Ambio 2021, 50:425–435
https://doi.org/10.1007/s13280-020-01358-0

KUNGL. VETENSKAPS-AKADEMIEN
THE ROYAL SWEDISH ACADEMY OF SCIENCES

REVIEW

Factors influencing perceptions of aquatic ecosystems

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Received: 2 December 2019 / Revised: 21 April 2020 / Accepted: 15 June 2020 / Published online: 22 July 2020

Abstract While factors influencing perceptions of drinking water have been well studied, those of aquatic ecosystems have been to lesser extent. We conducted a review to improve awareness of these factors. Environmental factors found to influence public perceptions of aquatic ecosystems were presence/absence of water plants and algae, presence/absence of floating debris, the odor, movement (for flowing waters) and clarity/turbidity of the water, and the type, condition, setting, naturalness, and overall aesthetic appeal of the ecosystem. Sociocultural factors found to influence public perceptions of aquatic ecosystems included age, education, gender, and place-based knowledge. We provide perspectives of how managers can better meet the diverse social demands placed on aquatic ecosystems. The importance and benefits of considering these perspectives may be especially beneficial where significant multi-generational and culturally relevant place-based knowledge exist.

Keywords Ecosystem services · Place-based knowledge · Public engagement · Riverscape aesthetics · Social demands · Sustainable aquatic ecosystem management

INTRODUCTION

Water is inextricably linked to all life on earth and humans are no exception. In response to the increasing size of the human population, however, and the increasing want and ability to extract services provided by surface waters (MEA 2005), many governments oversee concerns of water pollution and contaminants. In the United States, the primary federal law governing water quality and quantity is The Federal Water Pollution Control Act (i.e., Clean Water Act, 33 U.S.C. §§1251–1387). The objective of the Clean Water Act is to restore and maintain the chemical, physical, and biological integrity of the nation's waters. As part of this, water bodies are classified and subsequently managed for the types of beneficial uses they provide to society. These "beneficial uses" are often categorized and managed using an ecosystem services framework (MEA 2005) that places services into four categories; provisioning, regulating, habitat (or supporting), and cultural (MEA 2005). Resource managers and decision makers are increasingly considering services across these categories as an integrative approach can increase effectiveness, equality, and efficiency of management plans (Perreault et al. 1998, as cited in Stratford and Davidson 2002; Kondolf and Yang 2008; Milcu et al. 2013; Khew et al. 2014; Walker-Springett et al. 2016). Managing in terms of multiple ecosystem services is also increasing the relevance of natural resources to a larger audience in multiple ways (e.g., Stratford and Davidson 2002; Stålhammar and Pedersen 2017). This is significant as the increased engagement of people with ecosystem services contributes to human well-being (Chiesura and de Groot 2003; Summers et al. 2012; Milcu et al. 2013; Plieninger et al. 2013, 2015; Bryce et al. 2016; Moyle and Weiler 2017).

Regarding the engagement of people with aquatic ecosystems, people sensibly prefer resources they perceive to be of good quality and having attributes that are aesthetically pleasing (Kondolf and Yang 2008; Martín-López et al. 2012; López-Santiago et al. 2014; Julian et al. 2018). Logic follows that ecosystem service-oriented management plans would therefore include management options that embrace these preferences. However, perceptions of quality can differ among sectors of the public (David 1971; Colley and Craig 2019) as well as between the lay and

expert community (Smith et al. 1995; Kotovirta et al. 2014).

