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WHERE DOES THE HYPERSALINE PLAIN (APICUM) BEGIN AND END IN THE INTERTIDAL ZONE OF THE BRAZILIAN COAST?

ONDE COMEÇA E TERMINA A PLANÍCIE HIPERSALINA (APICUM) NA ZONA ENTREMARÉS DA COSTA BRASILEIRA?

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Abstract
The relevance of this study lies in the fact that the apicum ecotone presents conceptual imprecision. This makes it a field of dispute with direct implications for its use and management. The objective of this study was to map and characterize the state of knowledge on apicum in academic and scientific literature. To this end, a scoping review was conducted and reported in accordance with the PRISMA guidelines. The results show that interest in apicum in academic and scientific research is relatively recent, but has grown significantly in recent years. Brazil plays a central role in this knowledge production, representing more than 60% of the studies analyzed. The study also found that governance and public policy perspectives remain sporadic and underdeveloped, revealing a gap between scientific research and management practices. Ultimately, the study emphasizes the need to consider diverse perspectives on the apicum ecotone to support its effective management and conservation.

Keywords: Scoping Review. Brazilian Legislation. Salt Flats. Supratidal Flats. Territory.

Resumo
A relevância deste estudo reside no fato de que o ecótono do apicum apresenta imprecisões conceituais. Isso o torna um campo de controvérsia com implicações diretas para seu uso e manejo. O objetivo deste estudo foi mapear e caracterizar o estado do conhecimento sobre o apicum na literatura acadêmica e científica. Para tal. foi realizada uma revisão exploratória. relatada de acordo com as diretrizes PRISMA. Os resultados mostram que o interesse pelo apicum na pesquisa acadêmica e científica é relativamente recente. mas cresceu significativamente nos últimos anos. O Brasil desempenha um papel central nessa produção de conhecimento. representando mais de 60% dos estudos analisados. O estudo também constatou que as perspectivas de governança e políticas públicas permanecem esporádicas e subdesenvolvidas. revelando uma lacuna entre a pesquisa científica e as práticas de gestão. Por fim. o estudo enfatiza a necessidade de considerar diversas perspectivas sobre o ecótono do apicum para apoiar sua gestão e conservação eficazes.

Palavras-chave: *Revisão Exploratória. Legislação Brasileira. Salinas. Planícies Supratidais. Território.*

1 INTRODUCTION

The term apicum is used by researchers to indicate the transition between the mangrove forest and the dry land. The apicum is also called a "hypersaline tidal flat" or "salt flat", characterized as a flat, saline or acidic area, generally located in the supratidal zone. This mangrove ecotone is the area least flooded by tides and devoid of arboreal vegetation and is predominant in intertropical regions around the globe (Shaeffer-Novelli 1995; Schaeffer-Novelli 2000; Pellegrini 2000; Ucha; Hadlich; Celino 2008; Hadlich; Ucha, 2009; Sá 2024). The term apicum derives from the “Tupi” word "ape'ku," which means tongue, elongated surface, such as a strip of coastal land or beach (Carvalho, 1987). Artisanal fishermen in Maranhão (Northeast Brazil) use this term to refer to any arid or vegetation-free stretch between the mangrove and the terrestrial environment (Santos 1996 apud Pellegrini 2000).

Apicuns can shelter mangrove-associated species and other organisms that use coastal zones during specific life stages and have been highlighted as “nursery” areas for ecologically important groups such as mollusks, crustaceans, and migratory birds (Schaeffer-Novelli 2000; Firmo *et al.* 2012; Schmidt; Bemvenuti; Diele 2013). This ecotone is also of great socioeconomic and cultural importance. Local populations (fishers) needed for their diets in mangroves and associated areas; moreover, they use apicum regions to access the mangroves. Some crustaceans, such as *Ucides cordatus* (Linnaeus 1763) and *Cardisoma guanhumi* (Latreille, 1828), which have high economic value, are often harvested mainly in apicum areas. In addition, apicuns near fishers’ homes may be used for recreational activities (Firmo *et al.* 2012; Schmidt; Bemvenuti; Diele 2013; Santos; Ribeiro 2019; Silveira; Buti 2020).

