functional categories based on their primary professional roles, though we acknowledge substantial overlap between categories (Table 1). These categories—"PA Administration", "Ecological Researchers", "Community Practitioners and Educators", and "Tourism and Development Professionals"—were identified post hoc to illustrate the breadth of expertise rather than

as rigid classifications. This categorization emerged from recognizing that effective buffer zone governance requires integration of regulatory authority (administrators), scientific evidence (researchers), local knowledge and social dynamics (community practitioners), and economic development perspectives (tourism/development professionals) [19,27].

Table 1. Transdisciplinary expert contributions across research questions (RQ).

Expert category	*n*	RQ1: Protected Area (PA)–Landscape Interface Conceptualization	RQ2: Ecosystem Service (ES) Priorities	RQ3: Territorial Transition Strategies
PA administration	4	Practical boundary management experience; enforcement challenges; visitor-use patterns	Direct ES management; conservation-use trade-offs; monitoring data	Policy implementation feasibility; compliance mechanisms; institutional capacity
Ecological researchers	8	Landscape connectivity; edge effects; spatial ecological processes	Biodiversity assessment; regulating service quantification; climate impacts	Evidence-based interventions; monitoring frameworks; adaptive management
Community practitioners and educators	7	Local knowledge of land use; cultural boundaries; community needs	Cultural service valuation; traditional practices; educational services	Bottom-up strategies; voluntary compliance; social learning processes
Tourism and development professionals	4	Gateway community dynamics; amenity migration patterns; land subdivision drivers	Recreation services; economic valuation; tourism–conservation synergies	Private sector engagement; economic incentives; sustainable development models

The study achieved complete participant retention, with all 23 experts participating in each of the three Delphi rounds (100% retention rate). This eliminated concerns about attrition bias and ensured that consensus patterns reflected the consistent perspectives of the same expert panel throughout the iterative process. The panel achieved theoretical saturation in Round 1 qualitative responses, suggesting adequate representation of relevant perspectives.

In transdisciplinary Delphi studies, experts contribute holistic perspectives across all research dimensions rather than being assigned to specific questions [27,29,50,51]. This cross-cutting expertise is precisely why we selected a unified transdisciplinary panel rather than separate panels for each research question. For example, the veterinarian promoting sustainable livestock practices offers insights on boundary definitions through grazing zone delineation, ES through livestock–wildlife interactions and cultural ranching practices, and transition strategies through voluntary compliance mechanisms. Similarly, the tourism company co-founder contributes to interface conceptualization through gateway community dynamics, ES priorities through recreation and cultural values, and governance strategies through private sector engagement. Table 1 illustrates how different expert categories contribute across all three research questions, demonstrating the value of transdisciplinary integration.

The panel's expertise reflected critical conservation challenges in the region, with particular depth in huemul conservation, biodiversity research, ES assessment, glacial system monitoring, invasive species management, fire ecology, cultural heritage, local agricultural and ranching practices, local government and governance, and sustainable tourism development. Many participants demonstrated multi-decade commitment to regional conservation, with experience ranging from 7 to 38 years in Patagonian ecosystem and rural community management.

The interdisciplinary composition was essential given the buffer zone governance's inherently cross-sectoral nature. Chambers et al. [27] demonstrated that sustainability transformations require "co-productive agility" across knowledge domains, which our panel composition appears to have achieved. Environmental governance challenges, particularly in PA interfaces, cannot be adequately addressed through single-discipline perspectives [12]. Our panel's diversity (PA administrators, ecological researchers, community practitioners, and tourism professionals) mirrors the multiple stakeholder groups whose cooperation is essential for effective buffer zone management. This aligns with IPBES guidance on integrating diverse knowledge systems for complex socio-ecological assessments [7].

2.2.2. Data Collection Process

An open-ended questionnaire with 15 questions was administered in Round 1 to explore participant perspectives on buffer zone characteristics, ES provided by CCNP and its surrounding area, potential impacts of land subdivision, and strategies for sustainable territorial transition (STT; see Appendix A.2). Questions were designed to elicit detailed qualitative responses without constraining participant perspectives.

Following established qualitative analysis protocols [52] and the Delphi methodology guidelines [28,53], 56 statements were generated through a rigorous multi-stage thematic analysis process designed to ensure coding reliability and methodological rigor. First, a preliminary coding framework was developed based on the research objectives and the existing literature. Two independent researchers then conducted initial coding of all Round 1 responses using this framework. To assess coding reliability, inter-rater agreement was calculated for the complete dataset, achieving 85% agreement using the percentage agreement method [54]. Additionally, a subset of 25% of responses underwent double-coding as a quality control measure. Coding discrepancies were systematically documented and resolved through structured discussion sessions until consensus was reached, with the coding framework refined iteratively throughout this process [54].

Following collaborative theme development and statement refinement, this rigorous analytical process generated both the 56 structured statements for Round 2 assessment and a set of 15 STT components representing potential territorial transition pathways over a 10-year horizon. These components emerged from systematic identification of key governance challenges, policy interventions, and community-based solutions that appeared consistently across Round 1 responses, ensuring that the final statements accurately reflected the full range of expert perspectives while maintaining analytical rigor.

In Round 2, informed by the Millennium Ecosystem Assessment (MEA) and the IPBES ES frameworks [7,24], the 56 statements emerging from the thematic analysis of Round 1 responses were organized within a structured questionnaire across four thematic areas: buffer zone general concepts and definitions (7 statements), buffer zone criteria (9 items), ES (34 statements), and overall concepts related to territorial transition strategies (6 statements).

Participants rated their agreement with each statement using a 6-point Likert scale (1 = strongly disagree, 6 = strongly agree). Additionally, participants evaluated the 15 strategy components derived from Round 1 using dual assessment criteria: importance for achieving STTs (1–7 scale, where 1 = not at all important, and 7 = extremely important) and probability of occurrence over a 10-year horizon (0–100%, where 0 = no possibility of occurrence, and 100% = certain to occur).

Round 3 focused on the validation and refinement of statements that did not achieve consensus in Round 2. Thirty-eight of the 56 original statements (67.9%) achieved the 75% high consensus threshold after Round 2. The remaining 18 statements (32.1%) were systematically refined based on participant feedback. Eight statements were modified for

Round 3 (WATER_3; FAUNA_2; CULTURE_5; CULTURE_11; CULTURE_12; CULTURE_15; CULTURE_16; and CULTURE_18); and 9 statements (DEFINE_1, CRITERIA_2, CRITERIA_3, CRITERIA_4, CRITERIA_6, CRITERIA_7, CRITERIA_8, FAUNA_2, CULTURE_17, and TRANSTER_4) were resubmitted unchanged to assess whether continued dialogue might achieve consensus. Two new statements were developed addressing Chilean Biodiversity and Protected Areas Service (SBAP) legislation (DEFINE_3) and buffer zone criteria adequacy (CRITERIA_10). Participants also reviewed group-level results from Round 2, including both statement consensus patterns and component assessment outcomes, confirming their levels of agreement with the probabilities and importance levels that had been defined and providing additional reflections on STT priorities.

2.2.3. IPBES Framework Integration

The ES question in the Round 1 interviews provided participants with visual prompts for both the MEA ES framework and IPBES Nature's Contributions to People classification (See Appendix A.2). We asked participants to observe these frameworks and reflect on contributions provided by Cerro Castillo National Park, identifying those they consider vital for guaranteeing human well-being around the park and achieving the park's conservation objectives. As Round 1 responses were coded and Round 2 affirmations emerged, the IPBES framework was selected over alternative classification systems (e.g., MEA or CICES) for the organization of the ES items for several theoretical and practical considerations [7,55]. Unlike the MEA's anthropocentric focus on services to humans, the IPBES framework adopts a more holistic approach that integrates nature's contributions to people (NCPs) with cultural and relational values [5]. This broader conceptualization was deemed more appropriate for the buffer zone context, where Indigenous and local community perspectives on nature–society relationships are critical [6]. Additionally, the IPBES framework's explicit inclusion of context-specific cultural ES better captures the transdisciplinary perspectives of our expert panel and the Patagonian study area, where traditional land uses intersect with conservation objectives. Provisioning ES encompass material and energy outputs from ecosystems (water supply, food, raw materials, and genetic resources). Regulating ES include the regulation of environmental conditions (water purification, climate regulation, biological control, and habitat connectivity). Cultural ES comprise non-material benefits from ecosystems (recreation, spiritual values, education, and cultural heritage). Supporting ES represent basic ecosystem processes that maintain other services (biodiversity maintenance, ecosystem connectivity, and habitat provision). The IPBES framework provided a systematic structure for classifying the transdisciplinary responses of Delphi group participants. This approach enabled participants to reflect on and build consensus around the technical aspects of ES based on their own ways of knowing and relating to nature and its contributions to people while analyzing ES priorities and their relevance to buffer zone governance.

