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Opinion

Transboundary Transitional Waters: Concept, Methods, Issues

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Abstract: This opinion paper highlights the concept of transboundary transitional waters (TTW)—A socio-ecosystem category at the interface of freshwater and marine environments that straddle international borders. The central message of the paper is that while the European Union's Water Framework Directive (WFD) has advanced the recognition and protection of transitional waters, it is insufficient to capture the socio-ecological and political complexities of TTW, especially in regions where countries outside the EU are involved. The sustainable governance of TTW requires recognition of their unique ecological, socio-economic, cultural, and geopolitical dimensions. The paper delivers three main insights. First, it introduces the Emerald Economy as a new concept that integrates Blue and Green Economy principles, establishing an ecosystem-based, transboundary framework to address the ecological, economic, and governance challenges of TTW. Second, the study highlights the methodological principles of combining remote sensing, geostatistical analysis, and spatiotemporal modelling to overcome data fragmentation, identify development patterns, vulnerabilities, and risks in 123 TTW worldwide and reinforce their transboundary monitoring and decision-making. Third, the paper also highlights the critical transboundary governance barriers of political tensions, illicit cross-border activities, and uneven data quality as pivotal yet often overlooked factors that obscure the real picture of cross-border connections, thereby distorting management outcomes. The paper's concluding statement is that TTW are not only vital ecological corridors but also contested geopolitical spaces, and that their sustainability and resilience, reducing the risks of ecological degradation and geopolitical confrontation, depend on harmonized environmental policies, coordinated mosaic governance, shared scientific research and monitoring platforms, and management strategies that transcend political boundaries.

Keywords: emerald economy; geostatistics; mosaic governance; water framework directive

1. Introduction

The European Union (EU) introduced the term 'transitional waters' (TW) in 2000 through the Water Framework Directive (WFD) of the European Communities (WFD, 2000/60/EC) to define areas that exist between freshwater, coastal, and marine environments. The WFD describes TW in the Official Journal of the European Communities [1] as "*bodies of surface water near river mouths that have a partially saline nature due to their closeness to coastal waters but are significantly impacted by freshwater influx*". The human impact on TW has significant ramifications for coastal communities' wellbeing, as the goods and services that TW and their ecosystems provide are often compromised.

Consequently, there is an increasing legislative emphasis on TW within the EU. The WFD requires that EU Member States create and regularly (every six years) update river basin management plans, which include coastal and TW areas extending up to 1 nautical mile (NM). The EU Member States mainly designate river estuaries and coastal lagoons as TW. However, the classification also encompasses various coastal aquatic habitats with differing physical and ecological characteristics, such as river deltas, brackish wetlands, hypersaline ecosystems, fjords, and nearshore areas of freshwater discharge plumes [2].

TW act as a bridge between freshwater basins and the open sea, creating gradients supporting ecosystems which are very productive [3]. Although they are relatively small, their unique locations and the stressors they face allow TW to host diverse ecological communities with complex self-regulatory mechanisms. Unfortunately, these areas often exist near urban centers and ports, where activities like shipping, fishing, dredging, pollution from urban, agricultural, and industrial activities, as well as aquaculture, have caused considerable environmental harm. The regions of Europe that experience the most severe ecological pressures on transitional and coastal waters are primarily found along the North Sea and Baltic Sea coastlines [4].

Many transitional waters consist of estuaries formed by major rivers or straits that conveniently mark international borders. Our research identifies 123 transboundary transitional waters (TTW) worldwide. We define TTW as scenarios where two or more nations share an estuary, delta, lagoon, strait, etc., with a contiguous border in the adjoining territorial waters [5]. The terms "transboundary" and "transitional" can be misleading, particularly due to the focus on managing transboundary river basins and the conflicts that can arise over the sharing of water resources.

However, the coastal nature of TTW presents unique management challenges and issues that differ significantly from those encountered in managing inland river basins. Unlike transboundary rivers flowing across borders, or coastal waters extending across national maritime boundaries, the dual character of TTW—partly fluvial and partly marine—creates a set of ecological, legal, and socio-political challenges that elude the legal frameworks governing either rivers or coastal seas. Ecologically, TTW function as dynamic ecotones, hubs of nutrient cycling, transboundary nurseries and migratory corridors for marine fish, and stopover sites for migratory waders, shaped by both riverine and marine drivers.

