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CHAPTER 2

Connectivity science and the Central Forest Spine: Reconnecting a fragmented future

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Abstract: The Central Forest Spine (CFS) represents Malaysia's flagship initiative to restore ecological connectivity across fragmented tropical forests. Spanning 6.71 million hectares and 39 ecological linkages, the CFS aims to maintain biodiversity and ecosystem functions amid expanding infrastructure and land-use change. This paper reviews the scientific foundations of connectivity conservation and assesses progress under the CFS Master Plan for Ecological Linkages 2022–2040, with emphasis on lessons from the UNDP–GEF Improving Connectivity in the Central Forest Spine Landscape (IC-CFS) project (2015–2024). The findings show that while initiatives such as corridor restoration, biodiversity monitoring protocols, and SMART patrolling have strengthened conservation governance, persistent gaps remain in legal institutionalisation, long-term financing, and federal–state coordination. Embedding connectivity within spatial planning, infrastructure design, and fiscal mechanisms such as the Ecological Fiscal Transfer (EFT) is critical to sustaining outcomes. It further examines how wildlife drives the recovery of degraded habitats, and how forest connectivity supports water regulation and other ecosystem functions at the river-basin scale. The paper elaborates on challenges faced in the implementation of CFS Master Plan and concludes with policy directions to advance the CFS as Malaysia's central ecological network supporting biodiversity, climate resilience, and sustainable development.

INTRODUCTION

Connectivity science teaches us that survival is not about isolation but interaction, between forests and fields, rivers and roads, people and planet. In reconnecting our landscapes, we are also restoring balance between progress and protection, between the needs of today and the hopes of tomorrow. – Adapted from Hilty *et al.* (2019)

Landscape fragmentation remains one of the primary threats to biodiversity in tropical regions. Across Peninsular Malaysia, ancient forests form a living network of life, stretching from the montane peaks of the Titiwangsa Range to the lowland dipterocarp forests of Pahang and Johor (FDPM 2022). The total forest area in Peninsular Malaysia, which spans approximately 4.69 million hectares or about 43% of the region's total land area, is characterised by a patchwork of forested landscapes rather than a single, uninterrupted expanse. These forests are vital for maintaining biodiversity, regulating climate, protecting watersheds, and supporting local communities. This forest network is now under threat as expanding infrastructure, plantations, and urbanisation fragment once continuous landscapes. The resulting isolation of forest patches impedes wildlife movement, gene flow, and ecosystem functions, threatening the persistence of wide-ranging species such as the Malayan tiger (*Panthera tigris jacksoni*), Asian elephant (*Elephas maximus*), and Malayan tapir (*Tapirus indicus*).

Connectivity science offers both insight and solutions, helping us understand how ecosystems, species, and people remain linked across space and time, and how these vital relationships can be restored. In Peninsular Malaysia, this vision takes shape through the

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CFS, a bold national effort to reconnect fragmented forests into a continuous ecological corridor. The CFS represents not only scientific determination, but also a lasting promise that Malaysia's forests will remain whole for generations to come.

