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Integrating Community-Based Conservation Strategies in Freshwater Biodiversity Preservation

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Abstract
Freshwater ecosystems are biodiversity hotspots vital to human livelihoods, yet they face accelerating degradation from hydrological alteration, over-extraction, pollution, invasive species, land-use change, and climate change. Traditional, centralised conservation approaches have often struggled to halt these trends due to limited adaptability, fragmented governance, and inadequate local engagement. This review synthesises global evidence on the integration of Community-Based Conservation (CBC) strategies into freshwater biodiversity preservation.
Drawing on conceptual, ecological, and governance literature, the paper explores CBC's defining features, its alignment with social–ecological systems thinking, and its capacity to deliver biodiversity and socio-economic outcomes. The analysis covers global and regional biodiversity contexts, key operational mechanisms—including co-management, livelihood diversification, capacity building, community-based monitoring, and climate adaptation—and the socio-cultural factors that underpin stewardship.
Findings indicate that CBC's flexibility, incorporation of local ecological knowledge, and focus on participatory governance enhance legitimacy, compliance, and adaptive capacity. Success is maximized when CBC is embedded in multi-scalar governance frameworks, supported by secure tenure rights, equitable benefit-sharing, and sustained capacity development. The review concludes that CBC offers a viable, scalable pathway to reconcile conservation and development objectives, particularly in the dynamic and interdependent contexts of freshwater ecosystems.

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1. Introduction

1.1 Global Freshwater Biodiversity Crisis

Freshwater ecosystems—including rivers, lakes, wetlands, and aquifers—cover less than 1% of the Earth's surface yet host an estimated 10% of all known species and around one-third of vertebrate diversity (Dudgeon *et al*., 2006; Reid *et al*., 2019). Despite their ecological significance, freshwater biodiversity has been declining at alarming rates, with the Living Planet Index for freshwater species indicating an average 84% population reduction between 1970 and 2018 (WWF, 2020). This rate of decline surpasses that observed in terrestrial or marine biomes (Tickner *et al*., 2020).

The drivers of this crisis are multifaceted. Hydrological alterations from damming and water abstraction disrupt natural flow regimes, impair migratory routes, and fragment habitats critical to life cycle completion (Grill *et al*., 2019). Pollution from agricultural runoff, mining effluents, and untreated sewage degrades water quality, triggering eutrophication and biodiversity loss (Vörösmarty *et al*., 2010; Carpenter *et al*., 2011).

Overexploitation of fisheries, invasive species introductions, and climate-induced hydrological changes further exacerbate the problem (Lynch *et al*., 2016).

Beyond ecological losses, the decline of freshwater biodiversity carries profound socio-economic implications. Freshwater systems supply drinking water, support inland fisheries that feed hundreds of millions, regulate floods, and maintain cultural and spiritual values for diverse communities (Arthington *et al*., 2016). In regions where livelihoods are highly dependent on these systems, biodiversity decline can undermine food security, erode resilience to climate extremes, and diminish cultural heritage (McIntyre *et al*., 2016).

Global assessments reveal that existing conservation commitments have fallen short. Most freshwater-related Aichi Biodiversity Targets under the Convention on Biological Diversity were not met by 2020 (CBD, 2020). Without transformative change, projections indicate further extinctions, functional homogenisation, and loss of ecosystem services in many freshwater biodiversity hotspots by mid-century (Reid *et al*., 2019; Tickner *et al*., 2020).

This ecological emergency underscores the urgent need for integrated, multi-level strategies that combine scientific knowledge with participatory governance. Within this context, community-based conservation (CBC) emerges as a promising framework capable of aligning biodiversity protection with human well-being—an approach that will be explored throughout this review.

1.2. Historical Approaches to Freshwater Conservation and Their Limitations

Historically, freshwater conservation strategies have been dominated by top-down, protectionist approaches modelled largely on terrestrial protected area frameworks. These interventions—ranging from freshwater nature reserves to legally designated fish sanctuaries—were designed and implemented primarily by state agencies or international organisations, often without meaningful local participation (Abell *et al*., 2007). Such measures have, in some cases, prevented immediate habitat destruction and curtailed overexploitation within designated boundaries (Nel *et al*., 2007). However, their effectiveness has been constrained by several inherent limitations.

One persistent shortcoming has been the mismatch between ecological and administrative boundaries. Freshwater ecosystems are hydrologically connected, with species and ecological processes moving across political and jurisdictional lines. Protected areas rarely cover entire catchments, and without integrated basin-scale planning, threats from upstream development, pollution, or flow alteration can undermine conservation goals downstream (Kingsford *et al*., 2017; Rollasonet al., 2022).

Institutional fragmentation further compounds the problem. Water management is often split between multiple agencies—such as those governing irrigation, fisheries, hydropower, and environment—resulting in regulatory overlaps, conflicting objectives, and inefficient resource allocation (Huitemaet al., 2009; Mitchell, 2005).

Moreover, weak community engagement has limited the long-term sustainability of these top-down measures. Many early freshwater conservation interventions restricted access to traditional fishing grounds or water sources without providing alternative livelihoods or decision-making roles for affected populations (Berkes, 2004; Pretty & Smith, 2004). This exclusion not only generated social conflict but also reduced compliance, with communities perceiving conservation as externally imposed and misaligned with local needs (Cinner *et al*., 2012; Brooks *et al*., 2013).

Protected area–centric strategies have also struggled to address dynamic threats such as climate change, invasive species, and shifting land-use pressures. Static designations offer limited flexibility to adapt management in response to ecological change, particularly in systems with high interannual variability like floodplain wetlands or ephemeral streams (Arthington *et al*., 2010; Acreman *et al*., 2014).

Lessons from these shortcomings have informed the emergence of more inclusive, adaptive, and multi-level approaches. In particular, recognition of the importance of local ecological knowledge, shared governance, and socio-economic alignment has led to the growth of community-based conservation paradigms—designed to bridge the gap between ecological needs and human priorities—discussed in the next section.

1.3. Emergence of Community-Based Conservation Paradigms

The shift from exclusionary, state-led freshwater conservation toward community-based conservation (CBC) reflects a broader transformation in environmental governance since the late 20th century. This paradigm emerged in response to the recognised shortcomings of centralised, top-down management and the growing awareness that sustainable conservation requires integrating ecological goals with the social, economic, and cultural priorities of local stakeholders (Berkes, 2004; Brooks *et al*., 2013).

CBC is rooted in the participatory development movement of the 1980s and early 1990s, which advocated for greater community control over natural resources as a means of enhancing both conservation effectiveness and rural livelihoods (Western & Wright, 1994; Pretty & Smith, 2004). In freshwater contexts, CBC takes forms such as community-managed fisheries, participatory wetland restoration, and Indigenous-led water governance frameworks. These approaches recognise that communities are not merely resource users but active stewards whose knowledge and incentives can drive ecological resilience (Armitage *et al*., 2009; Andrade & Rhodes, 2012).

The paradigm aligns closely with the concept of social–ecological systems (SES), in which humans and ecosystems are interlinked, adaptive, and co-evolving (Berkes *et al*., 2008). Within SES thinking, CBC provides a governance framework that can strengthen feedback loops between ecological health and human well-being, creating mutual reinforcement rather than trade-offs (Berkes, 2007).

Global policy frameworks, including the Convention on Biological Diversity's post-2020 Global Biodiversity Framework and the Sustainable Development Goals, have further legitimised CBC by recognising the role of local communities and Indigenous peoples as custodians of biodiversity (CBD, 2020). CBC has also been supported by empirical evidence demonstrating its potential to deliver both ecological and socio-economic benefits when rights are secure, institutions are inclusive, and external threats are managed collaboratively (Gutiérrez *et al*., 2011; Oldekop *et al*., 2016).

In freshwater systems specifically, CBC's flexibility allows for management approaches tailored to seasonal flow

variability, migratory species needs, and culturally specific stewardship practices (Béné *et al*., 2007). This adaptability, combined with the integration of local ecological knowledge (LEK) and scientific monitoring, positions CBC as a promising approach for addressing the complex, multi-scalar challenges facing global freshwater biodiversity.