Considering the legal and socio-political aspects, international water law covers two distinctive domains: the 1997 UN Watercourses Convention governs transboundary rivers and aquifers, whereas the 1982 United Nations Convention on the Law of the Sea governs coastal waters defining states' responsibilities and rights in territorial seas and exclusive economic zones. TTW, however, hardly fit within these regulations. Legal disputes between countries sharing TTW may arise over territorial delimitations, fisheries, or offshore resources not adequately regulated by river-basin treaties or marine conventions. They may arise even between friendly neighboring countries, e.g., between the Netherlands and Germany over Dollard Bay [6].

Despite the importance of the technical definition outlined in the WFD for establishing environmental standards and promoting the protection of TW, the complexity of regulations pertinent to TTW is exacerbated by the TTW shared between the EU Member States and the Russian Federation in the Baltic Sea (Curonian Lagoon, Vistula Lagoon, Narva River Estuary, and Virolahti Bight), along with one shared with Norway (Idde Fjord and Svinesund). Since neither Russia nor Norway are EU member states, the TW concept holds no regulatory significance within these countries' respective TTW areas. A similar situation recently emerged in Ireland after Brexit, where the Republic of Ireland and the United Kingdom share two TTW (Carlingford and Foyle loughs).

According to the WFD, when a river basin (including TW) extends beyond EU borders, member states are required to pursue appropriate coordination with the relevant non-member states. The achievement of Good Environmental Status (GES) in TTW, as mandated by the WFD, becomes complex when these socio-ecosystems are shared between EU member states and neighboring non-EU countries, compounded by jurisdictional asymmetries between them and stressing the urgency of an integrative management framework. Another main challenge for collaboration in TTW between EU member states and their non-EU counterparts, within the WFD context, lies in the establishment of complementary monitoring systems.

There are also challenges in applying the EU Bird and Habitat Directives, particularly regarding the establishment of NATURA 2000 sites in TTW and their adjacent areas that span EU and non-EU territories, such as the Vistula and Curonian lagoons, the Vistula and Curonian spits, and the Nemunas River delta shared by Lithuania, Poland, and the Russian Federation. Establishing a jointly designated transboundary Ramsar site on both sides of the border could be advantageous, given that numerous non-EU nations have endorsed and ratified the Ramsar Convention, a legally binding agreement aimed at protecting wetlands [7].

In 2020, Tagliapietra et al. suggested the Emerald Growth concept [8] to manage TW effectively. This concept blends the pertinent principles of Blue and Green Growth to designate more aptly the administration of ecosystem goods and services in the space between land and sea. The Emerald Growth, or rather Emerald Economy concept, adapts primarily Blue Growth principles tailored to TW's unique ecological and physical characteristics [9]. It is a framework concept built on aquatic ecosystem-based management and connectivity tenets (Table 1).

Table 1. Drivers, indicators and planning approaches relevant in the spatial planning contexts (a revised version adapted from [8,10]).

Notions	Green Economy	Emerald Economy	Blue Economy
Key drivers	(1) Economic diversification and competitiveness; (2) Energy security and resource efficiency; (3) Green job creation and employment; (4) Inclusive growth; (5) Technological innovation and green investment; (6) Climate change and extreme weather; (7) Biodiversity loss and ecosystem degradation; (8) Environmental pollution; (9) Resource scarcity; (10) Urbanization and land use change; (11) Global environmental governance.	(1) Economic diversification; (2) Emerald investment; (3) Emerald jobs and employment; (4) Ecosystem degradation; (5) Sea level rise and flood risk; (6) Depletion of living resources; (7) Eutrophication; (8) Water and sediment pollution; (9) Land reclamation; (10) Increased recreational use.	(1) Coastal economic diversification; (2) Trade, transport, and global connectivity; (3) Blue jobs and employment; (4) Energy security and blue renewable energy; (5) Climate change and ocean impacts; (6) Overfishing and illegal fishing; (7) Marine pollution; (8) Biodiversity loss and habitat degradation; (9) Resource scarcity and demand growth; (10) Urban sprawl; (11) Global ocean governance.
Main indicator groups	(1) Economic growth, productivity and competitiveness; (2) Labor markets, education and income; (3) Carbon and energy productivity; (4) Resource productivity; (5) Multi-factor productivity; (6) Natural asset base; (7) Renewable stocks; (8) Non-renewable stocks		
Central planning approaches	(1) Hierarchy (2) Master-planning (3) Sectorial planning (4) Functional zoning (5) Special planning	(1) Hierarchy (2) Sectorial planning (3) Functional zoning (4) Balancing trade-offs (5) Ecosystem approach (6) Transboundary	(1) Master-planning (2) Sectorial planning (3) Functional zoning (4) Balancing trade-offs (5) Ecosystem approach (6) Transboundary

