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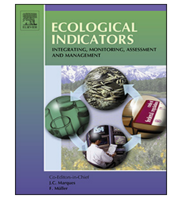

Original Articles

Water clarity measures as indicators of recreational benefits provided by U.S. lakes: Swimming and aesthetics

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ABSTRACT

Lakes provide recreational benefits related to water quality. Using data from the 2007 and 2012 United States National Lake Assessments ($N = 2067$ lake visits), we developed indicators for three benefits: swimming, general recreational value, and aesthetic appeal. For two combined ecoregions ("Mountains" and "Plains") we related objective measures of water clarity, including Secchi depth, turbidity, and water-column chlorophyll-*a* concentration to subjective visual assessments of recreational benefit quality. There were significant associations between water clarity measures and visual assessments from which we derived water-clarity based thresholds between benefit quality classes (exceptional, high, low, marginal) for each benefit type. More variation in Secchi depth and turbidity was explained by benefit quality than was variation in chlorophyll-*a*. Threshold values were different between combined ecoregions. Compared to lakes in the Mountains ecoregion, recreational users of Plains lakes have lower expectations for water clarity. Thresholds were generally in accord with water clarity thresholds and guidance derived from published regional studies. Including indicators of the quality of benefits humans receive from lakes in assessments of lake conditions can increase public participation in decision-making and reveal changes in benefit quality over time.

1. Introduction

Lakes provide recreational benefits related directly and indirectly to water quality, including swimming, boating, fishing, and the aesthetic experience of viewing the lake. Assessments of lake water quality for reporting on the condition of lake ecosystems are most often based on biophysical indicators and reference condition-based thresholds (Herlihy et al., 2013) rather than on indicators of human benefits. There have been attempts (discussed in Section 4.4) to develop empirical indicators or set assessment thresholds using information on how recreational beneficiaries perceive the recreational value of lakes as a function of water quality, but these studies are few (West et al., 2015). In most lake assessment reporting, water quality indicators are generally not linked to the recreational benefits provided by the sample lakes.

The use of environmental indicators that are directly meaningful to people improves communication across social boundaries and increases public participation in decision-making (Heiskary and Walker, 1988; USEPA, 2009; Keeler et al., 2012; Boyd et al., 2015; West et al., 2016). By directly meaningful, we imply the indicator requires minimal translation for people to understand the connection to things they value. Unlike nutrient or ion concentration, water clarity is an attribute of lake water that is readily understood by a non-expert audience. Water clarity may be perceived as a reliable surrogate measure for how safe and suitable the water appears to be for contact recreation (e.g., Is the bottom visible? Is the water "clean"?). Beyond swimming, the aesthetic appeal of the lake setting itself may also depend in part on the visual clarity of the water. The use of perception surveys to develop indicators of benefits follows from the idea that "behavior [or use] is based on preferences formed from perceptions" and "people's perceptions of environmental amenities should therefore provide the most accurate estimates of the values attached to those amenities (Artell et al., 2013)."

In this paper, we examined how perceptions of a lake's suitability for recreation or its aesthetic appeal can be related to biophysical indicators of water clarity: Secchi depth, turbidity, and chlorophyll-*a* concentration. We showed how these relationships can be used to derive thresholds in recreational benefit quality for lakes of the

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conterminous United States. These water clarity thresholds, when calibrated for regional variation, can be used for regional assessment of lake ecosystem benefits and, in some contexts, as supporting evidence for deriving new water quality criteria for lake uses. This approach has been used to support development of water quality thresholds for several US states (Heiskary and Walker, 1988; Smeltzer and Heiskary, 1990; Hoyer et al., 2004; Smith et al., 2015). Ours is the first attempt to use national-scale water clarity and lake benefit quality perception data (e.g., relative suitability for swimming or "swimmability") to derive thresholds for assessing the quality of recreational benefits provided by US lakes.

We used the results of two national-scale lake condition assessments to address questions related to the quality of benefits provided by freshwater lakes: 1. How are subjective characterizations based on visual assessment of recreational value related to Secchi depth, turbidity, and water column chlorophyll-*a* concentration? 2. Are thresholds in water clarity based on recreational benefits consistent across ecoregions? 3. Are thresholds for water clarity based on different benefit types (e.g., swimming, other recreation, and aesthetic values) consistent and equally "protective?" Our overarching goal was to specify indicators of and thresholds for the quality of recreational benefits from lakes based on ecosystem attributes causally linked to ecosystem processes.

2. Methods

2.1. Lake ecosystem benefits

In this paper, we follow the hierarchical classification of ecosystem beneficiaries set forth in the Final Ecosystem Goods and Services Classification System (FEGS-CS) developed by the United States Environmental Protection Agency (USEPA) (Landers and Nahlik, 2013). FEGS-CS is explicitly organized around human beneficiaries of the environment and the attributes of ecosystem outputs directly relevant to human well-being. The FEGS in this case is lake water for recreation. The relevant attribute of lake water is visual water clarity. The applicable beneficiary class is "recreational." The four relevant beneficiary subclasses we considered included 1) waders, swimmers, and divers; 2) boaters; 3) recreational anglers; and 4) experiencers and viewers. There are other attributes of lake ecosystems like nutrient concentration that are causally linked to water clarity (Wetzel, 2001; Jones et al., 2008), but they are unlikely to be valued directly by most recreational beneficiaries (Ringold et al., 2013).

