Instituto Nacional
de Ciências e Tecnologia de Timor-Leste

Relatório de
Investigação Científica INCT 2025

Investigate the ecological and socio-economic impact of community-based Marine Protected Areas (MPAs) on artisanal fisheries communities in Beloi and Ilimano

José Lucas do Carmo da Silva

Dezembro de 2025

Instituto Nacional
de Ciências e Tecnologia de Timor-Leste

Relatório de
Investigação Científica INCT 2025

Investigate the ecological and socio-economic impact of ~~co~~mmunity-based Marine Protected Areas (MPAs) on artisanal fisheries communities in Beloi and Ilimano

Área de Conhecimento: Ambiente
Estudo Elaborado por:

Investigador Responsável: José Lucas do Carmo da Silva
Investigador 1: Fidel de Castro Guterres
Investigador 2: Helena Gomes
Investigador 3: Elizario Soares Filipe
Investigador 4: Sandra dos Santos Pereira

Díli, 2 de Dezembro de 2025

DECLARAÇÃO

Nome do Investigador Responsável: José Lucas do Carmo da Silva

Endereço Eletrónico: zetolucasscot@gmail.com

Telefone/Telemóvel: +670 77235443

Número de Bilhete de Identidade: 06060602037070638

Título da Pesquisa Científica INCT 2025: Investigate the ecological and socio-economic impact of community-based Marine Protected Areas on artisanal fisheries communities in Beloi and Ilimano.

Área de Conhecimento: Ambiente

Ano de Conclusão: 2025

Declaro, por minha honra, que os dados aqui apresentados são verdadeiros e originais e que neste estudo apresentado não foi cometido plágio nem nenhuma ilegalidade em termos de direitos de autor.

Autorizo a reprodução integral deste relatório para o Repositório Digital Nacional do INCT, sítios eletrónicos do mesmo e para efeitos de investigação Científica.

Instituto Nacional de Ciências e Tecnologia, 2 de Dezembro de 2025.

Assinatura do Investigador Responsável :______________________________________.

ACKNOWLEDGEMENT

Author of this study wishes to express their sincere appreciation to the Instituição Nacional da Ciênçia e Tecnolojia de Timor-Leste (INCT) for its financial and institutional support, which was fundamental to the successful implementation of this research.

The author also extends their gratitude to the Research Team for their professionalism, technical contribution, and unwavering commitment throughout all phases of the study.

The author gratefully acknowledges the communities and fishers of Beloi and Ilimano for their cooperation, participation, and valuable knowledge, which greatly contributed to the relevance and depth of this research.

Special acknowledgement is to the volunteers of APM-TL, whose participation and assistance in field activities significantly enhances the quality and completeness of the data collected.

The author further acknowledges the valuable support of our partners, including the Lenuk Tasi team, Nelson Amaral, and Natalia da Silva, for generously providing necessary field equipment, including camera and GPS units.

Finally, the author wishes to thank all individuals, include Jenia's fathers for patients and support in preparing the frame for research, all institutions who contributed in various ways to this research, even if not mentioned individually, for their cooperation and support.

Investigate the ecological and socio-economic impact of community-based Marine Protected Areas (MPAs) on artisanal fisheries communities in Beloi and Ilimano

Abstract

This report assesses the ecological and socio-economic impacts of community-based Marine Protected Areas (MPAs) in Beloi and Ilimano, Timor-Leste. Ecological surveys using 28 Baited Underwater Video (BUV) deployments measured fish abundance, species diversity, and coral cover across reserve and non-reserve sites. Fish abundance was significantly higher in no-take zones ($p = 0.0015$), with Beloi Reserve recording the highest MAXN values. Coral cover also varied strongly, reaching ~65% inside Beloi's reserve compared to 15–20% in non-reserve areas. A positive relationship between coral cover and fish abundance was detected ($y = 2.1629x + 23.489$; $R^2 = 0.3205$), indicating that healthier benthic habitats support higher fish presence. Socio-economic surveys with 30 respondents revealed strong community engagement in *tara bandu* management. Fishers reported increased fish abundance, larger fish size, improved income, and growing tourism interest around protected areas. Beloi showed higher compliance and stronger support, consistent with its longer-established MPA status, while Ilimano reflected early recovery trends. Overall, the findings demonstrate that community-based MPAs are enhancing ecological conditions and providing socio-economic benefits, emphasizing the value of community leadership and continued monitoring.

Keywords:

Tara Bandu; Community-Based MPAs; Marine Ecology; Artisanal Fisheries; Coral Reefs; Community Perceptions; Timor-Leste.

TABLE OF CONTENTS

LIST OF FIGURES

1. INTRODUCTION

1.1. CONTEXTUALIZATION

Fisheries resources serve as major food sources for coastal communities and small-scale fisheries (SSF) in many developing countries (Arthur et al., 2021). However, climate change, overfishing, habitat destruction, and coastal development threaten these communities by diminishing their food sources and fishing grounds. Marine Protected Areas (MPAs) are tools recognized as essential conservation tools for sustainable fisheries and safeguarding marine resources. They enhance biodiversity conservation while contributing to the livelihoods of coastal communities (Jiang et al., 2024).

MPAs are spatially defined marine regions where human activities are regulated to achieve conservation and management objectives (Schratzberger et al., 2019). Furthermore, the International Union for Conservation of Nature (IUCN) define MPAs as areas of ocean that's clearly define and sets asides for conservation purposes. MPAs play a crucial role in sustainable fisheries management by protecting critical habitats, replenishing fish stocks, and maintaining ecosystem functions (Di Cintio et al., 2024). MPAs support global efforts to achieve Sustainable Development Goal 14 (SDG 14), which aims to conserve and sustainably use ocean resources (Andriamahefazafy et al., 2022).

The implementation of MPAs varies globally based on governance structures and levels of community participation. In small island nations and coastal regions, community-based MPAs integrate traditional ecological knowledge with modern conservation strategies to enhance resource stewardship (Gabela-Flores & Dierdrich (201); Teniwut et al., 2023). Successful cases in the Pacific, such as in Fiji and Palau, have demonstrated that locally managed marine areas (LMMAs) can lead to an increased fish biomass, habitat recovery, and improved livelihoods for dependent communities (Robertson et al., 2020).

Timor-Leste, a small island nation in Southeast Asia, its coastal communities heavily depend on small-scale fisheries for subsistence and economic livelihoods (Mills et al., 2017). Although the government has recognized the importance of MPAs, their establishment remains undetermined with limited resources and lack empirical evidence (Marine Conservation Institution, 2025). Moreover, there is limited scientific evidence on the ecological effectiveness and socio-economic impact of MPAs in Timor-Leste, highlighting the need for further research to assess their role in biodiversity conservation and fisheries management.

Furthermore, as part of the Coral Triangle Initiatives (CTI), Timor-Leste has committed to regional cooperation in marine conservation efforts which align with the regional goals (CTI, 2025). While collaborating within CTI provides opportunities to enhance MPA effectiveness, national implementation faces challenges due to governance and capacity constraints (CTI-CFF Annual Report, 2023).

Timor-Leste struggles with unsustainable fishing practices, habitat degradation, and weak governance structures. Overfishing and destructive fishing methods, such as blast and cyanide fishing, have led to declining fish stocks and coral reef degradation (Fabinyi et al., 2022). Weak of enforcement, limited scientific data, and inadequate community engagement further hinder conservation efforts (Lopez-Angarita et al., 2020).

While traditional ecological knowledge is present, local communities are not sufficiently integrated into MPA governance (Balata & Williams, 2020). This disconnects between policy frameworks and community participation affects the long-term success of MPAs in Timor-Leste. A holistic approach that incorporates ecological, social, and economic considerations is needed to strengthen marine conservation planning. Additionally, the absence of comprehensive scientific data assessing the effectiveness of MPAs limits the ability to develop adaptive management strategies.

By critically examining the ecological and socio-economic impact of Marine Protected Areas (MPAs), this study will provide essential scientific insights to enhance comprehensive planning, governance, and policy development for MPAs in the future. The findings will offer practical recommendations for strengthening MPA governance and enhancing community participation in marine conservation efforts in Timor-Leste.

1.2. LITERATURE REVIEW

1.2.1. MARINE PROTECTED AREAS (MPAS) AND TARA-BANDU

Community-based marine protected areas (MPAs), frequently established and enforced through customary institutions, are a prominent conservation and fisheries-management strategy across the Indo-Pacific (Collier, 2020; Stephenson et al., 2025). In Timor-Leste, the *tara bandu* (also spelled tara bandu/tarabandu) customary practice has been instrumental in creating locally accepted no-take or restricted zones, with communities invoking traditional law to regulate access and sanction violators (The Asia Foundation, 2013). Studies of *tara bandu* emphasize its cultural legitimacy, rapid uptake in some communities, and the potential to generate both conservation and social outcomes but also point to variability in effectiveness depending on enforcement capacity, tenure arrangements and linkages to livelihood benefits.

Two complementary evidence streams are necessary to assess MPA outcomes: (1) fish community responses (ecological effect) and (2) community perceptions and socio-economic outcomes (social effect). The present study design, relying on baited underwater video (BUV) for ecological monitoring and community perception surveys for socio-economic assessment, reflects a pragmatic approach where UVC is not used. The following sections synthesize literature on (A) ecological responses detectable using BUV (and BUV vs UVC methodological trade-offs), (B) socio-economic and perception studies of community-based MPAs in the Coral Triangle and similar contexts, and (C) implications for interpreting results from a BUV-only ecological dataset paired with perception surveys.

1.2.2. BUV as a tool for survey and monitoring in Marine Protected Areas

Baited underwater video (BUV; also known as BRUV/BRUVS) has emerged globally as a non-extracted method for surveying mobile marine fauna (Zhang et al., 2024), particularly demersal and reef-associated fishes, in both shallow and deeper habitats (Haggitt et al., 2013). BUV are widely used in MPA monitoring because they permit sampling across a broad depth range, reduce diver-related biases, and increase detection of predators/target species that respond to bait plumes (Brough et al., 2018). The method's principal strengths are standardized, non-extractive sampling; high detectability of mobile and wary species (large predators, groupers, snappers); and permanent video records that can be re-examined for species, abundance indices and behaviour. BUV datasets generate commonly used metrics such as MaxN (the maximum number of individuals of a species seen in a single frame), which is robust for between-deployment comparisons because it avoids double counting (Stobart et al., 2015).

However, BUVs also have well documented limitations that affect interpretation. Several comparative studies show that UVC often records greater overall species richness, particularly for small, cryptic, patchily distributed or site-attached species that do not respond to bait, whereas BUVs perform particularly well at detecting larger, mobile, bait-attracted predators (French et al., 2021). Thus, BUV tends to bias assemblage samples toward carrion/bait-responsive taxa and may underestimate cryptic reef fish diversity and abundance. Because of these method-specific detection biases, BUV results must be framed as reflecting the "bait-attracted component" of the assemblage rather than the whole fish community (Erickson et al., 2023).

