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BioTIME: A database of biodiversity time series for the Anthropocene

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water

MDPI

Article

Priorities and Interactions of Sustainable Development Goals (SDGs) with Focus on Wetlands

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Abstract: Wetlands are often vital physical and social components of a country's natural capital, as well as providers of ecosystem services to local and national communities. We performed a network analysis to prioritize Sustainable Development Goal (SDG) targets for sustainable development in iconic wetlands and wetlandscapes around the world. The analysis was based on the information and perceptions on 45 wetlandscapes worldwide by 49 wetland researchers of the Global Wetland Ecohydrological Network (GWEN). We identified three 2030 Agenda targets of high priority across the wetlandscapes needed to achieve sustainable development: Target 6.3—"Improve water quality"; 2.4—"Sustainable food production"; and 12.2—"Sustainable management of resources". Moreover, we found specific feedback mechanisms and synergies between SDG targets in the context of wetlands. The most consistent reinforcing interactions were the influence of Target 12.2 on 8.4—"Efficient resource consumption"; and that of Target 6.3 on 12.2. The wetlandscapes could be differentiated in four bundles of distinctive priority SDG-targets: "Basic human needs", "Sustainable tourism", "Environmental impact in urban wetlands", and "Improving and conserving environment". In general, we find that the SDG groups, targets, and interactions stress that maintaining good water quality and a "wise use" of wetlandscapes are vital to attaining sustainable development within these sensitive ecosystems.

Keywords: wetlands; wetlandscapes; SDGs; network analysis; sustainable development goals; priorities; interactions

1. Introduction

The 2030 Agenda for Sustainable Development of the United Nations is a 15-year global framework centered on 17 Sustainable Development Goals (SDGs), 169 targets, and 232 indicators, designed to secure a world free of poverty and hunger, with full and productive employment, access to high quality education and health coverage, gender equality, empowerment of all women and girls, and an end to environmental degradation [1]. The SDGs have been designed to provide guidelines for individual countries to develop and implement holistic policies that foster development while minimizing detrimental environmental impacts [2]. Ideally, this process incorporates the knowledge and needs of all relevant sectors and actors. The implementation of the SDGs is to be done at the national level, allowing every nation to set specific targets based on priorities regarding economic, social, and environmental dimensions that may be unique to the country. Within this framework, SDGs are relevant for the sustainable use of wetlands or "wetlandscapes" (a network of hydrologically connected wetlands; [3]), which are often vital physical and social components of a country's natural capital, as well as providers of ecosystem services to local and national communities [4–7].

Worldwide, wetlandscapes contribute in diverse ways to the livelihoods of many communities [4]. For example, wetlands provide habitat, food, and refuge for aquatic and terrestrial fauna and flora [8]. They act as natural hydrologic buffers to natural hazards such as floods and droughts [9–12]. They may also reduce and/or delay storm runoff peaks, increase base flows [13], and regulate water, sediment quality [14–16], pollutants and nutrients [17]. Wetlands are sources of freshwater for domestic and agricultural use and are important for the livelihoods and food security of many local communities [4,18,19]. Besides, they are suspected to contribute to global long-term carbon sequestration [20,21].

The interactions between the economic, social, and environmental dimensions of wetlandscapes and those of other systems are inherently linked with the need for sustainable development, defined as the development that meets the needs of the present without compromising the ability of future generations to meet their own needs [22]. Reference [4] warns that if wetlandscapes are not used sustainably, the functions that support agriculture, as well as other food security and ecosystem services, become undermined. Furthermore, cases abound where wetland unsustainable use and development have already resulted in permanent damage to their socioecological systems and impairment of wetland functions (e.g., References [23,24]). However, the basis for making sound decisions on the manner and extent to which wetlands can be sustainably used is weak [4]. Since the Ramsar Convention on wetlands (Ramsar, Iran, 1971) to encourage "the wise use of wetlands" [25,26], there has been much research on wetland ecosystem services and the negative impacts of human activities, but only recently have guidelines started to emerge.

For instance, the Ramsar Convention's Fourth Strategic Plan for the period 2016 to 2024 [7] identifies four overarching goals, with 19 targets, relevant to wetlands: (1) Addressing the drivers of wetland loss and degradation; (2) Effectively conserving and managing the Ramsar site network; (3) Wisely using all wetlands; and (4) Enhancing implementation. It also mentions 10 SDGs that are associated with wetlands and 19 corresponding Aichi targets set by the Convention on Biological Diversity (GBO-4, 2014): End poverty (SDG 1); Zero hunger (SDG 2); Gender equality (SDG 5); Clean water and sanitation (SDG 6); Decent work and economic growth (SDG 8); Industry, Innovation and infrastructure (SDG 9); Sustainable cities and communities (SDG 11); Climate action (SDG 13); Life below water (SDG 14); and Life on land (SDG 15). Further, Wetlands International [27] includes an additional goal: Responsible consumption and production (SDG 12).

These top-down SDGs prioritizations may be too general for application to specific wetlands without particular considerations on the interactions, synergies, and trade-offs among targets. Bottom-up approaches starting at the wetland scale, which combine as networks at larger scales, could be useful for prioritizing SDGs. Reference [28] proposes to simultaneously examine interactions among multiple sectors—a so-called nexus approach—to progress toward meeting the SDGs. The analysis in Reference [2] treated the SDGs as a network, i.e., considering relationships, synergies, and trade-offs between SDG goals and targets. Such an approach has been applied for specific contexts such as the water–food–energy nexus in Sweden [29], support for nation-based decision-making in the Arab Region [1], and the design of sustainable cities [30]. In the context of wetlands, however, an SDG-network approach has not yet been considered directly.

The main objectives of this research are threefold: (1) to determine the SDGs and corresponding targets that should be prioritized in wetlandscapes to help achieve sustainable development; (2) identify potential feedbacks and synergies across these targets with focus on wetlands; and (3) group wetlandscapes in bundles of SDG targets that facilitate decision making, since meeting prioritized SDG targets for wetlandscapes should promote sustainable development at national and regional scales. Through a bottom-up approach starting at the wetlandscape scale, we would like to determine if the identified priority SDG targets across wetlandscapes converge into key groups, and if this groups agree with those targets and goals broadly set by the Secretariat of the Convention on Biodiversity (CBD) [31], Wetlands International [27], and the Ramsar Convention [7]. In general, we aim to define the relationships, synergies, and trade-offs between SDG targets with focus on wetlands to ease the task of stakeholders and policy makers to adequately and efficiently implement them in their respective wetlands.

2. Materials and Methods

2.1. Selection of the SDG Targets Used in the Survey

A group of six core investigators meeting in the Global Wetland Ecohydrology Network (GWEN; http://www.gwennetwork.se/) General Meeting in Santa Marta, Colombia in April, 2018 designed a questionnaire to be surveyed by the researchers attending the meeting and their extended research networks. In total, 49 researchers, including the six core investigators, answered the survey in relation to 45 wetlandscapes which they were familiar with or had or were conducting research on (Table 1 and Table S1 in Supplementary Information for details on each wetlandscape). The wetlandscapes included in the survey cover five continents over 21 countries, and vary in size from small local wetlands to large wetlandscapes such as river deltas or lake systems (Figure 1a). Following previous conceptualization of social networks [32,33], we performed a network analysis on the data and perceptions obtained from the survey by creating four bidirectional unimodal networks of SDG targets related to the type of the interactions among targets. A bidirectional unimodal network has only one type of node with two different interactions among pairs of nodes. To classify the interactions, we used an interaction scoring conceptualization that not only aims to find synergies and trade-offs among SDGs, but also weighs their strength [34,35]. We adapted the interaction typology of Reference [34], focusing on five types of interactions: counteracting (−2; clashes with another target) and constraining (−1; limits options on another target), consistent (0; no significant positive or negative interactions), enabling (+1; creates conditions that further another target), and reinforcing (+2; aids achievement of another target). The first two imply a negative effect, the latter two a positive effect, and the consistent interaction represents no effect.

