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Mapping Freshwater Aquaculture's Diverse Ecosystem Services with Participatory Techniques: A Case Study from White Lake, Hungary

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Abstract: Freshwater aquaculture has a significant role in fish production and biodiversity conservation. Due to climate change, however, the sustenance of fish farms became more challenging, endangering both people and natural values. The establishment of multi-purpose fishpond systems, utilizing ecosystem services besides fish production, could serve as a long-term solution for this problem. However, the lack of knowledge about fishponds' ecosystem services creates an obstacle in the process. We would like to lower this barrier by mapping 13 different ecosystem services of White Lake, one of the most prominent fishpond systems in Hungary. The results of two different participatory mapping techniques indicated that standing waters, reedy areas, and canals, possessed the highest potential values in the provision of the listed ecosystem services, marking them as the most important areas for future developments. In the case of current sources, local experts linked the highest values to reedy areas and lookout towers. Participatory mapping also indicated that microclimate regulation and bird watching were the most widely used ecosystem services after fish production. By collecting and visualizing experts' spatial data about White Lakes' ecosystem services, our unique paper has the potential to serve future decision-making and provide a basis for further studies on this topic.

Keywords: ecosystem service; freshwater aquaculture; fishpond system; participatory mapping; geographic information system; Hungary

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1. Introduction

In 2018, freshwater aquaculture production was approximately 51.3 million tons, or 62.5 percent of world fisheries production, making it one of the most important areas of the aquaculture industry [1]. Uprising global climate change, however, is expected to have a significant negative effect on fisheries due to extreme temperature fluctuations, changes in the amount and distribution of precipitation, and through different human activities triggered by this phenomenon (e.g., increasing demand for freshwater from other sectors) [2]. To evaluate the potential impacts of such changes, multiple international studies have been conducted in the past decade, using various methods and approaches [2–6]. Despite their differences, the previous studies estimated a general decrease in fisheries production, as the decreasing amount of available water and the increasing costs of production could make most traditional fish farms unsustainable [7,8]. The partial or entire abandonment of freshwater fish farms could have great consequences on societies more dependent on fish and other freshwater products (e.g., algae, crayfish, clams) [1].

Besides social impacts, the disappearance of natural and semi-natural fish farms with earthern ponds might also cause significant damage to the local biodiversity. In the scientific literature, there are examples for environmentally friendly fishpond systems providing perfect habitats and food sources for a great variety of water-related, protected bird species [9,10]. The absence of these stable ponds would endanger the livelihood of the previous taxa, as natural wetlands are continuously shrinking due to their increased sensitivity to global climate change [11–17].

In the work of Barange et al. (2018) [2] and Naylor et al. (2000) [18], the creation of more sustainable, multifunctional fish farms was highlighted as the most promising option to ensure the long-term functionality of natural or semi-natural fishpond systems under the effects of climate change. Achieving this state, however, will depend greatly on the utilization of fishpond systems' ecosystem services [1]. Ecosystem services are all the benefits and services people obtain from different ecosystems [19]. Based on the latest version of the Common International Classification of Ecosystem Services (CICES) [20], these services have three distinct groups: provisioning, cultural, and regulating ecosystem services. In 2019, Willot et al. identified 41 potential services in their theoretical study that all inland aquaculture could provide globally, confirming the importance of freshwater fish farms in this field, as well [21]. Despite the results of Willot et al., the number of empirical studies on this topic is still very scarce in the scientific literature, as between 1997 and 2017 only 94 papers have been published worldwide about the actual assessment of fish farms' ecosystem services, and from them, only nine were conducted in freshwater environments [22]. This makes freshwater fish farms one of the most underrepresented areas in the case of ecosystem services. The lack of information about freshwater fishpond systems' service providing capabilities could result in poorly designed land-use strategies unable to counterweight the long-term effects of climate change, thus creating a major drawback in the future establishment of more sustainable fish farms.

The purpose of our study is to offer vital, empirical information about freshwater fishpond systems' ecosystem service providing capabilities by identifying and mapping the services of a renowned Hungarian fish farm called White Lake, using different participatory geographic information system (PGIS) techniques [23], as almost no relevant experiences are available in the literature for this ecosystem type. PGIS is an interactive approach to landscape planning that represents peoples' spatial knowledge in the forms of maps by combining a range of different geo-spatial information management tools. Due to its potential in integrating different perceptions of stakeholders related to ecosystem services, it has become an important method in ecosystem assessments [24,25]. One of the challenges of this study was that both Hungary and freshwater fish farms are very underrepresented in this topic, highly limiting the use of available literature data. Utilizing PGIS techniques through interviews with local experts and stakeholders, however, allowed us to collect relevant information in a relatively short time. Additionally, as one of the first studies in the scientific literature about the actual assessment of freshwater fishponds' multiple ecosystem services, this paper could serve as an example for the assessment of more fishpond systems around the world.

2. Database

2.1. Study Area

With an approximate area of 2200 hectares, White Lake is considered one of the biggest, artificially created fishpond systems in Hungary [26]. The system consists of two main units: the western Old White Lake (1150 ha), and the eastern New White Lake (650 ha) (Figure 1). Both of these can be found in the northern periphery of Szeged city. The name of the fishpond system refers to the original color of its water, as before the creation of the fishponds White Lake was a natural alkaline lake with a great role in collecting inland water run-offs from neighboring areas [26].

