ASSESSING THE HOLISTIC IMPACT OF MANGED AQUIFER RECHARGE ON ECOSYSTEM SERVICES

INTERNATIONAL WORKSHOP PROCEEDINGS

Dresden, Germany 12 April 2021

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Assessing the holistic impact of managed aquifer recharge on ecosystem services

Proceedings of the International Workshop

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Collaborated by:

Latin American MAR Community of Practice (LatinMAR)

About this report

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BACKGROUND

The United Nations University for Integrated Management of Material Fluxes and of Resources (UNU-FLORES) promotes the application of nature-based solution (NBS) to mitigate climate change, further providing ecological benefits and strengthening our knowledge for a sustainable management of environmental resources. Managed aquifer recharge (MAR) is one of the best examples of NBS for viable and sustainable water supply in urban and peri-urban areas that can prevent high evaporation losses, capture, and store the effluent of constructed wetlands, wastewater treatment plants, safeguarding the removal of viruses, pathogens and organic matter.

Despite the abundance of natural water resources in Latin America and the Caribbean (LAC), urban areas face major shortcomings in the delivery of basic services such as safe water supply. The cause is manifold, including spatial and temporal heterogeneity of water resources, negative water balance caused by overexploitation, and insufficient human capacities and governance. The conventional solutions based on “grey” infrastructure cannot cope with the basic needs of the population; so, an urgent need of appropriate, locally accepted technical options is required.

To address these challenges, a multi-partnered project entitled “Digitally-enabled Green Infrastructure for Sustainable Water Resources Management (DIGIRES)” was kicked-off in May 2019 with financial support from the German Federal Ministry of Education and Research (BMBF) and other national funding agencies from Brazil, Guatemala and Cuba under ERANet-LAC 3rd Multi-Thematic Joint Call 2017/2018. ID: ERANet17/ICT2 0196 DIGIRES. The overall goal of DIGIRES is to develop and mobilise information and communications technology (ICT), coupled with citizen science observations for the design and implementation of MAR as nature-inspired components of sustainable water resources management in the LAC region. In this project, managed aquifer recharge (MAR) is proposed for replacing traditional water infrastructure with greener, NBS that allow for a more equitable water provisioning. The efficiency of the solutions proposed will be demonstrated through success stories, by designing and implementing small-scale, demonstrative MAR schemes with the active participation of stakeholders and by developing capacities for sustainable urban development.

Within the umbrella of DIGIRES, UNU-FLORES was pleased to join forces with TUD, to co-organise this International Workshop on assessing the holistic impacts of MAR on ecosystem services. The UNU-FLORES and TUD team collaborated with LatinMAR community which primarily focuses to promote managed aquifer recharge for project development, execution, and knowledge dissemination in Latin America.

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Section 1: Setting the Scene

1.1 Introduction

The world has been experiencing increasing water scarcity problems due to rising populations, socio-economic activities, and land use management in recent years. The most vulnerable zones to the growing pressure on water resources correspond to arid and semi-arid regions where average temperatures rise and precipitation levels fall, leading to prolonged droughts. This compromises the availability and quality of water. For rural and urban areas, engineering innovations that reduce the environmental footprint, limit space consumption, reduce evaporation, or mitigate flooding or droughts will likely improve the overall quality of life.

Managing aquifer recharge (MAR) is an important water management strategy for maintaining, improving, and protecting stressed groundwater systems, protecting, and improving water quality, and assisting in climate change adaptation and conservation of freshwater biodiversity. However, MAR is still underutilized as a water management tool due to a lack of awareness of its potential. It is believed that its benefits are just confined to maximizing the natural water storage and managing the water quality. The interaction of MAR among ecosystem services and synergies and trade-offs between them is also poorly understood scientifically.

Aim of the workshop: The aim of the workshop was to identify knowledge gaps and raise awareness about the holistic potential of MAR and its contribution to multiple ecosystem services. The workshop demonstrated how collaboration among various stakeholders could strengthen water security by helping to achieve multiple objectives among which a greener transition into unconventional water management for Latin America. The outcomes of the workshop helped to define the bottlenecks and success factors for future MAR implementation in the region and worldwide.

1.2 Methodology

A. Preliminary research on ecosystem services perception

The workshop is based on a preliminary work run by the Technical University of Dresden and the UNU-FLORES on the characterization of the direct and indirect contributions of MAR to the environment and human well-being.

The reported influence of MAR on the environment in the scientific literature has been assessed previously. The MAR ecosystem services have been categorized in concordance to the Common International Classification of Ecosystem Services (CICES V5.1).

The synergies and tradeoffs resulted from MAR influence on ecosystem services were evaluated according to the methodology proposed by (Bennett, Peterson, and Gordon 2009) using an expert-based assessment. The outcomes of the analysis were validated via present workshop and dedicated surveys.

A1. Participatory assessment of the perceived MAR related ecosystem services

An online survey (Annex 1) targeting to Latin American experts regarding managed aquifer recharge from the Latin American MAR Community of Practice (LatinMAR) was designed prior to the workshop. Following the standards of CICES categorization, the survey aimed to collect respondent's perception on impact of MAR on ES. The survey specifically investigated experts' experience on the identification and recognition of MAR services. It was published in the online platform "*Survey: Der Umfragedienst für sächsische Hochschulen und Berufsakademien*", which translates as "The survey service for Saxon universities and vocational academies" (https://bildungsportal.sachsen.de/umfragen/). Besides English, the survey was also made available in Spanish and Portuguese to facilitate the inclusion and participation of more people.

A total of 20 experts participated, and the total number of answers per ES varied between 17 and 20. The majority of the participants believe that MAR can influence the environment throughout all 33 ES groups.

B. Methodology of the Workshop

The main goals of the online workshop were to validate the survey and assess the perceived ecosystem service interactions resulting from MAR.

Target of the workshop were the respondent of the online survey and additional Latin-American experts related to the field of Managed Aquifer Recharge.

The interactive online workshop specifically looked at (a) validating the responses from the previous survey, (b) obtaining information on possible interactions between the ES resulting from the implementation of MAR, (c) receiving feedback on the activities themselves, and (d) assessing whether expert's perception of MAR and its possible benefits had changed.

With the workshop specific objectives must be addressed:

- To conceptualize the interlinkages between nature and human systems from a water resources management perspective.
- To characterize the influence of MAR on the environment (effect on ecosystem services).
- To assess the interactions among ecosystem services triggered by MAR activities

C. Workshop activities

The workshop was held in the ZOOM platform, where there were introductory presentations about the research background and objectives. The workshop's core revolved around two activities, conducted in Miro Whiteboards, enabling real-time collaboration between staff and participants. Before these activities, brief presentations consisting of explanations and examples of the tasks at hand were conducted. Here, the participants were introduced to visual support denominated "flashcards" (Annex 2) to be used in the activities (see Figure 1). These flashcards were colour-coded to help in the interpretation of results: on the name band, green represents biotic ES, while red abiotic ones; the bottom band shows to which CICES section the ecosystem services correspond, yellow is used for Provisioning, grey for Regulation & Maintenance, and blue for Cultural). For the activities, the participants only required the flashcards names and images.

