

# Integrating Knowledge for Sustainable Mangroves in Portuguese-Speaking African Countries (PALOP) through the Nature's Contributions to People Framework

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## Systematic Review

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# Abstract

Mangrove ecosystems provide vital socio-ecological services, yet severe epistemic asymmetries leave coastal governance structurally understudied across Portuguese-Speaking African Countries (PALOP). Following PRISMA guidelines, this systematic review analyzes 132 peer-reviewed Web of Science publications (1991–2024) across Angola, Equatorial Guinea, Guinea-Bissau, Mozambique, and São Tomé and Príncipe. Using the 18 categories of the IPBES Nature's Contributions to People (NCP) framework as a diagnostic lens, we map geographical disparities, thematic gaps, and socio-ecological representation across the region. Results reveal stark spatial inequalities, with Mozambique (62.1%) and Guinea-Bissau (25.7%) concentrating nearly 88% of regional scientific output, leaving the remaining three nations in severe empirical deficits. Across documented contributions, a reductionist "carbon-centric" bias dominates biophysical regulating functions account for over 60% of all recorded entries, whereas material dependencies (under 12%) and non-material values remain severely marginalized. Critically, we identify absolute knowledge vacuums in indirect regulating processes, namely pollination (NCP2), ocean acidification regulation (NCP5), and freshwater control (NCP6). These epistemic gaps decouple coastal management from local community dependencies, risking top-down "green-grabbing" under global climate agendas. Decolonizing research priorities, fostering regional cooperation, and integrating traditional ecological knowledge into co-designed management are essential to build sovereign evidence bases, protect community livelihoods, and equitably inform international climate and biodiversity targets.

## Introduction

Mangroves play a vital role in coastal ecosystems, providing a multitude of benefits to both human communities and the environment, contributing to global climate regulation through carbon sequestration/storage, by supplying habitat and nursery grounds to many species (that in turn support a multiple ecosystem provision services, processes, and functions), protecting local communities from coastal hazards, and providing a wide range of cultural ecosystem services (Alliance 2019; Friess et al. 2020). For coastal communities, mangrove conservation seems more obvious, as it directly affects their livelihoods, economic support, way of life and the maintenance of their cultural identity related to these environments. However, for societies to recognize the need to conserve and manage mangrove areas, it is important that there is political and popular support, emphasizing the knowledge and relevance of the main products and services provided by this ecosystem (Pinheiro and Talamoni 2018; Moore et al. 2022). As mangroves occupy areas of increasing human population density and conflicting coastal management priorities, they are highly threatened in large parts of their range (Friess et al. 2020). Mangrove conservation is thus at the heart of international agendas that aim to eliminate deforestation and increase global mangrove area by 20% over current extent by 2030 through conservation and rehabilitation in close cooperation with people (Alliance 2019; Friess et al. 2020).

Mangroves are salt-tolerant evergreen forests that persist under ecologically stressful conditions and are found in the intertidal zones of sheltered shores, estuaries, tidal creeks, backwaters, lagoon, marshes, and mudflats of the tropical and subtropical latitudes (Sandilyan & Kathiresan 2012). Representing

approximately 0.7% of tropical forest around the world, these ecosystems have been used by coastal inhabitants for the many types of ecosystem services they provide (Webber et al. 2016). Currently, mangrove forests occur in 121 countries, distributed between latitudes 30°N and 30°S, covering an area of about 137,760 km<sup>2</sup>, with greater development near the equator, between 5°N and 5°S (Zeng et al. 2021). Although the socio-ecological importance of mangroves has been recognized for decades, this type of ecosystem continues to decline globally (Su et al. 2021; FAO 2022), with substantial variations between countries. In fact, overall tendencies in continents such as Africa, North and Central America reversed the trend of continuous loss and recorded a net gain in mangrove area between 2010 and 2020 (FAO 2022). However, along certain climatic and biophysical conditions, mangroves are expected to continue to decline due to several interconnected factors such as: agriculture and aquaculture (rice, shrimp, fish), construction of access roads, firewood and charcoal production, hydroelectric projects, land-based sources of pollution, oil exploration, drilling and production, garbage dumping, sand extraction, sewage and pollution, unsustainable gathering, fishing and hunting, urban and tourism development (UNEP 2007; Thomas et al. 2017; Saintilan et al. 2020; Su et al. 2021). There is a consensus that these anthropogenic activities are affecting both the mangroves and the ecosystem services they provide, further accentuating the vulnerabilities of communities that depend heavily on these services (Sousa et al. 2023). The assessment and evaluation of these nature contributions to people is thus of crucial importance to outline conservation strategies and initiatives.

The concept of Nature Contributions to People (NCP), as defined by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), encompasses all the positive and negative impacts of living nature on human well-being. It acknowledges the multifaceted ways in which nature affects human well-being and the pivotal role played by culture in defining the intricate links between people and nature (Diaz et al. 2018). This holistic approach considers 18 NCP categories, organized in material (elements from nature that directly sustain people's physical existence and material asset), non-material (nature's effects on subjective or psychological aspects underpinning people's quality of life) and regulating (functional and structural aspects of organisms and ecosystems that modify environmental conditions) contributions. This framework thus allows for an understanding of the status and interconnected trends of biodiversity, ecosystems and their associated ecological and evolutionary processes, and in turn, how these relate to human livelihoods and quality of life (Brauman et al. 2020; Diaz et al. 2018).

Despite their crucial importance, the full range of NCP provided by mangroves in Africa remains significantly understudied. While recent global frameworks have increasingly adopted the NCP approach to better assess the complexity of ecosystem and human interactions (Pascual-Rico et al. 2021), its application to mangrove ecosystems (particularly in Africa) has been limited. Some studies have shown the potential of the NCP framework to capture the multifunctionality of complex social-ecological systems and to guide interdisciplinary assessments (Dean et al. 2021; Palacios-Pacheco et al. 2024), reinforcing its relevance for evaluating mangrove-related benefits and trade-offs. By systematically analyzing the presence or absence of NCP dimensions in the scientific literature on mangroves, we can identify dominant research trends and existing knowledge gaps. This, in turn, is essential to support

more integrative, equitable, and effective strategies for mangrove conservation and management. In this context, the Portuguese-speaking African Countries (PALOP) present a highly compelling cohort to examine these dynamics. Strategically spanning both West and East Africa, these nations exhibit stark contrasts in their biophysical coastal settings, mangrove patch dynamics, and conservation status, ranging from the extensive estuarine systems of Mozambique and Guinea-Bissau, which host the second and fourth largest mangrove forest areas on the continent, respectively, to the smaller island and coastal configurations of Angola, Equatorial Guinea, and São Tomé and Príncipe (Bunting et al. 2022; Naidoo, 2023). While sharing deep historical, linguistic, and post-colonial cooperation ties, their diverse ecological baselines and highly disparate national research capacities make the PALOP an ideal group to operationalize a reflexive diagnostic of the knowledge foundations upon which environmental governance is built (Díaz et al. 2018; Hill et al. 2021). Understanding what the scientific community chooses to document, and what it neglects, across these ecologically diverse but historically connected nations is a prerequisite for equitable regional conservation, ensuring that global carbon-centric or conservationist agendas do not marginalize local socio-ecological realities and community needs (Feka, 2015; Trisos et al. 2021).

This study aims to conduct a comprehensive literature review to identify and assess the NCP provided by mangroves in the PALOP, highlighting existing knowledge and identifying areas for future research. The specific objectives are a) To review the state of the art of research on mangroves in Portuguese-speaking African countries (Angola, Guinea-Bissau, Equatorial Guinea, Mozambique, São Tomé and Príncipe); b) To identify the most frequently studied/underrepresented NCP by country through content analysis of the publications. c) To identify knowledge gaps in the study of mangroves using the NCP as a proxy, how they may relate to the local communities and their livelihoods, detect potential conflicts or trade-offs between the conservation of mangroves and human needs and emerging threats or challenges to the provision of NCP in the PALOP.

