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Rethinking protected area governance: beyond resilience toward antifragility

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Protected areas are central to achieving global biodiversity conservation targets; however, their actual contribution depends on how effectively they are governed and managed. Governance is increasingly challenged by volatility stemming from rapid environmental change and land-use pressures, as well as political and socio-economic uncertainties. Using the fragile–resilient–antifragile triad, we apply an antifragility lens to seven established governance principles- legitimacy, transparency, accountability, inclusiveness, fairness, connectivity, and resilience- to examine how each may respond to and develop through stress. The resulting typology provides a diagnostic and reflective tool through which managers can identify vulnerabilities, prioritise reforms, and design governance systems that learn and strengthen through disturbance. To illustrate its practical application, we present protected area cases in which disturbance led to measurable improvements in governance. By framing antifragility as a complementary perspective that extends resilience thinking, the paper treats disturbance not only as a threat to be managed, but also as a possible driver of institutional strengthening.

Keywords: antifragility; protected area governance; resilience; governance principles; adaptive governance

1. Introduction

Protected areas are widely recognised as essential instruments for achieving global biodiversity conservation targets (Chape *et al.* 2005; Visconti *et al.* 2019; Watson *et al.* 2014). The global protected area estate has expanded substantially in recent years, increasing from an estimated 14.1% of terrestrial and freshwater environments in 2010 (Maxwell *et al.* 2020) to approximately 17.6% in 2024 (UNEP-WCMC and IUCN 2024). Yet the value of this estate depends less on its size than on how well individual protected areas are managed, particularly in the context of constrained conservation budgets (Beverdam *et al.* 2025; Cumming *et al.* 2021) and well-documented management shortfalls (He and Cliquet 2020; Zabala *et al.* 2024). Improving the management of existing protected areas is, therefore, at least as consequential as further expansion

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(Adams, Iacona, and Possingham 2019), but management outcomes are themselves shaped and constrained by the governance arrangements within which protected areas operate.

Protected area governance refers to the overarching frameworks, structures and processes that determine who makes decisions, how those decisions are made and which values guide them (Graham, Amos, and Plumptre 2003). It therefore strongly influences protected area management outcomes (Zhang *et al.* 2023). Strengthening protected area governance can improve management outcomes and, in turn, support more effective conservation. However, governance systems do not operate in isolation. Rapidly changing political, social, economic, cultural, and environmental conditions shape them (Borrini-Feyerabend *et al.* 2013). These systems also operate through different governance arrangements, including state, private, community and shared governance. Each involves different decision making structures, distributions of authority, and levels of stakeholder participation. This diversity matters when considering how governance principles respond to stress, because different arrangements have different capacities to adapt as conditions change.

Despite this diversity, protected area governance shows several recurring weaknesses when exposed to disturbance. First, governance arrangements can become trapped in rigid procedures and centralised control. These may provide short-term stability, but over time they can reduce institutions' ability to absorb shocks, adapt, and learn from them (Walker *et al.* 2004). Second, those who make governance decisions are often partly shielded from the consequences when those decisions fail. The costs are then carried by other affected stakeholders or by biodiversity, while the decision makers themselves face little pressure to change course. Third, responses to crisis are often restorative. The aim is to return the system to its previous state, even when that state contained the very weaknesses that allowed the crisis to develop. Disturbance is therefore treated as something to recover from, rather than as an opportunity to identify and address underlying sources of weakness. Fourth, most governance assessment tools provide a snapshot of performance at a particular point in time. They reveal much less about whether a system emerges from disturbance stronger or weaker than before (Franks 2023; Lockwood 2010). Taken together, these weaknesses describe governance systems that may withstand or recover from stress, but are not designed to improve because of it.

These shifting political, social, economic, cultural, and environmental contexts often give rise to unexpected changes, ranging from accelerated land use change (Winkler *et al.* 2021), to instability in socio-economic systems (Kozlinskis 2016) and growing political uncertainty (Baker *et al.* 2020), all of which place governance structures under considerable pressure (Hoffmann 2022). While conventional thinking would argue that, considering the above, governance systems should be robust or resilient against various stressors (Capano and Woo 2017; Folke *et al.* 2005; Walker *et al.* 2004), resilience thinking within socio-ecological systems already extends beyond preservation of the *status quo* by exhibiting characteristics such as anticipation, adaptability, reflection, innovation and transformability (Folke *et al.* 2010). This perspective emphasises learning, adjustment, and re-organisation as systems respond to changing conditions, feedback loops and, when necessary, a shift towards new configurations within. However, these systems remain primarily oriented toward coping with disturbance, absorbing shocks, adjusting practices, or, in exceptional cases, shifting to new governance regimes. They do not explicitly ask whether institutional capacity,

legitimacy, or coordination improve because of disturbance. Nor do existing assessment tools give much attention to the structural features that make such improvement more likely. This raises a more direct question: can protected area governance systems be designed to anticipate change, rather than only respond to, withstand, or adapt to it?

The concept of antifragility, as introduced by Taleb (2012), presents a useful lens for approaching this question. Antifragility describes systems that not only withstand disturbances but also improve because of them. It therefore moves beyond the concepts of robustness and resilience, which imply the ability to return to equilibrium. In contrast, antifragile systems benefit from volatility, uncertainty, and stress. Taleb (2012) explains this through a triad: (1) fragile systems are harmed by shocks and (2) resilient systems withstand them. However, (3) antifragile systems differ in that, while resilient systems resist shocks and largely remain the same, "the antifragile gets better" (Taleb 2012, 3), i.e. they, by design, learn, reorganise, and improve because of them.

Recent scholarship suggests that antifragility is attracting attention beyond its original use in risk management and finance. Axenie *et al.* (2025), for example, develop an applied antifragility framework for natural systems at ecological, evolutionary, and intervention levels. Wickman, Klausmeier, and Litchman (2026), in turn, propose antifragility as a broader concept for understanding ecological responses to environmental variability. This growing body of work provides a basis for considering its relevance to protected area governance, where institutions are also exposed to uncertainty, disturbance, and recurring stress.

