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Can people detect the loss of water quality? A field experiment to evaluate the correlation between visual perception and water eutrophication degree

As pessoas podem detectar a perda de qualidade da água? Um experimento de campo para avaliar a correlação entre a percepção visual e o grau de eutrofização da água

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Abstract: Aim: The quantity and quality of water are essential to many ecosystem services, biodiversity and human well-being. In the present paper, we used a field experiment to evaluate the visual perception of the public regarding the loss of water quality associated with eutrophication and greening of water. We hypothesized that with an increase in eutrophication (i.e. greening of water due to increased Chlorophyll-a), people can detect a loss of water quality and threats to ecosystem services. **Methods:** We used an experimental area composed of six mesocosms (500L water tanks) with a gradient of chlorophyll-a varying from clear water (without chlorophyll-a) up to eutrophic mesocosms (very green water). A total of 100 people visited the experimental area in-situ, and 83 people visualized pictures of the mesocosms. **Results:** Our results indicated that people were able to detect the loss of water quality associated with increased concentrations of chlorophyll-a, and recognized that these were less suitable for recreational activity and consumption. Moreover, this perception did not vary by gender, formal education, or frequency of visits to aquatic ecosystems. **Conclusions:** The results highlight the clear potential of visual public perception to be used as a simple, rapid, early-warning strategy for monitoring programs of water quality and also an approach that strengthens the link between science and society.

Keywords: Chlorophyll-a; mesocosm; tropical; pictures; interview; citizen science.

Resumo: Objetivo: A quantidade e a qualidade da água são essenciais para manutenção de muitos serviços ecossistêmicos, biodiversidade e bem-estar humano. No presente trabalho, utilizamos um experimento de campo para avaliar a percepção visual do público em relação à perda de qualidade da água associada à eutrofização e esverdeamento da água. Nós hipotetizamos que, com um aumento na eutrofização (ou seja, esverdeamento da água devido ao aumento da clorofila-a), as pessoas podem detectar uma perda de qualidade da água e ameaças aos serviços ecossistêmicos. **Métodos:** Nós utilizamos uma área experimental composta por seis mesocosmos (caixas d'água de 500L) com gradiente de clorofila-a variando de águas claras (sem clorofila-a) até mesocosmos eutróficos (águas muito verdes). Um total de 100 pessoas visitaram a área experimental in-situ, e 83 pessoas visualizaram imagens dos mesocosmos. **Resultados:** Nossos resultados indicaram que as pessoas foram capazes de detectar a perda de qualidade da água associada ao aumento das concentrações de clorofila-a, e reconheceram que estas eram menos adequadas para atividade recreativa e consumo. Além disso, essa percepção não variou por gênero, educação formal ou frequência de visitas aos ecossistemas aquáticos. **Conclusões:** Os resultados evidenciam potencial da percepção visual do público como uma estratégia simples, rápida e de alerta precoce para programas de monitoramento da qualidade da água e também uma abordagem que fortalece o vínculo entre ciência e sociedade.

Palavras-chave: Clorofila-a; mesocosmo; tropical; fotografias; entrevista; ciência cidadã.

1. Introduction

Water is an essential resource to the occurrence and maintenance of life (Chaplin, 2001), and the importance of water availability and quality are clearly recognized by people. Aquatic ecosystems directly generate important ecosystem services, such as fish production and water supply, in addition to indirectly affecting climate regulation (Grizzetti et al. 2016). Moreover, urban lakes are frequently used for recreation and watersport activity. Therefore, water quality impacts human well-being in different ways. Nonetheless, in recent years, many water resources have undergone severe degradation, driven mainly by human activities (Bashir et al., 2020). This intense exploitation of water resources has led to changes in pivotal ecosystem services provided by these environments (Green et al., 2015; Culhane et al., 2019), loss of biodiversity associated with these services (Dudgeon et al., 2006; Vaughn, 2010), as well as changes in the quality and quantity of water consumed by humans (Keeler et al., 2012).

Eutrophication of water bodies, which occurs by the increase in nutrient concentrations mainly due to urban and agricultural development, is one of the most widespread problems in aquatic systems (Jeppesen et al., 2010). Higher concentrations of nitrogen and phosphorus in the water can promote algal blooms, besides changing water properties such as colour, odour, and taste (Codd, 2000; Smith et al., 2006; Keeler et al., 2012). Cyanobacterial blooms can produce toxins, causing severe risks to human and animal health (Paerl & Otten, 2013). As a consequence, essential ecosystem services are lost, including fishing, swimming, and drinkable water (Keeler et al., 2012).

Numerous strategies have already been developed to detect changes in water quality (Behmel et al., 2016). In the specific case of cyanobacterial blooms, cell counts and cyanotoxin detection have been used for a while, and are included in legislation as a method of assessing water quality (Brasil, 2005). However, due to the increasing and rapid deterioration of water resources, other strategies may be necessary to rapidly detect and mitigate the eutrophication process and bloom events. Some initiatives that have emerged involve volunteer citizens and communities in the detection of these events (Jöborn et al., 2005; Castilla et al., 2015).

Citizen science involves the participation of the population in the development of scientific knowledge. This participation can happen in different ways. Citizen science can act as a tool, in which citizens providing data and information for the development of scientific projects; Citizen science can be seen as a movement that democratizes scientific knowledge and eliminates barriers to access to science; or even with a social aspect, including communities in the production of knowledge and decision-making (Eitzel et al., 2017). In fact, the importance of public perception for monitoring and evaluating water quality has been recognized as a contribution to scientific knowledge (Niinioja et al., 2004; Jollymore et al., 2017), besides increasing the public interest in the conservation of water resources (Gholson et al., 2019). Thus, local communities can be involved in all stages of management programmes, including water monitoring and protection of drinking water supplies (WHO, 2017). In Brazil, for example, participation of the local community is required and permitted in the hydrographic committees, as stipulated by law about the Política Nacional dos Recursos Hídricos.

Several factors can determine the public perception of water quality, including colour, smell, and taste (e.g. House, 1996; Doria et al., 2009; Rojas & Megerle, 2013). In the case of eutrophication, sensory attributes of the water can be modified (Davies & Shaw, 2010), making these aspects one of the first to be perceived by the population, as an indication of water quality alteration. The public, for example, has been able to visually discern the presence of wastewater by colour (e.g. House, 1996), the influence of benthic algae (e.g. Suplee et al., 2009), and to judge whether or not those environments were suitable for recreational activities according to these characteristics.