1.4. Scope, Objectives, and Structure of the Review

This review investigates the integration of Community-Based Conservation (CBC) strategies into freshwater biodiversity preservation, focusing on the interplay between ecological protection and community engagement. It examines rivers, lakes, wetlands, and aquifers across diverse climatic and socio-economic contexts, drawing on cross-disciplinary insights from ecology, governance, and development studies. The main objectives are threefold. First, to outline the conceptual evolution of CBC in the freshwater context, identifying how it differs from and improves upon traditional conservation models. Second, to explore the mechanisms—such as co-management, livelihood diversification, environmental education, community-based monitoring, and climate change adaptation—through which CBC influences biodiversity outcomes and socio-economic resilience. Third, to assess the enabling conditions, governance arrangements, and contextual factors that determine the success or limitations of CBC initiatives.

The review is structured in five main parts. Section 2 presents the conceptual foundations of CBC, covering definitions, theoretical frameworks, and the conservation–development nexus. Section 3 examines global and regional contexts, identifying biodiversity hotspots, key drivers of loss, socio-cultural dimensions, and the role of traditional ecological knowledge. Section 4 analyses the mechanisms of CBC in freshwater systems, with emphasis on governance, economic incentives, education, monitoring, and adaptation strategies. Section 5 concludes with a synthesis of findings, an evaluation of whether the study's aims are met, and recommendations for policy and practice.

2. Conceptual Foundations

2.1. Defining Community-Based Conservation in the Freshwater Context

Community-Based Conservation (CBC) in freshwater systems can be defined as a participatory approach to the management and stewardship of aquatic ecosystems—rivers, lakes, wetlands, and groundwater—where local communities share authority, responsibility, and benefits with external factors such as government agencies, NGOs, or research institutions. The overarching goal is to align biodiversity protection with the social, cultural, and economic priorities of the people who depend on these systems (Berkes, 2004; Andrade & Rhodes, 2012).

Key characteristics of freshwater CBC include decentralised decision-making, whereby governance authority is devolved to local bodies; recognition of customary rights, ensuring that conservation frameworks respect existing tenure and cultural norms; integration of local ecological knowledge (LEK) with scientific data to guide adaptive management; and direct benefit-sharing mechanisms, such as access to sustainable fisheries or ecotourism revenues, that incentivise long-term stewardship (Berkes *et al*., 2008; Gutiérrez *et al*., 2011).

Freshwater contexts present governance challenges distinct from terrestrial systems. Water is a mobile, interconnected resource, linking upstream and downstream communities, and its ecological integrity is affected by hydrological connectivity, seasonal flow patterns, and multi-use demands (Acreman *et al*., 2014). This requires management approaches that can operate at multiple scales—from local habitat protection to basin-wide coordination—while remaining sensitive to site-specific socio-ecological dynamics (Huitemaet al., 2009; Arthington *et al*., 2010).

CBC contrasts with centralised models that often impose rigid regulations without accommodating local realities. While state-led frameworks can mobilise legal authority and technical expertise, they frequently lack the flexibility to adapt to the dynamic nature of freshwater systems or the socio-cultural contexts in which they are embedded (Western & Wright, 1994; Abell *et al*., 2007). In contrast, CBC's emphasis on inclusivity, local autonomy, and iterative learning enables it to respond more effectively to ecological variability and shifting socio-economic conditions.

Ultimately, defining CBC in freshwater systems is as much about **process** as it is about governance structures. Effective CBC is rooted in sustained collaboration, mutual trust, and the co-production of knowledge, ensuring that conservation measures are ecologically sound, socially equitable, and resilient to environmental and political change.

2.2. The Social–Ecological Systems Perspective

Viewing Community-Based Conservation (CBC) in freshwater contexts through the lens of Social–Ecological Systems (SES) theory provides a framework for understanding the interdependence of ecological processes and human societies. SES approaches recognise that ecological change influences human behaviour and that human actions, in turn, shape ecosystem structure and function (Berkes *et al*., 2008; Folke *et al*., 2010).

Freshwater systems are dynamic and interconnected, with hydrological flows linking upstream and downstream communities, ecosystems, and economies. Changes in one part of a catchment—such as pollution discharge, dam construction, or deforestation—can cascade through the system, producing far-reaching ecological and social impacts (Vörösmarty *et al*., 2010). SES thinking highlights the need for governance models, like CBC, that can address such cross-scale linkages and feedback loops (Huitemaet al., 2009).

A central concept in SES theory is resilience, defined as the capacity of a system to absorb disturbances and reorganise while retaining its essential functions and structures (Holling, 1973). In freshwater CBC, resilience encompasses both ecological resilience—such as maintaining flow regimes that support species diversity—and social resilience, including the ability of communities to adapt management practices in response to environmental change (Walker *et al*., 2004).

Feedback mechanisms are particularly important in CBC. Positive feedback loops occur when sustainable management enhances biodiversity, which in turn improves ecosystem services, reinforcing local incentives for stewardship. Conversely, negative feedbacks emerge when overexploitation degrades resources, eroding livelihoods and driving further unsustainable use (Cinner *et al*., 2012). Recognising and managing these feedbacks is essential for sustaining SES health.

SES perspectives also emphasise thresholds and regime shifts—critical points beyond which systems may transition into degraded states that are difficult or impossible to reverse. CBC strategies that integrate scientific monitoring with local

ecological knowledge (LEK) can identify early warning signs of threshold proximity, enabling pre-emptive action (Biggs *et al*., 2015; Armitage *et al*., 2009).

Finally, SES theory underscores the importance of polycentric governance—multiple centres of decision-making at different scales that interact to manage shared resources. In freshwater CBC, this may involve local fishery committees working alongside basin-level water authorities and national conservation agencies, creating a governance network capable of addressing both local and external threats (Ostrom, 2017).

By embedding CBC in an SES framework, freshwater conservation can move beyond short-term, site-specific interventions toward adaptive, multi-scale strategies that build ecological integrity and community resilience simultaneously.

2.3. Theoretical Pathways Linking CBC to Biodiversity Outcomes

The link between Community-Based Conservation (CBC) and measurable biodiversity gains in freshwater systems can be explained through several interconnected theoretical pathways. These mechanisms integrate ecological science with governance theory, emphasising how social processes shape environmental outcomes.

1. Local Ecological Knowledge (LEK) integration

CBC leverages the fine-scale, longitudinal environmental knowledge held by resource users to complement scientific monitoring (Berkes, 2004). In freshwater contexts, LEK can reveal subtle ecological indicators—such as changes in fish migration timing or wetland vegetation shifts—that inform adaptive management before large-scale degradation occurs (Fernández-Llamazares & Cabeza, 2018).

2. Stewardship incentives

CBC frameworks often link rights to resource use with responsibilities for conservation, creating direct economic and cultural incentives for biodiversity protection (Gutiérrez *et al*., 2011; Cinner *et al*., 2012). Rights-based fisheries and community-managed aquatic reserves have shown positive effects on species biomass, size structure, and habitat condition (Hilborn *et al*., 2005).

3. Adaptive co-management

By combining decentralised authority with iterative learning, adaptive co-management allows rules to be updated in response to environmental feedback (Armitage *et al*., 2009; Olsson *et al*., 2004). In freshwater CBC, this may involve adjusting harvest limits or seasonal closures based on water level fluctuations, species recruitment rates, or climatic anomalies.

4. Compliance and legitimacy

Participatory rule-making increases community buy-in and voluntary compliance, reducing enforcement costs (Pretty & Smith, 2004). Social norms, peer monitoring, and local enforcement often outperform centralised policing in sustaining biodiversity outcomes.

5. Social learning and innovation

CBC fosters horizontal learning among communities and vertical learning between communities and external actors. This exchange can produce innovations—such as selective fishing gear or integrated aquaculture–wetland systems—that improve ecological and economic performance (Reed *et al*., 2010).

6. Ecosystem service feedbacks

Biodiversity gains from CBC can enhance ecosystem services such as water purification, sediment regulation, and fisheries productivity. These benefits, in turn, reinforce conservation behaviour, creating a virtuous cycle of stewardship (Biggs *et al*., 2015; Folke *et al*., 2010).