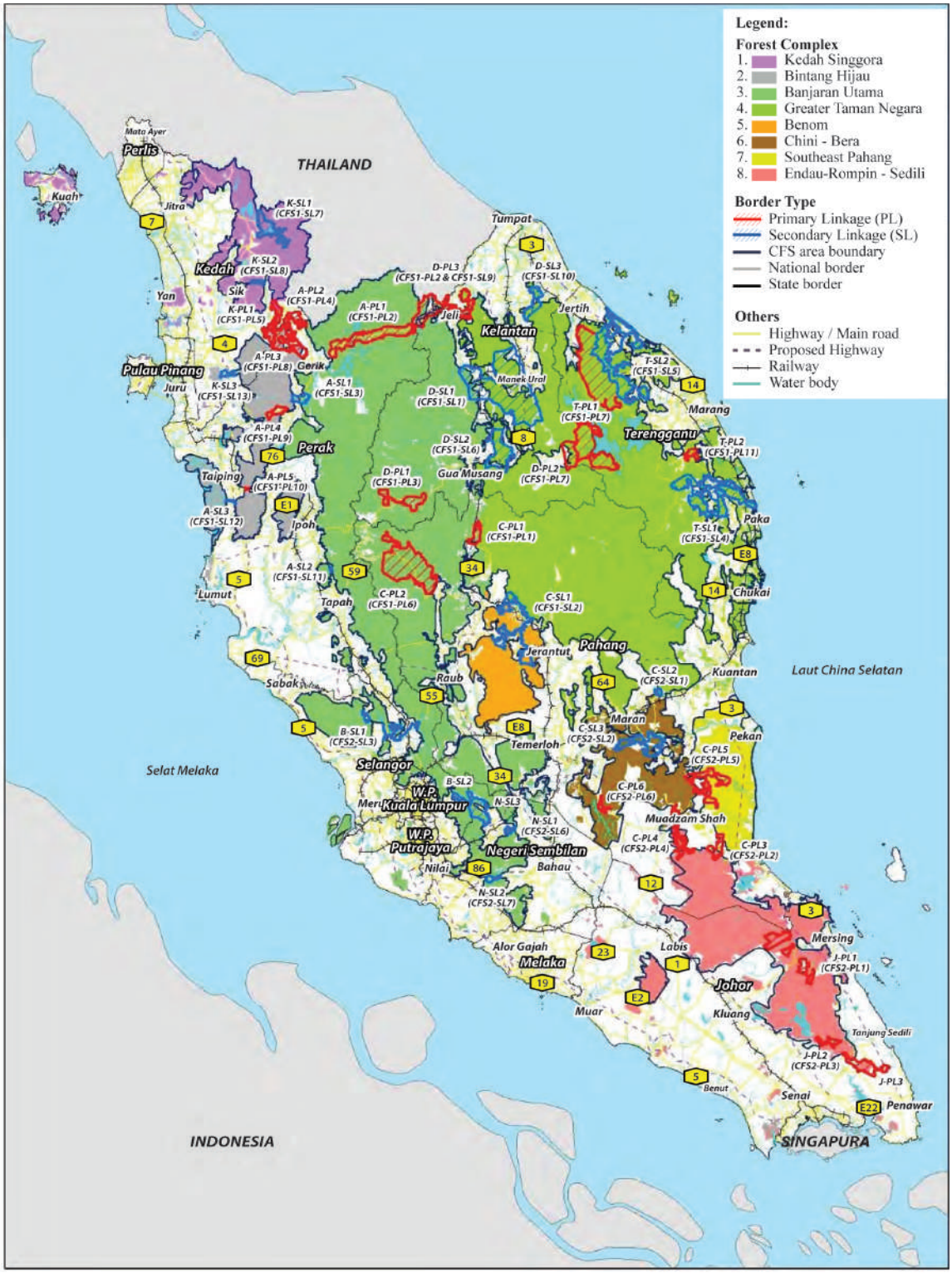

Figure 1. The CFS boundaries for the CFS Ecological Network Master Plan 2022, include coastal forest areas (PLANMalaysia 2022).

As the national blueprint to keep remaining forests connected across a mosaic of protected areas and national / state parks, Permanent Reserved Forests (PRF), state land forests, and other lands, the CFS totals 6.71 million hectares in area (PLANMalaysia 2022). It spans across eight states in Peninsular Malaysia: Kedah, Perak, Kelantan, Terengganu, Johor, Pahang, Selangor, and Negeri Sembilan and consists of eight major forest complexes, namely Titiwangsa Range-Bintang Range-Nakawan Range, National Park-Timur Range, Southeast Pahang, Chini and Bera Wetlands, and Endau Rompin National Park-Kluang Wildlife Reserve (Figure 1). The CFS has identified 39 ecological linkages comprising 20 Primary Linkages and 19 Secondary Linkages, and its implementation is guided by the Master Plan for Ecological Linkages Central Forest Spine 2022–2040 [a], which reinforces the vision, revised actions to be implemented, and stakeholder roles for restoring and maintaining these linkages (PLANMalaysia 2022). The plan outlines five main objectives, 14 strategies, and 38 specified actions.

THEORETICAL FOUNDATIONS OF CONNECTIVITY SCIENCE

Connectivity science provides a robust conceptual and empirical framework to understand and manage ecological flows of organisms, genes, water, and nutrients across complex landscapes. It integrates structural connectivity, referring to the physical configuration and spatial arrangement of habitat patches and corridors, and functional connectivity, which captures the realised movement of species and ecological processes (Taylor *et al.* 1993; Crooks and Sanjayan 2006; Meiklejohn *et al.* 2019). This dual perspective (structural connectivity and functional connectivity) is essential for assessing how landscapes support biodiversity and ecosystem function amid increasing habitat fragmentation.