This ecotone has been subjected to a wide variety of anthropogenic stresses due to economic activities such as aquaculture (e.g., shrimp farming) and saltworks (Meireles *et al*. 2007; Oliveira; Mattos 2007; Ucha 2008; Hadlich *et al*. 2008; Abreu *et al*. 2011; Silva-Júnior; Nicacio; Rodrigues 2020; Lacerda *et al*. 2021).

The term apicum has become an environment permeated by conceptual disputes with implications for its use (Schmidt; Bemvenuti; Diele 2013; Ferreira; Lacerda 2016a; Oliveira-Filho 2016; Santos; Ribeiro 2019). Thus, there is a need to analyze the various meanings that apicum can assume to ensure conceptual clarity about this mangrove ecotone. The guiding question of this study is: what meanings do apicum assume in the academic and scientific literature, and how are these reflected in legislation? To answer this question, a scoping review was conducted following the structure proposed by Levac, Colquhoun, and O'Brien (2010), and reported according to the PRISMA-ScR guidelines (Tricco *et al*. 2018). First, the research protocol was described, and subsequently, a bibliometric analysis was performed as an exploratory and indicative mapping of this emerging field. Finally, the main results and discussions were presented.

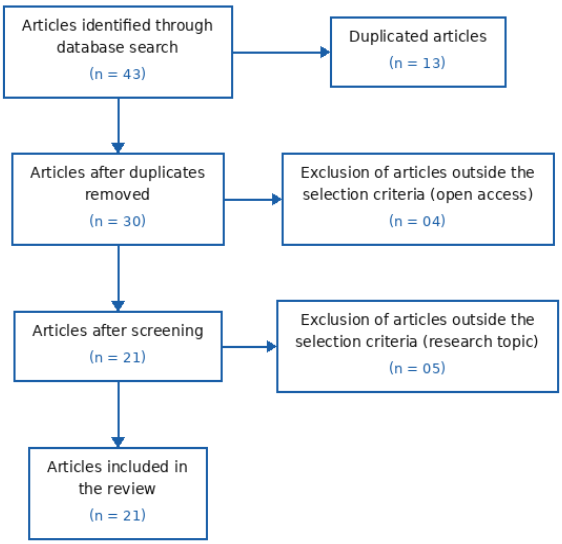
2 MATERIAL AND METHODS

Based on the Convention on Wetlands (Ramsar 1972) and on empirical surveys in scientific studies, the terms "*apicum*," "*apicuns*", "intertidal salt flat," and "hypersaline tidal flat" were selected for use in search systems. It was defined that only open-access, full-text studies in Portuguese, Spanish, or English, peer-reviewed, and presenting an observational basis or concrete measurement regarding apicum would be considered.

In July and August 2025, the selected strings were applied in the Web of Science and Scopus databases, specifically in "titles," "abstracts," and "keywords." To detect duplicate studies and apply the study selection criteria (Figure 1), the Rayyan platform (Ouzzani, 2016) was used.

Figure 1

Illustrative PRISMA-ScR flow of the scoping review protocol applied in August 2025.



The PRISMA-ScR protocol (Tricco *et al*. 2018) was applied for screening and selecting studies for analysis, beginning with the identification of 43 studies in the Web of Science and Scopus databases, followed by the exclusion of 13 duplicate records, resulting in 30 distinct scientific articles. Next, the eligibility criteria were applied, which led to the exclusion of nine studies, reducing the set to 21 scientific articles to be charted (Figure 1).