We then created a large undirected bimodal network of SDG targets and wetlandscapes. An undirected bimodal network has two types of nodes and only one interaction between a pair of nodes. All researchers are co-authors of this study and contributed to the analysis of the SDG priorities and interconnections with focus on each wetlandscape, taking advantage of the cross-cultural and multidisciplinary nature of GWEN.

Because Agenda 2030 is composed of 169 targets, considering all interactions between SDG targets with focus on each wetlandscape would result in too many interactions to be analyzed by each researcher (i.e., $169^2 - 169 = 28{,}561$ interactions). Hence, for the design of the survey, we reduced the number of targets by concentrating only on those that are expected to be achieved at the national scale by 2030 and that the core group considered were related to wetlands. We pre-screened the SDG targets by having each of the core six researchers determine their relevance to wetlands. The core group included the targets in the survey when at least four of the six core researchers scored the target as relevant. Since none of the targets of Goals 5, 10, and 17 made it pass this filter, the core group agreed to add at least one target of each of these Goals to the final group of selected targets. This final screening produced a list of 33 targets, spanning all SDGs that were included in the survey structure described below and distributed to the researchers (Table 2).

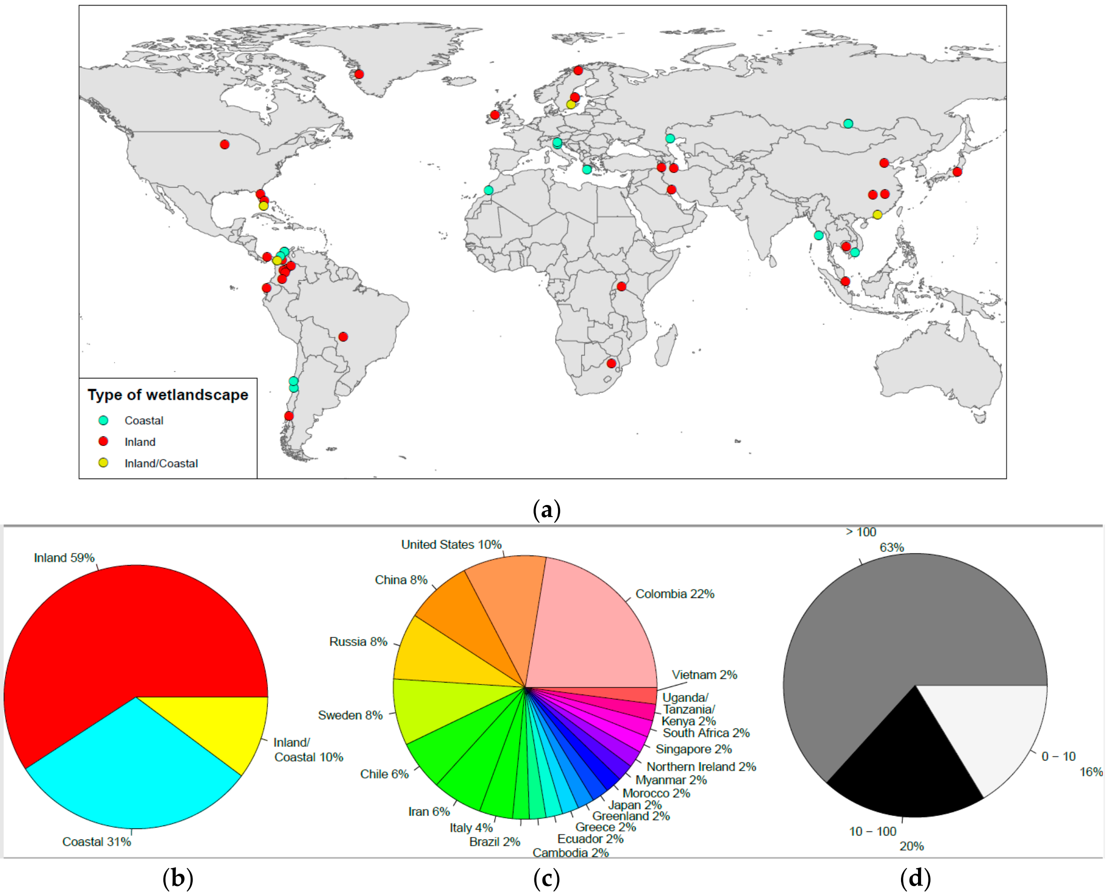


Figure 1. (**a**) Location of the 45 wetlandscapes in the Sustainable Development Goals (SDG) assessment, (**b**) Proportion of inland and coastal wetlandscapes, or both, (**c**) Countries where the wetlandscapes of the study are located with proportion of the total number of wetlandscapes, (**d**) Proportion of sizes of the wetlandscapes, classified in the ranges 0 to 10 km^2, 10 to 100 km^2 and more than 100 km^2.

2.2. Structure of the Survey

The survey initially asked for a general physical and social information on the location, spatial extent, and type of the wetland/wetlandscape (See Survey format in Figure S1, Supplementary

Information). Furthermore, the survey required each researcher to assign a value from 1 to 10 to each of the 33 selected targets based on relevance and importance to achieving sustainable development with focus to that particular wetlandscape (with 1 being not important and 10 being very important). We considered the ten highest-scoring targets as the priority targets to be achieved with focus on each particular wetlandscape. In case of tied scores, each of the 33 targets was assigned a random number as a weight that was used to break the ties. The survey further assessed respondent perspectives on the interactions among targets in each wetlandscape. To do so we used the interactions between the ten highest-scoring targets (Figure S1 in Supplementary Information). While a particular researcher only assessed a set of interactions that were based on the priorities within their wetlandscape, the aggregated interaction assessment from all researchers gave an overall perspective on the linkages among targets in relation to wetlands.

2.3. Network Analysis

We performed a network analysis in the R platform using the igraph [36] and bipartite [37] packages to: (1) Determine which targets are considered priority with focus on wetlands; (2) identify interaction patterns between all 33 targets; and (3) group wetlands into clusters or bundles based on the SDG targets considered priority for their cases. Following Reference [35], we first evaluated the SDG targets as a bidirectional unimodal network where nodes represented the SDG targets and the interlinkages represented the interactions between targets. Because all 33 targets were chosen at least once as a top-ten priority by at least one of the 49 researchers, the resulting bidirectional network included all 33 targets. Of the potential 4410 interactions of the survey (i.e., $10^2 - 10 = 90$ interactions/researcher, so 90×49 researchers = 4410 interactions), 1261 were rated as consistent/non-interacting and 3149 had some type of interaction. The 3149 interactions were grouped into four similar bidirectional unimodal subnetworks based on their influence: reinforcing (33 node and 1577 interactions); enabling (33 nodes and 1472 interactions); constraining (25 nodes and 85 interactions); and counteracting (10 nodes and 15 interactions). We identified the most important and relevant targets and interactions based on their degree of influence on other targets (i.e., out-degree metric), and grouped targets by clusters based on their most typical interactions. We performed this clustering with the fast greedy modularity optimization algorithm for community structure [38]. The algorithm infers the structure of a community (in this case a group of SDG targets within the SDG network) based on network topology, by greedily optimizing the modularity of the network. This algorithm is relatively faster than its pairs, allowing community structure analysis in large networks.

