Accelerate the Mobilization of African and International Scientific Expertise to Boost Interdisciplinary Research for the Success of the Sahelian Great Green Wall by 2030

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Abstract: The Sahelian Great Green Wall (SGGW) is an influential project to combat desertification and promote sustainable land management on a large scale, involving 11 countries in the Sahel region of Africa. The UNCCD's 2020 progress report showed a mixed picture concerning the meeting of the initial targets. At the One Planet Summit in 2021, announcements were made to consolidate the implementation of the SGGW, most notably with the creation of the Great Green Wall Accelerator. In this context, our paper sets out to review the scientific work conducted with regard to the SGGW. We have thus carried out a bibliometric analysis of the literature on SGGW. Although the initiative involves 11 countries and covers a large spectrum of scientific disciplines, our results show the predominance of ecological studies in the SGGW literature and a concentration of studies in certain geographies of interest, such as northern Senegal. Moreover, based on a secondary analysis of publications on land restoration and sustainable ecosystem management in Sahelian countries, we show that the literature relevant to SGGW topics is richer and fills in the information gaps we have identified at thematic and geographical levels. By showing that SGGW studies are overly focused on certain topics and geographical areas, our paper argues for a better interdisciplinary mobilization of researchers working on GGW-related topics. The scientific and operational success of the project depends on stronger networking between the different research teams and themes, both in Africa and internationally.

Keywords: Great Green Wall; Sahel; land restoration; review; adaptation

1. Introduction

Land is the basis of all terrestrial ecological processes. Land degradation is characterized by a negative trend in land condition [1], typically involving the total or partial loss of vegetation cover, soil fertility, productivity and/or biodiversity, leading to a decline in ecosystem services and both ecosystem and community resilience [2]. More than 70% of the Earth's ice-free terrestrial ecosystems have been transformed from their natural state and countries have reported that one-fifth of all land (more than 2 billion hectares) is now considered degraded [1,3]). Economic losses equivalent to 10–17% of the world's gross domestic product have been attributed to land degradation and land use change [4], undermining the well-being of 3.2 billion people and contributing to the projected extinction of 1 million species by 2050 [3]. In Africa, we estimate that 45% of the land is degraded, more than half of which is severely so [3]. In the Sahel, land degradation affects 135 million people going about their daily lives [5].

In the Sahel, among the different initiatives to combat desertification, i.e., land degradation in the drylands, and its impacts on ecosystems and societies, one of the most emblematic is the Great Green Wall initiative (GGW), launched in 2007 by the African Union. The initial objective of the Sahelian GGW (SGGW) was to plant trees along a 15 km-wide strip of land along a 7000 km-long belt from Dakar to Djibouti. This strip is located around the 400-mm isohyet in an area that is home to 232 million people [6]. It aimed to restore the vegetation cover and ensure soil protection while promoting the development of the rural Sahelian territories. The SGGW was one of the first international land management initiatives to bring together several African countries, coordinated since 2010 by the Pan-African Agency of the Great Green Wall (PAGGW). It involves 11 states. The vision of the GGW has evolved from a focus on afforestation to an integrated ecosystem management approach that aims to develop a mosaic of different sustainable land use and agricultural production systems. The SGGW is seen as the sustainable management of ecosystems to restore land health.

The 2020 progress report [5] showed a very mixed picture. About 20 million hectares of land out of the planned 100 million had been restored, 350,000 jobs had been created and 300 million tons of CO_2 (30% of the planned target) had been sequestered. Given this record, the environment ministers of the SGGW countries have called for coordinated efforts to implement the GGW (see the 2021–2030 DPIP Decennial Priority Investment Plan, https://www.grandemurailleverte.org/images/ENG-DPIP.pdf). At the One Planet Summit in 2021, several announcements were made, including the pledging of 19 billion US dollars in funding for 2020–2025 and the creation of the Great Green Wall Accelerator.

Relaunching the Great Green Wall, mobilizing the funds required to achieve the initial objectives by 2030, and making this initiative a success in the 2030 Agenda for Sustainable Development all require a paradigm shift. Scientific research could support this revised agenda by providing insights from fieldwork, theoretical and modelling studies but there is a need to take stock of the scientific work published to date. We have therefore focused our analysis on the issues at stake in Pillar 2 of the GGW Accelerator, "Land restoration and sustainable management of ecosystems".

The aim of this paper is (i) to take stock of the scientific work carried out in the Great Green Wall countries in the Sahel, (ii) to identify the themes addressed by this work. A bibliometric analysis of scientific publications in several databases was conducted in two complementary stages to extend our analysis beyond the keyword, Great Green Wall.