Furthermore, contextual indicators (where the water was taken from), previous experience (contact with drinking and contaminated water), influence from other people, cultural, demographic (e.g. gender and educational level) and economic (benefits of improve water quality) factor can also affect the perception of water quality (House, 1996; Doria et al., 2009; Doria, 2010; Larson et al., 2011; Greenley et al., 2020; Flotemersch & Aho, 2021). Women generally have a greater perception of the risks offered by water, which can be attributed to the major feeling of vulnerability, different world views, socio-political factors, gender structure (Doria, 2010), or by carrying out a considerable part of domestic activities that involve the use of water (Okumah et al., 2020). Some studies indicate that the higher the level of a person`s education, the greater their ability to discern about the quality of the aquatic environment (see reviews Doria, 2010; Flotemersch & Aho, 2021 and literature cited), although other studies have failed to find this association (e.g. Ioana-Toroimac et al., 2020). However, contextual indicators and sensory properties can interact with demographic factors and influence the perception of water quality (Doria, 2010). Many studies have already been conducted evaluating the public perception of water quality. Early investigations generally assessed public perception by observing the natural aquatic environment (Smith et al., 1991; Smith & Davies-Colley, 1992). However, other strategies have emerged over time, including the application of questionnaires by postal surveys (Jones et al., 2006; Gholson et al., 2019), phone surveys (Delpla et al., 2020), experiments (Johnson, 2003), or pictures (Suplee et al., 2009), which can facilitate the process of assessing the public perception of water quality.

In this study, we use a field experiment to evaluate the public`s perception of the visual loss of water quality associated with eutrophication and greening of water. Here, we combine the strategy of observing the aquatic environment in-situ and through photographs, seeking to assess people's perception of water quality and whether that perception differs in relation to the type of observational strategy used, or if its perception is affected by demographic factors. We expected that, with the increase in eutrophication (i.e. greening the water with an increase in chlorophyll-a), people can detect the loss of water quality and threats to ecosystem services. Thus, the citizen must be able to act as information providers for monitoring water quality. Specifically, we aimed to investigate the following questions: i) What was the relationship between water quality perception by people with the chlorophyll-a concentration of the water? ii) Does observation of water in-situ and through pictures resulted in similar patterns? iii) Did the relationship between water quality perception and chlorophyll-*a* vary by gender, level of formal education, and frequency of contact with the aquatic environment? The answers to these questions can help support environmental education and potentially broaden the role of society in monitoring programs of water quality and freshwater ecosystem services, as well as assisting in the production of knowledge and decision making in relation to the use and management of water resources.

2. Material and Methods

2.1. Experimental approach and water quality gradient

The experiment was carried out in the experimental area of the Tropical Aquatic Ecology Group, located on the Campus of the Universidade Estadual de Goiás (UEG), Brazil (see MESOCOSM, 2022). The experimental setup ensured that exogenous factors (e.g. sunlight, lake size, trees) did not affect the visual perception of people. The only factor that varied among treatments was water colour as a result of different concentrations of phytoplankton chlorophyll-a.

We used six mesocosms (A, B, C, D, E and F) represented by a 500L water tank each. A eutrophication gradient was established in the mesocosms from clear water (without chlorophyll-a) to eutrophic mesocosms (very green water due to high chlorophyll-a concentration). All mesocosms were initially filled with water from an artesian well without chlorophyll-a. Mesocosm A contained only artesian water. The other mesocosms were filled with a mixture of water from the artesian well (470 liters) and a reservoir (30 liters) containing chlorophyll-a (planktonic algae species). The reservoir water had a low chlorophyll-a concentration of 3.2 $\mu g\ L^{-1}$. The nitrate-NO3 (0.80 $mg\ L^{-1}$) and phosphate-PO4 (0.01 $mg\ L^{-1}$) concentrations are also low, characterizing it as an oligotrophic environment. However, reservoir water contained different taxonomic groups of planktonic algae (e.g. Cyanobacteria, Zygnemaphyceae, Bacillariophyceae, Cryptophyeae, Chlorophyceae, and Euglenophyceae, see Machado et al., 2019). Nitrate and phosphate, obtained from solutions of sodium nitrate and potassium phosphate, were added to mesocosms C to F to stimulate algal growth and increase the chlorophyll-a. 0.16 $mg\ L^{-1}$

of nitrate and 0.01 mg L^{-1} of phosphate were added to mesocosms C and D every four days. This was a relatively low concentration that promoted the growth of small algae. Higher concentrations of nitrate and phosphate were added to mesocosms E and F every four days, to stimulate a high algal biomass. For each addition, we increased nutrients by 10% in comparison to the lake's original concentration, considering the Redfield ratio (Table 1). In mesocosm B, no nutrients were added and this resulted in very low chlorophyll-a concentration. The mesocosms were randomly distributed in the experimental area.

Table 1. Nitrate and phosphate concentrations added to promote eutrophication of E and F mesocosms. The additions were maintained during the interview period (October 29, 2019 to November 12, 2019) seeking to maintain blooming.

Date	Nitrate (mg/L)	Phosphate (mg/L)
September 11, 2019	0.176	0.011
September 15, 2019	0.192	0.012
September 19, 2019	0.208	0.013
September 23, 2019	0.224	0.014
September 27, 2019	0.24	0.015
October 01, 2019	0.256	0.016
October 05, 2019	0.272	0.017
October 09, 2019	0.288	0.018
October 13, 2019	0.304	0.019
October 17, 2019	0.32	0.020
October 21, 2019	0.336	0.021
October 25, 2019	0.352	0.022
October 29, 2019	0.368	0.023
November 02, 2019	0.384	0.024
November 06, 2019	0.40	0.025
November 10, 2019	0.416	0.026

Before the interviews, the chlorophyll-a, nitrate, and orthophosphate concentrations of each mesocosm were measured (Table 2). Although we added the same concentration of nutrients to treatments C-D and E-F, the concentration of chlorophyll-a varied very slightly at the start of the experiment. However, we classified these pairs of treatments within the same trophic state (see paragraph below). The Carlson (1977) index, modified by Lamparelli (2004), was used to classify the trophic state of the mesocosms based on chlorophyll-a concentration (Table 2), moreover, according to Brazilian resolution about the use of the water (Conama resolution 357, of March 17, 2005, Brasil, 2005), the mesocosms can be used to human consumption, primary contact recreation, irrigation of vegetables and fruits, aquaculture and fishing (but see the variation among mesocosms in Table 2).