Factors influencing public perceptions of drinking water have been well studied. For example, the World Health Organization (2008, 2011) found that the primary attributes considered by the public were taste, odor, color, and appearance/turbidity. When the public generally perceived an undesirable level of any of these attributes, the water was considered potentially harmful and unsafe for consumption. These findings concur with those of de França Doria (2010) and Rojas and Megerle (2013) who concluded that the public largely evaluated drinking water quality based on organoleptic properties (i.e., using the sense organs). Rojas and Megerle (2013) also found that perceptions of drinking water quality can differ among social groups. Sanchez et al. (2014) echoed the importance of social aspects in shaping perceptions and added that perceptions also varied by stakeholder cultural values. This should not be surprising as perceptions are one of many aspects of human behavior that are indeed influenced by the sociocultural setting of the individual (Segall et al. 1968; Triandis 1994; Sorrentino 2005). These assertions hold true with regard to our perceptions about the environment (Hein et al. 2006; Sagie et al. 2013), interactions with the environment (Finn and Jackson 2011), and historical connections to the environment (Oestreicher et al. 2014).

Public perceptions of aquatic ecosystems, including environmental water quality, have been examined to a lesser extent than specific services such as drinking water (Ioana-Toroimac et al. 2020). How aquatic ecosystems are perceived by the public is important because it can influence public support for management strategies (Genskow and Born 2006; Larned et al. 2006; Kondolf and Yang 2008; Ives and Kendal 2014). An increased understanding of factors that influence perception, as well as the role of aesthetic preferences in perceptions, would support the development of management strategies that better align with public opinion of good aquatic ecosystems. This could logically lead to increased public engagement with aquatic ecosystem services and, consequently, improve public support and satisfaction of management actions (Moyle and Weiler 2017).

In this paper, we explore perceptions, preferences, and, to lesser extent, perspectives (i.e., lay vs. expert) of aquatic systems reported in the literature. The objective of this review is to improve awareness of these factors and ultimately contribute to the development of management options that are more mindful of the diverse social demands the public places on aquatic ecosystems (Bikangaga et al. 2007; Howard 2008; Jackson et al. 2008). Note that we do not provide definitive conclusions on how reported factors influence perceptions as these can and do vary geographically, situationally, and temporally.

MATERIALS AND METHODS

We conducted a "critical review," which aimed to research the literature, evaluate quality of the literature, synthesize sources, and produce a hypothesis on how resource managers can better consider public perception in resource management (c.f. Grant and Booth 2009). This "critical review" focuses on providing a conceptual contribution from a critical analysis of existing literature rather than a systematic review. Our intent was to synthesize information from a variety of sources and encourage further research on factors that influence perceptions and preferences of aquatic ecosystems. This notably excludes discussions of factors influencing social demands of aquatic ecosystems, which are thoroughly addressed by Flotemersch et al. (2019) as our focus was at the ecosystem level. We limit our discussion to those factors mentioned in the reviewed literature. For comparative purposes, findings pertaining to drinking water are included in the paper.

In our review, we only considered articles in the English language. There were no geographic or temporal bounds on the literature. This lack of a time frame, coupled with the realization that perceptions have changed through time, could be concerning if our intent was to provide definitive conclusions on how reported factors influence perceptions. Information was categorized into self-emergent categories relevant to our objective. Under each theme, we present the results focused on aquatic ecosystems, supplemented at times with findings from other water-focused studies which may not be entirely focused on aquatic ecosystems.

Terminology varied between articles. To the extent possible, we have used terminology of the published work being cited, exceptions being when doing so impeded clarity. In general, we use the term 'perception' when referring to things a person becomes aware of through the senses, 'preferences' when referring to a person's liking of something (e.g., aesthetics), and 'opinion' to represent the judgement formed. Other terms benefiting from clarification are 'attribute,' which we use to refer to an aspect of the environment, 'characteristic,' when referring to aspects of a person or persons, and 'factor' when referring to two or more of the above.

RESULTS

Findings of our review are organized in two sections. The first considers which attributes of the environment contribute to public opinions of aquatic ecosystems. The

second considers how opinions are influenced by sociocultural characteristics of the individual.