The strength of these pathways is contingent on enabling conditions, including secure tenure rights, equitable participation, effective institutions, and integration with broader watershed governance. Without these, CBC risks underperforming or even exacerbating ecological decline.

2.4. Synergies and Tensions between Conservation and Development

Community-Based Conservation (CBC) in freshwater systems is often framed as a strategy capable of achieving win–win outcomes for biodiversity and local livelihoods. When designed effectively, CBC can generate ecological gains—such as species recovery, habitat restoration, and improved ecosystem function—while enhancing food security, income, and cultural values (Andrade & Rhodes, 2012; Gutiérrez *et al*., 2011). For example, community-managed inland fisheries have shown increased biomass and catch stability alongside socio-economic improvements in regions like the Amazon and Mekong (Campos-Silva & Peres, 2016; Béné *et al*., 2007).

However, conservation–development relationships are rarely free of trade-offs. Measures such as seasonal fishing bans, gear restrictions, or no-take zones can impose short-term livelihood costs, particularly on poorer households with few alternatives (Cinner *et al*., 2012; Brooks *et al*., 2013). Market-driven diversification strategies, such as ecotourism or aquaculture, can shift benefits unevenly within communities, potentially exacerbating inequities along gender, generational, or socio-economic lines (Fabinyi *et al*., 2015).

Equity considerations are central to balancing these tensions. Participatory decision-making, transparent benefit-sharing, and targeted support for vulnerable groups can enhance both conservation legitimacy and social acceptance (Pretty & Smith, 2004; Oldekop *et al*., 2016). Without such safeguards, CBC risks becoming a tool for elite capture or external resource appropriation, undermining trust and long-term sustainability (Agrawal & Gibson, 1999).

External pressures—such as upstream pollution, hydropower expansion, or climate-induced hydrological change—can also diminish local conservation benefits despite strong community governance (Huitemaet al., 2009; Rollason *et al*., 2022). This highlights the importance of multi-scalar governance linkages, integrating community-level initiatives with basin-scale and national policy frameworks to mitigate external threats and reinforce local gains.

Ultimately, the potential of CBC to harmonise conservation and development depends on governance quality, equity safeguards, and adaptive capacity. While tensions cannot be eliminated, they can be managed in ways that strengthen both biodiversity protection and socio-economic resilience.

3. Freshwater Biodiversity Hotspots and Priority Ecoregions

Freshwater biodiversity is distributed unevenly across the globe, with certain regions exhibiting exceptionally high species richness, endemism, and ecological uniqueness. These hotspots and priority ecoregions are critical to global conservation because the species and functions they contain are often irreplaceable if lost (Abell *et al*., 2008; Darwall *et al*., 2011).

Tropical river basins such as the Amazon, Congo, and Mekong are among the most biodiverse freshwater systems on Earth, harbouring thousands of fish species, many of which are endemic (Winemiller *et al*., 2016; Reis *et al*., 2016). The Amazon Basin alone supports over 2,500 described fish species, with estimates suggesting hundreds more remain undiscovered (Jézéquel *et al*., 2020). In Africa, the Great Lakes—Victoria, Tanganyika, and Malawi—are globally significant for their extraordinary adaptive radiations of cichlid fishes, representing one of the fastest vertebrate diversification events recorded (Seehausen, 2006).

In Asia, the Mekong River sustains the world's largest inland fishery, with migratory pathways that depend on seasonal floodplain connectivity (Ziv *et al*., 2012). North America's Mississippi Basin and the Southeastern United States harbour high freshwater mussel and crayfish diversity, while Australia's Murray–Darling Basin supports unique fish assemblages adapted to extreme hydrological variability (Kingsford *et al*., 2017).

Wetlands designated under the Ramsar Convention also represent biodiversity priorities. The Pantanal in South America is the largest tropical wetland in the world, providing habitat for diverse fish, bird, and mammal species (Junk *et al*., 2006). The Okavango Delta in Botswana sustains an intricate mosaic of aquatic habitats and supports both biodiversity and human livelihoods (Ramberg *et al*., 2006).

Prioritisation frameworks, such as the Freshwater Ecoregions of the World (FEOW) and WWF's Global 200, use metrics including species richness, endemism, threat level, and ecosystem integrity to identify critical areas for conservation (Abell *et al*., 2008; Thieme *et al*., 2005). In a CBC context, prioritisation must also consider social feasibility—including governance capacity, cultural values, and community readiness—since ecological importance alone does not guarantee effective protection (Vörösmarty *et al*., 2010).

Safeguarding these hotspots through CBC offers the potential to align biodiversity outcomes with local development goals. However, because many face threats that extend beyond local control, integrating community efforts into basin-scale and transboundary governance frameworks is essential for long-term success.

3.1. Drivers of Biodiversity Loss in Freshwater Systems

The degradation of freshwater biodiversity results from a complex interplay of anthropogenic pressures that vary geographically but frequently act in combination, producing cumulative impacts. These drivers can be categorised into six major groups: flow alteration, over-extraction, pollution, invasive species, land use change, and climate change.

Flow alteration from dams, weirs, and channelisation modifies natural hydrological regimes, disrupting cues for spawning and migration, fragmenting habitats, and altering sediment and nutrient transport (Poff *et al*., 2007; Grill *et al*., 2019). Large-scale dam building in the Mekong, for example, has fundamentally changed floodplain dynamics, with severe implications for fisheries productivity (Ziv *et al*., 2012).

Over-extraction of surface and groundwater for irrigation, industry, and domestic use reduces water availability for ecological processes. In arid basins such as the Murray–Darling in Australia, over-abstraction has diminished wetland inundation frequency, reducing waterbird breeding success and native fish recruitment (Kingsford *et al*., 2017).

Pollution remains pervasive. Agricultural runoff laden with nutrients drives eutrophication and harmful algal blooms, while industrial effluents and mining by-products introduce toxic contaminants (Carpenter *et al*., 2011). In many developing regions, untreated sewage continues to degrade water quality and public health (Vörösmarty *et al*., 2010).

Invasive species—introduced intentionally or accidentally—compete with, prey upon, or hybridise with native species. The introduction of Nile perch (*Lates niloticus*) to Lake Victoria caused dramatic declines in endemic cichlids (Seehausen *et al*., 1997), while zebra mussels (*Dreissena polymorpha*) have transformed nutrient cycling in North American lakes (Strayer, 2009).

Land use change in catchments, such as deforestation, agricultural expansion, and urbanisation, alters runoff patterns, increases sediment loads, and removes riparian buffers critical for water quality and habitat integrity (Allan, 2004).

Climate change amplifies existing threats through altered precipitation regimes, increased frequency of droughts and floods, and warming water temperatures that exceed species' thermal tolerances (Heino *et al*., 2009; Reid *et al*., 2019).

Interactions among these drivers can intensify impacts. For instance, climate-driven droughts magnify the effects of over-extraction, and degraded habitats are often more susceptible to invasion by non-native species (Jackson *et al*., 2016). Addressing such **cumulative threats** requires integrated, multi-scale governance approaches—of which CBC can be a key component—linking local actions to basin-scale management and policy reform.

3.2. Socio-Cultural Dimensions of Freshwater Use and Stewardship

Freshwater ecosystems are embedded in the cultural, spiritual, and economic lives of communities worldwide. Beyond their ecological importance, rivers, lakes, and wetlands provide food, water, medicine, and cultural identity, making them both natural and social systems that must be managed holistically (Berkes, 2004; Pretty & Smith, 2004). Recognising these socio-cultural dimensions is essential for designing Community-Based Conservation (CBC) approaches that are both ecologically sound and socially legitimate.

For many Indigenous and local communities, freshwater systems are sacred spaces, integral to creation stories, religious ceremonies, and seasonal festivals (Ramirez-Gomez *et al*., 2016). In the Mekong Basin, annual fish migrations are celebrated through traditional festivals that also transmit ecological knowledge to younger generations (Béné *et al*., 2007). In Amazonian floodplains, rivers are often considered living entities, with reciprocal responsibilities between humans and nature embedded in local cosmologies (Berkes, 2004). These cultural beliefs can result in informal conservation practices, such as taboos against fishing in sacred stretches of rivers, which function as de facto protected zones. Incorporating such traditions into CBC can enhance compliance and legitimacy (Pretty & Smith, 2004).