The Emerald Economy framework offers an original perspective on studying and comprehending the sustainability of these vulnerable ecosystems since it tackles ecosystem-based management and sustainable development issues within a broader framework of river basins, TTW, and marine ecosystems [11]. European countries share 35 of the world's 123 TTW. Therefore, due to its maritime geography, the transboundary approach to the Emerald Economy is essential for Europe. However, the goods and services that form the basis of the Emerald Economy in the transboundary context need a better definition [12].

The transboundary Emerald Economy concept relies on connecting Blue and Green Economy concepts in TW shared by several countries, implying that the TW continuum integrates socio-ecological systems [13], particularly in water management policies, to avoid cross-border upstream and downstream conflicts. TTW are connected and interrelated with their drainage areas and adjacent offshore marine areas. Therefore, any disparities or bottlenecks across the border in implementing Emerald Economy principles can adversely affect TTW ecosystems and human communities relying on them on both sides of the border [14].

To address these and other challenges, the transboundary Emerald Economy concept incorporates the cross-border connectivity and ecosystem-based management tenets for that continuum, including physical and chemical interactions and their gradients, connectivity of biological populations and ecological communities, interconnected ecosystem goods and services, a cross-border environmental policy coherence, economic integration, consistent legislative framework, societal connections, cross-border ecological and management integrity of adjacent protected areas as stepping stones and migration corridors, coordinated monitoring and assessment, and other TTW management issues essential for their sustainability, integrity, and resilience.

As mentioned earlier, achieving GES in TTW becomes a 'moving target', particularly when various drivers and pressures originate on one side of the border but deteriorate ecological conditions across the entire TTW, undermining the ecosystem services upon which both societies and economies rely. By blending the Blue Economy's focus on aquatic ecosystems and the Green Economy's focus on riparian ecosystems, the Emerald Economy integrates the sustainability criteria of the TW ecosystem services in all countries sharing the TTW (Figure 1). Thus, when applied to TTW, the framework can create a common platform for dialogue and cooperation, even in situations where regulatory asymmetry exists.

Unlike the WFD, which is binding only within the EU, the Emerald Economy can be anchored in international conventions and cooperative mechanisms already ratified by many non-EU countries, such as the Ramsar Convention, the Convention on Biological Diversity, or action plans adopted within the frameworks of regional seas conventions (e.g., Helsinki, Oslo-Paris, or Barcelona conventions). For example, while non-EU states may not be obliged to adopt WFD prescriptions, they may still participate in Emerald Economy initiatives focused on activities that generate both socio-economic benefits and ecological co-benefits. In this way, the Emerald Economy concept enables WFD GES targets to be a kind of "soft law" that complements the obligations of the WFD, which are politically and economically relevant to both EU and non-EU countries.