In the context of protected areas, this points to a shift from static governance models towards more adaptive and reflexive arrangements that can respond to change. Antifragility does not replace resilience. It extends resilience thinking by recognising that certain forms of pressure, when properly absorbed and used for learning, can help produce stronger and more responsive governance systems.

The key distinction is therefore temporal and directional. Resilience and adaptive governance already recognise change, learning and adjustment over time. Antifragility asks a more specific question: does a manageable disturbance leave the governance system institutionally stronger than it was before the shock? In this sense, the issue is whether post-disturbance capacity, coordination, or performance exceeds the pre-disturbance baseline. Institutional strengthening is defined here as a lasting improvement in governance capacity following disturbance. This may be reflected in stronger legitimacy, clearer accountability, improved coordination across scales, more inclusive participation, greater procedural transparency, or better conservation performance than before the disturbance. Strengthening is therefore assessed comparatively, by considering conditions before and after disturbance, and temporally, by asking whether the gains persist beyond the immediate crisis response. This implies a convex institutional response to stress, where moderate disturbances produce greater institutional gains than losses. Governance structures should therefore do more than absorb shocks or adjust incrementally. They should be arranged so that manageable volatility can strengthen legitimacy, coordination, accountability or performance. Adaptive governance already recognises learning and iterative adjustment, but it does not require disturbance to result in a net institutional gain. Antifragility, by contrast, requires a directional and asymmetric response in which disturbance leaves the governance system measurably stronger than before. The distinction between resilience, adaptation, transformation, and antifragility can be understood as differing institutional trajectories under repeated

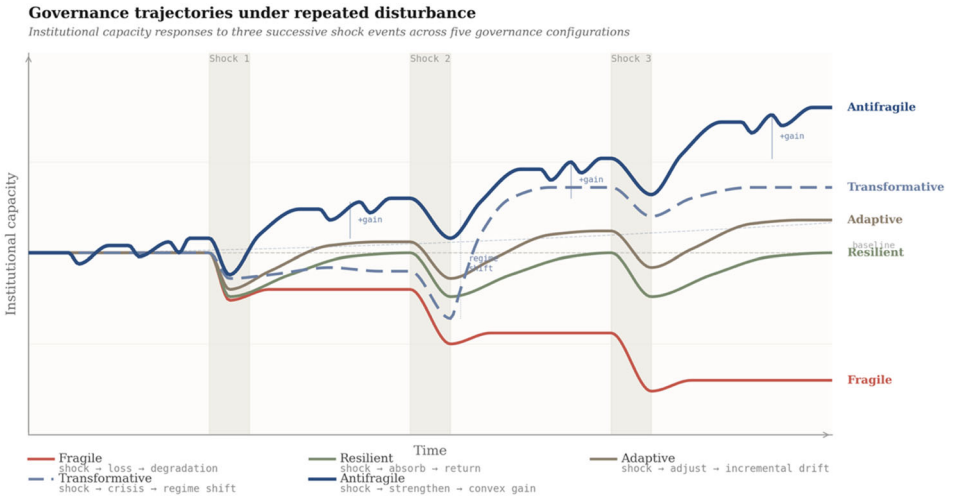


Figure 1. Illustrative institutional capacity trajectories across successive shock events for fragile, resilient, adaptive, transformative, and antifragile governance configurations. Institutional capacity represents a composite of governance quality dimensions (e.g. legitimacy, accountability, coordination, and performance). The antifragile response assumes manageable stress within institutional tolerance; catastrophic shocks may overwhelm any governance configuration. The transformative trajectory depicts a regime shift following Shock 2, after which subsequent disturbances are absorbed within the new governance regime. The "+gain" markers on the antifragile trajectory show how far each post-shock plateau exceeds the preceding pre-shock peak, illustrating asymmetric gains from moderate stress relative to losses.

disturbance (Figure 1), with antifragility characterised by a convex response in which post-shock governance capacity exceeds its pre-disturbance baseline.

Seen through this lens, the aim is not simply to preserve governance systems in their current form, but to create the structural conditions under which manageable stress can lead to institutional strengthening. This does not mean that crises or disturbances are desirable. Rather, it treats volatility not only as a risk to be managed, but also as a condition that can, under the right institutional arrangements, be used to improve governance. Such an approach could strengthen the long-term effectiveness of protected area governance and its contribution to biodiversity conservation under continued uncertainty. Table 1 provides a comparative overview of antifragility and established governance models.

The paper applies Taleb's (2012) triad of fragile-resilient-antifragile to the protected area governance principles proposed by Lockwood (2010): legitimacy, transparency, accountability, inclusiveness, fairness, connectivity, and resilience. Our aim, then, is to examine how these principles might behave under different conditions of fragility, resilience, or antifragility. In doing so, it provides a basis for evaluating whether governance arrangements are structured to degrade, merely persist, or systematically strengthen under stress.

2. Protected area governance principles

We base the analysis on Lockwood's (2010) seven principles of good governance for terrestrial protected areas: legitimacy, transparency, accountability, inclusiveness,

Table 1. Comparing governance models under disturbance.