Globally, research demonstrates that ecological networks and corridors enhance landscape resilience and biodiversity persistence when incorporated into spatial and development planning (Bennett and Mulongoy 2006; Hilty *et al.* 2020). Initiatives such as the Terai Arc Landscape (India-Nepal), the Yellowstone to Yukon (Y2Y) initiative (North America), and Europe's Natura 2000 network illustrate the power of connectivity science in driving effective landscape-scale conservation and cross-jurisdictional cooperation (Chester 2015; Jongman *et al.* 2021; Y2Y 2023). These examples show that durable connectivity outcomes require not only sound ecological design but also institutional frameworks that embed connectivity principles into planning, infrastructure, and finance.

In Malaysia, empirical research has confirmed the critical role of functional connectivity in sustaining viable populations of forest-dependent wildlife. For example, habitat rehabilitation and tree planting within CFS ecological linkages have restored degraded lands and enhanced wildlife movement through former barrier zones (FDPM 2024). At the same time, studies highlight persistent governance and land-use barriers that hinder effective implementation, including overlapping land tenure, inconsistent policy coordination, and competing development priorities (Maniam and Singaravelloo 2015; Aliman 2019).

These findings affirm that connectivity is measurable, mappable, and actionable. When integrated with spatial planning, infrastructure design, and governance systems, connectivity science becomes a practical guide for prioritising conservation investments, designing wildlife crossings, and restoring ecological linkages. Embedding connectivity science into Malaysia's national and state policies can therefore help safeguard biodiversity, sustain ecosystem services, and reduce human-wildlife conflicts, creating living landscapes that support both nature and society.

[a] In 2022, this new master plan replaced the original Central Forest Spine Master Plan 2010 after undergoing an evaluation for achievements and effectiveness.

Wildlife as agents of ecosystem recovery

Connectivity is usually framed as a means of allowing wildlife to move between habitat patches. The reverse relationship is equally important: wildlife moving through ecological linkages actively shapes how degraded habitats recover. In tropical forests, an estimated 70 – 90% of woody plant species depend on vertebrates to disperse their seeds (Howe and Smallwood 1982; Corlett 2017). Hornbills, pigeons, bulbuls, primates, civets and fruit bats carry seeds from intact forest into regenerating land, while the Asian elephant disperses large-seeded species that few other animals can move, a role that has earned it the description of a "megagardener" of the forest (Campos-Arceiz and Blake 2011). Not all large mammals perform this role equally; the Malayan tapir, for example, is a far less effective disperser of large seeds than the elephant (Campos-Arceiz *et al*. 2012). This underlines the value of retaining a diverse community of seed dispersers rather than relying on a single flagship species.

Wildlife therefore influences both the direction and the pace of succession. On degraded land, natural regeneration is frequently limited not only by soil conditions but by the failure of seeds to arrive, particularly the larger seeds of animal-dispersed, shade-tolerant trees (Wunderle 1997; Chazdon 2008). Sites that frugivores visit regularly tend to progress from pioneer-dominated vegetation towards a more diverse, mature forest composition, whereas sites cut off from dispersers can stall at a grass, fern or pioneer stage for decades. Other animal groups also shape this trajectory: pollinators such as bees and bats sustain the reproduction of planted and colonising trees; seed predators and browsers, including wild pig and deer, filter which species establish; dung beetles bury seeds and recycle nutrients; and elephants open gaps and trails that create new regeneration niches. Conversely, where hunting removes large frugivores, tree communities shift towards small-seeded and wind- or gravity-dispersed species, as demonstrated in defaunated forest in Sarawak (Harrison *et al.* 2013).

For the CFS, this has two practical implications. First, connectivity and restoration reinforce each other. Planting "framework" species that grow quickly and flower or fruit early attracts seed-dispersing animals, which in turn bring in seeds of many further species and accelerate recovery beyond what planting alone can achieve (Elliott *et al.* 2003); the Assisted Natural Regeneration approach applied under the IC-CFS project relies on this process. Second, a linkage that is structurally restored but emptied of its dispersers through poaching, snaring or disturbance will recover slowly, if at all. Monitoring of restored CFS linkages should therefore track not only tree survival and canopy cover, but also frugivore visitation, recruitment of non-planted species, and the shift from pioneer to mature-phase composition, as evidence that wildlife-mediated succession is under way.

