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MANAGEMENT BRIEF

Reservoir Area of Influence and Implications for Fisheries Management

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Abstract
Understanding the spatial area that a reservoir draws anglers from, defined as the reservoir's area of influence, and the potential overlap of that area of influence between reservoirs is important for fishery managers. Our objective was to define the area of influence for reservoirs of the Salt Valley regional fishery in southeastern Nebraska using kernel density estimation. We used angler survey data obtained from in-person interviews at 17 reservoirs during 2009–2012. The area of influence, defined by the 95% kernel density, for reservoirs within the Salt Valley regional fishery varied, indicating that anglers use reservoirs differently across the regional fishery. Areas of influence reveal angler preferences in a regional context, indicating preferred reservoirs with a greater area of influence. Further, differences in areas of influences across time and among reservoirs can be used as an assessment following management changes on an individual reservoir or within a regional fishery. Kernel density estimation provided a clear method for creating spatial maps of areas of influence and provided a two-dimensional view of angler travel, as opposed to the traditional mean travel distance assessment.

The research of motives and site-selection behavior is common in recreational fisheries (Jakus et al. 1997; Schramm et al. 2003; Hunt 2005; Sutton and Ditton 2005; Carlin et al. 2012; Aas and Onstad 2013; De Freitas et al. 2013). One important component highlighted in the research on site selection is the importance of travel distances (Arlinghaus and Mehner 2004). Travel distance is defined as the distance required for a participant to travel from their home to participate in the activity and is often used as a surrogate for travel cost or the cost to participate in the activity at that given location.

One technique that may be used to analyze spatial data is kernel density estimation (Worton 1989; Seaman and Powell 1996). Kernel density estimation provides a clear method for creating spatial maps of areas of influence, providing a two-dimensional view of angler travel as opposed to the traditional one-dimensional mean travel distance assessment. This technique has been used for many years to define the home ranges of study animals. Kernel density estimation has also been used in the business and social science fields to determine the best placement of new hospitals for distributing customer usage (Donthu and Rust 1989), determine the distribution of traffic accidents (Xie and Yan 2008), and determine the distribution of crime hot spots (Wang et al. 2013). However, kernel density estimation has not yet been widely applied to recreational fisheries (see Vokoun 2003 for an example of univariate kernel density home range analysis).

Our objectives were to (1) describe the distributions of distance traveled, (2) compare travel distance between reservoirs and day-type, and (3) define the area of influence for each reservoir using kernel density estimation for the Salt Valley regional fishery in southeastern Nebraska. We used angler survey data obtained from in-person interviews conducted at these reservoirs to assess these three objectives.

METHODS

Study site.—The Salt Valley regional fishery is located in the southeastern portion of Nebraska (Figure 1) in the Salt Creek watershed. Portions of this watershed are highly developed (i.e., Lincoln and Omaha, Nebraska), and other portions

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remain rural. There are 19 reservoirs in the Salt Valley regional fishery, ranging in size from 5 to 730 hectares. The recreational catch in these reservoirs is dominated by Largemouth Bass *Micropterus salmoides*, Channel Catfish *Ictalurus punctatus*, Bluegill *Lepomis macrochirus*, and Black and White crappie *Pomoxis* spp., but Walleye *Sander vitreus* and Rainbow Trout *Oncorhynchus mykiss* are caught seasonally. Annual angling pressure on these reservoirs during 2010 ranged from 61 to 3,931 h/ha.

Angler interviews.—In-person angler interviews were conducted at 17 of the 19 reservoirs in the Salt Valley. Angler interviews were conducted during monthly periods from April 2009 to December 2012. Sampling was conducted year-round, except for times when ice was unsafe, primarily late November–December and late February of each year. Interviews were conducted at 7 randomly selected reservoirs each year, whereas the remaining 12 reservoirs were assessed for fishing effort only.