Environmental factors considered by the public when forming perceptions of aquatic ecosystems

The term perception generally refers to becoming aware of something through the senses. Research on the water component of an aquatic ecosystem has shown that the public generally consider a limited number of parameters when forming perceptions of condition. Moser (1984), for example, examined public perceptions of river water quality and showed the public considered color (as in hue), presence/absence of water plants and algae, presence/absence of floating debris, odor, movement, and clarity (due to suspended particles). These findings agreed with previous work on this topic cited by Moser (1984) (i.e., Willeke 1968; Barker 1971; Ditton 1971; Ditton and Goodale 1973). What Moser (1984) added to previous findings was insight to how some attributes can supersede others. For example, Moser (1984) found that odor and floating debris were the most important criteria to the public when judging water quality. These results were somewhat corroborated in urban waters where smell (or odor) and turbidity (or clarity), naturalness of the banks, and overall aesthetic quality were cited as the most important indicators of water quality to the public (Steinwender et al. 2008). Steinwender et al. (2008) added that non-visual physical indicators, such as oxygen content and water temperature, were unrelated to public perceptions.

Other studies have shown how public appraisal of aquatic ecosystems can be influenced by the type (Artell et al. 2013), condition (Steinwender et al. 2008), and setting (Rooney et al. 2015) of the resource itself. Studies involving wetlands provide good examples of public perceptions of a resource that differ by the type of system being considered. Dobbie and Green (2013) found that public perceptions and the self-emergent wetland types from those data did not correspond to the hydrology-based classification system used by scientists. From an ecosystem services perspective, Rooney et al. (2015) found that residents more often perceived constructed wetlands as providing quality services (which they did not), and natural wetlands as not providing these services (which they did). Rooney et al. (2015) noted the importance of context (i.e., juxtaposition) by hypothesizing the observed results could be due to wetlands in their study being in an agricultural setting standing out as natural oases against the managed, often monocultured, agricultural landscape.

A few studies we found informed how overall condition of an aquatic ecosystem can impact public perceptions. Artell et al. (2013), for example, reported that lay and expert perceptions of condition differed, particularly when the water quality of the resource being considered was rated as below average from the expert perspective and when "scientific measures" were used. This is not to say that public perceptions were wrong, but only that they differed from the perspective of the scientists. Agreeing with these results, although stated differently, Steinwender et al. (2008) found that the public's ability to accurately perceive environmental water quality increased as water quality conditions themselves increased, according to "scientific measures." An additional observation by Steinwender was that unfavorable subjective assessments by the public were more frequent when cloudy weather prevailed. These assessments may have reflected the less picturesque appearance (i.e., aesthetic appeal) of the overall landscape (water banks and surroundings).

Regarding the influence of aesthetic appeal on perceptions, House and Sangster (1991) found that the public had an "overwhelming desire for trees and a strong preference for vegetational diversity" and that there was "an equally strong preference for mature, sinuous rivers with natural channels and banks." Systems possessing these features were viewed more favorably than those lacking them. This may be the natural state for some systems, but certainly not for all rivers. In other studies, grassy banks and manicured landscapes were reported as preferred over "less tidy" vegetation (Piégay et al. 2005; Kondolf and Yang 2008 and cited references; Khew et al. 2014). Le Lay et al. (2013) reported similar preferred-feature findings regarding braided rivers in Italy where natural features such as gravel bars were rated as less aesthetically pleasing by the public. Both cases provide examples of where observation of features of an aquatic system (albeit natural or otherwise) led to differing opinions regarding the condition of the resource. With somewhat contrary results, studies by Junker and Buchecker (2008) and McCormick et al. (2015) found aesthetic evaluations by the public were largely concordant with expert perceptions of ecological health. Junker and Buchecker (2008) importantly added that "the public's aesthetic preferences are primarily influenced by perceived naturalness of the setting."

Sociocultural factors that contribute to individual perceptions of aquatic ecosystems

Characteristics of the individual were also reported in the literature as influencing perception. For example, Sanchez et al. (2014) found a degree of clustering of demographics with reported stream condition (e.g., highly educated populations tended to live near streams with high ecological value). Additional research exploring subcategories of demography, such as gender, race, and income, have found that disadvantaged groups in general have a more acute sense of environmental risk and vulnerability (cf.