Careful attention to deployment design mitigates many practical issues. Optimal soak times and replicate numbers are critical: recent work indicates extended soak times (e.g., ~15-30 minutes) improve species detection, particularly for less abundant taxa, though diminishing returns occur after an optimal interval. Standardizing bait type, quantity, camera height and soak time across sites and seasons is essential to make defensible inside-vs-outside MPA comparisons. Analysts should also be cautious when using MaxN as a proxy for absolute abundance, it is an index suited to relative comparisons but can compress variation for schooling species and does not translate directly to biomass without additional length/weight information or stereo-video methods (Heupel, 2019). Likewise, BUV detection probability varies among species and habitats and should inform interpretation.

1.2.3. Detecting MPA effects with BUV: what the literature shows

BUV studies have frequently detected positive responses to protection, notably higher relative abundance and frequency of occurrence of commercially important predators and larger body size classes, inside well-enforced no-take zones compared with adjacent fished areas. These effects are most apparent for species that are large, mobile and strongly targeted by fishers (e.g., groupers, snappers, sharks). However, the magnitude and detectability of reserve effects depend on reserve age, size, connectivity, enforcement and the life history of focal species. Short-lived, fast-recruiting species may show rapid responses; long-lived, slow-growing species require longer protection periods before recovery is evident. Because BUV is particularly sensitive to larger, mobile species, it can be a powerful method to assess these fisheries-relevant responses even where UVC might better quantify small cryptic assemblages.

1.2.4. Socio-economic perceptions of community-based MPAs

Socio-economic research in the Coral Triangle and other tropical small-scale fisheries contexts repeatedly shows that community perceptions of MPAs are shaped by tangible benefits (catch improvements, spillover, livelihoods diversification, tourism income), fairness in design (who benefits), and governance factors (degree of local control, clarity and enforcement of rules). Perception surveys are a valuable diagnostic: they reveal local compliance drivers, latent conflict, and perceived costs, especially when restrictions disproportionately affect more vulnerable fishers. Integrating socio-economic criteria into MPA planning, such as explicit compensation, alternative livelihood support, or tourism revenue sharing, improves legitimacy and long-term compliance. Studies argue for pairing ecological monitoring with socio-economic monitoring to interpret ecological signals in light of human behaviour and to guide adaptive management.

In *tara bandu* contexts like Atauro and other Timor-Leste communities, qualitative and quantitative studies have documented that cultural salience and local ceremony can accelerate adoption of rules, but that enforcement, benefit distribution (who gets tourism money or improved catches), and inter-household equity shape sustainability. Perception surveys therefore provide essential context for BUV results: an observed ecological response (or lack of one) may be linked to governance effectiveness and community buy-in revealed in survey responses.

1.2.5. Methodological implications for the Beloi–Ilimano study

Account for deployment designed to ensure soak time, bait protocol and camera setup are standardized across It is important to interpret ecological findings conservatively in light of the methodological scope and limitations of the Baited Underwater Video (BUV) approach. BUV derived metrics such as MaxN (the maximum number of individuals of a given species observed simultaneously within a single frame) and species occurrence are well-established for detecting relative differences in the abundance and presence of the bait-attracted component of fish assemblages. However, these measures do not provide a complete census of total assemblage richness or overall ecosystem biodiversity.

Increases in MaxN observed inside MPAs should therefore be understood as indicative of relative increases in bait-responsive fishes, which often include larger-bodied, mobile, and commercially important taxa such as snappers, groupers, and other predatory species. These groups are particularly responsive to protection due to reduced fishing pressure, making them suitable indicators of early reserve effects. Nevertheless, such increases should not be over-interpreted as evidence of comprehensive community-wide recovery. Cryptic, herbivorous, or non-bait-attracted species may remain underrepresented in BUV surveys, and broader patterns of ecological restoration, such as shifts in trophic structure, recruitment, or benthic-pelagic linkages, cannot be inferred solely from BUV-derived data.

Accordingly, while the BUV results provide robust evidence of localized increases in bait-attracted and commercially relevant fishes within established MPAs, they must be contextualized within the methodological limitations of the survey. Integrating complementary data sources, such as habitat assessments and community perceptions, remains essential to developing a more holistic understanding of ecological recovery and management effectiveness.

To strengthen the robustness of ecological inferences, complementary analytical approaches should be employed alongside MaxN summaries. While MaxN provides a standardized and conservative measure of relative abundance for bait-attracted fishes, it is most informative when combined with additional metrics. Species-level frequency-of-occurrence analyses can reveal consistent patterns of species presence across deployments, while comparisons of functional groups (e.g., herbivores, piscivores, planktivores) allow detection of differential responses to protection across trophic levels. Furthermore, multivariate community analyses can provide a broader view of assemblage-level structure, enabling assessment of whether fish communities inside MPAs diverge significantly from those in adjacent fished areas. Such a multi-metric framework strengthens ecological interpretation while also reducing reliance on a single indicator.

At the same time, methodological limitations must be explicitly acknowledged. BUV surveys underrepresent cryptic, small-bodied, or nocturnal taxa that do not readily approach bait, and they may overemphasize schooling or highly mobile species, which can inflate MaxN counts. Recognizing these biases is critical to avoiding overstatement of ecological outcomes and ensuring results are interpreted as evidence of relative rather than absolute changes in fish assemblages.

Equally important is the integration of socio-ecological perspectives to contextualize observed ecological patterns. Community perception surveys provide insight into governance, compliance, and perceived benefits that directly mediate ecological outcomes. For instance, in Beloi, stronger perceptions of effective enforcement, coupled with recognized tourism benefits and widespread community acceptance of Tara Bandu rules, align with clearer BUV-detectable reserve effects, including higher abundance and diversity of bait-attracted fishes. Conversely, in Ilimano, where perceptions remain more cautious due to the novelty of the Tara Bandu MPA and uncertainty about its benefits, ecological signals appear muted, with comparatively lower fish abundance and coral cover observed in preliminary analyses. These findings highlight the feedback between social legitimacy and ecological performance: robust community support can accelerate and sustain reserve effectiveness, whereas uncertainty or perceptions of inequitable benefit-sharing may slow or dampen ecological recovery.

The existing literature underscores the value of Baited Underwater Video (BUV) as a robust, fishery-independent tool for detecting reserve effects, particularly in larger, mobile, and commercially important taxa. Nevertheless, critical limitations are well documented, especially concerning its reduced sensitivity to cryptic or small-bodied species and the interpretive challenges that arise when Underwater Visual Census (UVC) data are unavailable for comparison. In parallel, socio-economic perception studies are widely recognized as essential for understanding the governance structures, compliance dynamics, and community attitudes that ultimately mediate ecological outcomes.

In the context of Beloi and Ilimano, the integration of BUV-based ecological monitoring with community perception surveys represents a defensible and regionally consistent approach. Its validity, however, depends on transparent articulation of methodological biases, strict standardization of video deployments, and the explicit integration of ecological patterns with socio-economic narratives derived from survey data. Looking forward, the scientific rigor of such assessments could be substantially enhanced by the incorporation of longer temporal datasets, complementary ecological methods (e.g. stereo-BUV for fish size and biomass estimation, or periodic UVC for cryptic taxa), and expanded socio-economic indicators that move beyond perceptions to include quantifiable measures of household income, food security, and livelihood resilience.

1.3. PROBLEM STATEMENT

Marine protected areas (MPAs) have been widely recognized as effective tools for conserving biodiversity and supporting sustainable fisheries. In Timor-Leste, community-based MPAs, locally implemented under the Tara Bandu traditional governance system, have been established to regulate fishing activities and protect coastal ecosystems. However, despite their growing number, there is limited empirical evidence on the ecological effectiveness and socio-economic outcomes of these MPAs.

The key problem addressed by this study is the lack of integrated, fisheries-relevant assessments that quantify both ecological responses (e.g., fish abundance, species diversity, coral cover) and community perceptions of benefits and compliance. While anecdotal reports suggest that some Tara Bandu MPAs may enhance fish stocks and provide tourism opportunities, systematic data are scarce, particularly for newly established sites such as Ilimano, where community awareness and ecological recovery may still be in early stages.

Research in Timor-Leste is often constrained by high costs, including expenses for specialized equipment, field logistics, and personnel. Consequently, there is a need for alternative, cost-effective methodologies that can still provide reliable ecological and socio-economic information. The combined use of baited underwater video (BUV) surveys and digital socio-economic assessments, as applied in this study, offers a practical and lower-cost approach that enables monitoring of fish assemblages, coral habitat, and community perceptions without the financial burden of more traditional survey methods.

This gap in knowledge and methodological accessibility poses challenges for evaluating MPA performance, informing adaptive management, and guiding policy decisions aimed at sustainable fisheries and coastal livelihoods. Therefore, this study focuses on assessing how Tara Bandu-based MPAs in Beloi and Ilimano influence both reef-associated fish assemblages and socio-economic outcomes, providing evidence to support effective community-based management and the long-term sustainability of coastal resources in Timor-Leste.

1.4. HYPOTHESIS

This study hypothesizes that:

H1: Higher fish abundance and coral covers within established Tara-bandu MPAs compared to adjacent fished areas, with stringer effects observe in longer history of protection.

H2: Fish abundance is positively correlated with coral covers.

H3: Positive community perceptions of MPAs are associated with stronger ecological signals (higher fish abundance and diversity) detectable via BUV.

1.5. OBJECTIVE

This study primarily examines the effectiveness of community-based Marine Protected Areas (MPAs) in fostering sustainable fisheries in Atauro Island, and Ilimano. Additionally, it investigates the economically significant fish species targeted by artisanal fisheries in Timor-Leste.

Specific Objectives:

- To evaluate the ecological benefits of MPA on fish abundance for artisanal fisheries in Timor-Leste.
- To analyze the socio-economic impact of MPAs on local fishing communities.
- To identify challenges and opportunities for implementing community-based MPAs.
- To provide recommendations for scaling up community-based MPA initiatives.

1.6. IMPORTANCE OF THE RESEARCH

The sustainable management of coastal resources is a critical challenge for Timor-Leste, where artisanal fisheries provide food security, livelihoods, and economic opportunities for local communities. Community-based marine protected areas (MPAs), established under the Tara Bandu traditional governance system, represent an innovative approach to balancing conservation and resource use. However, the lack of empirical data on their ecological effectiveness and socio-economic outcomes limits the ability of policymakers, local authorities, and communities to make informed decisions regarding MPA design, enforcement, and adaptive management.

This study is highly relevant because it addresses these knowledge gaps by integrating ecological assessments of reef-associated fish assemblages and coral habitats with socio-economic surveys of community perceptions and benefits. The findings are expected to provide actionable insights that can strengthen the management of existing MPAs and inform the establishment of new sites. By demonstrating a cost-effective methodology combining baited underwater video (BUV) and digital perception surveys, the study also offers a practical model for sustainable research in Timor-Leste, where conventional monitoring programs can be prohibitively expensive.