Bibliometric analysis was performed using the Bibliometrix package (Aria & Cuccurullo 2017) in the R environment. The discussions were based on (i) which concepts, (ii) the central problem, and (iii) which conflicts were identified in each selected study (Tranfield *et al*. 2003). A matrix was created with the subject, the problem approach, and the theories used in each study. The subsequent step of the analysis consisted of categorizing the selected studies based on the spatial concepts of Environment and Territory (Souza 2019) and the concept of Public Policies (Dias 2012). It should be noted, however, that the application of formal bibliometric software such as Bibliometrix to a corpus of 21 studies imposes clear statistical limitations. Bibliometric indicators, including co-citation networks, keyword co-occurrence maps, and h-index-based rankings, are designed for large corpora (typically several hundred records or more)

and may lack robustness when applied to small samples (Donthu *et al*. 2021). With only 21 sources, the resulting networks and frequency distributions must be interpreted as exploratory and indicative rather than statistically definitive. Patterns identified here, such as the prominence of certain authors or keyword clusters, are likely sensitive to the inclusion or exclusion of even a single study. This is consistent with the nature of a scoping review, which does not aim to produce statistically mature mappings of a field, but rather to provide a structured overview of an emerging literature, identify knowledge gaps, and inform future research agendas (Levac; Colquhoun; O'Brien 2010; Munn *et al*. 2018). Readers should therefore treat the bibliometric outputs as a structured and exploratory characterization of the apicum knowledge base, not as a definitive quantitative assessment.

For grammatical revision and improved clarity of this work, ChatGPT (OpenAI 2025) was used as an auxiliary resource. This resource contributed to the standardization of language, fully maintaining the original content and interpretations of the authors.

3 RESULTS AND DISCUSSION

This section presents bibliometric analysis and discussions, based on the 21 selected scientific articles. Scientific articles were selected only if they were registered in the Web of Science and Scopus databases (Table 1).

Table 1

Articles located in the databases (n=21) (search conducted in July and August 2025).

Title	Year	Document type
1. Soil genesis on hypersaline tidal flats (apicum ecosystem) in a tropical semi-arid estuary (Ceará, Brazil).	2014	Article
2. Protection of Mangrove Ecosystems by Brazilian Environmental Legislation.	2015	Article
3. Hypersaline tidal flats (apicum ecosystems): The weak link in the tropical wetlands chain.	2014	Review
4. Apicum do estuário de Barra de Gramame-PB: Análises físicas e químicas (The Use of Space-Temporal Geostatistics in the Prediction of Maximum Air Temperature).	2019	Article

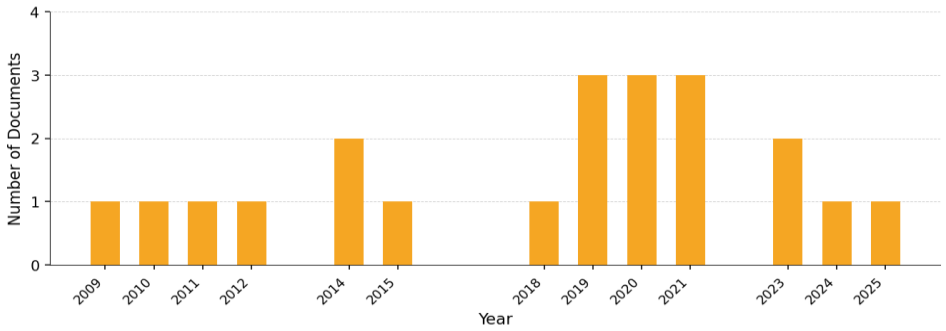
5. Índices de contaminação de metais traço em encostas, manguezais e apicuns, Madre de Deus, Bahia.	2011	Article
6. Hypersaline tidal flats as important “blue carbon” systems: A case study from three ecosystems.	2021	Article
7. How Do Plants and Climatic Conditions Control Soil Properties in Hypersaline Tidal Flats?	2020	Article
8. Marisma, Manguezal (Mangue E Apicum): Ecossistemas De Transição Terra-Mar Do Brasil.	2020	Article
9. 20-years cumulative impact from shrimp farming on mangroves of Northeast Brazil.	2021	Review
10. Aspectos geográficos e a gestão de ambientes costeiros: Um enfoque na Resex do Delta do Parnaíba.	2019	Article
11. Capture and commercialization of blue land crabs (“guaiamum”) *Cardisoma guanhumi* (Lattreille, 1825) along the coast of Bahia State, Brazil: An ethnoecological approach.	2012	Article
12. Apicuns: Aspectos Gerais, Evolução Recente E Mudanças Climáticas Globais.	2009	Article
13. Diferenciação físico-química entre apicuns, manguezais e encostas na Baía de Todos os Santos, Nordeste do Brasil.	2010	Article
14. Challenges to mangroves of the semiarid equatorial coast of Brazil in the Anthropocene.	2024	Article
15. Mapeamento das áreas de apicum disponíveis para carcinicultura no estado do Ceará, Nordeste, Brasil.	2025	Article
16. Are hypersaline tidal flat soils potential silicon sinks in coastal wetlands?	2019	Article
17. Caracterização sedimentológica da planície flúvio-marinha do rio Acaraú, Ceará (NE-Brasil).	2023	Article
18. Evolução espacial de apicuns: Fatores antrópicos e naturais na Baía de Todos os Santos, Costa Nordeste do Brasil.	2021	Article
19. Hypersaline Tidal Flats Detection Using Deep Learning Over 37 Years of Landsat Data.	2023	Article
20. Detecção de mudanças no manguezal ao longo do estuário do rio Coreaú, Nordeste do Brasil a partir da classificação orientada a objeto em imagens orbitais.	2020	Article
21. Role of redox processes in the pedogenesis of hypersaline tidal flat soils on the Brazilian coast.	2018	Article