2.3. Data Analysis

Round 1 data was analyzed using thematic coding with triangulation among research team members to enhance reliability [55,56]. Quantitative analysis of Rounds 2 and 3 employed descriptive statistics and consensus analysis using RStudio 2025.05.1+513.

Following established Delphi methodology standards, consensus was defined as 75% of participants rating items within the upper two points (ratings 5–6) or lower two points (ratings 1–2) of the 6-point Likert scale, representing agreement or disagreement consensus, respectively. This threshold was selected based on systematic evidence from environmental governance and conservation Delphi studies. Diamond et al. [30] demonstrated that percentage agreement at scale extremes represents the most common consensus definition.

Von Der Gracht [57] found 70–80% thresholds to be standard in environmental research, with 75% balancing inclusivity and rigor. Mukherjee et al. [29] specifically noted that heterogeneous expert panels in ecology and conservation typically employ 70–75% thresholds to account for disciplinary diversity. Our selection aligns with these established precedents while being conservative enough to ensure meaningful agreement.

In Round 2, all 56 statements were evaluated by 23 expert participants. The 38 statements achieving consensus required no further assessment, while those lacking consensus were systematically refined for Round 3 evaluation. The dataset structure reflects this process: statements achieving Round 2 consensus or new statements added in Round 3 for the first time show $n = 23$ (single round data), while statements requiring Round 3 refinement show $n = 46$, representing sequential data collection from the same 23 participants across both rounds. For each of the three Round 2 statements that were combined into a single Round 3 statement, we maintained the entire $n = 46$ data structure to be able to analyze consensus change trends between the rounds. Statement refinement for Round 3 addressed four primary expert concerns: (1) requests for a stronger empirical evidence base, (2) a need for scientific baselines before definitive impact assessments, (3) clarification of cultural context and traditional practices, and (4) consolidation of related statements for conceptual clarity.

For the territorial transition strategic components, all components were evaluated in Round 2 by 23 participants using dual assessment criteria: importance (1–7 scale) and probability of occurrence (0–100%). For probability assessments, we calculated the feasibility consensus (FC) range using a percentile-based approach that captures the central 70% of expert responses (15th to 85th percentile), effectively excluding the most extreme 15% of responses on each end of the distribution. This method identifies the range where approximately 75% of expert opinions converge while filtering out outlier assessments that may not represent a realistic consensus [30,58].

For importance assessments, consensus was determined using the established 75% agreement threshold within the upper two consecutive points on the 1–7 scale [30]. We calculated additional metrics, including (1) Range Span—the numerical difference between the FC range boundaries (smaller values indicating tighter consensus), (2) Participant Coverage—the percentage of expert responses falling within the FC range, and (3) FC Efficiency—a composite measure combining participation breadth with estimate precision (Coverage% ÷ Span).

These variables were combined to establish a tightness score representing a composite metric for prioritization and resource allocation decisions, calculated as:

$$\text{Tightness Score} = (\text{Importance} \times \text{Consensus} \times \text{Efficiency}) \div 2000$$

The scaling factor of 2000 was determined through systematic calibration to present scores within a practical 2–5 range for decision-making purposes [57,59]. Given our variable ranges (importance: 1–7, consensus: 0–1, efficiency: varies based on coverage/span ratios), this scaling factor (1) prevents score compression at the lower end, (2) maintains meaningful differentiation between components, and (3) produces interpretable values consistent with established composite scoring approaches in multi-criteria decision analysis [7]. The scaling factor serves as a presentation tool and does not affect the relative ranking of components.

2.4. Ethical Considerations

All data collection followed informed consent protocols with participant anonymity maintained throughout the process. Prior to participation, all experts received detailed information about the study objectives, procedures, and their rights as participants. Informed consent was obtained from all participants through signed consent forms that explained the voluntary nature of participation, the right to withdraw at any time without penalty, confidentiality protections, and data storage procedures. Participants were informed that they could contact the institutional Ethics Committee for Human Research for any questions or concerns regarding the research process. Participants could withdraw at any time, and data storage followed institutional guidelines for confidential research data [60].

2.5. Use of Generative Artificial Intelligence (AI)

The authors of this paper speak three different native languages. To facilitate effective collaboration during the research process, AI translation tools like DeepL Pro were used in early drafts of the manuscript to bridge between languages. All machine translation was reviewed and adapted by the authors. During manuscript preparation, Claude AI (Anthropic) was used to assist with organizing expert-generated content, generated in multiple languages, into coherent thematic categories for presentation in English. The AI also assisted with manuscript organization, thematic structuring of discussion sections around the three research questions, and reference formatting during the writing process. All study design, data collection, analysis, and interpretation, including graphics development, were conducted entirely by the research team without AI assistance. The AI did not generate any research content, data, or analytical interpretations.

3. Results

3.1. Overall Consensus Patterns and Iterative Refinement Process

During the three-round Delphi process, experts systematically evaluated and worked toward achieving consensus on 73 concept statements across three thematic areas (Figure 2). The iterative nature of the Delphi method allowed participants to refine their assessments and build consensus progressively, with statements continuing to evolve through successive rounds. First, experts developed a conceptual framework for PA interfaces, beginning with 22 original statements in Round 1 and incorporating two additional statements that emerged during Round 2. The collaborative refinement process ultimately yielded consensus on 18 of 24 total statements (75%). Second, participants examined ES provided by CCNP and its surrounding landscape, alongside potential impacts from accelerated subdivision pressures. The 34 original statements in this category achieved the highest overall consensus rate, with 31 statements (91.2%) reaching agreement by Round 3. Third, experts evaluated 15 STT components for PA interface areas, rating both importance for success and probability of occurrence over the next decade to identify priority intervention areas. The composite results demonstrate substantial expert agreement across all thematic areas, with 56 of 73 statements (76.7%) ultimately achieving consensus.

3.2. Protected Area Interface Conceptual Statements and Consensus Patterns

Twenty-four statements emerged across four thematic categories, achieving an overall consensus rate of 79.2% (Figure 3). Consensus patterns revealed stronger agreement on broad conceptual principles than on specific technical criteria. The five non-consensus statements: “planning deficiencies impacting ES provision” (S8, 43%), “ES provision radius” (S13, 57%), “soil integrity maintenance” (S17, 70%), “public access management” (S19, 52%), and three-criteria sufficiency: wildlife habitat, watershed continuity, biological corridors” (S21, 74%) shared common characteristics: they involved quantitative thresholds,

operational definitions, or technical specifications requiring additional empirical validation. Conversely, statements achieving the highest consensus levels (>90%) emphasized fundamental relationships between PA and their surrounding landscapes.