Freshwater resources underpin the subsistence and

livelihoods of millions. Inland fisheries, aquatic plants, and riparian resources are vital for food security, particularly in rural and low-income settings (Béné *et al*., 2007). In sub-Saharan Africa, inland fisheries provide over 60% of animal protein in some communities, while seasonal floodplains supply fertile soils for agriculture (Kingsford *et al*., 2017). Dependence on these resources can foster stewardship when ecosystem health directly impacts community well-being. However, without alternative livelihoods, economic pressures may lead to overharvesting, undermining biodiversity goals (Brooks *et al*., 2013). CBC initiatives in such contexts must integrate livelihood diversification to balance ecological sustainability and human needs (Cinner *et al*., 2012).

Customary governance systems regulate access, harvest timing, and gear use based on ecological rhythms and community consensus (Pretty & Smith, 2004). Examples include fishing calendars in South Asia that align with spawning seasons and gear restrictions in Pacific Island wetlands to prevent overexploitation (Berkes, 2004). However, these systems are increasingly challenged by legal centralisation and market integration, which may erode traditional authority (Cinner *et al*., 2012). CBC models that recognise and incorporate customary rules can restore local legitimacy and strengthen compliance (Ramirez-Gomez *et al*., 2016).

Social capital—the trust, networks, and norms enabling cooperation—plays a decisive role in CBC outcomes (Pretty & Smith, 2004). High social capital facilitates enforcement of rules, conflict resolution, and collective responses to ecological challenges. Communities with strong internal cohesion are better positioned to negotiate with external actors and manage shared benefits equitably (Brooks *et al*., 2013). Conversely, low trust, inequitable benefit distribution, and unresolved conflicts can fragment collective action, weakening conservation outcomes (Cinner *et al*., 2012).

Roles in freshwater resource use often vary by gender and age. Women may be primary collectors of water, aquatic plants, or small-scale fishery products, while men dominate larger-scale commercial fishing or hold more formal leadership positions (Béné *et al*., 2007). Ignoring these distinctions in CBC planning risks excluding essential knowledge holders. Intergenerational perspectives are also important: elders often retain deep local ecological knowledge (LEK), while younger members may bring technological skills for monitoring (Ramirez-Gomez *et al*., 2016). Inclusive governance structures that recognise these contributions can enhance CBC resilience.

Globalisation, migration, and infrastructure projects can reshape socio-cultural relationships with freshwater. Hydropower dams or industrial agriculture developments may displace communities, disrupt ecological processes, and erode traditional stewardship systems (Kingsford *et al*., 2017). Market pressures can shift harvesting from subsistence to commercial scales, often with negative ecological consequences (Cinner *et al*., 2012). CBC frameworks must therefore remain adaptable, safeguarding cultural heritage while responding to changing socio-economic conditions (Berkes, 2004).

Recognising socio-cultural dimensions is fundamental to freshwater CBC. Conservation strategies that disregard cultural and livelihood realities risk alienating communities, while those that embrace local traditions, governance norms, and social networks can foster durable stewardship (Pretty & Smith, 2004). In practice, this means mapping cultural heritage alongside ecological priorities, ensuring inclusive representation in governance, and supporting the transmission of LEK through community-led education. Integrating these elements strengthens both social legitimacy and ecological sustainability.

3.3. The Role of Traditional Ecological Knowledge (TEK)

Traditional Ecological Knowledge (TEK) refers to the cumulative body of knowledge, practices, and beliefs that Indigenous peoples and local communities develop through long-term interaction with their environments. It is transmitted through generations, often orally or through practice, and is deeply embedded in cultural, spiritual, and livelihood systems (Berkes, 2008). In the context of freshwater ecosystems, TEK offers detailed, place-specific insights into hydrology, species behaviour, seasonal cycles, and ecological change.

The scope of TEK in freshwater systems

TEK in freshwater contexts encompasses knowledge of fish spawning seasons, migratory routes, water level fluctuations, aquatic plant phenology, and habitat-specific biodiversity patterns. For example, communities along the Mekong River have developed nuanced understanding of seasonal flood pulses, which they use to regulate fishing effort and crop planting. Similarly, in the Amazon floodplain, Indigenous fishers monitor water clarity, rainfall patterns, and vegetation cues to anticipate fish movements and adjust harvesting accordingly (Fernández-Llamazares & Cabeza, 2018).

TEK is rarely static. It evolves as communities adapt to environmental shifts, market integration, or new technologies. This dynamism allows TEK to respond to changing ecological conditions, although it may also be eroded by loss of language, migration, or the breakdown of customary governance systems (Berkes, 2008).

Contributions to freshwater biodiversity conservation

TEK supports freshwater biodiversity conservation in several ways:

1. **Informal regulation through customary practices** – Many TEK systems incorporate taboos, seasonal bans, and spatial restrictions that align with conservation objectives. For example, prohibitions on fishing during spawning periods or in sacred water bodies effectively protect reproductive habitats and keystone species.
2. **Fine-scale monitoring and early warning** – TEK holders can detect subtle environmental changes—such as shifts in fish taste or behaviour—that precede broader ecological decline. This capacity is invaluable for early intervention in conservation and restoration efforts (Reid *et al*., 2021).
3. **Habitat management and restoration** – Practices such as maintaining riparian vegetation, managing floodplain connectivity, and controlling fishing gear types reflect long-standing adaptive strategies for sustaining ecosystem function.
4. **Knowledge co-production with science** – Integrating TEK with scientific methods can enrich ecological baselines, improve predictive models, and strengthen adaptive management. For instance, co-managed fisheries that blend TEK-derived spatial closures with scientifically determined quotas have demonstrated higher compliance and better ecological outcomes

(Gutiérrez *et al*., 2011).

Challenges in integrating TEK into CBC

While the integration of TEK into CBC frameworks offers significant opportunities, it is not without challenges.

- **Epistemological differences** between TEK and Western science can lead to misunderstandings or undervaluation of Indigenous knowledge. Scientific frameworks often prioritise quantitative data, while TEK is frequently qualitative, holistic, and embedded in cultural narratives. Bridging these differences requires respectful dialogue, trust-building, and an openness to multiple ways of knowing (Berkes, 2008).
- **Knowledge appropriation** is another critical concern. Documenting TEK without proper consent or equitable benefit-sharing can exploit knowledge holders and damage trust. Ethical integration of TEK into conservation requires adherence to principles such as Free, Prior, and Informed Consent (FPIC) and recognition of intellectual property rights.
- **Erosion of TEK** is a growing issue. Rapid socio-economic change, loss of language, and youth migration can weaken the intergenerational transmission of knowledge. Conservation programs that do not actively support cultural revitalisation risk losing this knowledge base altogether.
- **Principles for ethical integration of TEK into CBC**
  For TEK to be effectively and ethically incorporated into freshwater CBC strategies, several guiding principles should be followed:
  1. **Respect and recognition** – TEK should be valued as a legitimate knowledge system in its own right, not merely as supplementary to scientific data.
  2. **Equitable participation** – TEK holders must have an active role in decision-making processes and in defining how their knowledge is used.
  3. **Benefit-sharing** – Communities contributing TEK should share in the benefits—whether financial, cultural, or ecological—derived from its application in conservation.
  4. **Capacity building** – Strengthening community capacity for both TEK preservation and scientific engagement can enhance resilience and adaptive capacity.
  5. **Co-production of knowledge** – Joint development of monitoring protocols, restoration plans, and policy recommendations can merge the strengths of TEK and science.

TEK in practice: implications for policy and management

Embedding TEK in freshwater CBC requires institutional recognition at multiple governance levels. National and regional policies should formally acknowledge TEK's role in environmental management, while local governance structures should ensure TEK holders' voices shape conservation priorities.

In practical terms, TEK can guide site selection for restoration projects, inform adaptive fishing regulations, and help anticipate the ecological impacts of climate change. By anchoring conservation strategies in the lived experiences of those who depend on freshwater systems, TEK strengthens both the ecological and social foundations of CBC.