When analyzing the temporal trajectory of scientific articles, the first record appears in 2008; from that point on, output remained steady, although volumes were modest in the early years (Figure 2). Publication activity consolidated from 2019 onwards, with 2019, 2020 and 2021 standing out as the years with the highest number of articles. The establishment of studies on apicum as a topic of consistent interest is evident.

The graph (Figure 2) shows that interest in the topic has grown in the last two decades. The years 2019, 2020 and 2021 stand out as reference points, concentrating the highest number of scientific articles and signaling the consolidation of the subject in the field of research. The small number of studies selected can be explained mainly by the methodology of this research, which adopted selection criteria that may have excluded some specific studies on apicum. Furthermore, it is observed that apicum has always been considered a component of the mangrove ecosystem, sharing attention with mangrove forests and associated biodiversity (Maciel 1991; Schaeffer-Novelli 1995; Nascimento 1999; Schaeffer-Novelli 2000; Oliveira *et al*. 2000; Coelho-Jr 2012). A first reflection that is pertinent here is what conditioned or determined the increase in specific studies on apicum from the 2000s onwards.

Figure 2

Annual publication output for scientific articles, based on searches conducted in August 2025.



The word cloud showed the terms that occurred most frequently in the analyzed studies. The higher occurrence of the term "mangrove" in relation to the terms "hypersaline tidal flats" and "saline" (Figure 3) corroborates the definitions of scientific studies that define the apicum as an ecotone of the mangrove ecosystem and that have ecological importance (Schcaeffer-Novelli 1989; Schcaeffer-Novelli *et al*. 1990; Pellegrini 2000; Hadlich; Ucha 2009; Junk *et al*. 2013; Albuquerque 2014; Sá 2024; Schaeffer-Novelli *et al*., 2024). Also noteworthy is the presence of the terms "geochemistry," "clay minerals," "soil salinity," "redox," and "soil" (Figure 3), which indicate a concentration of physicochemical studies of the apicum. Among the physicochemical aspects, one of the most discussed was that related to salinity. According

to Schaeffer-Novelli (1990), Pellegrini (2000), and Ucha, Hadlich, and Celino (2008), apicuns present high salinity of the interstitial water due to the evaporation of water remaining in the substrate after the spring tide, combined with low rainfall. Here it can be noted that the apicum is defined by its salinity.