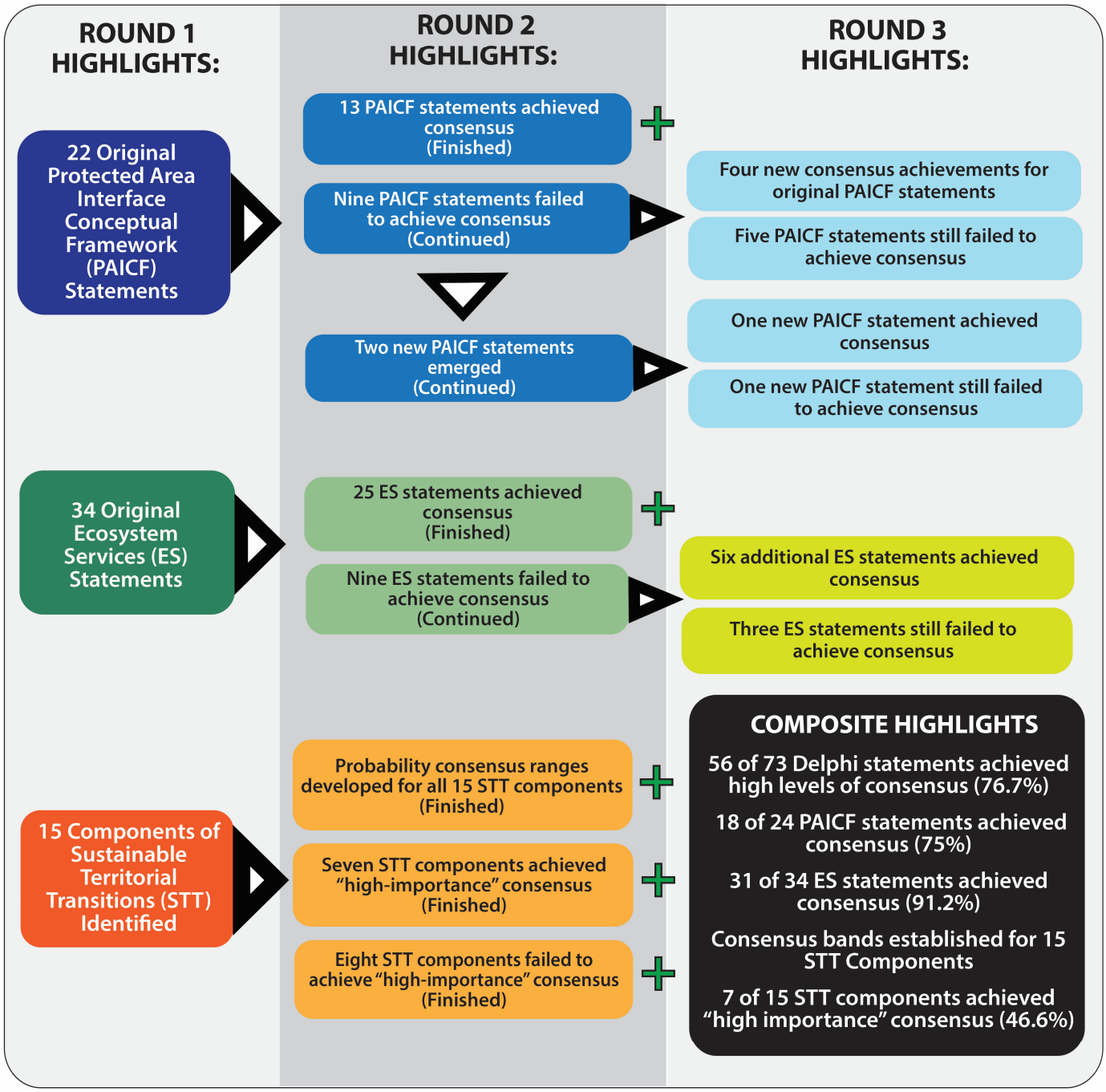

Figure 2. Delphi process flow and consensus outcomes.

3.3. Ecosystem Services Assessment

Expert evaluation of 34 ES statements yielded a consensus rate of 91.2% (31 of 34 statements), with 25 statements achieving consensus during Round 2 (Figure 4). Only three ES statements failed to reach the 75% consensus threshold: "traditional fire practices" (CULTURE_11, 57%), "biocultural conservation benefits" (CULTURE_17, 48%), and "genetic material supply and biodiversity" (FAUNA_2, 74%). Supporting ES achieved consensus for four out of five statements, with the fifth, "genetic material supply and biodiversity"

(FAUNA_2) falling just one point short. Provisioning ES reached consensus on all four statements, with "water supply from glaciers and snow deposits" (WATER_1) achieving 100% consensus and "non-wood forest products supply" (FLORA_1) achieving 78%. All nine regulating ES statements achieved consensus, with levels ranging from 78% to 100%. Four statements, "water quality and ecosystem regulation" (WATER_2), "biological corridor regulation" (FAUNA_3), "native fauna displacement control" (FAUNA 4), and "fire and forest management and regulation" (CULTURE_13), achieved consensus levels above 90%. Cultural ES showed the most variation, with consensus levels ranging from 48% to 100%. Fourteen of the 16 statements achieved consensus, with unanimous agreement around the importance of PNCC as an outdoor classroom for educational services (CULTURE_8, 100%). Two other statements achieved consensus rates of 91%, including CULTURE_2, which addressed the heritage value of the PNCC, and CULTURE_5, which addressed the gender differences in PNCC ES. The lowest performing cultural ES statements included "cultural fire practices; traditional uses" (CULTURE_11, 57%) and "biocultural conservation benefits of subdivision" (CULTURE_17, 48%), which did not achieve the consensus thresholds. Of the six statements that achieved consensus during Round 3, five were from the cultural ES category. Expert consensus on water-related ES was exceptionally strong, with all four statements achieving agreement thresholds. Among provisioning ES, "water supply from glaciers and snow deposits" (WATER_1) reached unanimous consensus (100%). Water-related regulating ES also demonstrated high agreement levels: "water quality and ecosystem regulation" (WATER_2, 96%), "groundwater contamination regulation" (WATER_3, 83%), and "aquifer vulnerability and pollution control" (WATER_4, 78%).

3.4. Building Blocks for a Sustainable Territorial Transition Strategy

Round 2 assessment of the 15 STT components proposed by participants during Round 1 revealed hierarchical importance preferences and varying consensus levels around high-priority interventions (Figure 5). The mean importance score for the 15 components was 6.2, with a range from 5.6 to 6.7. The "national legislation" (A) and "environmental education" (E) components achieved the highest importance ratings of the group, with both achieving a mean rating of 6.7. These were followed by the "land use planning" (B) and "pro-environmental behavior" (F) components, which were both rated with mean values of 6.6. Consensus was reached around the importance ratings for 7 of the 15 STT components: "national legislation" (A, $\bar{x}$ = 6.7, 96%), "land use planning" (B, $\bar{x}$ = 6.6, 83%), "new CCNP management plan" (D, $\bar{x}$ = 6.3, 78%), "environmental education" (E, $\bar{x}$ = 6.7, 91%), "pro-environmental behavior" (F, $\bar{x}$ = 6.6, 87%), "shared CCNP governance" (L, $\bar{x}$ = 6.3, 78%), and "voluntary compliance" (M, $\bar{x}$ = 6.3, 78%).

The "voluntary compliance" component (M) demonstrated the highest tightness score (4.99), with 82.6% of participants estimating probability percentages of between 50% and 80% that this component would occur within the coming decade. The "environmental education" component (E) represented the second-highest tightness score (4.53), also demonstrating high levels of consensus (91%) around its high importance ($\bar{x}$ = 6.7) for SST. Lower-rated components displayed greater variation in expert consensus, characterized by lower importance scores, weaker consensus, and less precise feasibility estimates. Examples include the "compliance mechanisms" component (C, $\bar{x}$ = 5.9, high-importance consensus = 70%, composite tightness score = 2.94), the "collaborative development of rules and fines" component (K, $\bar{x}$ = 5.7, high-importance consensus = 61%, composite tightness score = 3.09), the "circular local economy" component (N, $\bar{x}$ = 5.6, high-importance consensus = 52%, composite tightness score = 2.87), and the "formal biocultural education" component (O, $\bar{x}$ = 5.9, high-importance consensus = 70%, composite tightness score = 2.56).

Figure 3. Expert-generated conceptual framework for protected area landscape interfaces.

