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Comprehensive Land Consolidation and Ecological Restoration: A Review of Innovative Team-Based Approaches

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Abstract

Comprehensive land consolidation has evolved from a narrow engineering-oriented practice of plot reorganization into a holistic territorial governance strategy that integrates farmland improvement, rural settlement restructuring, and ecological restoration. This shift reflects growing recognition that land systems are coupled social–ecological systems requiring interdisciplinary intervention. Innovation in this field increasingly depends on the formation and operation of research and practice teams that combine landscape ecology, hydrology, soil science, spatial planning, remote sensing, and institutional analysis. This review synthesizes recent conceptual and methodological advances associated with innovative team-based approaches to comprehensive land consolidation and ecological restoration. It first clarifies the policy and scientific foundations of comprehensive land consolidation, then examines how interdisciplinary teams contribute to diagnostic assessment, scenario modeling, ecological network design, and adaptive monitoring. Drawing on international literature, the review highlights successful cases in which team-based integration has improved both production efficiency and ecosystem service delivery. Key challenges are then discussed, including the tension between short-term engineering targets and long-term ecological resilience, the difficulty of balancing stakeholder interests, and the need for context-sensitive restoration standards. The review concludes by identifying future directions for innovative teams, emphasizing transdisciplinary collaboration, digital twin technologies, and co-production of knowledge with local communities.

Keywords

Comprehensive Land Consolidation; Ecological Restoration; Interdisciplinary Teams; Ecosystem Services; Land System Governance.

1. Introduction

Land consolidation has traditionally been understood as a set of technical and administrative procedures for reducing farmland fragmentation, improving field accessibility, and upgrading rural infrastructure (Long, 2014). In China and many other rapidly urbanizing regions, however, the goals of land consolidation have expanded substantially. The concept of comprehensive land consolidation now encompasses the coordinated reorganization of cultivated land, rural settlements, water networks, forest patches, and ecological corridors within a defined territorial unit (Liu et al., 2014). At the same time, ecological restoration has moved from site-

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specific revegetation toward landscape-scale interventions that aim to recover biodiversity, hydrological connectivity, and ecosystem services (Suding, 2011). These two trajectories have converged, giving rise to integrated programs that treat land consolidation and ecological restoration as mutually reinforcing components of territorial governance.

This convergence must be understood within the broader framework of land system science, which examines land change as a coupled human–environment process operating across multiple scales (Verburg et al., 2015). Land use transitions research further reveals that consolidation and restoration are not static technical fixes but dynamic responses to shifting rural development stages (Long & Qu, 2018). The complexity of these processes cannot be managed by single-discipline teams. Effective comprehensive land consolidation requires simultaneous attention to soil productivity, water balance, habitat connectivity, cultural landscape values, property rights, and rural livelihoods. Consequently, innovative teams—comprising geographers, ecologists, engineers, planners, data scientists, and social scientists—have become central to both research and practice. Liu and Li (2017) argue that rural revitalization and land-system sustainability depend on precisely such integrative capacities. Bryan et al. (2018) similarly emphasize that addressing China's land-system sustainability emergency requires cross-sectoral and cross-scale scientific cooperation. More broadly, transdisciplinary research—defined as the co-production of knowledge across academic disciplines and with societal actors—has been identified as a core requirement for sustainability science (Lang et al., 2012).

This review synthesizes the contributions of innovative team-based approaches to comprehensive land consolidation and ecological restoration. Section 2 defines the conceptual and policy foundations. Section 3 examines methodological innovations. Section 4 reviews empirical evidence and applications. Section 5 discusses persistent challenges and future directions.

2. Conceptual and Policy Foundations

Comprehensive land consolidation differs from conventional land consolidation in at least three respects. First, its spatial unit is not the individual farm plot but the whole territorial system, including production, living, and ecological spaces. Second, its objectives are not limited to agricultural productivity; they also include ecological security, rural settlement improvement, and cultural heritage preservation. Third, its instruments are no longer confined to earthworks and cadastral adjustment but extend to land-use zoning, ecological engineering, and institutional reform (Long, 2014; Liu et al., 2014).

This broadening reflects the ecosystem service paradigm. Land consolidation projects can enhance provisioning services through farmland improvement, but they may also degrade regulating and cultural services if they simplify landscape structure, channelize streams, or remove semi-natural habitats. Understanding the relationships among multiple ecosystem services is therefore critical, because trade-offs and synergies are often nonlinear and context-dependent (Bennett et al., 2009). Decision-making frameworks must explicitly account for these interactions if ecosystem services are to be maintained rather than inadvertently diminished (Daily et al., 2009). Ecological restoration, by contrast, explicitly targets the recovery of biodiversity and regulating services (Rey Benayas et al., 2009). Therefore, integrating restoration principles into land consolidation is essential to avoid trade-offs and generate synergies. Keesstra et al. (2018) show that nature-based solutions in land management can deliver multiple ecosystem services while improving soil health and water regulation.