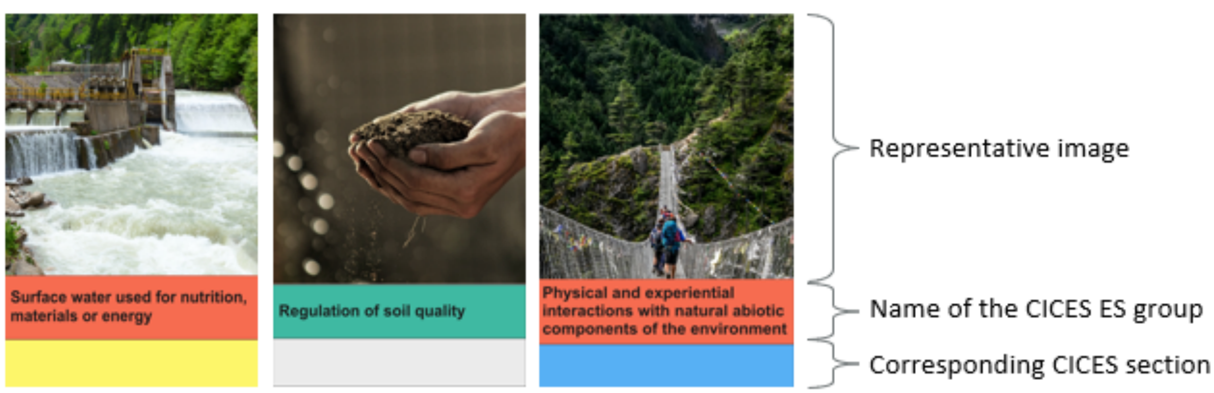


Figure 1: Example of Flashcards

After the explanation, multiple ZOOM rooms were created and facilitated by Spanish-speaking moderators.

In activity 1 the experts were asked to select the most relevant ES affected by the implementation of MAR (both positively and negatively influenced). Also, experts were asked to show examples where ES are not affected by MAR by using a Miro Board tool.

Figure 2: Activity 1 - MAR workshop - Miro Board

Activity 2 instead consisted in generating hypothetical MAR cases in which all the interactions between ecosystem services (unidirectional, bidirectional, positive or negative) could be included (Figure 3).

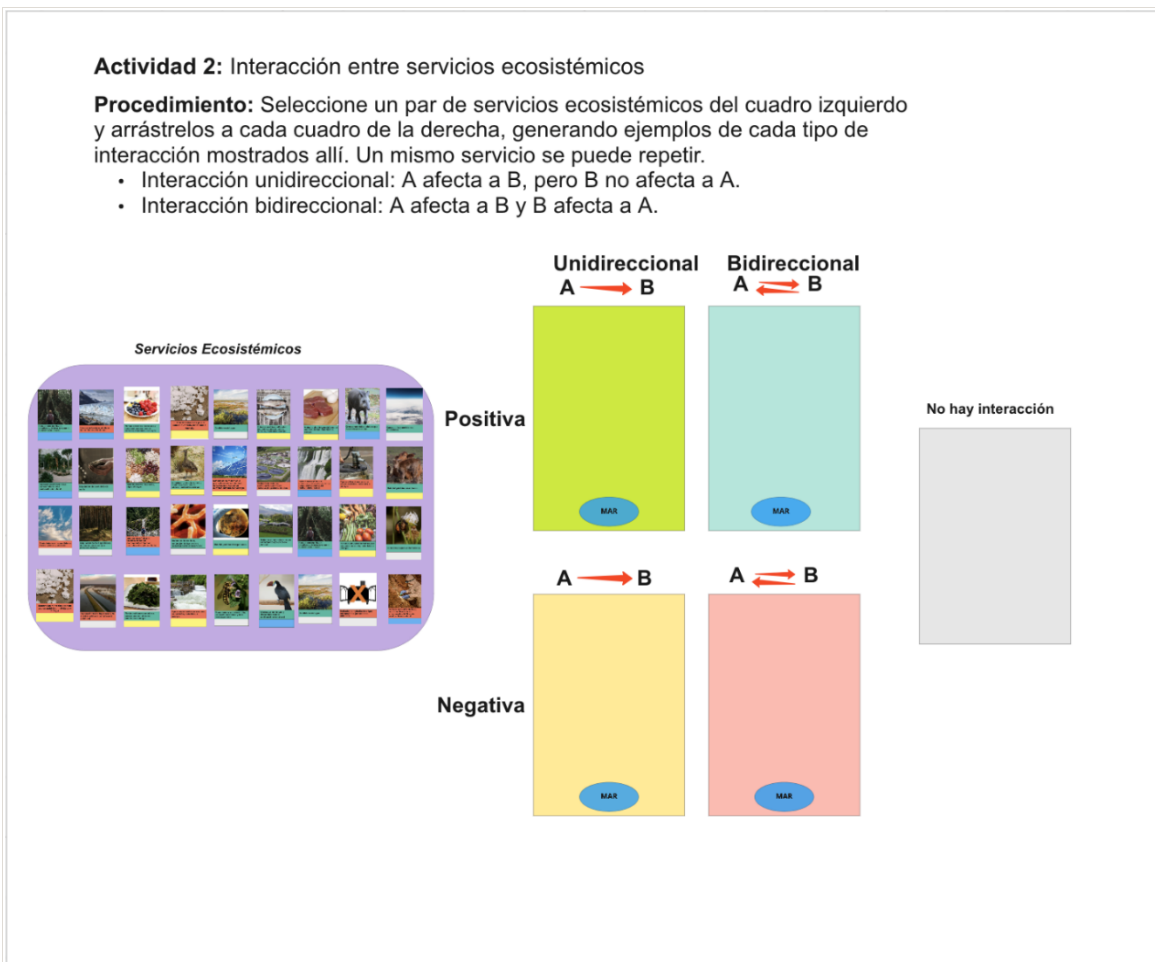


Figure 3: Activity 2 - MAR workshop – Miro Board

D. Links between preliminary research, Survey and Workshop

The existing reported influence exerted by MAR on the environment have been evaluated according to the methodology proposed by (Bennett, Peterson, and Gordon 2009) using an expert-based assessment via workshops and surveys. The ecosystem services were classified in concordance with CICES V5.1. On the one hand, this method focuses on the effect (if it exists) a certain driver has on ecosystem services, which can be positive or negative. On the other hand, it attempts to analyze the interaction occurring between a given pair of ecosystem services. These interactions are characterized as uni- or bi-directional and positive or negative, or no-interaction. The aggregation of the previous two step will lead to the identification of synergies and trade-offs generated by MAR activities.

Linking the preliminary results with the survey will be of use in this workshop for the purpose of highlighting the full range of potential of the non-conventional water resources management strategies beyond the technical benefits mostly recognised with the MAR.

1.3 Workshop Overview

During his welcome, Dr Catalin Stefan (TUD) explained the purpose of organising the interactive workshop on managed aquifer recharge at an international level as despite the increasing level of scientific knowledge and number of applications worldwide, MAR is often confined merely as a tool to secure and enhance drinking water provisioning and agricultural productivity. However, recent empirical knowledge hints towards a huge potential impact of MAR on wide range of ecosystem services (ES). Dr Stefan expressed the vision of utilising the results from the research study to enhance multiple ES through this water management technique (MAR).