## Methodology

### Study area

Mangroves require long-term ecological and social resilience to maintain their conservation status and support the well-being and livelihoods of the communities living in and around these ecosystems. The Community of Portuguese-Speaking Countries (CPLP) is a multilateral cooperation platform of nine member states covering 10,742,000 km<sup>2</sup>, equivalent to 7.2% of the planet's land area on four continents - Africa (Angola, Cape Verde, Equatorial Guinea, Guinea-Bissau, Mozambique and São Tomé and Príncipe), South America (Brazil), Asia (East Timor) and Europe (Portugal) (CPLP 2023) (Fig. 1).

The PALOP group represents 18–20% of the total African mangrove area, characterized by highly uneven physical distributions, where Mozambique and Guinea-Bissau host approximately 95% of the regional mangrove habitats (Leal and Spalding, 2024). Using the PALOP as a study area allows us to operationalize a systematic review as a tool for political-ecological diagnosis of scientific asymmetries

(Sousa et al. 2023; Quenum et al. 2024). By mapping the presence and absence of peer-reviewed research indexed in global databases, we do not analyze governance structures directly but rather interrogate the equity of the scientific evidence base available to support decision-making in each country (Quenum et al. 2024). This approach highlights how structural barriers, such as restricted access to international publishing venues, dependency on foreign funding, and linguistic marginalization, shape the regional science-policy interface (Sousa et al. 2023; Quenum et al. 2024).

Due to the extensive area of Brazilian mangroves and the very large volume of scientific output (an exploratory search restricted to the past decade already yielded more than 350 publications in four Brazilian states), this study focuses exclusively on PALOP. Mangrove cover in the PALOP is estimated at 6255.8 km<sup>2</sup>, representing 18–20% of the total African mangrove area (Alliance 2019; Leal and Spalding 2024). These ecosystems comprise roughly 59.2% of PALOP coastal zones, with Mozambique alone accounting for about 45% of East African mangrove cover (Leal and Spalding 2024) (Table 1). PALOP mangroves provide essential ecological functions, including coastal protection, carbon sequestration, and support for fisheries, thereby directly sustaining local populations (Mondal et al. 2019; Bunting et al. 2022).

Table 1

Mangrove habitat characteristics and coastal representation for PALOP countries with confirmed mangrove ecosystems. PALOP Portuguese-Speaking African Countries, UNEP United Nations Environment Programme, GMA Global Mangrove Alliance.

Source: Compiled and adapted from UNEP (2007) and GMA (2024)

| Country               | Coastline extension (km) | Mangrove habitat (km <sup>2</sup> ) | Linear coverage (%) |
|-----------------------|--------------------------|-------------------------------------|---------------------|
| São Tomé and Príncipe | 255.3                    | 1.02                                | 0.4                 |
| Angola                | 2,734.3                  | 429.29                              | 15.7                |
| Equatorial Guinea     | 768.5                    | 235.16                              | 30.6                |
| Mozambique            | 11,768.1                 | 6,425.38                            | 54.6                |
| Guinea-Bissau         | 7,737.5                  | 6,685.20                            | 86.4                |
| Total (PALOP)         | 23,263.7                 | 13,776.05                           | 59.2                |

## Systematic literature survey on PALOP mangroves

A systematic literature review was conducted to assess the state of scientific knowledge on mangrove ecosystems within the PALOP countries: Angola, Equatorial Guinea, Guinea-Bissau, Mozambique, and São Tomé and Príncipe. The review aimed to identify studies addressing NCP in these regions, as well as those discussing the conservation status, and the ecological, social, or economic importance of mangroves. To ensure the highest scientific rigor and methodological transparency, this study was

conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al. 2009) (Fig. 2). A secondary objective was to identify research gaps and priority areas for future study. Furthermore, the selection process was strictly limited to peer-reviewed literature to guarantee the quality and reliability of the synthesized data.

## Search strategy and data sources

The search was performed in the Web of Science (WoS) Core Collection, accessed through the University of Coimbra. To ensure a highly transparent, rigorous, and reproducible sample, we implemented a two-stage hybrid search and validation strategy.

In the first stage (systematic query), we combined the wildcard keyword "*mangrove\**" with the official names and recognized geographical variants of each PALOP country using Boolean operators (e.g., "*mangrove\**" AND ("*Mozambique*" OR "*Moçambique*")). Cape Verde was excluded a priori from the individual country searches because, despite being a PALOP nation, it lacks mangrove habitats. The search string was applied to WoS topic fields (title, abstract, author keywords, and Keywords Plus), capturing all lexical variations. No temporal filters were applied, and all peer-reviewed studies published up to 30 September 2024 were considered. This initial systematic search retrieved 244 publications.

In the second stage, to address the inherent limitations of database-specific keyword indexing and ensure sampling saturation, we conducted backward and forward snowballing based on standard methodological guidelines (Wohlin 2014). Backward involved manually screening the reference lists of all selected publications ( $n = 132$ ) and key regional reviews (e.g., Feka 2015; Naidoo 2023). Forward snowballing tracked newer papers that cited our initial sample. This rigorous secondary validation stage confirmed that our systematic search had already achieved complete taxonomic and geographic saturation, as no additional peer-reviewed articles meeting our strict eligibility criteria were uncovered. After applying the predefined inclusion and exclusion criteria (Fig. 2), 112 records were excluded, leaving a robust final dataset of 132 publications suitable for quantitative and qualitative synthesis.

## Inclusion and exclusion criteria

Studies were included if they met all the following criteria:

- (1) Explicit focus on mangrove ecosystems within at least one PALOP country.
- (2) Empirical or theoretical scientific content (e.g., primary research, applied studies, or reviews), regardless of whether NCP terminology was explicitly used.
- (3) Peer-reviewed and indexed in the WoS Core Collection.

Studies were excluded when they satisfied any of the following conditions:

- (1) Were editorial, opinion, or other non-peer-reviewed materials, including conference abstracts or reports lacking full methodological content.
- (2) Were purely bibliographic or methodological in nature or addressed coastal or estuarine environments without explicit reference to mangrove ecosystems.
- (3) Focused on Portuguese-speaking countries outside the PALOP (e.g., Brazil, Portugal), unless they were directly linked to mangroves in PALOP countries.

## Screening and classification

All retrieved publications were screened by title, abstract, and keywords to ensure their relevance to PALOP mangroves and their alignment with the NCP framework. A blind screening process was conducted independently by the three authors to reduce subjectivity, and disagreements were resolved through collaborative discussion. Publications were coded by country and NCP category according to Díaz et al. (2018), with guidance from Brauman et al. (2020). The final dataset (n = 132) was analyzed quantitatively and qualitatively to identify ecological, social, and economic patterns, and to highlight major research gaps regarding human-nature interactions.

## The classification through NCP approach

The NCP framework (Díaz et al. 2018; Brauman et al. 2020) provides an integrative lens for evaluating human–nature relations. It comprises 18 categories across three broad domains: material, non-material, and regulating contributions. Material NCP include tangible benefits (e.g., food, energy, timber), non-material NCP encompass cultural, spiritual, and identity-based values, and regulating NCP refer to ecosystem processes that maintain environmental quality and resilience.

Classifying studies under NCP 18 (“Maintenance of options”) presented specific methodological challenges, as this category concerns the long-term potential of ecosystems to sustain future uses through biodiversity, genetic resources, and ecological integrity. This contribution is seldom explicitly stated in research objectives or results and typically emerges as a latent or indirect theme.

To address this complexity, studies were classified under NCP 18 when they referred (explicitly or implicitly) to biodiversity conservation, habitat resilience, or genetic resources in ways that could plausibly support long-term ecosystem potential. Ambiguous cases were evaluated through consensus among the three authors to ensure consistency and avoid misclassification. This multidimensional classification approach allowed for a more comprehensive mapping of knowledge production and socio-ecological research gaps across PALOP countries. The resulting patterns of presence, absence, and thematic concentration within the NCP categories were taken into account in the qualitative analysis and discussion regarding each country’s specific environmental governance profiles (e.g., integration into international NGO networks, legal frameworks for community co-management, and national political

economies) and were used as potential contextual factors to explain the structural differences in knowledge production among the five nations.

