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Quantifying Economic Losses and Reef Degradation from Illegal Fishing in Tanzanian Coastal Communities

Upendo H. Mwaisunga
Ministry of Livestock and Fisheries
Ambakisye M.P. Simtoe
Ministry of Livestock and Fisheries
Godfrey Ngupula
godfrey.ngupula@marineparks.go.tz

Marine Parks and Reserves Unit (MPRU)

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Abstract

Illegal and unsustainable fishing including blast fishing, cyanide use, and beach seining causes severe degradation of Tanzania's coral reefs, threatening marine biodiversity and coastal livelihoods. This study quantifies economic trade-offs between short-term extractive gains and long-term ecosystem service losses to inform evidence-based conservation policy. We integrated ecological monitoring data on coral cover and fish biomass with socioeconomic surveys of 412 fishing households across six seascapes (Kilwa, Mtwara, Dar es Salaam, Mafia Island, Pemba, and Tanga). Using a Total Economic Value framework, we assessed market and non-market benefits, including fisheries production, tourism revenue, coastal protection, and existence values. Regression models comparing Marine Protected Areas (MPAs) and non-MPA sites identified key drivers of reef degradation. Destructive fishing has reduced live coral cover by 30–50% and fish biomass by 40% over two decades. Continued degradation results in USD 9.65 billion in annual national losses from habitat destruction, lost fisheries productivity, reduced tourism, and restoration costs. Conversely, sustainable management could yield USD 7.07 billion annually in ecosystem service benefits, achieving a 22.37:1 benefit–cost ratio. Social impacts are severe: 88% of fishers report declining incomes, 69.2% experience worsening food insecurity, and women face persistent exclusion from higher-value post-harvest markets. Long-term socioeconomic losses far outweigh short-term private gains. To advance climate resilience and a sustainable blue economy, Tanzania's National Adaptation Plan must prioritize strengthened enforcement, expanded MPAs targeting 30% reef coverage, community-led restoration, and diversified livelihood pathways.

1.0 Introduction

Coral reefs are foundational to tropical marine ecosystems, supporting an estimated 25% of global marine biodiversity despite occupying less than 1% of the ocean floor (Fisher et al., 2015; Obura et al., 2017). Their complex ecological functions underpin coastal fisheries productivity, shoreline stability, and tourism economies across the Western Indian Ocean (WIO) region. In Tanzania, healthy reef matrices dissipate up to 97% of nearshore wave energy, significantly reducing coastal erosion and shoreline vulnerability (Ferrario et al., 2014). Furthermore, reef resources contribute 70–90% of dietary animal protein in specific coastal settlements, with approximately 30% of the coastal population relying directly on marine resources for household income and food security (Hicks et al., 2019; World Bank, 2020).

However, Tanzanian reefs are experiencing rapid ecological degradation driven by a combination of localized anthropogenic and global stressors. Destructive extraction methods including blast fishing, cyanide use, and beach seining have reduced standing fish biomass by up to 40% in non-protected maritime zones. The ongoing overexploitation of key functional groups, such as herbivores and macro-invertebrates, combined with severe terrestrial sedimentation and nutrient loading from land-based sources, accelerates macroalgae dominance and suppresses juvenile coral recruitment pathways. Collectively, these intense localized pressures have caused a 30–40% decline in live coral cover across Tanzanian reefs since 2000 (Obura et al., 2017).

Global climate change further intensifies regional reef vulnerability. Severe thermal stress during the 2016 global bleaching event caused up to 70% coral mortality across localized zones in Zanzibar. Concurrently, accelerating ocean acidification marked by a 0.1 pH unit decline since pre-industrial baselines; reduces net calcification and calciferous accretion rates. At the same time, increasing storm frequencies and sea-level rise diminish light availability for symbiodiniaceae assemblages. These cumulative, synergistic stressors increase the mathematical probability of functional reef ecosystem collapse by mid-century if current extraction and environmental trajectories persist.

In response, the Coral Reef Rescue Initiative (CRRI), implemented through Tanzania's Marine Parks and Reserves Unit (MPRU), promotes an integrated resilience-building framework. This approach combines ecological restoration pathways, sustainable fisheries co-management regimes, active community engagement, and applied socio-ecological research. Gender equity is explicitly mainstreamed throughout the implementation of the initiative, recognizing the central role of women, who constitute 60% of the post-harvest workforce within regional marine resource governance frameworks and artisanal value chains.

A core component of the initiative centers on generating empirical economic evidence to inform national policy architectures and strategic blue-economy investment decisions. To this end, an ecosystem services assessment was executed to evaluate the long-term ecological, economic, and social trade-offs associated with unsustainable fishing practices. The assessment contrasts the immediate financial gains captured by illegal extractors with systemic long-term losses across multi-sectoral fisheries productivity, nature-based tourism revenue, and shoreline protection, while explicitly mapping gender-differentiated impacts and regulatory enforcement gaps (Ferrario et al., 2014; Samoilys et al., 2019; World Bank, 2020).