Ms Catalina Zapata (TUD) presented the results of a preliminary qualitative assessment to investigate the impact of MAR on ES and how those ecosystem services interact. This included the problems such as lack of awareness among stakeholders about the direct and indirect benefits of MAR from an ecological and economic perspective as well as the brief introduction on Common International Classification of Ecosystem Services (CICES). This was followed by the visual representation of synergies and trade-off among ES through MAR. Right after Ms Zapata' s presentation, Dr Serena Caucci comprehensively explained following two activities to the participants:

For participants to interact with each other on an online platform, two breakout rooms were prepared on Zoom. Thereafter the participants were redirected to a virtual Miro whiteboard where everyone had the access to the perform group activity. Different flashcards of ES were provided to the participants on the Miro board. The breakout session was moderated by Ms Andera Müller (UNU-FLORES) and Ms Catalina Zapata (TUD), respectively. They provided required guidance to the workshop participants.

For an effective communication between the participants, the flashcards and the activity procedure were provided in Spanish.

At the end of the breakout room sessions, the participants were reconvened in the in plenary session and the rapporteur from individual breakout room presented the main outcome of the group activity. Thereafter, feedback about the organisation of the workshop was collected from the participants followed by the survey analysis done by Ms Zapata on expert-based judgments on the influence MAR on the environment and the interactions of ecosystem services.

Section 2: Understanding the problem

2.1 Current knowledge about benefits of managed aquifer recharge

Ms Catalina Zapata introduced the current and past knowledge related to the benefits of managed aquifer recharge on environment.

Ms Zapata called the attention of the participants to the technical hurdles on MAR being restricted to as water quality improver and capable of increasing groundwater availability. The ecosystem services related to MAR are indeed more than that. The lack of awareness among majority of stakeholders to understand the holistic benefits (socio-economic and cultural) of MAR applications is thus potentially huge and it could lead to an underestimation of MAR applications. TUD and UNU-FLORES ran preliminary research on this topic and tried to verify in literature whether MAR is mentioned as ecosystem service provider beside the one related to water availability and instead looked at MAR as means to enrich local biodiversity, mitigate water-related disasters, promote ecotourism, enhance land use management practices etc.

Ms Zapata presented the results of a literature review that comprised over 50 case studies of MAR at a global level. Through her analysis, she confirmed that very few research articles focuses upon other benefits of MAR besides enhancing groundwater quantity and water quality.

As is illustrated in Figure 4, almost 64% of the cases studied focused on the earlier mentioned functions but did not mention MAR's use in ecosystem restoration or another application. There remains a great deal of untapped potential for implementing MAR in a wide range of contexts.

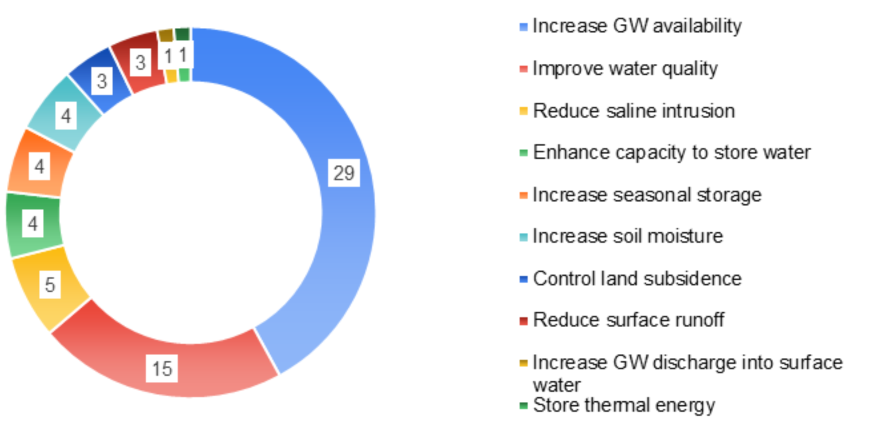


Figure 4: MAR potential for sustainable greening transition of water resource management

2.2 Interaction between Managed Aquifer Recharge and Ecosystem Services

The results from the literature review directed towards the opportunity to assess the holistic impacts of MAR on the environment.

The CICES classification was designed to help measure, account for, and assess Ecosystem Services. They are defined as the outputs of ecosystems that most directly affect the well-being of people and are different from the goods and benefits that people subsequently derive from them. CICES Version 5.1 was used for their classification, which includes the ES that depends on living systems (i.e., biodiversity) and the non-living parts of ecosystems that can also contribute to human well-being (i.e., abiotic components). CICES consists of a five-level hierarchical structure, where each level is increasingly more detailed and specific. At the highest level of the hierarchy, there are three different sections:

- Provisioning: All nutritional, non-nutritional material and energetic outputs from living systems and abiotic outputs (aqueous and non-aqueous outputs).
- Regulation and Maintenance: All how living organisms can mediate or moderate the ambient environment that affects human health, safety, or comfort, together with abiotic equivalents. This definition covers both the transformation of biochemical or physical inputs to ecosystems in the form of wastes, toxic substances and other nuisances, and the regulation of physical, chemical, biological conditions.
- Cultural: All the non-material and normally non-rival and non-consumptive outputs of ecosystems (biotic and abiotic) that affect people's physical and mental states. Cultural services are primarily regarded as the environmental settings, locations or situations that give rise to changes in people's physical or mental conditions. The character of those settings is fundamentally dependent on living processes; they can involve individual species, habitats, and whole ecosystems.

The distribution of interactions seemed to be strongly influenced by the section of CICES in which they occur. Cultural ecosystem classes can interact with each other in 100% of cases. Cultural ecosystem services are not mutually exclusive, and therefore can be accessed simultaneously by many people. Additionally, the interlinkage between Provisioning and other ecosystem services shows the most negative interactions, likely since resources are finite and that if one resource is removed beyond its recovery capacity, others will be affected as well.

Here are represented the first preliminary results from the workshop activities:

Table 1: Workshop Activity 1: Percentage of ES selected in each category (average).

Ecosystem Service	Provisioning	Regulation & Maintenance	Cultural	Total
Biotic	61% (n=9)	44% (n=8)	25% (n=4)	48% (n=21)
Abiotic	25% (n=4)	75% (n=4)	25% (n=4)	42% (n=12)
Total	50% (n=13)	54% (n=12)	25% (n=8)	45% (n=33)

Table 2: Workshop Activity 2: Percentage of ES selected in each category (average).

Ecosystem Service	Provisioning	Regulation & Maintenance	Cultural	Total
Biotic	39% (n=9)	50% (n=8)	50% (n=4)	45% (n=21)
Abiotic	25% (n=4)	38% (n=4)	38% (n=4)	33% (n=12)
Total	35% (n=13)	46% (n=12)	44% (n=8)	41% (n=33)

Section 3: Discussion

3.1 Effects of Managed Aquifer Recharge on Ecosystem Services

- **Positive influence**

The participants of group 1 identified managed aquifer recharge as the potential driver of multiple ecosystem services. However, the participants recognised only few ecosystem services having synergies between them. As an example, from biotic components of ecosystem services; managed aquifer recharge could have a positive impact on

a) cultivable terrestrial as well as wild plants (terrestrial and aquatic) for nutrition, materials and

energy

b) animals (terrestrial and aquatic) for nutrition, material and energy

In addition, the participants noticed a positive effect of MAR on the provision of water supply for nutrients, materials, and energy, as well as water conditions.