Bickerstaff 2004; Wester-Herber 2004; Weber 2006; Kahan et al. 2007). This could, in part, reflect the relationship between economic well-being and direct use of ecosystem services (Horcea-Milcu et al. 2016). The absence of what may seem to be rather obvious demographic factors (e.g., income) is not intended to minimize their importance as influential factors, but rather a consequence of them not showing up directly in the literature we reviewed.

Age has been shown to influence environmental preferences and perceptions about aquatic ecosystems (Yamashita 2002). House (1996) found that younger respondents tended to be more critical of poor water quality than older adults. These results correspond with those of Steinwender et al. (2008) who reported that younger respondents were more pessimistic than older respondents. Age as a factor influencing environmental perceptions in general has been well reported in the literature (e.g., Heer et al. 2003; Brody et al. 2005; Xu et al. 2006: as cited by Steinwender et al. 2008; Moyle and Weiler 2017). Of special interest is a study conducted in resource-dependent arctic communities (Alessa et al. 2008) where age and perception of changes in freshwater resources were found to be positively correlated. This finding aligns well with the later-discussed presupposition that older individuals have greater historical perspective. Yet, the researchers noted that younger people were more influenced by western institutional schooling and incomplete transmission of oral histories, whereas older members of communities were more reliant on oral histories, a component of traditional ecological knowledge.

Education has been well documented as a factor that can influence perceptions of aquatic ecosystems. Several studies document disagreement between lay and expert communities (e.g., de França Doria 2010), yet others report reasonable agreement (e.g., Smith et al. 1995; Cottet et al. 2013; Ioana-Toroimac et al. 2020). Referencing Finucane et al.'s research (2000), de França Doria (2010) found that the level of education correlates with perception of risk, attitude towards chemicals, familiarity of water properties, trust in suppliers, and previous experiences with water quality issues. Mentioned earlier, the results of Dobbie and Green (2013) reported misalignment between self-emergent wetland types derived from public perception data and hydrology-based classification system used by scientists. In contrast, Smith et al. (1995) reported public perception of water quality aligned well with results of concomitantly conducted water quality tests by professionals. In particular, the public accurately identified water clarity levels, and those respondents with greater scientific knowledge recognized good water quality despite unusual characteristics, such as a yellow water color due to humic staining. These differences in agreement could be due to the study site, or condition of the environment being considered, but it could also be due to the knowledge base used in the formation of perceptions or the perception parameters considered.

In general, education, or knowledge, on a topic leads to a broader perspective, thus expanding the information available for perception formation (Cottet et al. 2013 and cited references). This in part explains perception differences observed between lay people, students and scientists (Cottet et al. 2013), but what about the studies where reasonable agreement was found across these disparately informed groups. We propound that this may be partially explained by the perception parameters considered. At the most basic level, perceptions are based in emotion (Cottet et al. 2013). When the scientifically informed perspective is added, this offers a different way of perceiving the environment. Yet even where these differences in knowledge exist, reasonable agreement can occur among parameters that are more visual and emotionally based (Cottet et al. 2013). This observation represents an opportunity to identify parameters more suited for perception surveys that span education levels. We importantly note that the knowledge (i.e., education) contributing to expanded perceptions may be derived from formal education, or derived from place-based or traditional ecological knowledge (Berkes et al. 2000; Olsson et al. 2004; Lepesteur et al. 2008; Cottet et al. 2013).

It is important to note that the influence of the sociocultural setting is not limited to "the public," but indeed extends to the expert community. Scientists generally view their study subject from the perspective of their discipline (Kondolf and Yang 2008; Pennock 2019) and this can obfuscate one to the perspectives of others. For example, an aquatic ecosystem could be viewed as having high integrity from the perspective of a geomorphologist or hydrologist, yet highly impaired by a biologist or botanist (Wyżga et al. 2009). Differences of opinion can even exist within disciplines as documented by Le Lay et al. (2013) who reported that scientists from Italy rated the condition of the same river differently than scientists from France. Latour and Woolgar (1986) took the topic a little further and discussed how culture of the scientific setting itself can influence scientific outcomes.