The contributions of this research are multifaceted: at the national level, it provides evidence-based guidance for sustainable fisheries management and coastal conservation policies; at the municipal level, it supports local governance in implementing and enforcing Tara Bandu MPAs; for communities, it highlights the link between conservation compliance and tangible socio-economic benefits; and for science, it advances methods for integrated socio-ecological monitoring in small-scale fisheries and community-based protected areas. Overall, this study seeks to generate knowledge that enhances both ecological resilience and human well-being in Timor-Leste's coastal regions.

1.7. ORGANIZATION OF THE WORK

The study was structured to systematically assess both ecological and socio-economic dimensions of Tara Bandu-based MPAs in Beloi and Ilimano. The work was organized in sequential stages as follows:

First, a preliminary literature review was conducted to contextualize community-based MPA management in Timor-Leste, identify knowledge gaps, and select relevant ecological and socio-economic indicators for assessment. This step provided the theoretical foundation for the study design and informed methodological choices.

Second, ecological data collection was carried out using baited underwater video (BUV) systems to quantify fish abundance, species richness, functional group composition, and coral reef characteristics. BUV frames were deployed across multiple sites inside MPAs and in adjacent fished areas, with video recordings analyzed to generate metrics such as MaxN, species occurrence, and coral cover.

Third, socio-economic data were collected through structured community perception surveys administered via KoboToolbox. Enumerators conducted interviews with local residents to assess attitudes toward MPAs, compliance with Tara Bandu rules, perceived benefits, and potential challenges in resource management. Digital data collection enabled real-time recording and secure storage of responses.

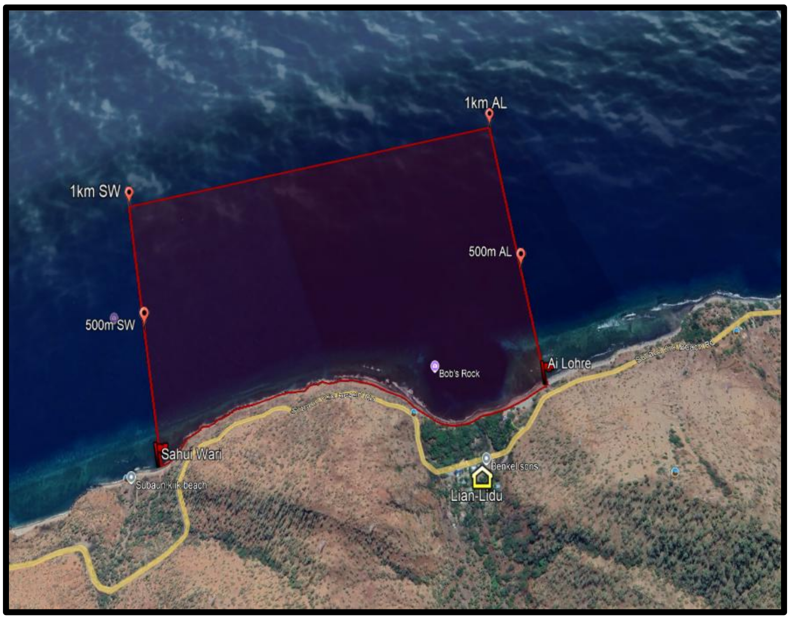
Fourth, collected ecological and socio-economic data were analyzed in an integrated manner. Ecological metrics were summarized and compared between protected and fished sites, and multivariate analyses were used to examine community composition and functional group patterns. Socio-economic data were analyzed to identify trends in community perceptions and to relate these to observed ecological patterns.

Finally, findings were synthesized to provide a comprehensive assessment of the ecological effectiveness and social acceptance of Tara Bandu MPAs. The results aim to inform recommendations for improved MPA management, adaptive governance strategies, and cost-effective monitoring approaches that can support sustainable fisheries and coastal livelihoods in Timor-Leste.

1.8. STUDY AREA

This study was conducted in two coastal communities of Timor-Leste, specifically Beloi and Ilimano, where community-based marine protected areas (MPAs) under the Tara Bandu governance system have been established. These locations were selected because they represent different stages of MPA implementation: Beloi hosts a long-established MPA with observed ecological and socio-economic outcomes, while Ilimano's MPA is newly established, providing an opportunity to assess early-stage effects.

a) Ilimano MPA map



b) Atauro MPA map

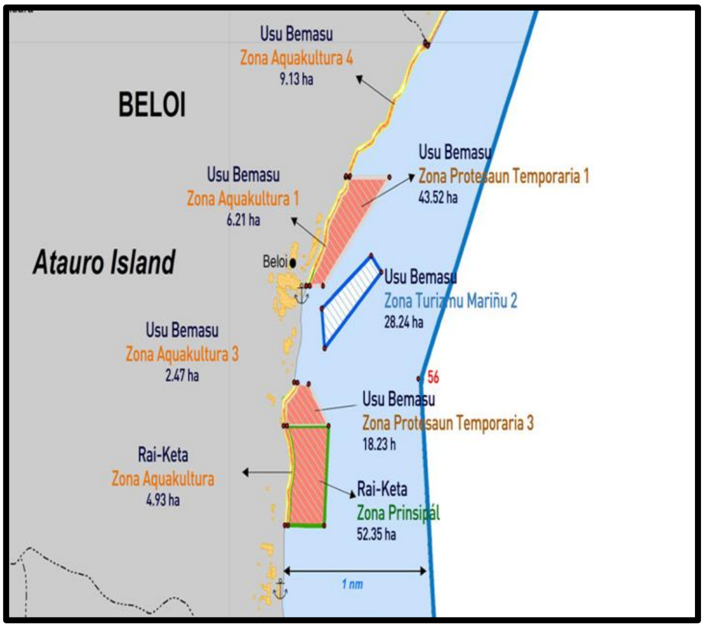


Figure 1. Map of our study sites a) Ilimano MPA maps and b) Atauro MPA map. a) The red polygon in Ilimano map is no-take zone areas or reserves, where all the extractive activities are prohibited, and outside of red polygons is fishing area or non-reserves (Source: Blue Ventures Timor-Leste). b) In Atauro Island, our study focuses on Usubemasu Tourism zones (blue polygons) as reserves sites, where there are no extractive activities or no-take zones, and the area adjacent to the tourism area as non-reserves sites (source: Coral Triangle Center).

Fieldwork was carried out in defined reef areas within and adjacent to the MPAs. Ecological surveys focused on shallow coral reef habitats (depths ranging approximately 3–15 meters) where reef-associated fish assemblages and benthic structures could be observed. Coral and fish data were collected using baited underwater video (BUV) systems deployed at multiple fixed sites inside the MPAs and at comparable unprotected control sites nearby.

Socio-economic surveys were conducted with residents of the respective communities, including fishers, local leaders, and other stakeholders directly affected by the MPAs. Data collection targeted perceptions of Tara Bandu compliance, ecological changes, and socio-economic benefits.

Geographical coordinates of survey sites were recorded using GPS devices to enable precise mapping of sampling locations. Digital mapping tools were employed to visualize spatial patterns of ecological metrics and relate these to MPA boundaries, fishing zones, and community usage areas. This detailed geographic information provides a spatial framework for comparing ecological recovery and community engagement across the two study sites.

METHODOLOGY

2.1. RESEARCH METHODOLOGY

This study adopts a **mixed-methods research strategy**, combining quantitative and qualitative approaches. The selection of a mixed-methods approach is justified by the need to capture both ecological metrics (quantitative) and socio-economic perceptions (qualitative), allowing for a comprehensive understanding of the effects of Tara Bandu-based MPAs on reef ecosystems and local communities (Santos et al., 2019).

The research employs a **field-based case study design**, focusing on two specific communities, Beloi and Ilimano, in Timor-Leste. Ecological data were collected through **baited underwater video (BUV) surveys**, and socio-economic data were collected through **digital community surveys**. This integration enables a holistic assessment of both ecological outcomes and community perceptions.

2.2. DEFINITION OF THE RESEARCH UNIVERSE (POPULATION) AND SAMPLE

Population and Sample

The research population includes:

- Ecological component: all reef-associated fish and coral assemblages within selected reef sites inside MPAs and adjacent fished areas in Beloi and Ilimano.
- Socio-economic component: local community members, including fishers, household heads, and key stakeholders directly affected by MPA implementation.

Sampling was conducted as follows:

- Ecological sampling: Multiple BUV deployments at predefined coordinates within MPAs and control sites, with replicate videos to capture variability in fish and coral communities.
- Socio-economic sampling: Purposive sampling of 30–50 respondents per community, targeting fishers and households directly dependent on coastal resources, with attention to gender and age diversity. Variables collected include attitudes toward MPAs, compliance with Tara Bandu rules, perceived ecological and economic benefits, and level of awareness regarding MPA rules.

Ecological surveys follow a quasi-experimental design comparing protected (MPA) vs. unprotected (control) sites. Independent variables include MPA status (inside/outside), duration of protection, and enforcement intensity. Dependent variables include MaxN, species richness, functional group composition, and coral cover. The relationship between independent and dependent variables is examined through comparative and multivariate analyses.

2.3. DATA COLLECTION TECHNIQUES AND INSTRUMENTS

Ecological Data Collection – Baited Underwater Video (BUV) Survey:

- Instruments: Handmade steel-frame BUV systems with surface buoys for vertical positioning; GoPro Hero 7 and Hero 12 cameras.
- Technique: Each camera deployment recorded 8–10 minutes of video, with multiple replicate drops per site. White scad (*Decapterus spp.*) was used as standardized bait to attract reef-associated and commercially important fishes.
- Benthic Assessment: BUV frames incorporated an integrated quadrat system to delineate standardized survey areas on the seabed. All coral colonies and associated substrate types within the quadrats were recorded. Coral analyses included quantifying live coral cover, identifying coral genera, and documenting other benthic categories (rubble, algae, sand).
- Data Analysis: Videos were analyzed to extract ecological indicators, including:
    - Relative abundance (MaxN) of key species,
    - Species richness and diversity indices, and

- Coral cover and species identification.

Socio-economic Data Collection - Community Surveys:

- Instruments: Structured and semi-structured questionnaires administered via KoboToolbox mobile application.
- The Respondents obtain in Beloi was 16 fishers and 14 respondents in Ilimano.
- Technique: Enumerators conducted interviews directly through the app, recording responses in real time. Once internet connectivity was available, data were automatically uploaded and synchronized to the central server, ensuring secure storage and minimizing transcription errors. Surveys captured local perceptions of MPA effectiveness, compliance with Tara Bandu rules, perceived impacts on fisheries and livelihoods, and alternative opportunities such as tourism and cultural recognition.