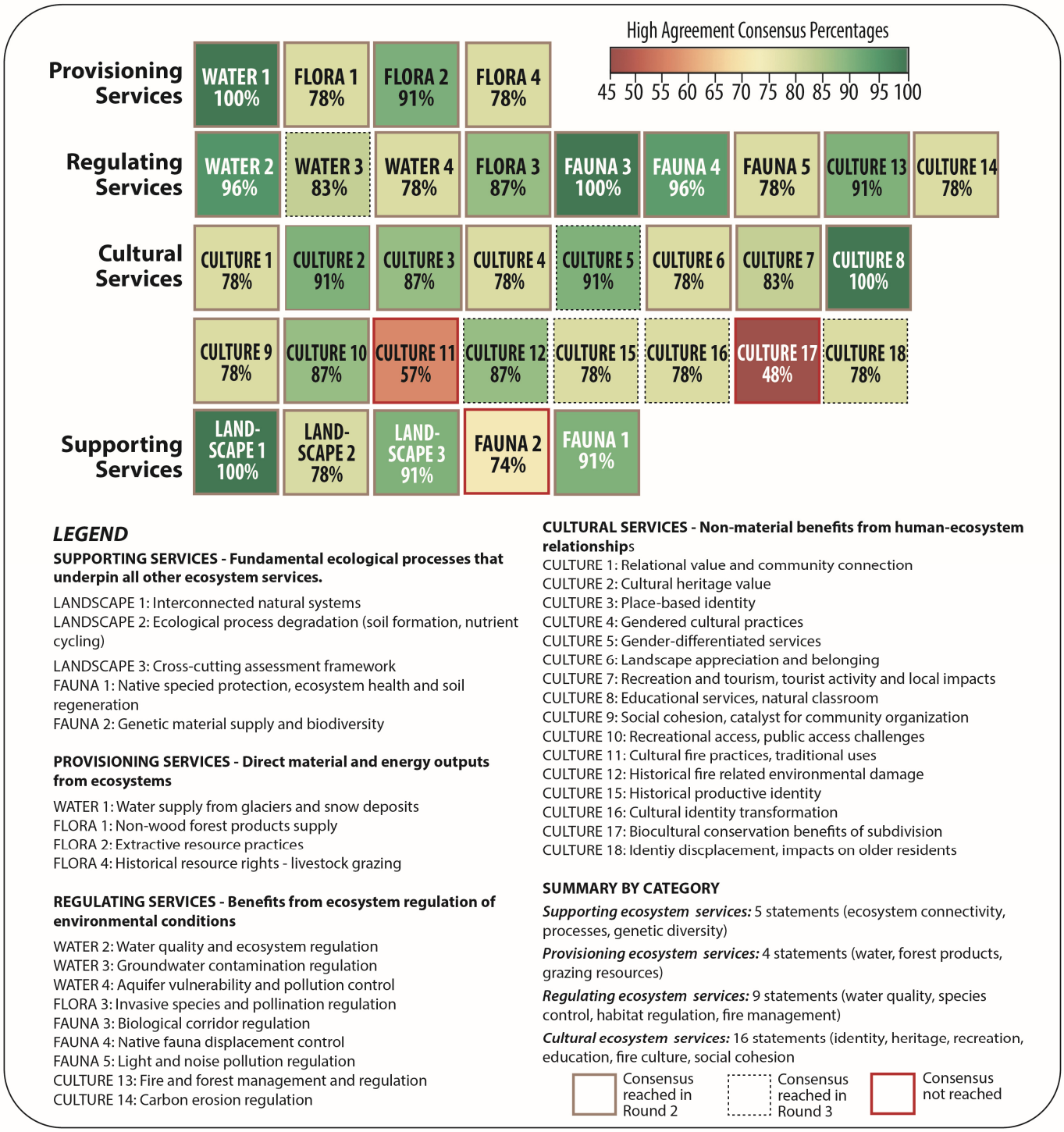

Figure 4. Ecosystem services consensus heatmap.

Sustainable Territorial Transitions: Importance and Probability Assessment

Expert evaluation of 15 strategic components for STTs revealed distinct clustering patterns across importance and feasibility dimensions (Figure 6). Seven components achieved high importance consensus (≥75%): "national legislation" (A, 96% consensus), "environmental education" (E, 91% consensus), "pro-environmental behavior" (F, 87% consensus), "land use planning" (B, 83% consensus), "new CCNP management plan" (D, 78% consensus), "shared governance" (L, 78% consensus), and "voluntary compliance" (M, 78% consensus). The scatter plot (Figure 6) is divided into four quadrants based on

mean importance scores and feasibility consensus tightness rankings. Quadrant B (high importance/tight feasibility consensus) contains "environmental education" (E, $\bar{x}$ = 6.7), "pro-environmental behavior" (F, $\bar{x}$ = 6.6), "voluntary compliance" (M, $\bar{x}$ = 6.3), "new CCNP management plan" (D, $\bar{x}$ = 6.3), and "shared governance" (L, $\bar{x}$ = 6.3), representing the most favorable combinations of expert-perceived importance and feasibility consensus. Quadrant D (high importance/loose consensus) includes "national legislation" (A, $\bar{x}$ = 6.7) and "land use planning" (B, $\bar{x}$ = 6.6), indicating high importance but divided expert opinion on implementation feasibility. "Property management plans" (J, $\bar{x}$ = 6.1) is positioned at the boundary between Quadrants C and D, suggesting its mid-range importance and loose consensus around implementation feasibility. Quadrant A (low importance/tight consensus) contains "incentive programs" (H, $\bar{x}$ = 5.9) and "neighborhood rules and fines" (I, $\bar{x}$ = 5.6), while "basic community services" (G, $\bar{x}$ = 6.0) plotted on the boundary between Quadrants A and C. Quadrant C (low importance/loose consensus) includes "collaborative development of rules" (K, $\bar{x}$ = 5.7), "compliance mechanisms" (C, $\bar{x}$ = 5.9), "circular local economy" (N, $\bar{x}$ = 5.6), and "formal biocultural education" (O, $\bar{x}$ = 5.9). Eight components fell below the 75% consensus threshold for high importance, with importance scores ranging from 5.6 to 6.1.

Strategic Component Scenario Consensus Analysis with Feasibility Range Assessment.

Strategic component	Mean Importance Score	High Importance Consensus Level	Feasibility Consensus (FC) Range	FC Rank	FC Range Participant Coverage	FC Range Span	FC Efficiency	Composite Tightness Score
A - National legislation	6.7	96%	30–80	10	18 (78.3%)	50	11.2%	3.21
B - Land-use planning	6.6	83%	30–90	13	19 (82.6%)	60	10.3%	2.91
C - Compliance mechanisms	5.9	70%	5–60	12	18 (78.3%)	55	9.8%	2.94
D - New CCNP management plan	6.3	78%	50–100	5	19 (82.6%)	50	13.8%	3.49
E - Environmental education	6.7	91%	50–90	2	18 (78.3%)	40	19.6%	4.53
F - Pro-environmental behavior	6.6	87%	40–90	6	18 (78.3%)	50	13.1%	3.45
G - Basic community services	6.0	70%	40–100	8	19 (82.6%)	60	13.8%	3.33
H - Incentive programs	5.9	70%	30–90	7	21 (91.3%)	60	15.2%	3.41
I - Neighborhood rules and fines	5.6	52%	5–50	3	18 (78.3%)	45	13.1%	3.56
J - Property management plans	6.1	70%	10–55	9	18 (78.3%)	45	11.2%	3.32
K - Collaborative development of rules and fines	5.7	61%	10–70	11	19 (82.6%)	60	11.8%	3.09
L - Shared CCNP governance	6.3	78%	10–80	4	18 (78.3%)	70	15.7%	3.50
M - Voluntary compliance	6.3	78%	50–80	1	19 (82.6%)	30	20.7%	4.99
N - Circular local economy	5.6	52%	40–100	14	18 (78.3%)	60	9.8%	2.87
O - Formal biocultural education	5.9	70%	10–90	15	19 (82.6%)	80	9.2%	2.56

Notes about the variables:

1. **FC Range:** The feasibility consensus range calculated using the central 70% of expert probability assessments (15th to 85th percentile), capturing approximately 75% consensus while excluding extreme outlier responses
2. **FC Participant Coverage:** Number and percentage of expert responses falling within the FC Range
3. **FC Range Span:** Numerical difference between the FC Range boundaries (smaller = tighter consensus)
4. **FC Efficiency:** Composite measure combining participation breadth with estimate precision (Coverage % ÷ Range Span)
5. ***Tightness Score:*** Composite metric for prioritization combining importance ratings, consensus strength, and efficiency using the formula: Tightness Score = (Mean Importance × High Importance Consensus × FC Efficiency) ÷ 2000. The scaling factor of 2000 calibrates scores to a practical 2–5 range for decision-making purposes without affecting component rankings.

Figure 5. Strategic component scenario consensus analysis with probability range assessment.