For the quantitative synthesis of the three overarching NCP categories (Regulating, Material, and Non-Material) across countries, relative frequencies (percentages) were calculated based on the total number of NCP classifications identified per country rather than the total number of publications. Because a single scientific article frequently addresses multiple NCP simultaneously (e.g., assessing both climate regulation and food provision), the cumulative number of NCP classifications inherently exceeds the number of individual studies. To accurately reflect the proportional distribution of research effort and avoid cumulative percentages exceeding 100%, the denominator used for these calculations was the total sum of NCP recorded for each specific country.

## Results

A total of 132 publications met the inclusion criteria and were analyzed. The distribution of research effort across the study area shows that Mozambique accounts for the largest share of the literature (n = 82, 62.1%), followed by Guinea-Bissau (n = 34, 25.7%). The remaining scientific output is distributed among São Tomé and Príncipe (n = 7, 5.3%), Angola (n = 7, 5.3%), and Equatorial Guinea (n = 2, 1.5%). To map the current state of knowledge across these countries, all publications were categorized using the 18 categories of the IPBES Nature’s Contributions to People (NCP) framework. Table 2 presents the gap analysis matrix, detailing the absolute number of classifications identified per country across these categories.

Table 2

Gap analysis matrix of scientific publications according to the Nature's Contributions to People (NCP) framework across PALOP countries. Values indicate the absolute number of classifications identified per country; zeros highlight critical knowledge gaps. NCP Nature's Contributions to People, IPBES Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, PALOP Portuguese-Speaking African Countries.

| <b>Nature's Contributions to People (NCP)</b> | <b>Angola</b> | <b>Equatorial Guinea</b> | <b>Guinea-Bissau</b> | <b>Mozambique</b> | <b>São Tomé and Príncipe</b> | <b>Total PALOP</b> |
|-----------------------------------------------|---------------|--------------------------|----------------------|-------------------|------------------------------|--------------------|
| <b>Regulating Contributions</b>               |               |                          |                      |                   |                              |                    |
| NCP 1: Habitat creation & maintenance         | 7             | 2                        | 20                   | 68                | 7                            | 104                |
| NCP 2: Pollination & dispersal                | –             | –                        | –                    | –                 | –                            | 0                  |
| NCP 3: Regulation of air quality              | –             | –                        | 2                    | 1                 | 1                            | 4                  |
| NCP 4: Regulation of climate                  | 1             | –                        | 4                    | 10                | 1                            | 16                 |
| NCP 5: Regulation of ocean acidification      | –             | –                        | –                    | –                 | –                            | 0                  |
| NCP 6: Regulation of freshwater quantity      | –             | –                        | –                    | –                 | –                            | 0                  |
| NCP 7: Regulation of water quality            | –             | –                        | 1                    | 2                 | 1                            | 4                  |
| NCP 8: Soil formation & protection            | –             | –                        | 7                    | 7                 | –                            | 14                 |
| NCP 9: Regulation of hazards & extreme events | 2             | –                        | 1                    | 3                 | 1                            | 7                  |
| NCP 10: Regulation of detrimental organisms   | –             | –                        | 2                    | 1                 | 1                            | 4                  |
| <b>Material Contributions</b>                 |               |                          |                      |                   |                              |                    |
| NCP 11: Energy                                | 1             | –                        | 2                    | 2                 | –                            | 5                  |
| NCP 12: Food and feed                         | –             | –                        | 8                    | 7                 | 3                            | 18                 |
| NCP 13: Materials, companionship & labor      | 1             | –                        | –                    | 4                 | –                            | 5                  |

| <b>Nature's Contributions to People (NCP)</b> | <b>Angola</b> | <b>Equatorial Guinea</b> | <b>Guinea-Bissau</b> | <b>Mozambique</b> | <b>São Tomé and Príncipe</b> | <b>Total PALOP</b> |
|-----------------------------------------------|---------------|--------------------------|----------------------|-------------------|------------------------------|--------------------|
| NCP 14: Medicinal & genetic resources         | –             | 1                        | 1                    | –                 | –                            | 2                  |
| Non-Material Contributions                    |               |                          |                      |                   |                              |                    |
| NCP 15: Learning and inspiration              | –             | –                        | 3                    | –                 | –                            | 3                  |
| NCP 16: Physical & psychological experiences  | –             | –                        | 1                    | –                 | 1                            | 2                  |
| NCP 17: Supporting identities                 | –             | –                        | 10                   | 2                 | 1                            | 13                 |
| NCP 18: Maintenance of options                | 2             | 1                        | 21                   | 20                | 6                            | 50                 |

The systematic classification shows that 15 out of the 18 NCP categories were documented in the retrieved literature, while three regulating categories were entirely unrepresented across the region: pollination and seed/propagule dispersal (NCP 2), regulation of ocean acidification (NCP 5), and regulation of freshwater quantity, location and timing (NCP 6). The number of absent NCP categories varied among the studied countries. Equatorial Guinea had the highest number of unrepresented categories, with 15 out of 18 categories missing from its literature ( $n = 15$ , 83.3%), followed by Angola with 12 unrepresented categories ( $n = 12$ , 66.7%), São Tomé and Príncipe with 8 unrepresented categories ( $n = 8$ , 44.4%), and Mozambique with 6 unrepresented categories ( $n = 6$ , 33.3%). In contrast, Guinea-Bissau had only 4 categories unaddressed ( $n = 4$ , 22.2%), displaying the widest representation of NCP categories in the analyzed regional dataset.

A detailed examination of the present categories shows that only Habitat creation and maintenance (NCP 1,  $n = 104$ , 41.4% of total regional classifications) and Maintenance of options (NCP 18,  $n = 50$ , 19.9% of total regional classifications) were documented across all five nations. Regulating contributions comprised most of the documented classifications. In contrast, material contributions were less frequent; for instance, Materials, companionship, and labor (NCP 13) was only recorded in Angola ( $n = 1$ , 7.1% of national classifications) and Mozambique ( $n = 4$ , 3.1% of national classifications). Within Non-Material contributions, Guinea-Bissau recorded 10 classifications for Supporting identities (NCP 17,  $n = 10$ , 12.0% of national classifications), whereas the other four PALOP countries recorded a combined total of three classifications across the cultural and spiritual dimensions (NCPs 15, 16, and 17).

# Comparison of regulating, material, and non-material NCP in PALOP countries

The aggregated results of the broader NCP categories (Table 3) ranked, in descending order, Regulating (153 classifications), Non-Material (68), and Material (30). Regulating NCP dominate the research agenda across all PALOP countries, representing most of the identified classifications, ranging from 44.6% in Guinea-Bissau to 72.4% in Mozambique. This overarching dominance underscores a strong biophysical and conservationist focus on the regional literature, prioritizing the central role of mangroves in ecosystem maintenance and coastal protection.

Table 3

Distribution of scientific publications across the three main NCP supra-categories in PALOP countries. Values quantify cumulative frequencies (n) and relative frequencies (percentages) calculated from the total sum of NCP classifications per country. NCP Nature's Contributions to People, PALOP Portuguese-Speaking African Countries.

| Country               | Regulating (nº, %) | Material (nº, %) | Non-Material (nº, %) |
|-----------------------|--------------------|------------------|----------------------|
| Equatorial Guinea     | 2 (50.0)           | 1 (25.0)         | 1 (25.0)             |
| Angola                | 10 (71.4)          | 2 (14.3)         | 2 (14.3)             |
| São Tomé and Príncipe | 12 (52.2)          | 3 (13.0)         | 8 (34.8)             |
| Guinea-Bissau         | 37 (44.6)          | 11 (13.3)        | 35 (42.2)            |
| Mozambique            | 92 (72.4)          | 13 (10.2)        | 22 (17.3)            |
| <b>Total</b>          | <b>153</b>         | <b>30</b>        | <b>68</b>            |

Regulating NCP are the most frequently mentioned category across all countries, with the highest absolute count recorded in Mozambique (n = 92), followed by Guinea-Bissau (n = 37), São Tomé and Príncipe (n = 12), Angola (n = 10), and Equatorial Guinea (n = 2). In relative terms, this category dominates the research agenda, representing most of the identified classifications, ranging from 44.6% in Guinea-Bissau to 72.4% in Mozambique.