Considering the word cloud, the terms "hydrodynamics," "ecosystem formation," and "sedimentary nutrients" (Figure 3) reveal the presence of geomorphological aspects of the apicum. Regarding the formation of this ecotone, some authors argue that it is due to the deposition of fine sand during high tide, while others maintain that the sand comes from nearby slopes. However, how this burial occurred is still debated (Schmidt; Bemvenuti; Diele 2013). According to Maciel (1991), Soares *et al.* (2008) and Soares (2009), tidal flooding is another criterion for defining apicum areas. For Maciel (1991), this ecotone would be delimited by the average level of spring tides (lower limit) and the level of equinoctial spring tides (upper limit), while Soares *et al.* (2008) and Soares (2009) adopt the limits of the apicum between the average level of neap tides (lower limit) and the average level of spring tides (upper limit). These researchers, in turn, define the apicum by the tidal flooding.

The terms "anthropogenic," "conservation," "management," and "human impacts" (Figure 3, 4) refer to the interactions between humans and the apicuns. Ferreira and Lacerda (2016a, 2016b), Oliveira *et al*. (2016), and de Lacerda *et al*. (2021) analyzed the cumulative effects of approximately twenty years of shrimp farming in mangroves in Northeast Brazil and the mechanisms by which these effects occurred (construction of ponds on the apices, hydrological connectivity and effluent impacts, and changes in regulation). These studies, which used territorial approaches, focused on land use and occupation, coastal planning, and conflicts associated with salt production and shrimp farming.

Figure 3

Keyword word cloud showing the frequency of terms used in the key-words of scientific articles.

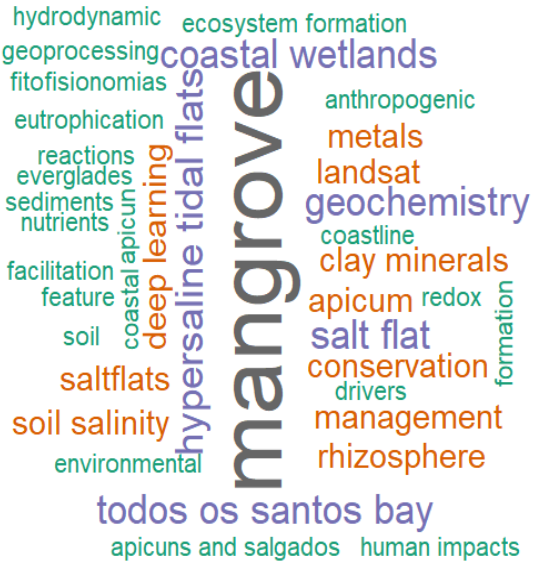


Figure 4

Aerial image showing anthropogenic impacts on Itarema, Ceará State, Brazil, in 2024 (Foto: Ana Caroline Damasceno de Sá).

The analysis of the occurrence of the words in the selected studies indicates two criteria for defining apicuns, namely salinity and flooding. Several authors argue that apicum should be considered a type of "herbaceous mangrove," therefore using vegetation as a criterion for defining apicum (Maciel 1991; Nascimento 1999; Schaeffe-

Novelli *et al.* 1999; Schaeffe-Novelli *et al.* 2012; Schmidt *et al.* 2013). Given this diversity of criteria for defining apicum, the Brazilian Forest Code defined this ecotone based on salinity. Furthermore, this code subdivided this ecotone into apicum and "salgado". "Salgado" are defined as those with salinity between 100 and 150 parts per thousand, and apicum as those with salinity greater than 150 parts per thousand (Brazil 2012). This conceptual division of the ecotone, based on salinity, differs from researchers who consider this ecotone as a single entity and do not conceptually subdivide it (Schaeffer-Novelli 1990; Pellegrini 2000; Ucha; Hadlich; Celino 2008; Hadlich; Celino; Ucha 2010; Sá 2024) (Figure 5).

Figure 5

Aerial image of an apicum on Itamaracá Island, Pernambuco State, Brazil in 2025 (Foto: Fabiano Pimentel Ribeiro).