Gender was one of the more interesting demographic factors found to influence perceptions of aquatic ecosystems. David (1971) and House (1996), both reported that males tended to perceive that water-related risks were lower than their female counterparts' perceived risks. These findings align well with those of Finucane et al. (2000) and Marshall (2004) who reported that males generally perceived lower risk than females due to greater risk acceptance by males. Results provided by David (1971) on perceptions of water quality may provide some insight on drivers contributing to observed differences. David found

that mothers, regardless of age of their children, were more likely to be concerned than fathers. And interestingly, among fathers, those with young children were more likely to express concern; this potentially a reflection of the wife's concern or inconvenience (David 1971). It should be noted that the role of parents has likely evolved since David's study (Dotti Sani and Treas 2016).

Gender has also been demonstrated to influence aesthetic appeal of aquatic ecosystems. In a study examining public perceptions of urban waters, Steinwender et al. (2008) reported that males gave significantly worse assessments of aesthetics than female respondents. No theory was offered by the authors for this observation.

Place-based knowledge was reported in several papers as contributing to perceptions. Place-based knowledge generally refers to one's experience with a place's history, environment, culture, economy, literature, or art (Shamah and MacTavish 2009). Such knowledge can influence perceptions in many ways. For example, Lepesteur et al. (2008) found that locals with greater place-based knowledge tended to evaluate water quality of an estuary based on historical conditions, noting improvements in smell and clarity. Non-locals, however, tended to be more critical of prevailing water quality. Those without place-based knowledge most likely lack historical insight that may provide perspective on prevailing conditions. In fact, we found two studies that present the contrary. House (1996), for example, found a positive relationship between number of visits and critical perspective of water quality among individuals in England. White et al. (2008) found that as individuals visited sites over a longer time-span, they were more critical of environmental impacts. Place-based knowledge can also have what might be better referred to as a legacy effect. Studying communities in Russia, Walker et al. (2006) found that perspectives of inhabitants of communities impacted by a previously occurring oil spill had increased concerns and awareness of environmental issues.

DISCUSSION

How an individual perceives something, scientists and non-scientists alike, is an aspect of human behavior shaped by life experiences (Segall et al. 1968). Given this, it is reasonable to expect that people may have different preferences and perceptions regarding aquatic ecosystems. Our objectives were to review literature for attributes of the environment and characteristics of the individual that influence preferences and perceptions of aquatic ecosystems.

The reported environmental attributes most found to influence public perceptions of aquatic ecosystems were color, presence/absence of water plants and algae, presence/absence of floating debris, odor, movement (for flowing waters), clarity/turbidity, naturalness (e.g., of the banks), and overall aesthetic quality (Fig. 1). Except for the last two factors (i.e., naturalness and aesthetic quality) which will be discussed later, these results largely agree with studies investigating factors that influence public perceptions of drinking water. For example, the World Health Organization (2008, 2011) lists taste, odor, color, and appearance/turbidity as factors used by the public for the evaluation of drinking water; or what de França Doria (2010) and Rojas and Megerle (2013) referred to as organoleptic properties.

It is easy to conceive how organoleptic factors relate, and likely arose from risk aversion. More specifically, high levels of these factors are perceived as indicators of potentially harmful substances (World Health Organization (2008, 2011). The origin of what might be considered 'more instinctive' perceptions is likely linked to evolutionally derived responses to ancestral threats to survival and reproductive fitness (Neuberg et al. 2011). This is relevant as it could potentially contribute to identification of additional factors that contribute to perceptions. Worthy of discussion is the finding by Steinwender et al. (2008) that water oxygen content and water temperature were unrelated to public perceptions. Regarding temperature, it is clearly an organoleptic parameter (i.e., one that can be perceived by the senses; in this case touch), but interviewees in that study relied on visual inspection and did not touch the water, which would have provided information on temperature. As for water oxygen levels, a non-organoleptic parameter, even with physical contact, humans do not have the ability to perceive oxygen levels in water. That is, we generally lack the evolutionary-derived threat management adaptions that would instill us with the instinctive ability to perceive the parameter.