This study contributes to the international scientific body of evidence by providing a rigorous, data-driven assessment of the costs and benefits of illegal extraction across Tanzanian coral reefs. Ultimately, these findings offer empirical insights designed to strengthen management effectiveness, enhance community resilience, and support sustainable blue economy development under accelerating climate shifts.

2.0 Methodology

2.1 Study Sites

The study was conducted across six major coastal seascapes in Tanzania Kilwa, Mtwara, Dar es Salaam, Mafia Island, Pemba, and Tanga selected for their ecological importance and high dependence on coral reef resources (Obura et al., 2017; Collins et al., 2021) (Fig. 1).

In each seascape, two villages were sampled: one located inside a Marine Protected Area (MPA) and one outside, enabling structured comparison of conservation outcomes between protected and non-protected zones. Village selection followed random sampling procedures, while fisheries officers were purposively selected due to their regulatory roles and technical expertise (World Bank, 2020). A

participatory approach engaged fishers, village leaders, and marine authorities throughout the process to enhance contextual accuracy and strengthen local ownership of the findings (Samoilys et al., 2019). Sampled villages included Mnono Msangamkuu and Mnete (Mtwara); Kasela and Deep Sea (Tanga); Somanga North and Somanga South (Kilwa); Kunduchi and Msasani (Dar es Salaam); Mkoani and Chakechake (Pemba); and Kiegeani and Utende village in Mafia.

2.2 Data Collection

A mixed-methods design captured ecological, socio-economic, and governance dimensions of coral reef resource use. Data were collected from 402 respondents, with balanced representation across MPA and non-MPA villages, approximately 70 respondents per sea scape. Household surveys provided quantitative information on fishing livelihoods, gear use, income trends, and perceptions of reef condition. Key informant interviews with fisheries officers, marine park managers, and village leaders assessed enforcement challenges, institutional gaps, and management responses (Collins et al., 2021). Focus group discussions (FGDs) explored historical ecological change, community coping strategies, and conflicts among marine user groups, while field observations documented landing sites, gear types, and compliance with fisheries regulations. Secondary data from government reports, SWIOFish studies, and scientific literature (Obura et al., 2017; Browne et al., 2022) contextualised long-term ecological and socio-economic trends. A qualitative participatory Cost–Benefit Analysis (CBA) compared short-term gains from fishing practices with long-term ecological and economic costs, supported by scientific evidence (Ferrario et al., 2014).

2.3 Data Analysis

Quantitative and qualitative techniques were integrated to assess the impacts of illegal fishing. Descriptive statistics and comparative analyses between MPA and non-MPA sites were generated using R software, while regression models identified drivers of reef-related economic losses based on established natural resource valuation frameworks (World Bank, 2020). Cost–benefit calculations contrasted immediate financial gains with long-term ecological and economic losses using both primary survey data and secondary valuation estimates. Triangulation of household surveys, key informant interviews, FGDs, field observations, and literature strengthened the reliability and policy relevance of the results (Samoilys et al., 2019).

2.4 Ethical Considerations

Ethical protocols were rigorously applied throughout the study. All participants provided **informed consent**, and confidentiality was ensured through secure, coded handling of respondent information. Gender-sensitive approaches promoted equitable participation, recognising the often underrepresented roles of women in reef-dependent livelihoods (Hicks et al., 2019). The research team respected local customs and community protocols, adhering to accepted standards for **social and ecological research**.

3.0 Results and Discussion

3.1 Socio-Economic Status of Coastal Communities

The Cost–Benefit Analysis demonstrates that coastal communities across all six Tanzanian seascapes remain deeply dependent on coral reef resources for food security, income generation, and daily subsistence. Survey results show that 88% of fishers reported declining incomes, while 69% experienced worsening food insecurity, underscoring the severe socio-economic consequences of reef degradation and illegal fishing. These findings align with broader evidence of livelihood vulnerability in coastal Tanzania (Fröcklin et al., 2013).

Small-scale fishing continues to dominate as the primary livelihood, supported by local trading networks and post-harvest processing activities. Despite declining catch volumes, marine extraction remains the most viable economic option for most households, highlighting limited livelihood alternatives and high exposure to accelerating reef decline.

Women play essential roles in reef-dependent livelihoods particularly gleaning, processing, and local marketing, but remain structurally disadvantaged. The study found that women constitute 13% of reef-dependent livelihoods, yet face persistent exclusion from higher-value markets, access to credit, and participation in formal decision-making bodies (Fröcklin et al., 2013). This gender imbalance reduces household adaptive capacity and limits equitable participation in emerging blue-economy opportunities.