The analysis of scientific publications by country showed that Brazil plays a central role in generating knowledge about apicum, representing more than 90% of the analyzed production. This concentrated distribution in Brazil, mainly since 2013, may be related to the factor would be the exclusion of this ecotone from the "Permanent Preservation Area" (PPA) with the publication of the Brazilian Forest Code of 2012 (Brazil 1965; 1985; 2002; 2012). This exclusion of apicum from PPAs, in turn, has been associated with heightened economic interest in these areas, especially for activities such as shrimp farming and salt production/extraction (Schmidt; Bemvenuti; Diele 2013; Ferreira; Lacerda 2016a; Oliveira-Filho 2016; Santos; Ribeiro 2019). Schmidt,

Bemvenuti and Diele (2013) criticize this exclusion and argue that apicum should be classified as a PPA. Similarly, Santos and Ribeiro (2019) contend that changes to the Brazilian Forest Code occurred under political pressure from groups linked to large enterprises, including the shrimp-farming sector, to enable the use of apicum. These amendments sparked extensive debate and revealed a field of political disputes regarding the occupation and regulation of apicum in Brazil. In this context, authorizing large-scale projects in apicum areas has been characterized as a process of "environmental injustice" affecting artisanal fishers in Northeast Brazil (Santos; Ribeiro 2019). It is necessary, however, to critically examine whether this strong Brazilian dominance reflects a genuine global pattern or, at least in part, constitutes an artifact of the search strategy employed. The terms "apicum" and "apicuns" are exclusively Portuguese-language designations of Tupi origin, and their use in indexed databases is virtually restricted to Brazilian authors. While the English-language terms "intertidal salt flat" and "hypersaline tidal flat" were included in the search strings, they may not capture the full spectrum of regional terminology used internationally to describe ecologically equivalent environments. Functionally analogous ecosystems are documented in Mexico and Central America under the designation "salitrales" or "playas hipersalinas" (Cervantes Escobar *et al*. 2023), in Australia and the Indo-Pacific as "samphire flats" or "saltpans," and in West Africa as "tannes." Studies on these systems, published under such regional designations, would not have been retrieved by the search strings used. Consequently, it is plausible that the greater than 90% Brazilian share identified here is partly an artifact of terminology rather than solely a reflection of disproportionate Brazilian scientific output. Future reviews on this ecotone should adopt a broader and more explicitly multilingual search protocol to test this hypothesis and to situate apicum research within a genuinely global context of hypersaline intertidal flat science.

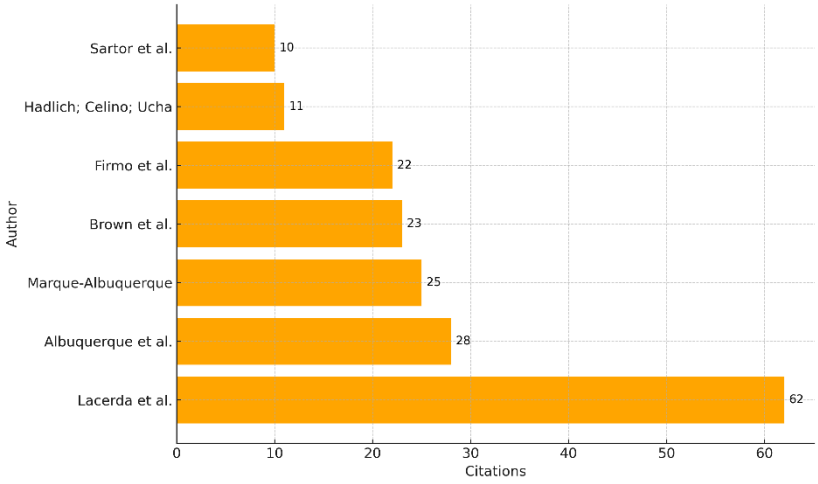
The results showed a strong concentration of citations in Lacerda *et al*. (2021), the most cited work, with 62 mentions (Figure 6). In that study, the authors synthesize the impacts of aquaculture on the provision of ecosystem services and on the environmental condition of associated mangrove habitats in Northeast Brazil, concluding that recent changes in Brazilian legislation, particularly in the Forest Code, have weakened the protection of mangroves and apicum areas. Along the same lines, Schmidt, Bemvenuti, and Diele (2013) draw attention to the occupation of apicum by shrimp-farming ventures.