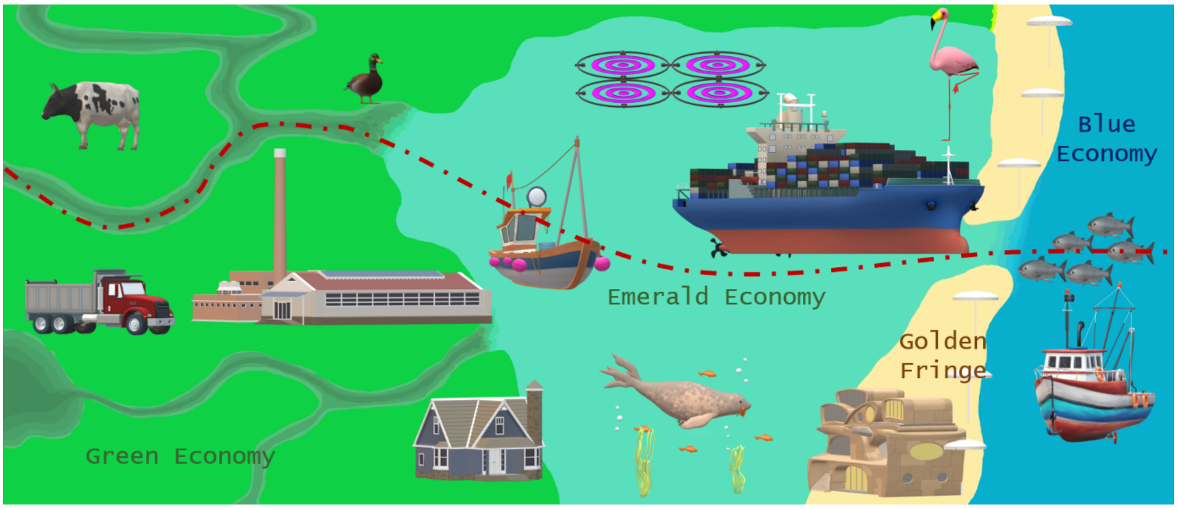

Figure 1. A conceptual diagram that situates TTW within the wider landscape of water governance.

2. Research Methodology

A wide array of quantitative and qualitative investigation methods and data sources can be applied to investigate TTW, their cross-border integrity and the robustness of the Emerald Economy, socio-economic and environmental policies and factors that facilitate or hinder cross-border cooperation in TTW areas, and confrontation risks between the countries sharing the areas. In our investigations of TTW and efforts to compile the global database of the TTW, we primarily relied on large-scale charts and maps from Google Earth™, which is a Graphic Satellite Interface for the inventory and semi-instrumental spatial study of land and coastal features [15].

Google Earth™ allows for pinpointing and zooming in on interesting spatial issues of transboundary relationships and gaps. However, like with any other scrutiny of ecologically sensitive issues, the picture's validity depends on the researcher's alertness [16]. Our particular focus was on open-source GIS-based data sets such as EU Digital Observatory of Protected Areas Explorer, HELCOM, Marine Regions, Global Forest Watch, Open Infra Map, Ramsar Sites Information Service, Google Night Lights, IUU Fishing Risk Index and many more sources) to available topographical maps and nautical charts by digitizing them. Then, we applied the ArcGIS-based calculations and created and overlayed additional ArcGIS layers [17].

To be selected for the quantitative comparative TTW analysis, the data sources must meet the following criteria [5]:

- Regional or national coverage: Appropriate data must be available for all TTW covered by the investigation, ideally, all 123 TTW around the globe;
- Relevance: The data must represent a suitable metric for the addressed aspect;
- Comparability: The data must be comparable between similar-level administrative units and throughout the time series;
- Update regularity: The data is regularly updated;
- Source objectivity: The data is taken from a single objective source, first reputable international bodies like the UN or the World Bank.

With the increasing development of remote sensing and GIS tools, and the evolution of sampling facilities, geospatial-temporal datasets are becoming increasingly large, informing a growing number of variables, and covering ever larger areas, including the TTW [18]. Matheron [19] coined the term *regionalized variable*, which is essential for the geostatistical interpretation of a wide array of spatiotemporal data. It emphasizes two apparently contradictory aspects of these types of variables: a random aspect, which accounts for local irregularities, and a structured aspect, which reflects large scale spatiotemporal development tendencies and patterns.

We propose four stages of the geostatistical analysis of the regionalized variables describing the socio-economic and ecological conditions and development tendencies and patterns of TTW:

(a) Properly designed quarrying of spatial data;
(b) Exploratory data analysis;
(c) Variographic analysis (computing the covariance, variograms, and developing models);
(d) Linear prediction (Kriging), clusterization and classification.

Geostatistical data interpretation for the comprehensive analysis of the large-scale spatiotemporal development tendencies and patterns of TTW refers to the application of geostatistical methods to analyze and model the spatial and temporal variability of ecosystem-related data across international borders. This approach helps in understanding the distribution and harvesting of aquatic and riparian ecosystem goods and services shared by several countries, facilitating informed cross-border management and cooperation. The analysis of geostatistical spatiotemporal data requires that both temporal correlations and spatial correlations be considered. Usually, that data comprises physical, chemical, biological, and ecological characteristics of TTW focusing on quantitative features (variables) as data, which is recurrently updated.

Particularly the multivariate spatial time series or dynamical spatiotemporal models with quantitative (discrete and continuous) and qualitative variables are appropriate for the analysis of this type of data. However, assessing both the temporal and spatial dimensions of data adds significant complexity to the data analysis process for two major reasons:

(1) Continuous and discrete changes of spatial and non-spatial properties of spatiotemporal objects, i.e., geographical entities such as linear and areal littoral habitats on both sides of the border dividing the TTW [20];
(2) The influence of collocated neighboring spatiotemporal objects on one another.