Dimension	Resilience governance	Transformative governance	Adaptive Co-management	Antifragile governance
Primary goal under stress	Maintain function; return to prior state after disturbance, e.g., *rebuilding ranger capacity to pre-crisis levels following a budget shock.*	Shift to a fundamentally new and more appropriate governance regime, e.g., *replacing government only management with a co-governance system including other role-players*	Adjust practices iteratively through structured learning cycles, e.g., *refining managing practices each season based on monitoring data.*	Improve institutional capacity, legitimacy, and coordination because of stress, e.g., *a reserve that emerges from a security or funding crisis with stronger community institutions than it had before.*
Relationship to disturbance	Threat to be absorbed; system should buffer against shocks, e.g., *treating a drought or fire as a threat to buffer against so the park can recover to its normal state.*	Catalyst for necessary regime change when current arrangements are untenable, e.g., *a governance breakdown leading to a complete change in management approach.*	Inevitable condition requiring ongoing monitoring and response, e.g., *treating recurring human-wildlife conflict as an ongoing issue to monitor and manage.*	Structural input that, under appropriate conditions, generates institutional strengthening, e.g., *a land claim or boundary dispute that becomes the basis for a co-management agreement, rather than resulting in the loss of the protected area.*
Response asymmetry	Symmetric: absorb shock, restore equilibrium; gains do not exceed losses, e.g., *restoring infrastructure after a flood so the reserve returns to its prior state.*	Asymmetric but episodic: large disruption triggers wholesale regime shift, e.g., *a corruption scandal forcing an overhaul of the entire management authority.*	Broadly symmetric: incremental adjustments proportional to disturbance signals, e.g., *adjusting access rules by tightening or relaxing them based on monitored pressure.*	Convex: institutional gains from manageable stress systematically exceed losses; bounded downside, open upside, e.g., *a poaching crisis that leads to permanent independent audits and community oversight,, leaving the governance system stronger than it was before.*

(*Continued*)

Table 1. (*Continued*).

Dimension	Resilience governance	Transformative governance	Adaptive Co-management	Antifragile governance
Dominant response mode	Buffering, persistence, recovery, e.g., *maintaining reserve funds for use in difficult years.*	Innovation, institutional reconfiguration, regime replacement, e.g., *dissolving an ineffective management body and replacing it with a new co-management entity.*	Iterative learning-by-doing, stakeholder participation, policy revision, e.g., *revising the management plan through stakeholder workshops.*	Optionality and tinkering: reconfiguration through safe-to-fail experimentation, decentralised trials with bounded downside, and structural redundancy, e.g., *a buffer zone used to test community patrols, tourism initiatives and benefit-sharing arrangements in parallel.*
Approach to improvement	Additive: build greater absorptive capacity through additional resources or buffers, e.g., *increasing the number of rangers and improving infrastructure to withstand pressure.*	Additive: design new institutional arrangements to replace failing ones, e.g., *establishing a new management entity to replace an ineffective management board.*	Additive: introduce monitoring systems, feedback mechanisms, and revised management plans, e.g., *implementing new monitoring and feedback systems to support management decision making.*	Primarily subtractive via negativa: remove sources of fragility, naive interventionism, and perverse incentives before adding new structures, e.g., *removing failed centralised protocols after a crisis, rather than simply restoring them.*
Role of failure	To be prevented or minimised; failure signals inadequate buffering, e.g., *a rise in poaching was seen as an indication that additional buffering might be necessary.*	Failure of the existing regime is the trigger for transformation, e.g., *systemic management failure leading to a transition to a new governance regime.*	Tolerated as information; failures feed learning and adjustment, e.g., *a quota trial that failed could inform the approach for a next round.*	Actively leveraged through safe-to-fail design: small, contained failures are essential inputs that strengthen the system and prevent catastrophic collapse, e.g., *contained failures, such as spikes in poaching, trigger review cycles that strengthen monitoring and future responses.*

Exposure of decision-makers to consequences	Often insulated; centralised authority may be shielded from local impacts, e.g., *a distant head office imposing rules while local role-players bear the costs.*	Variable; transformation may be driven by affected actors or imposed externally, e.g., *reform led by affected communities or by a donor.*	Partially addressed through stakeholder participation and co-management, e.g., *stakeholder forums that allow affected groups to have a say in decision making.*	Skin in the game as structural requirement: decision-makers bear direct consequences of governance failures, aligning authority with accountability and eliminating moral hazard, e.g., *community members serving on a joint management board who experience the direct consequences of the decisions they help make.*
Capacity for decentralised experimentation	Low: standardised responses applied uniformly to maintain system stability, e.g., *a single standard operating procedure applied across the whole park.*	Low during stable periods; high during transformation windows e.g., *there is little experimentation until a crisis creates an opportunity for comprehensive change.*	Moderate: pilot projects and adaptive experiments within structured frameworks e.g., *time-bound pilot projects run under a central management plan.*	High: modular governance architecture enables concurrent, independent experiments with bounded downside (optionality and tinkering), e.g., *co-management boards and community conservancies operating different local arrangements in parallel within the same PA estate.*
Treatment of time-tested institutional forms	Valued for stability; established practices maintained unless demonstrably failing, e.g., *retaining long standing park rules because they have proved stable.*	May be discarded if identified as part of a failing regime, e.g., *scrapping certain arrangements seen as part of an outdated approach.*	Acknowledged but subject to revision through adaptive cycles, e.g., *periodically revising rules as conditions change.*	Privileged (Lindy effect): long-surviving institutions carry embedded intelligence proportional to their age; default to retaining them over untested replacements, e.g., *customary tenure and place-based institutions retained within contractual park arrangements.*

(*Continued*)

Table 1. (*Continued*).