STATUS OF THE CFS IMPLEMENTATION

Since its launch in 2010, CFS has progressed unevenly from policy conception to on-ground implementation. The Central Forest Spine Master Plan for Ecological Linkages 2022–2040 (*Pelan Induk Rangkaian Ekologi CFS 2022–2040*) replaced the original 2010 Master Plan, updating the vision, objectives, and institutional mechanisms for restoring and maintaining ecological connectivity across Peninsular Malaysia (PLANMalaysia 2022). This revision reflects a growing recognition that ecological linkages cannot be sustained through federal planning alone, but require continuous coordination between federal and state institutions, a challenge long noted by Maniam (2019) in her analysis of the federal-state dynamics shaping the CFS's implementation trajectory and Aliman's (2019) work on fiscal incentives.

Between 2015 and 2024, the UNDP-GEF-funded Improving Connectivity in the Central Forest Spine Landscape (IC-CFS) project provided significant technical and financial impetus to the initiative. With in-kind contributions from the Government of Malaysia, the

project operationalised selected ecological corridors [b] through habitat restoration, wildlife crossing structures, and community engagement in priority landscapes (UNDP 2023). These interventions have demonstrated the viability of collaborative models involving federal agencies, state forestry departments, and NGOs. However, Maniam (2019) underscores that such project-based mechanisms often operate within administrative silos, limiting their capacity to institutionalise cross-sectoral cooperation beyond the project's lifespan.

At state level, CFS Technical Committees were established and linked to the National Steering Committee, but their performance remains uneven. States such as Perak, Pahang, and Johor have advanced corridor restoration, while others face constraints from competing land-use pressures including plantation expansion, infrastructure development, and quarrying (Maniam and Singaravelloo 2015; Aliman 2019). To move the CFS from a master plan to a functioning landscape governance framework, Maniam's (2019) recommendation to institutionalise the CFS within statutory state planning documents (such as State Structure Plans and Local Plans) was pursued under the IC-CFS project, backed by enforceable guidelines and incentives for compliance. However, it still lacks legal force, coupled with sustainable financing for long-term monitoring, maintenance, and stakeholder coordination.

The IC-CFS project delivered substantial progress in strengthening the enabling environment for ecological connectivity within Peninsular Malaysia. By project completion, 664.26 hectares of degraded forests across Perak (489.16 ha), Pahang (152.00 ha), and Johor (23.10 ha) were rehabilitated using native species under the Assisted Natural Regeneration method. A total of 32,783 hectares of state land were gazetted as PRF, exceeding the initial project target. SMART patrolling systems were institutionalised across pilot states, enhancing enforcement capacity against illegal logging and wildlife crime. The project also developed the Biodiversity Monitoring Protocol and Ecosystem Services Assessment using InVEST, now integrated into Forestry Department of Peninsular Malaysia (FDPM)'s One Stop Centre for CFS data management. Moreover, four district local plans and three state structural plans incorporated CFS ecological corridors, ensuring long-term spatial protection. Through its community-based initiatives, including non-consumptive ecotourism and indigenous livelihood programmes, the IC-CFS demonstrated that restoring forest connectivity could be harmonised with local socio-economic resilience (UNDP 2023; FDPM 2024).

Despite progress, many priority linkages remain degraded or blocked by linear infrastructure and monoculture plantations. Monitoring and enforcement remain inconsistent, with ecological assessments varying across taxa and jurisdictions. Maniam (2019) noted that monitoring often depends on ad-hoc project funding, a situation still evident today. Recognising these fiscal constraints, Malaysia has introduced new financing instruments: the Ecological Fiscal Transfer (EFT) mechanism under the Twelfth Malaysia Plan (2021–2025). EFT provides performance-based state allocations for forest and biodiversity conservation. The Malaysian Forest Fund (MFF) was also established in 2021 to implement the national REDD+ Finance Framework and mobilises federal, state, and private-sector resources for forest-connectivity and conservation investments. Aligning the CFS with both the EFT and MFF could operationalise Maniam's (2019) call for stronger fiscal instruments that reconcile federal ecological goals with state development needs, ensuring sustained funding for