In that case, the above complexities can be resolved by the following geostatistical methods:

(a) Spatial and spatiotemporal linear prediction (Kriging) (Reason 1);
(b) Clusterization in spatial framework based on suitable distance metric (Manhattan, Euclide) and neighborhood systems (Nearest neighbor, Delauny graph etc.) (Reason 2);
(c) Decoding by spatial Hidden Markov models (Reasons 1 and 2);
(d) Classification by Bayesian rules and artificial neural networks (Reasons 1 and 2).

3. Case Study: Curonian Lagoon (Lithuania/Russian Federation)

The Curonian Lagoon is Europe's largest non-tidal coastal lagoon (total area 1586 km^2) located on the Baltic Sea's southeast rim. Politically, the southern part of the Curonian Lagoon and the adjacent area belong to the Russian Federation within its Kaliningrad Oblast exclave. The northern part of the Curonian Lagoon, including the Klaipeda Strait and the Baltic Sea nearshore, belongs to the Republic of Lithuania. The Curonian Lagoon was part of Prussia and, later, Germany for five hundred years. After World War II, it was part of the USSR until 1991.

The Curonian Lagoon is a shallow, semi-enclosed, and nearly freshwater TTW due to the annual discharge from the Nemunas River, which brings approximately 21 km^3 of inflow compared to about 6 km^3 of the Curonian Lagoon water volume. The average depth of the Curonian Lagoon is 3.6 m, and the maximum depth is 5.6 m. Its water salinity ranges from 8‰ in the northern part (the Klaipeda Strait) to 0‰ in the southern part (the Gilija River mouth). The Curonian Lagoon is a eutrophic lagoon characterised by a surplus of nutrients and extensive areas of emergent vegetation.

Cross-border cooperation in the Curonian Lagoon has strong historical roots. A single, effective transboundary management plan covering the entire lagoon, based on the Emerald Economy principles, as well as a unified management plan for the Curonian Spit World Heritage property, were under preparation in the 2010s. Until 2022, when Russia invaded Ukraine, which broke any transboundary cooperation between Lithuania and Russia, the Curonian Lagoon was an exemplary case study to demonstrate the advantages of the Emerald Economy framework for managing TTW, which emphasises ecosystem-centric planning, mosaic governance, and cross-border benefit-sharing compared with conventional sectoral or single-country approaches.

It gradually led to improved alignment of ecosystem services and local livelihoods, stronger resilience to pollution and climate change, more efficient resource use, and closer cooperation. For instance, transboundary fishing quotas and fish stock management agreements integrated habitat protection, spawning area restoration, and diversified livelihood programs (sustainable recreational fishing and rural tourism development) [21]. Scholars from Lithuania and Russia participated in joint place-branding efforts around high-value cultural and natural experiences (e.g., coordinated visitor management across the Curonian Spit and lagoon-side attractions) [22], advising on investments to extend the seasons (e.g., lagoon beaches and marinas), and revenue-sharing models to fund conservation [7].

Russia and Lithuania share the catchment of the Nemunas River, the largest tributary of the Curonian Lagoon. Following the political orientation of the Russian Federation's government to integrate with Europe in the early 2000s, both the Lithuanian and Russian parts of the Nemunas River catchment became compatible with the EU WFD GES terms and regulations [5]. The process was gradually leading to an overarching, transboundary Emerald Economy framework that underpinned ecological connectivity (river-lagoon-sea), ecosystem-based management, multisector integration, stakeholder participation, coherent environmental monitoring, and social and economic dimensions as drivers of the ecosystem-based management [23].

The joint and interdisciplinary Lithuanian-Russian team designed and implemented pilot Emerald Economy measures across the river–lagoon–sea continuum, taking dedicated efforts to prevent mismatches where upstream nutrient reductions in one country were undone by downstream loads or lack of coordination in the other. It evaluated conservation and human use together (including fisheries, rural tourism, port development, wastewater, and agriculture), enabling trade-off analysis and joint value creation. It made cooperation explicit and measurable, and was therefore better at building institutional resilience [16,24]. However, the fruitful transboundary cooperation based on the Emerald Economy principles has suffered complete deterioration in recent years [5].