A multiparameter probe (Manta 2 Eureka) was used to quantify chlorophyll-a concentrations, and nutrients analysis was carried out following the methods described in Golterman et al. (1978). Photographs of the same mesocosms were used to evaluate the visual perception of the water.

2.2. Visual perception

The public were interviewed through visits to the experimental area (in-situ group) or through analysis of pictures of the mesocosms (picture group) to evaluate their perception of water quality. For the in-situ approach, we selected people that frequent the university (including students, employees, teachers) and the municipality of Anápolis. People were selected seeking to contemplate a variation in age, gender and level of education. The invitation to participants was made

Table 2. Concentration of Nitrate, Orthophosphate, Chlorophyll-a (Chl-a), trophic state and water class of each mesocosms used in experiment. The columns water class indicates the classification of water bodies in accordance with Conama resolution 357, of March17, 2005 and its rectifications.

Mesocosm	Nitrate (mg/L)	Orthophosphate (mg/L)	Chl-a (μg/L)	Trophic State	Class
A	0.1	0.01	0	Ultra-oligotrophic	1*
B	0.14	0.01	3.5	Oligotrophic	1*
C	0.06	0.013	6	Mesotrophic	1*
D	0.13	0.015	8	Mesotrophic	1*
E	0.09	0.035	17	Eutrophic	2#
F	0.15	0.039	18	Eutrophic	2#

*Class of water used for human consumption after simplified treatment, primary contact recreation, irrigation of vegetables and fruits consumed raw, and protection of aquatic communities in indigenous lands. # Class of water used for human consumption after conventional treatment, protection of aquatic communities, primary contact recreation, irrigation, aquaculture and fishing.

in person, verbally. At this moment, we explain the purpose of the project and schedule a visit to the aquatic environments. The visit to the experimental area was performed in groups of up to 10 volunteers at a time, from October 28th until November 14th of 2019. The volunteers were unable to touch in the water and were around 1 meter away from the experiment. The volunteers were always taken to the experimental area during mild sunny days, such as early morning and late afternoon. The interview was performed by the same researcher (ACMD) who explained once again the research goal and the structure of questionnaire to the volunteers at the start. The interviewees were then invited to sign an informed consent form, authorizing us to use the questionnaire data and guaranteeing the interviewee security in terms of confidentiality. The research project was approved by the research ethics committee of the State University of Goiás (CEP 8113 - State University of Goiás - UEG).

During the interview, each interviewee individually observed the water in the mesocosms in-situ and answered the questionnaire, without any exchange of information between the others participants or with the researcher. The questionnaire was composed of: i) personal information (gender, age, and level of formal education); ii) six questions about their perception of the water quality and its potential use (Table 3); iii) information about their number of visits to aquatic environments in the last month (Table 3). The six perception questions were elaborated considering that people use water resources in different ways, for example, for swimming, fishing, sports, or consumption.

The six questions (item ii of questionnaire) were answered for each mesocosm, and the interviewees chose one option based on a Likert scale varying from 1 to 5, where one represents a very favorable perception about of the water in the mesocosm, and five represents a very negative perception of the water in the mesocosm.

The experiment was repeated using pictures. The pictures used are from the same mesocosms used in in-situ experiment, and each picture was taken at the same angle (superior view) and at a resolution of 15.9 megapixels, using a Nikon camera (model Coolpix P510). For this, we turned the same in-situ questionnaire into an online questionnaire. For this approach, we used only questions 1 and 5 of the in-situ questionnaire. A hyperlink to the form was promoted on social media and emailed to people from Anápolis. This contained the same information disclosed to the in-situ approach participants. The volunteers of the picture approach had the same time to fill out the questionnaire as in the in-situ approach. A total of 87 volunteers completed the online survey.

Table 3. Questionnaire applied to 100 interviewees seeking to assess their visual perception regarding water quality in the six mesocosms in-situ. We used only question 1 and 5 to 83 interviewees used pictures approach. The questionnaire was applied in Portuguese.

Personal Information
Gender: Age: Scholarly level:
Question 1. What do you feel when you see this water?
(1) nice (2) good (3) bad (4) disagreeable (5) completely disagreeable
Question 2. Would you go for walks or tours around a lake with this water?
(1) very likely (2) likely (3) maybe (4) unlikely (5) completely unlikely
Question 3. Would you use this water for consumption?
(1) very likely (2) likely (3) maybe (4) unlikely (5) completely unlikely
Question 4. Would you practice recreational fishing in a lake with this water?
(1) very likely (2) likely (3) maybe (4) unlikely (5) completely unlikely
Question 5. If you were aware, would you consume fish that were fished in a lake with this water?
(1) very likely (2) likely (3) maybe (4) unlikely (5) completely unlikely
Question 6. Would you swim in a lake with this water?
(1) very likely (2) likely (3) maybe (4) unlikely (5) completely unlikely
How often do you visited aquatic environments (river, lakes, reservoirs) in the last month? ( ) Don't visited ( ) One or two times. ( ) More than three times.

2.3. Data analysis

The following statistical steps were used to evaluate visual perceptions of the water quality: i) For each person, were obtained the scores of visual perceptions in-situ and through pictures (Likert scale value), then we performed an ANOVA One-Way, to evaluate if the visual perceptions (Likert values), differed between treatments with different water quality; ii) We correlated, to each person, the visual perception (Likert scale) with the chlorophyll-a concentration of each mesocosm. This correlation show how visual perception are changing in response to change in water quality; iii) The correlations registered in-situ and through pictures were compared to evaluate if the perception about the water quality is different when people see water in-situ or through pictures. We used the One-

Way ANOVA to compare these two groups; iii) All correlations were investigated to see if they varied among personal traits (e.g. social, educational, and gender). We performed the PERMANOVA to compare the correlations registered among different groups. The experimental and statistical steps are summarized in Figure 1 and detailed below.

We used the One-Way ANOVA to determine whether people are capable of detecting changes in water quality. For this, the interviewee score about water quality was the response variables, and the treatments were the mesocosms (six levels of chlorophyll-a). The test significance was assessed using Monte Carlo simulation with 1000 permutations, without the need to check for normality. Tukey's HSD (Honestly Significant Difference) test was used to investigate post-hoc pairwise comparisons among the mesocosms. We used the Bonferroni correction for conservative statistical decision, where the new p-value should be based on the number of statistical tests that have been repeated (i.e. six ANOVAs). Thus, that a ANOVA will be considered significant only if p-value is smaller than 0.008 (calculated considering 0.05/6 tests).