We then constructed an undirected bimodal network with both targets and wetlandscapes as nodes [37]. The purpose of this clustering analysis was to determine the bundles of wetlandscapes with similar priority SDG targets that may help to adequately and efficiently implement targets for a group of wetlandscapes at the national or global scale. We used the DIRTLPAwb+ algorithm [39] to maximize the weighted modularity in our bipartite network of SDG targets and wetlandscapes, allowing up to 50 repetitions, and the determine community structure for both wetlandscapes and SDG targets. The algorithm aggregates network bundles until no further improvement of modularity can be achieved, yielding the most optimal bundles of both targets and wetlandscapes.

In the case of wetlandscapes that were addressed by more than one researcher (i.e., the Ciénaga Grande de Santa Marta, the Florida Everglades and the Selenga River Delta), we used the perspective of each of the researchers of the particular wetlandscape to construct four bidirectional unimodal networks, but to select the top 10 targets for each wetlandscape and construct the large SDG-wetlandscape bipartite network we added the scores of each of the researchers.

Table 1. Wetlands and wetlandscapes included in this study. The column of Type of Wetland is based on the definition of the classification* of the Ramsar convention; http://www.environment.gov.au/water/wetlands/ramsar/wetland-type-classification.

Wetland Name	Country	Inland/Coastal	Type of Wetlands or Wetlandscapes	Area (km^2)
Amazonian Piedmont in Caquetá	Colombia	Inland	M, N, Tp, W, f	>100
Anzali	Iran	Inland	K, Tp	>100
Bahía de Cispatá	Colombia	Coastal	I, J	10–100
Baiyangdian Lake	China	Inland	O	>100
Chacororé-Sinhá Mariana Lake system	Brazil	Inland	M, N, O, P, W	10–100
Ciénaga de Ayapel	Colombia	Inland	O, U	>100
Ciénaga Grande de Santa Marta	Colombia	Coastal	I, J	>100
Ciénaga La Segua	Ecuador	Inland	P	>100
Dong Dong Ting Hu	China	Inland	O	>100
Florida everglades	United States	Inland/Coastal	A, B, F, G, H, I, J, Zk, M, N, O, Tp, Ts, U, W, Xf, 2, 3, 4, 6, 7, 9	10–100
Ga-Mampa wetland	South Africa	Inland	Sp	0–10
Gialova Lagoon	Greece	Coastal	J	0–10
Eqalummiut Nunaat and Nassuttuup Nunaa (Kangerlussuaq)	Greenland	Inland	M, N, O, Q, Tp, Vt	>100
Lagó Gatún	Panamá	Inland	6	>100
Laguna de Fúquene	Colombia	Inland	O	>10
Laguna La Plaza	Colombia	Inland	O	10–100
Lake Victoria	Uganda, Tanzania, Kenya	Inland	Tp, P, M, Xf, O, Ts, P	>100
Llanquihue city wetlands	Chile	Inland	M, O	0–10
Meinmahla Kuyn	Myanmar	Coastal	F, G, I	>100
Mekong Delta	Vietnam	Coastal	A, B, C, F, G, H, I, J, M, N, O, P, Q, R, Ss, Tp, Ts, U, Xf, Xp, 1, 2, 3, 4, 6, 7, 8, 9	>100
Minnesota River Basin	United States	Inland	M, O, Tp, Ts, Xf, 4, 9	>100
Nee Soon Swamp Forest	Singapore	Inland	Xf, M, N	0–10
Norrström basin wetlands	Sweden	Inland	M, O	
Okeechobee Isolated wetlands	United States	Inland	M, O, Tp, Ts, U, W, Xf, Y, Zk(b)	>100
Páramo de Sumapaz	Colombia	Inland	Xp	>100
Pichicuy	Chile	Coastal	K	0–10
Floodplain Río León-Río Atrato	Colombia	Inland/Coastal	H, I, U, 3, 9	>100
Poyang Lake	China	Inland	O	>100
Sacca di Goro	Italy	Coastal	J	≈26
San Juan floodplains	Colombia	Inland	M, O, P, Xf	>100
Selenga River Delta	Russia	Coastal	L	>100
Shadegan Lake	Iran	Inland	L	>100
Silver Springs Isolated Wetlands	United States	Inland	M, O, Tp, Ts, U, W, Xf, Y, Zk(b)	>100
Simpevarp	Sweden	Inland/Coastal	A, M, O, U	0–10
Souss	Morocco	Coastal	F	0–10
Tavvavuoma	Sweden	Inland	Vt, U, Vt	10–100
Tin Shui Wai Wetland	China	Coastal/Inland	H, Tp, 1, 3	0–10
Tongoy	Chile	Coastal	K, H	10–100
Tonle Sap	Cambodia	Inland	M, N, O, P, Tp, Ts, Xf	>100

Table 1. *Cont.*

Wetland Name	Country	Inland/Coastal	Type of Wetlands or Wetlandscapes	Area (km^2)
Upper Lough Erne system	Northern Ireland	Inland	O	>100
Urmia Lake	Iran	Inland	Q, P, M	>100
Vattholma wetlands	Sweden	Inland	M, O, Tp, U, Xf	>100
Venetian Lagoon	Italy	Coastal	J	>100
Volga River Delta	Russia	Coastal	L, J	>100
Watarase-yusuichi	Japan	Inland	M, 6	10–100

* Legend of wetlandscape types is as follows: Marine/Coastal Wetlands; A—Permanent shallow marine waters in most cases less than six metres deep at low tide; includes sea bays and straits. B—Marine subtidal aquatic beds; includes kelp beds, sea-grass beds, tropical marine meadows. C—Coral reefs. D—Rocky marine shores; includes rocky offshore islands, sea cliffs. E—Sand, shingle or pebble shores; includes sand bars, spits and sandy islets; includes dune systems and humid dune slacks. F—Estuarine waters; permanent water of estuaries and estuarine systems of deltas. G—Intertidal mud, sand or salt flats. H—Intertidal marshes; includes salt marshes, salt meadows, saltings, raised salt marshes; includes tidal brackish and freshwater marshes. I—Intertidal forested wetlands; includes mangrove swamps, nipah swamps and tidal freshwater swamp forests. J—Coastal brackish/saline lagoons; brackish to saline lagoons with at least one relatively narrow connection to the sea. K—Coastal freshwater lagoons; includes freshwater delta lagoons. Zk(a)—Karst and other subterranean hydrological systems, marine/coastal; Inland Wetlands; L—Permanent inland deltas, M—Permanent rivers/streams/creeks; includes waterfalls, N—Seasonal/intermittent/irregular rivers/streams/creeks, O—Permanent freshwater lakes (over 8 ha); includes large oxbow lakes, P—Seasonal/intermittent freshwater lakes (over 8 ha); includes floodplain lakes, Q—Permanent saline/brackish/alkaline lakes, R—Seasonal/intermittent saline/brackish/alkaline lakes and flats, Sp—Permanent saline/brackish/alkaline marshes/pools, Ss—Seasonal/intermittent saline/brackish/alkaline marshes/pools, Tp—Permanent freshwater marshes/pools; ponds (below 8 ha), marshes and swamps on inorganic soils; with emergent vegetation water-logged for at least most of the growing season, Ts—Seasonal/intermittent freshwater marshes/pools on inorganic soils; includes sloughs, potholes, seasonally flooded meadows, sedge marshes, U—Non-forested peatlands; includes shrub or open bogs, swamps, fens. Va—Alpine wetlands; includes alpine meadows, temporary waters from snowmelt, Vt—Tundra wetlands; includes tundra pools, temporary waters from snowmelt, W—Shrub-dominated wetlands; shrub swamps, shrub-dominated freshwater marshes, shrub carr, alder thicket on inorganic soils, Xf—Freshwater, tree-dominated wetlands; includes freshwater swamp forests, seasonally flooded forests, wooded swamps on inorganic soils, Xp—Forested peatlands; peatswamp forests, Y—Freshwater springs; oases, Zg—Geothermal wetlands, Zk(b)—Karst and other subterranean hydrological systems, inland, Zk(c)—Karst and other subterranean hydrological systems, human-made, Human-made wetlands; 1—Aquaculture (e.g., fish/shrimp) ponds, 2—Ponds; includes farm ponds, stock ponds, small tanks; (generally below 8 ha), 3—Irrigated land; includes irrigation channels and rice fields, 4—Seasonally flooded agricultural land (including intensively managed or grazed wet meadow or pasture), 5—Salt exploitation sites; salt pans, salines, etc., 6—Water storage areas; reservoirs/barrages/dams/impoundments (generally over 8 ha), 7—Excavations; gravel/brick/clay pits; borrow pits, mining pools, 8—Wastewater treatment areas; sewage farms, settling ponds, oxidation basins, etc., 9—Canals and drainage channels, ditches.