Creel survey days (n = 12/month) and times were chosen following a stratified multistage probability-sampling regime (Malvestuto 1996). Sample days each month were split evenly (equal probability of sampling) into six categories (weekday–early [0000–0800 hours], weekday–mid [0800–1600 hours], weekday–late [1600–2400 hours], weekend–early, weekend–

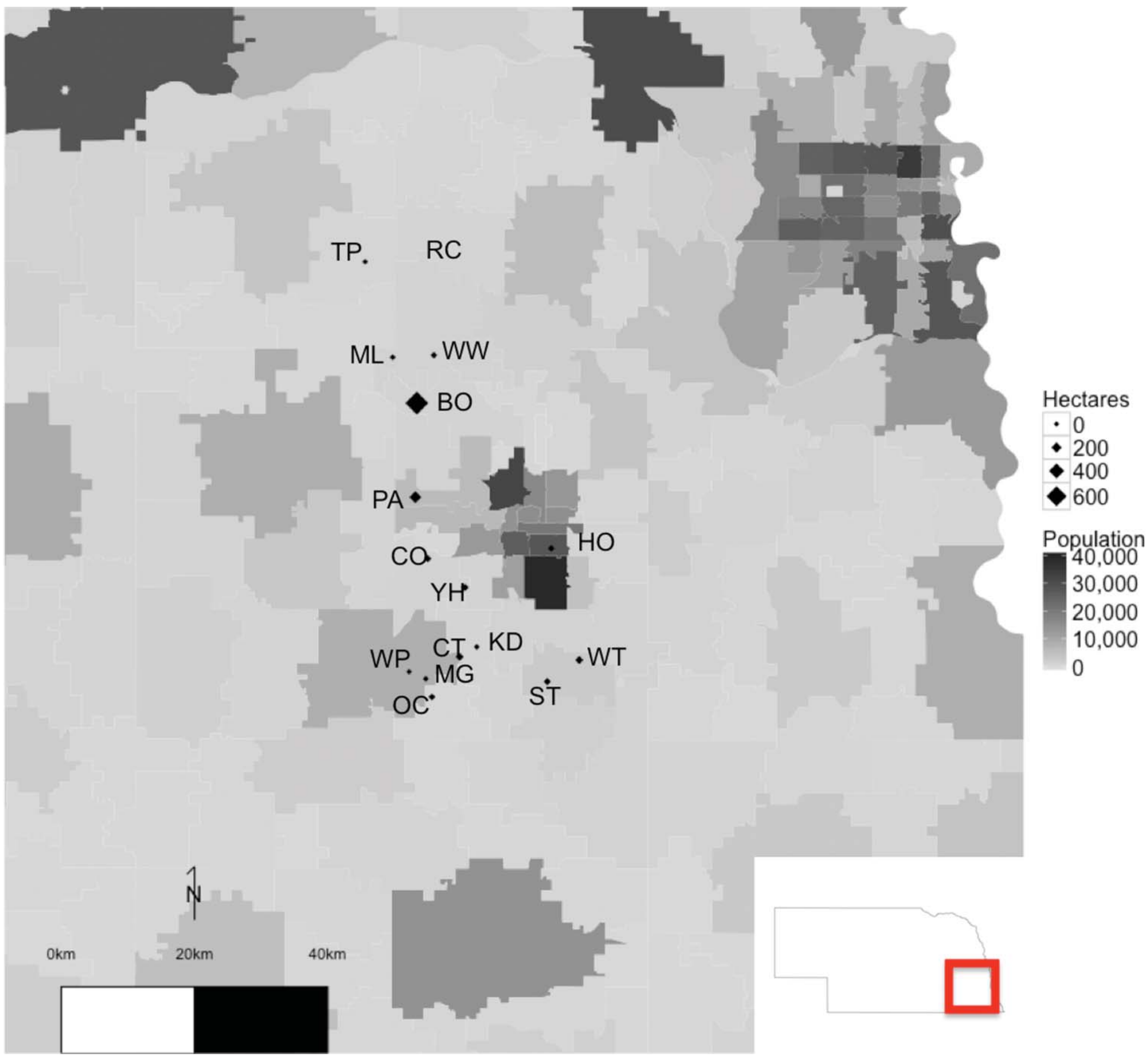

FIGURE 1. Map of the Salt Valley regional fishery with population density by zip code. The population density by zip code was based on data from the 2010 United States Census. The reservoir two-letter codes are as follows: BO = Branched Oak Lake, BS = Bluestem Lake, CO = Conestoga Lake, CT = Cottontail Lake, KD = Killdeer Lake, HO = Holmes Lake, MG = Merganser Lake, ML = Meadowlark Lake, OC = Olive Creek Lake, PA = Pawnee Lake, RC = Red Cedar Lake, ST = Stagecoach Lake, TP = Timber Point Lake, WT = Wagon Train Lake, WP = Wild Plum Lake, WW = Wildwood Lake, and YH = Yankee Hill Lake.

mid, and weekend–late). Weekday sample days were selected from all nonholiday Monday–Friday days within each month, and weekend sample days were selected from all Saturday–Sunday days plus all federal holidays within each month. Creel technicians intercepted angling parties at the completion of their trips at access points and conducted interviews to gather information on fishing effort, catch, and harvest.