Dimension	Resilience governance	Transformative governance	Adaptive Co-management	Antifragile governance
Temporal orientation of assessment	Point-in-time: evaluates current absorptive capacity and functional integrity, e.g., *a single score measuring management effectiveness at a specific moment.*	Before-and-after: assesses whether regime shift has occurred and whether new regime is viable, e.g., *comparing governance models prior to and following the transition to co-management.*	Cyclical: tracks adjustments across adaptive management iterations, e.g., *evaluating results after each adaptive-management cycle.*	Trajectory-based: evaluates whether institutional capacity, legitimacy, and coordination have improved across multiple disturbance episodes, e.g., *judging a reserve by whether capacity recovers beyond the pre-crisis baseline, rather than assessing it at a single point in time.*
Key design heuristics	Redundancy, buffering, diversity of response options, maintaining thresholds, e.g., *maintaining spare staff, funds, and various income streams as buffers.*	Institutional innovation, network reconfiguration, cross-scale linkages, e.g., *building new partnerships and cross-scale links to enable regime change.*	Monitoring, evaluation, stakeholder engagement, iterative policy revision, e.g., *a monitoring-and-review cycle guiding regular policy updates.*	Via negativa, skin in the game, optionality, modularity, redundancy, institutionalised learning, retention of Lindy-validated arrangements, e.g., *these design features can be combined within a single protected area governance arrangement.*
Principal limitations	Rigidity trap: over-investment in stability suppresses adaptive capacity and may produce catastrophic failure, e.g., *rigid procedures maintain park stability but hinder adaptability to shifting pressures.*	Requires crisis or threshold breach to trigger; difficult to design for in advance; high transition costs e.g., *reform is delayed until a crisis occurs, which then leads to high transition costs.*	Remains oriented toward coping; does not explicitly require or assess institutional strengthening through stress, e.g., *constant adjustments to handle pressure do not strengthen institutions.*	Requires minimum baseline institutional capacity; not suited to catastrophic or existential stress; conditions for gain must be empirically specified, e.g., antifragile gains still depend on *a minimum level of institutional stability, such as the presence of a reliable co-management partner.*

Different governance frameworks provide different ways of understanding and responding to shocks and uncertainty. This table compares resilience, transformative governance, adaptive co-management and antifragility in terms of how each engages with variability, the design choices it encourages and its main limitations.
Source. Authors' synthesis drawing on Holling (1973), Gunderson and Holling (2002), Walker *et al.* (2004), Folke (2006), Folke *et al.* (2010), Olsson, Folke, and Berkes (2004), Olsson *et al.* (2006), Chaffin *et al.* (2016), Armitage *et al.* (2009), Berkes (2009), Plummer and Armitage (2007), Lockwood (2010), Borrini-Feyerabend *et al.* (2013), Taleb (2012, 2018).

fairness, connectivity, and resilience. Although developed specifically for protected areas, the framework is consistent with broader approaches to good governance (Independent Commission on Good Governance in Public Services 2004; MSRM (Ministry of Sustainable Resource Management) 2004; UNDP (United Nations Development Programme) 1997) and can be applied across the four IUCN protected area governance types: state, private, community, and shared. The mechanisms through which the principles are expressed may, however, differ between these types. We use Lockwood's framework in preference to more recent consolidations because each principle is linked to a distinct set of observable performance outcomes. This level of detail allows us to assess how each principle may be expressed in fragile, resilient, or antifragile form. These principles serve here as a heuristic scaffold onto which antifragility dynamics are mapped, rather than as a complete diagnostic instrument. They provide a useful analytical scaffold for disaggregating governance dimensions. Since then, the IUCN (Borrini-Feyerabend *et al.* 2013) framework and the SAGE (Franks 2023) methodology have consolidated and operationalised governance around equity and effectiveness, particularly emphasising rights and performance. These frameworks, however, largely assess governance quality at a given point in time. The antifragility lens proposed here adds a trajectory-based assessment of these existing approaches by asking whether a governance system becomes stronger relative to its pre-disturbance condition. It is, therefore, intended to complement, rather than replace, established governance frameworks. Full definitions, supporting literature, and Lockwood's (2010) standard performance outcomes for each of the seven principles are provided in the Supplementary Material (Table S1). Here, we briefly introduce the principles before examining them through the fragile–resilient–antifragile triad.

Legitimacy concerns whether authority is properly mandated and accepted. Transparency refers to the openness of decisions and the reasoning behind them. Accountability concerns the extent to which governance actors are answerable in both upward and downward relationships. Inclusiveness refers to the meaningful participation of stakeholders in governance processes, including marginalised groups. Fairness concerns the equitable treatment of rights and interests, as well as the distribution of costs and benefits. Connectivity refers to vertical and horizontal coordination across governance levels and sectors. Resilience concerns the capacity to anticipate, absorb and adapt to disturbance. Each principle is considered below through the fragile–resilient–antifragile triad, rather than only in terms of its standard performance outcomes.

To operationalise the antifragility lens, we mapped each of Lockwood's (2010) governance principles onto Taleb's (2012) fragile–resilient–antifragile triad. For each principle, we asked under what conditions it would deteriorate under stress, remain functional or recover after disturbance, or produce measurable institutional strengthening beyond the pre-disturbance baseline. These states were classified as fragile, resilient and antifragile, respectively. The typology was developed through iterative discussion among the authors, drawing on the governance literature, the antifragility framework and the structural design features identified in Table 1. For each antifragile state, we required both an observable governance outcome and an identifiable structural mechanism that made the improvement possible. This reflects our view that antifragility should be understood as a property of institutional design, rather than as a fortunate outcome observed only after the event. The resulting typology presented in Table 2 should therefore be read as a diagnostic heuristic, rather than as an empirically validated classification. It provides a structured way of assessing where governance

Table 2. Principles through the lens of Taleb's triad.

Governance principle (Lockwood 2010)		Fragile	Resilient	Antifragile
Legitimacy	*Authority is legally or democratically mandated*	Legal authority exists, but it has a weak democratic grounding, being largely top-down or externally imposed.	Authority is secured through legal and democratic processes and is broadly accepted.	Mandate is stress-tested and renegotiated in periods of strain, supported by participatory review mechanisms and decentralised authority structures that reinforce legitimacy.
	Stakeholders accept the authority	Stakeholder support is often weak, disputed, or quickly withdrawn under pressure.	Stakeholder support is stable under normal conditions and enables cooperation.	Crises prompt stronger community ownership and widen the circle of trusted decision-makers through modular co-governance arrangements (optionality in authority structures).
	Cultural connection to the land is respected	Cultural ties are ignored or disrupted, producing resistance.	Cultural values are recognised and respected within governance arrangements.	Shocks drive reconnection to place-based knowledge, with institutionalised channels for incorporating local knowledge into formal decision making.
	Governing body acts in line with mandate	The mandate is inconsistently applied or set aside when inconvenient.	The mandate is consistently applied and guides decision-making.	Under pressure, the mandate is reinterpreted through structured review processes (institutionalised learning) that refine and strengthen its practical application.
	Governors act with integrity and commitment	Opportunism and weak commitment erodes trust.	Governors act with integrity and are committed to the protected area's purpose.	Integrity is tested under pressure: governors who bear the consequences of their decisions (skin in the game) emerge more committed, and lapses exposed by the crisis