2. Materials and Methods

We conducted a systematic review that endeavours to be transparent, rigorous and replicable. To document scientific work on the GGW and "Land restoration and sustainable management of ecosystems", we conducted a two-stage search (Figure 1) for which the list of all references collected is available [7].
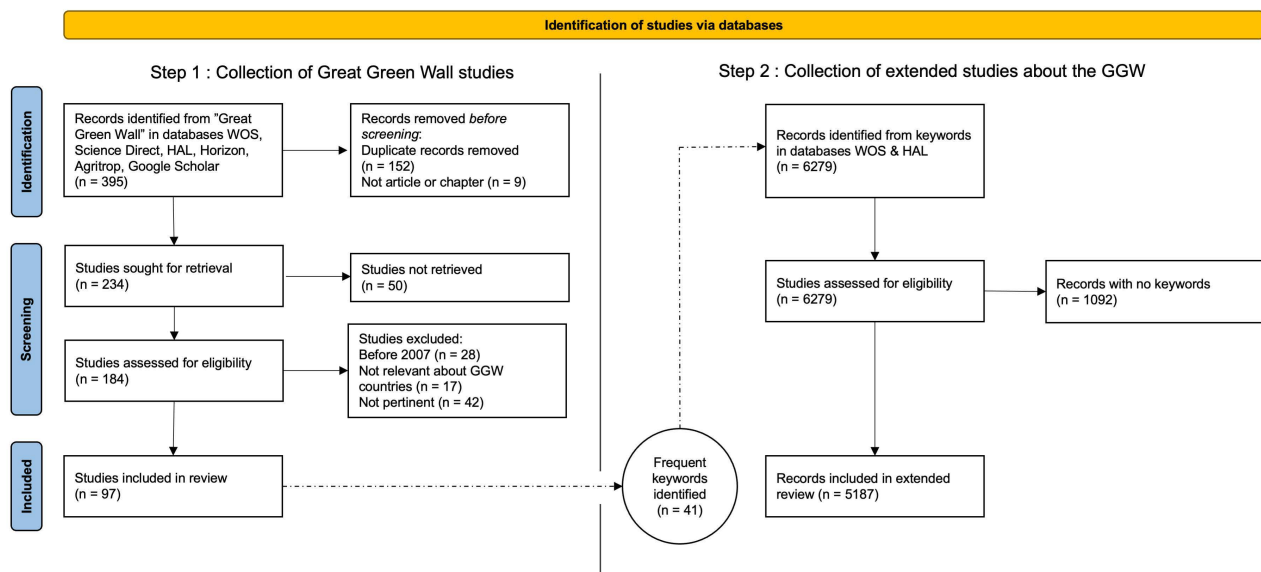
Figure 1. Review methodology based on PRISMA flow.

2.1. Bibliometric Analysis of Articles Related to the Great Green Wall

The first stage of the collection covered several databases using the keyword 'Great Green Wall' in English and 'Grande Muraille Verte' in French, to target and analyse the research that works directly on the GGW. Searches were carried out in the two international databases Web of Science (WoS) and Science Direct, and in French databases, namely the Horizon database established by the IRD (French National Research Institute for Sustainable Development) and Agritrop by the CIRAD (French Agricultural Research Centre for International Development), the two main stakeholders in French research for development, and in the HAL open archive, which references the work of French researchers from different disciplines (Table S1). It is precisely because the main areas of the SGGW are located in French-speaking West Africa that it has been useful to compile studies produced in French, even though this may have introduced an over-representation of French studies in the collection of references. The criteria for collecting and selecting publications were as follows:

* The geographical area of our work spans the 11 countries of the GGW initiative: Senegal, Mauritania, Mali, Niger, Burkina Faso, Nigeria, Chad, Sudan, Ethiopia, Djibouti and Eritrea. In addition, the work may be field-based, either because it is conceptual or because it is carried out in the laboratory.

* The articles referenced must be from 2007 onwards, the year that the GGW initiative was established in the Sahel. Thus, all subsequent publications are considered to be directly related to the GGW initiative.

* Only journal articles, book chapters and books are considered, with the underlying idea that this type of work is peer-reviewed and therefore subject to scientific consensus.

* We only retain references with accessible documents so that they can be read.

* Finally, when reading the abstracts of the publications, only the articles whose subject appears relevant to the SGGW and its objectives are considered.

Subsequently, 184 references were collected. After reading the abstracts to define the relevance of the work, and how its study areas correspond to the Sahel GGW, we ended up with 97 references to be integrated into our bibliographic database and analysed (bibliometric, messages, results, data).

A bibliometric analysis was then performed to extract information on the affiliation of the first authors, their discipline, the countries and areas of study, and the main message of the article.

2.2. Extended Analysis of Publications Related to 'Land Restoration and Sustainable Management of Ecosystems'

As the research could have focused on land restoration in the Sahel without reference to the GGW, we broadened our analysis. Given the diversity of themes, fields of study and teams, we sought to identify publications that could be considered indirectly relevant to sustainable land management (SLM), corresponding to Pillar 2 of the GGW Accelerator, by searching for documents using various keywords. For this purpose, we used the most frequent keywords from the previously collected publications, to which we added keywords presenting the GGW objectives. The keywords with the highest occurrences were selected from the 97 references selected in our first analysis. General keywords, such as forest, soil (>50 occurrences), climate, and trees appear most often, followed by more informative keywords on the processes, such as degradation, desertification, and restoration (>20 occurrences). In comparison, the keyword 'GGW' occurs more than 100 times and 'environment' more than 60 times. The other selected keywords appeared less frequently, between 5 and 20 times. In addition to the use of these thematic keywords, we combined them with geographical keywords to narrow things down to the Sahel GGW zone. The geographical keywords in the GGW references were retrieved. The most frequent occurrences are Sahel, Africa, Senegal and the arid zone (>40 occurrences). Other keywords represent different spatial scales of study: national, such as Chad, sub-continental, such as West Africa, and local such as the Ferlo (>10 occurrences). In total, 34 thematic keywords and 13 geographical keywords were compiled (Box 1). The thematic keywords were divided into those describing a process of combating desertification (reforestation, afforestation, conservation, stabilization) and those describing specific themes (pastoralism, grazing, livelihood, water, erosion, etc.). The proposed query in the topics was as follows:

Box 1. Keywords used for the second collection of extended publications associated with SGGW and Land Restoration and Sustainable Management of Ecosystems

'Agropastoralism OR agroforestry OR forestry OR health OR livelihood OR "Land management" OR governance OR Drought OR water OR Mycorrhiza OR dust OR roots OR erosion OR microbiology OR forest OR trees OR "wood energy" OR adaptation OR jatropha OR land tenure OR land OR "rangeland management" OR employment OR sequestration OR soil OR vegetation OR climate
AND
degradation OR restoration OR Reforestation OR afforestation OR conservation OR stabilization OR regeneration
AND
Mauritania OR Senegal OR Mali OR Burkina OR Niger OR Nigeria OR Sudan OR Chad OR Ethiopia OR Djibouti OR Eritrea OR Sahel OR dryland'.