Regarding the influence of environmental factors on perceptions of aquatic ecosystems, we found evidence that perceptions can be influenced by type of resource (Artell et al. 2013), condition (Steinwender et al. 2008), and setting (Rooney et al. 2015) being considered. As stated earlier, perceptions are an aspect of human behavior shaped by life experiences (Segall et al. 1968). For scientists, this life experience includes the perspective of their discipline (Kondolf and Yang 2008). Life experience is highly relevant to perception of type and condition of a resource. In the case of Artell et al. (2013), alignment between lay and expert perceptions of habitat condition increased as public familiarity with habitat increased. And in the case of resource condition, alignment between lay and expert perceptions decreased as resource condition degraded from the scientific perspective (Steinwender et al. 2008; Rooney et al. 2015). The latter is likely the result of scientific

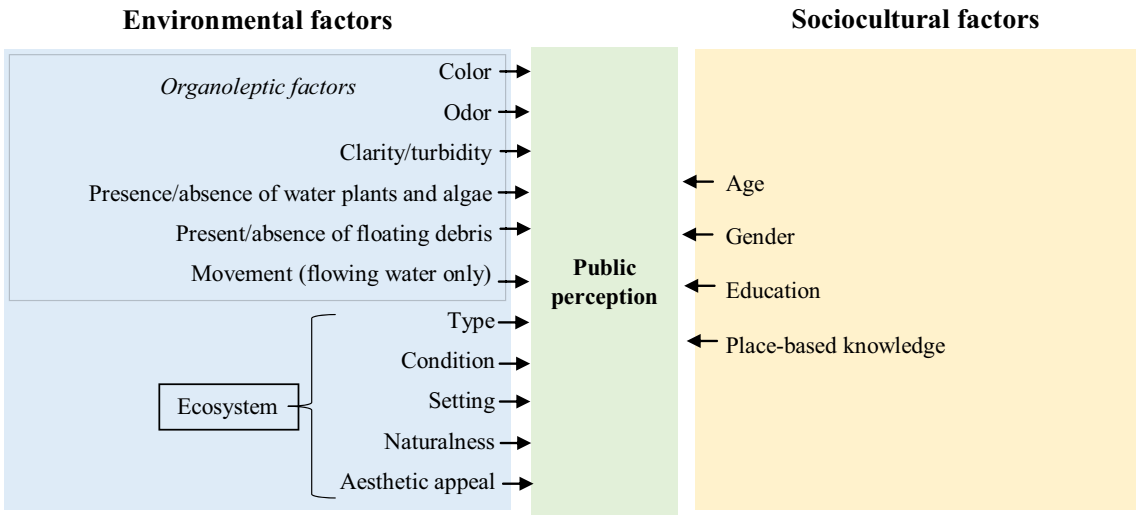

Fig. 1 Factors reported in the literature as influencing public perceptions of aquatic ecosystems

perspectives (e.g., metrics) that examined factors outside those normally considered, or at levels perceivable, by the public.

We reviewed several studies that informed how aesthetics can influence public perceptions of aquatic ecosystem condition. In some cases, aesthetic appeal of a resource correlated well with scientific perspective of condition (Junker and Buchecker 2008; McCormick et al. 2015). Junker and Buchecker (2008) noted that the perceived naturalness of the resource was linked to the publics' aesthetic preferences. Others, however, reported cases where alignment was poor (House and Sangster 1991; Le Lay et al. 2013). Dobbie and Green (2013) potentially provide insight on this topic in their statement that people *see* 'water visible,' 'trees present,' and 'terrestrial grasses' more often and before they see constructs such as the health (i.e., condition). As a consequence, aesthetic factors are perceived to represent "healthy" or "high-quality" ecosystems (Scholte et al. 2016 and references therein). Aesthetic factors specifically noted in the literature as contributing to aesthetic appeal in ecosystems included residential lawns (Larson et al. 2016), perennial farm practices in rural settings (Atwell et al. 2009), and protected areas like national parks (Martín-López et al. 2012). While recognizing that many of these factors could serve as cultural cues of an environment that is being cared for (Nassauer 2004; Khew et al. 2014), they also can represent misconceptions of what the public identifies as natural (Cronon 1996). This is certainly the case where it has been reported that the public preferred wetlands with a tidy, well-managed appearance (Nassauer 2004; Rooney et al. 2015; Scholte et al. 2016 and references therein).