[b] The IC-CFS project was implemented across three priority ecological corridors identified under the CFS Master Plan: (1) CFS A-PL1 Temengor FR-Amanjaya FR-Belum FR, Perak, (2) CFS C-PL1 Sungai Yu FR-Tanum, Pahang, and (3) CFS J-PL2 Panti FR-Ulu Sedili FR, Johor. These corridors were selected for their ecological significance in maintaining connectivity between major forest complexes and tiger priority landscapes. The project involved multiple interventions, including the preparation of Special Management Plans, establishment of reforestation plots, installation of SMART patrol and intelligence systems, and integration of corridor boundaries into state and district spatial plans (UNDP 2023; FDPM 2024).

monitoring, maintenance, and connectivity restoration. However, key implementation gaps remain, including:

- Absence of legal recognition of ecological linkages within state-level spatial and land-use planning instruments;
- Limited long-term financing for maintenance and adaptive management; and,
- Weak institutional integration at the state-level between conservation planning and economic development decision-making.

Besides that, Malaysia's expanding road network, now nearing 290,000 kilometres [c] (JKR 2023), has become a major driver of forest fragmentation, disrupting wildlife movement and severing ecological linkages central to the CFS (Wadey *et al.* 2018; Hui *et al.* 2021). Roadkill and movement studies identify consistent hotspots along highways adjacent to forest reserves in Pahang, Kelantan and Johor (Norhafezah Kasmuri *et al.* 2021). Recent analyses demonstrate that engineered wildlife crossings and underpasses, when appropriately sited, are frequently used by elephants, tapirs and other vertebrates (Jasme *et al.* 2022). However, without nationwide road-ecology standards and mandatory connectivity assessments, these linear infrastructures will continue to undermine the ecological functionality of the CFS despite ongoing restoration efforts.

While the CFS 2022–2040 Master Plan and IC-CFS project have enhanced technical clarity and stakeholder engagement, enduring challenges in federal-state coordination, legal integration, and long-term financing continue to constrain the full realisation of the CFS vision of an ecologically connected Peninsular Malaysia (Maniam 2019; PLANMalaysia 2022; FDPM 2023).

CONNECTIVITY BEYOND WILDLIFE: WATER AND CATCHMENT FUNCTIONS

Connectivity in the CFS has largely been justified by the movement needs of wide-ranging mammals. Yet Peninsular Malaysia's forests are also the headwaters of its major rivers, and national policy has long recognised this link at the river-basin scale. The Malaysian National Conservation Strategy (EPU 1993) was among the first national documents to connect forest conservation with the protection of water catchments. The National Physical Plan, in which the CFS concept itself originated, classifies forests and water catchments as Environmentally Sensitive Areas (PLANMalaysia 2021). The National Water Resources Policy adopts Integrated River Basin Management (IRBM) as the basis for managing the nation's water (NRE 2012), and the National Policy on Biological Diversity 2022–2030 emphasises the conservation of ecosystems and the services they provide at the landscape level (KeTSA 2022). These river-basin perspectives are, however, not yet systematically reflected in how CFS linkages are prioritised, restored and monitored.

How much a forest contributes to water regulation depends on its size, ecological condition and position within the catchment. Large, intact blocks in headwater areas maintain high soil infiltration, sustain dry-season baseflow and keep sediment yields low; much of this benefit comes from undisturbed soils and litter layers rather than from tree cover alone (Bruijnzeel 2004). Small or degraded fragments have a higher proportion of edge exposed to drying and disturbance (Laurance et al. 2011), and often more compacted

[c] According to the Buku Statistik Jalan Malaysia Edisi 2023 published by Jabatan Kerja Raya Malaysia (JKR), the total length of Malaysia's federal and state roads as of 31 December 2022 stood at 289,996.655 kilometres, comprising 20,017.97 km of federal roads and 269,978.685 km of state roads (JKR. 2023. *Buku Statistik Jalan Malaysia Edisi 2023*. Kuala Lumpur: Jabatan Kerja Raya Malaysia).

and exposed soils, so their hydrological contribution per hectare is lower and less reliable. Riparian forest contributes disproportionately for its area by trapping sediment and nutrients, stabilising banks and shading streams (Luke *et al*. 2019). Reconnecting fragments, especially along watercourses, therefore does more than open a route for wildlife. It lengthens continuous riparian cover, reduces the edge-to-area ratio of the remaining forest, and links the hydrological functions of separate patches into a catchment-wide system (Mitchell *et al.* 2013).