Conversely, Material and Non-Material NCP showed variable and generally limited coverage. Material NCP are the most infrequent category overall; although Mozambique and Guinea-Bissau have the highest absolute numbers (n = 13 and n = 11, respectively), this service represents a consistently low proportion of the research focus across the most studied nations (e.g., 10.2% in Mozambique and 13.3% in Guinea-Bissau).

Non-material NCP reveal notable geographic disparities. They were consistently considered in Guinea-Bissau (n = 35; 42.2%) and São Tomé and Príncipe (n = 8; 34.8%), reflecting a stronger integration of socio-cultural dimensions in these countries. However, despite Mozambique having the second-highest absolute count (n = 22), this category received proportionally limited attention there (17.3%) and in Angola (n = 2; 14.3%). These patterns expose significant research gaps, particularly concerning the

marginalization of material services in Mozambique and non-material services in both Angola and Mozambique.

Table 4 provides an overview of the characteristics used to classify NCP categories within the review corpus, together with illustrative examples from the literature. The classification process revealed conceptual overlaps among certain categories, particularly between NCP3 (Regulation of air quality) and NCP4 (Regulation of climate). While NCP3 relates to ecosystem capacities to filter pollutants and improve local air quality, NCP4 encompasses broader processes influencing climate regulation (e.g. carbon sequestration, methane dynamics, evapotranspiration, phytoplankton productivity). In practice, several studies addressed processes contributing simultaneously to both categories, reflecting the interdependence of regulating services.

Table 4

Summary of scientific publication frequency across NCP categories and illustrative literature examples. Categories are distinguished by absent or limited coverage versus frequently studied topics. NCP Nature's Contributions to People. Detailed study characteristics are provided in the Supplementary Material.

| <b>NCP Category</b> | <b>Brief explanation</b>                               | <b>Absence/Few classifications</b> | <b>Most classified<br/>(nº, %)</b> | <b>Example of work</b>                                                                                                                 | <b>Reference Example</b>  |
|---------------------|--------------------------------------------------------|------------------------------------|------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------|---------------------------|
| <b>Regulating</b>   |                                                        |                                    |                                    |                                                                                                                                        |                           |
| NCP1                | Habitat creation and maintenance                       | –                                  | 104 (78.8)                         | Land cover change in two protected areas of Guinea-Bissau (1956–1998).                                                                 | Vasconcelos et al. (2002) |
| NCP2                | Pollination and seed/propagule dispersal               | None                               | –                                  | –                                                                                                                                      | –                         |
| NCP3                | Regulation of air quality                              | Few classifications                | –                                  | Mangrove habitats in São Tomé and Príncipe: Conservation and management status.                                                        | Haroun et al. (2018)      |
| NCP4                | Regulation of climate                                  | –                                  | 16 (12.1)                          | Biomass and Carbon Stocks of Sofala Bay Mangrove Forests.                                                                              | Sitoe et al. (2014)       |
| NCP5                | Regulation of ocean acidification                      | None                               | –                                  | –                                                                                                                                      | –                         |
| NCP6                | Regulation of freshwater quantity, location and timing | None                               | –                                  | –                                                                                                                                      | –                         |
| NCP7                | Regulation of freshwater and coastal water quality     | Few classifications                | –                                  | Phytoplankton in two tropical mangroves of São Tomé Island (Gulf of Guinea): A contribution towards sustainable management strategies. | Brito et al. (2017)       |
| NCP8                | Formation, protection and                              | –                                  | 14 (10.6)                          | Mangrove rice productivity and                                                                                                         | D'Amico et al. (2023)     |

| NCP Category      | Brief explanation                                            | Absence/Few classifications | Most classified<br>(n°, %) | Example of work                                                                                                                                    | Reference Example      |
|-------------------|--------------------------------------------------------------|-----------------------------|----------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|------------------------|
| <b>Regulating</b> |                                                              |                             |                            |                                                                                                                                                    |                        |
|                   | decontamination of soils/sediments                           |                             |                            | pedogenic trends in Guinea-Bissau.                                                                                                                 |                        |
| NCP9              | Regulation of hazards and extreme events                     | Few classifications         | –                          | Predicting future coastal land use/cover change and associated sea-level impact on habitat quality in the Northwestern Coastline of Guinea-Bissau. | Lopes et al. (2023)    |
| NCP10             | Regulation of detrimental organisms and biological processes | Few classifications         | –                          | Mangrove-mudflat connectivity shapes benthic communities in a tropical intertidal system.                                                          | Meijer et al. (2021)   |
| <b>Material</b>   |                                                              |                             |                            |                                                                                                                                                    |                        |
| NCP11             | Energy                                                       | Few classifications         | –                          | A Social Assessment of Forest Degradation in the Cacheu Mangroves Natural Park, Guinea-Bissau                                                      | Faria et al. (2014)    |
| NCP12             | Food and feed                                                | –                           | 18 (13.6)                  | Fish assemblages in a small mangrove system on Príncipe Island, Guld of Guinea.                                                                    | Cravo et al. (2021)    |
| NCP13             | Materials, companionship and labor                           | Few classifications         | –                          | Evaluation of mangrove structure and condition in two trans-boundary areas in the Western Indian Ocean.                                            | Bandeira et al. (2009) |

| <b>NCP Category</b> | <b>Brief explanation</b>                     | <b>Absence/Few classifications</b> | <b>Most classified<br/>(n°, %)</b> | <b>Example of work</b>                                                                                                                                    | <b>Reference Example</b>    |
|---------------------|----------------------------------------------|------------------------------------|------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|
| <b>Regulating</b>   |                                              |                                    |                                    |                                                                                                                                                           |                             |
| NCP14               | Medicinal, biochemical and genetic resources | Few classifications                | –                                  | Mangrove rice biodiversity valorization in Guinea-Bissau.                                                                                                 | Tesio et al. (2021)         |
| <b>Non-Material</b> |                                              |                                    |                                    |                                                                                                                                                           |                             |
| NCP15               | Learning and inspiration                     | Few classifications                | –                                  | Integrated Assessment of the Canary Current large marine ecosystem with a focus on Senegal-Gambia-Guinea-Bissau subregion.                                | Cabrera-Busto et al. (2023) |
| NCP16               | Physical and psychological experiences       | Few classifications                | –                                  | Community perceptions about mangrove ecosystem services and threats                                                                                       | Afonso et al. (2022)        |
| NCP17               | Supporting identities                        | –                                  | 13 (9.8)                           | "The tides rhyme with the moon": Knowledge transmission and rice farming in Guinea-Bissau.                                                                | Sousa and Luz (2018)        |
| NCP18               | Maintenance of options                       | –                                  | 50 (37.9)                          | Evolution of equatorial vegetation communities mapped using Thematic Mapper images through a geographical information system (Guinea, Equatorial Africa). | Riaza et al. (1998)         |

Material NCP were more straightforward to classify. For example, studies under NCP12 (Food and feed) consistently described mangroves as direct providers of resources (e.g. fisheries, oyster harvesting, rice cultivation). Similarly, NCP8 (Soil formation, protection and decontamination) was assigned to studies focusing on abiotic processes (erosion, organic and inorganic cycles) as well as biotic processes (microorganisms, builder crabs, bioindicators).

Non-material NCP also exhibited distinctive patterns. NCP17 (Supporting identities) was strongly represented, encompassing explicit terms such as “basis for religion”, “social cohesion”, and “sense of place”, as well as references to rituals, cultural heritage and identity connected to mangroves as emblematic ecosystems. This highlights the role of mangroves not only as ecological systems but also as cultural and identity-forming landscapes for local populations.