Table 2. The 33 Sustainable Development Targets selected as most relevant to wetlands.

Target	Description
1.1	By 2030, eradicate extreme poverty for all people, currently measured as people living on less than US$ 1.25 a day.
1.2	By 2030, reduce at least by half the proportion of men, women, and children of all ages living in poverty in all its dimensions according to national definitions.
1.5	By 2030, build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters.
2.1	By 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious, and sufficient food all year round.
2.4	By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding, and other disasters and that progressively improve land and soil quality.
3.3	By 2030, end the epidemics of AIDS, tuberculosis, malaria, and neglected tropical diseases and combat hepatitis, water-borne diseases, and other communicable diseases.
3.9	By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water, and soil pollution and contamination.
4.7	By 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and non-violence, global citizenship, and appreciation of cultural diversity and of culture's contribution to sustainable development.

Table 2. *Cont.*

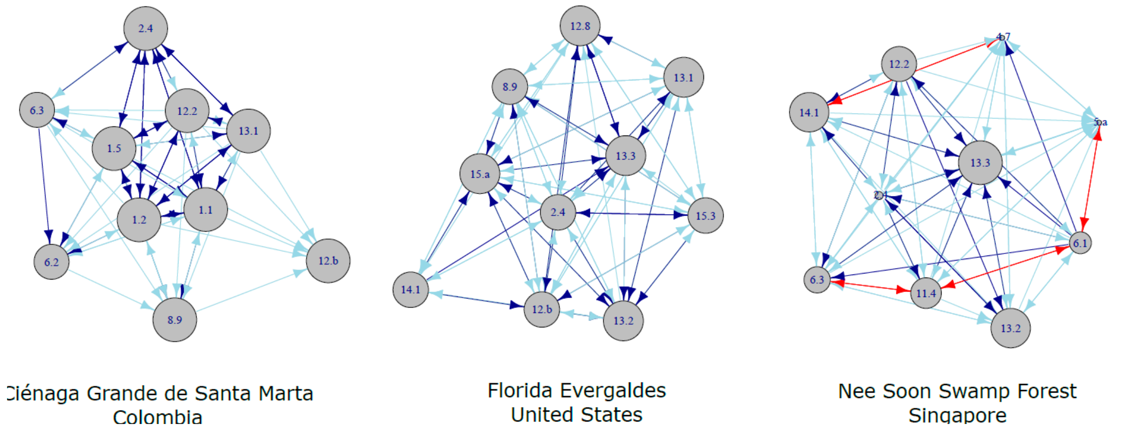
Target	Description
5.a	Undertake reforms to give women equal rights to economic resources, as well as access to ownership and control over land and other forms of property, financial services, inheritance, and natural resources, in accordance with national laws.
6.1	By 2030, achieve universal and equitable access to safe and affordable drinking water for all.
6.2	By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations.
6.3	By 2030, improve water quality by reducing pollution, eliminating dumping, and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally.
7.2	By 2030, increase substantially the share of renewable energy in the energy mix.
8.4	Improve progressively, through 2030, resource efficiency in consumption and production and endeavor to decouple economic growth from environmental degradation, in accordance with the 10-Year Framework of Programmes on Sustainable Consumption and Production.
8.9	By 2030, devise and implement policies to promote sustainable tourism that creates jobs and promotes local culture and products.
9.1	Develop quality, reliable, sustainable, and resilient infrastructure, including regional and transborder infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all.
10.1	By 2030, progressively achieve and sustain income growth of the bottom 40 percent of the population at a rate higher than the national average.
11.1	By 2030, ensure access for all to adequate, safe, and affordable housing and basic services and upgrade slums.
11.4	Strengthen efforts to protect and safeguard the world's cultural and natural heritage.
11.5	By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations.
11.6	By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management.
12.2	By 2030, achieve the sustainable management and efficient use of natural resources.
12.8	By 2030, ensure that people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature.
12.b	Develop and implement tools to monitor sustainable development impacts for sustainable tourism that creates jobs and promotes local culture and products.
13.1	Strengthen resilience and adaptive capacity to climate related hazards and natural disasters.
13.2	Integrate climate change measures into national policies, strategies, and planning.
13.3	Improve education, awareness-raising, and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning.
14.1	By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution.
15.3	By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation neutral world.
15.a	Mobilize and significantly increase financial resources from all sources to conserve and sustainably use biodiversity and ecosystems.
15.b	Mobilize significant resources from all sources and at all levels to finance sustainable forest management and provide adequate incentives to developing countries to advance such management, including for conservation and reforestation.
16.5	Substantially reduce corruption and bribery in all their forms.
17.7	Promote the development, transfer, dissemination, and diffusion of environmentally sound technologies to developing countries on favorable terms, including on concessional and preferential terms, as mutually agreed.

3. Results

3.1. SDG Network Structures for Iconic Wetlandscapes

Our analysis involved 45 wetlandscapes distributed across the five continents (except Oceania) and 21 countries, of which the slight majority were categorized as inland wetlands or as wetlandscapes that included inland wetlands (69%), and the largest specific category was lacustrine (Figure 1b and Table 1). A large number of the wetlandscapes (22%) are found in Colombia, as several Colombian researchers were present in the GWEN meeting, but other countries such as the United States, China, and Sweden also had several wetlandscapes in the study. Most of the wetlandscapes had a surface area larger than 100 km^2, including large wetlandscapes such as Lake Victoria in Africa, the Selenga

Delta in Russia, the Florida Everglades in United States, and the Mekong River Delta in Vietnam. However, the GWEN includes also small wetlands with surface areas below 10 km^2 such as the Nee Soon Swamp Forest in Singapore, Tin Shui Wai wetland in China, the Vattholm wetlands in Sweden or the Pichicuy wetland in Chile. Target prioritizations varied among the studied wetlandscapes, but the SDG networks for three iconic wetlands are shown as examples (Figure 2): Ciénaga Grande de Santa Marta in Colombia, The Florida Everglades in the USA, and Nee Soon Swamp Forest in Singapore.