Driving distance analysis.—Driving distances were calculated for all angler parties using the taRifx.geo package (Friedman 2012) and Bing Maps (Microsoft 2013). The geographical coordinates of reservoirs were converted to the nearest street address, and driving distances were calculated from this address to the center point of the angler's home zip code. All interviews outside of southeastern Nebraska, defined by a bounding box with coordinates (−97.6, 40.1; −97.6, 41.5; −95.8, 40.1; and −95.8, 41.5 WGS1984 Projection), were considered outliers and removed for this analysis. Parties that originated outside of this bounding box were removed because they were considered to be most likely visiting this lake as a vacation or destination lake instead of making a daily trip. Differences in travel distance between anglers fishing on weekday and weekend days were compared using a Wilcoxon rank-sum test, and differences among lakes were compared using a Kruskal–Wallis test. All analyses were conducted using R 3.1.2 (R Development Core Team 2012).

Area of influence analysis.—The error in the assignment of spatial location because of varying sizes of zip code area was reduced by taking a bootstrapping approach and randomly assigning anglers to a smaller spatial scale (i.e., census blocks) within the zip code. To accomplish this, a random census block from the list of available census blocks within each angler's home zip code was chosen. The centroid of the census block was then chosen to represent their home location instead of the centroid of the entire zip code. This randomization was used in a bootstrapping approach (n = 1,000 iterations with replacement) to account for uncertainty in spatial location within a zip code.

Kernel utilization distributions (Worton 1989) were calculated using the kernelUD function in the adehabitatHR package (Calenge 2006) in R. This analysis consists of two results: (1) a kernel density estimate for each grid cell (set at 4 km^2) across the region that can be compared across the region and (2) a kernel utilization distribution (area of influence), which is a delineation of the area from which a certain level of use comes from, in this instance focused on the 95% area of influence. A bivariate normal kernel was used, which places a bivariate normal kernel over each observed point and uses the smoothing parameter, h, to control the width of the bivariate normal kernel. We set h at the ad hoc level, "href," after testing different levels of h (Silverman 1986) as "href" yielded the best, most continuous estimates of area, not under- or over-smoothing the data. The extent, or spatial range to estimate the utilization distribution, was set at 0.5 past the observed range, which indicates that we estimated kernel density values at 0.5 × the range of coordinates (for example, on the Y-coordinates an extent of 0.5 would be estimating the kernel density from a minimum Y-coordinate of $Y_{min} - 0.5 \times R_Y$ to a maximum Y-coordinate of $Y_{max} + 0.5 \times R_Y$, where R_Y is the observed range of Y-coordinate values). The grid, or set cells to estimate utilization distribution, for kernel estimation was set as a raster of 4-km^2 cells encompassing the survey area. Kernel distributions were calculated for each of the 1,000 iterations, and the mean value of each cell of the grid across the 1,000 census block iterations was used as an estimate of the utilization across the region for each lake.

The area of influence (hectares) was calculated for the 10, 50, and 95% utilization distributions for each reservoir. Reservoirs with less than 25 anglers (i.e., Killdeer and Red Cedar lakes) were excluded from area of influence calculations because of low sample size. The variation of kernel density estimates was calculated using a bootstrap approach (Kernohan et al. 2001) by randomly drawing (with replacement) 50% of the zip code locations for each reservoir for each iteration. The kernel density procedure was followed as described above to get 10, 50, and 95% utilization distributions, and the mean and variance across 1,000 iterations was taken.

RESULTS

A total of 3,739 parties were interviewed across the 4-year survey period. The driving distance from home zip code to reservoir ranged from 2.7 to 164.9 km with a mean ± SE of 35.1 ± 0.4 km. The driving distance varied among reservoirs, with the urban reservoir, Holmes Lake, having the smallest mean ± SE driving distance (12.9 ± 0.6 km; Figure 2). For most other reservoirs, the median travel distance was approximately the distance between the population center, Lincoln, and the reservoir. Travel distance varied between anglers fishing weekday (33.5 ± 0.57) and weekend (36.5 ± 0.54) days (Wilcoxon test: W = 1,571,615; $P < 0.001$). Similarly, travel distance varied among reservoirs (Kruskal–Wallis: χ^2 = 1,451.78, df = 15, $P < 0.001$; Figure 2).