## Discussion

### Overall significance of mangroves in PALOP

Our systematic review of 132 publications reveals that PALOP mangrove research is fragmented, geographically skewed, and structurally uneven across the Nature’s Contributions to People (NCP) spectrum (Moreira et al. 2025). Rather than a neutral reflection of scientific progress, this uneven distribution serves as an empirical validation of the epistemic asymmetries and knowledge equity gaps predicted in our introduction (Trisos et al. 2021; Quenum et al. 2024). Our analysis shows that Mozambique and Guinea-Bissau dominate the scientific output, while Angola, São Tomé and Príncipe, and Equatorial Guinea remain nearly invisible. At first glance, this scientific concentration appears to align with the biophysical scale of the region, since Mozambique and Guinea-Bissau host approximately 95% of the total mangrove habitat in the PALOP (Leal and Spalding 2024). However, this biophysical proportionality masks a profound equity and knowledge governance failure. The near-complete scientific exclusion of Angola, São Tomé and Príncipe, and Equatorial Guinea, despite these nations hosting ecologically significant mangrove areas (such as 429.29 km<sup>2</sup> in Angola and 235.16 km<sup>2</sup> in Equatorial Guinea; UNEP, 2007; GMA, 2024)), means they are operating within an absolute epistemic vacuum (Díaz et al. 2018; Quenum et al. 2024). Without localized empirical baselines, coordinated regional conservation strategies remain structurally unviable, forcing under-researched nations to rely on “one-size-fits-all” frameworks calibrated elsewhere that fail to match their specific socio-ecological realities (Feka 2015; Quenum et al. 2024).

This geographic imbalance is compounded by structural barriers and post-colonial asymmetries in global knowledge production (Trisos et al. 2021). As noted by Quenum et al. (2024), the scientific marginalization of nations like Angola and Equatorial Guinea reflects systemic limitations in national research infrastructure, restricted access to high-impact international publishing venues indexed in the Web of Science, and an acute dependency on external, foreign-led funding streams. In the PALOP context, these structural barriers determine not only *where* research is conducted, but also *what* questions are deemed worth asking. Consequently, the science-policy interface in under-researched nations is frequently driven by international, donor-centric conservation agendas rather than national environmental priorities or local community needs, reinforcing epistemic dependencies that hinder autonomous environmental governance (Trisos et al. 2021; Quenum et al. 2024) and limit their ability to participate equitably in international climate mechanisms, such as blue carbon markets or NDCs (Ofori et al. 2025).

Reflexively analyzing our corpus through the IPBES framework reveals a systemic bias towards biophysical and regulating contributions, which dominate the regional research agenda (n = 153 classifications). This pronounced concentration, particularly on habitat maintenance (NCP 1) and climate regulation (NCP 4), reflects the global prioritization of mangroves as critical carbon sinks and coastal buffers within international climate mitigation frameworks (Sitoe et al. 2014; Alongi 2020). However, this “carbon-centric” scientific focus effectively monopolizes research resources, rendering invisible the tangible material contributions and non-material relational values that are fundamental to local well-being (Díaz et al. 2018; Dean et al. 2024). For instance, despite the high dependency of coastal populations on mangroves for timber, fuel, and artisanal fisheries, material contributions such as NCP 13 (Materials, companionship, and labor) are virtually ignored in the peer-reviewed literature outside of Angola and Mozambique (Naidoo 2023). This mismatch represents a reductionist approach to socio-ecological systems, wherein global regulatory targets are prioritized at the expense of local livelihood dependencies (Haines-Young & Potschin 2010; Brauman et al. 2020).

Breaking this biophysical bias requires a concerted effort toward the decolonization of mangrove science through the integration of plural and traditional ecological knowledges (Trisos et al. 2021). Guinea-Bissau serves as a key regional exception in our dataset, demonstrating a stronger integration of socio-cultural and relational dimensions, particularly regarding the deep intertwinement between mangrove preservation, cultural identity, and local traditions like mangrove rice farming (NCP 17; Sousa and Luz 2018). Incorporating such hybrid knowledge systems, where formal transdisciplinary science weaves with the lived experiences and historical practices of local stakeholders, is essential to prevent “*green grabbing*” and to co-design conservation strategies that are both ecologically sound and socially equitable (Fairhead et al. 2012; Dean et al. 2024). The research within our corpus highlights the importance of specific regulating contributions, notably NCP 1 and NCP 8, which underscore the mangroves' role in providing habitat for diverse species and maintaining coastal integrity (Feka 2015). Integrating this hybrid knowledge in the PALOP context is essential to co-design strategies that are both ecologically sound and socially equitable. Key economic activities such as rice cultivation and artisanal fishing depend on mangrove ecosystems (Haines-Young & Potschin 2010; Dias et al. 2022), yet further research is needed to quantify these contributions and support sustainable management.

These findings align with previous work stressing that non-material NCP (including cultural, spiritual, and social values) are integral to the relationship between ecosystems and people (Haines-Young & Potschin 2010). Mangroves contribute to community identity, social cohesion, and cultural heritage through rituals and spiritual practices, reinforcing the socio-cultural dimensions of ecosystem management (Mendes 2021; Keleman et al. 2023). To bridge these epistemic gaps, studies from Portuguese Biosphere Reserves suggest that participatory mapping can effectively capture and spatially represent non-material NCP, including cultural identity, spiritual attachment, and psychological experiences, which are often overlooked in conventional ecological assessments (Moreira et al. 2024). Applying such participatory approaches in the PALOP could strengthen both conservation outcomes and local engagement (Santos et al. 2025).

# Knowledge gaps

Studies of African mangroves have revealed key insights into NCP, with some notable gaps: NCP2, NCP5 and NCP6. These three absent categories share a common structural feature in that they represent indirect, process-mediated ecological functions that are methodologically harder to detect and quantify than provisioning or habitat services. Their consistent absence across all PALOP countries is therefore unlikely to be coincidental, and more probably reflects systematic biases in research design, funding priorities, and available methodological expertise.

A particularly striking finding is the complete absence of NCP2 across all surveyed countries, highlighting a critical ecological oversight. This absence is unexpected given the ecological relevance of pollination in mangrove systems and its direct links to both biodiversity maintenance and ecosystem resilience (Feller et al. 2010; Landry 2013; Cormier-Salem 2017). Although mangrove trees largely disperse seeds via water, successful reproduction in many species still depends on pollination mechanisms involving insects, birds, and other fauna (Landry 2013). The absence of studies in this area suggests an underappreciation of the ecological roles of pollinators in supporting floral diversity, fruit production, and forest regeneration. This, in turn, may influence overall mangrove ecosystem stability. Additionally, pollinator activity may enhance the availability of mangrove-derived products such as honey and wax, resources of considerable socio-economic importance to local communities (Cormier-Salem 2017). Thus, the omission of NCP2 reflects both ecological and livelihood-related blind spots, with implications for mangrove resilience, tree replacement rates, and adjacent agricultural productivity (Feller et al. 2010).

Similarly, the absence of NCP5 in PALOP mangrove research represents a critical blind spot. Mangroves are globally recognized for their capacity to sequester carbon in both above- and below-ground biomass, thereby contributing indirectly to ocean pH regulation (Alongi 2020; Kauffman et al. 2020). The mechanism operates through the burial of organic carbon in mangrove sediments, which reduces CO<sub>2</sub> flux to the atmosphere and thereby moderates shifts in seawater carbonate chemistry. This function not only mitigates ocean acidification but also supports marine biodiversity and sustains small-scale fisheries. Despite these established global patterns, region-specific data on carbon storage and its linkage to ocean chemistry remain extremely limited. This gap hampers integrated climate adaptation and mitigation strategies, particularly in socio-ecologically vulnerable coastal zones (Maunder et al. 2017; Thomas et al. 2017; Naidoo 2023). Targeted, region-specific studies are needed to quantify carbon stocks, assess biogeochemical pathways, and model buffering capacity under local conditions.

NCP6 is another critical yet understudied ecosystem function of mangroves in the PALOP. In a region where seasonal rainfall variability, salinization, and water scarcity increasingly threaten agricultural productivity and human well-being, mangroves capacity to buffer freshwater flows and prevent saltwater intrusion is essential (Baggio et al. 2021). These ecosystems stabilize hydrological regimes and maintain soil and water quality in adjacent lowland agricultural systems, directly supporting rural coastal communities that rely on groundwater and surface freshwater for drinking, irrigation, and food

production (Twilley et al. 2001; Alongi 2008; Baggio et al. 2021). Alongi (2008) highlighted the importance of mangroves in sustaining hydrological cycles, while Twilley et al. (2001) emphasized their contribution to nutrient cycling and water purification. Despite its relevance for climate adaptation and coastal agriculture, this function remains virtually undocumented in PALOP research, underscoring a major gap in hydrological and socio-ecological knowledge. This knowledge gap is directly relevant to national water governance and coastal agricultural planning, particularly in Guinea-Bissau and Mozambique, where rice cultivation systems adjacent to mangroves are under increasing pressure from salinization and erratic seasonal rainfall.