(**a**) (**b**) (**c**)

Figure 2. Networks of Sustainable Development Goal (SDG) targets in: (**a**) The Ciénaga Grande de Santa Marta, Colombia, (**b**) the Florida Everglades, United States and (**c**) the Nee Soon Swamp Forest, Singapore. Nodes represent the SDG targets and the bidirectional interlinkages between targets are reinforcing (dark blue), enabling (light blue), constraining (orange), counteracting (red), and consistent (not shown as they imply no relation). Node labels refer to the SDG targets and size of the nodes to the number of targets that are dependent on that specific node (target).

For the case of the 1260-km^2 mangrove-dominated Ciénaga Grande de Santa Marta (CGSM), the targets of Goals 1 (end poverty), 2 (zero hunger), and 12 (sustainable consumption and production) were considered the priorities for achieving sustainable development. The similar node sizes indicate that most of the targets were given the same high score, where only the targets of adequate and equitable sanitation (6.2) and improving water quality (6.3) show a lower level of priority. Two distinctive subnetworks of reinforcing (dark blue) and enabling (light blue) interactions can be identified. For instance, in the first subnetwork, the targets of eradicating extreme poverty (1.1), reducing poverty by half (1.2), building vulnerability resilience (1.5), enhancing sustainable food production (2.4), sustainable management and efficient use of natural resources (12.2), and building climate and hazard resilience (13.1) are highly connected, showing the reinforcing interactions between targets and how working towards one specific target can have positive effects on the others. The CGSM faces a high diversity of socio-ecological challenges targeting the SDGs mentioned above. Targets 1.1 and 1.2 are directly connected to sustainable consumption and production and the CGSM hosts a wide diversity of stakeholders that unfortunately do not seem to cooperate towards more sustainable development; moreover, despite the reported and known ecosystems services that support local community economies, this wetlandscape continues to portray high environmental and social vulnerability concerning local resilience (Target 1.5). Particularly for this wetlandscape, the poverty of local communities and complexity of stakeholders' relations hinders sustainable development and resilience to climate hazards such as droughts, that can only be achieved by empowering local environmental governance [24,40].

For the Florida Everglades, priorities as indicated by the larger size of the nodes included: awareness of sustainability development with nature (12.8); strengthening resilience, education, strategies, and policies related to climate change (13.1, 13.2, 13.3), and increasing financial resources for conservation of biodiversity and ecosystems (15.a). Secondary goals for the Everglades are enhancing sustainable food production (2.4), creating sustainable tourism that promotes jobs (8.9), and reducing marine pollution of all kinds (14.1). The Everglades, located in Florida, USA, shares designations as a UNESCO World Heritage site and an Iconic Landscape Designation by the United States National Parks and Conservation Association. The Greater Everglades watershed encompasses 28,000 km^2 and over half of its original wetland area has been lost due to drainage and development for agricultural and urban uses [41]. Over 8 Million residents depend on the Greater Everglades for water supply, as do farms and industries [42]. Farming in the Everglades agricultural area is primarily for sugar cane, followed by fruits, vegetables, and livestock. A long history of over fertilization within the agricultural industry has led to concentrations of nutrients responsible for ecosystem change transported to the waterways, wetlands, and coastal regions of south Florida [43]. Current best management practices have seen a reduction in nutrient concentrations in some waterways [44], but a legacy of nutrients stored in the soils are still available for leaching as an agricultural non-point source pollution for years to come [45].

Despite the fact that the Everglades are included in one of the largest ecosystem restoration efforts to date, additional threats to the remaining Everglades ecosystem include further anthropogenic development and climate change. In terms of climate change, an increase in temperature, changes in rainfall patterns, and sea level rise all pose a threat to the sustainability of the Everglades watershed, including its inhabitants and ecosystem [46], therefore the importance of Targets 13.1, 13.2 and 13.3. For the inhabitants of south Florida, climate change impacts include flooding from high rainfall events that may be associated with tropical storms and sunny day flooding of seawater during high tides, as well as a loss of freshwater supply of the underlying aquifer due to saltwater intrusion [47]. Ecosystem changes observed due to sea level rise include peat collapse creating a conversion of land to open water areas [48] as well as an invasion of salt tolerant plant species, such as mangroves, into regions previously dominated by fresh water-dependent plant species [49]. The results of this study's analysis suggest that additional education, financial resources, and policy strategies in terms of development and climate change are needed to sustain the remaining Everglades wetland ecosystem. Tourism is a large economy in south Florida, mainly sustained by its tropical waters, beaches, corals reefs, and sport fishing. Protecting marine areas from pollution as well as enhancing the tourism industry to include the Greater Everglades ecosystem would enhance the local economy while conserving and maintaining its important ecosystems from freshwater to marine.

In the case of the 0.5-km^2 Nee Soon Swamp Forest in Singapore (Figure 2c), the targets of reducing marine pollution of all kinds (14.1); strengthening education, strategies, and policies related to climate change (13.2, 13.3) and improving water quality (6.3) are obvious targets for the preservation of habitat for incumbent species and the protection of a clean water source in the headwaters of the most intact forested catchment in Singapore. Secondary priority targets include sustainable management and efficient use of natural resources (12.2) and the conservation of natural and cultural heritage (11.4). Target 12.2 relates peripherally in that consumption/production habits should not affect the wetland in a negative manner (e.g., usage of wetland forest products). Target 11.4 is inherently linked as the wetland exists within an urban environment, for which there is a priority to preserve lingering natural heritage. Unfortunately, the wetland is too small to truly contribute to making a large city more sustainable. Climate action is linked, as the status of the wetland is threatened by acid rain which is, in part, related to industrial emissions within the Singapore-Johor-Riau Growth Triangle and automobile exhaust, and these sources also contribute to greenhouse gas emissions that affect climate, and therefore, climate policy. In terms of interactions among targets and goals, a priority on economic growth may counteract the target of maintaining ecosystem health. Policies implemented to improve water quality and sanitation and to reduce carbon emissions would reinforce the goal to preserve the wetland. At the same time, education advances could enable targets for improving water quality and reducing carbon emissions. The above challenges for urban wetlands are not unique to Singapore; the Tin Shui Wai wetlands in Hong Kong have similar challenges.

3.2. The Global Wetland Ecohydrological Network of SDG targets

The selected targets in the top ten priorities at the GWEN scale relate to Goals 2 (zero hunger), 4 (quality education), 6 (clean water and sanitation), 8 (decent work and economic growth), 11 (sustainable cities and communities, 12 (sustainable consumption and production), and 13 (climate action). Of the 33 targets selected, seven were considered a priority by at least 20 (42%) of the researchers (Figure 3). Improving water quality (6.3) was included in the top ten by 32 of the 49 researchers (67%), followed by sustainable management and efficient use of natural resources (12.2) (28 researchers; 58%) and sustainable food production (2.4) (26 researchers; 54%). Of these, Targets 6.3 and 12.2 were consistently ranked in the top three, identifying them as important targets that researchers think should be primarily accomplished to achieve a sustainable development in their wetlands. The three researchers studying the Selenga Basin ranked Target 6.3 as the top priority, suggesting that the importance of enhancing water conditions goes beyond the individual perceptions of the researchers with a specific wetlandscape.