A collection of 6279 references from the WoS and HAL databases was selected. We only used these two databases because the other databases encountered difficulties in finding references for so many keywords. This is a limitation, but our aim is not to summarize all the studies that can be related to SGGW, but rather to provide an overview. The large number of references collected shows the difficulty in identifying work that can be considered GGW-related and shows the discrepancy between the small number of works tagged GGW (n = 184) and the number of references found when using GGW-related keywords. In this component of our review, we decided to use only the countries of study and the research topics, as referenced in the Web of Science database, as bibliometric indicators. Given the large number of publications, information on the authors is not included. Finally, we also analysed the frequency of keywords of the 5187 references that include keywords information for a more precise understanding of the topics of these numerous papers.

3. Results

In total, we selected 97 publications that offer information on the Great Green Wall. The publications range from 2010 to 2021 with an increase in number from 2019. Indeed,

43% of the papers have been published since 2019. This shows a growing interest in the GGW, especially in the 2020 review, but also reflects the trend towards a general increase in the number of articles published.

3.1. Ecology Is the Main Topic in SGGW-Related Publications

The work on the SGGW addresses several research topics, which have been classified into 10 different categories (Table 1).

Table 1. The main topics of SGGW research and the methodologies, spatial scales and main countries associated with these studies collected by the keyword GGW in WoS, Science Direct, HAL, Horizon and Agritrop databases (n = 97).

Topics	Recurring Subjects	Methods	Spatial Scales	Main Countries
Ecology (n = 21)	Characteristics of woody and herbaceous populations	Surveys and inventories	Local	Senegal/ Chad/ Ethiopia
Land Cover (n = 12)	Land use and vegetation trends	Remote sensing	Regional	Multi-countries
Ecosystem services (n = 9)	Roles of plants and trees	Surveys	Local	Senegal
Microbiology (n = 8)	Mycorhyzation	Experimentation and synthesis	Local/regional	Senegal/ Multi-countries
SGGW: concepts, policies and conditions of implementation (n = 14)	GGW Challenges Project approach	Synthesis & review	Regional/local	Multi-countries
Adaptation and feedbacks (n = 10)	GGW feedbacks and societal impacts	Surveys & synthesis	Local/ regional	Senegal/ Multi-countries
Local approach for SSGW (n = 8)	Need for integrating local context and local stakeholders	Synthesis	Regional	Multi-countries
Soil sciences (n = 7)	Evolution of the physico-chemical characteristics of soils	Soil testing and analysis	Local/ regional	Various countries GGW
Climate (n = 4)	Earth-atmosphere relations	Modelling and synthesis	Regional (Sahel)	Multi-countries

Ecology is the main area of research, with work aimed at characterizing the distribution of woody and herbaceous populations along the SGGW path and the conditions for successful reforestation programmes (n = 21). The data are mainly derived from field surveys (sampling, biomass analysis, circumferences, etc.) carried out locally in the countries implementing GGW programmes: Senegal, Chad and Ethiopia. These studies seek to make an assessment of woody communities, such as the monitoring carried out in Chad [8,9] or in Senegal [10]. Other examples seek to define carbon storage from allometric models [11] or the effects of the litter of different woody species on herbaceous biomass [12]. Finally, some seek to assess more directly the effect of certain reforestation practises on vegetation development [13]. At larger scales (Sahel, country), several publications (n = 12) investigate land cover and land use change (LULC) in the SGGW area. Remote sensing is the main method used in these studies. The study of ecosystem services related to reforestation is represented in some work (n = 9) where the objective is to evaluate the interest and use of tree species for societies through the provision of wood, fruit, honey or other support services (nutrient cycle, interest for agriculture). This research is mainly based on surveys of the populations concerned and therefore on a local scale, particularly in Senegal (6 studies out of 9). Microbiology also appears to be an important research theme in the implementation of the SGGW (n = 8), through work on mycorrhization. The aim is to support the success of reforestation projects using this approach with experiments on different useful species, such as jujube [14,15]. Research on this issue is conducted mainly on a local scale in the Senegalese Ferlo or in laboratory experiments.

The second-largest topic of study is focused on challenges in implementing the SGGW. These articles attempt to improve the feasibility and effectiveness of GGW programs in the Sahel by describing the conditions necessary for its success or the approaches to be deployed. Several papers (n = 14) focused on how the SGGW can be effectively implemented on the ground through reflections on issues, approaches and implementation logic. This type of study is mainly based on synthesis work, but also derives from surveys and modelling. The majority of the work is multi-country, and some of the work is

'generic' studies, not centred on a particular country or location. Others focus on case studies in Nigeria, Senegal and Mauritania. The topics of these works, which are based on different disciplines (economy, geography, political science), focus on the need to think more holistically about the implementation of the SGGW, considering the complexity of the socio-ecological systems in which it is embedded [16] and the historical context [17]. Some specific studies highlighted the importance of access to markets in SLM [18], the complementarity of shrubs with trees [19], non-monospecific reforestation [20], or the ability to integrate SGGW projects with other more local projects to facilitate their success. Among these papers, few (n = 8) address the specific issue of taking local context, knowledge and communities into account for the successful implementation of the SGGW. They point to the importance of coordination between scales of action and the popularization and dissemination of knowledge between scales. Studies on feedback and adaptation of rural societies focus on the analysis of direct and indirect effects of SGGW programmes on populations, in terms of their activity systems, poverty and health. These studies are based on field surveys for research conducted at local levels, mostly in Ferlo (Senegal), and reviews of work conducted at national or regional levels in SGGW countries. In this category, we can specifically mention three books in French which intend to provide feedback on and a compilation of programmes and research around the SGGW [21–23].