Our findings regarding sociocultural factors that specifically influenced public perceptions of aquatic ecosystems were surprisingly limited. Most of the literature we found related to influence of place-based knowledge. An interesting side note is that individuals with more contextual knowledge of the aquatic resource (e.g., historical, cultural, climatic) were found to be more critical of existing environmental impacts. This is likely due to their increased sense-of-place and subsequent place attachment to the location (Hay 1998; Larson 2012).

Several demographic factors were found to influence public perceptions of aquatic ecosystems (Fig. 1). Age had a mixed impact, but generally, younger people tended to be more pessimistic and critical of water quality. And as age increased, the alignment of public perceptions and scientific perceptions of aquatic ecosystems generally increased. This finding is obviously somewhat confounded with education. Education was generally found to increase the alignment of public perceptions with scientifically derived assessments. In terms of gender, males generally perceived less risk, and found the habitats to be less aesthetically appealing than females (Steinwender et al. 2008). This finding that perceptions of lower risk may lead to greater appeal for a given location could be considered contrary. However, it draws attention to the distinction between aesthetic appeal, and the appeal of a site for more non-cultural service-related activities (e.g., provisioning).

Two demographic factors for which our search did not produce much information were race and income. Race has been shown to influence perceptions of risk (Finucane et al. 2000; Marshall 2004): with people of 'color' perceiving greater risk than 'whites.' Yet we found very little information that examined this question with regard to aquatic ecosystems. We likewise found little information on the influence of income on public perceptions of aquatic ecosystems. Confoundment of these demographic factors

with other demographics which we have discussed has been reported. For example, it has been well established in the literature that education is related to income (e.g., Davis-Kean 2005); and by Quintas-Soriano et al. (2018) who reported on the interaction of demographics factors influencing perceptions of ecosystem services. Research that directly seeks to provide knowledge on how these factors influence perceptions is needed.

Anthropogenic impacts (e.g., oil spill) were also discussed as a place-based knowledge factor influencing current perceptions of aquatic ecosystems. In brief, the public may be more critical of current conditions, but also more aware of potential risks posed by current or proposed activities that may threaten a resource. De França Doria (2010) similarly noted how historic problems can influence current perceptions of the quality of drinking water. Specifically, historic problems can lead to increased risk judgements regarding current perceptions. Being cognizant of the potential influence of past events on current perceptions is relevant and worthy of special attention by those engaged in activities related to the restoration of critical services in post-disaster settings, albeit natural or anthropogenic.

In closing, we note that while there does seem to be a growing body of literature on the importance of understanding public perceptions of natural resources, especially regarding management, the number of papers specifically focused on aquatic ecosystems is limited. We therefore encourage research that examines perceptions of aquatic ecosystems with a special emphasis on how and why perceptions can vary across geographies.

CONCLUSION AND PERSPECTIVES

The findings of our review can be summarized with the following statements:

- Perceptions of aquatic ecosystem condition can differ between members of the public, and between the public and professional scientists.
- The primary attributes of aquatic ecosystems that the public considers are color, odor, clarity/turbidity, presence/absence of water plants and algae, presence/absence of floating debris, setting, condition, and aesthetic appeal.
- The primary characteristics of the public that influence their perceptions of aquatic ecosystems are age, education, gender (i.e., demographic factors), and place-based knowledge (i.e., social and cultural factors).