According to the second group, MAR could substantially enhance provisioning, regulating, and maintaining ecosystem services. Some of these recognised ecosystem services were aligned with the first group and pointed out the biotic components of ecosystem services like

- cultivated and wild plants for nutrition, materials, and energy
- lifecycle maintenance, habitat, and gene pool protection
- groundwater uses for nutrition, materials, and energy

The participants of group 2 additionally to what group 1 highlighted, stressed the importance of water accessibility, regulating baseline flows, and preventing extreme events. The rapporteur gave an example of irregular rainfall patterns in central America, followed by a recharging surface water runoff recommendation.

- **Negative influence**

MAR activities were not found to have had a negative impact on the environment, as reported by the rapporteur. However, one has been identified as a potential negative impact based on general perception, i.e., mediation of waste, toxins, and other nuisances by non-living processes. According to MAR's current knowledge, either it could be beneficial to improving surface water quality, or it could risk deteriorating groundwater quality.

The group's rapporteur pinpoints that the MAR could negatively influence all the previous identified ES if it lacks strategic implementation. In addition, the group concluded that MAR could harm the mediation of waste or substances of anthropogenic origin by living processes.

- **Neutral influence**

The group identified the following ecosystem services to not influence due to MAR activities.
Provisioning: genetic material from organisms, mineral substances for nutrition, materials, and energy
Regulation and maintenance: mediation of nuisances of anthropogenic origin.
Cultural: intellectual and representative interactions with the environment are another abiotic characteristic that have a no use-value.
Insufficient genetic information from organisms, plants, animals, algae, and fungi among the participants made it difficult to speculate whether MAR activities influence them.

3.2 Interactions among Ecosystem Services due to Managed Aquifer Recharge

According to a previous academic study on the topic (Imran et al., 2021) and the participatory analysis conducted in this research, MAR has the potential to affect most ecosystem services (ES) and that this effect is mainly positive. Still, the connection to Cultural ES was the hardest to visualize for the participants, coinciding with the study above, which found that the cultural dimension is often disregarded (no mention of the link between MAR and Cultural ES in 69 case studies). The current research also noted that some ecosystem services seem to be mutually exclusive (mostly Provisioning

ES). Overall, there were more synergies (81% of 292 possible interactions), indicating that the application of MAR techniques can have an increasingly positive and far-reaching influence on the environment than when the interconnection between ES is not considered.

3.3 Survey analysis and post workshop activities

Ms Zapata presented the main findings from the survey analysis during the plenary discussion. The main results of the survey are summarised as follows:

According to most research experts, MAR activities can influence environmental conservation, research and educational activities, and soil quality management, alongside drinking water supply and agricultural production. However, research experts in the survey had few disagreements regarding genetic material from organisms, other renewable energy sources that are not hydro-powered, and mediation of anthropogenic origin's nuisances by abiotic processes. The result of workshop group activities showed coherence with survey results indicating the uniformity from a scientific perspective.

During the plenary discussion, Ms Zapata showed the main findings from the survey analysis a few weeks before the workshop. The survey's primary purpose was to validate the result of the literature review on MAR examined if there is a general agreement on which ecosystem service groups are being influenced by MAR and those which are not. Subsequently, the response frequency for each ES group was analysed to determine the differences in the awareness of MAR potential. Research experts and MAR practitioners from LAC were the target group of the survey. The main findings of the survey are summarised as follows:

The analysis showed that the ES were clustered by CICES sections (provisioning, regulation, and maintenance and cultural). In general, the research experts seem to agree upon the influence that MAR activities could have on the environmental conservation (cultural), research and educational activities (cultural), regulation of soil quality (regulation and maintenance) besides drinking water provisioning and agricultural productivity (provisioning). However, few disagreements were shown by research experts in the survey w.r.t genetic material from organisms, other renewable energy sources that are not hydro-powered (provisioning), mediation of nuisance s of anthropogenic origin by abiotic processes (regulation and maintenance). The result of workshop group activities showed coherence with survey results indicating the uniformity from a scientific perspective.

Workshop in the context of the DIGIRES project

Based on the survey results and workshop activities, participants shared their views on the impacts of MAR activities on renewable sources of energy and asked whether MAR should be implemented considering geographic location. A digital MAR portal with over 1200 projects from around the world was presented to workshop participants by Dr Stefan. The portal consists of multiple case studies extensively indicated the distribution of MAR applications. For instance, the central part of MAR activities in Europe is focused on improving the water quality through riverbank filtration, whereas, in Africa, the MAR activities aim to increase the natural storage of water. As a result, the implementation of MAR considers a wide range of socio-economic conditions, scientific and technical expertise, and environmental conditions. Dr Stefan emphasized that collaboration among various stakeholders could help strengthen water security by helping achieve multiple objectives.

Section 4: Conclusions

MAR development and application have promoted a wide variety of intellectual, educational and leisure activities while supporting the correct functioning of watershed services, enriching local biodiversity, and mitigating water related disasters, among others. However, despite its numerous benefits, there are still negative impacts and barriers against its implementation (such as profound knowledge gaps, lack of applied economic valuation studies and dedicated regulations. All of which makes additional promotion necessary for an increased acceptance and uptake. This workshop represents the first effort at systematically recognizing, demonstrating the relevance of multiple MAR ecosystem services from a transdisciplinary perspective.

Shifting MAR application from silos to holistic value of managed aquifer recharge is still difficult as the main drivers for wider implementation in Latin America and the Caribbean (LAC) are commodity-based economies that intensify the unsustainable use of many resources, including groundwater. MAR was suggested in this workshop as a type of nature-based solution that would support the delivery and strength of a wide variety of ecosystem services and simultaneously contributes to sustainable water management and a tool to provide evidence for sustainable policy recommendations. Nonetheless, the application of this technique remains severely underutilized in LAC.

In the workshop we demonstrated the multi-faceted potential of non-conventional water resources management strategies for the achievement of a wider range of technical, environmental, and social-economic targets. Based on existing and perceived evidence the workshop made realizing the underpin ecosystem services related to MAR beyond the water quantity provisioning and showed how the MAR-related measures for climate change adaptation, human wellbeing and biodiversity conservation are highly interdependent.

General feedback of the workshop

The attendees were provided with the opportunity to express their views about the workshop after the plenary discussion.

Time allocation

A total of 33 flashcards regarding ecosystem services was presented to the participants, and they found that more time was necessary to study the flashcards thoroughly and carry out effective discussion among themselves. In order to resolve time allocation for subsequent workshops, participants will receive flashcards before the workshop.

Technical issues

The international MAR workshop was hosted on a digital platform, allowing researchers from different countries to collaborate. However, few participants encountered audio-related issues.

Flashcards were provided to the participants so they could participate in the group activities on a virtual whiteboard. A few participants had difficulty reading several flashcards because of the zoom function of the virtual whiteboard. For future workshop events, the flashcards will be improved in their aesthetics.

Knowledge and expertise

The participants faced challenge to interpret few ecosystem services and assess the impact of MAR activities. One reason was due to specific ES. For example, genetic materials. On the contrary, the rapporteur of both groups reported that participants expressed that the workshop could lead multi-disciplinary researchers to reconsider the indirect influence of MAR in ES. This further validates the vision to enhance multiple ES through this water management technique (MAR).

Bibliography

Bennett, Elena M., Garry D. Peterson, and Line J. Gordon. 2009. 'Understanding Relationships among Multiple Ecosystem Services: Relationships among Multiple Ecosystem Services'. *Ecology Letters* 12 (12): 1394–1404. https://doi.org/10.1111/j.1461-0248.2009.01387.x.