Ultimately, the integration of TEK is not just about knowledge—it is about power, respect, and reciprocity. In freshwater systems facing unprecedented ecological pressures, TEK offers both a repository of proven management strategies and a framework for co-existence between people and ecosystems. When honoured and applied ethically, TEK can enhance the effectiveness, equity, and resilience of community-based freshwater conservation.

4. Co-Management and Participatory Governance Models

Co-management in freshwater Community-Based Conservation (CBC) refers to the shared governance of resources between communities and external actors—typically government agencies, NGOs, or research institutions—through formal or informal agreements. It seeks to combine local autonomy with external support, enabling management systems that are both context-specific and linked to broader policy frameworks (Berkes, 2009).

At its core, co-management is a power-sharing arrangement. The degree of community authority can range from advisory roles to full decision-making powers, depending on the legal framework and the willingness of external actors to devolve control. In some contexts, such as Cambodia's community fisheries model, legislation formally recognises local committees as primary managers of specific freshwater areas. In others, co-management emerges through negotiated agreements without statutory backing (Pomeroy & Berkes, 1997).

Key institutional features of successful co-management include clearly defined rights and responsibilities, legally recognised tenure arrangements, transparent decision-making processes, and mechanisms for conflict resolution. Without secure tenure, communities have limited incentives to invest in long-term stewardship, as benefits can be appropriated by outsiders (Gutiérrez *et al*., 2011).

Freshwater systems often exist in governance landscapes where statutory law overlaps with customary systems. This legal pluralism can either enhance or undermine management effectiveness. Where customary rules align with ecological objectives—such as seasonal fishing bans or gear restrictions—they can be integrated into formal governance frameworks, enhancing legitimacy and compliance. Conversely, conflicting rules between state and community systems can cause confusion, enforcement difficulties, and erosion of trust (Ratner *et al*., 2012).

Hybrid governance models that deliberately bridge statutory and customary systems are particularly effective in culturally diverse freshwater contexts. These models respect local authority while ensuring that conservation objectives are consistent with broader watershed management plans.

Participation is more than token consultation; it involves genuine influence over outcomes. Effective co-management requires inclusive decision-making that accounts for gender, age, and socio-economic diversity within communities. Tools such as participatory mapping, community assemblies, and joint planning workshops enable stakeholders to co-create rules and management plans.

Inclusion is critical for building legitimacy. When diverse community members are involved in defining regulations—such as harvest limits, closed seasons, or restoration priorities—compliance improves because rules are seen as collectively owned rather than externally imposed (Pomeroy & Berkes, 1997).

Adaptive co-management combines participatory

governance with iterative learning, enabling systems to adjust to ecological feedback and social change. In freshwater contexts, this might involve modifying fishing quotas based on water levels and recruitment rates, or adjusting riparian restoration plans in response to flood events. Monitoring—both scientific and community-based—feeds into decision cycles, ensuring that management remains responsive (Olsson *et al*., 2004).

Adaptive processes also help navigate uncertainty, particularly under climate variability. For instance, in parts of the Canadian Arctic, co-managed char fisheries adjust harvest rules annually based on both local knowledge and scientific assessments, maintaining stock stability despite changing ice and flow patterns (Berkes, 2009).

Enabling conditions and challenges

Evidence shows that several enabling conditions underpin effective co-management in freshwater CBC:

- **Secure resource tenure** that grants communities recognised rights over defined areas or stocks.
- **Institutional support** from government agencies, NGOs, or academic partners for capacity building, monitoring, and enforcement.
- **Strong local leadership** capable of representing community interests and mediating internal disputes.
- **Access to information** that combines scientific and local knowledge for informed decision-making (Gutiérrez *et al*., 2011).

Despite these strengths, co-management faces challenges. Power imbalances between communities and state agencies can limit genuine influence. Local elites may dominate decision-making, marginalising poorer or less vocal members (Ratner *et al*., 2012). External pressures—such as upstream pollution, hydropower development, or market-driven overfishing—may undermine local efforts regardless of governance quality.

Maintaining engagement is another difficulty. Co-management processes can be time- and labour-intensive, requiring sustained participation that may strain community members balancing livelihood activities. Institutional fatigue can set in if tangible benefits are not visible in the short term.

Within CBC, co-management provides the institutional backbone that supports other conservation mechanisms. It offers the structure for integrating livelihood diversification, capacity building, monitoring, and climate adaptation into a coherent governance strategy. By distributing rights and responsibilities across multiple actors, co-management increases both resilience and legitimacy, making it a critical pathway to durable freshwater conservation outcomes.

4.1. Livelihood Diversification and Sustainable Economic Incentives

Livelihood diversification within Community-Based Conservation (CBC) frameworks is premised on the idea that conservation goals are more likely to be achieved and sustained when local communities derive tangible economic benefits from the ecosystems they help to protect. In freshwater systems, where livelihoods are often heavily dependent on fishing, agriculture, and the extraction of aquatic resources, overreliance on a single resource can lead to both ecological degradation and economic vulnerability. Diversification seeks to reduce this dependency by creating alternative income streams that are ecologically sustainable, socially equitable, and economically viable (Allison & Ellis, 2001).

One of the most common strategies is the development of sustainable fisheries under community management. Rights-based or co-managed fisheries can generate reliable income while maintaining stock health through regulated access, seasonal closures, gear restrictions, and size limits. In the Brazilian Amazon, community management of high-value fish such as *Arapaima gigas* has resulted in rapid population recovery and significant income gains for participating households, illustrating how economic incentives can reinforce conservation behaviour (Campos-Silva & Peres, 2016). Similar approaches in Asia's Mekong Basin, where community fishing grounds are protected during spawning periods, have increased both catch per unit effort and species diversity, benefiting livelihoods and food security.

Aquaculture, when designed with low environmental impact, is another means of reducing fishing pressure on wild stocks. Integrated systems, such as rice–fish farming, can maintain wetland functions while providing diversified food and income sources. However, aquaculture projects must be carefully managed to avoid ecological risks such as nutrient loading, introduction of non-native species, and habitat conversion (Beveridge *et al*., 2013). CBC initiatives that incorporate aquaculture often focus on native species and use closed or semi-closed systems to minimise environmental impacts.

Ecotourism is an increasingly popular diversification strategy in freshwater landscapes rich in biodiversity or cultural heritage. Wetland birdwatching, sport fishing, and cultural tours can generate substantial revenue, particularly when marketed to international visitors. For example, community-led ecotourism in the Okavango Delta has provided alternative livelihoods while incentivising the maintenance of riparian habitats and wildlife populations. The sustainability of such ventures depends on equitable benefit-sharing, capacity building in hospitality and business management, and careful regulation of visitor numbers to prevent environmental degradation (Goodwin, 2002).

Payment for ecosystem services (PES) schemes are another mechanism that can link conservation and livelihoods. In freshwater contexts, PES arrangements might involve compensating upstream communities for maintaining riparian vegetation that improves downstream water quality, or for preserving wetlands that act as natural flood buffers. These schemes can provide steady income while promoting practices that protect biodiversity and ecosystem function (Engel *et al*., 2008). However, PES requires clear property rights, transparent contracts, and reliable funding to avoid inequity or dependency.

While the potential benefits of livelihood diversification are significant, there are notable challenges. New income streams must be economically competitive with existing practices to be attractive; otherwise, they may be adopted only marginally or abandoned altogether. Market access can be a limiting factor, particularly in remote areas where transportation infrastructure is poor. Price volatility for products such as fish, crafts, or tourism services can undermine economic stability. Additionally, the costs of entering new markets—whether for training, equipment, or certification—can be prohibitive without external support.

Social equity is another critical consideration. Diversification initiatives may inadvertently benefit certain groups more than

others. For example, ecotourism opportunities may favour those with language skills or capital to invest in guest facilities, while marginalising poorer households or women who traditionally engage in subsistence activities. Similarly, aquaculture projects may be more accessible to wealthier individuals able to afford ponds and feed, potentially increasing inequality within communities (Bebbington, 1999). CBC frameworks must therefore design benefit-sharing arrangements that are transparent and inclusive, ensuring that vulnerable groups are not excluded from new opportunities.