Socio-economic pressures are further intensified by ecological decline. With fish biomass reduced by up to 40% in some areas, communities increasingly struggle to sustain livelihoods. As nearshore stocks diminish, 38% of fishers now travel more than 10 km offshore, increasing operational costs, safety risks, and financial strain. This shift reflects the diminishing productivity of nearshore reefs and growing pressure on already fragile ecosystems (McClanahan et al., 2008).

3.2 Fishing Behaviour, Effort, and Vessel Characteristics

Findings from the CBA reveal a marked intensification of fishing pressure along Tanzania's coastline. Fishers reported more frequent trips and longer travel distances, driven by declining nearshore fish stocks and reduced catch reliability. The study documented that 38% of fishers now travel more than 10 km offshore, illustrating the spatial expansion of fishing effort as nearshore reefs become increasingly degraded.

Artisanal fishers predominantly operate small wooden vessels, with non-motorized boats remaining the most common. This continued reliance on paddle-powered and sail-powered craft reflects limited financial capital and restricted adaptive capacity. The gradual shift toward motorized vessels is driven by necessity rather than economic surplus, as fishers are compelled to access distant fishing grounds due to declining catches (McClanahan et al., 2008).

Across all seascapes, respondents consistently reported:

- Reduced catch volumes

- Smaller average fish sizes
- Steep declines in high-value target species

These trends are most pronounced outside Marine Protected Areas (MPAs), where illegal and destructive fishing practices remain prevalent. Blast fishing alone destroys up to 90% of coral structures in affected zones, causing cascading declines in fish populations and reef health.

Overall, the integrated findings demonstrate that fishing behaviour, vessel characteristics, and fishing effort are tightly linked to ecological decline. As coral reef degradation accelerates, fishers are forced into riskier, more costly, and less productive strategies, reinforcing socio-economic vulnerability and highlighting the urgent need for strengthened management interventions.

3.3 Ecological and Economic Effects of Illegal and Unsustainable Practices

Illegal and unsustainable fishing practices including poison fishing, beach seining, undersized mesh nets, and sporadic blast-fishing incidents continue to exert severe ecological and economic pressure on Tanzania's coral reef systems. Although enforcement has reduced the frequency of blast fishing, field interviews confirm that destructive extraction persists because of **short-term financial incentives**. Non-compliant fishers earn **10,000–50,000 TZS (USD 4–20)** per day and perceive destructive gear as more "efficient," enabling faster catches, lower fuel use, and avoidance of licensing costs. These private gains, however, are quickly overshadowed by long-term ecological collapse and community-wide economic deficits.

Ecologically, **87.5% of fisheries officers** reported widespread reef degradation directly linked to destructive practices. Scientific evidence shows that **blast fishing and beach seining can reduce live coral cover by 60–90%** (Hawkins and Roberts, 1994; Rogers, 1990). Habitat destruction and nursery loss reported by **28.6% and 21.4%** of officers that translate into reduced multi-species fish abundance, diminished species richness, and smaller average fish sizes. These trends align with broader regional findings showing **30–50% declines in live coral cover** and **up to 40% reductions in reef-associated fish biomass** (Obura et al., 2017).

The ecological decline directly shapes fishing behaviour. As nearshore reefs lose productivity, **38% of fishers now travel more than 10 km offshore**, increasing operational costs, safety risks, and financial strain. This spatial expansion of fishing effort reflects a reinforcing feedback loop: degraded reefs reduce catch reliability, pushing fishers into riskier and more extractive strategies, which in turn accelerate ecological decline.

Socioeconomic impacts are equally severe. Survey data show that **88% of artisanal fishers** experienced declining catches and household incomes, while **69.2%** faced worsening food insecurity. Declining fish quality from destructive gear further depresses market prices, weakening local economies and reducing household resilience. Women who play critical roles in gleaning, processing, and marketing are

disproportionately affected due to limited access to credit, higher-value markets, and formal decision-making spaces.

Tourism losses compound these local impacts. Degraded reef structures rapidly lose the aesthetic and recreational value essential to nature-based tourism, a sector contributing **USD 36 billion annually** to the global blue economy (Spalding et al., 2001). Restoration adds further financial pressure, with active rehabilitation costing **USD 21,400–41,400 per km²**, placing substantial burdens on conservation budgets.

From a climate-resilience perspective, degraded reefs recover more slowly from marine heatwaves, with respondents reporting **30–50% lower post-bleaching recovery rates**. Loss of three-dimensional reef architecture also reduces natural shoreline protection, valued globally at **USD 94,000 per hectare annually** (Ferrario et al., 2014). This increases vulnerability to erosion, sea-level rise, and storm surges, amplifying national adaptation costs.