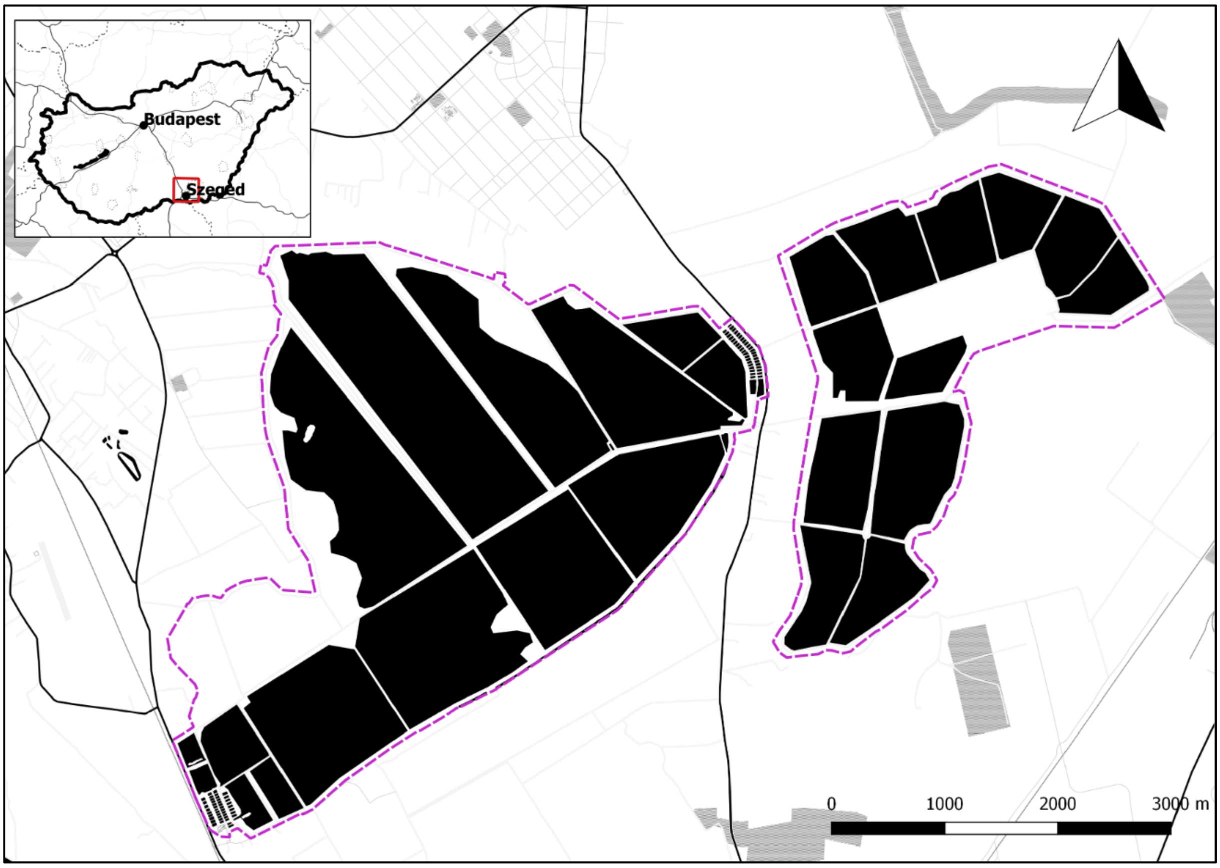

Figure 1. The location of White Lake. Purple interrupted line shows the borders of the study area.

Fish farming here focuses on the production of common carp (*Cyprinus carpio*) in polyculture [27] with european catfish (*Silurus glanis*), silver carp (*Hypophthalmichthys molitrix*), grass carp (*Ctenopharyngodon idella*), zander (*Sander lucioperca*), northern pike (*Esox lucius*), and tench (*Tinca tinca*) [28]. Fish growth is mainly based on the pond's natural food resources (algae and macroinvertebrates), enhanced by artificial manuring, and supplementary, grain-based feeding. This semi-intensive aquaculture [29,30] is the most prevalent form of fish production in Hungary [31].

Besides fish farming, White Lake also has a very important conservational role in the area, as it provides rich feeding, nursery, and wintering habitats for almost three hundred, mostly endangered, water-related bird species [32]. Due to these conditions, the whole pond system has been under the protection of the local national park directorate since 1976, and also a part of the Natura 2000 and Ramsar sites for almost two decades [33], which is the main reason why this fishpond system was chosen for our evaluation.

2.2. List of Ecosystem Services

White Lake's most relevant ecosystem services were identified in a preliminary study [34], by conducting structured interviews [35] with the representatives of every major stakeholder group related to the pond system. Gathering information through interviews was necessary as there was no previous data in this topic. To represent all groups, the method of snowball sampling [35] was applied. First, we contacted the representative of the local fish farm (SzegedFish Ltd., Szeged, Hungary). After the main interview about the lake's ecosystem services, we asked for a list of other related stakeholder groups in the area, possibly complemented with contact information for their representatives known as "key informants" [36]. Recommended key informants were also contacted and asked for more groups after their interview. The previous sequence was repeated until no new stakeholder group was mentioned by participants.

Interviews were always held in private, not in groups, to grant anonymity to our sources. This way, key-informants were more willing to share sensitive information with us. These interviews lasted between 1 and 2 h in general. Answers were usually written down, but additional sound recordings were also prepared as safety measures, with the permission of the key informants. For any problems, questions of the structured interview were previously tested by five other experts from the field of aquaculture. Every interview started with a general briefing about ecosystem services and the main purposes of our study. Here, extra efforts were made to avoid mentioning examples for ecosystem services to guarantee that interviewees' answers to further questions would be based only on their own knowledge. After the introduction, a list of ecosystem services was provided for the participants, where the most plausible ecosystem services of Hungarian fishpond systems were summed up, based on the work of Kerepeczki et al. from 2011 [37]. Key informants were asked to select all of those ecosystem services from the previous list that they could relate to White Lake. They were encouraged to solely rely on their experiences and not engage in uncertain assumptions [38]. Key informants were also allowed to suggest new ecosystem services outside of the list if they judged it necessary. We have found the application of a common list necessary to avoid different wordings and possible misunderstandings on the side of the interviewees. In the final list of White Lake's ecosystem services, we only included those services which were highlighted by at least one key informant during the interviews.

Collected ecosystem services were classified into provisioning, regulating, and cultural ecosystem services, based on the recommendations of the Common International Classification of Ecosystem Services (CICES) [20].

During our preliminary study, we contacted seven representative local experts related to the fishpond system. These experts included fish farmers, rangers from the local National Park Directorate (Kiskunsági National Park), water management experts, representatives of local NGOs, and investors in the tourism sector.

3. Methods

3.1. Habitat Mapping

Mapping White Lake's ecosystem services required the preliminary identification and characterization of the different habitat types composing the fishpond system. For this purpose, a habitat mapping exercise was conducted.

Based on the recommendations of the local key informants, White Lake's outer banks were chosen as the borders of this assessment. Different habitat patches had been identified by field observations, using the guidance of the General National Habitat Classification System of Hungary (Á-NÉR) [39], and depicted in QGIS 2.18 (Open Source Geospatial Foundation, Chicago, IL, USA) in Hungary's Uniform National Projection System (EOV). Reflecting on the work of the National Ecosystem Service Mapping and Valuating Project (NÖSZTÉP), aiming for the assessment of the country's ecosystem service providing capabilities, revealed habitat types with similar properties were assimilated into bigger habitat classes, representing the most dominant elements of the landscape. Based on the experiences of NÖSZTÉP, applying habitat classes is a reliable way to ease the work of the PGIS participants, and to highlight the strengths and weaknesses of the different habitats in ecosystem service provision [40].

After our preliminary study and habitat mapping, we used the list of ecosystem services and the habitat maps to organize two separate rounds of structured interviews with the key-informants from our preliminary study. The goal of these interviews was to assess the potential and actual service providing capabilities of White Lake. All the steps of this study are showcased in Figure 2.