Imran, T., Vikram, A., & Zapata, C. (2021). Valuation of Managed Aquifer Recharge (MAR) contribution to Ecosystem Services (ES) [Technische Universität Dresden, unpublished academic report]. https://docs.google.com/spreadsheets/d/1rC_0hyR2R6pNj3v_zp1kKlPQrdItcs6gDoCvLmU5NUc/

Annex 1: Survey Questionnaire provided to the Participants prior to the Workshop

Section	Group	Questions
Provisioning (Biotic)	Cultivated terrestrial plants for nutrition, materials or energy	Do you think that MAR can influence the quantity and quality of cultivated terrestrial plants used for nutrition, materials or energy (e.g., grains, timber or vegetal coal)?
Provisioning (Biotic)	Cultivated aquatic plants for nutrition, materials or energy	Do you think that MAR can influence the quantity and quality of cultivated aquatic plants used for nutrition, materials or energy (e.g., vitamin supplements or seaweed as an insulating material)?
Provisioning (Biotic)	Reared animals for nutrition, materials or energy	Do you think that MAR can influence the reared terrestrial animals or their subproducts (e.g., hide, grease, eggs, dung) we use for eating, or the production of materials or energy?
Provisioning (Biotic)	Reared aquatic animals for nutrition, materials or energy	Do you think that MAR can influence the reared aquatic animals or their subproducts (e.g., pearls, biogas from aquaculture waste) we use for eating, or the production of materials or energy?
Provisioning (Biotic)	Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Do you think that MAR can influence the quantity and quality of wild plants used for nutrition, materials or energy (e.g., berries, fuel wood or roofing material)?
Provisioning (Biotic)	Wild animals (terrestrial and aquatic) for nutrition,	Do you think that MAR can influence the wild animals (terrestrial or aquatic) or their subproducts (e.g., hide, grease, eggs, dung) we use for eating, or the production of materials or energy?

	materials or energy	
Provisioning (Biotic)	Genetic material from plants, algae or fungi	Do you think that MAR can influence plants, fungi or algae that we can use for breeding; or the seeds or spores we can harvest?
Provisioning (Biotic)	Genetic material from animals	Do you think MAR activities can influence reared or wild animals used for breading or replenishing stock?
Provisioning (Biotic)	Genetic material from organisms	Do you think that MAR activities can impact the design and construction of new biological entities through the extraction of individual genes from organisms (e.g., creation of a novel micro-organism to help produce a pharmaceutical product)?
Regulation & Maintenance (Biotic)	Mediation of wastes or toxic substances of anthropogenic origin by living processes	Do you think that MAR sites can impact the way wastes are filtered or decomposed by living organisms (e.g., bacteria or trees)?
Regulation & Maintenance (Biotic)	Mediation of nuisances of anthropogenic origin	Do you think that MAR sites can contribute to the mediation of nuisances of anthropogenic origin by biotic elements or processes (e.g., the use of shelter belts that filter particulates that carry odours)?
Regulation & Maintenance (Biotic)	Regulation of baseline flows and extreme events	Do you think MAR sites can influence the vegetation capacity to regulate baseline flows or extreme events (e.g., plants retain water and release it slowly, reduce soil erosion and help stop landslides?
Regulation & Maintenance (Biotic)	Lifecycle maintenance, habitat and gene pool protection	Do you think that MAR sites can impact the habitats of wild plants and animals, or impact pollination and seed dispersal?
Regulation & Maintenance (Biotic)	Pest and disease control	Do you think that MAR sites can impact the natural control of pests, invasive species, or diseases (e.g., native pests control agents or microbial disease antagonists)?

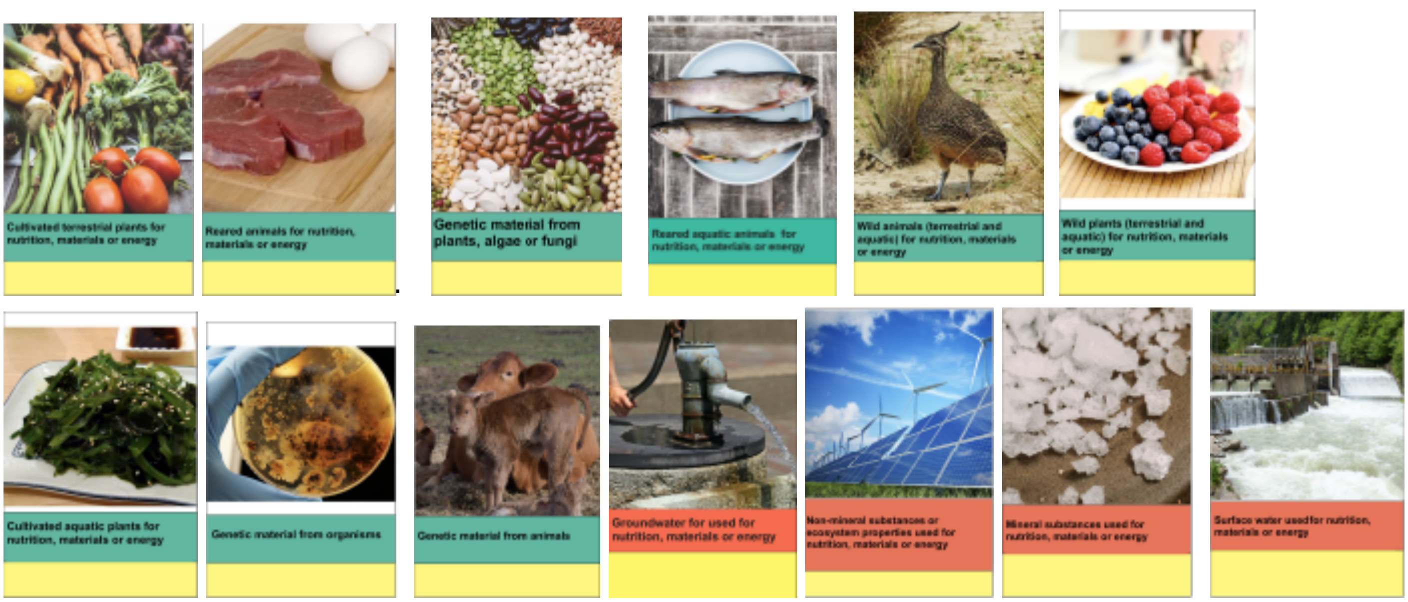
Regulation & Maintenance (Biotic)	Regulation of soil quality	Do you think that MAR sites can influence the regulation of soil quality (e.g., formation of soil or incorporation of organic matter into the soils)?
Regulation & Maintenance (Biotic)	Water conditions	Do you think that MAR sites can impact the regulation of the water chemical quality done by living organisms (e.g., plants/microorganisms that can remove excess nutrient in water)?
Regulation & Maintenance (Biotic)	Atmospheric composition and conditions	Do you think that MAR sites can regulate the air quality or the global climate?
Cultural (Biotic)	Physical and experiential interactions with natural environment	Do you think MAR activities can influence the way we use the environment to do sports, leisure activities or observational experiences (e.g., birdwatching)?
Cultural (Biotic)	Intellectual and representative interactions with natural environment	Do you think that MAR activities can influence the research or educational activities done in relation to the biotic components of the environment (e.g., flora or fauna)?
Cultural (Biotic)	Spiritual, symbolic and other interactions with natural environment	Do you think that MAR activities can influence the spiritual or symbolic interactions people have with the biotic environment (e.g., the relation with totemic species, doing flora/fauna documentaries/books, or the use of certain species as national emblems)?
Cultural (Biotic)	Other biotic characteristics that have a non-use value	Do you think that MAR activities can impact the conservation of the living part of environment that are important for future generations (e.g., endangered species or areas designated for conservation)?
Provisioning (Abiotic)	Surface water used for nutrition,	Do you think that MAR can influence the quantity and quality of surface water used for drinking, energy, irrigation or industrial purposes?