Kernel density estimates, or the estimate of angler parties coming from each individual 4-km^2 cell, across southeast Nebraska for all reservoirs ranged from 0.00 to 6.33×10^{-5} angler parties/ha^2, with a mean of 1.35×10^{-7} angler parties/ha^2. However, kernel density estimates from the 1,000 iterations varied little, with a mean ± SE coefficient of variation across iterations of $1.90 \times 10^{-5} \pm 1 \times 10^{-7}$ anglers/ha^2. Further analysis was completed on the original sample of the kernel density for simplicity.

The area of influence ranged among reservoirs from 1,208 ± 22 (mean ± SE) to 41,010 ± 381 ha for the 10% utilization distribution, 11,365 ± 70 to 311,075 ± 2,282 ha for the 50% utilization distribution, and 80,003 ± 827 to 1,241,354 ± 6,278 ha for the 95% utilization distribution (Table 1; Figure 3). All 17 reservoir areas of influence included Lincoln,

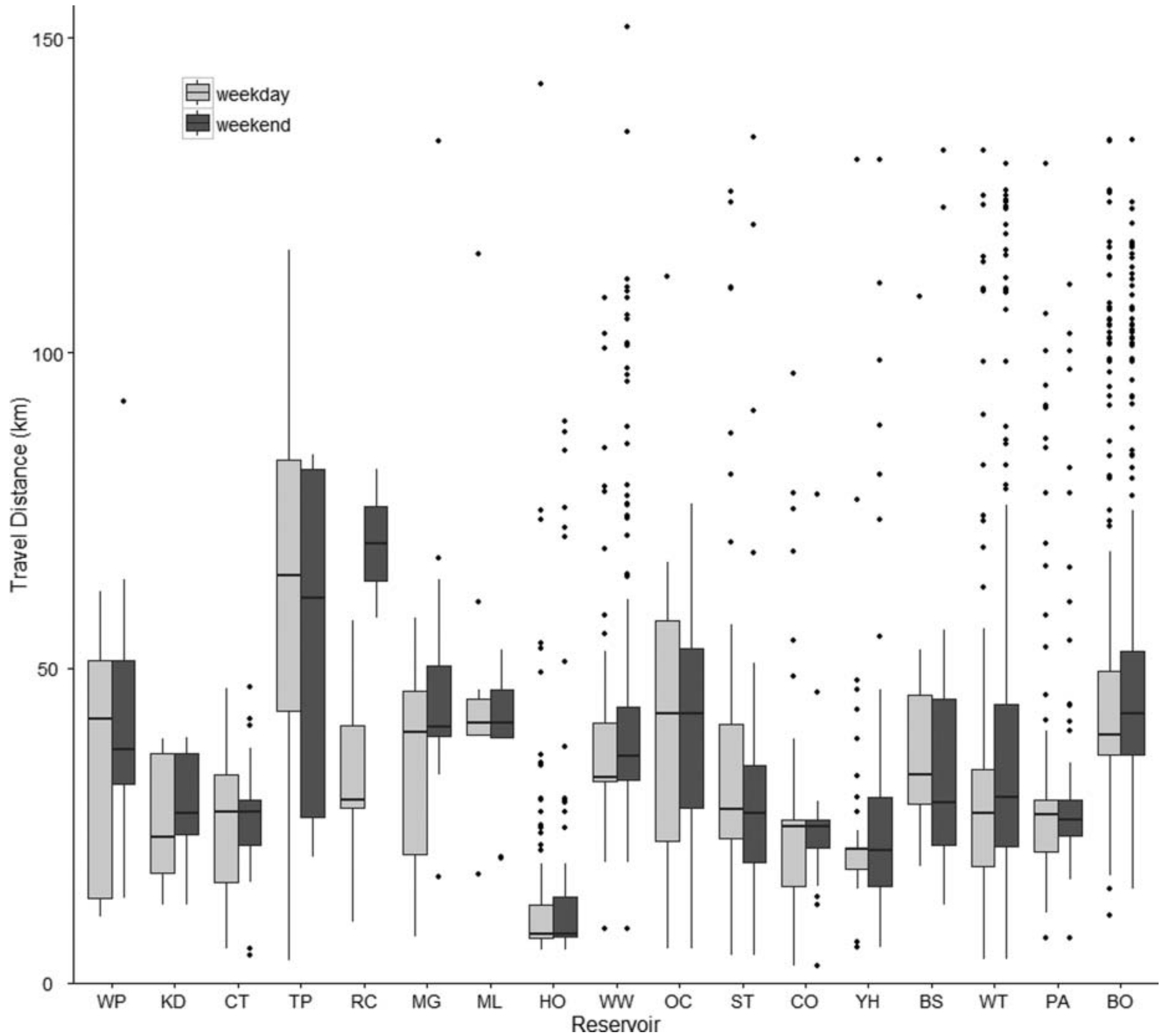

FIGURE 2. Box plot of driving distance traveled by anglers fishing the reservoirs on weekends (dark gray) and weekdays (light gray) from the home zip code of the angler to the geographical coordinates of the reservoir in the Salt Valley regional fishery. Horizontal black lines represent the median, boxes represent the range from the 25th to 75th percentile, whiskers extend from the box to the highest or lowest value within 1.5 times the interquartile range, and dots represent outliers. See Figure 1 for the definitions of the reservoir codes.

whereas only 12 of the 17 reservoir areas of influence included Omaha, an area of much greater population just to the northeast (Figure 3). In general, the 10% utilization distribution was centered on Lincoln. The smallest area of influence was for Holmes Lake, the urban reservoir in the regional fishery, whereas the largest area of influence was for Timber Point Reservoir, a small rural reservoir. The area of influence was unrelated to surface area (Spearman's correlation: $S = 409$, $P = 0.33$) or the number of parties interviewed at a reservoir ($S = 614$, $P = 0.73$).

DISCUSSION