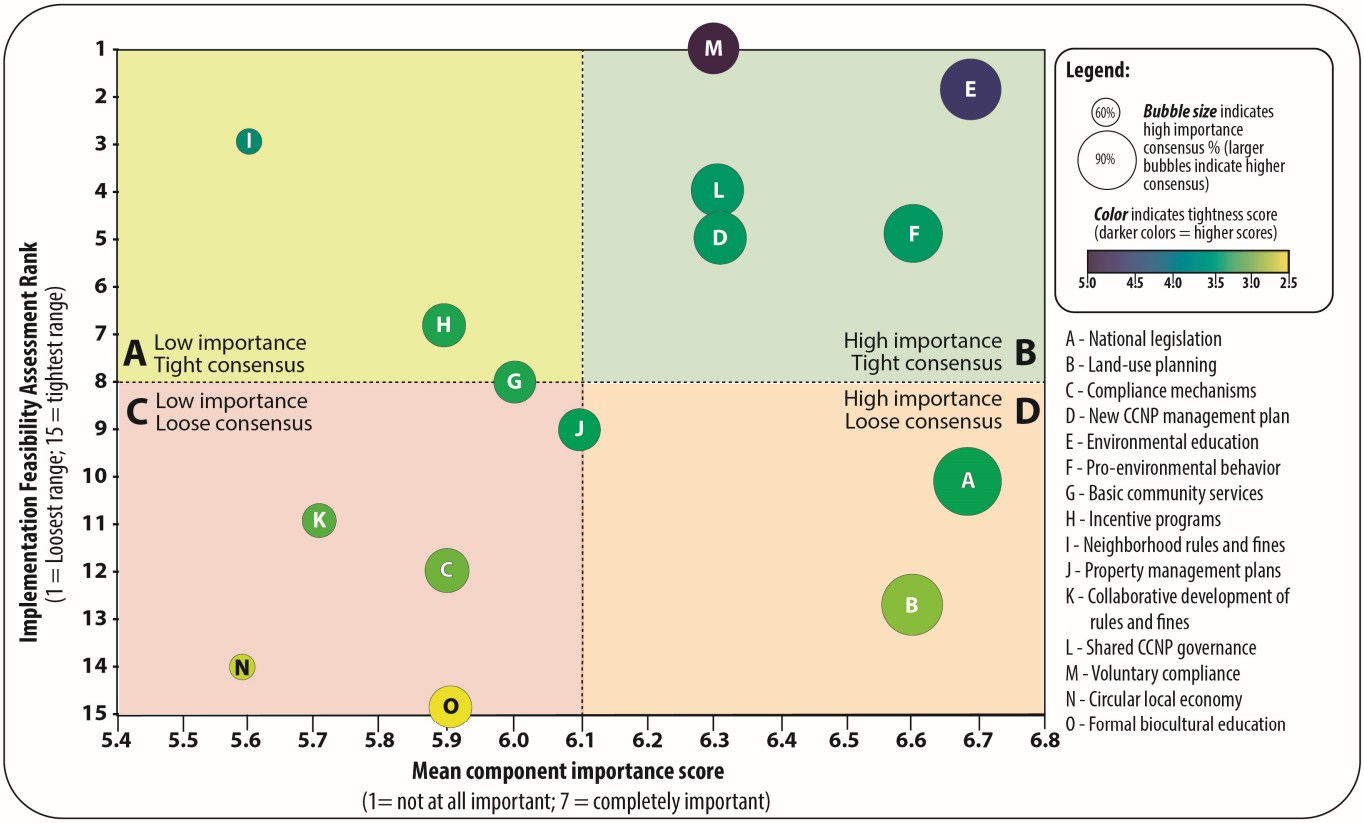

Figure 6. Matrix of sustainable territorial transition components plotting importance vs. feasibility.

4. Discussion

Expert consensus decisively rejected status quo approaches to buffer zone governance. The reverse-coded statement "A STT is possible if the situation remains as it has done to date" achieved 91% disagreement (mean 1.74), demonstrating professional recognition that current trajectories cannot achieve sustainable outcomes. This aligns with IPBES calls for transformative change [7,61,62] and validates the need for fundamental shifts in conservation governance approaches [1,62]. The following sections examine how experts conceptualized these necessary transformations across three dimensions: PA–landscape interfaces, ES priorities through the IPBES framework, and strategic pathways for territorial transitions.

4.1. Expert Conceptualization of Protected Area–Landscape Interfaces

Experts conceptualized PA–landscape interfaces as complex socio-ecological systems requiring integrated management approaches that transcend traditional sectoral boundaries. The 24-statement conceptual framework achieved an overall consensus rate of 79.2% (19 of 24 statements), revealing varying consensus patterns across four thematic categories and both areas of strong professional agreement and continuing debates requiring further development.

Expert consensus patterns varied significantly across thematic categories, with the "Ecosystem Service Recognition and Connectivity" category demonstrating the strongest agreement. All six statements in this category reached consensus (83–91% range), reflecting their fundamental importance to successful interface management. Notable agreement emerged around community awareness of water source origins from PA (Figure 3, S2: 91% consensus) and ecosystem continuity beyond boundaries (Figure 3, S5: 91% consensus). Ex-

perts prioritized tangible, demonstrable benefits that communities can directly experience and value.

The "Scientific Boundary Definition Criteria" category showed more variable consensus patterns, with six of ten statements achieving agreement. While experts reached a strong consensus on fundamental criteria such as "native wildlife habitat protection" (S12: 83% consensus) and "watershed continuity protection" (S16: 91% consensus), several technical criteria failed to achieve consensus. The lack of agreement on "ES provision radius" (S13: 57%), "soil integrity maintenance" (S17: 70%), and "public access management" (S19: 52%) reveals ongoing professional debates about specific delimitation approaches. The lack of consensus on criteria sufficiency (S21: 74%) indicates divided expert opinion, though the specific reasons for this disagreement—whether reflecting concerns about current approaches, need for additional criteria, or other factors—would require further investigation to clarify.

The "Integrated Zoning Frameworks" category achieved consensus across all three statements: the "UNESCO MAB Biosphere Reserve three-zone model" (S22: 78% consensus), the "IUCN Category V transition zone approach" (S23: 83% consensus), and the "Chilean SBAP law buffer zone definition" (S24: 83% consensus). Expert consensus on established zoning frameworks—UNESCO Biosphere Reserve (78%), IUCN Category V (83%), and Chilean SBAP legislation (83%)—achieved the threshold but remained at moderate levels. Whether this reflects genuine endorsement of these approaches or recognition of their limitations despite conceptual merit remains unclear from the consensus patterns alone.

While experts achieved consensus on established zoning frameworks—UNESCO Biosphere Reserve (78%), IUCN Category V (83%), and Chilean SBAP legislation (83%)—this agreement may reflect aspirational support rather than endorsement of current implementation. The moderate consensus levels may indicate complex expert perspectives on implementation realities. The UNESCO three-belt model faces practical constraints in the CCNP context, where private property fragmentation and unclear jurisdictional authority create implementation barriers [23]. Similarly, IUCN Category V's protected landscape approach, designed for lived-in working landscapes [22], encounters challenges from rapid land subdivision and amenity migration that fundamentally alter traditional land use patterns documented in our study area (37.5% of properties subdivided 2011–2023) [13]. Chile's SBAP legislation, despite providing a legal framework for buffer zones, contains critical gaps, including a lack of enforcement mechanisms for private lands, the absence of financial incentives for landowner participation, and limited coordination protocols between CONAF and municipal planning authorities. These implementation challenges reveal a consistent pattern: international and national frameworks provide valuable conceptual structure but require substantial adaptation to local contexts [12,18]. This disconnect between theoretical consensus and practical application may help explain why experts showed stronger agreement on education-based and voluntary compliance approaches than on regulatory mechanisms. This preference appears to reflect expert recognition that effective buffer zone management depends not merely on formal designations but on the institutional capacity, financial resources, and community buy-in necessary for successful implementation [17,19]. This gap between conceptual frameworks and operational realities underscores the need for hybrid governance approaches that combine formal zoning tools with locally-adapted implementation mechanisms responsive to property dynamics, institutional constraints, and community priorities [26,27].

The "Regulatory and Planning Gaps" category achieved consensus in four of five statements, highlighting perceived inadequacies in current land use planning approaches. Failure to achieve consensus on "planning deficiencies impacting ES provision" (S8: 43%)

may reflect insufficient empirical evidence for direct causal relationships, pointing toward the need for more systematic impact assessment research.

4.2. Ecosystem Service Priorities and IPBES Framework Application

Applying the IPBES framework revealed both its utility as an organizing structure and important insights into how professional expertise translates across different types of ecosystem benefits. The high consensus rate of 91.2% suggests strong expert agreement on ecosystem service priorities within the IPBES framework, while variation across service categories reveals different levels of professional certainty about specific human–nature interactions.

Unanimous agreement on water-related ES across multiple IPBES categories represents more than simple consensus; it reveals water as a boundary object that bridges conservation and development perspectives [63]. Boundary objects, as conceptualized by Star and Griesemer [64], are entities that maintain coherence across intersecting social worlds while remaining flexible enough to adapt to local needs and constraints. These objects facilitate coordination between diverse actors by being simultaneously concrete enough to be recognizable and abstract enough to allow different interpretations [65,66]. In our context, water-related ES function as boundary objects because they translate across the conservation–development divide: conservationists value water services for biodiversity maintenance and ecosystem integrity, while development stakeholders recognize their importance for tourism infrastructure, agricultural productivity, and community well-being. This shared recognition creates what Carlile [67] terms a "pragmatic boundary"—a space where different knowledge domains can negotiate shared understanding despite divergent underlying values and priorities. Unlike abstract concepts such as biodiversity or ecosystem integrity, water services provide tangible, immediate benefits that communities can directly experience and value. Water-based conservation strategies may, therefore, serve as effective entry points for broader landscape-scale cooperation, particularly in semi-arid regions where water scarcity heightens community awareness of ecosystem dependencies.

Perfect consensus achieved across all regulating services indicates expert recognition that these functions represent non-negotiable components of landscape stability. Evidence aligns with growing understanding that regulatory services become increasingly critical as human pressures intensify [68], suggesting that buffer zone strategies should prioritize maintaining these functions, even when trade-offs with other objectives arise.