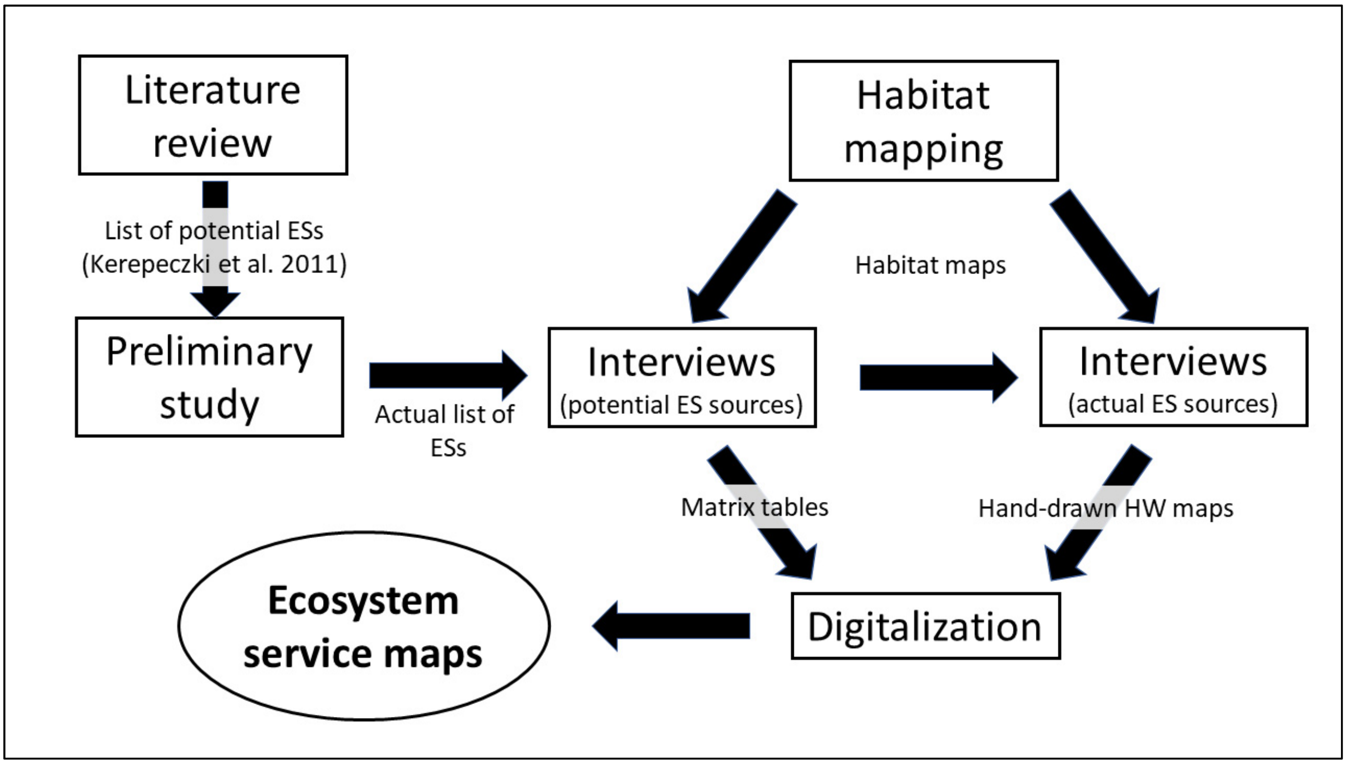

Figure 2. Study structure (squares: main research steps; ellipse: main result) (Source of the list of potential ESs: Kerepeczki et al. 2011 [37]).

3.2. Assessing White Lake's Potential Service Providing Capabilities

Based on their functions and characteristics, different habitats could have different potentials in the provision of an ecosystem service. Understanding how suitable a habitat is to provide certain ecosystem services is a key element to avoid overuse and reach long term sustainability [41]. To assess the potential abilities of White Lake's main habitat classes in the provision of the listed ecosystem services, we conducted a matrix-based participatory mapping [42], based on structured interviews with all the local key informants who have previously participated in the identification of the services [34]. As a reminder, every interview started with the introduction of our goals and the final list of White Lake's ecosystem services. In the second step, participants were asked separately to value the potential providing abilities of each habitat class in the case of every service, based only on their characteristics. The evaluation scale consisted the following values: 0 = no relevant capability, 1 = very low capability, 2 = low capability, 3 = medium capability, 4 = high capability and 5 = very high capability [42]. Following the work of Burkhard et al. (2009) [42], a very basic, Tier 1 valuation matrix [42–44] has been used to record the given values. Here, the y-axis of the table showcased the main habitat classes, while the x-axis contained the ecosystem services. Key informants were also encouraged to reason their choices.

All structured interviews were conducted in private with the permission of the key informants. Answers were only recorded with the absolute consent of the participants.

After the interviews, a focus group session [35] was held with the key informants, where all of their different valuations were revealed anonymously. As in this state, almost every habitat class had multiple and different given values related to each ecosystem service; the goal of this session was to make a consensus about the values and create a final matrix table where habitat classes have only one capability value for every ecosystem service. The session ended when all the questionable values were discussed and the final matrix table was created.

After the focus session, finalized matrix values were showcased on White Lake's habitat map in the case of each ecosystem service by using color codes (lower matrix values: light green, higher matrix values: dark green) [45]. Values were also summed up in the matrix table in the case of each habitat class for better comparison.

3.3. Assessing White Lake's Actual Service Providing Capabilities

Characterizing the potential ecosystem service providing capabilities of different habitats is a great tool to help create sustainable land-use planning strategies [42], however, it does not provide information about the actual level of usage. To assess this, we have utilized a modified version of the participatory GIS (PGIS) technique used in the deliberative work of Palomo et al. (2013) [46]. We refer to this method as "Hotspot-Warmspot" (H-W) mapping. The goal of this method is to categorize habitat patches into two main categories based on the usage of their ecosystem services: (1) Hotspots: frequently used habitat patches that could be considered as the main sources of an ecosystem service; and (2) Warmspots: rarely or mildly used habitat patches with only a little contribution to the use of an ecosystem service compared to Hotspots [46,47]. Hot- and Warmspots were identified by structured interviews conducted with the same key-informants who participated in the assessment of White Lake's potential ecosystem service providing capabilities. First, we asked them to locate the primary sources (Hotspots) of each ecosystem service by marking the most used habitat patches on a printed, colored habitat map (1:40,000). Then, they were also asked to locate the patches with lower levels of usage (Warmspots). Key informants were continuously encouraged to reason their choices.

Structured interviews were held in private, and conducted only with the permission of the key informants. Answers were recorded only after the participants gave their consent.

After the interviews, printed maps were digitalized in QGIS 2.18. In the case of every ecosystem service, both Hot- and Warmspots were highlighted on White Lake's habitat map by using color codes (Hotspot: red, Warmspot: orange) [45]. Habitat patches with no assigned role are left uncolored.

In this state, many habitat patches were marked as both Hot- and Warmspots in the case of multiple ecosystem services. To decide the exact role of these patches a focus group session was held with our key informants. The session ended when the Hotspot-Warmspot maps of all ecosystem services were finalized.

4. Results

4.1. List of Ecosystem Services

Based on the posterior feedback of the key informants, our study managed to cover every relevant stakeholder group of White Lake.

The results of the structured interviews indicated the presence of 13 different ecosystem services in the area. The category of provisioning services consisted of fish production and reed production, while regulating services were water quality regulation, water retention, water storage, microclimate regulation, and carbon sequestration and storage. The group of cultural services was also diverse, containing opportunities for scientific research, environmental education, inspiration, bird watching, recreational railroad traveling, and other recreational opportunities [34]. The full list of the collected services with their descriptions is demonstrated in Table A1 (see Appendix A).

Our study complied with all of the ethical regulations of social research (SRA Ethics Guidelines), in accordance with the Declaration of Helsinki. Subjects of the interviews also gave their informed consent before they participated in the study.

4.2. Habitat Classes

Habitat mapping has revealed 15 different Á-NÉR habitat types in the study area, that we have organized into nine main habitat classes, based on their characteristics (see Table A2 in Appendix A). Approximately 91% of White Lake's area was dominated by periodic standing waters (~1736 ha) and reedy areas (~280 ha), marked with horizontal and diagonal lanes in Figure 3. Canals, industrial areas, roads/railroads, grass-dominated banks, and shrub-dominated banks, could be also found around the ponds, playing supplementary roles in fish production (Figure 3). These classes only consisted of approximately 166 hectares altogether. The rarest components of the fishpond system were salty meadows (~20 ha) and woody patches (~6 ha) (Figure 3). It is also important to notice that some of White Lake's Á-NÉR habitat types were parts of multiple habitat classes at the same time (see Table A2 in Appendix A).