Together, these findings identify a gap that extends beyond ecology into governance. The absence of NCP2, NCP5, and NCP6 from the PALOP literature means that some of the mangrove functions more relevant to climate adaptation planning, food security, and coastal management remain invisible in the evidence base on which policy depends. Addressing them is thus as much a political priority as a scientific one.

## **Evaluation of using NCP as a proxy**

Using the NCP framework as a proxy to assess research trends in PALOP mangrove ecosystems provides a structured and comparative approach to identifying key knowledge gaps. Mangroves in the region deliver a wide range of ecological, socio-economic, and climate-regulating services, yet many of these remain poorly studied or entirely undocumented. Applying the NCP categories to the publication record allows us to move beyond descriptive assessments, revealing patterns in scientific attention and societal valuation of these ecosystems and highlighting systemic biases in research priorities. This review deliberately moves beyond a utilitarian model of nature by adopting the NCP framework rather than a conventional Ecosystem Services (ES) approach. While mainstream ES applications have tended to prioritize linear, market-valued benefit flows, the NCP framework recognizes reciprocal and culturally mediated relationships. This distinction is critical in the PALOP context, where the value of mangroves is frequently defined by spiritual heritage or communal labor, values that conventional ES assessments tend to render invisible. Crucially, however, the framework is applied here not merely descriptively to catalogue what mangroves provide but reflexively, treating the pattern of presence and absence across NCP categories as a diagnostic signal. What is studied, and what is not, reveals as much about the priorities of funders, institutions, and international research agendas as it does about the ecology of these systems.

This analytical deployment of the NCP framework is not without methodological tensions. The framework has been criticized, including by members of the IPBES community involved in its original design, for the difficulty of operationalizing non-material and relational values to the standard expected of biophysical assessments (Díaz et al. 2018; Pascual et al. 2017). In the PALOP context, where the evidence base is limited and data collection infrastructure is underdeveloped, these tensions are particularly intense. Here, we address these issues by treating NCP categories as analytical lenses rather than quantitative targets, viewing absence and underrepresentation as meaningful data points that reveal structural patterns.

Among the 18 NCP categories, several are conspicuously underrepresented or entirely absent in mangrove-related research across the PALOP countries, particularly in Angola and Equatorial Guinea. Interestingly, while previous reviews (e.g., Feka & Ajonina 2011; Naidoo 2023) noted that provisioning services globally receive more attention than regulating or cultural services, our analysis reveals an inverse trend in the PALOP region. Here, Regulating contributions dominate the peer-reviewed literature, whereas Material contributions are the least represented overall. This pronounced bias towards regulating functions, at the expense of socio-cultural dimensions, reflects a reductionist approach to complex socio-ecological systems. A strikingly similar trend was recently reported by Dean et al. (2024) in their systematic review of Mediterranean pastoral. Importantly, this critique does not stem from a normative assumption that research efforts or policy focus should be equally distributed across all 18 NCP categories, an expectation that would ignore biophysical realities and natural scientific specialization (Díaz et al. 2018; Pascual et al. 2017). Rather, the concern is that the current severe underrepresentation of material and non-material contributions hinders the development of balanced, multi-functional management strategies, effectively decoupling environmental policies from the daily socio-economic realities and livelihood needs of coastal communities (Brauman et al. 2020).

These geographic and thematic imbalances are structurally driven by the differing national environmental governance architectures and political economies across the PALOP (Quenum et al. 2024). In Mozambique, environmental governance is highly institutionalized and deeply integrated with international conservation NGOs and carbon-centric multilateral aid, which heavily directs funding toward biophysical metrics like carbon sequestration (NCP 4) and sediment protection (NCP 8) to satisfy international market standards (Sitoe et al. 2014; Ofori et al. 2025; Adams et al. 2026). Conversely, Guinea-Bissau operates under a more decentralized, community-centric model where the co-management of protected areas and biosphere reserves legally incorporates and co-exists with traditional practices like mangrove rice farming, explaining the higher documentation of cultural and identity values (NCP 17) (Keleman et al. 2023; Sousa et al. 2023). In contrast, the extreme knowledge gaps in Angola (429.29 km<sup>2</sup> of habitat) and Equatorial Guinea (235.16 km<sup>2</sup> of habitat) reflect rentier political economies focused on offshore petroleum extraction and rapid urban-industrial coastal development, where state-funded environmental research infrastructures have historically been marginalized, leaving local managers in an absolute empirical vacuum (UNEP 2007; Quenum et al. 2024).

Despite this lower overall frequency, specific provisioning categories such as NCP11 (Energy) and NCP12 (Food and feed) remain consistently documented in specific socio-economic contexts, reflecting the high dependence of local populations on tangible mangrove-derived resources (Adekola et al. 2015; Rivero & Villasante 2016; Afonso et al. 2021; Gnansounou et al., 2022). This thematic skew, prioritizing regulating functions over the socio-economic and cultural realities of local populations, indicates that conservation agendas in the PALOP may be driven more by global biophysical priorities than by local livelihood dependencies. Acknowledging and addressing this research gap is crucial, as undervaluing the study of material and non-material services risks disconnecting environmental policies from the daily socio-economic realities and livelihood needs of coastal communities.

These spatial disparities in research effort expose a profound equity gap that directly compromises regional environmental governance. When countries like Angola and Equatorial Guinea, which harbor ecologically significant mangrove tracts, are characterized by severe knowledge gaps, they are subjected to what can be termed epistemic marginalization (Trisos et al. 2021). If regional conservation policies or CPLP-wide management frameworks are calibrated primarily using data from Mozambique or Guinea-Bissau, there is a serious risk of 'one-size-fits-all' policy mismatches that fail to align with the unique biophysical, socio-political, and economic realities of these under-researched nations (Feka 2015; Quenum et al. 2024). Bridging this gap is therefore not merely a technical challenge to expand bibliographies; it is a matter of environmental justice and epistemic equity, ensuring that every PALOP nation possesses the sovereign scientific evidence base required to govern its coastal socio-ecological systems.

The NCP framework also enables the identification of synergies and trade-offs among ecosystem functions. For example, studies in Guinea-Bissau, Mozambique, and São Tomé and Príncipe highlight connections between NCP1 and NCP3, demonstrating that conservation-oriented interventions can yield multiple co-benefits, such as enhanced carbon sequestration and improved water quality (Sitoe et al. 2014; Vasconcelos et al. 2014; Haroun et al. 2018). Recognizing these interdependencies is essential for integrated ecosystem management, rather than focusing solely on provisioning services. Failing to recognize these interdependencies can lead to detrimental trade-offs. For example, focusing solely on maximizing carbon sequestration (NCP1) could restrict local access to materials and labor (NCP13), enabling “green-grabbing”, the appropriation of community-managed landscapes in the name of conservation (Fairhead et al. 2012). This risk is particularly acute under top-down, carbon-centric governance frameworks. When state policies prioritize global climate regulation goals (NCP 4) through strict forest preservation or blue carbon offsets without empirical data on local dependencies like fuelwood (NCP 11) or artisanal fisheries (NCP 12), they impose regulatory restrictions that trigger local compliance conflicts, resource user displacement, and governance failures (Feka 2015; Winston 2017; Naidoo 2023). The NCP framework is a vital safeguard in this respect, ensuring that management strategies priorities multiple co-benefits rather than compromising local livelihoods to meet global regulatory targets.