Overall, the findings reveal a clear economic pattern: **short-term financial gains from illegal and unsustainable practices are entirely eclipsed by long-term ecological damage, reduced fisheries productivity, tourism losses, and weakened climate resilience** (Hughes et al., 2003; Lapointe, 1997; Hoegh-Guldberg et al., 2007; Nagelkerken et al., 2000). By degrading fish stocks and destroying natural coastal barriers, illegal extraction traps vulnerable communities in a cycle of declining productivity, rising costs, and escalating ecological risk.

3.4 Drivers of Illegal and Unsustainable Fishing Practices

The Cost-Benefit Analysis identifies a set of interlinked drivers sustaining illegal and unsustainable fishing practices across Tanzania's coastal seascapes. These drivers operate at socio-economic, institutional, awareness-related, and environmental levels, collectively reinforcing destructive behaviours despite ongoing management interventions.

3.4.1 Socio-Economic Drivers

Poverty and livelihood dependency remain the most significant socio-economic drivers, reported by 72.9% of respondents. Declining fish stocks and reduced incomes experienced by 88% of fishers push households toward high-risk extraction methods that provide short-term gains but undermine long-term sustainability. Organised crime networks, cited by 32.1% of respondents, further facilitate access to destructive gear and weaken local governance structures (Samoilys et al., 2019). Reduced transfer of traditional ecological knowledge, particularly among youth, also contributes to unsustainable practices, reflecting broader gendered and generational dynamics in coastal livelihoods (Fröcklin et al., 2013).

3.4.2 Institutional and Governance Drivers

Weak enforcement capacity is the most prominent institutional driver, reported by 78.3% of respondents. Chronic shortages of funding, skilled personnel, and patrol resources combined with corruption (79.5%)

and patrolling difficulties (35.8%) limit the effectiveness of Marine Protected Areas (MPAs) and Beach Management Units (BMUs). Low community involvement (39.2%) further reduces compliance and undermines co-management efforts. These governance gaps allow illegal practices such as small-mesh nets, poison fishing, and fishing in restricted areas to persist even where regulatory frameworks are in place.

3.4.3 Awareness and Knowledge Drivers

Limited awareness of fisheries regulations (27.5%) and low environmental understanding (9.3%) contribute to continued use of harmful practices. In several seascapes, fishers demonstrated limited knowledge of the ecological impacts of poison fishing, beach seining, and juvenile harvesting. This knowledge gap is particularly pronounced in remote communities with limited access to extension services and environmental education.

3.4.4 Environmental and Ecological Drivers

Environmental decline itself reinforces illegal and unsustainable practices. With reef-associated fish biomass reduced by up to 40% (Obura et al., 2017), 38% of fishers now travel more than 10 km offshore to access remaining stocks. This spatial expansion increases operational costs and incentivizes illegal methods that yield higher short-term returns. Although blast fishing has significantly declined, its ecological impact remains severe when incidents occur, with a single blast capable of destroying up to 90% of coral skeletal structures (McManus et al., 1997). Additional stressors including sedimentation, pollution, and climate-induced bleaching further reduce reef productivity and intensify competition for dwindling resources.

Overall, the CBA demonstrates that illegal and unsustainable fishing practices are sustained by interacting socio-economic pressures, governance weaknesses, limited awareness, and environmental decline. While the prevalence of some destructive practices has decreased, their ecological and economic impacts remain substantial. Addressing these drivers requires strengthened enforcement, livelihood diversification, enhanced community participation, and integrated coastal management to reduce pressure on Tanzania's coral reef ecosystems.

3.5 The Coral Reefs Economic Valuation

The economic valuation of Tanzania's coral reefs demonstrates their substantial contribution to national development, ecological stability, and coastal community wellbeing. Using a combined market and non-market valuation framework, the Total Economic Value (TEV) of these ecosystems is estimated at USD 2,330,800 per km² per year (equivalent to USD 23,331.30 per hectare per year). These results highlight the critical role coral reefs play in sustaining coastal economies and reinforce the need for strengthened conservation and management frameworks.

Market Valuation

Coral reefs generate significant direct economic benefits through tourism, ecosystem services, and fisheries:

- **Reef-Based Tourism**: Approximately USD 200 million annually, equivalent to USD 57,142.85 per km² per year, driven by high-value recreational activities such as snorkeling, diving, and guided reef excursions across Zanzibar, Pemba, Mafia, Mnemba, and Misali (Spalding et al., 2017).
- **Ecosystem Services**: The largest market component, valued at USD 1.8 million per km² per year, consistent with global natural capital benchmarks (Costanza et al., 1997; 2014). This includes shoreline protection, nutrient cycling, carbon sequestration, and habitat support.
- **Reef-Associated Fisheries**: Contributing USD 15,000 per km² per year, this sector—though modest in monetary terms supports more than 70% of Tanzania's marine fish production, making it essential for food security and coastal livelihoods (Jiddawi and Öhman, 2002).