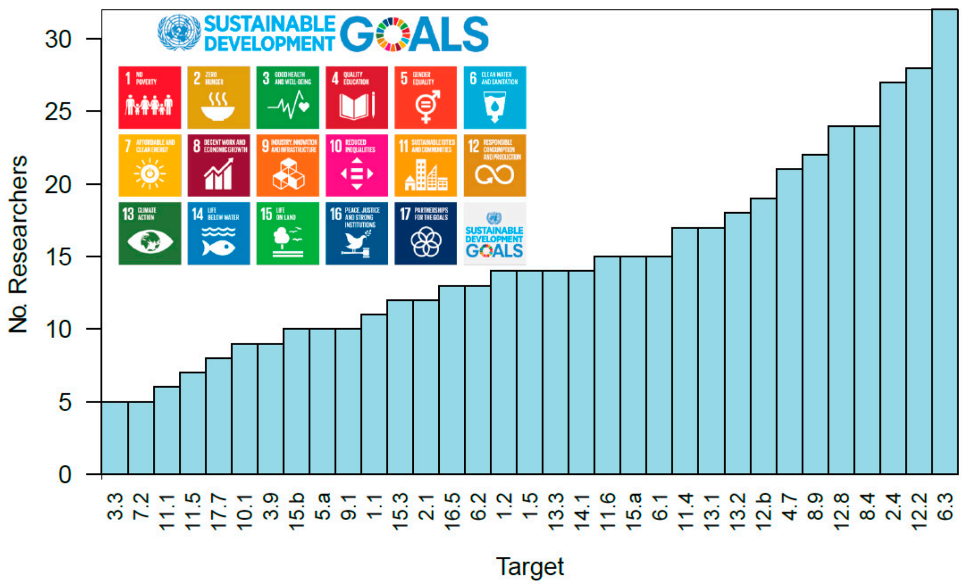
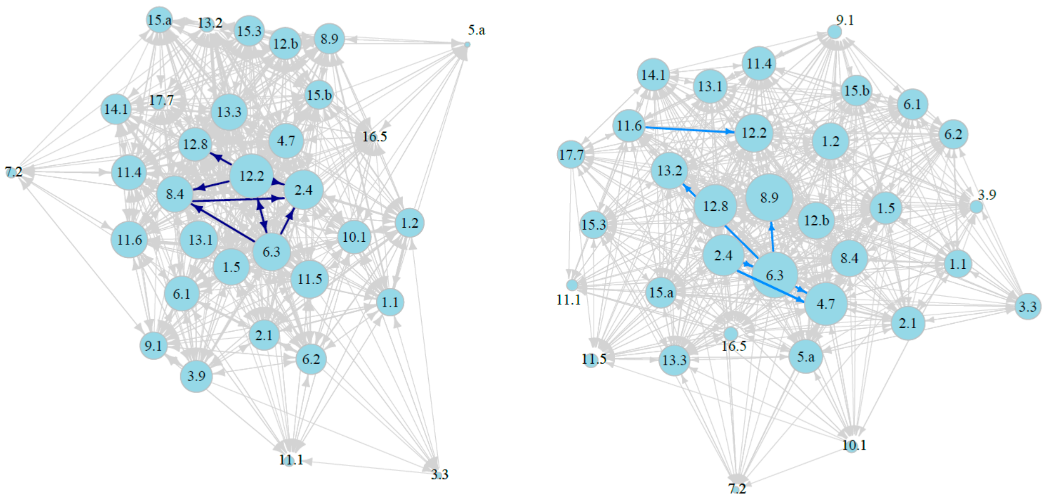


Figure 3. Number of times (y-axis) each Sustainable Development Goal (SDG) target (x-axis) has appeared in the surveys as one of the top 10-SDG target priorities with focus in the 45 wetlandscapes studied worldwide.

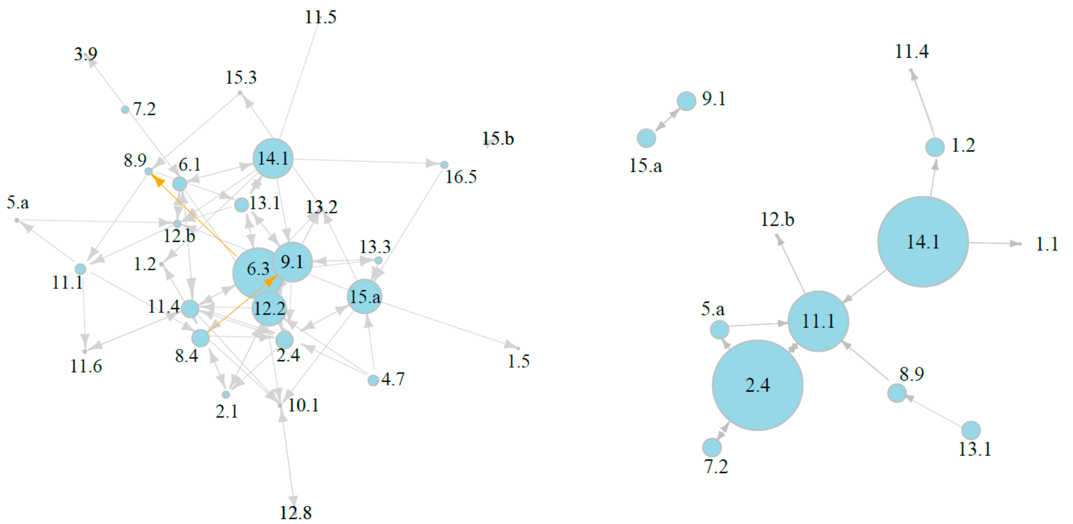
Regarding the interactions between the selected targets, both reinforcing and enhancing subnetwork analysis had an equal number of nodes and similar number of interconnections. The targets of Sustainable management and efficient use of natural resources (12.2) and sustainable food production (2.4) were systematically identified (in 60% and 54% of surveys, respectively) as having a reinforcing influence (+2) on other targets. The two most consistent reinforcing interactions were the influence of sustainable management of resources (12.2) on efficient resource consumption (8.4) and improving water quality (6.3) on Target 2.4, both occurring in 15 wetlandscapes surveys. In the same way, achieving sustainable tourism (8.9) and Target 6.3 had the most recurring enhancing (+1) influences. The most evident enhancing interactions were the influence of target of 2.4 on education for sustainability (4.7) and Target 6.3. The influence of the target aiming to reduce environmental impact (11.6) on 12.2 and the influence of Target 6.3 on integrating climate change measures (13.2), 4.7, and 8.9 were also common enhancing (+1) dependencies across wetlandscapes (Figure 4b).



(**a**) (**b**)

Figure 4. Bidirectional unimodal network of: (**a**) Positive reinforcing interactions (+2) between the targets considered priority by wetland researchers. Nodes are targets (light blue) and interactions the reinforcing linkages between targets (grey arrows). For visualization purposes, interactions existing in more than 8 surveys (4 standard deviations) are highlighted in dark blue. Node size depends on out-degree or influence of the target on other targets. (**b**) Positive enhancing interactions (+1) between the targets, but only highlighting the most important interactions (sky blue), in same way as in (**a**).

The network results of negative interactions were considerably smaller than those of positive interactions (Figure 5a,b). Only two constraining interactions of the network were mentioned by more than one survey respondent; the influence of improving water quality (6.3) on achieving sustainable tourism (8.9) and efficient resource consumption (8.4) on sustainable infrastructure (9.1). The targets with the most frequent counteracting influence (−2) were reducing marine pollution of all kinds (14.1) and Sustainable food production (2.4); yet, none of their interactions were mentioned in more than one wetlandscape.



(a) **(b)**

Figure 5. Bidirectional unimodal networks of: Negative (**a**) constraining (−1) with most frequent interactions shown in orange, and (**b**) counteracting (−2) interactions between the targets considered priority by wetland researchers, presented in a similar way to Figure 4. In (**b**), no interactions were mentioned by more than one researcher.