				lead to lasting conduct and conflict-of-interest safeguards.
Transparency	*Decision-making is open to scrutiny*	Decisions are made behind closed doors but are notified to the public.	Processes are transparent and well-documented; information is readily available.	During crises, scrutiny intensifies, prompting redundant reporting channels and strengthened participatory oversight.
	Reasoning behind decisions is evident	Justification is unclear or frequently shifts.	Reasons are clearly explained and placed on record.	Public challenge sharpens clarity and institutionalises post-crisis justification practices that persist beyond the disturbance.
	Achievements and failures are clear	Success is overstated and failure concealed; failures are selectively shared.	Successes and failures are reported at agreed intervals.	Failures trigger formalised review cycles that identify and remove sources of governance weakness (*via negativa*) and strengthen capacity over time.
	Information is appropriate to stakeholders	Information is overly technical, hard to access, or inconsistently shared.	Communication is tailored to stakeholder needs, formats and languages.	Communication systems adapt and diversify, creating multiple pathways for information flow that enhance institutional resilience.
Accountability	*Roles and responsibilities are defined*	Duties are unclear, overlapping, or avoided in crises.	Roles are clearly defined and implemented at appropriate levels.	Roles are reallocated through modular structures that distribute authority and reduce systemic fragility.
	Governing body accepts responsibilities	Responsibility is denied under challenge; blame is shifted.	Responsibilities are accepted and carried out even under scrutiny.	Responsibility expands under conditions of incentive symmetry (skin in the game): decision-makers who internalise consequences of failure are structurally motivated to improve governance quality.

(*Continued*)

Table 2. (*Continued*).

Governance principle (Lockwood 2010)		Fragile	Resilient	Antifragile
	Downward accountability exists	No meaningful feedback channels for community recourse exist.	Formal channels enable engagement and recourse.	Conflict activates redundant engagement channels (redundancy in oversight pathways) that deepen community recourse and strengthen accountability mechanisms.
	Upward accountability exists	Oversight is weak or politicised.	Reporting and audits provide credible oversight.	Oversight structures become flexible and responsive, with independent audit mechanisms reinforced after disputes.
	Power exercised at appropriate scale	Centralised control is misaligned with local realities.	Decisions are taken at the most appropriate level of governance.	Dialogue across scales leads to decentralised and polycentric arrangements (modularity) that enhance adaptability and reduce cascade risk.
Inclusiveness	*Stakeholders can participate*	Participation is minimal or purely symbolic; influence concentrates among elites.	Clear processes ensure fair and meaningful input from multiple groups.	Negotiation or protest results in durable co-governor structures and shared decision authority, creating multiple optional pathways for participation.
	Marginalised groups are engaged	Marginalised groups are ignored or superficially consulted.	Targeted efforts engage marginalised groups in practical ways.	Marginalised groups contribute to the redesign of engagement mechanisms, embedding inclusion into institutional structure.
Fairness	*Stakeholders treated with respect*	Some stakeholders are dismissed or disrespected.	Procedural respect is evident in interactions and decisions.	Conflict strengthens institutional norms of mutual respect through formalised review processes (institutionalised learning) that embed procedural safeguards into decision making.

	Respect across governance levels	Vertical relations are adversarial or rigidly hierarchical.	Cooperative arrangements uphold mutual respect across levels.	Tension produces shared frameworks and modular collaboration mechanisms across scales.
	Decisions made without bias	Bias or favouritism evident in decisions.	Consistent policy application checks bias.	Inclusive deliberation and transparent review processes corrects bias and recalibrate institutional rules.
	Rights are respected	Rights are neglected or compromised under political pressure.	Legal rights and cultural customs are consistently respected.	Rights are reinforced and codified through post-dispute rule strengthening (convex response: the gain in rights protection exceeds the pre-disturbance baseline).
	Nature's intrinsic value respected	Ecological concerns ignored in trade-offs.	Nature is weighed alongside development objectives.	Ecological crises prompt formal integration of intrinsic value considerations into planning frameworks, creating mandatory assessment protocols (institutionalised learning) that persist beyond the immediate crisis.
	Distribution of costs/ benefits considered	Burdens fall disproportionately on some groups.	Deliberate efforts balance impacts and ensure fairness.	Contestation drives redistribution mechanisms, creating redundant and flexible cross-scale channels.
Connectivity	*Vertical connectivity*	Limited contact across levels results in silos.	Vertical coordination mechanisms in place and maintained.	Crises stimulate reform of vertical coordination mechanisms, creating redundant and flexible cross-scale channels.

(*Continued*)

Table 2. (*Continued*).

Governance principle (Lockwood 2010)		Fragile	Resilient	Antifragile
	Horizontal connectivity	Peer collaboration and learning are absent.	Coordination across peers support shared challenges and learning.	Crisis-driven networks and mutual aid systems become embedded features of governance (redundancy in horizontal coordination), strengthening connectivity beyond pre-disturbance levels.
	Alignment with higher-level governance	Local practices often contradict or ignore national/regional strategies.	Policies are aligned and periodically reviewed across levels.	Alignment becomes negotiated and adaptive, supported by optional policy pathways and flexible rule interpretation.
Resilience	*Well-established learning culture*	Learning takes place through experience, but it is often lost due to staff turnover.	Processes in place to maintain learning across staff and cycles.	Learning becomes institutionalised through formal post-event review mechanisms and mandatory feedback loops that convert disturbance information into permanent governance modifications (institutionalised learning).
	Process flexibility	Detailed policy mandates and zealous oversight constrain flexibility.	Senior staff revise processes in response to feedback.	Crises stimulate structural reconfiguration toward modular and outcome-based management systems, producing greater process flexibility than existed under pre-disturbance arrangements.
	Formal mechanisms in place to provide long term security for PAs	Management processes are designed for administrative ease rather than ecosystem resilience.	Resilience is an explicit goal of conservation management.	Disturbance leads to strengthened legal and financial safeguards that enhance long-term institutional durability.