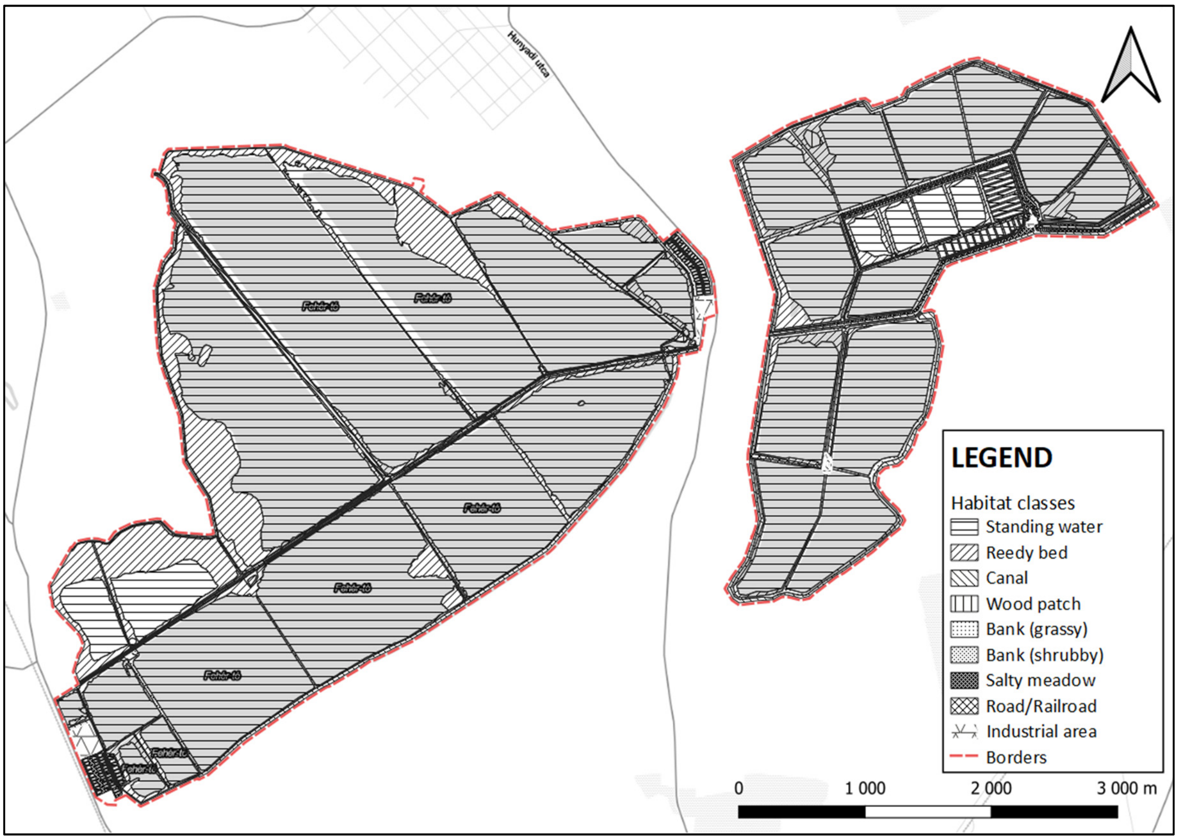

Figure 3. Main habitat classes of White Lake.

4.3. Results of Matrix Mapping

Interviews with local experts revealed diverse ecosystem service providing capabilities related to White Lake's habitat classes. Based on our results, the standing waters' potential ecosystem service providing capabilities were characterized by the highest possible value (5) in 10 cases, and with value 3 related to carbon sequestration and storage (Figures 4 and 5, Table A3 in Appendix A). Reedy beds were valued with 5 in the case of eight ecosystem services, with 4 in the case of water quality regulation, and with 1 related to fish production, water storage, and water retention (Figures 4 and 5, Table A3 in Appendix A). Similarly, to the previous classes, canals were also connected to the provision of almost every ecosystem service in our list. Their contributions, however, were mostly estimated to be lower: in the case of education, inspiration, and "other cultural services" they were valued with 4, and with 3 related to water quality regulation, opportunities for research, and bird watching. The rest of the ecosystem services were valued with 2, except for recreational railroad traveling where no contributions were assumed (Figures 4 and 5, Table A3 in Appendix A). The role of banks (both shrub- and grass-dominated banks), woody patches, and salty meadows, were all highlighted in the case of the 7 same ecosystem services (microclimate regulation, carbon sequestration, opportunities for scientific research, education, inspiration, bird watching, and other recreational opportunities). In the case of education and inspiration all of these classes were characterized with relatively high values.

Here, the role of woody patches in microclimate regulation and carbon sequestration was also estimated to be quite significant, due to their large leaf surfaces (Figures 4 and 5, Table A3 in Appendix A). Roads and railroads did not gain any remarkable values, except for cultural services (Figures 4 and 5, Table A3 in Appendix A). As the key informants explained, this habitat class might not have the ability to provide the previous ecosystem services by itself, but despite that, it has a great role in forwarding them to people; without roads White Lake's cultural services would be less available for tourists. The habitat class with the lowest potential values were industrial areas characterized by only a minimal contribution to some recreational activities (Figures 4 and 5, Table A3 in Appendix A).