We combined the results of all positive interactions (+1 and +2) into an undirected unimodal network to cluster the targets into three distinctive communities based on the interactions among them, ignoring for a moment the wetlandscapes where they were mentioned (Figure 6). In general, SDG pairs are more likely to be connected if they are both members of the same community and on the contrary less likely to be connected if they do not belong to the same community. Hence, working towards one target in one of these communities will then influence the progress on other targets in the same community. The clustering reveals that the three targets that were considered a priority for sustainable development in wetlands (Figure 3) are grouped into the same community (green). In general, the second community groups the remaining targets of the lower Goals, Goals 1 to 11, which are more related to basic human and societal needs and the last community groups the targets belonging to the more biophysical (Goal 12—Responsible Production and Consumption, Goal 13—Climate Action, Goal 14—Life below water and Goal 15—Life on land) and governance goals (Goals 16—Peace, Justice and Strong Institutions and Goal 17—Partnership for the Goals). Hence, the grouping of SDG targets with focus on wetlands is consistent with the general grouping of the 17 SDG Framework of Agenda 2030.

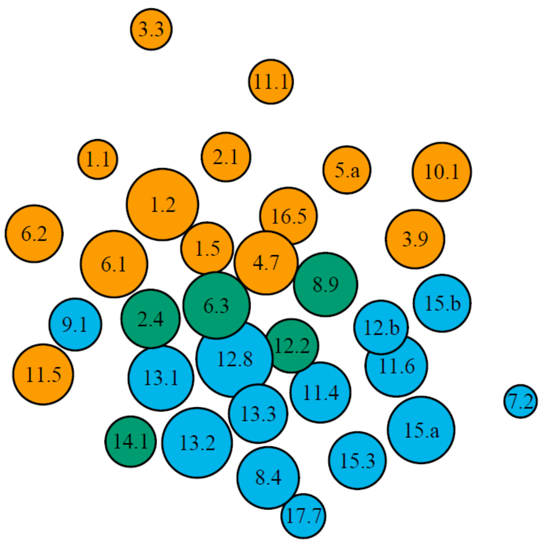


Figure 6. Unimodal networks of all reinforcing (+2) and enhancing (+1) interactions among selected Sustainable Development Goals (SDG) targets clustered into three communities that represent the different groups depending on their interactions. The size of the nodes represents the number of connections each target has to other targets. Interactions are not shown for visualizations purposes.

For policy management, it may be relevant to group wetlandscapes based on the priority SDG targets needed to achieve sustainable development within their area of influence. Constructing an undirected bimodal network of SDGs and wetlandscapes enables us to obtain bundles of wetlandscapes with similar SDG priorities (Figure 7). The first group comprises the wetlands where the "Basic human needs" are considered the main priorities to achieve sustainable development in their areas, spanning the targets across Goals 1 to 6, and involving access to food, health, education, clean water, and sanitation. The second group prioritizes the targets of sustainable development (8.9, 12.b) and reducing marine pollution of all kinds (14.1), in order to achieve sustainable development. The third group addresses "Environmental impact in urban wetlands" by prioritizing efficient resource consumption (8.4), reduce environmental impact in cities (11.6), and awareness of sustainability development with nature (12.8). The fourth group, "Improving and conserving environment," includes wetlandscapes where researchers prioritized targets in the biophysical and climate goals (Goals 13—Climate action, 14—Life under water and 15—Life on land), specifically the targets of strengthening resilience, education, strategies, and policies related to climate change (13.1, 13.2, 13.3) 13.3, and conservation of natural and cultural heritage (11.4). These four categories adequately group the 45 wetlandscapes of the GWEN network.

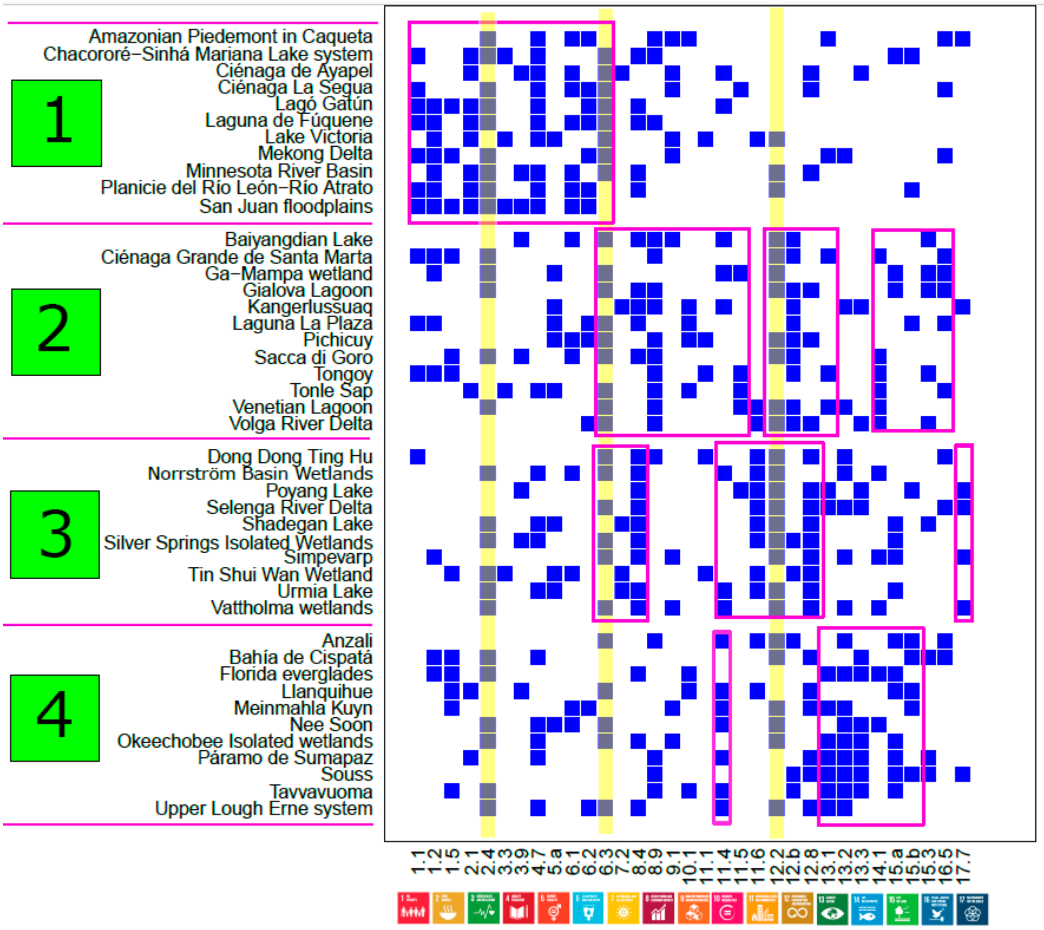


Figure 7. Bundles of both Sustainable Development Goals (SDG) targets (x-axis) and wetlandscapes (y-axis) based on the bimodal network of targets and wetlandscapes. For each wetlandscape, the ten priority SDG targets are shown (blue small squares). The four resulting bundles (green-box numbers) for wetlandscape management are: (1) "Basic human needs", (2) "Sustainable tourism", (3) "Environmental impact in urban wetlands", and (4) "Improving and conserving environment". The relationships making the bundles unique are shown within the pink rectangles. The three most common priority targets across surveys are highlighted in yellow (See Figure 3).

4. Discussion

With the exception of the Ciénaga Grande de Santa Marta and the Selenga River Delta, which were addressed by two and three researchers, respectively, the wetlandscapes were assessed in the survey by only one researcher. The results presented here are therefore highly dependent on the opinion of the researcher filling the survey and may vary considerably from the opinions of different researchers or stakeholders working and living in those areas. While similar patterns can be found across different individual wetlandscapes, more targets should be interrelated as the spatial scale of interest increases. Probably at a national scale, all may likely be related, even in the most developed countries.