Resilience thinking provides an additional conceptual foundation. Ecosystems do not respond linearly to management interventions; they may undergo regime shifts when critical thresholds

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are crossed (Folke et al., 2004). Land consolidation that ignores these dynamics risks pushing landscapes into degraded states that are difficult to reverse. At the same time, restoration goals must be framed with an awareness that many consolidated landscapes are unlikely to return to historical reference conditions; they may instead become novel ecosystems with new species combinations and functions (Hobbs et al., 2009). This perspective calls for flexible, process-based restoration targets rather than rigid historical baselines.

Policy frameworks increasingly support such integration. China's rural revitalization strategy and the global UN Decade on Ecosystem Restoration both call for holistic land management. However, translating policy aspirations into operational practice requires teams capable of linking strategic planning with site-level engineering and long-term monitoring.

3. Methodological Innovations by Interdisciplinary Teams

Innovative teams contribute to comprehensive land consolidation and ecological restoration through several methodological pathways: integrated diagnostic assessment, scenario-based spatial modeling, ecological network design, and adaptive monitoring.

Integrated diagnostic assessment. Before intervention, teams combine land-use mapping, soil sampling, hydrological modeling, biodiversity surveys, and socioeconomic interviews to identify constraints and opportunities. This multifunctional diagnosis helps avoid the narrow focus on plot geometry that characterized earlier consolidation programs (Long, 2014). Liu et al. (2014) demonstrate that such assessments can reveal hidden trade-offs between grain production and ecosystem protection, enabling planners to designate ecological redlines and high-standard farmland zones more rationally. The ecosystem service framework offers a useful common language for integrating biophysical and socioeconomic data in these assessments (Daily et al., 2009).

Scenario-based spatial modeling. Interdisciplinary teams increasingly use geographic information systems and land-use change models to simulate alternative consolidation and restoration scenarios. These models integrate biophysical data with policy constraints and stakeholder preferences. By comparing scenarios, teams can identify spatial configurations that maximize co-benefits across food production, flood regulation, carbon storage, and habitat connectivity (Bryan et al., 2018). Scenario modeling is particularly valuable in comprehensive land consolidation because interventions are difficult to reverse, and spatial lock-in effects are strong. The development of integrated planning and decision support systems has been shown to improve the transparency and effectiveness of consolidation decisions by allowing stakeholders to visualize trade-offs among land-use options (Demetriou et al., 2012).

Ecological network design. A central task for innovative teams is to design or restore ecological corridors, stepping-stone habitats, and buffer zones within consolidated landscapes. Principles from landscape ecology guide the selection of source habitats, the identification of movement pathways, and the placement of ecological nodes. When combined with farmland consolidation, such designs can maintain or enhance landscape connectivity even as field sizes increase and irrigation networks are modernized (Keesstra et al., 2018). Chazdon (2008) emphasizes that restoring forest patches and riparian buffers on degraded lands can deliver disproportionate biodiversity benefits while requiring relatively small areas. However, forest landscape restoration must be guided by clear definitions of what constitutes a forest, because ambiguous criteria can lead to inflated restoration claims or inappropriate tree planting (Chazdon et al., 2016). Successful forest landscape restoration requires not only increasing tree cover but also improving ecological functionality and delivering tangible benefits to local communities (Mansourian et al., 2017).

Adaptive monitoring and evaluation. Because ecological responses to land consolidation are uncertain and often delayed, innovative teams advocate adaptive management frameworks.

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Suding (2011) argues that restoration ecology has entered an era in which success is judged not merely by vegetation establishment but by ecosystem function, resilience, and stakeholder satisfaction. Resilience-based monitoring approaches emphasize early warning indicators of regime shifts, enabling managers to intervene before undesirable thresholds are crossed (Folke et al., 2004). Teams that integrate ecological monitoring with social evaluation can adjust management practices iteratively, improving long-term outcomes.

4. Case Evidence and Applications

Empirical studies illustrate both the potential and the complexity of integrating land consolidation and ecological restoration. In China's rapidly urbanizing regions, comprehensive land consolidation projects have been used to consolidate fragmented cropland, relocate scattered rural settlements, and restore degraded hillsides and wetlands. Long (2014) documents how spatial restructuring through land consolidation can release land for ecological uses while improving rural living conditions. However, he also cautions that engineering-dominated projects may homogenize landscapes and reduce habitat diversity if ecological criteria are not embedded from the outset. The mutual feedback between land use transitions and land management practices further complicates outcomes, as consolidation decisions made today constrain future adaptation options (Long & Qu, 2018).

At the national scale, Bryan et al. (2018) show that land-system change in China is approaching critical sustainability thresholds, with trade-offs among food production, water security, and biodiversity becoming increasingly acute. They argue that integrated land consolidation and restoration, supported by scientific teams, can help navigate these trade-offs by identifying priority areas for protection and restoration. Their analysis underscores the need for cross-scale coordination: local engineering decisions must be informed by regional and national sustainability goals.