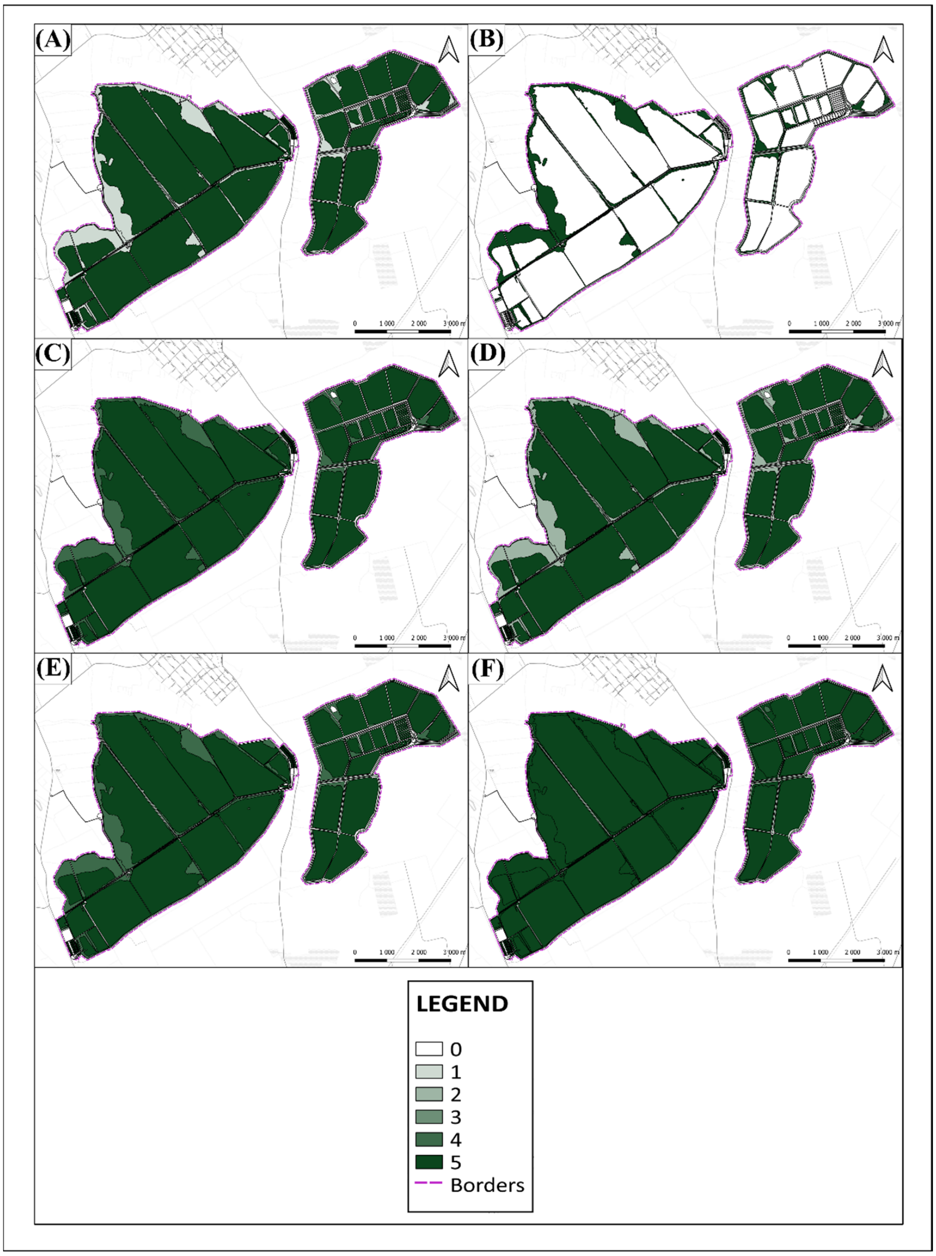

Figure 4. Matrix maps of White Lake's ecosystem services I. (**A**): Fish production. (**B**): Reed production. (**C**): Water quality regulation. (**D**): Water storage. (**E**): Water retention. (**F**): Microclimate regulation (Color white: no matrix value; Lighter green: lower matrix value; darker green: higher matrix value).

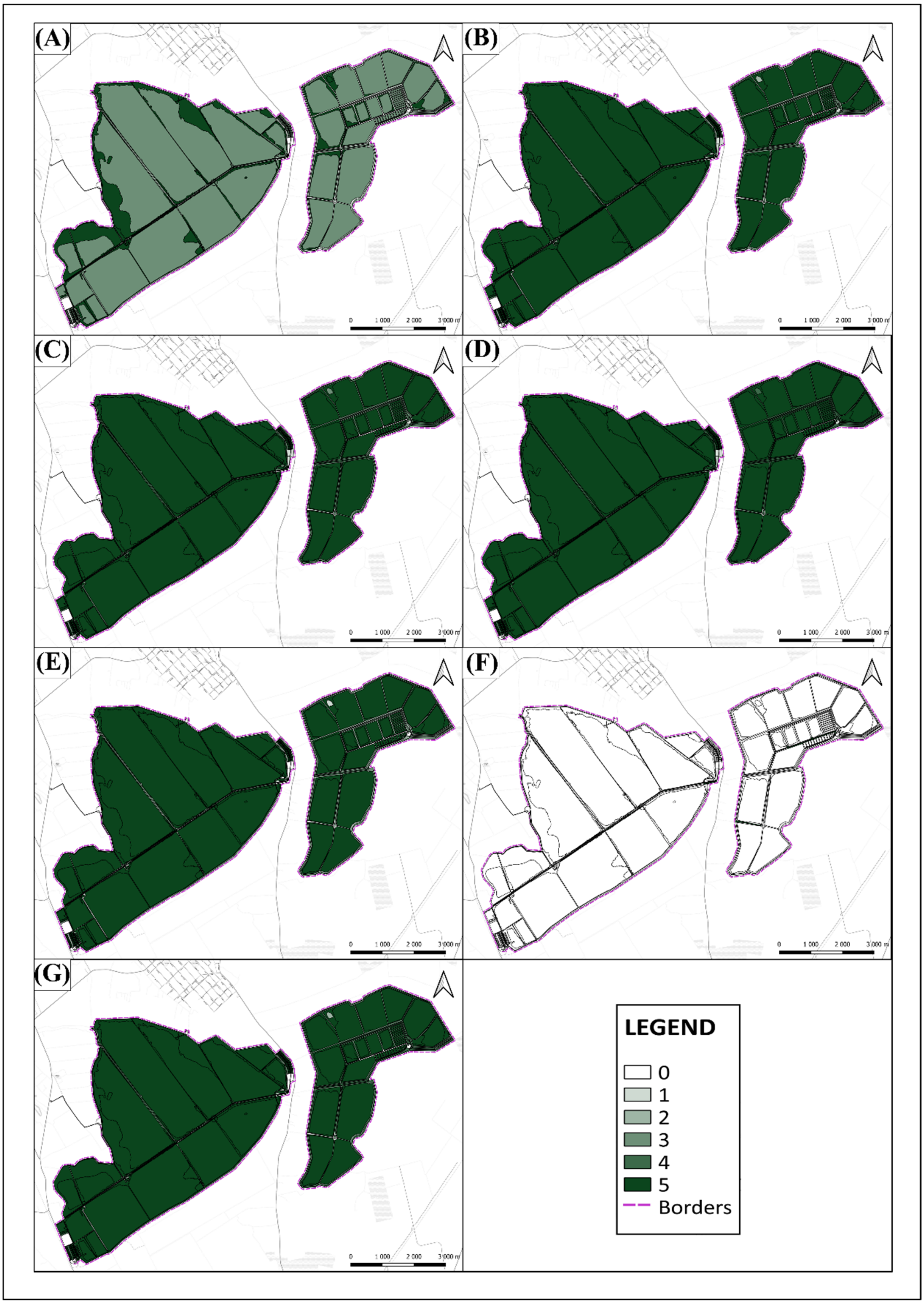

Figure 5. Matrix maps of White Lake's ecosystem services II. (**A**): Carbon sequestration and storage. (**B**): Opportunities for scientific research. (**C**): Environmental education. (**D**): Inspiration. (**E**): Bird watching. (**F**): Recreational railroad traveling. (**G**): Other recreational activities. (Color white: no matrix value; Lighter green: lower matrix value; darker green: higher matrix value).

4.4. Results of Hotspot-Warmspot Mapping

Based on their knowledge, key informants assigned the following Hotspots to White Lake's provisioning ecosystem services: (1) Fish production: every pond in the system, except the ones which were out of commission or were under the management of the national park directorate (1916.9 ha); (2) Reed production: specific reedy patches from where reed is cut off every year (160.8 ha) (Figures 6 and 7, Table A4 in Appendix A). Hotspots of regulating services; (3) Water quality regulation: reedy patches inside the ponds, providing extra filtration (272.4 ha); (4) Microclimate regulation: open water surfaces (1736.4 ha); (5) Carbon sequestration and storage: reedy areas and woody patches with large leaf area (348.8 ha) (Figures 6 and 7, Table A4 in Appendix A). Hotspots of cultural services; (6) Opportunities for scientific research: areas under national park management, bird islands, bird-watching center, research facilities (92.5 ha); (7) Environmental education: trails, lookout towers, bird-watching center and research facilities (82 ha); (8) Inspiration: areas under national park management, trails, lookout towers, bird-watching center, railroads (108.5 ha); (9) Bird watching: ponds which tourists are able to approach, complemented with a bird-watching center, roads, railroads and lookout points that people could use for this purpose (1471.3 ha); (10) Recreational railroad traveling: area of railroads (4.2 ha); (11) Other recreational activities: trails, lookout towers, bird-watching center (12.8 ha) (Figures 6 and 7, Table A4 in Appendix A). The only two ecosystem services without any assigned Hotspot areas were water storage and water retention.