To explore the potential of geostatistical analysis in describing the socio-economic and ecological conditions, as well as the development trends and patterns of TTW within the Emerald Economy framework, we applied a geostatistical analysis algorithm to the transboundary case study of the Curonian Lagoon. We used three datasets to determine the forest cover dynamics within the boundaries of the Curonian Lagoon region: 1. Spatial database of river basins and drainage basins (https://databasin.org (accessed on 18 July 2021)); 2. The Global Elevation Raster Database (https://databasin.org (accessed on 18 July 2021)); 3. Global Forest Watch spatiotemporal dataset on forest cover dynamics (https://www.globalforestwatch.org/ (accessed on 18 July 2021)).

As described in the methodology, we created and overlaid ArcGIS layers from these three spatial databases and applied ArcGIS-based geostatistical calculations to estimate the change in forest acreage between 2000 and 2019 within the defined boundaries of the Curonian Lagoon region. The results of our calculations are provided in Figure 2 and Table 2. They demonstrate that, before severing any cross-border collaboration in 2022, the Lithuanian and Russian parts of the Curonian Lagoon region had enjoyed a coherent, equitable, and sustainable forest management pattern based on the Emerald Economy principles. It remains to be seen whether this trend will continue in the current geopolitical confrontation between NATO and the Russian Federation.

Table 2. Estimated change in forest acreage between 2000 and 2019 within the defined boundaries of the Curonian Lagoon region.

Indicators	Lithuanian Part	Russian Part	Average in the Region
Forest cover in 2000 (%)	28.02	26.68	27.06
Forest loss (%)	3.13	0.93	1.54
Forest gain (%)	0.46	0.16	0.24
Net change	−2.67	−0.77	−1.30
Forest cover in 2019 (%)	25.35	25.91	25.75