Case study: CFS A-PL1 Temengor FR–Amanjaya FR–Belum FR, Perak

The A-PL1 linkage illustrates these wider functions. The Belum-Temengor forest complex forms the upper catchment of the Sungai Perak, the state's principal river, and drains into the Temengor reservoir, the uppermost of a cascade of hydroelectric dams along the river. The East–West Highway (Gerik–Jeli) divides this forest into northern and southern blocks, and the A-PL1 linkage through Amanjaya Forest Reserve is intended to reconnect them. Perak, where this linkage lies, accounted for 489.16 ha of the forest rehabilitated under the IC-CFS project.

Viewed through a catchment lens, the value of this linkage extends well beyond elephant and tiger movement. The large intact blocks of Royal Belum State Park and Temengor Forest Reserve would be expected to supply most of the baseflow and sediment retention; the logged-over and degraded forest along the highway corridor, together with land cleared for road works and settlements, presents a higher erosion risk close to the reservoir; and small riparian fragments along tributaries influence how much of that sediment reaches the water. Restoring forest across the linkage should therefore reduce sediment delivery to the reservoir, protecting storage capacity and hydropower generation, while sustaining water supply and flood regulation for downstream communities. An in-depth assessment would compare sub-catchments containing large, medium and small forest fragments of differing ecological quality, before and after restoration, using the InVEST sediment and water-yield models already applied under the IC-CFS project. Such an analysis would show whether, and at what thresholds of fragment size and condition, connectivity delivers measurable hydrological benefits, and would give state water, energy and planning agencies a direct stake in maintaining the linkage.

COMPARATIVE INSIGHTS: LESSONS FROM GLOBAL CORRIDORS

Global corridor initiatives offer transferable lessons for the CFS. The Terai Arc Landscape demonstrates how integrated protection, community stewardship, and targeted connectivity restoration can reverse fragmentation and contribute to tiger recovery (Harihar and Pandav 2012). The Yellowstone to Yukon initiative illustrates long horizon, cross jurisdictional collaboration that meshes scientific analyses, communications, and participatory governance to secure continent scale connectivity (Chester 2015). In Europe, Natura 2000 and the wider green infrastructure approach embed connectivity within legal and funding frameworks, creating deliverable pathways for transboundary ecological networks (Jongman *et al.* 2021).

From these models three practical lessons emerge: first, science must inform siting and design yet be coupled with durable institutions that can enforce outcomes across administrative boundaries; second, financing must be predictable and blended across public and private sources, and third, success depends on substantive involvement of local communities and rights holders so that connectivity delivers tangible livelihood and cultural benefits. These lessons are directly applicable to CFS implementation, where federal policy and state planning must be harmonised through statutory mechanisms and financing instruments.

CHALLENGES AND OPPORTUNITIES

Despite progress, implementation remains uneven. Monitoring systems are fragmented, corridor restoration funding is short-term, and federal-state coordination is often inconsistent. Poor inter-agency coordination between federal and state agencies obstructs consistent enforcement and can allow land use decisions to undercut corridor integrity (FDPM 2023). Data gaps persist for many species, particularly genetic and long-term movement datasets, limiting reliable assessments of functional connectivity. Funding for corridor maintenance is frequently short term, and community engagement is patchy, particularly with Indigenous and other forest-dependent people.

Yet opportunities are expanding. The rise of biodiversity finance instruments, including national biodiversity policy measures and exploratory biodiversity credit pilots, creates new revenue pathways to sustain restoration and long-term monitoring (BIOFIN Malaysia 2018; Carbon Pulse 2023). Natural capital accounting initiatives and open national data platforms provide mechanisms to value connectivity and incorporate those values into planning and investment decisions (Bank Negara Malaysia 2022; DOSM 2024). Advances in remote sensing, GPS telemetry, and circuit theory modelling also lower costs and increase precision in identifying priority interventions (de la Torre *et al.* 2019; Muhamad Nor *et al.* 2023).

Institutional innovation can capture these opportunities. For example, the Malaysian Space Agency (MySA) may be approached to integrate remote sensing, species tracking, road and land use layers and enable routine monitoring and provide a single source of data and information for planners and researchers. Blended finance mechanisms that combine federal and state budget contributions with private ESG capital and biodiversity credit revenues could provide predictable long-term funding. Integrating connectivity metrics into certification systems, such as the Malaysian Timber Certification Scheme (MTCS), Forest Stewardship Council (FSC), Malaysian Sustainable Palm Oil (MSPO), and Roundtable on Sustainable Palm Oil (RSPO), and into infrastructure procurement criteria, can align private actors with national conservation goals.