The relationship among water quality (indicated by chlorophyll-a) and interviewee perception was performed by Pearson correlation, where positive values indicated higher scores (i.e. water disgusting perception) were recorded in waters with higher

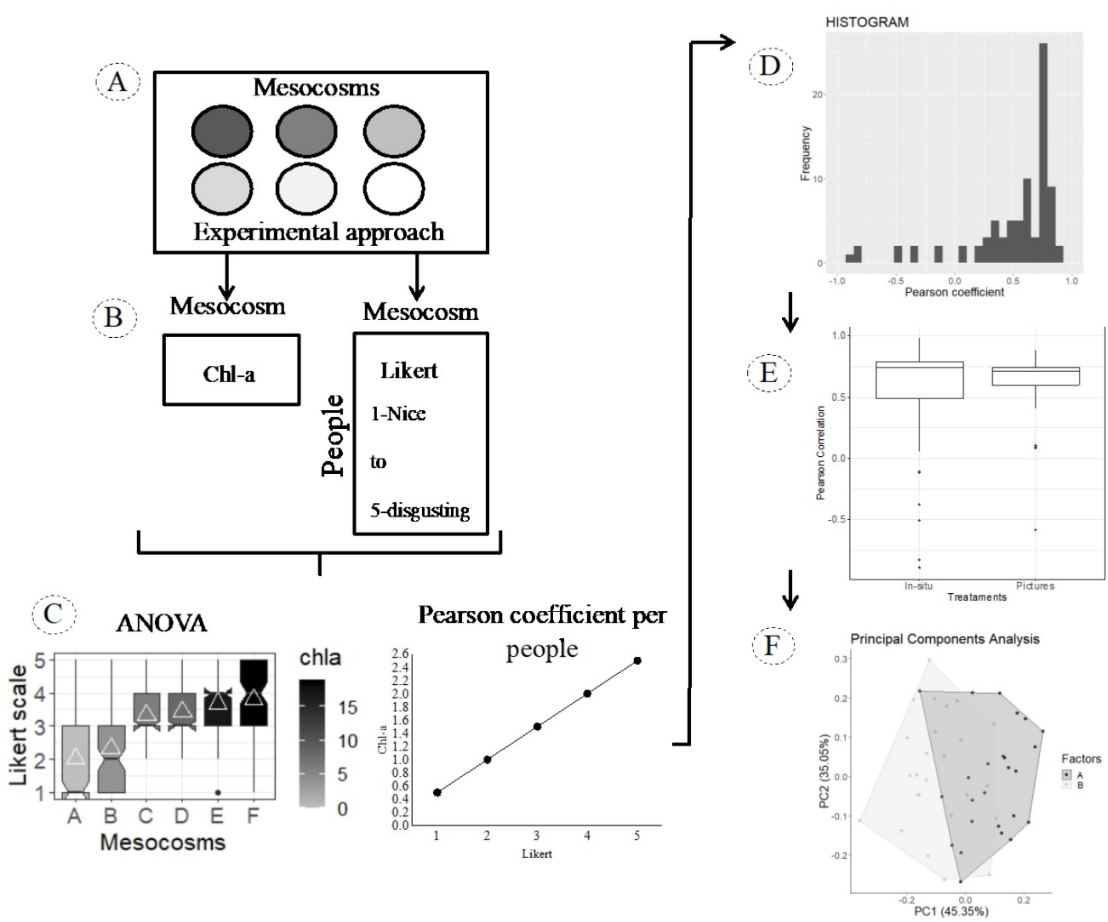

Figure 1. Schematic protocol used in the presented study. The mesocosms installed had a strong gradient of eutrophication according to the concentration of Chlorophyll-a (A). People were invited to respond to questionnaires with questions about the water quality of the mesocosms (B). People visualized the mesocosms in the experimental area (in-situ approach) or through pictures. People's perception of water quality (Likert scale) was analyzed in two ways: One-Way ANOVA comparing the mesocosms, and pearson correlation, to evaluate the relationship of Likert scale with the Chlorophyll-a concentration of the mesocosms (C). We used the result of Pearson correlation to estimate the histogram of r values (D), compare the visual perception obtained in-situ and through pictures (E), and summarized and modeled with predictor variables (gender, formal education, and frequency of visits to aquatic environments) using the PERMANOVA (F).

chlorophyll-a. In other words, the highest positive Pearson correlation values indicated that people are capable of detecting the water eutrophication degree. Negative or null Pearson correlation indicated that visual perception of the people are not capable to detect eutrophication degree. We used the Pearson correlation detected by each person in further analysis.

A one-way ANOVA was used to evaluate the similarity between the correlations registered in the in-situ and picture approaches (question ii). The significance was tested through the Monte Carlo simulation with 1000 permutations. The comparison was performed per each question of the in-situ and picture approaches (in this case, only questions 1 and 5). Thus, the Pearson correlation coefficient was the response variable and the predictors, were the type of experimental approach (pictures or in-situ).

The perceptions of the people to detected loss of water quality, indicated by the Pearson correlation coefficient, was modeled in function of personal and self-declared information of the people (question iii). We used the following information in the questionnaire: a) Gender: male or female; b) Level of Formal Education: last formal education that we reclassified into Basic level (up to high school); Undergraduate (up to undergraduate degree, including not complete); Graduate (Master's and Ph.D. degrees). c) Self-declared information of contact with aquatic environment: number of visits to aquatic environments in the last month. This information indicated the frequency of visits, which had three options: no visit (no frequency); visited once or twice last month (low); and visited more than three times last month (high frequency).

A PERMANOVA (Anderson, 2014) was used to evaluate if visual perception (r values) varies between gender, formal education, and frequency of visits to aquatic environments. This test compares the mean of Pearson correlation (r) values (centroids) found in each group (e.g. male or female) and determines if the centroids were similar or different. Thus, non-significant values indicated that the mean r values are equivalent for all groups. To perform the PERMANOVA, we used all questions of the questionnaire in a Euclidean distance matrix. The significance was tested using the Monte Carlo simulation with 1000 permutations. We tested the assumption of sphericity of group dispersion (see Anderson et al., 2006) in the PERMANOVA, which was assured. We used a Principal Component Analysis (PCA) using the Euclidean distance matrix to visualize the groups formed for each predictor variable. We performed an isolated PERMANOVA because some people did not respond all the questions in the questionnaires. Only 68 people answered the frequency of visits to aquatic environments, and 76 answered the questions about gender and formal education.