Silva-Júnior, Nicácio, and Rodrigues (2020), in turn, note that commercial shrimp farming mobilizes the discourse of "sustainable development," emphasizing economic growth and job creation, often at the expense of environmental, social, and cultural dimensions. Albuquerque *et al*. (2014b) (Figure 6) presented evidence of the need for more studies on ecological relationships in apicuns, as well as the determination of the ecological connection between apicuns and other wetlands. Filling this knowledge gap is essential to improve public policies and conservation laws for the protection of all coastal ecosystems. Oliveira e Freitas Filho (2017) e Pinto (2022) found significant losses of apicuns in shrimp farming (25.7%) and salt extraction (47%) ventures in their research. Furthermore, Gualberto, Sousa, and Bezerra (2023) reported that currently the main drivers of change in mangrove areas are urbanization and the growth of aquaculture, which accounted for more than 98% of anthropogenic changes between 1999 and 2019. The study emphasized the importance of mangroves as critical ecosystems that provide a range of ecological and economic services. Considering the selected studies, it becomes practically impossible to protect mangroves in Brazil.

Firmo *et al*. (2012) (Figure 6) and Schmidt *et al*. (2013) described that apicuns constitute essential habitats for the life cycle of crabs associated with mangroves, such as *Ucides chordatus* (Linnaeus 1763) and *Cardisoma guanhumi* (Latreille 1828), functioning as recruitment areas and as connectivity to higher ground as individuals grow, thus contributing to population maintenance. These resources are socioeconomically and culturally important, since the mangrove crab (*U. cordatus*) and the land crab (*C. guanhumi*) are consumed and traded by artisanal fishermen, sustaining income and livelihoods (Botelho *et al*., 2009; Santos; Ribeiro 2019). The fishermen themselves identified two categories of mangrove zones: "dry" areas, inhabited by land crabs, and "soft" areas, preferred by the mangrove crab. This classification revealed a nuanced territorial perception and an interpretation of the environment based on experience (Firmo *et al.* 2012).

Figure 6

Citation frequency by author in the databases in July and August 2025.



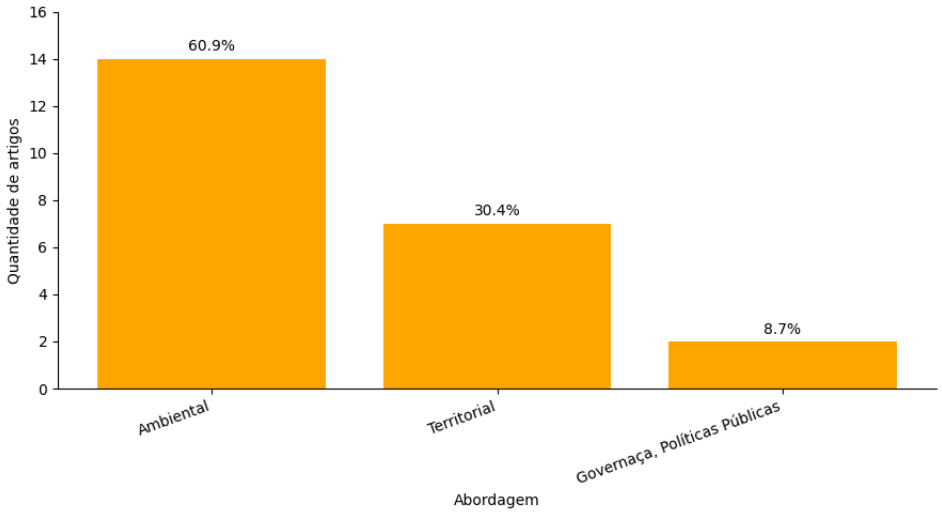
For this reason, several authors emphasize the need for management and protection, both to ensure environmental conservation and to safeguard traditional ways of life (Schmidt *et al*. 2013; Silveira; Buti 2020; Silva-Júnior; Nicácio; Rodrigues 2020). Moreover, environmental management and conservation require the local knowledge of fishing communities. Guaiamum fishermen have suffered impacts on their activities both from the loss of territory to large-scale projects and from fisheries management measures related to guaiamum fishing. Santos and Ribeiro (2019) analyzed the publication of Ordinance No. 445 (Brazil 2014) and its consequences and found that guaiamum fishermen suffered a process of environmental injustice. In the same vein, Silveira and Buti (2020), when analyzing the Guaiamum Recovery Plan, indicated that the plan was a pragmatic response aimed at preventing a fishing ban, yet it neglected fundamental issues such as the loss of the guaiamum's habitat, the apicum.