An integral component of the CFS Master Plan is the development of Special Area Management Plans (SAMPs). These plans enable site-specific strategies tailored to the ecological characteristics, biodiversity significance, and socio-economic contexts of each corridor segment. They ensure that management interventions are precise and effective, addressing the unique conservation needs of critical habitats within the CFS network. By integrating land-use planning and zoning into these sensitive areas, the SAMPs can help reconcile development pressures, such as infrastructure expansion, agriculture, and urbanisation, with ecological conservation priorities. This integrated approach allows economic growth to proceed without undermining the ecological integrity of the CFS. However, the development and implementation of SAMPs across all ecological corridors remain limited. This should be prioritised to ensure comprehensive and balanced management.

POLICY RECOMMENDATIONS

To ensure that CFS fulfils its vision of reconnecting Malaysia's fragmented landscapes, a series of institutional, regulatory, and financial reforms are urgently needed. Each of the recommendations below responds to a specific technical or institutional gap identified in the preceding sections. First, to address the federal–state coordination and legal recognition gaps, connectivity must carry statutory weight in state land-use decisions. Although the National Central Forest Spine Steering Committee and the National CFS Technical Committee were formed to facilitate coordination across federal and state levels, their effectiveness has been constrained by the constitutional reality that authority over land and

forest resources resides with the state governments. In parallel, stronger incentives should be introduced to encourage cooperation among multiple land users. Mechanisms such as conservation easements, biodiversity offsets, or co-investment frameworks could enable private landholders and state agencies to participate in maintaining ecological connectivity without forgoing economic benefits. Embedding such legal and economic instruments within the CFS governance structure would provide both the authority and the incentives necessary to sustain landscape-level conservation in the long term.

Second, responding to the fragmentation caused by Malaysia's expanding road network, all major infrastructure developments such as roads, railways, pipelines, and urban expansion projects, should be required to undergo ecological connectivity impact assessments. These assessments must be science-based, transparent, and mandatory before project approval, with mitigation and monitoring measures clearly stipulated. This measure will align infrastructure growth with biodiversity and climate commitments under the Twelfth Malaysia Plan and the National Policy on Biological Diversity. Complementing this, a National Road Ecology Framework should be developed to guide the integration of wildlife-friendly design standards across Malaysia's 290,000-kilometre road network. Standardising the use of wildlife crossings, fencing, signage, and roadkill monitoring can reduce mortality and restore safe movement for wide-ranging species (Hui *et al.* 2021; WWF 2024).

Third, consistent with the catchment-scale functions discussed above, connectivity must extend beyond forests. The CFS model should be adapted to encompass other critical ecosystems such as peatlands, mangroves, and riverine corridors, creating a more holistic landscape-scale network resilient to both biodiversity loss and climate impacts. Expanding the CFS into these ecosystems would advance the government's commitment to nature-based solutions and support Malaysia's adaptation goals under its Nationally Determined Contributions (NDCs).

Fourth, responding to the river-basin gap identified above, CFS linkages should be planned and prioritised at the catchment scale. Linkages that protect headwaters, riparian corridors or reservoir catchments should receive higher priority, and CFS planning should be integrated with IRBM plans and state water catchment protection, so that water, energy and planning agencies share both the responsibility for and the benefits of connectivity. Including hydrological indicators such as sediment load and dry-season flow in linkage assessments would make these benefits visible to decision-makers.

Fifth, building on the role of wildlife in forest recovery, restoration within CFS linkages should be designed to work with natural succession rather than rely on planting alone. This means favouring native framework species that fruit early and attract seed dispersers, protecting restoration sites from hunting and snaring so that dispersers remain present, and adopting natural recruitment as a core measure of restoration success.

Sixth, reforestation and tree-planting programmes should extend connectivity from forests into urban and peri-urban landscapes. River reserves, urban parks and green belts can serve as stepping stones and corridors linking urban green space to nearby forest reserves, benefiting pollinators, birds and smaller wildlife while also improving urban liveability. Species selection requires care. Planting should favour native species of local provenance and avoid exotic or potentially invasive species, particularly near rivers and water intakes. Some widely planted ornamentals, such as the African tulip tree (*Spathodea campanulata*), produce fluid-filled, mucilaginous flowers and can spread aggressively, and mass flower and fruit fall into streams adds organic matter that can degrade water quality. Clear native-species guidelines for public and corporate tree-planting campaigns would help ensure that planting serves both connectivity and catchment health.