Finally, the other studies concern the physicochemical characterization of soils at the local level in SGGW zones (n = 7) and climatology concerning the SGGW (n = 4) at a regional scale (the Sahel or West Africa).

Our analysis reveals that synthesis and reviews are the most used methods (n = 34) for SGGW papers. Other results presented in these SGGW papers are from soil analysis and ecological sampling (n = 24). Population-based surveys (n = 13) and remote sensing (n = 12) are also frequently used methods.

This classification of the topics addressed by papers on the SGGW shows that there are gaps in the research. We can identify key themes of the GGW not represented in these studies. Pastoralism, whose integration is an issue for the success of the SGGW, is dealt with mainly by one article [24]. Only two papers focus specifically on the issue of water resources [25,26]. Carbon and its storage within the SGGW are also absent, with only one paper aiming to assess a carbon balance of a GGW area in the north of Senegal [27]. The study of erosion is one of the main research gaps, even though implementation of the SGGW aims to reduce erosive processes that lead to land degradation. Finally, on the societal impacts of the GGW, there is no work on the issue of employment, although this is one of the major targets of the SGGW. The question of governance of the actions carried out in the framework of the GMV is also absent.

3.2. SGGW Research Is Both Local and Regional

Most of the work on the SGGW is carried out at the local (n = 44) and regional–in a supra-national sense–(n = 35) scales, while the remainder is concerned with the national (n = 4), global (n = 4) or continental (n = 2) spatial scales or have no scale (n = 8). This can be explained by the dual impact of the spatial footprint of the SGGW, which crosses several Sahelian countries and is also locally inscribed within the territories that the belt crosses. Most of the regional studies in the SGGW papers are multi-country (n = 35). This type of work seeks to analyse the implementation of the GGW and its impacts at the scale of several countries. They deal with several GGW countries (19%), the entire Sahel (55%) or West Africa (26%). At a local level, the Ferlo region in Senegal accounts for the majority of studies (n = 27) followed by work in Ethiopia (n = 8). It is interesting to note that studies in Ethiopia are concentrated in the semi-arid zone in the south of the country, while the GGW path is located in the north (Figure 2). This shows the existence of local variations of this path and the interest of researchers who consider themselves to be working on the GGW. The remaining publications deal with the GGW in other countries. It should be noted that several SGGW countries that are highly involved in the GGW initiative have very few publications referenced, such as Mauritania, Mali or Niger.
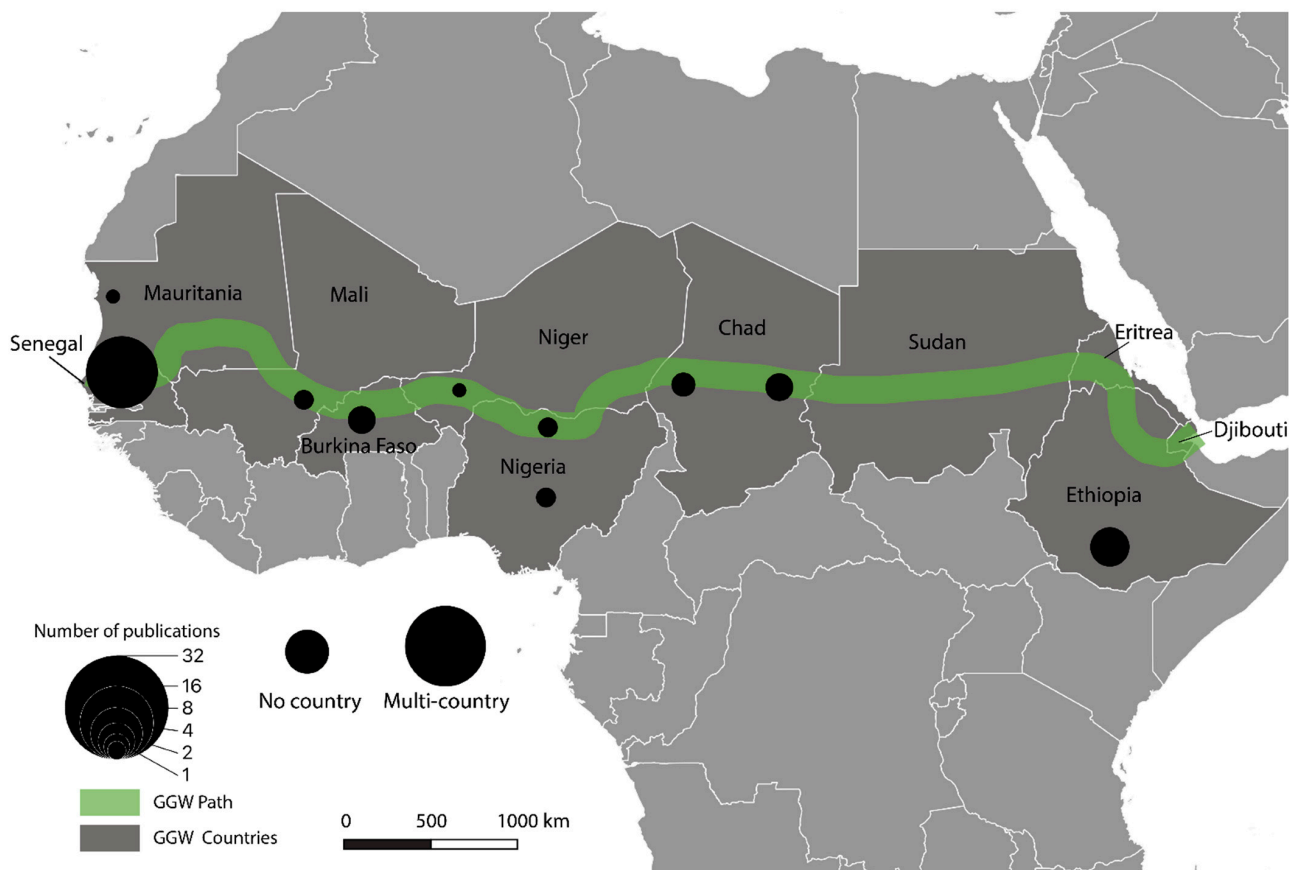
Figure 2. Map displaying the number of publications collected by region using the keyword GGW in WoS, Science Direct, HAL and Agritrop databases (n = 97).