We performed all statistical analyses using the R software (R Core Team, 2020). We tested the Pearson correlation, Tukey's test, and Principal Component Analysis using the functions cor.test, TukeyHSD, and prcomp, of package stats, respectively. The permutational one-way ANOVA was tested using the function perm.oneway.anova in the package wPerm (Weiss, 2015); The PERMANOVA was tested using the adonis function, and the assumptions tested using the beta.disper function, both available in the package vegan (Oksanen et al. 2019). The figures were generated using different functions of the packages ggplot2 (Wickham, 2016) and ggfortify (Tang et al. 2016).

3. Results

We interviewed a total of 187 people, including pictures (87 people) and in-situ experiment (100 people), where the average age of the interviewees was 26.5 years old (Standard Deviation = 10.2, minimum = 18, maximum = 70 years old). Regarding the gender, we interviewed 83 women (average = 25.1 years old) and 104 men (average = 27.6 years old). These data regarding gender and age were similar to patterns registered locally (IBGE, 2010).

Considering the in-situ experiment, people indicated different "perception scores" (indicated by the Likert scale) to all questions for each mesocosm, where mesocosms A and B had the lowest scores values. These mesocosms had the lowest concentration of chlorophyll-a. Moreover, mesocosms E and F had the highest scores values, as well as the highest concentration of chlorophyll-a (Figure 2). We found significant differences among mesocosms for all questions, even when using the Bonferroni correction ($p=0.008$): Question 1 ($F=42.6$; $P=0.001$); Question 2 ($F=34.3$; $P=0.001$); Question 3 ($F=54.9$; $P=0.001$); Question 4 ($F=24.6$; $P=0.001$); Question 5 ($F=29.4$; $P=0.001$); Question 6 ($F=53.6$; $P=0.001$). The Tukey's HSD test showed that mesocosms A and B, respectively ultra-oligotrophic and oligotrophic, had significantly lower Likert scale values than mesocosms C, D, E, and F. The mesocosms C and D are mesotrophic and E, F are eutrophic.

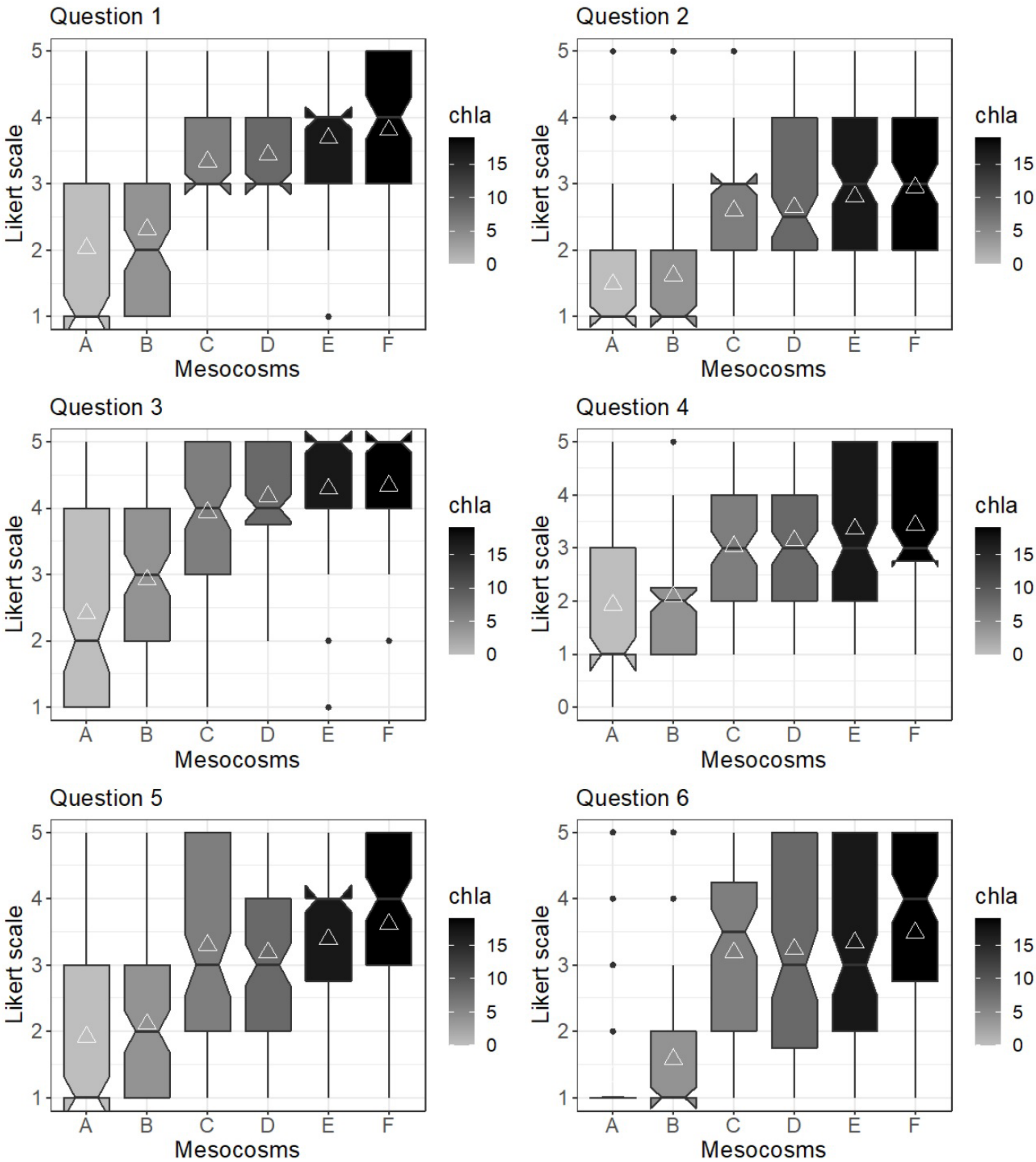

Figure 2. People's perception of the water quality indicated by mean (triangle) and dispersal of each question (Likert scale), for each mesocosm in the in-situ experiment. The concentration of Chlorophyll-a (chla) of each mesocosm is represented on a gradient scale. The Likert scale varies from 1 (nice feeling about the water quality) to 5 (disgusting feeling about the water quality). The chlorophyll-a concentration in mesocosms varies from 0 (mesocosm A) to 18 $\mu g/L^{-1}$ (mesocosm F).