	Adaptive planning and management used	Planning and management follow stipulated approaches irrespective of context.	Outcomes-based approaches facilitate adaptive planning and management policies.	Response to crises produces enduring planning reforms that embed optionality (multiple reversible pathways) and scenario flexibility.
	Risks identified, assessed and managed	Generic risks embedded in management policies.	Formal risk identification meetings take place at regular intervals with actions assigned.	Risk mismanagement triggers strengthened oversight, removal of failed risk protocols (via negativa), diversified mitigation strategies, and expanded early-warning systems.

*Antifragile states typically depend on structural features including incentive symmetry, redundant oversight and decision pathways, modular authority structures, optional funding and policy routes, and institutionalised learning mechanisms.

arrangements fall along the fragile-to-antifragile spectrum and where reform may strengthen their response to stress. Systematic testing across different governance types and disturbance contexts remains an important area for future research. Its value lies less in prediction than in clarifying which institutional features, supported by theory and case evidence, may allow governance systems to strengthen through disturbance and provide a basis for diagnosis and reform.

3. Principles through the lens of antifragility

To apply Taleb's triad to the seven principles, we develop a typology matrix in which we consider each principle under a fragile, resilient, or antifragile state. Although fragility, resilience, and antifragility may coexist within the same governance system and may differ across spatial and temporal scales, we treat them here as analytically distinct states to allow clearer comparison across the seven principles. The matrix should therefore be read both longitudinally, in terms of how governance changes over time, and structurally, in terms of the institutional features that shape that change. For each governance principle, antifragility requires more than improvement beyond the pre-disturbance baseline. It also depends on structural features, such as redundancy, modularity, and aligned incentives, that allow these gains to persist. The antifragile column should be interpreted as reflecting not only post-disturbance strengthening of governance principles, but the presence or emergence of structural design features, such as incentive alignment, redundancy, optionality, modularity, and institutionalised learning, that enable durable improvement under stress. Protected area examples of these antifragile states are developed further in the four case illustrations that follow (Cases 1–4).

4. Case illustrations of antifragility

Table 2 sets out how the seven governance principles may be expressed under fragile, resilient and antifragile conditions. To show its practical relevance, we draw on protected-area cases in which shocks or crises led to identifiable improvements in governance and the emergence of antifragile characteristics. In each case, disturbance led to structural changes that strengthened the governance system, often by broadening participation, clarifying mandates, or improving legitimacy. Collectively, these cases provide illustrative support for the antifragility dimension in Table 2. In each, the post-disturbance governance arrangement incorporated structural features, including co-management authority, formalised community participation and redistributed accountability, that were absent or less developed before the disturbance. Although these cases do not provide controlled before-and-after measurements of institutional capacity, they show clear directional changes that are consistent with the convex response proposed in the framework. Although these examples were not designed with antifragility in mind, they nonetheless exhibit its characteristics, illustrating how governance systems can evolve and strengthen in response to disturbances. This, in turn, highlights the potential gains of intentionally applying an antifragility lens when analysing or designing governance arrangements for protected areas. Figure 2 summarises the four cases as trajectories of governance capacity over time, showing how each moves from its pre-disturbance baseline to a stronger post-disturbance state.

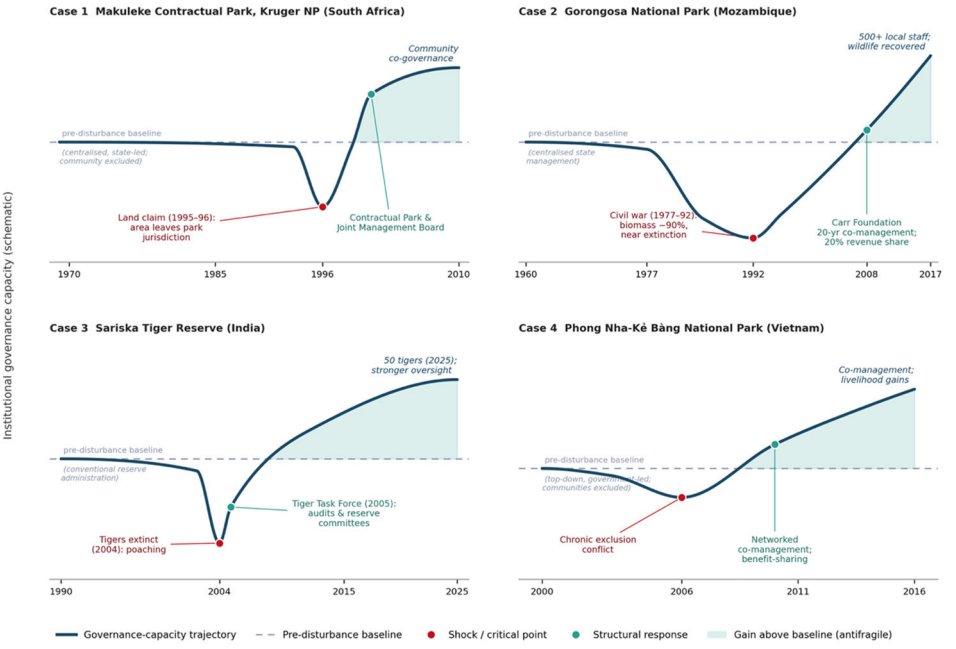


Figure 2. Process trajectories of the four protected-area cases. Each panel shows the schematic trajectory of institutional governance capacity over time: a pre-disturbance baseline (dashed line), a shock or critical point (red), a structural governance response (teal), and an elevated post-disturbance state that exceeds the baseline. The shaded area marks the gain above baseline that distinguishes a convex, antifragile response from mere recovery. Trajectories are schematic and illustrative rather than quantitative; dates and events are drawn from the case sources cited in the text.