However, significant variation in cultural services consensus reveals deeper tensions within conservation practice and exemplifies the "wicked problem" nature of territorial transitions (see Introduction) [15,16]. The contrast between perfect consensus on education services—"One of the cultural ES provided by the CCNP highlights its role as a natural laboratory, or classroom, for the development of outdoor education and learning processes that partly benefit schools located in the surrounding area" (CULTURE_8: 100% consensus)—and failure to achieve consensus on traditional fire practices (CULTURE_11: 57% consensus) illustrates these complexities.

Fire practices statements generated extensive expert debate that reveals the multidimensional nature of these challenges. Expert comments included concerns about climate change risks: "with climate change, the exotic forest plantations in the park, and the effects of land division and increased population density, there should be restrictions on the use of fire"; tensions between cultural importance and environmental safety: "It is culturally important, but. . . there should be restrictions"; and disagreements about preservation versus transformation: "recognized aspects of traditional culture that must change" versus calls for "policies for its rational use at the domestic level." Rich dialogue demonstrates how cultural

ESs involve contested values that resist simple technical solutions, requiring adaptive governance approaches that can navigate multiple valid but conflicting perspectives [4].

The evolution of fire-related statements across two rounds reveals the complex boundaries of expert consensus on contested cultural practices. CULTURE_11, addressing fire as a cultural practice, failed to achieve consensus in both Round 2 (57% agreement) and Round 3 (52% agreement), despite refinement based on participant feedback. The Round 2 statement framed fire as "a fundamental cultural practice that continues to develop today and is projected into the future," while the Round 3 revision removed future projections but maintained cultural legitimacy framing. The slight decrease in agreement (57% to 52%) suggests that refinement based on critical feedback may sometimes deepen rather than resolve expert divisions.

CULTURE_12, addressing fire's environmental impacts, followed a different trajectory. The Round 2 statement focusing on "historical impacts, including forest fires, air, soil, and water pollution, deforestation, erosion, flooding, and the elimination of important carbon deposits" achieved 74% agreement—just below the consensus threshold. However, the Round 3 revision that reframed fire as a current threat exacerbated by land fragmentation achieved strong consensus (87% agreement). This transformation suggests that expert agreement may be more achievable when shifting from historical attribution to contemporary risk assessment.

Expert comments on CULTURE_11 revealed fundamental philosophical disagreements. Some argued that "recognized aspects of traditional culture must change," while others called for "regulated use of fire, understanding that we can strengthen learning and education about fire and the historical value that local people give it." One expert questioned the fundamental categorization: "I don't understand if fire is being considered a cultural ES, since it is more of a cultural practice." These persistent disagreements indicate that some cultural practices resist consensus-building approaches, requiring governance mechanisms that can accommodate ongoing contestation rather than seeking technical resolution.

The contrasting outcomes of CULTURE_11 and CULTURE_12 illuminate important boundaries of consensus methodologies in cultural domains. While experts could not agree on fire's cultural legitimacy despite two rounds of refinement (57% $\rightarrow$ 52%), they achieved strong consensus (87%) when the framing shifted from historical impacts to contemporary threat assessment. This pattern suggests that consensus-building may be more effective for technical–managerial framings than for questions involving cultural recognition and historical interpretation.

Despite incorporating participant feedback, the failure to achieve consensus on CULTURE_11 challenged assumptions about the iterative improvement of statements through expert dialogue. Comments revealed not just disagreement about practices but fundamental conflicts about how to balance cultural heritage with environmental protection. Some experts argued, "The fact that it is a historical practice is not understandable, especially in a scenario of climate change that makes us more vulnerable to fires," while others called to "strengthen learning and education about fire and the historical value that local people give it."

Nevertheless, the successful transformation of CULTURE_12 from failed consensus (74%) to strong agreement (87%) demonstrates that reframing can unlock expert convergence, even on contested topics. By shifting focus from attributing historical environmental damage to assessing contemporary risks from land fragmentation, the statement moved from a culturally charged historical judgment to a technical assessment that experts could evaluate based on shared professional criteria.

Near-consensus on supporting services indicates broad professional agreement on fundamental ecosystem processes, yet the single non-consensus statement on genetic resources (FAUNA_2) reveals important management uncertainties. This statement achieved 74% agreement in both rounds—just below the 75% consensus threshold—representing stable near-consensus rather than random disagreement [30]. The persistence of this precise percentage across rounds, despite substantial statement refinement from "genetic material supply allows greater biodiversity" to incorporating "thorough understanding of potential impacts of human activities on genetic diversity," suggests genuine scientific uncertainty rather than methodological limitations.

Expert concerns centered on habitat fragmentation's impact on genetic diversity, with participants noting critical structural challenges: "There is a lack of biological corridors; the park consists of three islands surrounded by livestock, so there is no exchange between species." Species-specific concerns were also raised, with one expert noting "the huemul is genetically extinct in the CCNP." These observations align with conservation genetics research showing 6% average genetic diversity loss across 91 species over the past century [69,70], validating concerns about CCNP's fragmented structure. The GBF explicitly identifies maintaining genetic diversity as a primary 2030 conservation target, recognizing its essential role in species' adaptive capacity [1,71].

The 74% near-consensus has important management implications. Without definitive agreement on genetic diversity mechanisms, management should adopt precautionary approaches while implementing adaptive management strategies that reduce uncertainty through systematic monitoring [72,73]. This acknowledges both the critical importance of genetic diversity for long-term conservation and the current knowledge gaps requiring continued research and adaptive governance rather than prescriptive solutions.

4.3. Strategic Components for Territorial Transitions

Expert evaluation of territorial transition strategies reveals a sophisticated understanding of implementation challenges that goes beyond simple policy prescriptions. Clustering patterns observed in the strategic component analysis illuminate fundamental tensions between regulatory necessity and implementation feasibility, indicating that effective territorial transitions require carefully sequenced interventions that build momentum through early successes while working toward more challenging systemic changes [15,16,61,62].

Education and voluntary compliance emerged as high-feasibility strategies, reflecting expert recognition that STTs must be grounded in community understanding and voluntary participation rather than external imposition [19]. These results challenge traditional command-and-control approaches to conservation governance and align with growing evidence that collaborative approaches achieve more durable outcomes in complex socio-ecological systems [74]. High tightness scores for these components indicate not only expert agreement on their importance but also confidence in implementation pathways, which is a critical distinction for resource allocation decisions.

However, the positioning of national legislation and land use planning in the high importance/loose consensus quadrant may reveal a fundamental governance paradox. While experts appear to recognize these regulatory frameworks as essential for landscape-scale conservation, their uncertainty about implementation probability could reflect underlying concerns about political feasibility and institutional capacity constraints. This pattern suggests that effective territorial transition strategies might require multi-horizon approaches: building community-level capacity and engagement in the near term while simultaneously advocating for enabling policy environments over longer timeframes [26]. The preference for education-based and voluntary approaches may indicate a shift toward more inclusive paradigms that position local communities as partners rather than obstacles to conservation

objectives [17]. This orientation seems consistent with transformative agency theory, which emphasizes building collective capacity for endogenous change rather than imposing externally designed solutions [75].

The translation of expert-endorsed collaborative frameworks into effective local governance must also account for the complex social dynamics and power imbalances that operate within communities themselves. Research on established community-based conservation programs reveals that even well-funded initiatives with decades of experience continue to face challenges related to differential participation and internal conflicts among community members. For instance, Baral et al. [21] demonstrated persistent governance challenges in Nepal's Annapurna Conservation Area, a frequently cited model for community-based conservation that, despite four decades of investment and numerous interventions, still experiences uneven participation and local political dynamics that can undermine decision-making processes. Similar findings across diverse conservation contexts suggest that trust relationships, competing accountabilities, and evolving power structures create intervening variables that may prevent collaborative intentions from translating into equitable outcomes [76]. Such realities underscore that STTs may emerge through iterative processes of social learning and adaptive governance rather than through regulatory compliance alone, with optimal strategies necessarily varying according to local community characteristics, social structures, and their capacity to evolve over time. Despite these complexities, the transdisciplinary group of place-based experts comprising our Delphi panel demonstrated considerably greater confidence in community-level capacity building approaches than in the feasibility of achieving comprehensive legislative reform or effective land use planning implementation.

4.4. Integration and Broader Implications

Expert consultation bridges conceptual understanding with practical implementation strategies for territorial transitions. Consistent emphasis on ESs across all three research questions—from conceptual frameworks through specific service types to strategic components—indicates that successful territorial transitions must ground abstract conservation concepts in tangible community benefits.

The IPBES framework's demonstrated utility (91.2% consensus) indicates that systematic application of international frameworks can facilitate collaboration among diverse stakeholders, though variations across cultural services highlight areas requiring more nuanced approaches.