Finally, there are no GGW references for three countries: Sudan, Eritrea and Djibouti. This may sometimes be explained by political instability (Mali, Sudan, Niger), but also by the fact that local researchers may not publish much in referenced databases, publishing in local journals or through more institutional work instead. Studies with no specific countries are also important (n = 9), i.e., laboratory work or analysis on a global scale.

3.3. Differentiated Contribution of National vs. International Teams to SGGW Studies

The first authors of publications on the GGW are mostly affiliated with universities or research institutes (90%), with the other first authors mainly affiliated with international organizations (FAO, CGIAR, JRC-EC). About two-thirds of the authors are affiliated with a Northern institution (70%), with a predominance of France (n = 31), China (n = 12), Italy and the UK (n = 4 each). It should be noted that our choice to search for references in several French bibliographic databases (HAL, Horizon and Agritrop) necessarily leads to an overestimation of French authors. In the South, the majority of authors are from Senegal (n = 21), which is consistent with the majority distribution of work in this country. The other SGGW countries are less well represented, with between 1 and 8 publications.

The countries that are home to the first authors' institutions are cross-referenced with the countries of study to determine whether the countries of study are the object of privileged research by a given country and/or institution (Figure 3).
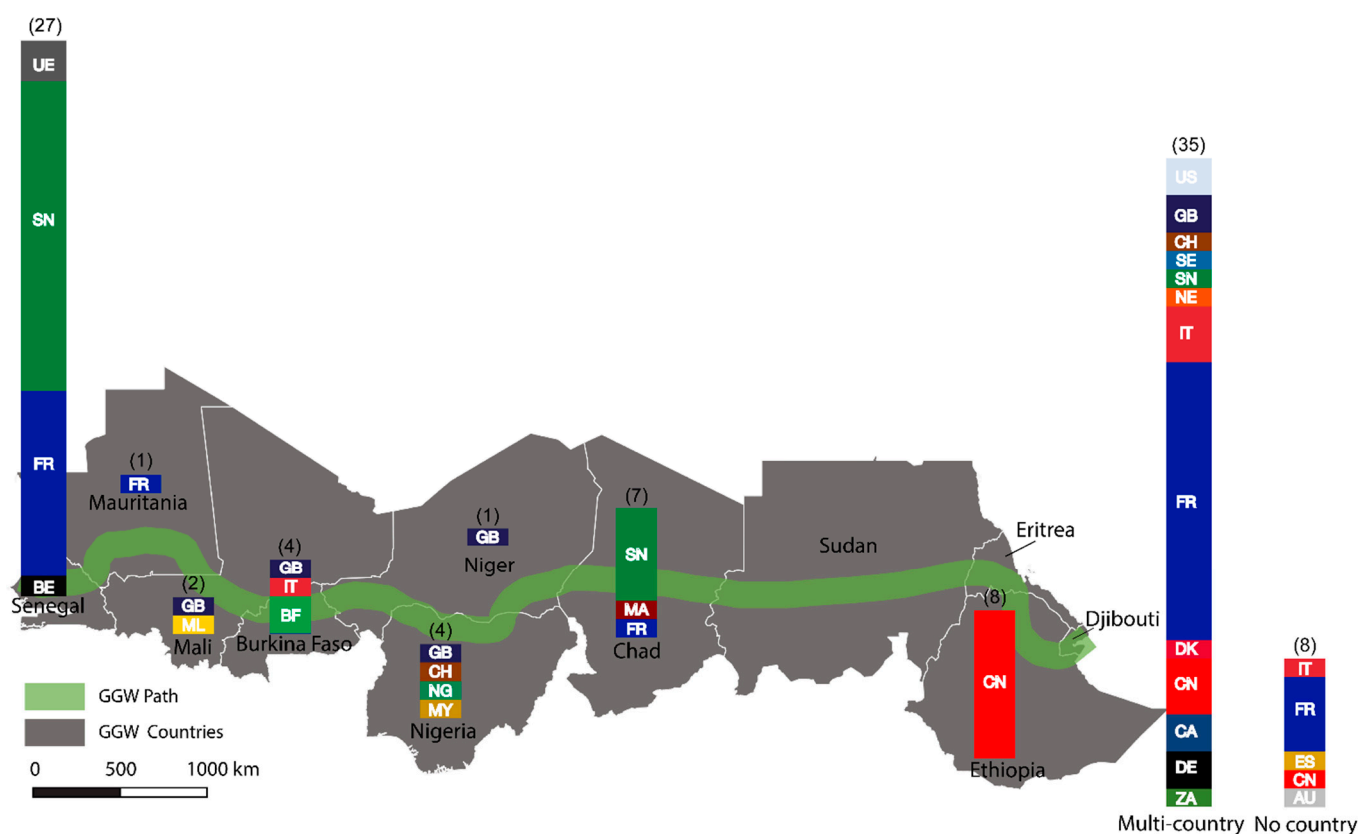
Figure 3. Map of SGGW studies and country of the first author associated. Country names are defined by the ISO3166 standard.