Warmspots were assigned to White Lake's provisioning ecosystem services as the following: (1) Fish production: ponds managed by the local national park (99.2 ha); (2) Reed production: every reedy area except Hotspots and the ones around the bird-watching center (as they providing nesting opportunities for birds) (181.9 ha) (Figures 6 and 7, Table A4 in Appendix A). Warmspots of regulating services; (3) Water quality regulation: open water surfaces of ponds and canals (1806.9 ha); (4) Water storage: every pond and canal (bordered by banks) (2072 ha); (5) Water retention: every pond and canal (bordered by banks) (2072 ha); (6) Microclimate regulation: reedy areas and woody patches (348.8 ha); (7) Carbon sequestration and storage: open water surfaces of ponds (1736.4 ha) (Figures 6 and 7, Table A4 in Appendix A). Warmspots of cultural services; (8) Opportunities for scientific research: the whole fishpond system, except Hotspots (2115.3 ha); (9) Environmental education: roads and railroads (3.9 ha); (10) Inspiration: the whole fishpond system, except Hotspots (2101.7 ha); (11) Bird watching: the whole fishpond system, except Hotspots (743.4 ha) (Figures 6 and 7, Table A4 in Appendix A). The only two ecosystem services without any assigned Warmspot areas were recreational railroad traveling and other recreational activities.

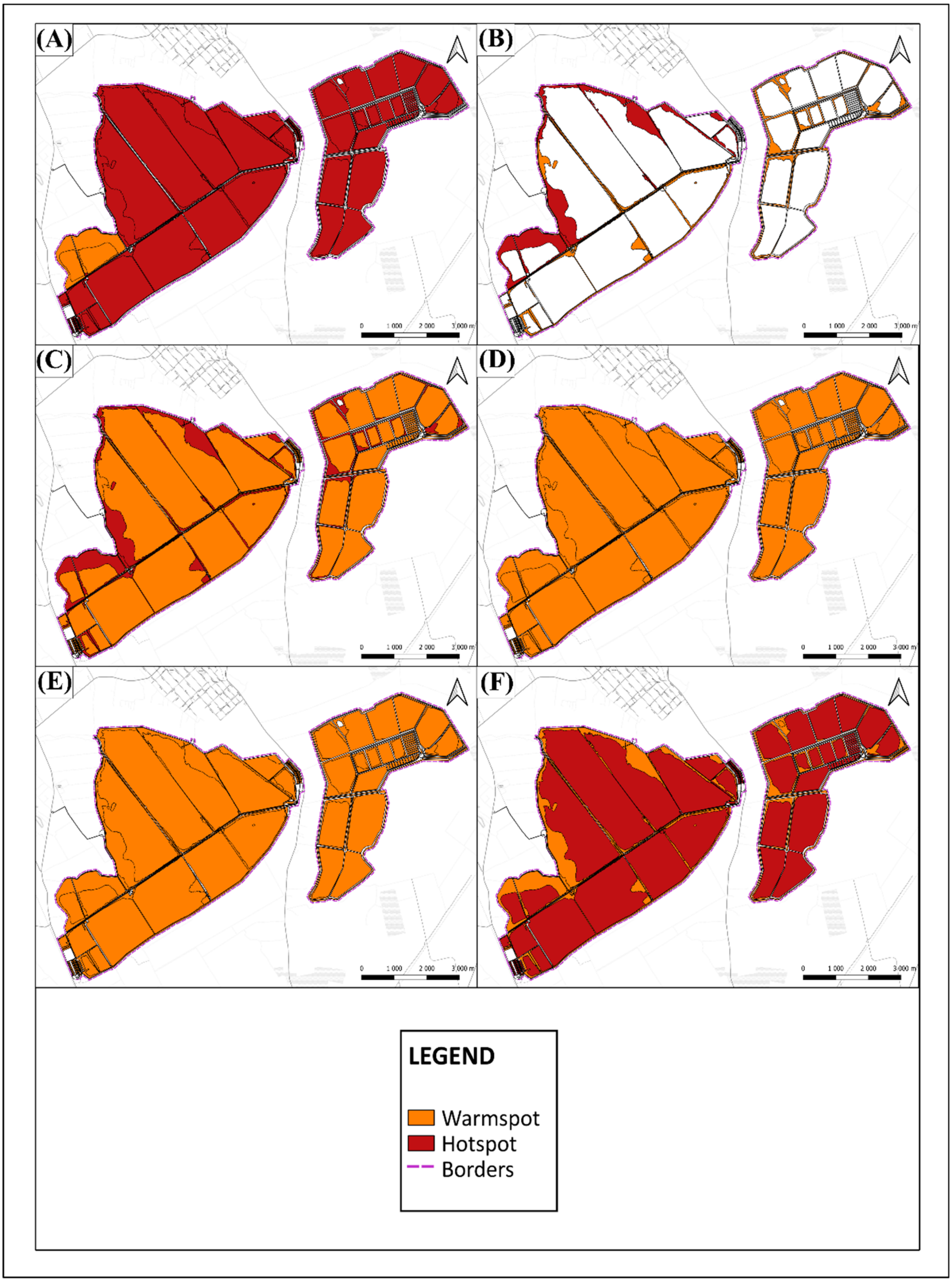

Figure 6. H-W maps of White Lake's ecosystem services I. (**A**): Fish production. (**B**): Reed production. (**C**): Water quality regulation. (**D**): Water storage. (**E**): Water retention. (**F**): Microclimate regulation. (Color orange: Warmspot area; color red: Hotspot area).