International evidence reinforces these findings. Rey Benayas et al. (2009), in a global meta-analysis, find that ecological restoration increases biodiversity and ecosystem services by substantial margins, although restored systems rarely reach the condition of undisturbed reference ecosystems. This implies that restoration within land consolidation should be designed to complement, rather than replace, the conservation of existing natural habitats. The concept of novel ecosystems further suggests that some consolidated landscapes may settle into alternative stable states that nonetheless provide valuable services (Hobbs et al., 2009). Palmer et al. (2014) similarly emphasize that river and stream restoration must address the root causes of degradation—such as altered flow regimes and excess nutrients—rather than merely reshaping channels. These lessons are directly applicable to the water network components of comprehensive land consolidation.

Team-based projects that integrate land consolidation with riparian restoration, wetland rehabilitation, and agroforestry have demonstrated measurable improvements in water quality, flood attenuation, and biodiversity. Perring et al. (2015) highlight that successful landscape-scale restoration requires a clear articulation of goals, an understanding of ecological trajectories, and the capacity to manage for multiple possible outcomes. Forest landscape restoration, in particular, has emerged as a promising approach for delivering both ecological and livelihood benefits at scale, provided that restoration objectives are co-defined with local stakeholders and that ecological functionality is prioritized over simple tree planting (Mansourian et al., 2017). This is especially relevant for consolidated landscapes, where soil conditions, hydrology, and species pools have been substantially altered by previous land use.

5. Challenges and Future Research Directions

Despite progress, innovative teams face several persistent challenges.

First, there is a tension between the short-term, engineering-oriented culture of land consolidation and the long-term, process-oriented nature of ecological recovery. Construction timelines and performance targets often favor visible physical outputs, such as newly leveled fields or lined canals, over ecological processes that may take decades to mature (Suding, 2011). Teams must therefore advocate for contractual and institutional arrangements that allow for phased restoration and extended post-project monitoring.

Second, balancing stakeholder interests remains difficult. Land consolidation redistributes property rights and changes access to land, water, and ecosystem services. Without robust participatory mechanisms, ecological restoration goals may be captured by powerful actors or perceived as imposing costs on local farmers (Liu & Li, 2017). Transdisciplinary approaches, in which researchers, practitioners, and local communities jointly define problems, generate knowledge, and evaluate outcomes, have been proposed as a means to enhance legitimacy and relevance (Lang et al., 2012). However, such approaches require time, trust, and facilitation skills that are not always rewarded in project-based funding systems.

Third, context sensitivity is essential. Ecological restoration standards developed in one region may not transfer directly to another because of differences in climate, soils, species composition, and socio-economic conditions. The international standards for ecological restoration emphasize that principles must be adapted to local ecological and cultural contexts (Gann et al., 2019). Teams must therefore resist blueprint approaches and invest in site-specific diagnosis and experimentation. The recognition of novel ecosystems further cautions against universally applied historical baselines; restoration targets may need to be adjusted to reflect irreversible environmental changes (Hobbs et al., 2009).

Fourth, data integration and technological capacity remain uneven. Although remote sensing, drones, and environmental sensors have greatly improved the ability to monitor landscape change, many land consolidation agencies lack the analytical capacity to convert raw data into actionable knowledge. Land system science offers integrative frameworks for synthesizing multi-source data across scales, but realizing this potential requires sustained investment in data infrastructure and training (Verburg et al., 2015). Future innovative teams should strengthen digital infrastructure, develop user-friendly decision-support tools, and train local practitioners in data interpretation (Perring et al., 2015). Digital twin technologies, which create dynamic virtual representations of landscapes, offer promising avenues for testing consolidation and restoration scenarios before implementation.

Finally, stronger links between science and policy are needed. Comprehensive land consolidation and ecological restoration are policy-intensive fields, yet scientific findings are often weakly integrated into planning standards and evaluation criteria. Teams that include policy analysts and institutional scholars can help translate ecological principles into enforceable guidelines, performance indicators, and incentive mechanisms (Bryan et al., 2018). Decision support systems that make ecosystem service trade-offs transparent can facilitate this translation by providing policy makers with accessible, evidence-based scenarios (Daily et al., 2009; Demetriou et al., 2012).

6. Conclusion

Comprehensive land consolidation and ecological restoration represent a frontier of integrated territorial governance. Their success depends on the ability to manage coupled social–ecological systems across multiple scales and sectors. Innovative interdisciplinary teams are indispensable to this task, providing the diagnostic, modeling, design, and monitoring capacities required to align agricultural productivity with ecological resilience. The literature reviewed here shows that when ecological principles are embedded early in the planning process, land consolidation can generate significant co-benefits for biodiversity, water regulation, and rural livelihoods. However, persistent institutional, participatory, and technical challenges must be addressed through adaptive management, stakeholder co-production, context-sensitive standards, and stronger science–policy integration. Future research should develop comparative frameworks to evaluate team-based interventions across diverse socio-ecological settings and invest in digital tools that support evidence-based, adaptive governance of consolidated landscapes.

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