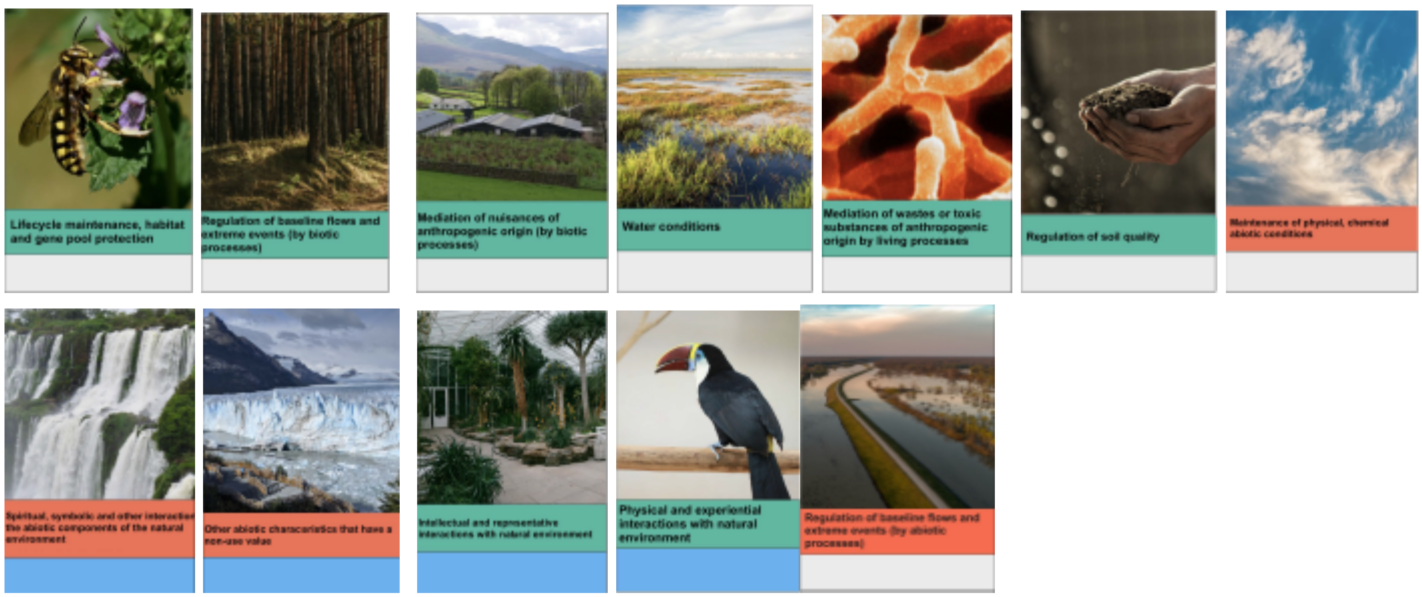
	materials or energy	
Provisioning (Abiotic)	Ground water for used for nutrition, materials or energy	Do you think that MAR can influence the quantity and quality of groundwater used for drinking, energy, irrigation or industrial purposes?
Provisioning (Abiotic)	Mineral substances used for nutrition, materials or energy	Do you think that MAR can influence the minerals that can be obtained from that same area (e.g., salt, pigments or radioactive minerals)?
Provisioning (Abiotic)	Non-mineral substances or ecosystem properties used for nutrition, materials or energy	Do you think that MAR can influence renewable energy sources (except for hydropower) such wind, solar, geothermal; or influence other non-mineral substances (e.g., ozone, opals)?
Regulation & Maintenance (Abiotic)	Mediation of waste, toxics and other nuisances by non-living processes	Do you think that MAR sites can impact the way pollutants are diluted in the environment (e.g., use water systems as pollution sink)?
Regulation & Maintenance (Abiotic)	Mediation of nuisances of anthropogenic origin	Do you think that MAR sites can influence the mediation of nuisances of anthropogenic origin by abiotic structures or processes (e.g. the topography can help to improve the visual quality by shielding unsightly objects or activities)?
Regulation & Maintenance (Abiotic)	Regulation of baseline flows and extreme events	Do you think that MAR sites can impact the regulation of baseflows or extreme events (e.g., through physical barriers against flows or landslides)?
Regulation &	Maintenance of physical, chemical, abiotic conditions	Do you think that MAR can impact the maintenance and regulation of the environment done by inorganic natural chemical and physical processes (e.g., land breezes)?

Maintenance (Abiotic)		
Cultural (Abiotic)	Physical and experiential interactions with natural abiotic components of the environment	Do you think MAR activities can influence the way we use the physical environment to do sports, leisure activities or observational experiences (e.g., observing an outcrop)?
Cultural (Abiotic)	Intellectual and representative interactions with abiotic components of the natural environment	Do you think that MAR activities can influence the research or educational activities done in relation to the abiotic components of the environment (e.g., geological features)?
Cultural (Abiotic)	Spiritual, symbolic and other interactions with the abiotic components of the natural environment	Do you think that MAR activities can influence the symbolic or spiritual interactions we have with the abiotic environment (e.g., the way we identify ourselves with iconic mountain peaks or rivers, or doing documentaries/books of the physical environment)?
Cultural (Abiotic)	Other abiotic characteristics that have a non-use value	Do you think that MAR activities can impact the conservation of physical environment (e.g., geological formations) that is important for future generations?

Annex 2: Flashcards Provided to the Workshop Participants during the Breakout Session

(English version followed by Spanish)




Lifecycle maintenance, habitat and gene pool protection
Regulation of baseline flows and extreme events (by biotic processes)
Mediation of nuisances of anthropogenic origin (by biotic processes)
Water conditions
Mediation of wastes or toxic substances of anthropogenic origin by living processes
Regulation of soil quality
Maintenance of physical, chemical abiotic conditions
Spiritual, symbolic and other interaction the abiotic components of the natural environment
Other abiotic characteristics that have a non-use value
Intellectual and representative interactions with natural environment
Physical and experiential interactions with natural environment
Regulation of baseline flows and extreme events (by abiotic processes)

Annex 3: International Team of Experts (arranged in alphabetical order)

Dr. Serena Caucci

UNU-FLORES

Dresden, Germany

Serena Caucci is an Associate Program Officer in the Water Resource Management Unit at UNU-FLORES. Prior to joining UNU-FLORES, Serena served as a researcher and scientific project manager at the Technische Universität Dresden, Germany and at the Helmholtz-Centre for Environmental Research – UFZ in Leipzig, Germany where she elaborated and coordinated efforts on water sanitation and the impact of contaminants of emerging concern in anthropogenic-driven environments. Serena has also worked as consultant for the EIT Climate KIC where she developed curricula for innovation trainings and knowledge transition in bioeconomy. She began her career as Environmental Science Fellow at the University of Florence, Italy where her work on carbon storage mechanism by microbial community in soils was part of a LIFE project Natura 2000. Serena's current research is geared towards sustainable development with a special interest in the impact that anthropogenic activities have on natural resources. Focusing on the sustainable management of wastewater and organic waste, Serena is working towards the development of a transdisciplinary framework that could make use of socioeconomic and environmental interlinkages to enhance sustainable natural resource management. The final goal of her activities leads to knowledge translation for evidence-based decision-making processes and its implementation at various scales.