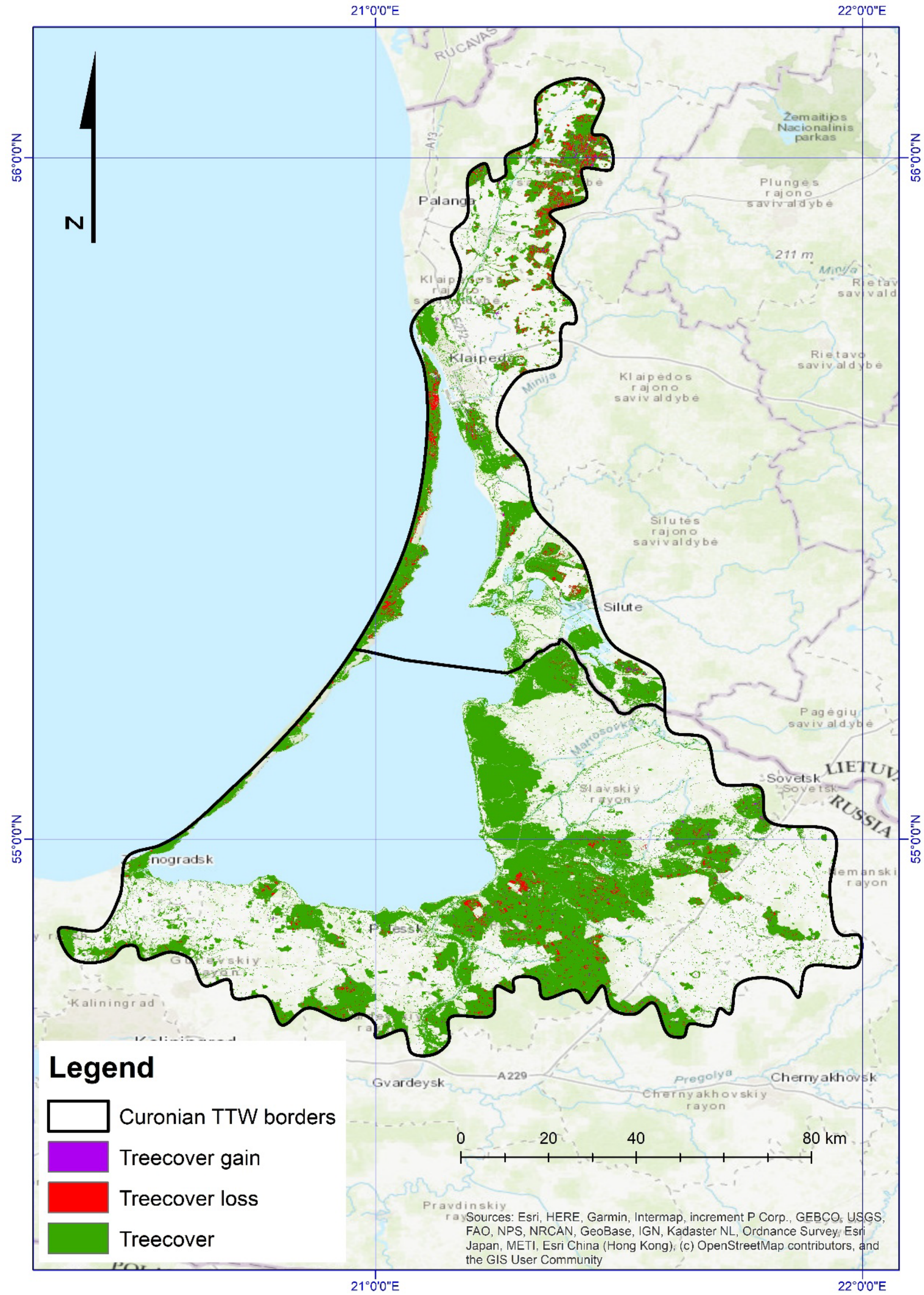

Figure 2. Estimated change in forest acreage between 2000 and 2019 within the defined boundaries of the Curonian Lagoon region.

4. Discussion

The collection of information in TTW regions is difficult due to the unique circumstances that these areas, which typically comprise the maze of water bodies, wetlands, reedbeds, river branches and oxbow lakes, form porous borders and are ideal places for fish poaching and other illegal resource harvesting on both sides of the TTW. This shadow economy may distort the picture of cross-border contacts and collaboration between countries sharing the TTW, as presented in the official statistical sources of the countries and riparian regions [5]. Smuggling networks and traffickers in the TTW regions pose significant governance challenges, including corruption and diverted resources, which erode institutional capacity and legitimacy [21].

For instance, the informal markets, smuggling of goods (fayuca), and migrant trafficking exploit the permeable Río Hondo estuary and the Chetumal Lagoon (Figure 3). It implicates socio-economic statistics, local governance, and cross-border cooperation between Belize and Mexico. The prevalence of informal economic activity, which accounts for approximately 40% of Belize's GDP [25], skews official statistics by underreporting activities tied to the shadow economy. This distortion complicates policy decisions, as the economic contributions of these informal exchanges remain obscure. With limited resources, local authorities are stretched thin.

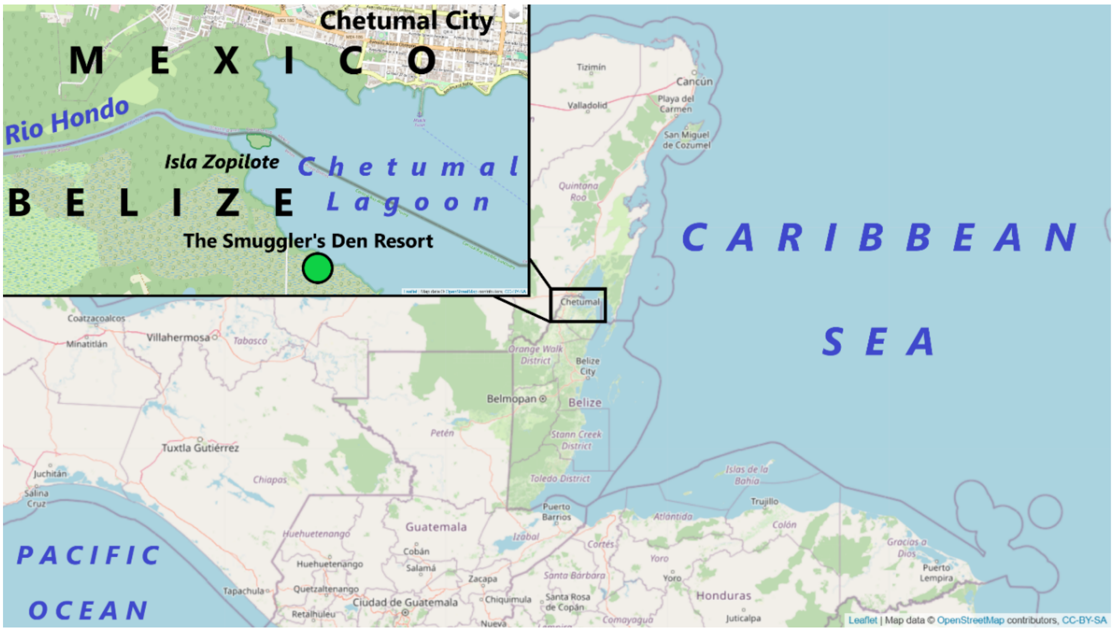

Figure 3. Bifurcation of the Hondo River estuary at the Chetumal Lagoon shared by Mexico and Belize causes border demarcation issues and a porous border (Source: FreeCountryMaps.com).