We believe that increased consideration of factors influencing perceptions of aquatic ecosystems can contribute to management in three ways:

(1) A thorough understanding of factors that shape perceptions of aquatic ecosystems, both lay and expert, can help scientists and resource managers identify gaps in understanding. Such missing established principles or new findings may require increased or different communication techniques (Nassauer 1995).
The gap between perceptions and attitudes of resource managers and those of the public can be harmful when ignored (Dearden 1981; Junker and Buchecker 2008; Kondolf and Yang 2008; Anderson et al. 2019). Nassauer et al. (2001) found that a lack of understanding of what is ecologically beneficial may limit the public's acceptance of management activities that are primarily aesthetically pleasing. For streams, this would include features such as meanders, riffles, and stony banks (Bonsignore 1992). Well-structured public outreach activities and educational programs (e.g., Bagdonis et al. 2009; Jeronen et al. 2009; Cottet et al. 2013; Grizzetti et al. 2016) can help close this gap in understanding and, in doing so, promote pro-environmental behaviors that protect and preserve aquatic ecosystems (Kollmuss and Agyeman 2002) and the many services they provide (Costanza et al. 1997; Postel and Carpenter 1997). Of special benefit may be environmental education efforts that better connect youth with nature (Louv 2008).

(2) Consideration of the aspects of aquatic ecosystems that the public perceives as aesthetically desirable can increase public acceptance of management outcomes. Most, if not all, aquatic ecosystems globally are social-ecological systems (Parsons et al. 2016). As such, their successful management should consider the full range of social interactions with these systems (Bikangaga et al. 2007; Howard 2008; Jackson et al. 2008; Ioana-Toroimac et al. 2020). This would result in a better understanding of public perceptions of aquatic ecosystems rather than relying exclusively on the perceptions of scientists, and what they believe the public perceptions are, or should be (Penning-Rowsell 1981). Failure to do so could result in actions based exclusively on objective criteria (Steinwender et al. 2008). Many consider the inclusion of public perceptions essential to sustainable management practices (Nassauer et al. 2001; Kondolf and Yang 2008; Steinwender et al. 2008; Ioana-Toroimac et al. 2020). However, we agree with Kondolf and Yang (2008) that scientifically defensible science should provide the bounds of management options.

(3) Increased public satisfaction of management actions could lead to increased public protection of aquatic ecosystems, ultimately leading to improved aquatic

ecosystem condition and measures of sustainability. Increased consideration of the environmental attributes the public perceives as representing good condition can garner greater support of management efforts and financial support of restoration and conservation activities (Yamashita 2002) and help mitigate potential conflict (House and Fordham 1997). In this regard, public perceptions and public preferences should be fully considered when exploring the range of scientifically sound aquatic ecosystem management options (Szagun and Pavlov 1995; Kondolf and Yang 2008; Lepesteur et al. 2008).

Broader integration of these tenants into the management of aquatic ecosystems is essential to the sustainability of these social-ecological systems (Grizzetti et al. 2016). We highlight the importance and benefits of considering these tenants where significant multi-generational and culturally ingrained place-based knowledge exist. This information may also be referred to as local ecological knowledge (e.g., Olsson et al. 2004), long-term knowledge (e.g., Lepesteur et al. 2008), and traditional ecological knowledge (Berkes et al. 2000).

Acknowledgements The U.S. Environmental Protection Agency (EPA), through its Office of Research and Development, partially funded and collaborated in the research described herein. We thank Samantha Shattuck, Clayton Cox, and Maryann Cairns for their contributions to the literature search. We also thank John Lin, Kiran Alapaty, Brent Johnson, and Joanna Zawiejska for their thorough review of an earlier version of this manuscript; and two anonymous reviewers whose comments greatly improved the paper. This paper has been reviewed in accordance with the EPA's peer and administrative review policies and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use. Statements in this publication reflect the authors' professional views and opinions and should not be construed to represent any determination or policy of the EPA.

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