Non-Market Valuation

Non-market values, often excluded from traditional assessments, form a substantial portion of reef benefits. These range from USD 515,800 to USD 1,565,800 per km² per year, with the conservative lower bound applied in the TEV model:

- **Coastal Protection**: USD 100,000–1,000,000 per km² per year, reflecting the role of reef structures as natural breakwaters that reduce wave energy and safeguard coastal infrastructure (Ferrario et al., 2014).
- **Existence and Bequest Values**: USD 340,000 per km² per year, representing the intrinsic value communities place on preserving coral ecosystems for future generations.
- **Scientific, Educational, and Genetic Services**: Research and training values contribute USD 10,000–20,000 per km² per year, while pharmaceutical and genetic resources add USD 5,800 per km² per year.

Summarized Valuation Formula

The TEV of Tanzania's coral reefs is computed using the following consolidated formula:

$$TEV = V_{tourism} + V_{ecosystem} + V_{fisheries} + V_{non\text{-}market}$$

Where:

- $V_{tourism}$ = 57,142.85 USD/km^2/year
- $V_{ecosystem}$ = 1,800,000 USD/ km^2/year
- $V_{fisheries}$ = 15,000 USD/km2/year
- $V_{non\text{-}market}$ = 515,800 USD/ km^2/year

TEV = 57,142.85 + 1,800,000 + 15,000 + 515,800 = 2,330,800 USD/km2/year

Synthesis and Implications

A TEV of **USD 2.33 million per km² per year** positions coral reefs among Tanzania's most economically valuable natural assets. Because ecosystem services and non-market values dominate this calculation, any degradation of reef structure or function would result in substantial economic losses far exceeding direct commercial revenues. These findings provide strong empirical justification for integrating coral reef conservation into national development planning, climate adaptation strategies, and blue economy initiatives.

3.6 Cost–Benefit Analysis of Illegal and Unsustainable Fishing Practices

The macroeconomic assessment of Tanzania's 3,500 km² coral reef ecosystems reveals a stark economic divide between continued destructive extraction and a transition toward sustainable co-management. Integrating market and non-market valuations demonstrates that illegal and unsustainable fishing practices impose massive national liabilities, while sustainable management unlocks substantial long-term economic gains.

Economic Liabilities of Illegal and Unsustainable Extraction

Destructive practices including blast fishing, cyanide use, beach seining, and persistent non-compliance provide short-term financial gains for operators but generate severe long-term ecological and socioeconomic costs. Over the past decade, these pressures have contributed to a 50% decline in coral cover and a 40% reduction in target fish biomass (WCS, 2024), undermining both ecosystem productivity and community resilience.

Using a Total Economic Value (TEV) framework, continued degradation results in USD 9.65 billion in annual national losses, driven primarily by reef structural collapse, tourism decline, and erosion of critical ecosystem services (Table 1).

Table 1
Annual Economic Losses from Illegal and Unsustainable Practices

Impact Category	Baseline Valuation	Annual Cost (USD)
Reef Destruction	USD 2.3M/km² × 3,500 km²	8.05B
Blast Fishing Losses	USD 306,800/km² × 3,500 km²	1.07B
MPA Violation Losses	Empirical estimate	230M
Tourism Loss	Spalding et al. (2017)	150M
Restoration Costs	USD 41,400/km² × 3,500 km²	144.9M
Total Losses		9.65B

These results confirm that illegal and unsustainable extraction is a major macroeconomic liability, far exceeding the short-term financial gains it produces. The economic burden is compounded by:

- Long-term declines in fisheries productivity, reducing household incomes and national food security.
- Loss of reef-based tourism value, particularly in Zanzibar and other high-visitation seascapes.
- Erosion of shoreline protection, increasing national adaptation costs and coastal vulnerability.
- High restoration expenses, which divert limited conservation budgets away from proactive management.

The CBA clearly demonstrates that destructive extraction traps coastal communities and the national economy in a reinforcing cycle of ecological decline and rising financial losses. Short-term profits often amounting to only 10,000–50,000 TZS (USD 4–20) per day for non-compliant fishers are dwarfed by the USD 9.65 billion in annual national losses driven by reef degradation, reduced fish biomass, tourism decline, and weakened climate resilience.

