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# Strengths and limitations of wetland studies in Panama

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## Main Text

According to the Ramsar Convention, wetlands are inundated areas, whether natural or artificial, permanent, or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters. Wetlands are found everywhere, from the tundra to the tropics [1]. Wetlands provide a wide variety of ecosystem services, such as biodiversity, water supply, water purification, climate and flood regulation, coastal protection, spiritual and cultural inspiration, and tourism. They also play a key role in economic activities related to transportation, food production, water risk management, pollution control, fishing and hunting, recreation, and the provision of ecological infrastructure [2].

Despite having a wide diversity of wetlands, most studies in Panama have focused on mangroves. In the lowlands, freshwater wetlands have been heavily transformed to agriculture or urban developments and the remaining ones are remote or inaccessible, particularly highland wetlands. As a result, most of the analysis presented here relates to mangroves. The study of coral reefs and sea grasses, as wetlands, is not included in this analysis.

Mangroves are primarily found along protected coastlines in the tropics and subtropics, where they serve important socioeconomic and environmental functions. Despite their value, mangroves are threatened by deforestation, land use change, and climate change [3, 4]. Since 1980, mangrove populations have decreased by approximately 20% worldwide due to development and the direct

and indirect impacts of pollution and sediment runoff.

Mangroves located in Panama are equally being impacted. The urban development of Panama City has transformed and polluted hundreds of hectares of mangroves [5, 6]. In the interior of the country, mangroves, and wetlands, in general, continue to be cleared primarily for establishing agricultural activities such as livestock farming, rice and oil palm cultivation, and the construction of tourism and port infrastructure. These transformations not only affect the existence of these valuable ecosystems and the environmental services they provide but also the sustainability of the economic activities that transform them, making them vulnerable, for example, to extreme weather events resulting from climate change.

With the aim of supporting the country in fulfilling the commitments made in its updated Nationally Determined Contribution (NDC1) to the United Nations Framework Convention on Climate Change, a national workshop was held with 20 Panamanian and foreign researchers conducting studies in wetlands throughout the country. A total of 26 research projects were reported, covering 51 sites nationwide, which have produced to date 20 scientific articles published in indexed journals, as well as a variety of other materials including policy briefs, technical reports, videos, and other outreach materials. Most of these investigations are focused on mapping and studying physical-chemical parameters, vegetation types, indicator species, and anthropogenic impacts.



Research projects on mangroves received greater attention and funding in the 1990s, after Panama signed the Ramsar Convention on Wetlands of International Importance. Currently, most research projects are funded by the National Secretariat of Science, Technology, and Innovation (SENACYT), although in recent years, funds have also been received from other organizations such as the Cornell Lab of Ornithology through the Regional Ramsar Center for the Western Hemisphere (CREHO), the Inter-American Development Bank (IDB), and the National Audubon Society. These funds primarily support studies on migratory shorebirds and carbon accumulation estimates.

A pre-workshop online survey showed that there are well-defined geographical areas where these research efforts are concentrated (see map of projects at [https://www.google.com/maps/d/u/0/edit?mid=19xOBSZZPmpDBhKblq2dj0\\_kPYCLy1KA&usp=sharing](https://www.google.com/maps/d/u/0/edit?mid=19xOBSZZPmpDBhKblq2dj0_kPYCLy1KA&usp=sharing)). In the Pacific, studies are focused in the mangroves of Panama Bay, Chame Bay, and Parita Bay, Coiba Island, and the Montijo and Chiriquí Gulfs. Further east, studies have been conducted in the freshwater wetlands of Matusagaratí in Darien. In the Caribbean, there are fewer studies compared to the Pacific, with a focus on San Pond Sack (mainly freshwater) and Isla Colón in the province of Bocas del Toro, Escudo de Veraguas, Damani, and Guariviara in the Ngöbe Buglé Indigenous Territory, and Galeta and Portobelo in Colón. Most of these studies are conducted in legally protected areas, and Ramsar sites. This analysis indicates good geographical coverage but also suggests potential limitations in the depth and duration of these studies.

In fact, some of the identified challenges in the study of wetlands in Panama include difficulties in conducting laboratory analysis in a timely and cost-effective manner, the lack of consolidated methodologies allowing comparisons between sites, and robust monitoring long-term data on meteorological and hydrological variables (over 10 years), especially considering the anthropogenic and climate changes impacting wetlands. Additionally, efforts to incorporate research results positively and effectively in environmental education and policy advocacy are mostly lacking. Finally, there have been few efforts to involve the private sector, communities, and specialists from the social sciences. Most of the studies are very focused on specific groups of animals or plants or on environmental parameters or impacts alone.

To overcome the identified challenges, it is proposed to create research groups that foster communication and information exchange among researchers working in the same geographical area. It is also suggested to promote cooperation with researchers from other countries in the region to increase scale, share resources such as laboratories and methodological experiences, and enhance the search for more significant and long-term funding as well as to integrate emerging technologies such as big data and artificial intelligence (AI).

Some of the research priorities identified in the short and medium term include monitoring changes in physical, chemical, and biological variables resulting from phenomena such as “El Niño” and climate change in general and strengthening national capacities for studying hydrodynamics in wetlands as changes in water characteristics and flows have a significant impact on the

survival of these ecosystems. Also, continuing the study of carbon stored in wetlands, as well as their storage capacity, while also improving our understanding of greenhouse gas fluxes and how these processes are affected by changes in land use. Additionally, there is a need to evaluate the content and impact of pesticides, microplastics, and heavy metals, which can affect not only wetlands but human health as well. Finally, there is need to foster more transdisciplinary research to obtain more a comprehensive picture of the functioning, use, and conservation status of these ecosystems and to propose sustainable and inclusive alternatives. In terms of geographical coverage, it would be beneficial to promote the inclusion or extension of the current research to other areas such as the Guna Yala Indigenous Territory and Donoso in the Caribbean, and the Pearl Islands Archipelago and the San Miguel Gulf in the Pacific. More emphasis should be given to other types of wetlands including freshwater and mountain wetlands. Expanding studies to these areas would contribute to a more comprehensive understanding of wetland ecosystems and their dynamics in diverse geographical contexts.

To further promote the integration and scaling of individual studies, it is essential to create mechanisms that facilitate the exchange of information and experiences, as well as the creation of wetland databases so that information is accessible to all stakeholders. Additionally, it is crucial to establish connections between research findings and the formulation of public policies, involving authorities at the district, provincial, and national levels. It is also key to engage the private sector to understand their information needs and work together to obtain the required resources. Finally, it is essential to study the relationship between local communities and productive activities with wetlands to develop alliances that promote socially and economically viable alternatives for the conservation and sustainable use of these ecosystems.

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