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Short communication

Waterbody size predicts bank- and boat-angler efforts

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ABSTRACT

Bank- and boat-angler efforts are logistically difficult and costly to estimate, preventing landscape-scale estimates that are required to address current and future challenges (e.g., climate change, invasive species) for inland recreational fisheries. Using a large Nebraska, USA, recreational fishery dataset (N = 67 waterbodies), we demonstrate that waterbody size can be used to predict bank- and boat-angler efforts across a heterogeneous landscape of extra small (< 104 ha) and large (> 647 ha) waterbodies. Bank and boat anglers respond to waterbody size, however these relationships appear to be unique between the two angler types. Boat-angler efforts increased as a function of waterbody size, whereas bank-angler efforts increased as a function of waterbody size for extra small waterbodies but not for large waterbodies. The ability to connect waterbody size and angler effort will be important for continued effective inland fisheries management.

1. Introduction

Angler effort is a key aspect of inland recreational fisheries, serving as a measure of fishery attractiveness, a management performance metric, and a prominent variable used to estimate catch, harvest, and mortality rates (Cooke and Cowx, 2004). The degree of influence that anglers have on fish populations is largely determined by the amount of angler effort exerted (Fayram and Schmalz, 2006). The magnitude of angler effort that a waterbody receives has social-ecological consequences, such as changes in levels of societal support of environmental conservation and alterations in fish mortality and size structure (Arlinghaus et al., 2002; Lewin et al., 2006; Carruthers et al., 2019). Thus, monitoring angler effort is fundamental for fisheries management and conservation.

There have been numerous calls to manage recreational fisheries at the landscape scale (e.g., Carruthers et al., 2019), but unfortunately quantifying angler effort is often labor-intensive and leads to only sampling a few select waterbodies. Most waterbodies must then be managed without any angler effort information, which could lead to unintended social-ecological consequences (Post et al., 2002). Previous research has attempted to predict angler effort to overcome these challenges, but most models involve collecting an extensive amount of additional data (e.g., Steffe et al., 2008; Trudeau et al., 2021), such as angler access and fish community metrics that are not typically available. Complex models are unlikely to be used and implemented by managers who are asked to do more with less. Therefore, there is an urgent need to develop a simple and reliable method for predicting angler effort at the landscape scale, especially given the recent influence of humans on natural resources and climate change.

Previous studies have highlighted that angler effort is related to waterbody size (Hunt, 2005; Trudeau et al., 2021), but surprisingly and only until recently, waterbody size has not been evaluated as a sole explanatory variable that can be used to predict angler effort (see Kane et al., 2022). Landscape variables (e.g., human development, roads) have also been useful, but their ability to explain patterns in angler effort are less reliable and less consistent than waterbody size (Hunt et al., 2011; Hunt et al., 2019; Trudeau et al., 2021). Perhaps also, waterbody size has been overlooked because it is perceived as too simple to explain an important attribute of a complex social-ecological system. We recently demonstrated that natural resource system size (e.g., surface area of a waterbody) can serve as a composite variable to predict recreational use (e.g., angler effort; Kane et al., 2022) given it has been

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previously related to many social (e.g., onsite amenities, attractiveness) and ecological (e.g., fish diversity, primary productivity) attributes. Although it seems promising that waterbody size can predict angler effort, it is unclear whether waterbody size can account for diversity and behavioral differences among anglers. We know that angler behavior (e.g., party size, time spent fishing, number of fish released and harvested) differs depending on how anglers are accessing a waterbody, either from the bank or a boat (Kane et al., 2020). Differences in angler behavior likely generate heterogeneous social-ecological experiences that could influence angler effort. We also know that there are discontinuities in waterbody size, and that anglers demonstrate behavioral differences depending on the size of the waterbody on which the angling is occurring (Kaemingk et al., 2019). Thus, a further comparison of the resource size-use relationships for both bank- and boat-angler efforts across different waterbody size categories (e.g., extra small vs. large waterbodies; sensu Kaemingk et al., 2019) is needed for fishery managers to effectively manage angler effort.

Building upon a simple model to predict natural resource use (Kane et al., 2022), developing waterbody size-angler effort models for bank and boat anglers could have profound implications for fisheries management. Fisheries managers are likely to adopt this approach due to its simplistic nature and therefore improve their ability to generate bank- and boat-angler efforts estimates at the landscape scale. These potentially unique waterbody size-angler effort relationships for bank and boat anglers can then be linked to social (e.g., crowding, satisfaction) and biological (e.g., abundance, size structure) effects that are valuable for effective fisheries management. Our objectives were therefore to 1) develop waterbody size-angler effort models for extra small (XS) and large (L) waterbodies, and 2) determine if waterbody size-angler effort models differ for bank and boat anglers.