Formal cross-border cooperation in TTW regions is hindered by evidence gaps, jurisdictional issues, and limited capacity, which are exacerbated by the porous geography [22]. Policymakers often overlook irregular migrants, leading to inaccuracies in public-service planning and undermining social policy targeting. Frequent ad-hoc security responses divert resources from sustainable development, creating local dependence on illicit incomes that complicate compliance and reform. Migrant trafficking leads to human rights abuses, straining local institutions. Short-term security measures fail to address the underlying incentives of corruption and lack of legal livelihoods [26].

To reinforce socio-economic data collection and harmonisation in politically fragmented TTW areas, scholars and practitioners apply a combination of mixed, qualitative, and quantitative methods, such as household surveys combined with targeted sampling and hotspot mapping, beneficial for estimating informal trade and migration flows [25]. Trade mirror analysis can be used by comparing customs records between countries to identify discrepancies and enhance data accuracy. Capacity building should lead to the harmonisation of mutual legal assistance protocols to streamline evidence sharing in trafficking cases, and the establishment of joint task forces for data sharing.

The Emerald Economy framework is well-suited for addressing the socio-economic and environmental challenges of TTW due to its emphasis on regeneration, equity, and cooperative governance [8]. It recognizes non-market benefits of cross-border sustainability such as cherishing unique cultural identity and traditional knowledge transgressing boundaries despite political hurdles [21]. With its polycentric focus, the Emerald Economy reframes TTW as shared ecological commons, encouraging cooperative management rather than competition for resources. Its principles of resilience-building may prepare TTW systems for climate shocks and socio-economic disruptions by emphasizing nature-based solutions and adaptive infrastructure.

Unlike traditional management approaches that focus on economic growth and sectoral priorities, the Emerald Economy combines systems thinking and mosaic, multi-level governance, fostering collaborative institutions that embrace ecological, cultural, and economic interdependencies. Key differences include an integrated management model that promotes cooperative, commons-based solutions over zero-sum approaches, and a long-term focus on resilience compared to the short-term cycles of growth. By embedding ecological integrity within economic strategies, the Emerald Economy aims to balance ecological health with social and intergenerational equity, ultimately fostering sustainable development in a collaborative manner across the borders.

5. Conclusion and Prospective

Our key concluding statement is that TTW are not only vital ecological corridors but also contested geopolitical spaces, and that their sustainability and resilience, reducing the risks of ecological degradation and geopolitical confrontation, depend on harmonized environmental policies, coordinated mosaic governance, shared scientific research and monitoring platforms, and management strategies that transcend political boundaries within the Emerald Economy framework. It is especially true for the TTW, where countries outside the EU are involved in managing their parts of the TTW, largely ignoring the EU WFD GES status prescriptions and mandatory regulations.

Hence, when establishing a cross-border research, monitoring, and management framework for a TTW, an interdisciplinary approach is necessary, taking a comprehensive transboundary stance. By examining both natural processes and the effects of human activity, an understanding of TTW can be achieved, facilitating a more effective cross-border management. It is essential to highlight the importance of mutually beneficial outcomes for all stakeholders involved, along with benefits from various types of ecosystem goods and services (environmental, social, and economic). It will increase the likelihood of 'win-win' transboundary cooperation and the adoption of management plans for TTW where stakeholders from all involved countries and levels are represented [27].
Several research directions stem from the highlighted insights:

(i) Developing and applying predictive GIS-based models to assess future scenarios for TTW under climate change in various climate zones of the globe;
(ii) Enhancing GIS interpretation to analyze the essential differences in long-term changes pertinent to the TTW coastlines and waterfronts (linear littoral habitats) and their hinterlands (areal littoral habitats) [20];
(iii) Analyzing spatial vulnerability recognition and distribution patterns using GIS and AI algorithms to take timely transboundary mitigation efforts;
(iv) investigating the resilience of TTW to adverse impacts of climate change, especially regarding the sustainability of tourism and fisheries in the TTW regions [21];
(v) Shifting the methodology from using the privately owned data sources like Google Earth Pro, as well as predictive GIS-based models and GIS interpretation from private platforms like ArcGIS, to open data sources and open-source software.

Author Contributions

All authors contributed equally. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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