The analytical utility of the NCP framework demonstrated in this methodological synthesis (Moher et al. 2009; Moreira et al. 2025) extends far beyond mangrove forests, offering a highly transferable diagnostic model for other African coastal and terrestrial socio-ecological systems facing similar international policy pressures (Dean et al. 2024; Quenum et al. 2024). By systematically deconstructing the literature, this approach quantitatively exposes how global funding regimes shape regional scientific focus (Moreira et al. 2025). Specifically, the absolute absence of indirect, process-mediated regulating functions (e.g., pollination (NCP 2), ocean acidification regulation (NCP 5) and freshwater regulation (NCP 6)) across all five PALOP nations, unveils a systemic research bias that privileges easily quantifiable global metrics over localized ecological processes (Díaz et al. 2018; Pascual et al. 2017).

Furthermore, our spatial comparison resolves a critical governance paradox. While the concentration of the bulk of the scientific literature in a few dominant nations appears to align with the regional distribution of physical mangrove cover, this geographic proportionality masks a epistemic injustice (Trisos et al. 2021). Ecologically significant mangrove nations, such as Angola and Equatorial Guinea, remain represented by a marginal fraction of regional research, creating a profound imbalance in sovereign scientific capacity across the region (Feka & Ajonina 2011; Quenum et al. 2024). This empirical deficit leaves coastal managers in under-researched nations in a complete information vacuum, forced to rely on generalized ecological and management assumptions calibrated in geographically and socially distinct regions, such as East Africa (Feka 2015; Quenum et al. 2024). Without localized baselines on community dependencies (e.g., fuelwood harvesting (NCP 11) or small-scale fisheries (NCP 12)), any attempt to formally model national environmental governance against mangrove degradation remains compromised by severe epistemic gaps (Brauman et al. 2020; Ofori et al. 2025). This study, therefore, establishes the necessary qualitative and structural foundation upon which future socio-ecological and policy-modeling frameworks can be equitably built, ensuring that local livelihoods are not marginalized to satisfy external, carbon-centric conservation agendas that overlook local human realities (Fairhead et al. 2012; Cormier-Salem 2017; Adams et al. 2026).

## **The NCP13 (materials, companionship and labor) case and Africa**

It is worth paying particular attention to NCP13 in the context of the African continent, and more specifically West Africa, where most PALOP countries are located. In mangrove ecosystems, NCP13 is particularly significant due to its close connection with the socio-labor culture of communities that rely on natural resources for both economic and cultural well-being. This NCP encompasses the use of cultivated or wild materials and the direct use of living organisms for industrial, ornamental, commercial, transport, labor, and other purposes (Brauman et al. 2020). Its relevance is amplified in low-income economies, where communities frequently depend directly on the materials and labor provided by natural ecosystems to sustain livelihoods (Díaz et al. 2018; Padonou et al. 2021; Naidoo 2023).

Mangrove ecosystems supply essential resources such as timber, fishing materials, and employment opportunities, thereby contributing substantially to local economies and cultural practices (Padonou et al. 2021, 2023). Failure to explicitly recognize NCP13 may marginalize community perspectives and undermine both conservation and livelihood goals.

For example, in Guinea-Bissau, where mangroves play a pivotal role in local livelihoods, the absence of NCP13 in research reflects a potential systematic undervaluation of socio-economic and labor-related ecosystem contributions. In many coastal communities, mangrove-derived resources are indispensable for daily subsistence and economic survival (Padonou et al. 2021; Hamza 2022). However, scientific assessments often overlook these dimensions, likely due to methodological limitations or a narrow interpretation of provisioning services that ignores the companionship, cultural attachment, and labor-related roles fulfilled by natural resources (Winston 2017; Díaz et al. 2018; Brauman et al. 2020; Naidoo

2023). This omission reflects a broader tension between generalizing scientific perspectives (typically driven by international research agendas) and context-specific realities. Prioritizing biophysical metrics over local labor cultures may effectively marginalize indigenous and community-based voices and lead to conflict with conservation authorities over access to mangrove resources. Integrating NCP13 offers a pathway towards the decolonization of mangroves (Trisos et al. 2021). This involves valuing mangroves as more than just carbon sinks and respecting them as landscapes that are inhabited, where human identity and ecosystem health are inseparable. As demonstrated in Portuguese biosphere reserves, participatory and educational approaches offer a concrete methodological pathway in this direction. These approaches engage younger stakeholders, facilitate the intergenerational transfer of ecological knowledge and foster long-term community stewardship of mangrove ecosystems (Santos et al. 2025). When adapted to the PALOP context, these approaches could bridge formal scientific assessment and traditional ecological knowledge, which is currently scarce on the reviewed literature. Addressing this research gap is therefore essential for a more accurate and inclusive understanding of how mangrove ecosystems support human well-being, not only through biodiversity and regulating services but also via socio-economic, cultural, and functions related labor. Recognizing the multifaceted contributions of NCP13 can guide more equitable management strategies, inform policy that aligns conservation with local needs, and strengthen the resilience of communities heavily reliant on these ecosystems (Winston 2017; Padonou et al. 2021; Hamza 2022).

## Research priorities

Closing the knowledge gaps, particularly those concerning NCP5 (ocean acidification regulation) and NCP9 (hazard and extreme event regulation), is essential for PALOP nations to align with current global policy commitments. Region-specific data on carbon stocks and coastal regulation are fundamental to updating Nationally Determined Contributions under the Paris Agreement (Ofori et al. 2025), as well as to meeting the 30×30 targets of the Kunming-Montreal Global Biodiversity Framework. Without this evidence base, PALOP nations risk being excluded from emerging international climate finance mechanisms, including high-integrity Blue Carbon markets (Adams et al. 2026).

Critical knowledge gaps in NCP within PALOP mangrove ecosystems highlight the urgent need for targeted research to inform both ecosystem management and policy design (Díaz et al. 2018; Brauman et al. 2020). Addressing these gaps is essential not only for conservation but also for sustaining livelihoods and enhancing socio-ecological resilience.

In the case of NCP2 (Pollination and seed dispersal), the ecological role of biotic pollinators remains largely unstudied in the PALOP region. Pollination directly influences reproductive success, forest regeneration, and population dynamics (Feller et al. 2010; Landry 2013). Additionally, pollinator species, including bees and birds, provide socio-economic benefits through honey and wax production, and may enhance surrounding agroecosystems (Cormier-Salem 2017). Neglecting this area leaves a dual knowledge gap, with consequences for both ecosystem resilience and local livelihoods.

NCP5 (Regulation of ocean acidification), associated with carbon sequestration and buffering of seawater pH, is globally recognized as a key mangrove function (Alongi 2020; Kauffman et al. 2020). In PALOP countries, empirical data assessing carbon stocks and chemical impacts on coastal waters remain scarce (Maunder et al. 2017; Thomas et al. 2017; Naidoo 2023), limiting the development of integrated climate adaptation strategies. Region-specific studies are urgently needed to quantify carbon pools, explore biogeochemical pathways, and model mangrove-mediated buffering under variable hydrological and land-use conditions.

For NCP6 (Regulation of freshwater flows), mangroves maintain soil and water quality and prevent saltwater intrusion in low-lying agricultural zones (Twilley et al. 2001; Alongi 2008; Baggio et al. 2021). Surprisingly, PALOP studies rarely address this function despite increasing threats from freshwater scarcity, salinization, and variable rainfall. Quantifying mangrove impacts on freshwater dynamics and integrating results into watershed-scale management is a critical research need.

NCP8 (Formation, protection, and decontamination of soils) reflects the capacity of mangroves to stabilize coastlines and reduce erosion risk, yet documentation in West African PALOP mangroves is sparse (Feka et al. 2015). Quantitative assessments should measure shoreline stabilization, vegetation–erosion interactions, and future risks under scenarios of mangrove degradation and sea-level rise.

Regarding NCP9 (Regulation of hazards and extreme events), while mangrove contributions to climate mitigation are acknowledged, evidence on broader regulating effects on microclimate and extreme weather remains limited in the region (Haines-Young & Potschin 2010; Brauman et al. 2020; Friess et al. 2020). Understanding these functions is vital for designing nature-based solutions and local adaptation strategies.