Knowing the spatial use of a regional fishery is an important first step in understanding what anglers want from the fishery resources within an area. The revealed preferences of anglers, through their actual use of reservoirs, are an effective means of examining and comparing the current angler base of reservoirs across a regional fishery. We used two analyses, distributions of travel distance and kernel density estimates of area of influence, to determine the areas of influence for each reservoir within the Salt Valley regional fishery to gain insights on differences among reservoirs.

Anglers travel a certain distance to a reservoir to fish on a given day, and this distance likely plays a major part when they are making daily decisions on where to go fishing (Brown and Mendelsohn 1984). Travel distances for anglers in the Salt Valley varied among different reservoirs, with the urban reservoir, Holmes Lake, having the smallest travel distance. Except for the urban reservoir, most reservoirs had a median travel

TABLE 1. Area of influence size (ha) for reservoirs, ordered by surface area from smallest to largest, of the Salt Valley regional fishery from kernel density estimates of 10, 50, and 95% utilization distributions, and *N* is the sample size of anglers included in the area of influence estimates. Standard errors (SEs) were calculated by a bootstrapping approach, as described in the text. See Figure 1 for the definitions of the reservoir codes.

Reservoir	*N*	10% (SE)	50% (SE)	95% (SE)
WP	30	19,538 (280)	148,218 (1,867)	671,493 (8,872)
CT	59	2,632 (31)	24,018 (223)	126,853 (1,108)
TP	55	41,010 (381)	311,075 (2,282)	1,241,354 (6,278)
MG	37	9,574 (184)	77,203 (1,375)	430,253 (7,433)
ML	29	12,002 (244)	97,416 (1,907)	530,976 (8,872)
HO	494	1,208 (22)	11,365 (70)	80,003 (827)
WW	482	6,157 (33)	54,750 (257)	619,806 (2,613)
OC	195	7,408 (47)	68,923 (439)	427,368 (2,170)
ST	254	4,050 (32)	35,122 (233)	314,877 (2,493)
CO	93	4,410 (63)	35,810 (455)	314,493 (5,278)
YH	196	3,770 (40)	30,851 (263)	275,578 (3,294)
BS	31	15,558 (266)	117,986 (1,967)	632,099 (10,332)
WT	254	4,373 (24)	38,750 (152)	531,925 (2,581)
PA	201	6,834 (58)	55,973 (470)	686,189 (5,640)
BO	814	6,443 (25)	57,235 (204)	771,858 (2,577)