2. Methods

2.1. Study area

To quantify waterbody size, we used the surface area (ha) at conservation pool, the intended water level of each waterbody. The waterbodies included in this study ranged in size from 1 to 12141 ha (mean = 593 ha; standard deviation = 2028 ha) and were used for a variety of purposes including flood control, irrigation storage, hydropower generation, and community recreation (for waterbody details, see Kane et al., 2022). These waterbodies were spatially spread throughout Nebraska, represented a diversity of fishing opportunities, "resided" in urban and rural settings, and varied in participation patterns between bank and boat anglers (Kaemingk et al., 2020; Kane et al., 2020).

2.2. Creel surveys

We used instantaneous counts of anglers at each waterbody to obtain angler-effort estimations (hours spent fishing). Daytime counts of anglers occurred from April through October at each of 67 waterbodies throughout Nebraska, USA from 2009 through 2019. Waterbodies included in this assessment were categorized as XS waterbodies (< 104 ha) or L waterbodies (> 647 ha) as previously determined by Kaemingk et al. (2019). Small and medium waterbodies were not included in this assessment due to a small sample size (i.e., most surveys of angler effort in Nebraska are targeted at waterbodies either less than 104 ha or more than 647 ha). A majority of the angler efforts on these waterbodies occurs during the daytime between April and October. Angler-effort estimations were calculated using previously outlined methods (Kane et al., 2022). Briefly, we conducted angler counts on weekdays, weekend days, and holidays from April through October. The number of anglers counted was multiplied by the number of hours in each survey period and divided by the probability of selecting a day period (0.5) to produce a daily use estimation and then extrapolated up to monthly estimates following procedures described in Newman et al. (1997). The extrapolated estimates for each month were summed to produce a yearly total-effort estimate. The number of days for angler counts varied across waterbodies, depending on the size of the waterbody and logistics (Kaemingk et al., 2018).

2.3. Analysis

We used a Bayesian multilevel model to assess the relationships between annual effort as a function of a three-way interaction of waterbody size category (XS: 0–104 ha, N = 53; L: 647–12140 ha, N = 14), access type (bank and boat), and waterbody size. We used this approach because of the multilevel nature of the data and because Bayesian models are better able to deal with singularity issues often observed in complex multilevel models using traditional approaches. Specifically, there were repeated measurements of annual angler effort among some waterbodies (i.e., multiple years sampled) suggesting random intercepts, and we would expect to have varying slopes by waterbody category suggesting random slopes. The specific model used was: $\log_{10}(\text{effort} + 1) \sim \text{scale(ha)} \times \text{access type} \times \text{size category} + (1 + \text{size category} \mid \text{waterbody})$. The log of extrapolated angler-effort estimations was used to reduce heteroscedasticity (e.g., Woolnough et al., 2009; Hunt and Dyck, 2011; Kane et al., 2022). We added one to estimates of effort before transformations, as $\log_{10}$ of zero is undefined, and some waterbodies (XS) had no boat-angler efforts. Further to improve model fitting, we scaled waterbody size by the grand mean and standard deviation, whereas the dependent variable, effort, was only $\log_{10}$ transformed. Analysis used brms (Bürkner, 2017; Bürkner, 2018; Bürkner, 2021) using the 'cmdstanr' (Gabry, 2022) backend. We used uniform priors (i.e., all parameters were equally likely). Our model used 4 chains each with 10000 iterations and 5000 warm-up with no thinning, resulting in 20000 total post-warm up draws. We assessed model convergence by visually inspecting chain histories and by using Gelman-Rubin convergence diagnostic and Pareto K estimates. Model performance was assessed using tidybayes (Kay, 2023) and easystats (Lüdecke et al., 2022) packages. All analyses were completed using R (R Core Team, 2023).

3. Results

Bank-angler efforts ranged from 44 to 52771 h per year at XS waterbodies (mean = 8670; standard deviation = 12516) and from 3240 to 32464 h per year at L waterbodies (mean = 11057; standard deviation = 8084). Boat-angler efforts ranged from 0 to 26271 h per year at XS waterbodies (mean = 3382; standard deviation = 5945) and from 10286 to 151381 h per year at L waterbodies (mean = 47829; standard deviation = 40475).