2.4. DATA TRANSCRIPTION AND ANALYSIS

Baited Underwater video

From each BUV deployment, the metric MAXN (Maximum Number of individuals observed in a single video frame) was used to quantify fish abundance. MAXN is widely recommended in BUV analysis as it avoids recounting the same individuals and provides a conservative but reliable estimate of relative abundance. For each site, MAXN values were recorded for all observed species. The values were aggregated to produce an average MAXN for:

- **No-Take Zones (NTZ)**
- **Fishing Areas**

A **two-way ANOVA** was conducted to assess whether differences in fish abundance (Average MAXN) were statistically significant between:

1. **Management regimes** (No-Take Zone vs. fishing area)
2. **Other influencing factors** (e.g., sites or habitat type - depending on study design)

The two-way ANOVA allowed for testing both the main effects and potential interaction effects between management zone and other variables. This statistical approach improves the robustness of the comparison and accounts for natural variation between sites.

Furthermore, coral cover was assessed using a **1 m × 1 m quadrat**, photographed or observed in situ. A **10 × 10 grid overlay** (100 sub cells) was applied to each quadrat image to enable quantitative estimation of benthic composition.

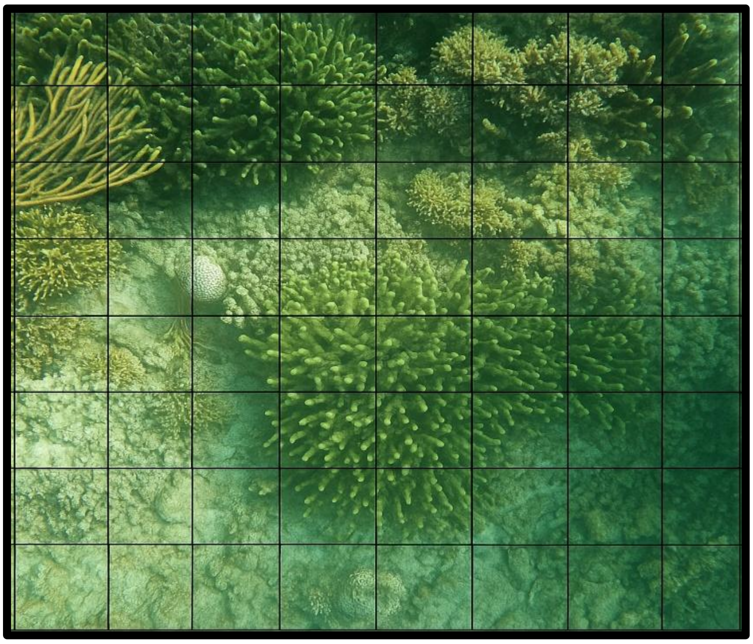


Figure 2. The coral covers count with 10x10 grid overlay. The overlay grid will help researchers quantifying the coral covers.

Each grid cell was classified into one of several benthic categories, including:

- Hard coral
- Soft coral
- Other substrates (e.g., rubble, sand, algae)

The percentage of benthic communities was then calculated based on the number of grid points corresponding to each category. This method provides a consistent and repeatable approach for estimating coral cover.

Coral cover for each quadrat was derived using the standard formula:

$$\textbf{Coral Cover (\%)} = \left(\frac{\textbf{Area of Coral (m}^2\textbf{)}}{\textbf{Total Area of Quadrant (m}^2\textbf{)}}\right) \times \mathbf{100}$$

Given the quadrat area of 1 m², the formula simplifies to:

$$\textbf{Coral Cover (\%)} = \textbf{Area of Coral} \times 100$$

The values across quadrats were averaged to represent coral cover at each site.

Coral cover provides an important indicator of habitat quality and reef resilience. Higher coral cover in the No-Take Zone relative to fishing areas would suggest positive habitat protection effects, whereas similar or degraded cover in protected sites could indicate broader ecosystem stressors such as climate impacts, sedimentation, or destructive fishing practices.

3. DEVELOPMENT OF THE WORK: DATA ANALYSIS AND DISCUSSION

3.1. ANALYSIS OF RESULT

3.1.1. BAITED UNDERWATER VIDEO

Fish abundance, expressed as MAXN counts, differed between reserve and non-reserve areas at both study sites (Figure 3a). In Beloi, the reserve showed the highest mean fish abundance, with MAXN values reaching approximately 12 individuals, whereas the non-reserve area displayed markedly lower values, averaging around 4 individuals. The variability in MAXN was also greater in the reserve compared to the non-reserve area. In Ilimano, fish abundance in the reserve averaged around 10 individuals, while the non-reserve site recorded substantially lower values of approximately 5 individuals. Although the magnitude of the difference between reserve and non-reserve areas was less pronounced in Ilimano compared to Beloi, the pattern of higher fish abundance within reserves was consistent across both sites.

Total coral cover (%) also varied across sites and protection status (Figure 3b). In Beloi, coral cover within the reserve reached mean values of around 70%, while the non-reserve area exhibited considerably lower cover of approximately 30%. Coral cover in Ilimano showed a similar trend, with the reserve area having mean values near 50% and the non-reserve area showing lower cover at approximately 20%. Error bars indicated some variation within each site and status, but in all cases, reserve areas displayed higher mean coral cover than their corresponding non-reserve areas. Across both Beloi and Ilimano, the reserves consistently supported greater coral cover compared to adjacent fished areas.

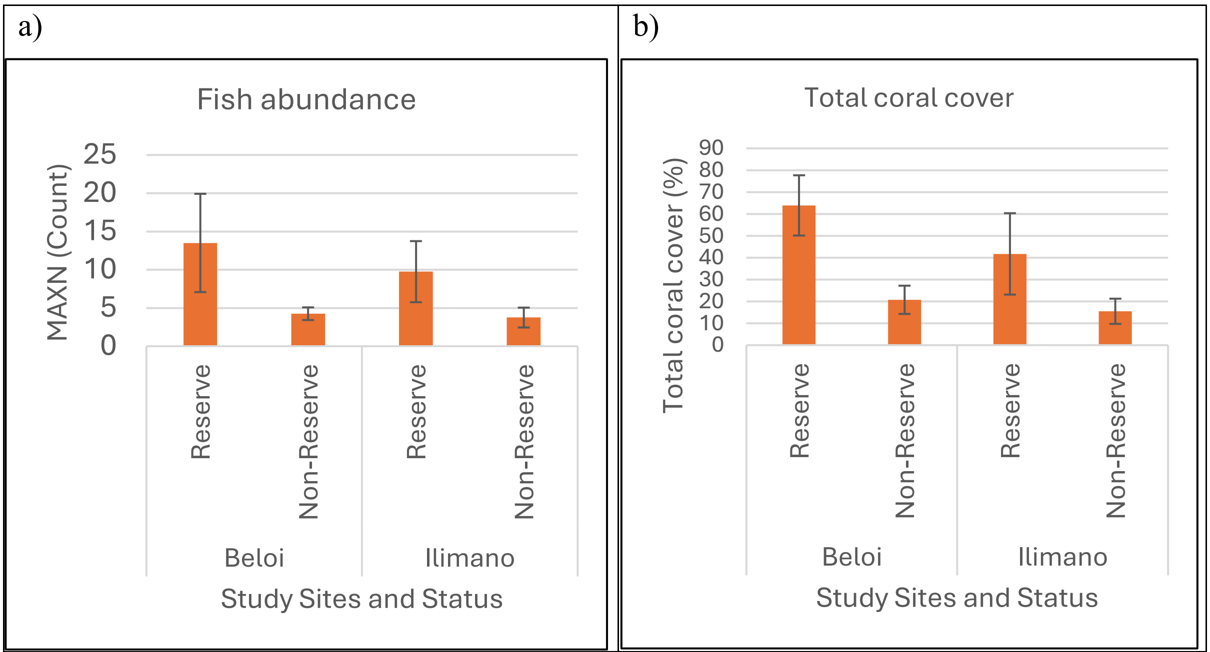


Figure 3. The comparison between (a) fish abundance and (b) total coral covers between marine protected areas and fishing areas in Beloi and Ilimano. The (a) fish abundance was count of MAXN and (b) total corals covers was in % of covers in area.

A linear regression analysis was conducted to examine the relationship between total coral cover (%) and fish abundance (MAXN) (Figure 4). The scatterplot shows a positive trend, with higher fish abundance generally associated with higher coral cover values. The fitted regression line is described by the equation $y = 2.1629x + 23.489$, indicating an upward slope across the observed range of MAXN values.

The coefficient of determination ($R^2 = 0.3205$) indicates that approximately 32% of the variation in total coral cover is explained by variation in fish abundance. Data points are distributed across a wide range of coral cover values (approximately 10–90%) and MAXN values (approximately 3–30), with the overall pattern showing an increase in coral cover as fish abundance increases.

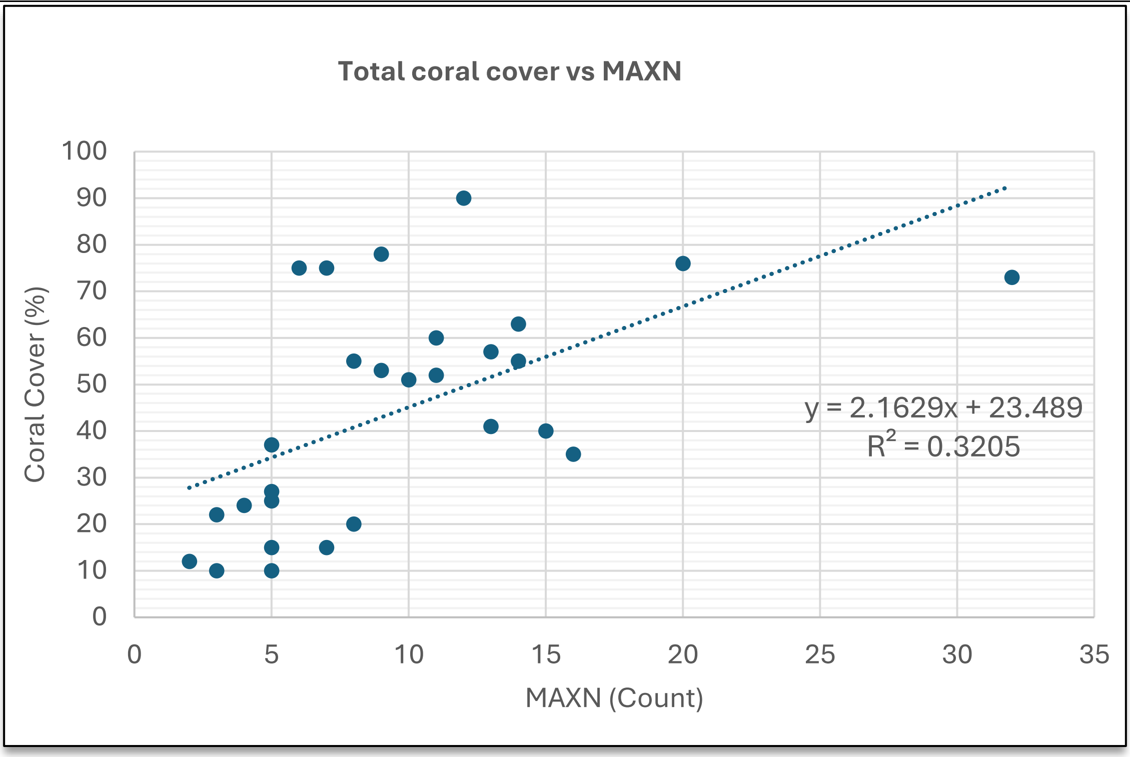


Figure 4. Linear regression on total coral covers and fish abundance (MAXN) for correlation analysis. The R^2= 03205 shows positive correlation between Coral covers and fish abundance.