The unanimous agreement on water services across multiple IPBES categories (see Section 4.2) reinforces their role as effective entry points for landscape-scale cooperation, particularly given Patagonia's watershed-dependent communities.

Variable consensus patterns confirm the "wicked problem" characterization introduced earlier [14–16], with strong agreement on fundamental principles (ES importance and community engagement necessity), contrasting with weaker consensus on implementation strategies. This differential reflects the multi-dimensional challenges inherent in contexts where multiple stakeholders hold divergent values, which are precisely the conditions that resist technical solutions and require adaptive governance approaches.

Transdisciplinary expert panel composition likely contributed to both the comprehensiveness of conceptual frameworks and the practical orientation of strategic components. Balanced representation of ecological, social, and institutional perspectives enabled more complete conceptualization than single-discipline approaches might achieve, though specific findings reflect contextual conditions that may require adaptation in other settings.

4.5. Limitations and Future Research

Several limitations should be considered when interpreting these findings. First, while the IPBES framework provided valuable structure for analysis, some ESs may not fit neatly into single categories, and our categorization decisions may influence interpretation [24]. Second, our expert panel, while diverse in professional backgrounds, may not fully represent all perspectives relevant to buffer zone governance, particularly those of private landowners who are not professionally engaged in conservation [19]. Third, the Delphi method reveals expert opinions and consensus but does not test the effectiveness of proposed strategies in practice [57]. Implementation research will be necessary to validate the practical utility of these recommendations.

Fourth, the fire management controversy reveals fundamental tensions between consensus-building methodologies and contested cultural practices. The persistent disagreement about traditional fire use (CULTURE_11: 57% → 52% agreement across rounds) despite iterative refinement suggests that some governance challenges require approaches that explicitly engage with cultural contestation rather than seeking technical resolution. The contrasting outcomes of fire-related statements—failure to achieve consensus on cultural legitimacy but strong agreement (87%) on contemporary risk assessment—demonstrate how temporal framing fundamentally shapes expert evaluation and the limits of consensus-building for value-laden cultural questions.

Fifth, our findings are fundamentally grounded in the specific socio-ecological context of Chilean Patagonia, where rapid tourism growth, amenity migration, and land subdivision intersect with traditional ranching practices, local heritage, and conservation imperatives around an internationally significant protected area. The high consensus achieved on water services, for example, likely reflects the particular importance of watershed functions in temperate Patagonian landscapes experiencing rapid land use change, while agreement on geomorphological safety considerations may reflect specific geological hazards present in volcanic and glacial environments. These place-based specificities mean our findings cannot be directly generalized to other contexts [60].

However, the methodological approach and conceptual insights may prove transferable to other protected area systems facing similar challenges of rapid rural transition, cultural practice conflicts, and buffer zone governance [60]. Future research should test framework transferability across different biogeographical, socioeconomic, and institutional contexts, with particular attention to how local cultural practices, environmental conditions, and governance systems shape expert consensus patterns. Comparative Delphi studies could validate broader applicability while maintaining sensitivity to place-based adaptation requirements essential for effective territorial transition strategies [29,51].

5. Conclusions

National parks face complex challenges in balancing ecological preservation with regional economic development, a central concern of this Special Issue exploring the socioeconomic impacts of conservation policies on local communities. The IPBES framework, combined with iterative consensus-building through Delphi methodology, provides a valuable structure for building expert consensus on previously contentious aspects of buffer zone governance around PA.

The results respond directly to three critical knowledge gaps identified in the buffer zone governance literature. First, regarding buffer zone definition and delimitation, expert consensus can be achieved around scientifically informed criteria that incorporate ES considerations, though technical specifications require further empirical validation. The 79.2% consensus rate across conceptual framework statements indicates substantial

professional agreement on fundamental principles, while variable consensus on specific criteria highlights areas requiring continued research and stakeholder engagement.

Second, concerning ES priorities within the IPBES framework, the 91.2% consensus rate across ES statements shows remarkable professional agreement, particularly for water-related services across multiple categories. Practitioners gain evidence-based priorities for community engagement strategies that can ground abstract conservation concepts in tangible benefits. Unanimous agreement on water supply and strong consensus on regulating services offer concrete entry points for multi-stakeholder collaboration that transcends traditional conservation–development conflicts.

Third, regarding territorial transition strategies, evaluation of 15 strategic components reveals that education-based approaches combined with flexible governance mechanisms achieve the strongest expert consensus for implementation feasibility. High importance ratings for national legislation and land use planning, coupled with concerns about implementation probability, highlight the need for multi-level governance approaches that combine regulatory frameworks with community-based initiatives.

5.1. Contributions to Theory and Practice

Several key theoretical advances emerge from this work. IPBES-informed ES assessment provided an effective structure for building consensus on previously contentious governance aspects. Consensus patterns observed validate the "wicked problem" characterization of territorial transitions, confirming that these challenges involve multiple stakeholders with divergent values and resist simple solutions while simultaneously showing that structured expert consultation can identify areas of professional agreement that provide foundations for collaborative solutions.

Water-related ES demonstrated capacity to bridge stakeholder divides (Section 4.2), providing practitioners with concrete entry points for initiating multi-stakeholder collaboration, particularly in water-scarce regions where ecosystem dependencies are most visible.

The results also contribute to transformative agency theory by showing how expert consensus-building can reveal pathways for collaborative governance that emphasize community capacity-building over external imposition [74,75]. Strong preference for educational and voluntary approaches over punitive mechanisms reflects a fundamental paradigmatic shift in conservation thinking from command-and-control to collaborative governance models that recognize local communities as partners in conservation.

The demonstrated feasibility of education and voluntary compliance strategies offers implementable pathways for near-term action while regulatory frameworks develop. These components achieved the highest tightness scores (4.99 and 4.53, respectively), indicating both expert confidence in implementation and recognition that sustainable transitions require community buy-in rather than external imposition. This preference for collaborative over command-and-control approaches represents a fundamental shift from traditional PA governance, providing practitioners with actionable entry points that can build momentum while longer-term institutional changes evolve. Combined with water services as initial collaboration focal points, these education-based strategies offer a pragmatic two-pronged approach: tangible ecosystem benefits that resonate across stakeholder groups, delivered through voluntary mechanisms that respect local agency and capacity.

5.2. Policy Implications and Future Directions

These findings directly support implementation of the GBF, particularly Target Three's emphasis on landscape-scale conservation that extends beyond PA boundaries [1]. Buffer zone governance strategies based on stakeholder consensus and ES assessment within the IPBES framework offer promising pathways for achieving the GBF 30% conserva-

tion target while supporting sustainable rural development. Identifying water-related ES as boundary objects provides policymakers with concrete entry points for building conservation–development collaboration, particularly in regions where water scarcity heightens community awareness of ecosystem dependencies.

The results reveal a fundamental governance paradox with important policy implications: while regulatory frameworks (national legislation and land use planning) are recognized as essential for landscape-scale conservation, their implementation faces significant political and institutional barriers. Effective policy strategies require dual approaches that build community-level capacity and engagement while simultaneously creating enabling policy environments. Strong expert consensus on collaborative pathways over command-and-control approaches provides evidence for policy frameworks that emphasize transformative agency and collective capacity-building [74].

Countries worldwide struggle to balance conservation objectives with community needs. The consensus-building approach demonstrated here provides a replicable methodology for addressing similar challenges. Emphasis on water ESs as collaboration entry points, combined with education-based strategies and flexible governance mechanisms, offers practical guidance for conservation practitioners working at PA interfaces.

Future research should expand this approach through comparative studies in different biogeographical and institutional contexts, with particular attention paid to testing the boundary object potential of different ESs across various social–ecological systems. Implementation research testing the effectiveness of proposed collaborative pathways is critically needed, along with studies examining how to overcome the regulatory implementation barriers identified in this research. Research should also explore how transformative governance approaches can be scaled from local consensus-building to broader institutional change processes.

Particular attention should be given to expanding stakeholder engagement beyond conservation professionals to include private landowners and other community groups whose perspectives are essential for successful implementation. A better understanding of evolving land ownership demographic patterns is warranted to help inform participative strategies and outreach. Additionally, longitudinal studies tracking territorial transition outcomes and the effectiveness of different boundary objects in facilitating collaboration would provide valuable insights into the durability and adaptability of consensus-based governance approaches.

The interface between PA and private land represents one of the most challenging frontiers in contemporary conservation. The evidence suggests that these challenges can be addressed through systematic consensus-building processes that integrate scientific frameworks with diverse forms of knowledge while maintaining analytical rigor. This paper advances understanding of transformative change approaches by showing how structured expert consultation can identify collaborative pathways that emphasize collective agency and community capacity-building over external imposition.