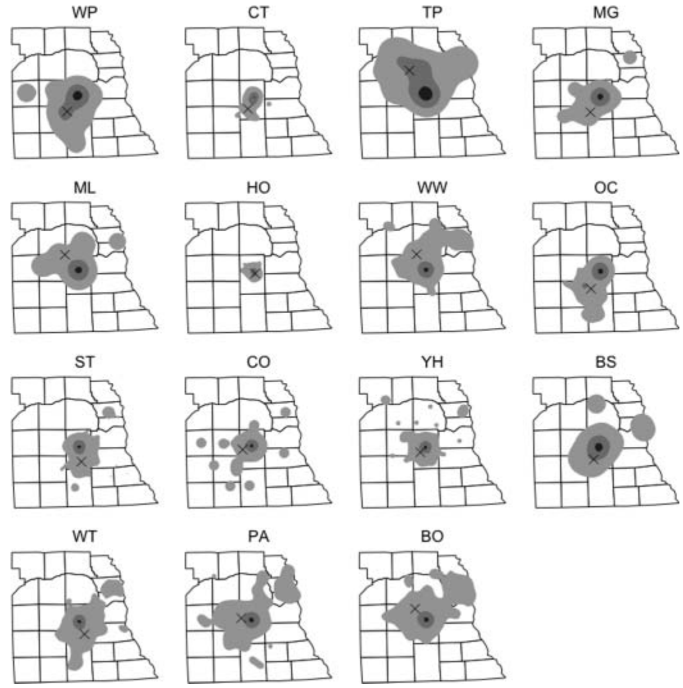

FIGURE 3. Area of influence for Salt Valley reservoirs. The black "×" represents the location of the reservoir, and the polygons represent the 10% (dark gray), 50% (gray), and 95% (light gray) area of influence of reservoirs based on kernel utilization distribution estimates. See Figure 1 for the definitions of the reservoir codes.

distance of between 25 and 40 km, which was the distance between those reservoirs and Lincoln. However, travel distance alone does not allow us to determine if these reservoirs were drawing anglers primarily from Lincoln or were drawing anglers that were uniformly dispersed in the 25–40 km travel distance.

The area of influence, defined by the 95% kernel density, for reservoirs within the Salt Valley regional fishery varied, indicating that anglers use the reservoirs differently across the regional fishery. In general, reservoirs further away from the urban center had larger areas of influence, whereas urban reservoirs (e.g., Holmes Lake) had smaller areas of influence. Therefore, management actions aimed at increasing participation at urban water bodies would be best directed at urban residents, whereas management actions aimed at increasing participation at rural water bodies should target all residents, including those in urban settings.

There appears to be a distinction between reservoirs that draw from Omaha and those that do not. Omaha is the largest city in Nebraska and is located on the eastern edge of our defined boundary. Only 12 of the 17 reservoirs included Omaha in their 95% area of influence, most of which are on the northern portion of the region, closer to Omaha, or are larger, more well-known reservoirs. This suggests that anglers are willing to travel farther to fish reservoirs that are more well-known and are perhaps discussed more frequently through either word-of-mouth communication or online social media (Martin et al. 2014). Furthermore, the area of influence did not increase as the number of observations (i.e., anglers interviewed) increased, contrary to what has been suggested (Seaman et al. 1999), indicating that our sample sizes were larger than those typical of studies using kernel density estimation.

The use of a kernel density analysis, adopted from wildlife home range analysis, is useful for defining the area of influence at individual reservoirs. However, there are several caveats that must be included with this analysis. First, this analysis is built on an assumption that all anglers in an angling party are coming from the same home zip code (i.e., location) and treating them as one observation may skew the spatial distribution of visits. For further refinement of this technique, location data should be collected on a per-angler zip code level. The randomization of location to census block did not change the results and suggests that zip code is a sufficiently small spatial unit for analysis. Second, this analysis is using a technique that was designed to calculate areas based on multiple locations of one individual; we are using one location of many individuals to calculate an area on a different spatial level (i.e., the reservoir). However, kernel density analysis has been used in a similar manner to define other areas of interest (e.g., Donthu and Rust 1989).

Defining reservoir area of influence in the Salt Valley regional fishery allows fishery managers to visualize specific areas from which anglers are coming to each reservoir. The visual, and testable, representation of the areas of influence is a significant advantage over traditional mean travel distance assessments. Further, the information contained within an area of influence, mainly the spatial estimates of angler density, are an improvement over a simple heat map of angler home locations. This information allows the use of the area of influence as a pre- and postassessment of angling participation, allowing managers to examine not only a numerical increase in angling participation following renovations, stockings, or changes in regulations but also changes in the spatial draw of anglers to the lake. Furthermore, this analysis technique allows for the determination of areas within the regional fishery that may be underused from a fishery perspective, such as areas with discrepancies between kernel density and population density (i.e., an area with low kernel density but high population density). Although not within the scope of this project, future research should focus on low-participation areas and determine whether a lack of anglers originating from a particular area is a function of no available fishing opportunities within their respective travel distance, low-quality fishing opportunities, or population and demographic factors.

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