Two-way T-test.

Fish abundance measured using MAXN from BUV surveys showed clear differences between reserve (R) and non-reserve (NR) areas across both Beloi and Ilimano (Figure 5). In Beloi, the reserve area recorded substantially higher MAXN values, with a higher median and a wider distribution compared to the consistently low and tightly clustered values observed in the non-reserve area. A similar pattern was found in Ilimano, where the reserve also showed higher median fish abundance and greater variability than the adjacent non-reserve site.

Fish abundance measured using MAXN from BUV surveys showed clear differences between reserve (R) and non-reserve (NR) areas in both Beloi and Ilimano (Figure 3). In Beloi, the reserve area displayed a higher median MAXN value and a wider range of observations compared to the consistently low and tightly clustered values recorded in the non-reserve area. A similar pattern was evident in Ilimano, where the reserve again showed higher median fish abundance and greater variability relative to the adjacent non-reserve site.

A two-way ANOVA revealed that fish abundance differed significantly between Reserve and Non-Reserve areas ($F_{1,24} = 12.83$, $p = 0.0015$), indicating a strong effect of protection status. In contrast, the effect of site (Beloi vs. Ilimano) was not statistically significant ($F_{1,24} = 3.08$, $p = 0.092$). There was also no significant interaction between site and status ($F_{1,24} = 0.57$, $p = 0.459$), showing that the positive reserve effect on fish abundance was consistent across both locations. These results demonstrate that protection status is the main factor influencing fish abundance in the study area.

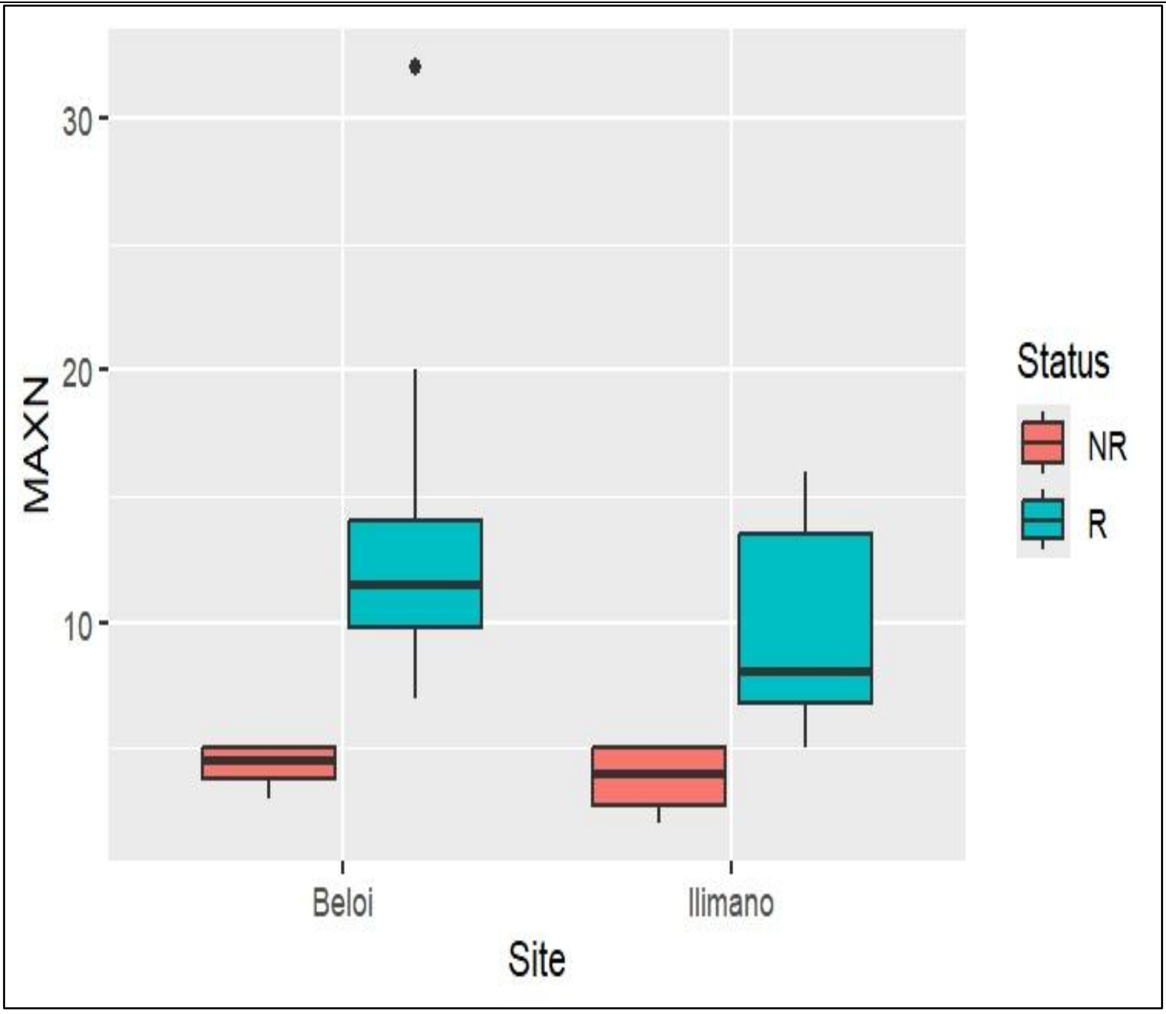


Figure 5. Boxplots showing fish abundance (MAXN) recorded by BUV across reserve (R) and non-reserve (NR) areas in Beloi and Ilimano. In both sites, reserve areas exhibit noticeably higher median MAXN values and greater variability compared to non-reserve areas, indicating higher fish abundance within protected zones.

3.1.2. Socio-economic survey

Figure 6 presents the occupation and fishing intensity of respondents involved in the study. Most respondents identified their occupation as *Peskador* (fisherman), representing the primary livelihood group participating in the survey, with a total of 25 individuals reporting fishing as their main profession. In contrast, only five respondents reported being part of the *Estrutura Tara-bandu*, a community-based management structure actively engaged in local marine resource governance.

Fishing intensity among respondents varied (Figure 6b). The largest group consisted of individuals who reported *Ba peska loron-loron* (fishing every day), totalling 17 respondents. A smaller number indicated fishing *Dala 1 ka 2* times per week (n = 7), while six respondents reported fishing *Dala 3 to 5* times per week. Overall, the results show that the majority of respondents are full-time fishers who engage in daily fishing activities, with fewer individuals involved in management roles or lower-frequency fishing.

a) Occupation of respondent

b) Fishing intensity

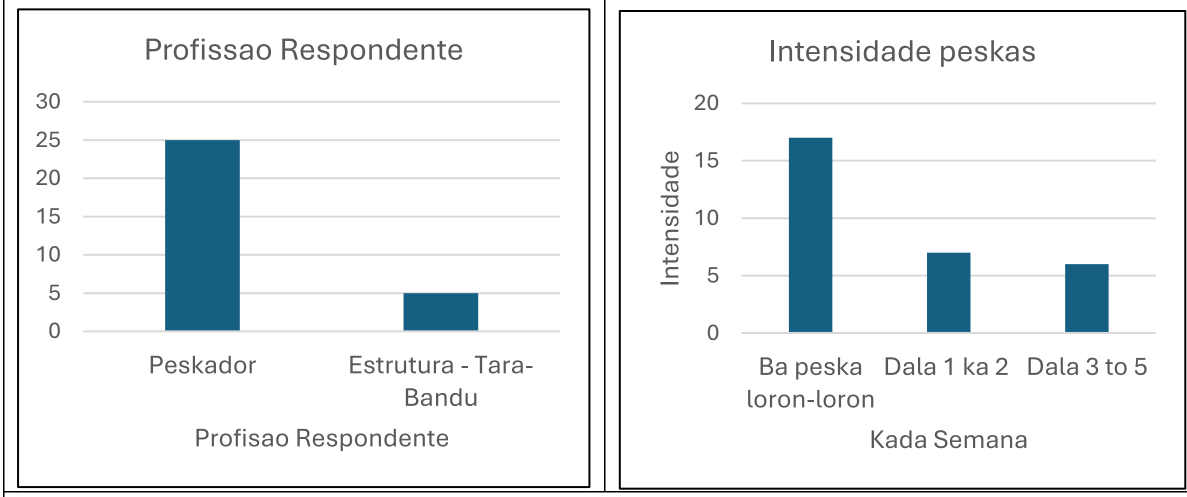
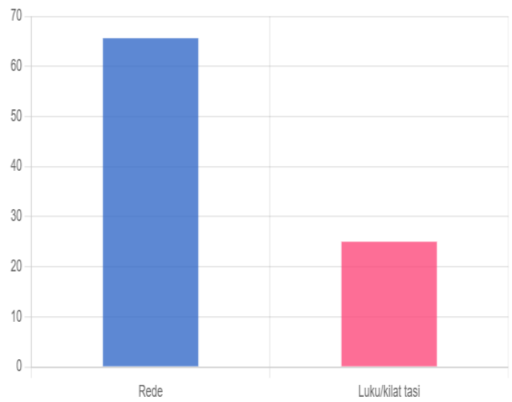


Figure 6. A) The background of respondents and b) the fishing intensity of the respondent involved in this study.

Figure 7 summarizes the fishing methods used by respondents and their knowledge of MPA establishment in Beloi and Ilimano. The majority of respondents reported using **rede (nets)** as their primary fishing method, with approximately 65 individuals indicating this gear type. In comparison, **luku tasi (spear fishing)** was used by around 25 respondents (Figure 7a).

Regarding knowledge and involvement in the establishment of the MPA, most respondents selected **“Sim, hau hatene”**, indicating that they were aware of and involved in the MPA establishment process. A small proportion selected **“Lae, hau la hatene”**, indicating awareness of the MPA but no involvement in its establishment procedures. (Figure 7b).

a) Fishing techniques



b) Knowledge on MPA establishment

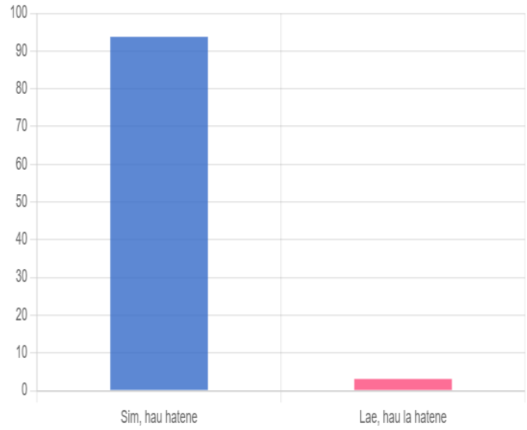


Figure 7. a) presents the respondents’ primary fishing methods and b) their level of involvement in the establishment of the Marine Protected Area (MPA) in Beloi and Ilimano.