The ecological sustainability of diversification activities is also paramount. Poorly managed aquaculture, tourism, or harvest substitution can introduce new environmental pressures, shifting rather than reducing degradation. For example, unregulated ecotourism can disturb wildlife, damage riparian vegetation, and strain water resources. Similarly, poorly planned PES schemes risk "green grabbing," where land is appropriated for conservation at the expense of local livelihoods. Careful planning, environmental safeguards, and adaptive management are essential to avoid such pitfalls.

Capacity building plays a pivotal role in ensuring that diversification initiatives deliver both economic and ecological benefits. Training in business management, sustainable production techniques, and market engagement can enhance long-term viability. Partnerships with NGOs, academic institutions, and government agencies can provide the technical support and financial resources necessary for start-up and scaling. In successful CBC examples, diversification is not treated as a stand-alone intervention but as one component of a broader conservation strategy that integrates governance, monitoring, and ecological restoration.

Ultimately, livelihood diversification within freshwater CBC serves two interlinked purposes: reducing reliance on resource extraction that threatens biodiversity, and enhancing the socio-economic resilience of communities facing environmental change. The most robust models adopt a portfolio approach, combining multiple income sources—such as regulated fishing, ecotourism, sustainable aquaculture, and PES—to spread risk and adapt to seasonal or market fluctuations. This approach is particularly important in the face of climate change, which can unpredictably alter freshwater productivity and availability. When well-designed, diversification not only mitigates ecological pressures but also fosters a stronger, more enduring commitment to conservation among communities whose livelihoods are directly tied to the health of freshwater ecosystems.

4.2. Education, Capacity Building, and Environmental Literacy

Education, capacity building, and environmental literacy form the social and cognitive foundation of effective Community-Based Conservation (CBC) in freshwater systems. Governance structures and economic incentives alone are unlikely to produce durable biodiversity outcomes without parallel investments in the skills, knowledge, and leadership capacities of the communities engaged in management (Pretty & Smith, 2004). Strengthening these human dimensions ensures that conservation is understood, supported, and driven from within.

Environmental literacy in freshwater contexts

Environmental literacy encompasses the knowledge, skills, attitudes, and motivations needed to make informed decisions about environmental stewardship (McBride *et al*., 2013). In freshwater systems, this means understanding hydrological cycles, aquatic food webs, habitat requirements of key species, and the socio-economic drivers of degradation.

In CBC, environmental literacy is often developed through a combination of formal education, non-formal training, and experiential learning. Workshops on water quality monitoring, for instance, can familiarise community members with parameters such as turbidity, pH, dissolved oxygen, and nutrient levels, enabling them to detect changes and act before problems escalate. Similarly, participatory biodiversity surveys can help communities identify indicator species and understand their ecological significance.

Capacity building for governance and management

Capacity building extends beyond ecological knowledge to include the institutional, organisational, and leadership skills required to plan, implement, and adapt conservation initiatives (Berkes, 2009). In freshwater CBC, these capacities might include conflict resolution, negotiation, proposal writing, financial management, and advocacy. Without these competencies, communities may struggle to enforce rules, secure funding, or engage effectively with external stakeholders.

For example, in the Brazilian Mamirauá Sustainable Development Reserve, training fishers in population assessment methods for *Arapaima gigas* not only improved management accuracy but also enhanced the sense of ownership over conservation outcomes (Campos-Silva & Peres, 2016). Similarly, in Nepal's community-managed irrigation systems, training in governance and maintenance has strengthened both resource productivity and social cohesion (Meinzen-Dick *et al*., 2002).

Leadership development is a key aspect of capacity building. Effective CBC depends on leaders who can mobilise collective action, mediate disputes, and represent community interests in multi-stakeholder forums. Investing in leadership training—particularly for women and youth—can broaden the pool of capable decision-makers, reduce dependence on a few individuals, and ensure intergenerational continuity in governance.

Integrating local ecological knowledge (LEK) into education

A critical element of CBC capacity building is the integration of local ecological knowledge (LEK) into training and education. LEK reflects generations of observation and practice and can provide nuanced insights into ecosystem dynamics that complement scientific data (Berkes, 2008). By embedding LEK into education programs, CBC initiatives validate community expertise, strengthen cultural identity, and create a two-way exchange that enriches both scientific and traditional perspectives.

For example, in parts of the Mekong Basin, fisheries training programs incorporate local observations about spawning seasons, migration cues, and species interactions alongside standard scientific assessments. This co-production of knowledge enhances both the accuracy of management measures and the legitimacy of conservation decisions.

Environmental literacy as a pathway to stewardship

The cultivation of environmental literacy is not an end in itself; its purpose is to foster stewardship—voluntary, long-

term commitment to conservation actions. Stewardship is more likely when individuals understand not only the ecological importance of freshwater biodiversity but also its links to their own livelihoods, health, and cultural values (Ardoin *et al*., 2013).

Community education initiatives often target youth to ensure intergenerational transmission of stewardship values. School-based environmental clubs, field trips to wetlands, and youth-led monitoring projects can cultivate environmental responsibility from an early age. In some cases, youth become effective ambassadors, influencing household practices and reinforcing community-wide norms for sustainable resource use.

Peer learning and knowledge exchange

Capacity building is not limited to formal instruction. Peer-to-peer learning—through exchange visits, regional networks, and collaborative projects—allows communities to share strategies, technologies, and governance innovations (Reed *et al*., 2010). Such exchanges can be particularly valuable for problem-solving, as they connect communities facing similar challenges in different ecological and cultural contexts.

For instance, fisher groups from the Philippines have exchanged experiences with counterparts in Indonesia and Vietnam on co-management structures, enforcement techniques, and livelihood diversification. This cross-pollination of ideas helps avoid "reinventing the wheel" and can accelerate the adoption of successful practices.

Challenges to education and capacity building

Despite its importance, education and capacity building in CBC face several obstacles. Funding limitations can constrain the duration and scope of programs, leading to one-off workshops with limited long-term impact. High turnover in community leadership positions may require repeated training cycles. Language barriers and low literacy levels can limit access to written materials, requiring the use of oral, visual, and experiential teaching methods.

Additionally, there is the risk of external dominance, where capacity building becomes a means of imposing outside agendas rather than strengthening locally defined priorities. To avoid this, education programs should be participatory in design, responsive to community-identified needs, and sensitive to cultural contexts.

Institutionalising education and capacity building in CBC

Sustainable CBC benefits from embedding education and capacity building into ongoing governance processes. This can be achieved by establishing community training committees, integrating environmental topics into local school curricula, and developing partnerships with universities, NGOs, and government agencies for continuous skill development. In some cases, communities have established their own training centres, enabling them to deliver context-specific education while reducing reliance on external trainers.

Institutionalisation also helps ensure continuity despite leadership changes, shifting donor priorities, or external shocks. Over time, this builds a culture of learning within the community, where adaptive management becomes the norm and new knowledge is actively sought out and applied.

The multiplier effect on other CBC mechanisms

Education, capacity building, and environmental literacy underpin the effectiveness of other CBC mechanisms. Co-management arrangements work better when communities understand legal frameworks and negotiation techniques. Livelihood diversification succeeds when people have the business skills to access markets. Community-based monitoring is more robust when participants are trained in accurate data collection and analysis. Climate change adaptation benefits from the ability to interpret environmental signals and plan accordingly.

Thus, education is not merely a support activity—it is the connective tissue that enables all other aspects of freshwater CBC to function effectively. Without it, governance can falter, monitoring can fail, and incentives can be misaligned. With it, communities are empowered to sustain both ecological and social resilience.

4.3. Community-Based Monitoring and Citizen Science

Community-Based Monitoring (CBM) and citizen science are core mechanisms in Community-Based Conservation (CBC) that enable communities to participate directly in the observation, documentation, and management of environmental resources. In freshwater contexts, CBM serves not only as a technical tool for collecting ecological data but also as a social process that strengthens stewardship, reinforces local governance, and links community priorities with broader conservation agendas (Danielsen *et al*., 2005).

Defining CBM and citizen science in freshwater CBC

CBM refers to the systematic collection and analysis of environmental data by community members, often in partnership with external factors such as government agencies, NGOs, or researchers. Citizen science, while overlapping with CBM, typically involves public participation in scientific projects initiated by external experts. In CBC, the two concepts converge: local communities are engaged from project design through to data use, ensuring that monitoring serves both scientific and community needs (Conrad & Hilchey, 2011).