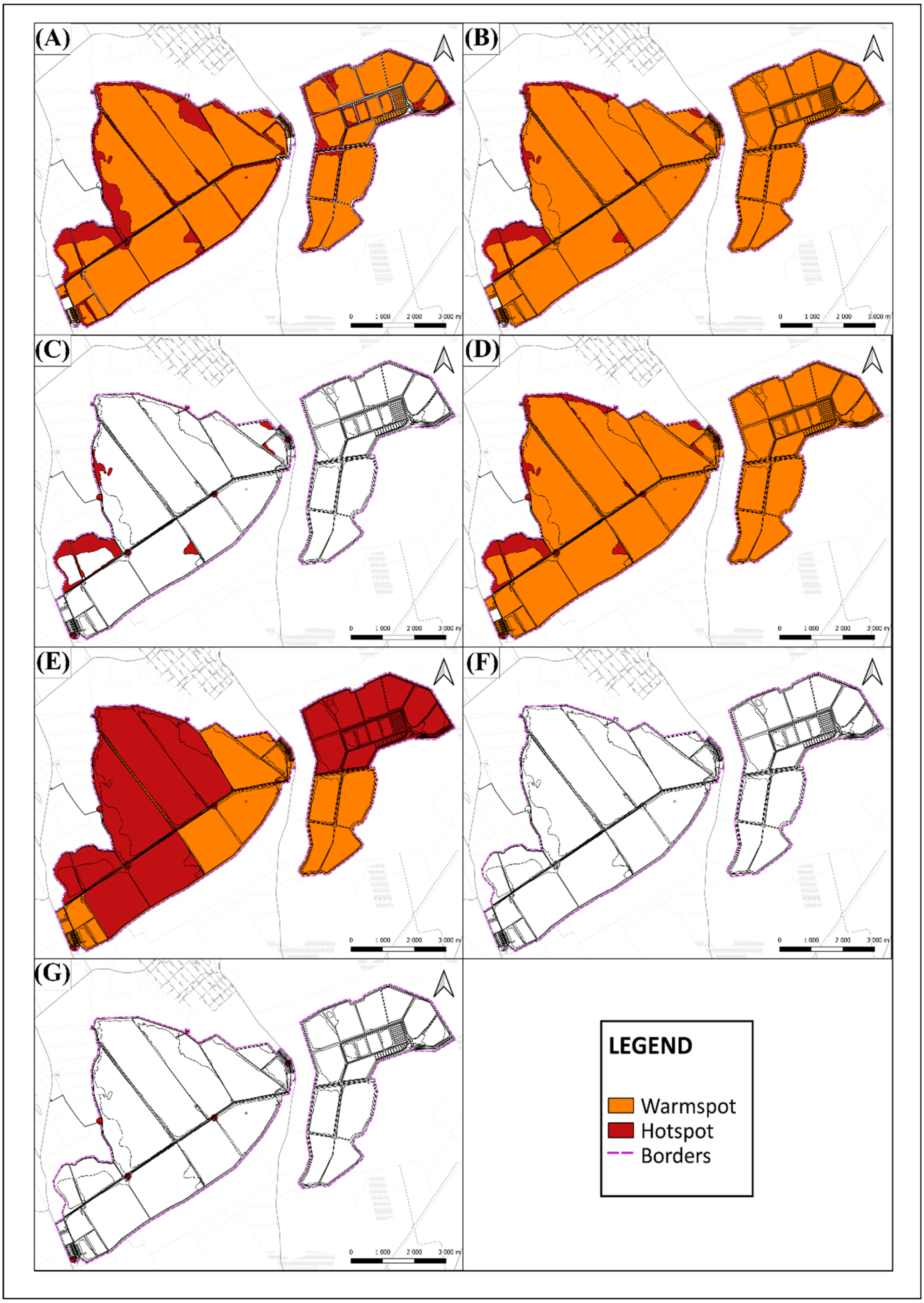

Figure 7. H-W maps of White Lake's ecosystem services II. (**A**): Carbon sequestration and storage. (**B**): Opportunities for scientific research. (**C**): Environmental education. (**D**): Inspiration. (**E**): Bird watching. (**F**): Recreational railroad traveling. (**G**): Other recreational activities. (Color orange: Warmspot area; color red: Hotspot area).

5. Discussion

The results of matrix mapping indicated that most of White Lake's habitat classes have the potential to provide multiple ecosystem services from our list. Moreover, if we sum up the given matrix values (0–5) of services in the case of each habitat classes, it becomes clear that standing waters have the highest potential ecosystem service providing capability of all (53), followed closely by reedy areas (47), and canals (33) (see Table A3 in Appendix A). Based on their characteristics, the previous water-related habitats could serve a very important role in the future development of a more sustainable, multifunctional White Lake as reliable sources of various ecosystem services. Here, it is also worth noting that although canals, similarly to standing waters, showed the potential to provide almost all ecosystem services from our list, the summarized value of reedy areas still precedes them. As we can see in the matrix table (see Table A3 in Appendix A), reedy areas might be less suitable to support fish production, water storage, and water retention, than canals, but key informants also characterized them with higher matrix values in almost every other case. Compared to the previous habitats, woody areas (21), roads and railroads (18), salty meadows (18), grass-dominated banks (16), and shrub-dominated banks (16), had lower summarized matrix values in general. The relatively high value of roads and railroads in this topic could be confusing: as key informants explained, these artificial habitats do not produce ecosystem services themselves, however they have a very important role in conveying other habitats' services to people. Without them, many functions and services of the fishpond system, mainly cultural ones (e.g., bird watching, inspiration, environmental education), would be used in lower levels or just remain unutilized. Industrial areas acquired the lowest summarized matrix value (3), as they were only related to the most abstract services (scientific research, inspiration, environmental education) with the lowest possible rate (1).

In the case of Hotspot-Warmspot mapping, key informants identified the most Hotspot areas in the relation to fish production (1916.9 ha), microclimate regulation (1736.4 ha), and bird watching (1471.3 ha), qualifying these services as the top three most widely used ecosystem services of White Lake in the study period (see Table A4 in Appendix A). From the available habitat patches, lookouts and reedy areas were highlighted as Hotspots in most cases. As key informants explained, lookout towers were deliberately installed close to the most valuable and diverse areas of the fishpond system in order to provide the greatest possible cultural experience for visitors, while reedy areas have important roles both in fish farming and nature conservation management. Roads and railroads of the pond system were highlighted in only a few cases, but mostly as hotspots. We can close the list with industrial areas: according to our key informants, these regions provide almost no services, as their task is primarily to serve the needs and processes of fish production.

As it could be seen above, participatory GIS techniques could provide a great amount of spatially explicit data, an important tool to support decision-making and communication between stakeholder groups [25]. Collecting and using expert knowledge, however, could be associated with some limiting factors, which we also had to consider and manage during this research to ensure that our previous results will provide the best possible support for future land-use planning related to White Lake. First, based on the study of Lechner et al. (2014) [48], the personal interests of key informants could lead to possible misinformation or the concealment of some critical data. The only way we found useful to raise the reliability of expert data was the integration of as many key informants into the assessment as possible, and reconciling with them continuously. In this way, misinformation could be quickly resolved, as they usually did not cope with the general experiences of other participants.

Second, contrary to most available studies on the topic of participatory GIS mapping [49–51], here, all seven key informants from White Lake's area were interviewed separately before the focus group sessions. This way, experts participating in focus group sessions were not able to identify the sources of each data, which generally lowered the risk of possible interest conflicts between them. This solution required more resources and time, however, as we experienced, key informants were more willing to share their sensitive, personal information, and opinions with us personally, than in an open group discussion. The limited number of respondents also gave us the opportunity to discover the depths of their knowledge and understand the reasons behind different perceptions, choices, and the current management strategies [52].

Third, expert data about the potential and actual usage could provide information about ecosystem services that no other methods could, however, this information could also be more uncertain than the ones based on field surveys and indicators [52]. Because of this, expert knowledge alone should be never used as the base of any land-use strategy. Instead, it should be supplemented every time with the biotic (e.g., nesting places of protected birds) and abiotic attributes (e.g., slopeness, temperature, soil types) of the studied fishpond systems, complemented with the biophysical, monetary, and socio-cultural values of the provided ecosystem services. As proper land-use strategies could only be achieved when all the previous aspects are covered [53], the next step of our research will be the assessment of these characteristics. Moreover, we also recommend the use of PGIS techniques only on a local scale, when specific land-use strategies are needed to be made, as participatory GIS mapping techniques require data from as many experts as possible for proper results [25]. Using them on a country or a global scale would require high costs and years of research work [25].