Seventh, the fragmented monitoring and data gaps noted earlier call for a national CFS dashboard. While the establishment of a national dashboard to monitor the implementation progress of CFS has been proposed, its final form and operational use have yet to be realised. The dashboard was initially conceived as a dynamic, data-driven tool to consolidate and visualise progress on forest connectivity, restoration, and land-use planning across the CFS landscape. Recent initiatives show encouraging movement in this direction. Telekom Malaysia Research & Development, in partnership with the Forestry Department of Peninsular Malaysia and several State Forestry Departments, has piloted smart forest dashboards in eight states to enhance forest monitoring and management (TM R&D 2023; Business Today 2023). Anticipated to be launched next year, these platforms integrate remote sensing, IoT sensors, and AI analytics to detect forest cover changes and potential threats, offering a technological foundation for scaling up to a national-level system. Beyond forest cover and threats, the dashboard should also track the ecological functions discussed in this paper, including wildlife use of linkages, natural recruitment in restored sites, and catchment indicators such as sediment load and dry-season flow.

However, rather than a fully open-access model, the proposed CFS Dashboard should adopt a controlled-access framework to safeguard sensitive spatial and biodiversity data. This tiered-access approach would allow for different levels of data visibility for government agencies, researchers, and verified stakeholders, and address legitimate concerns regarding data misuse while maintaining transparency and accountability in decision-making. As a centralised repository integrating forest cover, species movement, genetic connectivity, and infrastructure data, the dashboard could still serve as a powerful tool for adaptive management and cross-sectoral collaboration. By institutionalising data governance protocols and access controls, Malaysia can ensure that the system remains both secure and credible, while transitioning from fragmented, project-based monitoring to continuous, evidence-based management of ecological connectivity (FDPM 2023; DOSM 2024).

Eighth, because monitoring and maintenance still depend largely on short-term project funds, securing long-term financing remains essential. Blended finance mechanisms that combine federal and state allocations with private sector environmental, social, and governance (ESG) investments, biodiversity credits, and international climate finance can sustain restoration and monitoring efforts over time (BIOFIN 2018; Bank Negara Malaysia 2022). The integration of connectivity indicators into green finance and certification frameworks such as the Malaysian Timber Certification Scheme (MTCS/PEFC) can further align market incentives with conservation outcomes. Within the EFT in particular, allocation criteria could reward states not only for forest area retained but also for the condition of CFS linkages and the protection of water catchments, directly linking fiscal transfers to the ecological functions described above.

Finally, as the global corridor experience shows, lasting success depends on people. Empowering Indigenous and local communities as co-stewards of ecological linkages can enhance both legitimacy and effectiveness. Integrating traditional ecological knowledge into restoration and monitoring, while ensuring tangible livelihood benefits, will strengthen local ownership of conservation goals. Equally important is cultivating a shared national narrative (e.g., “Connected Forests, Connected Future”) that positions ecological connectivity as a source of national pride and collective responsibility. Together, these measures can transform the CFS from a policy framework into a living, adaptive system that safeguards Malaysia’s natural heritage while supporting sustainable development.

CONCLUSION

Connectivity science demonstrates that biodiversity conservation cannot be decoupled from spatial planning, transport design, and social systems. The Central Forest Spine is Malaysia's defining effort to translate this science into policy and practice. The Master Plan 2022–2040 sets out a credible pathway, but achieving durable outcomes requires institutionalised governance, compulsory connectivity assessments for infrastructure, robust data systems, and predictable financing. It also requires recognising that connectivity is more than a wildlife issue: reconnected forests sustain the animals that drive forest recovery and the catchments that supply the nation's water, and these functions should shape how linkages are prioritised, restored and financed. If Malaysia can combine science, law, finance, and community stewardship, the CFS has the potential to be the nucleus of a national ecological network that maintains biodiversity, supports ecosystem services, and reduces conflict between people and wildlife. Reconnecting forests is therefore both a technical and a societal project: a commitment to keep development and ecological continuity aligned as the nation advances toward 2030 and beyond.

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