In freshwater ecosystems, CBM may involve monitoring fish populations, water quality, invasive species presence, habitat condition, or hydrological parameters. The approach capitalises on the daily presence of community members in the landscape, enabling fine-scale, continuous observation that is rarely feasible for external agencies.

Roles and benefits of CBM in freshwater CBC

Enhancing ecological data coverage and resolution

Conventional monitoring programs are often limited by funding, logistics, and personnel. CBM can dramatically expand spatial and temporal data coverage by harnessing local effort (Danielsen *et al*., 2009). For example, fisher-led monitoring in the Philippines has generated high-resolution catch and effort data that inform co-management decisions more effectively than infrequent government surveys. Similarly, in Canadian Arctic rivers, Indigenous monitors have provided critical information on ice conditions and fish migrations that would otherwise be logistically prohibitive for researchers to collect.

Strengthening governance legitimacy and compliance

When communities are involved in generating the data that underpin management decisions, they are more likely to trust the results and support resulting regulations (Berkes, 2009). This participatory approach helps avoid the perception that

rules are imposed by distant authorities. In the Amazon floodplains, for example, fishers engaged in *Arapaima gigas* population counts have demonstrated higher compliance with harvest restrictions because they directly witnessed stock recovery trends (Campos-Silva & Peres, 2016).

Facilitating adaptive management

Adaptive management depends on timely, relevant feedback about system conditions. CBM enables rapid detection of ecological change and supports flexible responses, such as temporary fishing closures during spawning or targeted removal of invasive species. The ability to integrate local ecological knowledge (LEK) with scientific monitoring methods further enhances adaptability (Berkes, 2009).

Building community skills and empowerment

Participation in monitoring develops technical skills in sampling, data recording, and analysis. These skills can spill over into other aspects of community governance, such as financial management or environmental education. CBM can also build confidence and empower marginalised groups—particularly women and youth—by creating roles for them in resource management.

Bridging science and local knowledge

CBM fosters co-production of knowledge, where scientific methods are adapted to local contexts and informed by LEK. For instance, fishery monitoring protocols may integrate local indicators of stock health (e.g., body condition, seasonal behaviour) with quantitative measures such as biomass estimates. This blending of knowledge systems strengthens the relevance of data for both local and scientific audiences.

4.4. Designing effective CBM programs in freshwater CBC

Participatory design and goal setting

Effective CBM starts with participatory design to ensure that monitoring objectives align with both community concerns and conservation priorities (Conrad & Hilchey, 2011). Stakeholder workshops can identify which indicators to monitor, how data will be collected, and how results will be used in decision-making.

- **Capacity building and training:** Training is essential for generating reliable, standardised data. This may include instruction on sampling techniques, species identification, use of field equipment, and basic data analysis. Refresher courses and peer-to-peer mentoring can maintain quality over time.
- **Technology integration:** Technological innovations—such as mobile data entry apps, GPS-enabled cameras, and low-cost sensors—have expanded the scope of CBM. In East Africa, smartphone applications have allowed wetland monitors to record and transmit georeferenced observations, creating real-time datasets for waterbird and habitat management. However, technology must be appropriate to local infrastructure and capacities, with contingency plans for equipment failure or limited connectivity.
- **Data validation and credibility:** The credibility of CBM depends on ensuring data accuracy. Cross-checking by trained scientists, calibration of equipment, and inter-observer reliability tests can help maintain standards. Collaborative data analysis workshops allow community members to interpret results alongside scientists, reinforcing transparency and mutual learning (Danielsen *et al*., 2005).
- **Feedback loops and action:** Monitoring without action risks disengaging participants. Clear feedback loops—where data lead to tangible management decisions—are critical for maintaining motivation. For example, in Cambodian community fisheries, CBM data on declining catch rates triggered stricter enforcement of no-fishing zones, which later saw fish stocks rebound.

Challenges and limitations

- **Sustainability and funding -** CBM often relies on external funding for training, equipment, and facilitation. When projects end, monitoring can lapse unless alternative funding sources or institutional support are secured. Embedding CBM within local governance budgets or linking it to income-generating activities can improve sustainability.
- **Data ownership and power dynamics -** Questions of data ownership can arise when CBM results are used by external actors for research or policy without adequate recognition or benefit sharing. Clear agreements on data use and intellectual property rights are essential to prevent exploitation and maintain trust (Berkes, 2009).
- **Participation fatigue -** Long-term monitoring requires sustained effort, which can lead to fatigue, especially if results do not translate into visible change or benefits. Rotating responsibilities, integrating monitoring into existing livelihood activities, and celebrating milestones can help maintain engagement.
- **External threats beyond community control -** CBM can effectively address local-scale issues but may be limited in influencing broader threats such as upstream pollution, climate change, or large-scale hydrological alteration. Linking CBM to higher-level governance structures is necessary to address such drivers.
- **Integrating CBM into freshwater CBC strategies -** In the broader CBC framework, CBM complements other mechanisms such as co-management, livelihood diversification, and climate adaptation. Data generated through CBM can guide restoration priorities, inform adaptive harvest rules, and provide evidence for negotiating policy changes. When communities see that their monitoring efforts influence tangible decisions, trust in governance systems deepens and conservation behaviour is reinforced.

Furthermore, CBM can act as a platform for education and outreach. Sharing results through community meetings, school programs, and local media can broaden environmental literacy and mobilise wider participation in conservation. In transboundary river basins, CBM networks that share information across political boundaries can enhance regional cooperation.

CBM and citizen science in freshwater CBC represent more than just data-gathering tools—they are social processes that empower communities, legitimise governance, and bridge local knowledge with formal science. While challenges exist, careful design, adequate training, sustained support, and clear feedback loops can transform CBM into a cornerstone of effective, resilient, and inclusive freshwater conservation.

4.5. Integration of Climate Change Adaptation into CBC

Strategies

Freshwater ecosystems are among the most climate-sensitive environments on Earth. Changes in temperature, precipitation, and hydrological cycles directly influence water availability, quality, and ecological function. For communities whose livelihoods and cultural identities are tied to rivers, lakes, wetlands, and aquifers, these changes present both ecological and socio-economic risks. Integrating climate change adaptation into Community-Based Conservation (CBC) strategies is therefore essential to ensure that conservation efforts remain effective and resilient under future conditions (Poff *et al*., 2010).

Climate change affects freshwater systems through altered flow regimes, rising water temperatures, changes in ice cover, and shifts in species distributions (Heino *et al*., 2009). Extreme events—such as floods, droughts, and heatwaves—are becoming more frequent and intense, disrupting life cycles of aquatic species, degrading habitats, and threatening water-dependent livelihoods. In many tropical basins, altered seasonal flooding patterns undermine fisheries productivity, while in high-latitude systems, earlier ice melt and warming water can stress cold-water species such as salmonids.

These impacts often compound existing pressures like pollution, over-extraction, and habitat fragmentation, creating complex and cumulative threats (Reid *et al*., 2019). Communities reliant on freshwater resources are thus confronted with shrinking resource bases, increasing variability, and heightened uncertainty—all of which demand adaptive management approaches.

Climate adaptation in CBC begins with recognising the dual objectives of safeguarding biodiversity and sustaining human well-being. Adaptation measures must therefore be co-developed with communities, ensuring that they address locally perceived risks, draw on local ecological knowledge (LEK), and are compatible with existing governance systems (Berkes, 2009).

Participatory vulnerability assessments are a useful starting point. These involve mapping climate hazards, identifying vulnerable species and habitats, and evaluating socio-economic exposure. Such assessments can combine LEK—such as historical flood patterns or phenological cues—with climate projections to create robust adaptation plans.