The Pearson's correlation coefficients (r) were overwhelmingly positive for all of the questions (Figure 3). In fact, the median r values for all questions were similar and indicated high r values (question 1, median = 0.74; question 2, median = 0.7; question 3, median = 0.74; question 4, median = 0.63; question 5, median = 0.69; question 6, median = 0.74). The positive correlation shows that mesocosms with poor water quality (i.e. high chlorophyll-a concentration) received the highest Likert scale values (poor water quality). In other words, most people were able to perceive the change in water quality.

The approach regarding the perception of the water quality through pictures (87 people) showed similar patterns to the in-situ experiment. Thus, we found a positive correlation between the score values and chlorophyll-a concentration (Figure 4). In this approach, we considered only two questions of the questionnaire (questions 1 and 5). Therefore, we observed that for both questions, the correlation coefficients registered in the in-situ experiment were statistically similar to the coefficients registered in the experiment using pictures (Figure 5). We found no significant difference between these two groups:

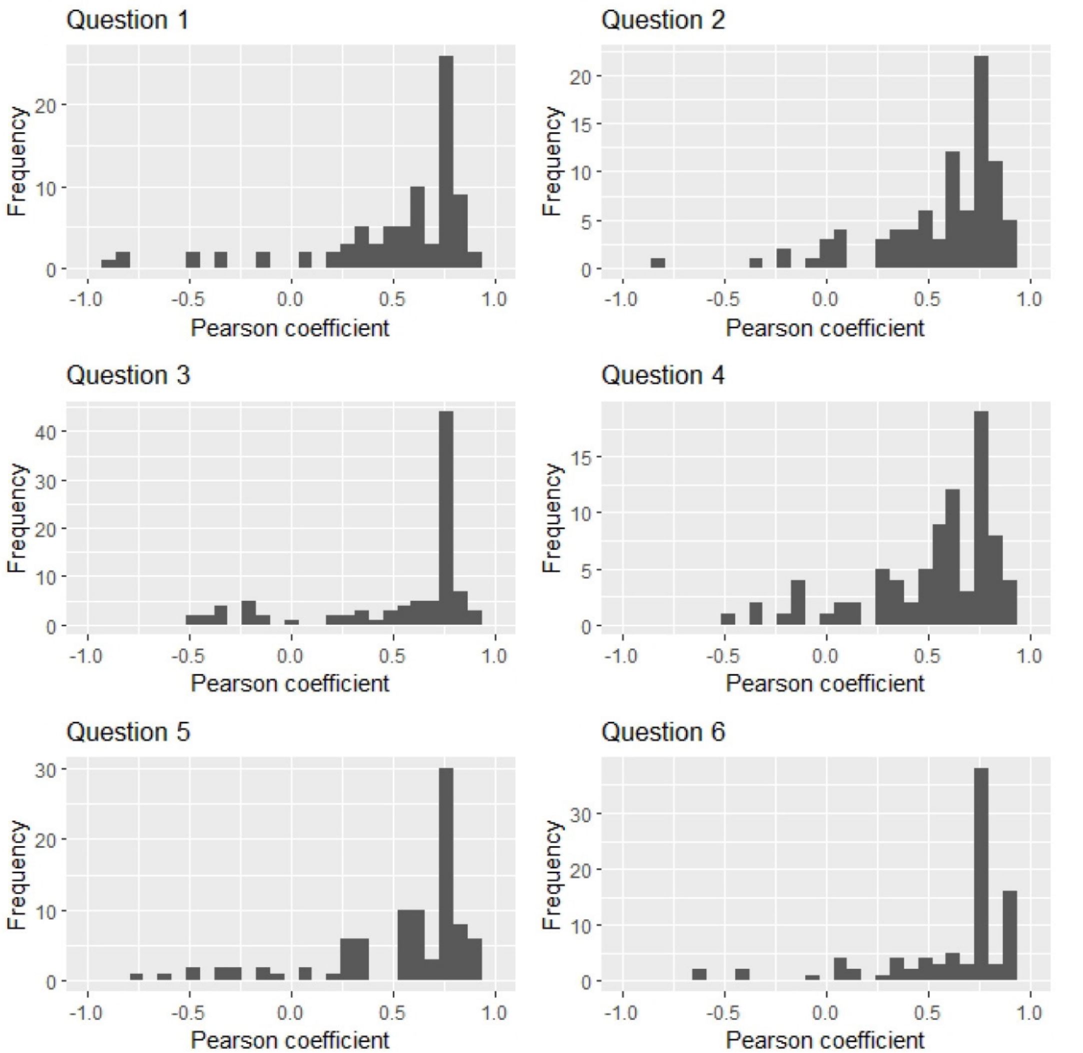

Figure 3. Histogram of Pearson correlation coefficients for each question, considering the 100 people analyzed in the in-situ experiment.

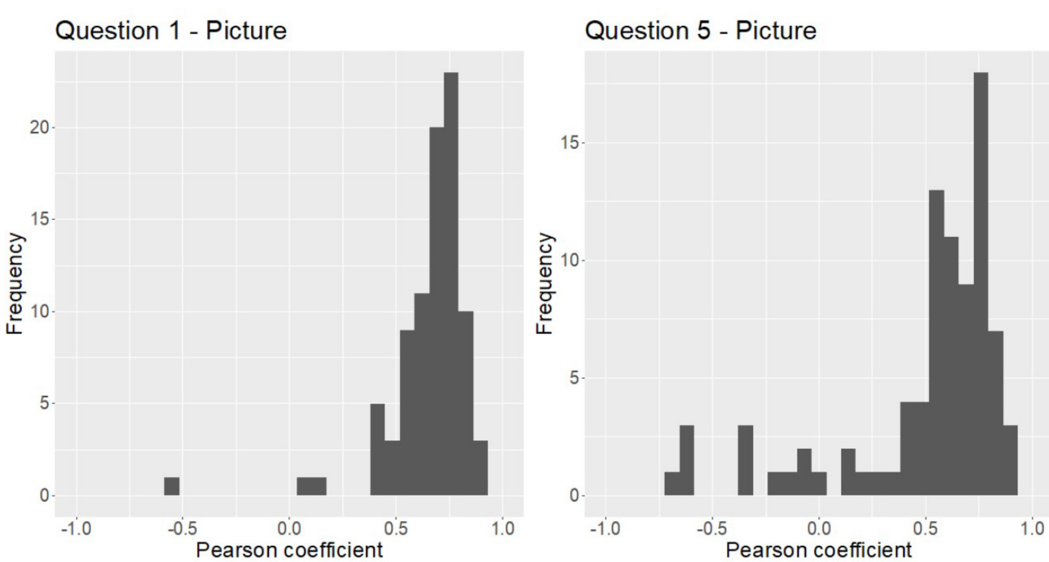

Figure 4. Histogram of Pearson correlation coefficients for each question, considering the 87 people analyzed in the pictures experiment.