There was a significant three-way interaction between waterbody size, waterbody size category, and access type (Table 1). The model predicted log-transformed effort reasonably well (Conditional R^2 = 0.811; Marginal R^2 = 0.685; RMSE = 0.478). Further, the intra-class correlation (Adjusted ICC = 0.435, Unadjusted ICC = 0.148) indicated support for using the random effects in our multilevel approach. The model predicted increasing efforts for both bank and boat anglers with increasing waterbody size in XS waterbodies, with boat anglers increasing at a faster rate (Table 1; Fig. 1). The model predicted no relationship for bank anglers with increasing waterbody size in L waterbodies and increasing effort for boat anglers with increasing waterbody size.

4. Discussion

Waterbody size was significantly related to both bank- and boat-angler efforts, thus serving as a simple and reliable predictor of diverse angler types at the landscape scale. Bank- and boat-angler efforts generally increased (except for bank anglers at L waterbodies) as a function of waterbody size, although the specific relationships differed

Table 1
Summary of the population-level effects of a Bayesian multilevel model examining the effect of waterbody size (scaled by grand mean and standard deviation), access type (bank and boat), size category (extra small [XS] and large [L]), and all associated interactions on $\log_{10}$ transformed fishing effort (yearly estimates + 1). Reported values include the median posterior values, 95% credible intervals, and the effective sample size (bulk and tail). The Gelman-Rubin convergence diagnostics ($\widehat{R}$) for all parameters were 1.00 and all Pareto k estimates were reasonable ($k < 0.7$). The model marginal R^2 (fixed effects only) was 0.811, conditional R^2 (includes random and fixed effects) was 0.685, and the RMSE was 0.478.

Parameter	Estimates	95% CI	Bulk ESS	Tail ESS
(Intercept)	24.69	15.24 – 33.79	3258	6584
waterbody size	47.87	26.67 – 68.32	3246	6593
access type	20.68	12.50 – 29.08	4610	7724
size category	-20.75	-29.83 – -11.31	3255	6572
waterbody size * access type (boat)	48.46	30.16 – 67.22	4609	7582
waterbody size * size category (L)	-47.89	-68.31 – -26.64	3245	6621
access type (boat) * size category (L)	-20.13	-28.55 – -11.95	4611	7668
waterbody size * access type (boat) * size category (L)	-48.27	-67.03 – -29.96	4609	7613

between angler-access types and between waterbody sizes. This outcome was not surprising because other authors have documented utility in using waterbody size to predict angler effort (e.g., Trudeau et al., 2021) and because bank and boat anglers are expected to exhibit behavioral differences (Kane et al., 2020). The key finding of our study was that waterbody size can be used to explain a substantial amount of boat- and bank-angler efforts. Developing waterbody-size angler effort models can allow managers to produce angler-effort estimates for waterbodies that have never been assessed due to logistical or cost constraints, which is a great improvement from current practices and options. We contend that waterbody size should reliably predict angler effort across most waterbodies, and we encourage additional studies to test this relationship so that it can become generalized.

There are several immediate management implications and benefits resulting from our outlined waterbody size-angler effort relationships for bank and boat anglers. Differences in the waterbody size-angler effort relationships indicate that each angler-access type uniquely responds to waterbodies of different size. Bank-angler effort dominates boat angler effort at the smallest of XS waterbodies, whereas boat-angler effort dominates bank-angler effort across all sizes of L waterbodies (Fig. 1). Thus, management actions will likely have different effects at XS and L waterbodies, as the angler's exerting effort at these waterbodies are different. For example, party size, time fished, and harvest rates differ between bank and boat anglers and changes in regulations will likely affect smaller waterbodies differently than they will affect larger waterbodies (Kane et al., 2020). Additionally, differences in the distribution of bank- and boat-angler efforts at waterbodies of differing sizes can aid managers in the allocation of resources at individual waterbodies by highlighting areas to target with physical habitat improvement projects intended to increase catchability of fish by anglers, as these projects require high levels of resource investment (Schriener et al., 2022). Modified habitat may be more useful for fish and anglers alike if fisheries managers consider waterbody size, angler-access type composition, and ultimately the depth of habitat placement (Tugend et al., 2002), when implementing habitat improvement projects. Given our results, perhaps focusing on habitat improvements nearshore in the littoral zone of XS waterbodies and offshore in deep-water areas of L waterbodies would provide the most benefit to the predominant angler type.