Senegal, the country with the largest number of publications, is studied first by national researchers, and by researchers from France. Researchers from Senegal also study Chad (5 publications). Ethiopia is unusual in that it is studied only by researchers affiliated with Chinese institutions. The other countries covered by the GGW are studied by researchers from either the country of study or other countries, mostly European ones. The multi-country work is carried out mainly by French researchers (n = 15) and researchers affiliated with institutions around the world (Italy, China, USA, Canada, Germany and South Africa). The particularities of the research fields are mainly linked to research networks and collaborations. In Senegal, work on ecology is carried out by the OHMI Téssékéré team from the CNRS/UCAD. French researchers mainly publish on issues related to SGGW implementation at regional scales, on the major issues of the SGGW, and the application of expertise or multi-country research programmes at local scales on the effects of SGGW on local societies, notably in the context of OHMI Tessékéré. There are also studies on microbiology and specifically on controlled mycorrhization technology for reforestation programmes. The research focus of the French researchers is on the critical evaluation of the SGGW and the mobilization of a specific technique for the SGGW (controlled mycorrhization). Researchers from China largely work on ecological issues in Ethiopia at a very local scale or on LULC issues at the Sahelian or West African scale. This research is oriented toward the issue of trees and reforestation, which can be explained by the Chinese institutions' expertise in this field with their experience with their own GGW (Three-North Shelter Forest Programme), implemented in northern China since the 1970s. The Senegalese researchers are mainly focused on local ecology, the characteristics of woody populations and the analysis of the ecosystem services of trees for the improvement of living conditions in the framework of the implementation of the SGGW. Other work concerns microbiology and soil science. Studies done by other researchers in SGGW countries focus on 'physical' science issues (ecology, LULC, climatology and ecosystem

services). The other Northern countries working on the SGGW have mainly published on issues concerning GGW implementation and feedback, the study of large-scale land restoration and economic analysis.

Ultimately, studies on ecology, ecosystem services, biology and soils are mainly produced by researchers who can easily access the area under study, while studies on SGGW implementation from a political, agricultural and governance point of view, and the related societal adaptations, are mainly produced by researchers from the North located at a certain distance from the SGGW project. Finally, there is a need for researchers in the countries concerned to assess the direct and indirect impacts of the SGGW.

3.4. Very Limited Production of Primary Data

A total of 36% of the SGGW studies are based on primary data, i.e., data collected in the field or the laboratory, while 58% use secondary data, i.e., data from analyses of other sources of primary data (reviews, syntheses). Review studies represent the main method for 56 papers. The studies that analyse primary data involve data collected in the field or through laboratory experiments: the analysis of spatialized data and remote sensing (n = 12), the analysis of data from surveys (focus groups, interviews, questionnaires) (n = 13), the analysis of field data from surveys (soil, vegetation) (n = 25), and the analysis of data from measurements in experimental stations (n = 5) or climate modelling (n = 3).

The data contained in the SGGW papers shed light on the variables studied by the researchers. These variables can be considered indicators for monitoring sustainable land management objectives in the Sahel. In the SGGW database, 59 publications contain three main categories of quantitative data.

3.4.1. Ecological Data

The largest proportion of the data (n = 19) deals with plant ecology based on vegetation surveys, tree size, growth, and biomass, as well as the physicochemical characteristics of the soil (n = 5). Studies that seek to evaluate the regeneration capacity of tree vegetation in the Sahel and improve reforestation operations are the most numerous. Most of the work on reforestation objectives is carried out at the local level in ecology, soil science or microbiology. They identify the specific diversity and characteristics of woody populations based on ecological surveys, particularly in the Ferlo and in Chad. This work shows the predominance of Acacia species (Raddiana and Senegalensis) and *Balanites aegyptiaca* in the success of reforestation operations [28] (Sagna et al., 2014). Other studies seek to define the influence of environmental conditions on woody populations and show the edaphic and topographic preferences of trees [29,30]. Finally, other studies attempt to define the influence of land regeneration, enclosure and land management practices on woody populations and soils and show that these practices positively influence tree mortality and growth, as well as soil fertility. The data collected in this work make it possible to assess the dynamics of the evolution of SGGW vegetation operations and contribute to monitoring restored land area objectives. Similarly, carbon sequestration is little studied at the SGGW level. Only two studies analysed this aspect: one is very localized and the second looks at a global scale, and there are no studies linking the two scales.

3.4.2. Land Cover and Vegetation Changes Using Remote Sensing

At the regional scale of the Sahelian strip, publications with quantitative data mainly seek to analyse the evolution of land cover and in particular the evolution of vegetation using remote sensing (n = 11). In this type of study, six papers try to assess and monitor vegetation only, notably by using NDVI or spatializing wooded areas. Two studies aim to directly analyse the impact of SGGW projects in North Senegal using only the area covered by vegetation as indicators [31,32]. More general land cover change assessment and evolution in GGW areas are covered in five papers. The results of these papers are complementary to others done locally in the field of reforestation ecology when it comes to defining options for the implementation and success of the GGW.