Transitioning to sustainable co-management therefore represents not only an ecological imperative but a macroeconomic necessity, offering a pathway to stabilize fisheries, safeguard ecosystem services, and unlock long-term economic gains.

3.7 Macroeconomic Benefits of Sustainable Management

Transitioning to sustainable reef management anchored in managed access, strengthened enforcement, and community-led conservation secures **USD 7.07 billion** in annual economic value across Tanzania's **3,500 km²** coral reef system. These gains arise from stabilized fisheries production, renewed confidence in marine tourism, avoided enforcement losses, and the preservation of critical non-market ecosystem services that underpin national blue-economy expansion.

Valuation of Annual Economic Benefits

Annual benefit values were assessed using a **Total Economic Value (TEV)** framework, integrating direct, indirect, and non-market contributions.

Fisheries Production - USD 525M: Stabilized yields, reduced destructive practices, and improved stock recovery generate **USD 525 million** annually. Managed access reduces catch variability and lowers operational costs for artisanal fishers.

Sustainable Tourism - USD 15M: Reef restoration enhances dive quality, visitor satisfaction, and destination competitiveness, contributing **USD 15 million** annually to coastal tourism recovery and resilience.

Ecosystem Services -USD 6.30B: Applying a valuation coefficient of **USD 1.8 million per km²** across Tanzania's **3,500 km²** reef system yields **USD 6.30 billion** annually: 1.8M×3,500 km2 = 6.3B. This

category includes shoreline protection, carbon sequestration, biodiversity maintenance, nutrient cycling, and other natural capital services essential to long-term economic stability.

MPA Enforcement Savings - USD 230M: Enhanced compliance and reduced illegal fishing generate **USD 230 million** annually in avoided losses, preventing ecosystem degradation and reducing future restoration liabilities.

Total Annual Benefits: Total Annual Benefits = 525M+15M + 6,300M+230M = 7.07 Billion (Table 2).

Table 2
Annual Economic Benefits from Sustainable Marine Management

Benefit Category	Baseline Valuation Method / Mechanism	Annual Value (USD)
Fisheries Production	Stabilized yields and stock recovery	525M
Sustainable Tourism	Reef recovery and sector growth	15M
Ecosystem Services	USD 1.8M/km² × 3,500 km² reef area	6.30B
MPA Enforcement Savings	Recovered losses and avoided damage	230M
Total Annual Benefits	Combined TEV Output	**7.07B**

Interpretation and Discussion

Fisheries Production (+ USD 525M): Stock recovery and reduced destructive gear use (e.g., blast fishing) increase catch reliability and reduce travel distances for artisanal fishers, lowering operational costs and stabilizing household incomes.

Sustainable Tourism (+ USD 15M): Healthy coral ecosystems enhance underwater visibility, biodiversity richness, and overall visitor experience strengthening Tanzania's competitiveness in the regional marine tourism market.

Ecosystem Services (+ USD 6.30B): Representing **approximately 89%** of total annual benefits, natural capital services far exceed extractive revenues. Coastal defense and carbon sequestration alone provide macro-critical support to national climate resilience and infrastructure protection.

MPA Enforcement Savings (+ USD 230M):Effective enforcement acts as a preventative economic strategy. By reducing non-compliance, Tanzania avoids long-term ecological damage and costly restoration interventions.

Integrated Cost–Benefit Context: Comparing annual benefits with ongoing ecological losses reveals a significant macroeconomic deficit: Net Annual Impact = 7.07B (Benefits) − 9.65B (Losses) = USD−2.58 Billion

3.6 Comparison of Marine Protected Areas (MPAs) and Non-MPAs

Interviewees drawing on 10 years of personal experience reveal clear ecological contrasts between Marine Protected Areas (MPAs) and adjacent unprotected zones. Based on their decade of observations, local resource users and experts consistently report that reefs within MPAs exhibit healthier coral communities, stronger structural integrity, and higher biological richness. In contrast, they note pronounced degradation in unprotected areas, driven largely by destructive practices such as blast fishing, poison fishing, and beach seining. Interviewees highlighted that blast fishing alone can destroy up to 90% of localized coral skeletal structure, while poison fishing and beach seining disproportionately impact juvenile fish and critical benthic habitats, accelerating long-term ecosystem decline (McManus et al., 1997).

Ecological Trends Based on 10 Years of Interviewee Experience

Aggregated responses tracking what interviewees observed throughout their 10 years of experience demonstrate sustained ecological advantages within MPAs:

- **Healthier coral reefs**: 66% of respondents observed lower bleaching, reduced algal overgrowth, and fewer signs of physical damage over their decade of experience.
- **Higher coral diversity**: 66% indicated they noticed greater coral species richness within the protected zones.
- **Higher fish abundance**: 62.3% recorded an increase in fish abundance within MPAs over their 10 years of observation.
- **Larger fish sizes**: 56.9% reported regularly seeing larger individual fish within MPAs.
- **Greater fish species diversity**: 54.6% noted higher species richness for fish during their time working the area.
- **No difference**: Only 14.5% of respondents perceived no noticeable change between MPAs and unprotected areas over the 10-year period.
- **Negative trends**: Fewer than 10% reported lower abundance or smaller fish sizes near MPAs.