Respondents were asked whether they had observed any changes since the establishment of the MPA, and all the respondent indicated that **they have noticed improvements** in both ecological and socio-economic conditions (Figure 8). Ecological changes frequently mentioned included **an increase in fish abundance**, **changes in fish behavior** where fish were perceived as “more friendly,” **healthier coral**, and increases in **octopus’ sightings** and occasional **dolphin presence** in the area. In addition to ecological improvements, respondents also reported positive socio-economic changes. Several noted an **increase in household income**, which they associated with better fishing conditions or alternative livelihood opportunities. Others highlighted **growth in tourism visits**, with more tourists coming to the area after the MPA was established. These responses collectively describe the range of changes perceived by the community following MPA implementation.

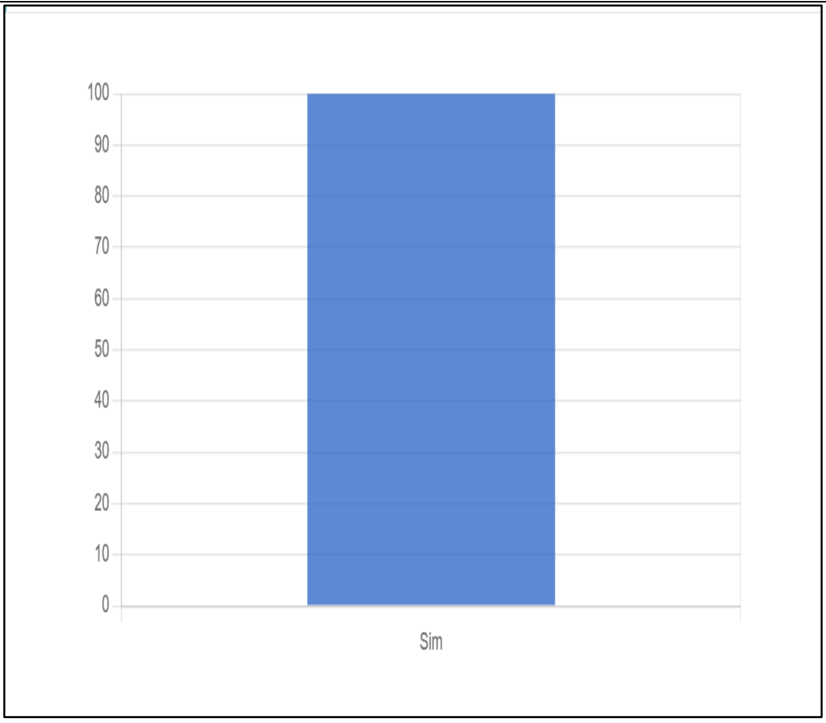


Figure 8. Shows all the respondents agreed that after the establishment of marine protected areas provided significance changes on their fishing activity and changes in their livelihoods.

3.2.DISCUSSION OF RESULT

The present study faced several methodological limitations that should be considered when interpreting results. The ecological survey relied exclusively on BUV, which, although effective for quantifying relative abundance, may underrepresent cryptic or small-bodied species. In addition, socio-economic data are perception-based and may capture short-term concerns more strongly than long-term trends. BUV deployments were constrained by equipment limitations, with soak times ranging from eight to ten minutes, below the recommended 15 minutes, and underwater visual census (UVC) methods could not be conducted due to logistical and financial constraints. Despite these limitations, the combination of ecological and socio-economic data provides a robust foundation for understanding the impacts of Tara Bandu-based MPAs in these communities.

3.2.1. ECOLOGICAL PATTERN IN FISH CONDITION AND HABITAT CONDITIONS.

The consistently higher fish abundance recorded within the reserve areas of Beloi and Ilimano indicates that protection status plays a key role in maintaining and enhancing fish populations. The two-way ANOVA confirmed that protection status, rather than site differences, significantly influenced fish abundance, demonstrating that reserves are functioning effectively in supporting reef fish communities. This pattern aligns with extensive evidence showing that no-take marine reserves often result in greater fish biomass, abundance, and size structure compared to adjacent fished areas (Sala & Giakoumi, 2018; McClure et al., 2020). Increased fish abundance in reserves is commonly attributed to reductions in fishing pressure, allowing populations to recover, age structures to increase, and trophic interactions to re-establish (Sala & Giakoumi, 2018).

The results also demonstrated substantial differences in coral cover between protected and non-protected areas, with reserves exhibiting notably higher mean coral cover in both study sites. This outcome reflects a pattern widely documented across Indo-Pacific coral reefs, where reduced local stressors, particularly fishing and destructive practices, are associated with improved coral condition, structural complexity, and benthic stability (Harahap et al., 2025). The higher coral cover observed inside the reserves may contribute to enhanced habitat availability and complexity, which in turn supports higher fish abundance, particularly for reef-associated and habitat-dependent species (Graham et al, 2020). Because coral cover and structural complexity underpin reef fish recruitment, shelter, and foraging opportunities, improvements in coral habitat quality can directly influence fish assemblage structure (Komyakova et al., 2013).

The positive relationship between coral cover and fish abundance identified in the linear regression further highlights the importance of benthic habitat condition in shaping fish communities. Although the model explained 32% of the variation, the upward trend suggests that areas with greater coral cover generally support higher fish abundance. Similar positive coral–fish relationships have been reported across reef systems globally, demonstrating that coral-dominated habitats typically host more diverse and abundant fish assemblages due to higher refuge availability and resource niches (Gonzales-Barrios et al., 2025). The remaining unexplained variation may relate to other ecological drivers not captured in this analysis, such as predator–prey dynamics, fishing intensity, habitat rugosity, or species-specific ecological traits.

Overall, the combined results from the MAXN analysis, coral cover comparison, and regression outputs reinforce the functional link between marine protection, habitat condition, and fish abundance. The consistency of reserve effects across both Beloi and Ilimano supports growing evidence that small community-based MPAs can generate measurable ecological benefits when effectively managed and enforced (Del Vito et al., 2025). These findings offer a strong indication that the reserves are contributing to improved habitat quality and fish assemblage recovery within the study areas.

3.2.2. Socio-economic survey

The findings of this study illustrate clear patterns in livelihood dependence, fishing intensity, gear use, and community perceptions following the establishment of the Beloi and Ilimano Marine Protected Areas (MPAs). The dominance of full-time fishers among respondents, most identifying as *Peskador* and engaging in daily fishing, highlights the strong socio-economic reliance on coastal resources within the community. This aligns with broader patterns documented in small-scale fisheries across Southeast Asia, where fishing often serves as the main livelihood and cultural identity (Stacey et al., 2021). The comparatively small representation of individuals involved in the *Estrutura Tara-Bandu* reflects the division between resource users and customary governance structures, which is common in co-managed systems where participation levels vary across stakeholder groups (Kim, 2021).

Fishing gear usage patterns also provide insight into local fishing pressure. The heavy reliance on nets (*rede*) and the substantial number of spear fishers (*luku tasi*) is consistent with gear types typically used in nearshore reef fisheries (Hridayadasan et al., 2025). Nets, in particular, are often associated with higher fishing efficiency and can contribute to localized depletion if not managed appropriately (Bhanja et al., 2024). The prevalence of daily fishing activity further underscores the high dependency on marine resources and suggests that reefs in Beloi and Ilimano may experience substantial fishing pressure outside the no-take zone. Similar conditions have been reported in other Pacific Island communities where subsistence and income-generating activities are closely tied to reef ecosystems.

Despite this dependence, respondents demonstrated strong awareness of the MPA's establishment, with many reporting involvements in the process. This degree of community knowledge aligns with successful MPA frameworks where local participation enhances legitimacy and compliance (Galveia et al., 2025). The Tara-Bandu system, a traditional governance mechanism in Timor-Leste, likely contributes to this engagement, as customary institutions often strengthen conservation outcomes by embedding ecological rules within social norms (Casquilho & Martins, 2021).

Crucially, respondents unanimously reported ecological improvements since the establishment of the MPA. Increased fish abundance, healthier coral cover, and sightings of octopus and dolphins correspond with well-documented ecological benefits of effectively managed no-take areas, where reductions in fishing pressure allow biomass and biodiversity to recover (Ibanez-Erquiaga et al., 2025). The reported change in fish behaviour, fish becoming “more friendly”, is consistent with observations from long-established MPAs where fish show reduced flight responses due to decreased exposure to fishing (Frid et al., 2021). The perception of coral health improvements may reflect either real ecological recovery or increased awareness due to community involvement in monitoring activities.

In addition to ecological gains, the study highlights perceived socio-economic benefits. Respondents’ reports of increased income and tourism visitation are consistent with literature showing that MPAs can generate livelihood opportunities through spillover, ecotourism, and strengthened resource governance (Liu et al., 2022). Tourism-related benefits are particularly significant, as small island communities often leverage MPAs to attract visitors seeking healthy reefs and wildlife encounters (Agarwal et al., 2023). The alignment between ecological and socio-economic improvements is important, as MPAs are more likely to achieve long-term success when they generate tangible benefits for local communities (Rasmussen et al., 2021).

Together, these findings suggest that the MPAs in Beloi and Ilimano are perceived as delivering both ecological and socio-economic gains, reinforcing global evidence that co-managed MPAs, particularly those embedded in traditional governance systems like Tara-Bandu, can enhance resource sustainability while supporting community well-being. Continued monitoring and community engagement will be essential to maintain these positive outcomes and ensure equitable distribution of benefits as ecological conditions evolve.

4. CONCLUSION AND RECOMMENDATIONS

4.1. CONCLUSION

This study assessed the ecological and socio-economic effectiveness of community-based Marine Protected Areas (MPAs) in Atauro Island, specifically Beloi and Ilimano, and evaluated their role in supporting sustainable artisanal fisheries in Timor-Leste. The combined results from ecological observations, fishing activity patterns, and community perceptions provide strong evidence that the Tara-Bandu MPAs are generating measurable benefits consistent with the study’s objectives and hypotheses.

Ecologically, respondents unanimously reported improvements since MPA establishment, including increased fish abundance, healthier coral cover, and more frequent sightings of ecologically important species such as octopus and dolphins. These community observations align with the expected outcomes of well-managed no-take zones and support **Hypothesis 1 (H1)**, which predicts higher fish abundance and coral cover within MPAs relative to adjacent fished areas. Although direct benthic or fish abundance measurements are not detailed here, the strong local knowledge and observable ecological changes indicate positive recovery trajectories, particularly in areas with longer histories of protection.

The study also supports **Hypothesis 2 (H2)**, which proposes a positive correlation between fish abundance and coral cover. Respondents' descriptions of "healthier coral" occurring alongside increases in fish abundance are consistent with established ecological relationships between habitat complexity and reef fish biomass. The perceived improvements in benthic conditions suggest that reductions in fishing pressure are enabling coral recovery, which in turn supports higher fish abundance, a dynamic widely documented in tropical reef systems.