4.1. Case 1 - Makuleke Contractual Park within the Kruger National Park, South Africa

The Makuleke region spans approximately 20,000 hectares and is located in the northernmost section of the Kruger National Park in South Africa. It was incorporated in the late 1960s, and the community that occupied the land at the time relocated (Reid 2001). In 1995, the community lodged a successful land claim, which resulted in the land being restored to their ownership in 1996, albeit with limitations on use (Reid 2001). Although some community members wished to resettle the land, the majority supported engaging with the government and the private sector to establish the area as a contractual protected area and to develop game lodges (Reid 2001). The community offered to lease the land to South African National Parks (SANParks) for a 50-year period. SANParks agreed, and as part of the agreement, a Joint Management Board comprising equal representatives of SANParks and the community was established.

The Makuleke case illustrates a high-stakes governance crisis in which a land claim effectively removed the area from the park's exclusive management jurisdiction. Rather than resulting in fragmentation or loss, the crisis was resolved through negotiation and the establishment of shared governance structures that restored legitimacy and enabled collaboration. It shows how inclusion can convert potential conflict into co-governance and reflects the antifragile expression identified in Table 2: ***Inclusiveness*** *(Stakeholders can participate)* where "negotiation or protest results in durable co-governor structures and shared decision authority."

4.2. Case 2 - Gorongosa National Park, Mozambique

Gorongosa National Park, established in 1960, spans approximately 367,000 hectares and is situated in the Sofala Province of Mozambique (Stalmans *et al.* 2019). Mozambique was engulfed in a civil war from 1977 to 1992, during which time wildlife in Gorongosa was heavily hunted, and ivory was poached to fund the conflict (Hatton, Couto, and Oglethorpe 2001). Total biomass declined by over 90% during this period (Stalmans *et al.* 2019), approaching a point of local extinction, with large herbivores being especially affected (Dutton 1994). Following the conflict, instead of reinstating the pre-war system, the Mozambican government negotiated a 20-year co-management agreement with the Gregory C. Carr Foundation to manage the park and its surroundings and to develop a sustainable tourism product (Pringle 2017). The agreement emphasised education, livelihoods, and neighbourliness. A community relations department was established to liaise with local representatives, manage a 20% revenue-sharing arrangement, employ local staff, and facilitate access through initiatives such as school field trips (Pringle 2017). The initiative resulted in a recovery of wildlife populations to nearly pre-war levels following the resumption of protection under the Carr agreement (Pringle 2017; Stalmans *et al.* 2019). Additionally, the park employed more than 500 permanent staff members in 2017, the majority of whom came from surrounding communities (Pringle 2017).

The Gorongosa case is an example of a governance system pushed to the brink of collapse, illustrating how a near-total collapse can be turned around into a conservation success. Rather than attempting to restore the pre-war model, the post-conflict partnership between the Mozambican government, local communities and the Carr Foundation redefined governance through co-management, community development, and investment in social infrastructure. It serves as an example of how a crisis can catalyse legitimacy and local ownership, illustrating the antifragile potential captured in Table 2: ***Legitimacy*** *(Stakeholders accept the authority)* where "crises prompt stronger community ownership and widen the circle of trusted decision-makers."

4.3. Case 3 - Sariska Tiger Reserve, India

The Sariska Tiger Reserve is located in the Aravalli Hills of north-western India and covers approximately 88,000 ha, of which about 27,000 ha is designated as a national park (Sankar *et al.* 2010). By 2004, tigers had been declared locally extinct in the reserve, primarily as a result of poaching (Jain and Sajjad 2016; Shahabuddin, Kumar, and Shrivastava 2007). After losing all its tigers, Sariska faced intense political pressure and widespread scepticism about its future, with some even suggesting that the land should be converted for farming since the reserve had 'no value' without its tigers (Sharma 2015). This led the Government of India to establish a Tiger Task Force in 2005 to investigate the matter (TTF 2005). The Task Force report presented the Sariska collapse as evidence of a broader weakness in India's conservation model, arguing that the protection of tigers, forests and people could not be addressed as separate issues. It contrasted recentralisation with what it described as "a participatory philosophy of institution-building" (TTF 2005, vii), and supported the latter as the basis for reform. Key recommendations included granting tiger conservation institutions greater autonomy, establishing dedicated authorities with legal powers, creating reserve level management committees with local representation, introducing independent audits and public reporting, and developing collaborative research networks to

strengthen monitoring and accountability (TTF 2005). The report also supported policies that would allow tigers, forests and people to coexist, describing this as a form of inclusive growth capable of supporting tiger conservation. By 2025, the tiger population in Sariska Tiger Reserve was reported to have recovered to 50 individuals (Pillai 2025).

The Sariska case illustrates how institutional failure can lead to broader governance reforms rather than just returning to the previous state. The crisis prompted a rethinking of risk management, oversight and participation across India's tiger reserves, illustrating the antifragile potential captured in Table 2 under ***Resilience*** *(Risks identified, assessed and managed)* where "risk mismanagement triggers strengthened oversight, removal of failed risk protocols (via negativa), diversified mitigation strategies, and expanded early-warning systems", and ***Accountability*** *(Roles and responsibilities)* where "roles are reallocated through modular structures that distribute authority and reduce systemic fragility."