Jash Dharmendra Parmar M.Eng.

UNU-FLORES

Dresden, Germany

Jash Parmar is an Environmental Engineer from the University of Applied Science, Dresden. He recently completed his internship at UNU-FLORES in the waste management unit under Dr. Serena Caucci. Prior to his internship at UNU-FLORES, he worked on independent research that addresses the interrelation between soil organic matter composition and water holding capacity at a laboratory level. Jash completed his bachelors in Mechanical engineering from the Indus University, India. During his academic journey, Jash got several opportunities to work as a research assistant, developing small scale projects, green business ideas and prototypes.

Dr. Catalin Stefan

TU Dresden (TUD)

Dresden, Germany

Catalin is the Head of the Research Group INOWAS at the Department of Hydrosciences of the Technische Universität Dresden, Germany. Together with his team, Catalin strives to achieve his research goals through a multicultural, international perspective. The research foundation of his work is based on two pillars: understanding the processes occurring during managed aquifer recharge and development of web-based simulation software for groundwater modelling applications. Catalin is the Co-Chair of the Commission on Managing Aquifer Recharge of the International Association of Hydrogeologists and member of Groundwater Solutions Initiative for Policy and Practice. His expertise includes planning, assessment and optimisation of managed aquifer recharge applications using physical models and computer-based simulations. He is the initiator and co-author of the Global MAR Portal, an inventory of over 1000 MAR case studies. Catalin has advanced experience in coordinating and managing international networks and partnerships as PI of several international projects with regional focus on Latin America, Central Asia and Southeast Asia.

Ms Catalina Zapata Barra B.Sc.

TU Dresden (TUD)

Dresden, Germany

Catalina is a Natural Resources Engineer from the University of Chile, where she participated in research related to strategic programs for sustainable river basins, hydroelectric development from a socio-environmental perspective and the links between snow cover and hydrological response. Later she obtained specialization diplomas in Project Evaluation and Management, and Hydrology and Watershed Management. Her core focus lies from a socio-environmental perspective and the links between snow cover and hydrological response. Later she obtained specialization diplomas in Project Evaluation and Management, and Hydrology and Watershed Management. Her core focus lies on IWRM, and sustainable environmental resources management and bridging the gap between science, policymakers, and civil society. Previously, she worked at the Superintendence of Environment in Chile, whose mission is to monitor and audit the environmental regulations established by the law. Currently she is pursuing a master's degree in Groundwater and Climate Change and is conducting her thesis in Managed Aquifer Recharge at TUD.

Annex 4: Organising institutions

United Nations University (UNU-FLORES)
Dresden, Germany
https://flores.unu.edu/en/
Founded in 2012, UNU-FLORES develops strategies to resolve pressing challenges in sustainable use and integrated management of environmental resources such as soil, water, and waste. Focusing on the needs of the UN and its Member States, particularly developing countries and emerging economies, the Institute engages in research, capacity development, advanced teaching and training, as well as dissemination of knowledge. In all activities, UNU-FLORES advances a Nexus Approach to the sustainable management of environmental resources.

Technische Universität Dresden (TUD)

Dresden, Germany

https://tu-dresden.de/
The Technische Universität Dresden (TUD) is one of the largest "Technische Universitäten" in Germany and one of the leading and most dynamic universities in the country. As a full-curriculum university with 17 faculties in five schools it offers a broad variety of 124 disciplines and covers a wide research spectrum. Its focuses on Health Sciences, Biomedicine & Bioengineering, Information Technology & Microelectronics, Smart Materials & Structures, Energy, Mobility & Environment as well as Culture & Societal Change are considered exemplary in Germany and throughout Europe.

FUNDING INSTITUTIONS

Bundesministerium für Bildung und Forschung (BMBF)

www.bmbf.de

Consejo Nacional de Ciencia y Tecnología (CONCYT)

www.concyt.gob.gt

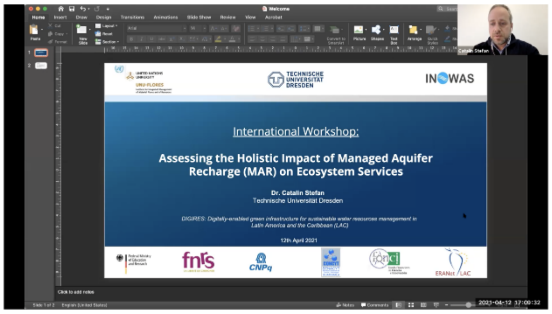
Fonds de la Recherche Scientifique (FNRS)
www.frs-fnrs.be/

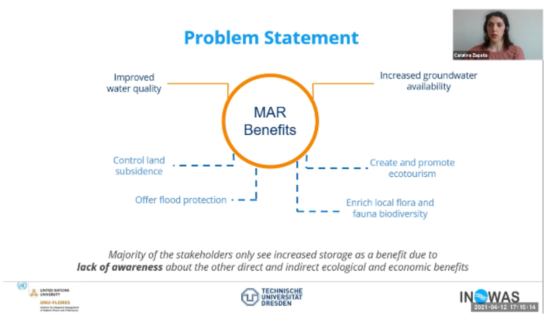
Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq)
www.gov.br/cnpq/pt-br

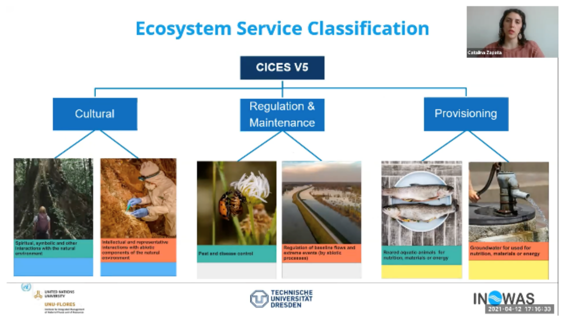
Fondo Financiero de Ciencia e Innovación (FONCI)
wwwcitma.gob.cu/fonci/

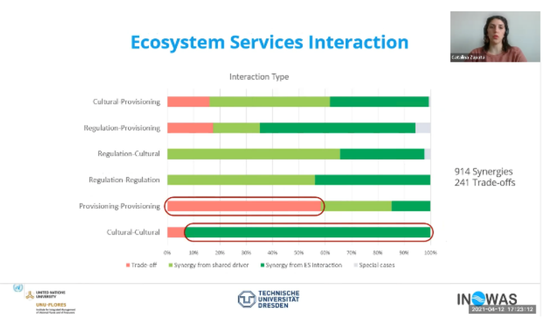
European Research Area Net-Latin America, Caribbean and European Union (ERANet-LAC)
https://eranet-lac.eu/