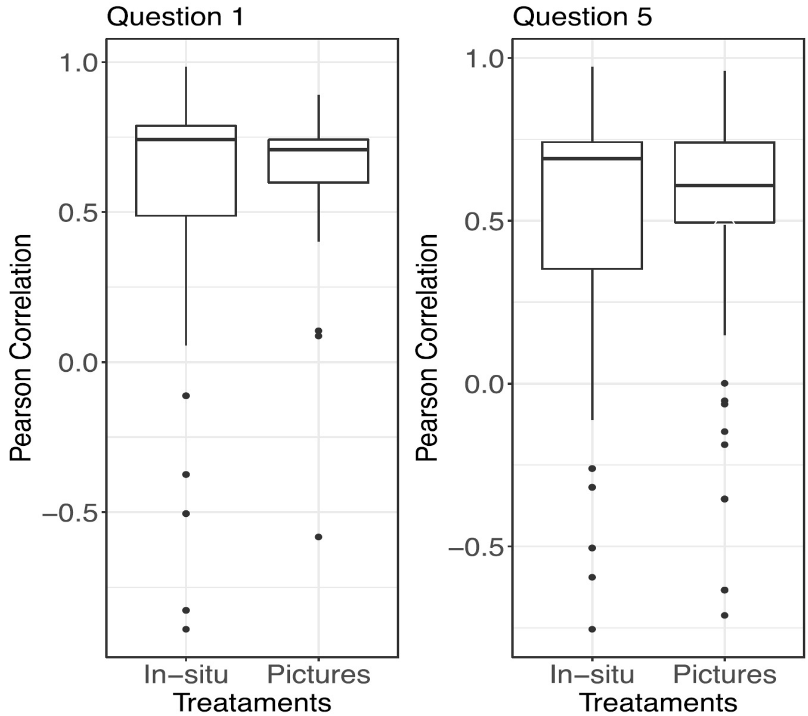

Figure 5. Boxplot comparing the Pearson coefficients of two questions between the experiments in-situ (100 people) and through pictures (87 people).

Question 1 (F=3.83; P=0.06), Question 5 (F=0.14; P=0.69).

The PERMANOVA showed no effect of frequency of visits to aquatic environments (F=1.47; P=0.19), gender (F=0.89; P=0.41), and formal education (F=0.77; P=0.51) on the Pearson coefficients (summarized in PCA – Figure 6). In other words, regardless of the number of visits, gender, and level of education, people rated similarly the loss of water quality. These results were similar for the experiment using pictures (Figure 7) with no effects for PERMANOVA (frequency of visits to aquatic environments: F=1.41; P=0.16, gender: F=0.15; P=0.83) and PERMDISPER (frequency of visits to aquatic environments: F=2.61; P=0.07, gender F=0.14; P=0.71).

4. Discussion

We have showed that people can detect a loss of water quality. They preferred cleaner water, more suitable for recreational activities and consumption, but did tolerate some level of chlorophyll-a. Moreover, this perception was similar through evaluations of water quality in-situ or through pictures. People's detection of water quality did not vary by gender, formal education, or frequency of visits to aquatic ecosystems.

People's perception of water quality indicated that water without (mesocosm A) or with a low concentration of Chlorophyll-a (mesocosm B) was more suitable for recreational activities (e.g. swimming, fishing) and consumption. Moreover, our results indicated that water eutrophication (increase in chlorophyll-a) reduced the attraction of the water to people. Previous studies of coastal waters have shown that people show preferences for "blue" waters over turbid waters (e.g. Smith & Davies-Colley, 1992; Smith et al., 1995; Lee, 2017).

Here, we observed that people readily detect differences in chlorophyll-a concentration among mesocosms and associate increased concentrations with poorer value for use (Angradi et al., 2018). Although our questionnaire was limited to just six questions, they covered several possible types of water use by the population and the responses to questions were consistent both in-situ and through photographs. Therefore, considering this association, the visual perception of people can be used as a simple approach to monitor the quality of aquatic ecosystems. Detecting early signals of algal blooms or water eutrophication are current frontiers of biomonitoring programs (e.g. Wilkinson et al., 2018). For this, it is necessary to invest in establishment and maintenance of citizen groups to support high frequency monitoring.