Ecosystem benefits are defined as the impacts, positive or negative on human well-being of the FEGS (Landers and Nahlik, 2013). Lakes, in combination with built capital such as beaches and boat ramps, and human capital (i.e., people able to appreciate the lake) provide opportunities for socialization, physical activity, engagement with nature, and other sensory experiences that promote physical health, reduce stress, enhance mood, and generally increase well-being (Bowler et al., 2010; Völker and Kistemann, 2011; Keniger et al., 2013; de Bell et al., 2017). Because we lack reliable data on recreational demand or built capital for our sample of lakes, we are not necessarily reporting on the quality of realized recreational benefits, but on the potential recreational benefits provided by these lakes.

For each beneficiary subclass, we used a visual assessment rating as the perception of benefit quality for a recreational activity related to water clarity as a proxy for benefit quality, or the relative impact on human welfare: perceived swimming benefit quality for swimmers, perceived general recreational benefit quality, and perceived aesthetic benefit quality for lake experiencers and viewers.

2.2. Datasets and indicators

Data used in this study are from the U.S. National Lakes Assessments (NLA) of 2007 and 2012 and are publicly available (https://www.epa.gov/national-aquatic-resource-surveys/nla; accessed 31 January 2018). The NLA is a quinquennial statistical survey of the ecological condition of the lakes of the conterminous U.S., designed to provide national and regional estimates of lake condition.

Water quality sampling and visual assessments were conducted by a single field crew for each lake during May-September. Crews generally included 3–5 trained personnel from state agencies or contracting vendors. Most crews sampled lakes within a single state. Larger states had multiple crews. In 2007 and 2012 there were 83 and 88 field crews, respectively. Overlap in personnel between assessments is not known. Mean (± 95% CI) number of lakes sampled per crew from which data are included in this paper was 14 ± 3 in 2007 and 13 ± 2 in 2012. Because training was standardized and each crew sampled relatively few lakes, we made no effort to partition analysis by crew.

From NLA data, we extracted water quality data and visual assessments of recreational benefits provided by each lake. Water clarity metrics included Secchi depth (m), turbidity (nephelometric turbidity units [NTU]), and water column chlorophyll-*a* (μg/L). Secchi depth was determined *in situ* using a 20–cm diameter weighted black and white disk. Turbidity was determined within 72 h by automated analysis (TitraSip, Man-Tech, Guelph, ON, Canada) or manual analysis using a turbidity meter for high turbidity samples (USEPA, 1987). Pheophytin-corrected chlorophyll-*a* was determined by flourometry within 30 days. Field and laboratory methods for water clarity metrics are described in detail elsewhere (USEPA, 2011, 2012). We did not use Secchi depth measurements when the disk could be seen resting on the bottom. We did not substitute lake depth for Secchi depth in these cases because this results in the underestimation of Secchi depth in clear shallow lakes. We therefore had missing Secchi depth measurements at five and nine percent of lakes in 2007 and 2012, respectively. In the 2007 NLA, lakes ≥4 ha were included in the sample; in 2012, lakes ≥1 ha were included in the sample. We did not distinguish the approximately 10% of lakes sampled in both NLAs. About 100 lakes were revisited during each assessment, but we only used data from the first visit to the lake in each assessment unless otherwise specified. Data from about 1120 lakes in each assessment year were analyzed. We did not distinguish between natural and man-made lakes in our analyses. In both assessment years, 55% of sampled lakes were man-made. We treat the 2007 and 2012 NLAs as replicate studies, and we generally do not combine the data except to illustrate general points related to application of results.

Visual assessments were conducted for three attributes of each lake: "swimmability", "recreational value", and "aesthetic appeal". For swimmability, crews were instructed to "record a subjective impression of the aesthetics of swimming in this lake" as either "good", "fair" or "not swimmable" (USEPA, 2012). This visual assessment metric was meant to reflect aesthetics or "pleasantness" of swimming rather than water safety or access, so the wording "not swimmable" is potentially misleading since no barrier to water contact is implied – it may be aesthetically unpleasant and unsafe, but water contact is physically possible. For recreational value, crews were instructed to base their scoring of "excellent", "good", "fair", or "poor" on the lake's "ability to support recreational uses such as swimming, fishing, and boating." The intention was for crews to "record their overall impression of the lake as a site for recreation." For aesthetic appeal, crews were instructed to rate the lake from 1 to 5 based on aesthetic appeal by integrating their overall impressions with "any factors that disturb you" such as trash, algal growth, "weed" abundance, or overcrowding. Scores of 1–5 corresponded, respectively, to "enjoyment nearly impossible", "level of enjoyment substantially reduced", "enjoyment slightly impaired", "there are minor aesthetic problems [but] it is otherwise excellent for swimming, boating, and enjoyment", and "it is beautiful and could not be any nicer." The wording for the NLA aesthetic appeal assessment scoring is very similar to lake and river user survey questions used in previous state-scale assessment (e.g., Smeltzer and Heiskary, 1990; Smith et al., 2015).

The subjective perceptions of benefit quality (i.e., the scoring based