Socio-economically, the MPAs appear to have contributed to enhanced well-being among local communities. Respondents reported increased household income, improved fishing conditions, and a rise in tourism activity following MPA establishment. These outcomes address the second objective and provide strong support for **Hypothesis 3 (H3)**, which posits that positive community perceptions are associated with stronger ecological outcomes. The widespread awareness of MPAs and involvement in their establishment reflect high levels of community ownership, which is critical for compliance, stewardship, and long-term MPA success.

The results also shed light on several challenges and opportunities relevant to scaling up community-based MPAs in Timor-Leste. While daily fishing remains the dominant livelihood activity and fishing intensity is high, the presence of traditional governance structures such as Tara-Bandu offers a strong foundation for community engagement. Opportunities exist to strengthen management through improved monitoring, reinforcement of customary rules, and integration of sustainable tourism initiatives. At the same time, challenges such as dependence on reef fisheries, limited alternative livelihoods, and the risk of gear conflicts must be addressed to ensure equitable and durable conservation outcomes.

Overall, the findings indicate that community-based MPAs in Atauro Island are functioning as intended, improving ecological conditions, supporting socio-economic well-being, and fostering positive community attitudes toward marine conservation. These results underscore the value of locally driven management and provide evidence-based support for expanding community-based MPA initiatives across Timor-Leste. This study provides a comprehensive result from two different metrics, ecological and community impact from MPAs, and enriches scientific information on MPAs in Timor-Leste. Continued investment in ecological monitoring, community engagement, and livelihood diversification will be essential to sustain and scale these successes in the face of growing environmental and socio-economic pressures.

4.2. RECOMMENDATIONS

Based on the findings of this study and the demonstrated potential of community-based Marine Protected Areas (MPAs) under Tara-Bandu governance, several recommendations are proposed to strengthen future ecological monitoring, enhance community engagement, and support the long-term sustainability of MPAs in Timor-Leste.

1. Replicate and Scale the Study Methodology Across Additional Sites

The methods applied in this study, combining ecological assessments (e.g., BUV observations, coral cover estimation) with socio-economic interviews, were found to be both practical and cost-effective. Given their feasibility, these methods should be replicated in other coastal villages and community-managed MPAs throughout Timor-Leste. Replication will enable:

- Comparative analysis of MPA effectiveness across different islands and cultural contexts.
- Identification of site-specific challenges and success factors in Tara-Bandu governance.
- Development of a national baseline dataset on fish abundance, coral cover, and community perceptions.

Implementing standardized monitoring methods will also facilitate data integration at the national level and contribute to long-term marine biodiversity reporting and fisheries management planning.

2. Institutionalize Low-Cost Monitoring Approaches Within Government Agencies

The government, particularly the Department of Conservation and Aquatic Resources Management under the Ministry of Agriculture, Livestock, Fisheries and Forestry (MALFF), should adopt low-cost ecological monitoring tools as part of their routine MPA assessment programs. Techniques such as Baited Underwater Video (BUV), simple fish abundance surveys, and 1 m^2 coral quadrats offer the following advantages:

- They require minimal specialized equipment and training.
- They can be implemented collaboratively with local communities, reducing financial burden and enhancing community ownership.
- They generate consistent data that are sufficient for detecting temporal trends in fish abundance and habitat condition.

Strengthening the capacity of government staff through targeted training on these low-cost methods will support the development of a national monitoring framework that is robust, efficient, and well aligned with local resource management systems.

3. Conduct Biannual Monitoring to Track Ecological and Socio-Economic Changes

To ensure continuous evaluation of Tara-Bandu MPA performance, it is recommended that a similar integrated ecological and socio-economic study be conducted **every two years**. Regular monitoring will enable:

- Early detection of ecological changes, such as variations in fish biomass, coral cover, or species composition.
- Assessment of how management interventions, community compliance, and environmental pressures influence MPA outcomes.
- Documentation of socio-economic trends, including livelihood diversification, income changes, and tourism development associated with the MPA.
- Evidence-based decision-making for adaptive management within Tara-Bandu systems.

Biannual assessments will also provide valuable feedback to community leaders, fishers, and local governance structures, fostering transparency and reinforcing community trust in MPA processes.

4. Strengthen Community–Government Collaboration in MPA Governance

To maximize the effectiveness of Tara-Bandu MPAs, sustained collaboration between local communities and government agencies is essential. It is recommended that:

- Joint monitoring teams be established involving community members, local leaders, and government technical staff.
- Community feedback be consistently incorporated into MPA management decisions and enforcement strategies.
- Awareness programs be enhanced to strengthen understanding of ecological indicators and their link to community well-being.

Such co-management approaches will ensure that MPAs remain culturally grounded, socially acceptable, and ecologically effective.

5. Use Study Findings to Support National Expansion of Community-Based MPAs

Given the positive ecological and socio-economic trends identified in this study, the government and conservation partners should consider using these findings to:

- Advocate for the expansion of community-based MPAs across additional coastal communities.
- Integrate Tara-Bandu systems into national marine spatial planning initiatives.
- Develop policies that incentivize local stewardship, sustainable tourism, and reduced fishing pressure in sensitive habitats.

Scaling up successful locally managed MPAs can significantly contribute to national biodiversity conservation targets and improve fisheries sustainability across Timor-Leste.

5. REFERENCE BIBLIOGRAPHY

Agarwal, S., Isha, T., Lrappa, T.V., Akaremsetty, S., & Shekhar, C., (2023). The impact of Tourism on Local Communities: A Literature Review of Socio-economic Factors. *Journal of Harbin Engineering University, 44*(8), ISSN: 1006-7043.

Andriamahefazafy, M., Touron-Gardic, G., March, A., et al., (2022). Sustainable development goal 14: To what degree have we achieved the 2020 targets for our oceans?. *Ocean & Coastal Management, 227,* 106273. https://doi.org/10.1016/j.ocecoaman.2022.106273

Arthur, R. I., Skerritt, D. J., Schuhbauer, A., Ebrahim, N., Friend, R. M., & Sumaila, U. R., (2021). Small-scales fisheries and local food systems: Transforms, threats and opportunities. *Fish and Fisheries*, *23*(1), 109-124. https://doi.org/10.1111/faf.12602

Balata, F. & Williams, C., (2020). Chapter 6 - The role of coastal communities in the sustainable management of marine protected areas. *Marine Protected Areas,* 113-129. https://doi.org/10.1016/B978-0-08-102698-4.00006-X

Bhanja, A., Payra, P. & Mandal, B. (2024). A study on the Selectivity of Different Fishing Gear. *Indian Journal of Pure & Applied Bioscience, 12*(2), 8-19. https://doi.org/10.18782/2582-2845.9072

Brough, T., Mactavish, T., & Zintzen, V., (218). Biological monitoring of marine protected areas at Banks Peninsula using baited underwater video (BUV). *DOC Research and Development Series 354.* Department of Conservation, Wellington 37 p.

Caldwell, Z.R., Zgliczynski, B.J., Williams, G.J., & Sandin, S.A., (2016). Reef Fish Survey Techniques: Assessing the Potential for Standardizing Methodologies. *PLoS One, 11*(4), e0153066. doi:10.1371/journal.pone.0153066

Casquilho, J.P. & Martins, X., (2021). On the influence of Customary Law "Tara Bandu" in Community Based Forest Management at the Mountains of Timor-Leste. *Research Gate*. https://doi.org/10.13140/RG.2.2.26949.99044

Clements, C., Bonito, V., Grober-Dunsmore, R., & Sobey, M., (2012). Effects of small, Fijian Community-based marine protected areas on exploited reef fishes. *Marine Ecology Progress Series, 449*, 233-243. DOI:10.3354/meps09554

Collier, C.E., (2020). Enabling conditions for community based comanagement of marine protected areas in the United States. *Marine Policy, 122,* 104244. https://doi.org/10.1016/j.marpol.2020.104244

CTI-CFF Regional Secretariat, (2023). CTI-CFF Annual Report 2023. retrieved from https://www.coraltriangleinitiative.org/sites/default/files/resources/Annual%20Report%202023.pdf

Di Cintio, A., Fernandes-Salvador, J.A., Puntila-Dodd, R., Granado, I., Niccolini, F., & Bulleri, F., (2024). Socio-economic factors boosting the effectiveness of marine protected areas: A Bayesian network analysis. *Ecological Informatics, 84*, 102897. https://doi.org/10.1016/j.ecoinf.2024.102879

Del Vito, D., Prihadi, D.J., Pasaribu, B., Koenawan, C.J., & Harahap, S.A., (2025). Analysis of the Relationship Between Reef Fish Abundance and Coral Reef Cover in Karimun District, Riau Archipelago (Case study: Pandan Seranjau, Resam, Sekatip, Kelawan Besar, Kelawan Kecil, and Sebaik Island). *Egyptian Journal of Aquatic Biology and Fisheries, 29*(2), 2769-2788.

Erickson, K.R., Bugnot, A.B., & Figueira, W.F., (2023). Optimising sampling of fish assemblages on intertidal reefs using remote underwater video. *PeerJ,* 11:e15426. doi: 10.7717/peerj.15426

Fabinyi, M., Belton, B., Dressler, W., et al., (2022). Coastal transitions: Small-scale fisheries, livelihoods, and maritime zone developments in Southeast Asia. *Journal of Rural Studies, 91,* 184-194. https://doi.org/10.1016/j.jrurstud.2022.02.006

Frid, O., Lazarus, M., Malamud, S., Belmaker, J., & Yahel, R., (2022). Effects of marine protected areas on fish communities in a hotspot of climate change and invasion. *Mediterranean Marine Science, 23*(1). https://doi.org/10.12681/mms.26423

French, B., Wilson, S., Holmes, T., Kendrick, A., Rule, M., & Ryan, N. (2021). Comparing five methods for quantifying abundance and diversity of fish assemblages in seagrass habitat. *Ecological Indicators, 124*, 107415. https://doi.org/10.1016/j.ecolind.2021.107415

Gabela-Flores, M.V., & Dierdrich, A., (2021). Exploring leadership dynamics in community-based marine protected areas. *Marine Policy, 129*, 104569. https://doi.org/10.1016/j.marpol.2021.104569

Gallacher, J., Simmonds, N., Fellowes, H., et al., (2016). Evaluating the success of marine protected area: A systematic review approach. *Journal of Environmental Management, 183*, 280-293. https://doi.org/10.1016/j.jenvman.2016.08.029

Galveia, M.C., & Macusi, E.D., (2025). Management effectiveness of marine protected áreas (MPAs) in the Southeastern Mindanao, Philippines. *Marine Policy, 174,* 106596. https://doi.org/10.1016/j.marpol.2025.106596

Gonzalez-Barrios, F.J., Keith, S.A., Emslie, M.J., Ceccarelli, D.M., Williams, G.J., & Graham, N.A.J, (2025). Emergent Patterns of reef fish diversity correlated with coral assemblages shifts along the Great Barrier Reef. *Nature Communications, 16*, 303. https://doi.org/10.1038/s41467-024-55128-7

Graham, N.A.J., Robinson, J.P.W., Smith, S.E., Govinden, R., Gendron, G., & Wilson, S.K. (2020). Changing role of coral reef marine reserves in a warming climate. *Nature Communications, 11*. https://doi.org/10.1038/s41467-020-15863-z.