As territorial transitions accelerate globally, the methodological approach demonstrated here—combining IPBES-informed ES assessment with collaborative consensus-building—will become increasingly essential for achieving conservation objectives while supporting the socioeconomic welfare of local communities. Identifying boundary objects like water services provides a transferable framework for finding common ground across conservation-development divides, while validating collaborative governance approaches offers hope for moving beyond the conflicts that have historically characterized PA management.

Balance between conservation and community welfare—achieved through transformative governance approaches that recognize local agency and build collective capacity

for change—represents the essence of this Special Issue's mission and offers a pathway forward for conservation in an era of accelerating social–ecological change.

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Abbreviations

The following abbreviations are used in this manuscript:

AI	Artificial Intelligence
CCNP	Cerro Castillo National Park
CONAF	Chilean National Forestry Corporation
ES	Ecosystem Service(s)
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IUCN	International Union for Conservation of Nature
GBF	Kunming-Montreal Global Biodiversity Framework
PA	Protected Area(s)
PAICF	Protected Areas Interface Conceptual Framework
RQ	Research Question(s)
SBAP	Chilean Biodiversity and Protected Areas Service
SST	Sustainable Territorial Transition(s)
UNESCO	United Nations Educational, Scientific and Cultural Organization

Appendix A

Appendix A.1

The expert panel comprised 23 participants representing diverse conservation, research, and community engagement backgrounds across the Aysén Region and Chilean Patagonia. Participants were selected through purposive and snowball sampling to ensure transdisciplinary representation spanning conservation science, policy implementation, and

practical management domains. All participants met the inclusion criteria of a minimum of five years of conservation experience within the Aysén Region, encompassing ecological conservation, cultural heritage preservation, and biocultural stewardship approaches. The panel included 14 males and 9 females distributed across age ranges from 30–70 years, with primary geographic representation from the Aysén Region (n = 19) and additional expertise from the Chilean regions of Los Ríos (n = 1), Biobío (n = 1), and Magallanes (n = 2). Professional backgrounds spanned PA management, ecological research, community engagement, policy development, tourism planning, and territorial governance, with experience levels ranging from 7 to 38 years in Patagonian ecosystem and community management.

Table A1. Expert panel participant profiles and professional experience.

N°	Primary Category	Birth Sex	Age Range	Experience
1	Protected Area (PA) Administration	Male	40–49	Expert in biodiversity and huemul conservation, with extensive experience in ecosystem services(ES) management within Cerro Castillo National Park (CCNP). His 38 years of service at CONAF culminated in retirement in 2021, leaving a profound legacy in sustainable natural resource management.
2	PA Administration	Male	40–49	Interim administrator of CCNP, with 10 years of monitoring experience and a strong focus on public use management and environmental education regarding huemul populations.
3	Ecological Researchers	Female	40–49	Researcher, specializing in freshwater ecosystems and limnology. She focused on community engagement through citizen science projects, emphasizing the importance of environmental awareness in rural water management.
4	Tourism and Development Professionals	Male	50–59	Expert in scientific tourism and ES, aged 50–60, who has researched the intersection of tourism and social conflict for 15 years. His doctoral research addresses stakeholder dynamics in development.
5	Tourism and Development Professionals	Female	40–49	Co-founder of a tourism company in Cerro Castillo, promoting sustainable adventure tourism through horseback riding and trekking, significantly impacting local tourism.
6	PA Administration	Male	40–49	Executive Director of Protected Area Programs at Chile's Austral University in Valdivia, leading initiatives to enhance CCNP's management and its UNESCO Green List certification, with over 22 years of experience in planning and conservation.
7	Ecological Researchers	Male	40–49	Professional with expertise in territorial planning and natural resource management. His focus on remote sensing and climate change emphasized data-driven solutions for territorial challenges.
8	Ecological Researchers	Female	40–49	Landscape ecologist, focusing on land use change and wildfire impacts. Her nearly 7 years of experience working in Chilean Patagonia involved assessing ecosystem functions and services.

Table A1. *Cont.*

N°	Primary Category	Birth Sex	Age Range	Experience
9	Community Practitioners and Educators	Female	40–49	Veterinarian involved in promoting sustainable livestock practices near CCNP, with over 22 years of experience in conservation and education.
10	Community Practitioners and Educators	Female	40–49	Historical researcher, advocating for the biocentric perspective of Aysén through local narratives and a radio program that amplifies community voices.
11	Ecological Researchers	Male	30–39	Hydrogeologist, specializing in glaciology and water quality, with research focusing on the implications of glacial transformations in Cerro Castillo.
12	Ecological Researchers	Male	50–59	Plant ecologist, with two decades of experience studying invasive species and forest ecology, currently directing the Institute of Ecology and Biodiversity.
13	Ecological Researchers	Female	40–49	Environmental biologist, leading conservation efforts at the Torres del Paine Legacy Fund, focusing on biodiversity and tourism impacts in protected areas.
14	Community Practitioners and Educators	Female	40–49	Outdoor education advocate, emphasizing cultural preservation through her organization and community projects in Cerro Castillo.
15	Ecological Researchers	Male	40–49	Wildlife program director, focusing on ES and community engagement to mitigate livestock–wildlife conflicts.
16	Tourism and Development Professionals	Male	30–39	Tourism governance administrator, enhancing local tourism development and community engagement with CCNP.
17	Ecological Researchers	Female	30–39	Forest ecologist, specializing in native subantarctic forests and their management, with significant contributions to biodiversity conservation.
18	Community Practitioners and Educators	Female	40–49	Enhancing local engagement by connecting communities and protected areas in Chilean Patagonia through her role as coordinator of the Communities Portal program.
19	PA Administration	Male	50–59	ES expert with extensive experience in protected area management and a focus on sustainability in the Aysén Region.
20	Community Practitioners and Educators	Male	40–49	Physical education teacher, instrumental in developing tourism education and community engagement initiatives in CCNP.
21	Community Practitioners and Educators	Male	40–49	Educator and researcher, focusing on forest ecosystem restoration and degradation processes within the Aysén region.
22	Community Practitioners and Educators	Male	40–49	Environmental engineer with a background in public management, emphasizing local development and community engagement in territorial planning.
23	Tourism and Development Professionals	Male	50–59	Biological scientist with significant contributions to biodiversity research and regional development strategies within Aysén.

Note: Categories represent primary professional orientation for analytical purposes. Most experts contribute across multiple domains; for example, Expert 1 spans administrative, research, and community engagement roles throughout their 38-year career.

Appendix A.2. Round 1 Delphi Questionnaire

After reviewing study objectives and obtaining informed consent, interviewers engaged in the interview. Following established Delphi methodology guidelines [29,51], Round 1 employed semi-structured interviews with visual prompts and contextual scenarios to facilitate expert engagement with complex socio-ecological relationships. These included (1) a map of Cerro Castillo National Park and surrounding territory, (2) a land subdivision map (2011–2023), and the (3) MEA ecosystem services and IPBES Nature's Contributions frameworks.

The interview began with brief introductions by the participants, which included the following components: (Question 1) name; (Question 2) current occupation; (Question 3) place of residence; (Question 4) years of experience in the field; (Question 5) age; (Question 6) birth sex; and (Question 7) a brief narrative about their experience with Cerro Castillo National Park and its surrounding area. Then, the interview continued, guided by the following sections and questions:

Section 1: Buffer Zone Conceptualization. *[Visual prompt: A park boundary map with buffer zone.]* Based on your experience and knowledge: (Question 8) How would you characterize the space surrounding the Park?; (Question 9) What role do you consider this space plays in relation to the park's conservation objectives?; and (Question 10) How should the zone around the Park be defined and managed to ensure its development can also protect conservation objectives?

Section 2: Ecosystem Services (ES) Identification. *[Visual prompts: MEA ecosystem services framework and IPBES Nature's Contributions to People classification.]* Observe these frameworks and reflect on contributions provided by Cerro Castillo National Park. Identify those you consider vital for (Question 11) Guaranteeing human well-being around the park and (Question 12) Achieving the park's conservation objectives.

Section 3: Potential for Land Fragmentation Impacts. *[Visual prompt: Land subdivision map 2011–2023]* (Question 13) What impacts could this territorial fragmentation have on the ES described above?

Section 4: Local Practices. Currently, different property owners and inhabitants exist around CCNP (permanent residents, second-home owners, landowners with lots for sale). (Question 14) Describe at least 6 behaviors and practices that property owners and/or inhabitants in the area adjacent to the park could adopt to minimize and/or avoid increasing pressure on natural systems and ES provision.

Section 5: Governance Responsibility. (Question 15) Who should address potential subdivision impacts and/or promote good practices that minimize pressure on ES provided by Cerro Castillo National Park?

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