Developing waterbody size-angler effort relationships will benefit future management actions at the landscape scale. There are other aspects to explore besides developing our proposed angler effort (angler hours) and waterbody size (ha) relationships for other regions. For example, establishing effort density (angler hours/ha) and waterbody size relationships could be useful as a predictor of fishing mortality. There is also a need to establish whether a change in waterbody size will result in a change in angler effort, such as within a particular waterbody across time (e.g., a waterbody under drought conditions). Identifying these social-ecological relationships is important as the distribution and

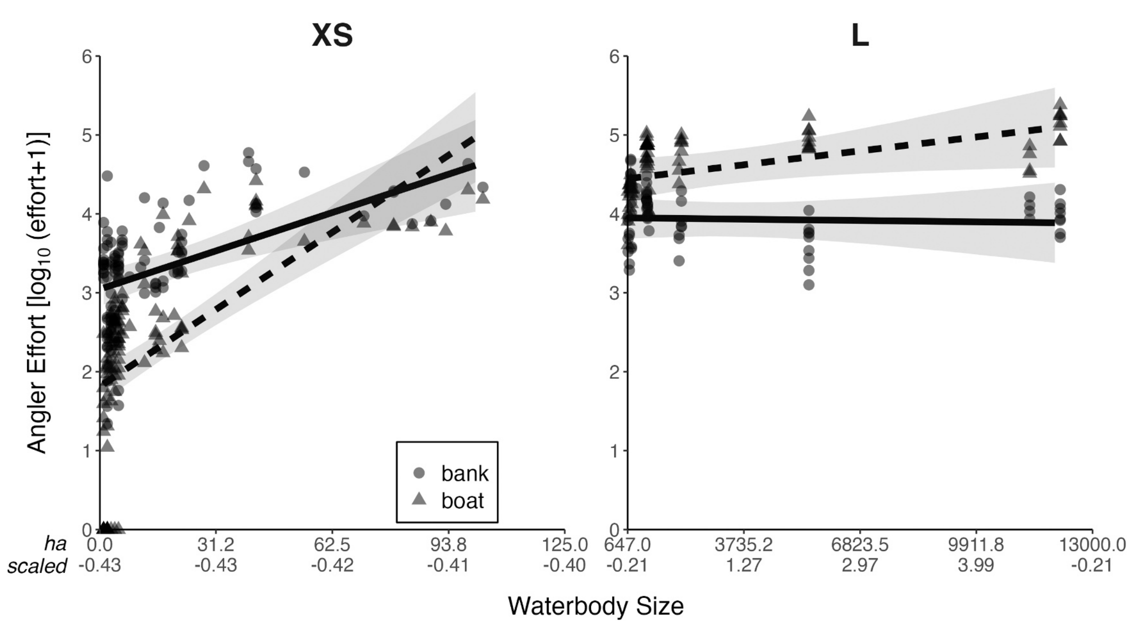

Fig. 1. Multilevel models displaying relationships between boat (dashed line) and bank (solid line) angler effort and waterbody size for extra small (XS) and large (L) waterbodies. Ribbons represent 95% confidence intervals of the models, and the upper and lower lines represent models' 95% prediction interval. Points on the plots represent the actual data collected from creel surveys. Waterbody sizes were scaled by the grand mean and standard deviation, and the axis provides both the scaled and unscaled values.

abundance of surface water at a global scale are dynamic (Pekel et al., 2016) and, according to our results, will affect angler effort and the composition of anglers. Remote sensing techniques (e.g., less labor-intensive) could improve our understanding of how bank and boat anglers will respond to climate change effects (e.g., drought and deluge periods) by measuring shifts in the distribution and size of surface water area available to anglers (Pekel et al., 2016; Kane et al., 2022). Invasive species monitoring and prevention could also benefit from establishing waterbody size-angler effort relationships given putatively unique transport mechanisms by bank and boat anglers (e.g., bait buckets, boats). Therefore, we anticipate that the ability to link future changes in waterbody size to angler effort will become even more important for effective inland fisheries management.

CRediT authorship contribution statement

Derek Kane: Conceptualization, Methodology, Formal analysis, Visualization, Writing – original draft. **Kevin Pope**: Conceptualization, Project administration, Funding acquisition, Methodology, Writing – review & editing. **Keith Koupal**: Methodology, Writing – review & editing. **Mark Pegg**: Methodology, Writing – review & editing. **Christoper Chizinski**: Project administration, Funding acquisition, Formal analysis, Visualization, Methodology, Supervision, Writing – review & editing. **Mark Kaemingk**: Conceptualization, Project administration, Methodology, Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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