In general, the studies analyzed adopted environmental, territorial, and governance/public policy approaches. Most studies adopted an environmental approach (60,9%) (Figure 7), indicating that the scientific field is still strongly based on the biophysical and ecological aspects of the salt marsh, with an emphasis on environmental diagnosis and the analysis of natural processes. The territorial approach represented approximately 30,4% (Figure 7) of the research and showed the highest growth rate in the analyzed period. This trend signals an expansion of the scientific perspective beyond environmental factors, including issues related to land use and occupation, socio-spatial

conflicts, and territorial planning. The governance/public policy approach represented 8,7% (Figure 7) of the studies selected in the review, suggesting stagnation in this field and indicating that this dimension has not yet been consolidated in scientific literature.

Figure 7

Frequency of the categories Environmental, Territorial, and Governance/Public Policies in the analyzed articles.



Collectively, these studies indicate that, within governance and public policy, the central issue is the tension between conservation and use, mediated by legislation and policy. In this setting, the apicum emerges as a legally contested area in which the interpretation and application of laws determine not only who is allowed to use it, but also how, and with what limitations. Thus, the meaning of the apicum becomes closely linked to negotiation and power relations.

4 CONCLUSIONS

This review sought to map and characterize the state of knowledge on apicum in scientific literature. Despite the ecological, socioeconomic, and cultural importance of this ecotone, its concept is still imprecise. Regarding mangrove conservation, apicum has always been the component that has received the least attention. This is because conservation marketing often focuses on the exuberance of biodiversity. In addition, this ecotone has become a field of territorial disputes. Artisanal fishermen have lost access to

their territories due to the occupation of apicums and mangroves by large enterprises such as shrimp farms, salt extraction, urban expansion, and the installation of infrastructure in the coastal zone.

In general, the importance of an integrated approach is highlighted, one that considers the apicum not only as part of the mangrove ecosystem, but also as a contested territory where economic interests, conservation objectives, and traditional practices coexist. Although the legislative conflicts observed here are rooted in Brazilian law, their conceptual and management implications extend well beyond national boundaries. The tension between the Brazilian Forest Code's operational subdivision of the ecotone into "apicum" (interstitial water salinity >150‰) and "salgado" (100–150‰), and the scientific literature's treatment of these zones as a single ecotone, illustrates a broader governance challenge recognized globally: the mismatch between legally imposed, threshold-based definitions and the ecological continuum of coastal wetlands. This tension is not unique to Brazil. The Ramsar Convention on Wetlands classifies hypersaline tidal flats under wetland type "Sp" (salt pans) without prescribing salinity thresholds, leaving member states to develop their own regulatory definitions, a gap that has produced analogous conflicts in Australia, Mexico, and West Africa, where economically valuable activities such as aquaculture and salt extraction have historically exploited definitional ambiguities to justify exclusion of these areas from protected status. Furthermore, the emerging role of apicum as reservoirs of "blue carbon" gives the conceptual issue renewed urgency at the international level, because if regulatory frameworks exclude hypersaline plains from protected areas based on salinity thresholds, these systems will also be excluded from national carbon accounting and climate mitigation commitments under the Paris Agreement. The Brazilian case therefore offers an instructive and cautionary example for coastal wetland managers worldwide, demonstrating that conceptual imprecision in national legislation can directly translate into a decrease in ecosystem services, the displacement of traditional communities, and the weakening of global climate commitments.

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Authors' Contribution

All authors contributed equally to the development of this article.

Data availability

All datasets relevant to this study's findings are fully available within the article.

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