3.4.3. Data on Societal Impacts of SGGW

Beyond the reforestation objectives, publications containing data on the societal impacts of GGW programmes are scarce and partial. Nevertheless, some publications seek to link ecological and social indicators by assessing the ecosystem services of trees. Some of them try to identify the number and species of trees useful for food, energy, medicine and construction. Acacia Senegal and *Balanites aegyptiaca* are the trees most favoured by populations, who attribute many services to them [33]. There are few studies based on direct feedback from SGGW programmes. We have counted nine publications that deal directly with the beneficiaries in the context of feedback. These are based on survey and interview data. For example, studies by [34,35] at the FAO seek to analyse projects in terms of the number of beneficiaries, villages involved, or seedlings replanted, while two papers focus on the specific effects of GGW projects in the Ferlo on health [36] and migration [37]. When it comes to the societal objectives of the SGGW, the indicators for monitoring are thus very few in number and focused on a limited number of aspects (health) or study areas. It is presently very complex to evaluate the impacts of the SGGW on the objective of 400,000 beneficiaries or 10 million jobs created.

3.5. Wider Expertise in Publications Related to 'Land Restoration and Sustainable Management of Ecosystems': The Forest behind the Tree

The analysis of the keywords contained in the references shows that, in the extended GGW papers, the most frequent keywords (n > 1000) are soil, conservation, land, degradation, management, forest, water and vegetation. The comparison of the keywords between the SGGW and SGGW-extended research shows the existence of common subjects (Table 2), in particular around the issue of land restoration (land, soil) and plant ecology (forest, tree, vegetation, biomass).

The GGW-related studies seem to be more strongly interested in work on mycorrhization, roots and trees specific to SGGW such as *Balanites aegytiaca*. Likewise, the societal keywords of the two databases are initially quite similar and general (management, sustainability, landscape, ecosystem services). SSGW-related studies on this issue readily address development, resilience, health and governance issues. The SGGW-extended papers with keywords information (n = 5187) offer additional references on themes related to SGGW objectives that are notably: water (n = 814), erosion (n = 597) and runoff (n = 267), erosion control through mulching (n = 187) and agroforestry (n = 176). Regarding climate mitigation objectives, the extended studies are more numerous, with existing keywords such as carbon (n = 503), sequestration (n = 173) or mitigation (n = 59). Finally, concerning the societal objectives of the SGGW, the extended studies are oriented towards agricultural (n = 342) and food security issues and in particular towards the question of agricultural yields (n = 284) and plant productivity/growth (n = 250).

Geographically, the two bibliographic research studies (SGGW search and extended search) show a concentration of research in the Sahel, West Africa at a regional scale, and Senegal, Ethiopia and Nigeria at a local scale. As we have seen, the papers tagged SGGW are also more focused on the specific regions of the Ferlo and Borana. The analysis of extended papers using WoS tools concerns all SGGW countries, but unequally. Nigeria and Ethiopia are the two main countries with 1020 and 2025 publications respectively, followed by Niger (n = 981), Burkina (n = 393), Senegal (n = 334), Sudan (n = 279) and Mali (n = 170). Mauritania and Chad feature in fewer than 100 papers, while Eritrea and Djibouti appear in fewer than 20 each. As in the SGGW-related database, multi-country papers (or other laboratories, etc.) are numerous, with over 800 references. It is therefore possible to find scientific information on topics related to the SGGW in countries that are 'orphaned' in the pure SGGW database.

Table 2. Keywords found in both databases with occurrence > 3% of publications.

Keywords (Occurrence > 3% of Publications, Approx. 150 for Extended and 3 for GGW)	Geography	Generic & Methods	SGGW Objectives		
			Land Restoration	Climate & Carbon Sequestration	Effects on Society and Employment
In both database	Sahel, africa, senegal, ethiopia, nigeria	Conservation, degradation, restoration, desertification, systems, NDVI	Land, soil, vegetation, forest, species, tree, plant, ecosystem, biomass, ecology, biodiversity	Climate change	Management, sustainability, adaptation, landscape, ecosystem services, impacts,
GGW only	Ferlo; west africa; borana, niger	GGW	Mycorhize, woody, Balanites aegyptiaca, neutrality, root, rangeland	NA	Development, resilience, health, rural, practices, governance
Extended only	Desert, Tigray	Regeneration, model, index, remote sensing	Water, erosion, land cover, run off, sediment, patterns, tillage, river, nitrogen, biodegradation, agroforestry	Carbon, drought, rainfall, sequestration	Agriculture, yield, growth, productivity, farmers, crop, food, knowledge, security, population, production, organic, livelihoods

Concerning the Sahelian countries involved in the GGW, the works referenced in the WoS show a predominance of environmental sciences and ecology (Figure S1), accounting for around half of the papers published in these countries according to our research, and up to 60% in countries with little documentation (Mauritania, Djibouti). Work on agronomy, agriculture and forestry represents up to 30% of research in countries such as Burkina and Mali. Soil science is mainly found in Ethiopia and Burkina Faso. The issue of water, which is largely absent from the GGW papers, appears here in 5–10% of the publications per country. Biodiversity conservation is an important theme in some countries, particularly those included in little documentation, such as Mauritania, Chad and Djibouti. The SHS account for between 1% (Ethiopia) and up to 10% of research (Mali, Nigeria, Senegal). Finally, particularities can be observed in some countries. In Niger, 50% of the research does not fall into the above-mentioned categories: more than 200 publications deal with microbiology, while the rest concern biology and geosciences. In Nigeria, the main issue is green sustainable science, plant science, biotechnology and energy, likewise in Sudan (plant science, remote sensing and energy), bearing in mind that both are oil-producing countries.