Gurney, G.G., Pressey, Robert, L.P., Cinner, J.E., Pollnac, R., & Campbell, S.J. (2015). Integrated conservation and development: evaluating a community-based marine protected area project for equality of socioeconomic impact. *The Royal Society.* https://doi.org/10.1098/rstb.2014.0277

Haggitt, T., Freeman, D., & Lily, C., (2013). Baited Remote Underwater Video Guidelines. *Department of Conservation Science and Technical Group Wellinton, eCoast Ltd Marine Consulting and Research.*

Harahap, Z.A., Bengen, D.G. Nurjaya, I.W., Agus, S.B., Naulita, Y., & Siringoringo, R.M., (2025). The role of marine protected areas in enhancing coral cover and reef fish communities. *Global Journal of Environmental Science and Management, 11*(3), 963-982. https://doi.org/10.22034/gjesm.2025.03.06

Hridayadasan, S., Antony, S.C., & Umajyothi, V., (2025). Traditional fishing gear usage and its sustainability among motorised fishing crafts on the Southernmost Coast of Kerala, India. *Marine Economic and Management, 8*(2), 162-171. https://doi.org/10.1016/j.marpol.2021.104654

Ibanez-Erquiaga, B., Baktoft, H., Mildenberger, T.K., Teilmann, J., Kleivane, L., Kornau, L.M., Agersted, M.D., Hullert, S.M., & Svendsen, J.C., (2025). Increased fish abundance, biodiversity, and body size near a North Sea Oil and gas platform. *Marine Environmental Research, 204,* 106959. https://doi.org/10.1016/j.marenvres.2025.106959

Jiang, X., Liu, F., Yu, J., Zhang, K., et al., (2024). Global Trends and Prospects of Community Participation in Marine Protected Areas: A Bibliometric Analysis. *Sustainability, 16*(17). 7772. https://doi.org/10.3390/su16177772

Kim, J.S., (2021). Coral Reef Management and Tara Bandu on Atauro Island: an ecologist's perspective. *Conference paper*. Retrieved from https://www.researchgate.net/publication/354739293_Coral_Reef_Management_and_Tara_Bandu_on_Atauro_Island_an_ecologist's_perspective

Komyakova, V., Munday, P.L., & Jones, G.P., (2013). Relative Importance of Coral Cover, Habitat Complexity and Diversity in Determining in the Structure of Reef Fish Communities. *Plos one, 8*(12): e83178. https://doi.org/10.1371/journal.pone.0083178

Langlois, T.J., Chabanet, P., Pelletier, D., & Harvey, E.S., (2006). Baited Underwater Video for assessing reef fish populations in marine reserves. https://www.researchgate.net/publication/228685780_Baited_underwater_video_for_assessing_reef_fish_populations_in_marine_reserves#fullTextFileContent

Liu, A., Kim, Y.R., Song, H. (2022). Toward an accurate assessment of tourism economic impact: A systematic literature review. *Annals of Tourism Research Empirical Insights, 3*(2), 100054. https://doi.org/10.1016/j.annale.2022.100054

Lopez-Angarita, J., Hunnam, K.J., Pereira, M., Mills., D.J., Pant, J., et al., (2019). Fisheries and aquaculture of Timor-Leste in 2019: Current knowledge and opportunity. *Penang, Malaysia: WorldFish*. Program Report: 2019-5. https://www.researchgate.net/publication/341641968_Fisheries_and_aquaculture_of_Timor-Leste_in_2019_Current_knowledge_and_opportunities

Marine Conservation Institute, (2025). Marine Protection Atlas, retrieved from https://mpatlas.org/mpaguide/#126.14922,-9.07831@5.65

McClure, E.C., Sievers, K.T., Abesamis, R.A., Hoey, A.S., Alcala, A.C., & Russ, G.R., (2020). Higher fish biomass inside than outside marine protected areas despite typhoons impacts in a complex reefscape. *Biological Conservation, 241*, 1083354. https://doi.org/10.1016/j.biocon.2019.108354

Mills, D.J., Tilley, A., Pereira, M., et al. (2017). Livelihood diversity and dynamism in Timor-Leste; insights for coastal resources governance and livelihood development. *Marine Policy, 82,* 206-215. https://doi.org/10.1016/j.marpol.2017.04.021

Rasmussen L.V., Fold, N., Olesen, R.S., & Shackleton, S. (2021). Socio-economic outcomes of ecological infrastructure investments. *Ecosystem Services, 47*, 1012242. https://doi.org/10.1016/j.ecoser.2020.101242

Robertson, T., Greenhalgh, S., Korovulavula, I., et al., (2020). Locally managed marine areas: Implications for socio-economic impacts in Kadavu, Fiji. *Marine Policy, 117,* 103950. https://doi.org/10.1016/j.marpol.2020.103950

Sala, E., & Giakoumi, S., (2018), No-take marine reseves are the most effective protected areas in the ocean. *ICES Journal of Marine Science, 75*(3), 1166-1168. https://doi.org/10.1093/icesjms/fsx059

Schratzberger, M., Neville, S., Painting, S., et al., (2019). Ecological and Socio-economic Effect of Highly Protected Marine Areas (HPMAs) in Temperate Waters. *Frontier Marine Science. 6*. https://doi.org/10.3389/fmars.2019.00749

Slezak, M., (2016). Atauro Island: scientist discover the most biodiverse waters in the world. *The Guardian.* Retrieved from https://www.theguardian.com/world/2016/aug/17/atauro-island-timor-leste-the-push-to-protect-the-most-biodiverse-waters-in-the-world?

Stacey, N., Gibson, E., Loneragan, N.R., Warren, C., Wiryawan, B., Adhuri, D.S., Steenbergen, D.J., & Fitriana, R. (2021). Developing sustainable small-scale fisheries livelihoods in Indonesia: Trends, enabling and constraining factors, and future opportunities. *Marine Policy, 132,* 104654. https://doi.org/10.1016/j.marpol.2021.104654

Stephenson, F., Costa, B.H., Addamo, A.M., et al., (2025). Quality of marine protected areas is critical to achieving global biodiversity targets. *npj Ocean Sustainability, 4*, 63. https://doi.org/10.1038/s44183-025-00169-8

Stobart, B., Diaz, D., Alvarez, F., Alonso, C., Mallol, S., & Goñi, R. (2015). Performance of Baited Underwater Video: Does It Underestimate Abundance at High Population Densities? *PLoS ONE, 10*(5): e0127559. https://doi.org/10.1371/journal.pone.0127559

Sylvie, R., (2019). Witnessing the unknown: Coral spawning in Timor-Leste. *Blue Ventures blog.* Retrieved from https://blog.blueventures.org/en/witnessing-the-unknown-coral-spawning-in-timor-leste/

Teniwut, W. A., Hamid, S.K., Teniwut, R.M.K., Renhoran, M., & Pratama, C.D., (2023). Do Coastal in small island value marine resources through marine protected areas?: Evidence from Kei Islands Indonesia with choice modelling. *Marine Policy, 157,* 105838. https://doi.org/10.1016/j.marpol.2023.105838

The Asia Foundation, (2013). Tara bandu: Its Role and Use in Community Conflict Prevention in Timor-Leste. Retrieved from: https://belun.tl/wp-content/uploads/2013/08/Tara-Bandu-PB-English.pdf

Turnbull, J., Johnston, E.M., & Clark, G., (2021). Evaluating the social and ecological effectiveness of partially protected marine areas. *Conservation Biology, 35*(3). http://dx.doi.org/10.1111/cobi.13677

Wartenberg, R., & Booth, A.J., (2014). Video transects are the appropriate underwater visual census method for surveying high-latitude coral reef fishes in the southwestern Indian Ocean. *Marine Biodiversity,* DOI 10.1007/s12526-014-0262-z

White, J., Simpfendorfer, C.A., Tobin, A.J., & Haupel, M.R., (2013). Application of baited remote underwater video surveys to quantify spatial distribution of elasmobranchs at an ecosystem scale. *Journal of Experimental Marine Biology and Ecology, 448,* 281-288. https://doi.org/10.1016/j.jembe.2013.08.004

WWF Chile, (2020). Guide for planning and management of marine protected areas with participation of local and/or indigenous communities based on conservation standards Chile. retrieved from: https://wwflac.awsassets.panda.org/downloads/guide_for_planning_and_managing.pdf

Zhang, Y., Ou, Z., Tweedley, J.R., Loneragan, N.R., Zhang, X., Tian, T., & Wu, Z. (2024). Evaluating the effectiveness of baited video and traps for quantifying the mobile fauna on artificial reefs in northern China. *Journal of Experimental Marine Biology and Ecology, 573*, 152001. https://doi.org/10.1016/j.jembe.2024.152001

APPENDIX

Appendix 1. Questionnaire for Socio-economic survey:

Parte I: Demografia:

1. Naran kompleto respondente:
2. Husi Suko neebe?
   Drop down:
   - Uma-kaduak
   - Beloi
3. Ita nia tinan hira?
4. Ita nia profisaun hanesan saida?

Parte II: Aktividade Peskas:

Ita ba halo peska semana ida dala hira?

Drop down:

- Dala 1 ka 2 kada semana
- Dala 3 to 5 kada semana
- Ba peskas loron-loron

Ita boot ba peska besik Area Protejida Marine (Tara-bandu)

Ita ba peska ho saida:

Drop down list: Ro ka la h oro.

Ita boot ba pesak usa ekipamentus peska saida?

Drop down list:

- Rede

- Luku ho kilat tasi

- meti

Parte III: Persepsaun komunidade ba Tara-bandu

Ita boot hatene ka lae, iha ita boot nia bairo iha area protejida marina (Tara-bandu)?

Tuir ita boot nia observasaun, depois de estabelese Tara-bandu iha ita boot sira nia tasi, ita boot sente iha duni mudansa ba ita nia aktividade peskas?

Se resposta sim, ita boot bee esplika tok mudansa saida mak ita boot sente?

*(** fo oportunidade ba respondente atu explica mudança saída mak sira hetan husi Tara-bandu**)*

Depois de tara-bandu, ita boot hetan ikan barak liu ka nafatin deit hanesan molok Tara-bandu?

Appendix 2. Link for google drive for raw data from Ecological and socio-economic survey

Socio-economic:
https://docs.google.com/spreadsheets/d/11hUcupKB85Bi9iV0tSIByLigqXbQoySJ/edit?usp=sharing&ouid=102609525315193716982&rtpof=true&sd=true

Ecological (BUV) data:

https://docs.google.com/spreadsheets/d/1GzWzI48TtkspHaZvIUMnXINfnIbkERWb/edit?usp=sharing&ouid=102609525315193716982&rtpof=true&sd=true