These experienced-based trends confirm that MPAs consistently outperform unprotected areas in sustaining coral health and supporting diverse, abundant fish populations. According to local respondents, these positive outcomes reflect reduced fishing pressure, better protection of key herbivores and apex predators, lower habitat disturbance, and enhanced natural recovery processes. These community observations strongly align with Selig and Bruno (2010), who documented stable coral cover in MPAs compared to steep declines in unprotected reefs particularly where MPAs were older and effectively enforced. They further mirror broad empirical syntheses confirming that robust enforcement and strictly enforced no-take zones are foundational to reversing regional biomass depletion (Edgar et al., 2014; Gill et al., 2017).

Implications for Management

The 10 years of empirical experience shared by stakeholders strongly supports expanding MPA-style management to unprotected areas. Priority actions include:

- Scaling MPA-style management practices to non-MPA regions.
- Strengthening enforcement capabilities and compliance monitoring within existing MPAs.
- Integrating targeted habitat restoration pathways in degraded, unprotected reefs.

Collectively, these measures can significantly enhance reef resilience, preserve critical ecosystem services, and secure local recovery potential under intensifying climate stress.

4.0 Key Findings and Policy Implications for Tanzania's Coral Reef Leadership

Key Findings

- Illegal extraction losses: Unsustainable and illegal fishing practices generate USD 9.65B in annual national losses, driven primarily by coral reef destruction (Costanza et al., 1997; 2014), blast fishing impacts (Jiddawi and Öhman, 2002), and tourism/MPA leakage valued at USD 380M (Spalding et al., 2017).
- Sustainable management benefits: Effective reef governance can secure USD 7.07B annually, including USD 6.3B in ecosystem services and USD 540M from fisheries and tourism.
- Cost efficiency of prevention:Reef rehabilitation costs USD 144.9M per year, nearly 10 times more expensive than proactive protection (Ferrario et al., 2014).
- MPA enforcement returns: Strengthened compliance can recover USD 230M annually, while enhancing food security and shoreline resilience.

Policy Implications for Tanzania's Coral Reef Leadership

- Eliminate destructive extraction: Coordinated enforcement and community surveillance can recover USD 1.07B lost annually to blast fishing.
- Standardize ecotourism: Reef-friendly certification systems can recapture USD 150M in lost tourism value.
- Expand no-take zones: Protecting 30% of reef area can rebuild fish biomass by up to 40% (WCS, 2024).
- Mobilize climate finance:The USD 22.37B cost–benefit evidence base strengthens eligibility for GCF and World Bank climate adaptation financing.
- Scale community restoration: Localized restoration across 500 km² can reduce rehabilitation costs by up to 85% (Ferrario et al., 2014).

Illegal and unsustainable fishing practices impose USD 9.65B in annual losses, far exceeding any short-term gains. In contrast, sustainable reef management secures USD 8.38B in annual benefits, positioning coral ecosystems as strategic assets for climate resilience, food security, and inclusive blue economy growth under Tanzania's National Adaptation Plan.

5.0 Conclusion and Recommendations

5.1 Conclusion

Illegal and destructive fishing including blast fishing, cyanide use, and beach seining combined with accelerating climate stress, is driving severe ecological and economic decline along Tanzania's coastline. These pressures have caused a 30–40% reduction in live coral cover and a 40% decline in fish biomass in non-protected areas. The short-term gains from destructive extraction are eclipsed by USD 9.65B in annual national losses across fisheries, tourism, and coastal protection.

This degradation threatens the 30% of Tanzanians who depend directly on marine resources, with 88% of fishers reporting declining incomes and 69.2% experiencing worsening food security. Women in post-harvest roles remain disproportionately affected.

Marine Protected Areas (MPAs) demonstrate clear ecological benefits, yet enforcement gaps and resource constraints have limited their full potential. The Marine Parks and Reserves Unit (MPRU), through the GEF-CRRI (Global Environment Facility – Coral Reef Rescue Initiative), has made significant progress by establishing national frameworks and action plans that strengthen institutional capacity and support climate-resilient coral reef protection.