For NCP11 (Energy), mangrove biomass extraction for fuelwood and charcoal supports local energy needs but remains poorly quantified in PALOP countries. Future studies should examine extraction patterns, sustainability thresholds, socio-economic drivers, and the potential for community-based management (Padonou et al. 2021, 2023).

Finally, NCP14 (Medicinal and genetic resources) is underrepresented in PALOP mangrove research. Ethnobotanical and genetic studies could uncover underexplored medicinal or conservation-relevant resources (Mendes 2021; Padonou et al. 2021; Hamza 2022).

Collectively, addressing these research priorities is critical to close ecological, socio-economic, and cultural knowledge gaps. Strategic investigation of underrepresented NCP will enhance evidence-based policy, support community livelihoods, and strengthen resilience of PALOP mangrove ecosystems under ongoing environmental and socio-economic pressures.

## Conclusions

PALOP nations have advanced knowledge of mangrove contributions to society, yet substantial knowledge gaps persist, particularly regarding regulating, supporting, and cultural ecosystem functions. Key NCP categories, such as pollination (NCP2), ocean acidification regulation (NCP5), and freshwater regulation (NCP6), are completely absent from the literature, while materials and labor (NCP13) and medicinal/genetic resources (NCP14) are underrepresented, especially in Angola, Equatorial Guinea, and São Tomé and Príncipe. Addressing these epistemic vacuums is essential for a holistic understanding of nature's contributions and for informing evidence-based conservation and management strategies.

Strengthening regional collaboration through CPLP institutions, including the MAB Biosphere Reserve network, can harmonize assessment methods, build capacity, and enable cross-country comparisons of carbon stocks, hydrological regulation, coastal protection, and socio-cultural benefits. Regional cooperation frameworks should be designed to develop research capacity in the least represented countries (Angola, Equatorial Guinea, and São Tomé and Príncipe) rather than merely consolidating knowledge production in Mozambique and Guinea-Bissau. Integrating conventional research with indigenous knowledge and community-led initiatives will enhance ecosystem resilience, support sustainable livelihoods, and ensure local communities directly benefit from conservation efforts while empowering PALOP nations to equitably negotiate global policy commitments, including Nationally Determined Contributions (NDCs) and the Kunming-Montreal 30×30 targets.

A systematic application of the NCP framework facilitates the identification of synergies and trade-offs among ecosystem functions, guiding research priorities and sustainable management while anticipating environmental and social challenges. Improving the accessibility and transparency of ecological and socio-economic data will further enable effective monitoring, evaluation, and evidence-based decision-making. By addressing these knowledge gaps and promoting regional collaboration, PALOP nations can develop a more equitable and comprehensive understanding of the contributions of mangrove ecosystems, considering not only their ecological value, but also their social, cultural, and economic significance to local communities. Ultimately, applying the NCP framework moves beyond mere taxonomy; it provides a critical lens to uncover both the priorities that have shaped regional mangrove research and the vital knowledge gaps that remain to be addressed.

## **Declarations**

## **Author Contribution**

Conceptualization: A.V., H.F., A.C.G.; Methodology: A.V., H.F., A.C.G.; Formal analysis and investigation: A.V., H.F., A.C.G.; Data curation: A.V., H.F., A.C.G.; Writing - original draft preparation: A.V.; Writing - review and editing: A.V., H.F., A.C.G.; Validation: A.V., H.F., A.C.G.; Supervision: H.F., A.C.G.; Project administration: H.F., A.C.G.; Funding acquisition: H.F., A.C.G.

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## Data Availability

The complete PRISMA data extraction matrix supporting the findings of this study is publicly deposited and accessible in the Zenodo repository (DOI: 10.5281/zenodo.21393433).

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## Figures



**Figure 1**

Geographical context of the PALOP included in the study. Guinea-Bissau (Red), Cape Verde (Yellow), Equatorial Guinea (Dark Green), Angola (Light Blue), Mozambique (Dark Blue), and São Tomé and Príncipe (Purple). Cape Verde, a non-mangrove coastal nation, is included to represent the full regional scope of the PALOP group relevant to this study. **Source:** Adapted from data presented in *The State of the World's Mangroves* (2024). Map base generated using MapChart (Accessed: June 2025).

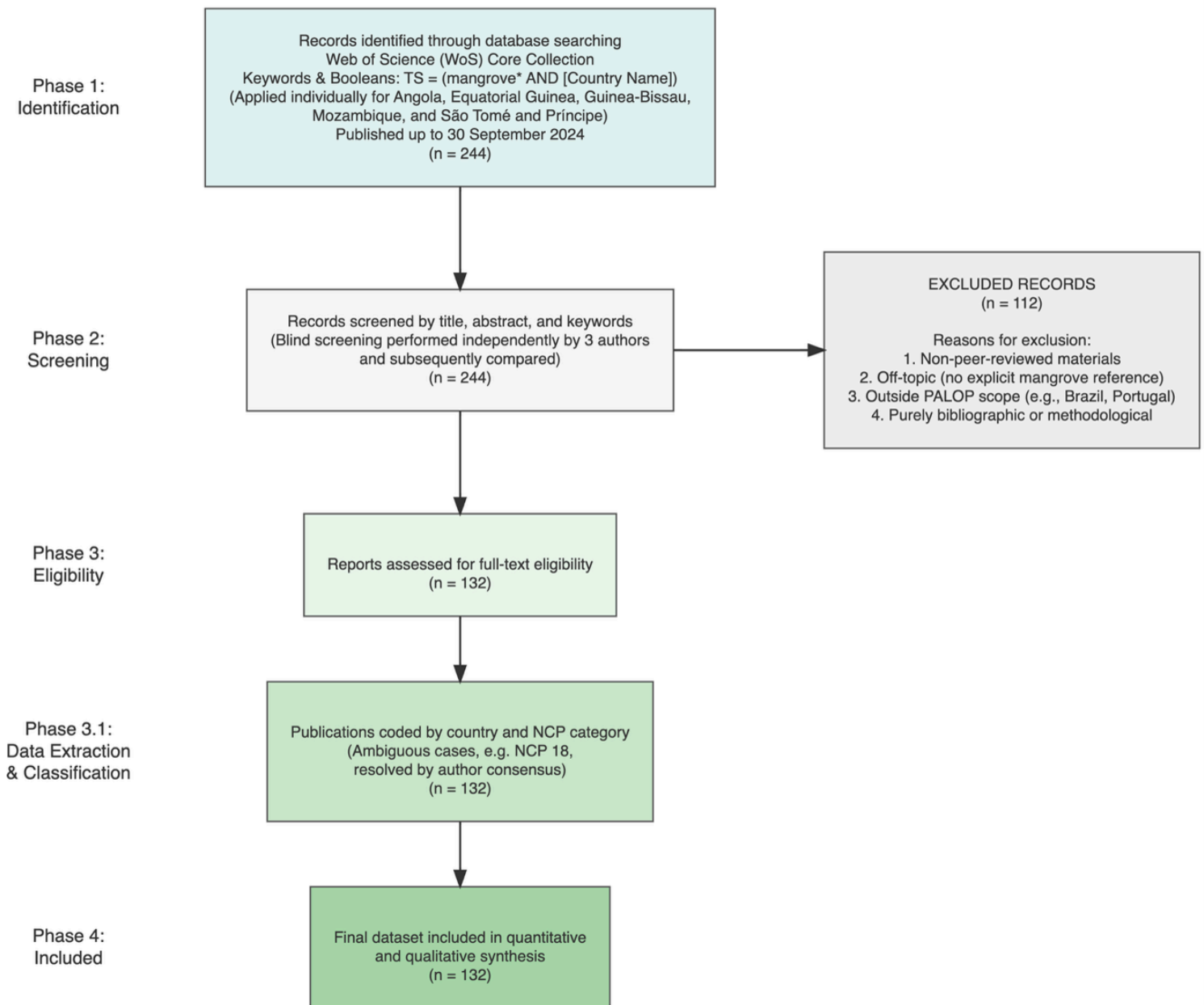


**Figure 2**

PRISMA flow diagram detailing the systematic literature search, screening, and selection process of publications addressing mangrove socio-ecological systems in the PALOP countries.

## Supplementary Files

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