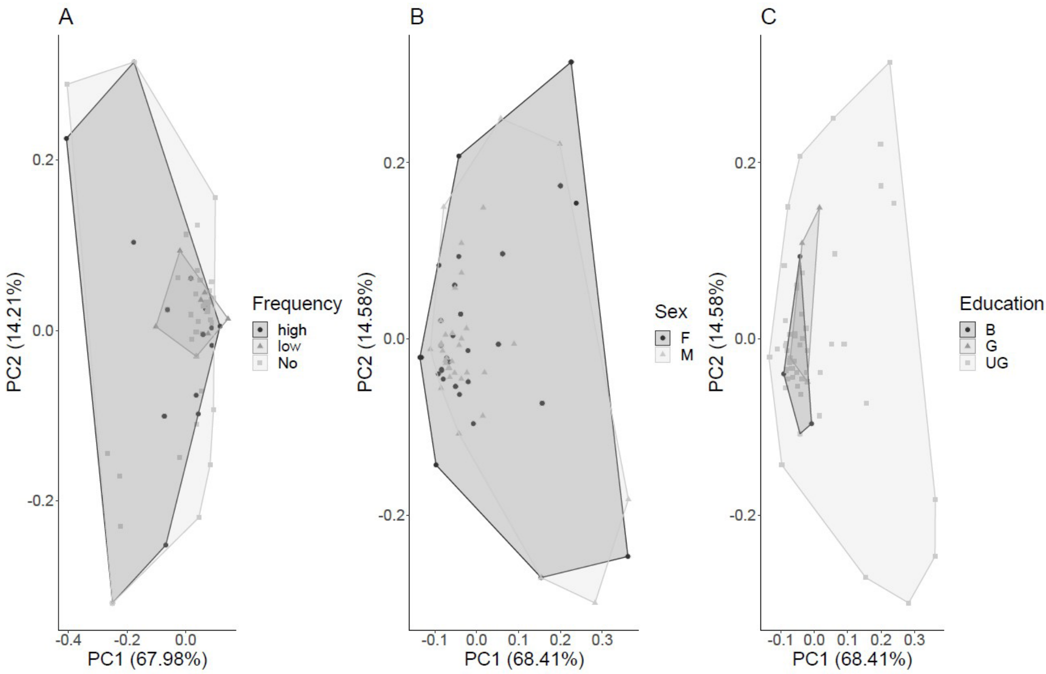

Figure 6. Principal Component Analysis regarding the correlation between people's perception and chlorophyll-a concentration of all questions obtained in the in-situ experiment. The polygons represent the groups of people classified by the frequency of visits to aquatic environments (A), gender (B), and level of formal education (C). The frequency of visits was classified in: no visit, low frequency, and high frequency. Gender was classified into Male (M) or Female (F). Formal education was classified into Basic (B), Graduate (G), and Undergraduate (UG).

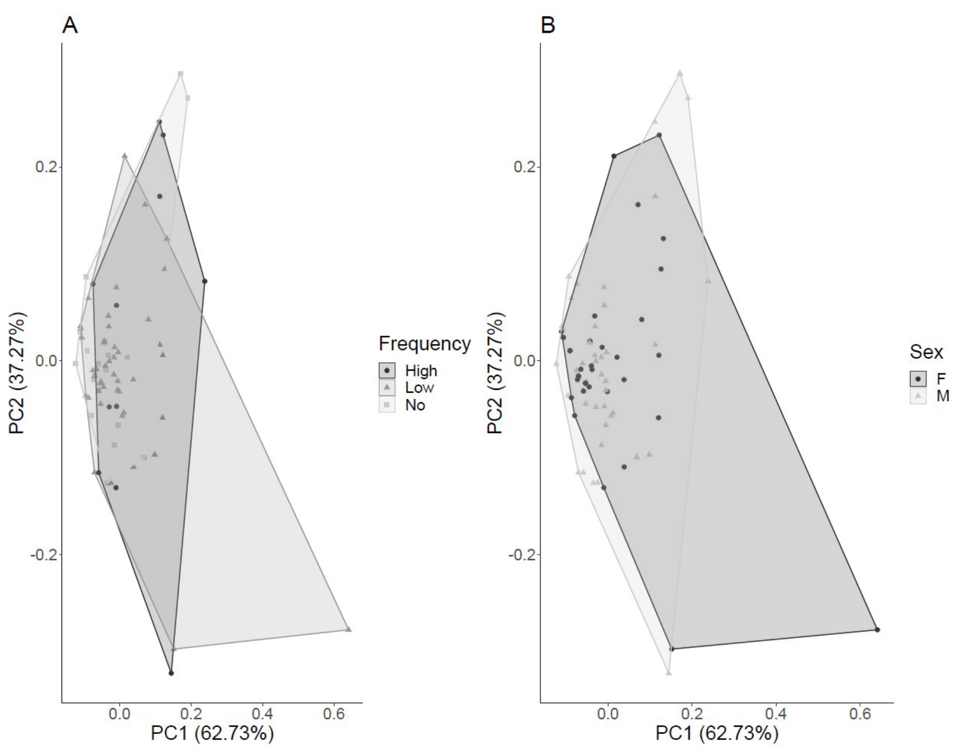

Figure 7. Principal Component Analysis regarding the correlation between people's perception and chlorophyll-a concentration of questions obtained in the pictures experiment. The polygons represent the groups of people classified by the frequency of visits to aquatic environments (A) and gender (B). The frequency of visits was classified in: no visit, low frequency, and high frequency. Gender was classified into Male (M) or Female (F). Formal education was classified into Basic (B), Graduate (G), and Undergraduate (UG).

Environment protection agencies and researchers can use the rapid, early warning information from people's perceptions to indicate regions (e.g. urban lakes, rivers, and reservoirs) that show unusual changes in the water colour and use this to target program for monitoring to provide more quantified measures of status and the presence or absence of toxic cyanobacteria

Citizen science has been applied to monitoring species occurrences (Steen et al., 2019), water parameters (Jollymore et al., 2017), and algal blooms (Kotovirta et al., 2014). This association between researchers and society can promote the development of science and increase the environmental awareness of the people, contributing (Johnson et al. 2014; McKinley et al., 2017). Public involvement in monitoring, vigilance, and evaluation of water quality is relevant because they are often the first to notice changes in water quality and can take immediate action to remedy this problem (WHO, 1997, 2017). This strategy is relevant, especially in developing countries where it is not always possible to maintain widespread water monitoring programs (Kirschke et al., 2020).

People's perception of changes in water quality can be affected by social and educational factors (see review in Flotemersch & Aho, 2021; Ochoo et al., 2017; Gifford & Nilsson, 2014). Moreover, it may be necessary to provide formal and non-formal instruction to detect some changes in biological structure (see, for example, Gomes et al., 2019). However, we found that formal education and contact with aquatic environments did not affect people's perception of the loss of water quality. This can be explained by the simplicity of the approach, based on just visual colour. Moreover, these results indicated that vast groups of people could potentially help researchers in monitoring aquatic environments if they can be sufficiently motivated. Despite that, we agree that formal education in environmental courses may increase the level of concordance among the responses of questionnaires, ensuring more confidence for monitoring actions.

Formal instructions (e.g. courses of scientific and environmental education) have been applied to increase the environmental awareness of people (Coertjens et al., 2010). Here, we observed that people that visualized mesocosms in-situ or through pictures showed similar results in detecting the loss of water quality. Although in-situ groups had contact with other water characteristics (e.g. smell), the change in the colour of the water was clearly the most outstanding characteristic for the two groups. Therefore, at least for studies of eutrophication and water greening, scientific and environmental education programmes could use photographs in their activities (c.f. Bloomin'Algae app – UKCEH, 2022).

5. Conclusions

We recommend further studies to use field experiments to evaluate people's perceptions of different types of impacts on nature (e.g. toxic algal blooms, global warming, biological invasion). Our results reinforce the potential for people's visual perception for monitoring aquatic ecosystems impacted by eutrophication. Thus, monitoring agencies and researchers could use that public perception as early-warning strategies for monitoring programs of water quality. Finally, we highlight the growing potential use of mobile phone apps and social media to connect people to researchers, and as a consequence, to connect science with society.

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