5.2 Recommendations

- Embed national frameworks: Integrate the coral reef conservation frameworks and action plans developed under MPRU's GEF-CRRI project into Tanzania's National Adaptation Plan.
- Strengthen enforcement: Scale up MPRU's enforcement models, expand patrol coverage, deploy modern surveillance technologies, and apply stricter legal penalties.
- Expand MPA management:Extend MPA boundaries to protect vulnerable non-protected reef zones, ensuring stable financing and strong community participation.
- Diversify livelihoods:Provide targeted capacity building and financial supportespecially for women to transition into seaweed farming, mariculture, and ecotourism.
- Invest in restoration: Fund community-led coral gardening and artificial reef programs while improving land-based waste management to reduce sedimentation.
- Enhance monitoring: Maintain strong partnerships with WIOMSA and other regional scientific institutions to support long-term, evidence-based monitoring.

Declarations

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Assumptions and Limitations

Assumptions

- Economic Valuation: Economic loss estimates assumed stable market conditions when evaluating the annual USD 9.65 billion national cost of degradation across tourism, fisheries, coastal protection, and restoration.
- Reef Valuation Metrics: Healthy coral reefs were assumed to generate a baseline value of USD 2.33M/km² annually, totaling a potential economic opportunity of USD 18.03 billion per year under comprehensive, sustainable management.
- Socio-Economic Data Reliability: Respondent survey data was assumed to be accurate and representative, using verified indicators including declining fisher incomes (88%), heightened food insecurity (69.2%), and limited female market integration.
- Institutional Governance: Marine Protected Areas (MPAs) were assumed to be operating under designated management plans, with variations in performance attributed primarily to enforcement and resource constraints.
- Geographic Extrapolation: Ecological and socioeconomic findings gathered from seven core study districts were assumed to scale proportionally across Tanzania's total national reef area (approx. 3,580 km²).

Limitations

- Extrapolation and Spatial Variation: Scaling local data from seven districts across a national level carries risks, as it may not fully capture localized ecological anomalies or socio-economic variations unique to other coastal regions.
- Non-Market Valuation Constraints: Assigning economic weight to intangible ecosystem benefits, such as cultural heritage and baseline biodiversity, carries inherent methodological uncertainty due to a lack of localized, standardized metrics.
- Climate Change Complexity: While historical bleaching events (e.g., 2016) were accounted for, future compounding impacts of ocean acidification, severe thermal stress, and extreme storm frequencies were not dynamically modeled.
- Social Data and Enforcement Gaps: Informal labor markets, seasonal migration, and nuanced gender roles within post-harvest fisheries may be under-reported, and the true extent of illegal blast fishing enforcement challenges may be understated due to sensitive legal implications.
- Temporal and Seasonal Constraints: The cross-sectional nature of the field data restricts the interpretation of seasonal fluctuations in fish biomass and income, while annualized valuations assume a linear continuation of current destructive fishing pressures.

Author Contributions

- Upendo H. Mwaisunga: Conceptualization, methodology development, field coordination, data curation, and original draft preparation.
- Dr. Ambakisye M. P. Simtoe: Literature review, statistical data analysis, ecological interpretation, and critical manuscript review and editing.
- Godfrey W. Ngupula: Project administration, funding acquisition, policy framing, community and multi-stakeholder engagement, and final manuscript approval.

All authors have contributed substantially to the work reported and have read and approved the final version of this manuscript.

Ethical Approval and Consent to Participate

The research was conducted in accordance with the ethical standards set forth by the Ministry of Livestock and Fisheries, Tanzania, and the Marine Parks and Reserves Unit (MPRU). The study protocol involving human participants was reviewed and approved by the **Marine Parks and Reserves Unit (MPRU) Research Ethics Committee** and the **Local Government Authorities**. These bodies approved the survey questionnaire and the interview guide used in this study. Verbal consent was sought from all household representatives before each interview began. All participants provided informed consent prior to their involvement in the study. The research complied with the research ethics guidelines of the Ministry of Livestock and Fisheries, Tanzania.

Consent for Publication

Not applicable. This manuscript does not contain any individual person's data in any form that would require consent for publication.

Data Availability Statement

The datasets generated during and/or analysed during the current study are owned by the Marine Parks and Reserves Unit (MPRU). The data are available from the Marine Parks and Reserves Unit (MPRU) upon reasonable request. Requests for data access should be directed to the corresponding author or to the Marine Parks and Reserves Unit (MPRU) through the contact details provided in this manuscript.

Competing Interests

The authors declare that they have no competing interests, financial or otherwise, that could have influenced the outcomes of this study. This study was funded by the Marine Parks and Reserves Unit (MPRU) through the CRRI Project, supported by the Global Environment Facility (GEF) and WWF-CRRI. The funding institutions had no role in study design, data collection, analysis, interpretation, or manuscript preparation.

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Figures



Figure 1

The Map of Tanzania indicating the Seascapes