4. Discussion: The Need for More Integrated Research

The analysis of SGGW and SGGW-extended research shows the need for research to better connect work and to include more studies in the SGGW category. Research that considers itself SGGW-oriented is focused on certain areas only, particularly ecology or the specific challenges for SGGW implementation, while researchers are engaged in a variety of research topics in SGGW terrains in the Sahel. Social and human sciences are the main field overlooked by SGGW studies. Several aspects of SGGW (security, migration, employment and agriculture) require an understanding of the socio-economic dynamics in the SGGW and surrounding areas. In the references tagged SGGW, few studies directly address the societal and human effects of GGW projects (<10), whereas, in the extended SGGW-related references, the keywords agriculture, farmers, community, adaptation, population, agroforestry, and livelihoods account for between 150 and 350 papers each. Moreover, research is concentrated in specific countries (Senegal, Ethiopia), most often where SGGW programmes have made the most important advance and where there has been the most funding. For the countries that are less represented, such as Burkina Faso, Mali and Niger, there are respectively 393, 170 and 991 references collected in the SGGW-related database, which shows that research exists in all countries and areas covered by the SGGW initiative. These studies need to be placed in perspective with the implementation and objectives of the SGGW if they are to contribute to it. Among the many extended publications related to SGGW, it can be assumed that a number of them address SGGW directly but are not labelled or designated as such by the authors.

The objective for the successful implementation of the SGGW in the Sahel is the mobilization, capitalization and mutualization of all research forces at all scales and not only those claiming so far to focus on the SGGW. This can be envisaged through the development and articulation of regional, national and local interdisciplinary research networks around the SSGW.

Similarly, other than the mobilization of researchers, work on the implementation of the SGGW shows a need to consider the context of GGW interventions to move beyond the usual approaches to development in the Sahel. Several studies note the need to develop a systemic, inclusive and transdisciplinary approach so as not to reduce the SGGW to ecological issues and national imperatives only. This reinforces the conclusion of our findings on the need for networking at all scales and mobilization across different strands and countries of study. Furthermore, the SGGW should not be considered only at a regional level, as its success also depends on integration into local projects, as is the case in the city of Chami in Mauritania [38]. Finally, many studies illustrate the difficult linkages between the national and local scales in SGGW programmes to show the importance of involving local communities and taking into account local knowledge for the success of the SGGW.

This result is consistent with much of the work on adaptation drivers and the need to integrate local knowledge into land degradation adaptation programmes [39,40]. Research can also be conducted using more participatory approaches to assess the needs and impacts of the GGW at the community level. It is crucial to engage a diversity of stakeholders in a dialogue for the success of the SGGW for 2030.

Monitoring the GGW and the achievement of its objectives must also be supported by research in order to develop harmonized indicators that describe the reality of the socio-ecological issues and dynamics around the SGGW. The indicators to be selected for effective monitoring must integrate multi-disciplinary aspects and cover all SGGW objectives. Therefore, the development of multi-criteria indicators is a major step in ensuring the success of SGGW programmes. Finally, these indicators need to be the subject of a consensus between the various stakeholders, including local communities, to ensure effective governance of GGW projects.

5. Conclusions

Launched in 2005 at the Conference of Heads of State and Government of the Community of Sahelo-Saharan States, the Great Green Wall initiative is a large-scale, ambitious response from the African Union to the challenges of combating desertification, climate change, biodiversity loss and poverty. This initiative prefigures what was advocated in 2015 by the Global Sustainable Development Report [41], namely that the sustainable development objectives will only be achieved if the initiatives focus on documenting the interactions between the targets of each of the SDGs. In other words, the Great Green Wall will only be a success if it contributes to the achievement of climate ambitions, neutrality in terms of land degradation, conservation and enhancement of biodiversity, the fight against poverty, food security, and so on.

In its 2021–2030 Decennial Priority Investment Plan, (https://www.grandemurailleverte.org/images/ENG-DPIP.pdf (accessed on 11 September 2022)), the Pan-African Agency of the Great Green Wall (PAGGW) identifies five groups of Priority Impact Programmes, one of which concerns "Strengthening scientific and technical capacities".

Our results have shown that research claiming to study SGGW is dominated by ecological topics, with the majority of work aiming to characterize the distribution of woody and herbaceous populations along the SGGW path and the conditions for successful reforestation programs. The second largest topic focuses on the challenges of implementing the SGGW, especially at the conceptual and policy level. Other topics are local community adaptation, tree ecosystem services, land cover change, microbiology, soil science and climate. Some gaps in research appear such as pastoralism, water, carbon storage, employment and governance. Studies on SGGW are conducted either at the local level or at the Sahel level, and few link the two. Some countries and areas are over-represented, notably Senegal. Most of the primary data on SGGW found in the literature relate to ecological and land cover changes and little to other objectives, especially societal ones. There is a need to define scientifically validated indicators for monitoring the SGGW.

Finally, a more in-depth collection on the issue of land degradation and sustainable ecosystem management showed that research that can contribute to the successful implementation of the SGGW exists and is able to fill the research gaps identified in the studies labelled SGGW.

By taking stock of the scientific work carried out in the Great Green Wall countries in the Sahel, and by highlighting the need to develop interdisciplinary, systemic and inclusive research, our paper provides elements for consolidating the contribution of scientific expertise to the PAGGW 2021–2030 agenda. This expertise requires financial resources to continue to produce knowledge to inform the scaling up of solutions adapted to the multiple challenges of the Great Green Wall, and it must be taken on board by the bodies responsible for planning and coordinating actions. South-South and South-North networks must be encouraged and supported in the long term. Similarly, a close partnership with funding agencies should be set up to co-design solution-oriented research projects.

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