Key adaptation strategies in freshwater CBC

- **Flow restoration and environmental flows**
  Maintaining or mimicking natural flow regimes is an essential strategy for sustaining ecological processes and the species adapted to them. Community-led flow restoration initiatives may involve negotiating environmental flow releases from upstream dams, removing small barriers, or reinstating floodplain connectivity. In the Murray–Darling Basin, for example, adaptive environmental flow management has been implemented to enhance native fish spawning and recruitment (Arthington *et al*., 2013).
- **Riparian buffer protection and restoration**
  Healthy riparian zones moderate water temperatures, filter sediments and pollutants, and provide habitat corridors. Climate-adapted CBC strategies prioritise the planting of native vegetation along banks, integrating species tolerant of future climate conditions. These buffers also enhance flood resilience by stabilising banks and absorbing excess flows.
- **Habitat diversification and refugia protection**
  As climate change alters species distributions, ensuring the availability of thermal refugia and diverse habitat types can support resilience. In tropical rivers, deep pools may provide cooler conditions for fish during heatwaves; in seasonal wetlands, permanent waterholes can serve as drought refuges. CBC initiatives can map and protect these key habitats, often integrating them into local zoning and harvesting regulations.
- **Adaptive harvest management**
  Flexible rules that adjust to climate variability—such as modifying fishing seasons based on water levels or species recruitment—help balance livelihood needs with biodiversity conservation. Adaptive harvest management requires reliable monitoring, which can be achieved by linking CBM (Section 4.4) with seasonal decision-making processes.
- **Early warning and disaster preparedness**
  CBC can integrate climate information services, such as seasonal forecasts or flood alerts, into community governance. These systems enable proactive responses, such as adjusting irrigation schedules, relocating gear, or implementing temporary closures ahead of predicted extreme events. In some river basins, mobile phone networks are used to disseminate early warnings, reaching even remote fishing villages.
- **Ecosystem-based adaptation (EbA)**
  EbA leverages natural systems to buffer communities from climate impacts while delivering biodiversity benefits. Examples in freshwater CBC include wetland restoration for flood mitigation, reforestation of headwaters to regulate flows, and removal of invasive species to improve ecosystem function. These measures offer cost-effective, long-term resilience compared to hard infrastructure.

Integrating climate adaptation into CBC requires certain enabling conditions. Secure tenure and resource rights empower communities to invest in long-term adaptation measures. Capacity building—particularly in climate risk assessment, adaptive management, and ecosystem restoration—equips communities with the tools to implement strategies effectively. Access to diversified funding sources, including climate finance mechanisms, can sustain adaptation over time.

Institutional linkages are equally important. Local adaptation initiatives are more effective when connected to basin-wide planning and national climate policies, ensuring alignment and access to technical and financial support. This also facilitates scaling up successful models across similar ecological and socio-cultural contexts.

Adaptation measures can entail trade-offs. For example, maintaining environmental flows may reduce water available for irrigation in the short term, while protecting riparian buffers might limit agricultural expansion. Transparent decision-making and equitable benefit-sharing are essential to navigate these trade-offs and maintain community support.

Another challenge lies in the uncertainty of climate projections, which complicates planning. CBC frameworks address this by emphasising flexibility, iterative learning, and scenario-based planning rather than rigid prescriptions. This approach aligns with the broader adaptive management principles already embedded in many CBC models.

Integrating climate change adaptation into freshwater CBC transforms conservation from a static protection model into a dynamic, forward-looking approach. By combining LEK with scientific projections, embedding flexibility into governance, and prioritising ecosystem-based measures, communities can enhance both ecological resilience and human well-being. As climate impacts intensify, CBC that incorporates adaptation is likely to be more robust, equitable, and sustainable—ensuring that freshwater systems continue to support biodiversity and livelihoods for generations to come.

5. Discussion

The findings of this review reveal that integrating Community-Based Conservation (CBC) into freshwater biodiversity preservation offers a multidimensional pathway to address ecological decline while supporting the socio-economic resilience of dependent communities. The synthesis of evidence from conceptual foundations, global biodiversity patterns, and operational mechanisms demonstrates that CBC is not merely an alternative to centralised management—it is a governance approach capable of addressing the complexity, scale, and social embeddedness of freshwater conservation challenges.

One of the clearest insights is that CBC thrives when built upon strong local institutions, secure tenure rights, and inclusive decision-making processes. Co-management arrangements, in particular, emerged as the institutional backbone that enables other mechanisms—such as livelihood diversification, community-based monitoring, and climate adaptation—to function effectively. Where communities have both the authority and the capacity to manage resources, biodiversity recovery and sustainable use become mutually reinforcing outcomes.

The review also highlights that CBC's strength lies in its flexibility. Freshwater ecosystems are dynamic, and the capacity to adapt governance rules, harvest limits, and restoration strategies to shifting ecological and socio-economic conditions is a decisive advantage over rigid, top-down models. Adaptive co-management, integrating local ecological knowledge with scientific monitoring, enables rapid responses to environmental feedback, reducing the risk of irreversible biodiversity loss.

Socio-cultural dimensions emerged as equally critical. Conservation strategies that recognise cultural values, traditional ecological knowledge, and customary governance systems tend to gain higher legitimacy and compliance. By respecting these dimensions, CBC fosters a sense of ownership that can withstand external pressures such as market integration or policy changes. Conversely, neglecting cultural contexts risks alienating communities, weakening stewardship, and undermining ecological goals.

The operational mechanisms examined—ranging from sustainable livelihood initiatives to citizen-led monitoring—illustrate the practical means by which CBC translates principles into action. Livelihood diversification, when equitably designed, reduces reliance on resource extraction while maintaining income security. Education and capacity building strengthen governance competence, environmental literacy, and leadership, ensuring that conservation efforts are not only technically sound but also socially durable. Community-based monitoring bridges the gap between science and practice, while climate adaptation measures safeguard both biodiversity and livelihoods in the face of environmental change.

However, the review also underscores persistent challenges. External threats—such as upstream industrial activity, hydropower development, or climate-induced hydrological shifts—can undermine local efforts regardless of governance quality. Power asymmetries between communities and external actors may limit genuine participation, while internal inequities can lead to elite capture of benefits. Furthermore, sustaining motivation and funding for long-term engagement remains a common difficulty, particularly once initial donor support ends.

From a strategic perspective, the most effective CBC interventions are those embedded within multi-scalar governance frameworks. Local actions alone cannot counter drivers that operate at regional or global levels. CBC must therefore be linked to basin-wide planning, national policy frameworks, and international conservation targets to ensure coherence and leverage broader resources. This nested governance approach not only aligns local priorities with larger-scale objectives but also strengthens communities' bargaining power in negotiations over resource use and conservation investment.

The discussion points to a central lesson: CBC in freshwater systems is not a singular model but a flexible, context-dependent process. Its success depends on a delicate balance of ecological, social, and institutional factors. The adaptability of CBC, combined with its capacity to integrate diverse knowledge systems, makes it a promising approach for the long-term preservation of freshwater biodiversity. Yet its potential will only be realised if it is implemented with a clear commitment to equity, cultural respect, and sustained support.

In summary, CBC offers a compelling vision for freshwater conservation—one where local communities are not just beneficiaries but active custodians of the ecosystems upon which they depend. When effectively integrated with higher-level governance, backed by enabling policies, and supported by continuous learning, CBC can reconcile biodiversity conservation with human development needs in a way that is both resilient and just.

6. Conclusion

This review set out to examine how Community-Based Conservation (CBC) can be effectively integrated into freshwater biodiversity preservation. The evidence demonstrates that CBC offers a powerful framework for aligning ecological protection with the socio-economic priorities of local communities. By embedding conservation within participatory governance, recognising cultural values, and linking biodiversity outcomes to livelihood security, CBC creates conditions where stewardship becomes both a moral and economic imperative.

The analysis confirms that CBC achieves its intended purpose when supported by secure tenure rights, inclusive decision-making, adaptive management, and multi-scalar governance connections. Operational mechanisms—such as co-management, livelihood diversification, environmental education, community-based monitoring, and climate adaptation—provide the practical means to translate CBC principles into durable outcomes.

Challenges remain, particularly in addressing external threats, preventing elite capture, and ensuring sustained engagement. Yet the adaptability of CBC, coupled with its ability to integrate scientific and traditional knowledge,

positions it as a cornerstone for future freshwater conservation strategies.

The recommendation is clear: CBC should be mainstreamed into national and basin-level policies, supported by long-term investment and capacity building, and designed with equity at its core. This integrated approach will be essential to safeguard freshwater biodiversity and the communities that depend upon

7. References

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