Differences in the SDG priority targets and their interactions depend on the diversity of physical, biological, hydrological, and socioeconomic factors that make each study wetlandscape unique. Likewise, opportunities for their management and the impacts that they experience from humans were also wetland-dependent due to specific combinations of these factors. Priority targets for wetlands usually pertain to preserving ecosystem health/functionality to protect life in the wetland, and allow the wetland to contribute naturally to local and downstream processes and phenomena. The targets depend on the unique situation of the individual wetland, as pertaining to type, current health, and level of interaction with humans. For instance, inland wetlands are fundamentally different from coastal wetlands such as mangroves; therefore, prioritized targets are expected to diverge.

In addition, wetlands in urban environments are managed differently than those in rural settings, which may be intact or preserved. These are geographical questions related to scale, physical/cultural setting, and history, supporting the view that SDGs monitoring and implementation should be tailored to the individual wetland, or at least to groups of wetlandscapes such as the SDG-priority bundles shown in Figure 7.

At the scale of the GWEN wetland network, we find converging perceptions of priority and interactions among targets and wetlandscapes. Our priority analysis flagged improving water quality (6.3) as a universal priority target to achieve sustainable development with focus in wetlands. This comes as a surprise, as there is substantial literature documenting the role of wetlands in the protection and/improvement of water quality [26] but not on the contrary, that is, the importance of improving water quality for the benefit of wetlands. Wetland functions, such as nutrient and pollutant transformation and sequestration, have expanded the use of wetlands as nature-based solutions for wastewater treatment [3,50]. In fact, most scientific publications deal with the construction of wetlands for wastewater treatment but few deal with the improvement of water quality in natural wetlands [50], with only some exceptions such as the studies of References [3,23,51]. Although wetlands are still seen as "opportunities" for resource use by adequate ecosystem management [52], growing concerns over water quality relate to risks carried by wetland-dependent human communities, fishery collapses, and pollution, as society and wetland ecosystem become more integrated [53,54].

Our results further showed that sustainable resource management and food production (Targets 2.4 and 12.2) are considered top priorities across the studied wetlandscapes. The call to generate a balance between wetland conversion, sustainable utilization, and conservation [55] is a reaction to progressing degradation of wetlands in developing economies, that is further aggravated by the complex land tenure regimes and land rights uncertainties [56,57]. The conservation of wetlands needs to fit better in terms of ecosystem processes and the social and political realities to which wetlands are subject to for their sustainable management [52,58,59].

The selected ten most critical SDG targets in our wetlandscapes lie within Goals 2, 4, 6, 8, 11, 12, and 13 (Figure 3). In general, these SDGs agree with those suggested to be critical by the Secretariat of the Convention on Biological Diversity (CDB), Wetlands International and the Ramsar Convention, especially with the latter. However, some important differences exist. For instance, our study identified several priority targets that belong to SDGs that are not included in the CBD's priority list (i.e., Goals 4—Quality education, 8—Decent work and economic growth, and 11—Sustainable cities and communities). Additionally, our analysis highlighted Target 4.7 ("Education for sustainability") as highly influential, even though Goal 4—"Quality education" is not identified as a priority SDG by the CBD, Wetlands International, or the Ramsar Convention.

This suggests that the integrated social-ecological nature of wetland systems is not yet fully recognized by these global conventions. Similarly, targets within the "End poverty" SDG did not make it into the 10-top rank of our study, despite being considered as a priority SDG by these three wetland-related authorities. The most plausible explanation is that several wetlands in our study are located in developed nations such as United States, Sweden, and Italy, or in locations within developing countries (e.g., Vatthomla wetlands and Tvvaramoa in Sweden and Laguna La Plaza in Colombia) that do not have significant human populations that depend on the "wise use" of these wetlands. Moreover, four of the top ten priority targets selected in our study (4.7, 12.b, 12.2, and 12.8) are not included in the Ramsar Convention's fourth Strategic Plan (2016–2024). The lack of any target of Goals 4 ("Quality education") and 12 ("Responsible consumption and production") in this strategic plan is noteworthy.

The analysis of interactions has also evidenced the dependency of targets dealing with climate change policy, sustainable tourism, and education for sustainable development on the improvement of water quality (Target 6.3). This finding agrees with recent studies highlighting the role of water quality improvements to achieve sustainable development [60–62]. Education for sustainable development aims to give coherence to environmental conservation in terms of environmental, social, economic, and political policies [63]. The dependency of education on water quality improvements in wetlands highlights the necessity of improving ecosystem health, in order to be used as success cases in outreach and promoting wetland ecosystems. Wetlands serve as a place of knowledge production, while education on the environmental benefits should promote better management practices. Improving water quality can enhance sustainable tourism, generating revenue for the wetland-dependent communities. However, ecotourism will need to be carefully monitored and regulated in order to maintain and enhance the integrity and attractiveness of the wetland ecosystems [64].

A consistent dependency throughout several wetlandscapes of improving water quality for wetland management and the sustainable resource consumption in these ecosystems is noted (i.e., influence of Target 6.3 on 12.2 on 8.4). As managers assess the riparian zones and floodplains as effective nutrient processors [65,66], there is a growing concern on the impacts of water quality deterioration on wetland biodiversity and greenhouse gas emissions [67]. The rational or "wise use" of wetlands requires further understanding of the ecosystem health, functionality, and natural capital and the human utilization of a wetland, often essential for the maintenance of important ecological wetland functions [26,68].

5. Conclusions

Here we conducted a network analysis developed to prioritize Sustainable Development Goal (SDG) targets for sustainable development in iconic wetlands/wetlandscapes around the world. We used information and perceptions of 49 wetland researchers of the Global Wetland Ecohydrological Network (GWEN) of about 45 wetlandscapes worldwide. The main highlights of the study are the following:

1. The study showed that the targets improving water quality (6.3), followed by sustainable management and efficient use of natural resources (12.2) and sustainable food production (2.4) were consistently ranked as priorities to achieve sustainable development from a wetland perspective.
2. Four of the top ten SDG targets that were found to be a priority according to our study (4.7, 12.b, 12.2, and 12.8) are not included in the Ramsar Convention's fourth Strategic Plan (2016–2024).
3. The most consistent positive interactions among SDGs in the context of wetlands were: (i) the influence of sustainable management of resources (12.2) on efficient resource consumption (8.4); (ii) the influence of improving water quality (6.3) on sustainable food production (2.4) and achieving sustainable tourism (8.9); and (iii) the influence of target of 2.4 on education for sustainability (4.7) and Target 6.3.
4. Our study evidenced the dependency of targets dealing with climate change policy, sustainable tourism, and education for sustainable development on the improvement of water quality (Target 6.3).
5. The network of wetlandscapes of the Global Wetland Ecohydrology Network (GWEN) was divided into four main categories related to the priority SDG targets necessary for sustainable development: "Basic human needs", "Sustainable tourism", "Environmental impact in urban wetlands", and "Improving and conserving environment".
6. We argue that the structure of interactions amongst SDG targets must be taken into account for the effective sustainable management of wetlands and their hydrological networks, wetlandscapes.

Supplementary Materials: The following are available online at http://www.mdpi.com/2073-4441/11/3/619/s1, Table S1: Detailed information on the 45 wetlandscapes used in the study, Figure S1: Example of the Questionnaire filled by each wetland researcher.

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