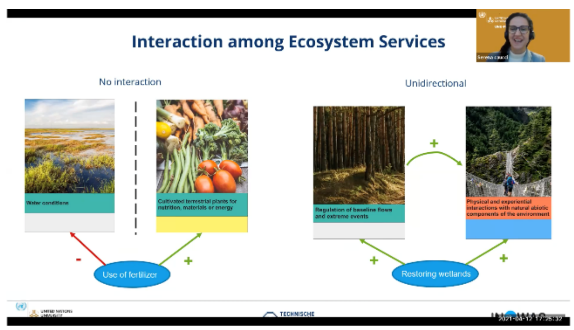
Annex. 5: Pictures of the Workshop

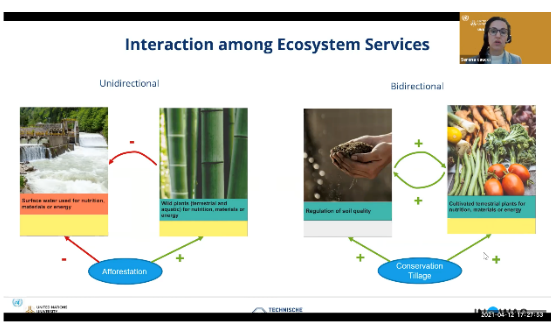


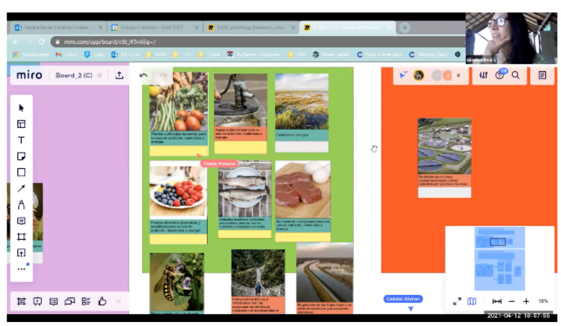


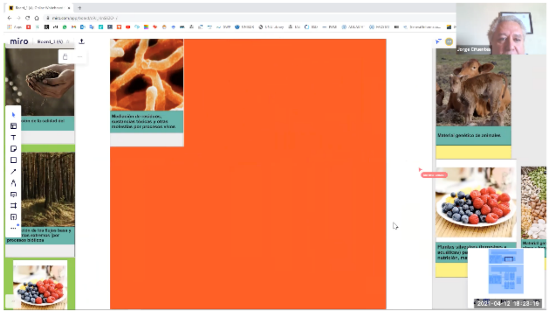


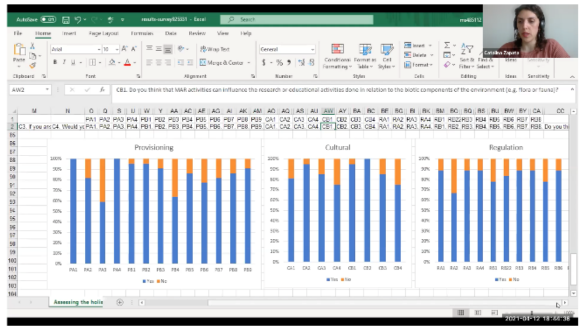


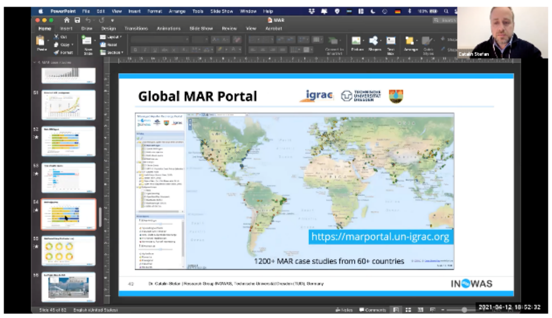


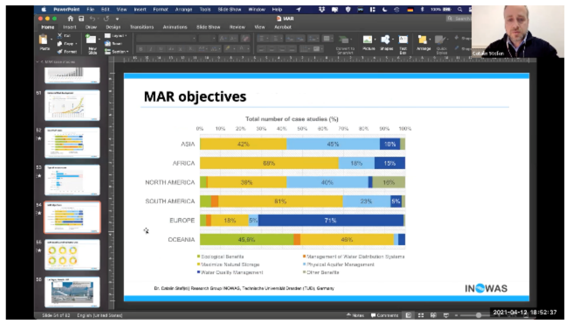




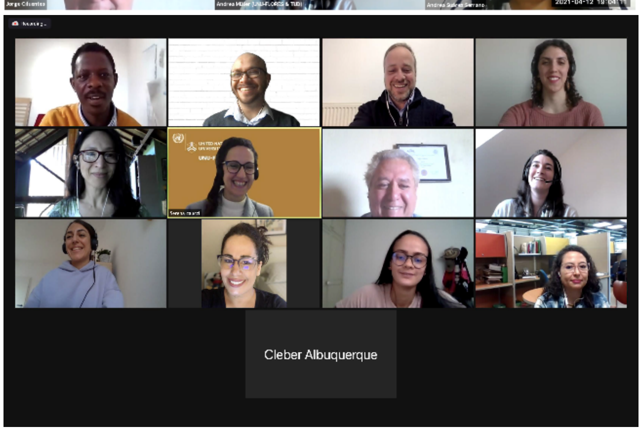

miro
2021-04-12 18:23:16


Provisioning
Cultural
Regulation
2021-04-12 18:44:38


Global MAR Portal
igrac
https://marportal.un-igrac.org
1200+ MAR case studies from 60+ countries
INOWAS
2021-04-12 18:52:32


MAR objectives
Total number of case studies (%)
ASIA
AFRICA
NORTH AMERICA
SOUTH AMERICA
EUROPE
OCEANIA
INOWAS
2021-04-12 18:52:37

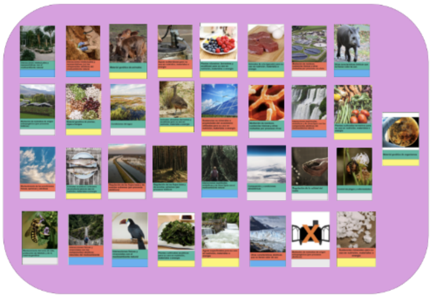

2021-04-12 19:04:11


Cleber Albuquerque

Actividad 1: Influencia de MAR en el medio ambiente

Procedimiento: Procedimiento: Seleccione tres (3) servicios ecosistémicos que no sean afectados por MAR, y de aquellos que sí están afectados, seleccione tres (3) que sean afectados positivamente y tres (3) negativamente. Arrástrelos al cuadro correspondiente.

Servicios Ecosistémicos



Influencia positiva ***Influencia negativa*** ***No hay influencia***

Actividad 2: Interacción entre servicios ecosistémicos

Procedimiento: Seleccione un par de servicios ecosistémicos del cuadro izquierdo y arrástrelos a cada cuadro de la derecha, generando ejemplos de cada tipo de interacción mostrados allí. Un mismo servicio se puede repetir.

- Interacción unidireccional: A afecta a B, pero B no afecta a A.
- Interacción bidireccional: A afecta a B y B afecta a A.

Servicios Ecosistémicos

	Unidireccional A → B	**Bidireccional** A ⇄ B
Positiva	MAR	MAR
	A → B	A ⇄ B
Negativa	MAR	MAR

No hay interacción