Despite the limitations of expert knowledge, this paper provides unique results in the field of ecosystem services: today, a great variety of studies are available in the scientific literature about PGIS mapping of different ecosystem services [25]. This paper, however, could be qualified as one of the first, where the services of a freshwater fishpond system are being mapped with participatory GIS techniques. This study also provides information about 13 of White Lake's ecosystem services, while in most available studies about freshwater fish farms' ecosystem services [38,54–56] only a few of them were assessed at the same time, which is a common problem in the field of aquaculture [22]. It is also important to notice that the ecosystem services characterized in our study are only a portion of those services that fish farms could provide to people. Willot et al. (2019) [21] listed and published more than 40 possible ecosystem services that all inland aquaculture could provide in general, consisting of 10 provisioning (e.g., "wild animals and their outputs", "surface water for drinking", "genetic materials from all biota"), 20 regulating (e.g., "mass stabilization and control of erosion rates", "pollination and seed dispersal", "disease control") and 11 cultural services (e.g., "physical use of landscapes and seascapes in environmental settings", "symbolic", "sacred and/or religious") [21]. To create the most sustainable, multifunctional land-use strategies for aquaculture, as many ecosystem services from this list should be assessed as possible, from different (biophysical, socio-cultural and monetary) aspects. This will require a great amount of time, energy, and resources, not only from researchers but also from decision-makers, who will have to take all the provided information about the studied ecosystem services into account. It is important to notice that our results only represent the characteristics of one exact fishpond system. The maps highlighted in this study do not provide enough data to describe the capabilities of every fish farm in general, due to different environmental conditions and management. However, we hope that the results of this paper will help to ease the work of decision-makers with its spatial data, and will also provide a base for subsequent, more complex ecosystem service assessments in the future.

6. Conclusions

White Lake is one of the most valuable fishpond systems of Hungary. It not only produces a high amount of food fish every year, but also provides rich feeding and nursing habitats for a great variety of birds and other species. To ensure the long-term stability of these economic and conservational values under the threat of climate change, White Lake has to become a multi-purpose fish farm relying less on the success of fish production and more on ecosystem services. The lack of knowledge about the ecosystem services of White

Lake, however, created a barrier before this purpose. To solve this problem, we utilized two different participatory mapping techniques in our study to assess the potential and actual usage of White Lake's 13 ecosystem services.

Matrix mapping indicated that standing waters, reedy areas, and canals, possessed the highest potential values in the provision of the listed ecosystem services. Based on their characteristics, these habitat classes could be the most important assets for White Lake's future development strategies. Hotspot-Warmspot mapping, on the other hand, highlighted reedy areas and lookout towers as the most significant current sources of ecosystem services, as they were marked as Hotspots more times during our research than any other area in the fishpond system. The previous mapping technique also revealed that microclimate regulation and bird watching were the most widely used ecosystem services of the area after fish production, the primary function of the local fishpond system, showcasing the importance of White Lake in the provision of regulating and cultural ecosystem services.

Our paper highlights not only freshwater fishpond systems' diverse ecosystem service providing capabilities, but also turns attention to the importance of expert knowledge and participatory GIS techniques. These results could serve as a basis for more scientific studies in this topic and could help decision-making processes in the area and in the case of other, similar fishpond systems, as well.

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Appendix A

Table A1. Ecosystem services of White Lake and their descriptions.

Ecosystem Services	Descriptions
Fish production	food fish produced by the fish farm
Reed production	reed (as raw material), harvested from the area of the fishpond systems
Water quality regulation	ability of the fishpond systems to regulate the level of organic and inorganic materials in the water
Water storage	stored water of the fishpond system in case of extreme droughts
Water retention	ability of the fishpond systems to store the water of surface runoffs in case of extreme precipitation levels
Microclimate regulation	ability of the fishpond systems to puffer the local effects of extreme temperature fluctuations
Carbon sequestration and storage	ability of the fishpond systems' vegetation to absorb and store CO_2 from the air as carbon
Opportunities for scientific research	the possibility to implement scientific researches in the area of the fishpond system
Environmental education	opportunities provided for educational activities linked to the environment
Inspiration	ability of the fishpond systems to raise the level of cultural heritage and awareness
Bird watching	opportunities for watching the pond system's avian fauna as a recreational activity
Recreational railroad traveling	opportunities for using fishpond system's railroad system for sightseeing
Other recreational activities	different other forms of recreational activities provided by the fishpond system (hiking, hunting, etc.)

Table A2. Á-NÉR habitat types and main habitat classes of White Lake, complemented with their area in hectares.

Á-NÉR Habitat Types	Main Habitat Classes	Area (Hectar)
U9—Standing waters	Periodic standing water	~1736
B1a—Eu- and mesotrophic reed and Typha beds	Reedy areas	~280
OG—Trampled and ruderal vegetation	Grass-dominated banks	~64.6
OA—Uncharacteristic wetlands		
BA—Fine scale mosaic or zonation of marsh comunities	Canals	~62.8
OG—Trampled and ruderal vegetation	Shrub-dominated banks	~22
OA—Uncharacteristic wetlands		
P2b—Dry and semi-dry pioneer scrub		
RA—Scattered native threes and narrow three lines		
S6—Spontaneous stands of non-native tree species		
S7—Scattered trees or narrow tree lines of non-natives tree species		
OG—Trampled and ruderal vegetation	Salty meadows	~20
F4—Dense and tall Puccinellia swards		
F5—Annual salt pioneer swards of steppes and lakes		
U11—Roads and railroads	Roads/railroad	~11
RA—Scattered native threes and narrow three lines	Woody patches	~6
RB—Uncharacteristic or pioneer softwood forests		
U4—Yards, wastelands, dumping grounds	Industrial area	~5.3

Table A3. Matrix table of White Lake's potential ecosystem service providing values.

	Fish Production	Reed Production	Water Quality Regulation	Water Storage	Water Retention	Microclimate Regulation	Carbon Sequestration	Opportunities for Sci. Res.	Environmental Education	Inspiration	Bird Watching	Recr. Railr-oad Traveling	Other Rec. Activities	SUM
Periodic standing waters	5	0	5	5	5	5	3	5	5	5	5	0	5	53
Reedy areas	1	5	4	1	1	5	5	5	5	5	5	0	5	47
Canals	2	2	3	2	2	2	2	3	4	4	3	0	4	33
Woody patches	0	0	0	0	0	4	5	2	3	4	1	0	2	21
Roads	0	0	0	0	0	0	0	0	3	2	4	5	4	18
Salty meadows	0	0	0	0	0	1	1	3	3	4	2	0	4	18
Bank (grassy)	0	0	0	0	0	1	1	2	3	4	2	0	3	16
Bank (shrubby)	0	0	0	0	0	2	2	2	3	4	1	0	2	16
Industrial area	0	0	0	0	0	0	0	1	1	1	0	0	0	3

Table A4. Hotspot and Warmspot areas (in hectares) of White Lake's ecosystem services.

Ecosystem Services	Hotspot Area (ha)	Warmspot Area (ha)	SUM (ha)
Bird watching	~1471.3	~743.4	~2214.7
Inspiration	~108.5	~2101.7	~2210.2
Opp. for scientific research	~92.5	~2115.3	~2207.8
Microclimate regulation	~1736.4	~348.8	~2085.2
Carbon sequestration and storage	~348.8	~1736.4	~2085.2
Water quality regulation	~272.4	~1806.9	~2079.3
Water storage	0	~2072	~2072
Water retention	0	~2072	~2072
Fish production	~1916.9	~99.2	~2016.1
Reed production	~160.8	~181.9	~342.7
Environmental education	~82	~3.9	~85.9
Other recreational activities	~12.8	0	~12.8
Recreational railroad traveling	~4.2	0	~4.2

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