4.4. Case 4 - Phong Nha-Kẻ Bàng National Park, Vietnam

Phong Nha-Kẻ Bàng National Park, located in Quảng Bình Province along Vietnam's border with Laos, covers approximately 85,000 ha of karst forest and is surrounded by a buffer zone of more than 180,000 ha (Larsen 2008). It was designated a national park in 2000 and became a UNESCO World Heritage Site in 2003 due to its exceptional geological importance. However, from the outset, governance was controlled by a top-down, government-led model that excluded many ethnic minority communities, who had long relied on forest resources for their livelihoods (Larsen 2008). This caused resource conflicts that, over time, pressured stakeholders like UNESCO to advocate for governance reform (Hübner, Phong, and Châu 2014; Larsen 2008). A co-management approach was developed, involving local community leaders, tourism operators, and NGOs in planning and decision-making processes (Hübner, Phong, and Châu 2014). This marked a major shift from strict administrative control towards a networked partnership in which the management board worked more directly with communities and local institutions to improve both conservation and livelihood outcomes (KimDung, Bush, and Mol 2016). Livelihood programmes, including participatory forest patrols, community-based tourism and benefit sharing arrangements, gradually changed how local communities viewed the park, from a place of restriction to one that also offered opportunity. Former illegal loggers and hunters became guides or forest monitors, while the buffer zone increasingly served as a space for testing how conservation and poverty reduction could be pursued together (Larsen 2008).

The PNKB case shows how sustained internal and external pressures can lead to governance renewal. Rather than returning to strict administrative control, the park moved towards co-management and collaboration among a wider group of actors. The case illustrates how governance stress can broaden participation and strengthen legitimacy. It therefore reflects the antifragile expressions identified in Table 2: ***Inclusiveness*** *(Stakeholders can participate)* where "negotiation or protest results in durable co-governor structures and shared decision authority" *and* ***Legitimacy*** *(Stakeholders accept the authority)* where "crises prompt stronger community ownership and widen the circle of trusted decision-makers."

5. Discussion and conclusion

This paper examines how seven governance principles, namely legitimacy, transparency, accountability, inclusiveness, fairness, connectivity and resilience, may be expressed under conditions of fragility, resilience and antifragility. In doing so, it shows how Taleb's triad can be used as a critical lens for understanding and strengthening protected area governance. As highlighted in Table 1, antifragility differs from resilience, which in social-ecological theory already encompasses adaptability and transformability (Folke *et al.* 2010), from adaptive governance, which emphasises iterative learning and collaboration (Chaffin, Gosnell, and Cosens 2014; Folke *et al.* 2005), and from transformative governance (Chaffin *et al.* 2016), which seeks system-wide changes. The examples discussed above show that these antifragile tendencies are not only theoretical. They can also be observed in practice, where disturbance has led to learning, reform, and renewed legitimacy. This further supports our argument that protected area governance can be designed to strengthen through stress, rather than only absorb shocks or restore its previous level of functioning after disturbance.

The distinct contribution of an antifragility lens becomes clearer when some of the same cases are considered through each framework. Gorongosa provides a useful example. A transformative-governance reading would emphasise the replacement of the pre-war, state-managed regime with a new co-management partnership, representing a deliberate shift to a different governance arrangement (Chaffin *et al.* 2016). An adaptive-governance reading would instead focus on the iterative learning and collaboration through which the partnership, communities, and park managers adjusted their practices over two decades (Chaffin, Gosnell, and Cosens 2014; Folke *et al.* 2005).

Antifragility does not displace either interpretation. It asks a more specific question: did the disturbance leave institutional capacity, legitimacy, and coordination stronger than before, and can that improvement be linked to identifiable structural changes rather than chance? In Gorongosa, several observable indicators suggest that it did. These include more than 500 permanent staff, largely recruited from neighbouring communities, a 20% revenue-sharing arrangement and a dedicated community-relations function, none of which were part of the pre-war model. These changes reflect several of the design features identified in the framework, including skin in the game, redistributed accountability and durable benefit-sharing.

The Sariska reforms can be read in the same way. They were transformative in reshaping India's tiger-conservation model and adaptive in developing new monitoring and research networks. Their antifragile character lies more specifically in the fact that the collapse produced permanent independent audits, reserve level oversight committees and the removal of failed centralised protocols (via negativa). Accountability was, therefore, left structurally stronger than before the crisis.

Read in this way, antifragility is not simply another term for transformation or adaptation. It offers a complementary diagnostic that focuses on the trajectory of institutional capacity and on the structural features that allow post-disturbance gains to persist.

Protected area governance is continually exposed to external pressures, including land use change, climate change and broader social, political and economic instability (Hoffmann 2022). These pressures are often unpredictable, volatile and non-linear in their effects. In this context, governance systems cannot rely only on withstanding shocks or adapting incrementally. They should also be designed to use disturbance as a basis for institutional strengthening. We therefore frame antifragility as a deliberate

design principle: governance arrangements should be able to learn and improve when placed under stress, rather than simply return to their previous condition.

An antifragility lens provides a way of assessing whether institutional capacity after a disturbance exceeds the pre-disturbance baseline. This depends not only on the direction of post-disturbance change, but also on the structural features already present in the governance system that allow volatility to be converted into institutional gain. Under the right conditions, policymakers and conservation authorities may be able to use disturbance to strengthen legitimacy, accountability and inclusiveness.

The typology developed in this paper provides a practical tool for reflection and design. It allows decision-makers to assess where existing governance arrangements fall along the fragile-to-antifragile spectrum, identify principles that are particularly vulnerable to failure and consider where reform may improve governance outcomes. This assessment can be applied to an individual protected area or across a wider agency, helping managers target reforms that improve adaptability and strengthen governance through stress.

Such changes may become increasingly important for the long-term effectiveness of protected areas in a changing and uncertain world. The framework can also be applied across different governance types. State-led systems may strengthen through institutional learning, while community and shared-governance arrangements may gain capacity through networked collaboration and distributed authority. Antifragility does not replace resilience or transformative governance. It extends these approaches by asking how disturbance can become a source of institutional learning and lasting improvement.

Declaration

AI-assisted tools, such as Grammarly and ChatGPT, were used for language editing, reference formatting, image generation, and to improve clarity. All substantive content, interpretations, and final decisions remain those of the authors.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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