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Angler effort and catch within a spatially complex system of small lakes

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ABSTRACT

Spatial layout of waterbodies and waterbody size can affect a creel clerk's ability to intercept anglers for interviews and to accurately count anglers, which will affect the accuracy and precision of estimates of effort and catch. This study aimed to quantify angling effort and catch across a spatially complex system of 19 small (<100 ha) lakes, the Fremont lakes. Total ($\pm$ SE) angling effort (hours) on individual lakes ranged from 0 (0) to 7,137 (305). Bank anglers utilized 18 of the 19 lakes, and their mean ($\pm$ SE) trip lengths (hours) ranged from 0.80 (0.31) to 7.75 (6.75), depending on the waterbody. In contrast, boat anglers utilized 14 of the 19 lakes, and their trip lengths ranged from 1.39 (0.24) to 4.25 (0.71), depending on the waterbody. The most sought fishes, as indexed by number of lakes on which effort was exerted, were anything (17 of 19 lakes), largemouth bass *Micropterus salmoides* (15 of 19 lakes), and channel catfish *Ictalurus punctatus* (13 of 19 lakes). Bluegill *Lepomis macrochirus*, crappie *Pomoxis* spp., and largemouth bass were caught most frequently across the lakes, but catch rates varied considerably by lake. Of the 1,138 parties interviewed, most parties (93%) visited a single lake but there were 77 (7%) parties that indicated that they had visited multiple lakes during a single day. The contingent of parties that visited more than one lake a day were primarily (87%) bank anglers. The number of lake-to-lake connections made by anglers visiting more than one waterbody during a single day was related to catch rates and total angling effort. The greater resolution that was achieved with a lake specific creel survey at Fremont lakes revealed a system of lakes with a large degree of spatial variation in angler effort and catch that would be missed by a coarser, system-wide survey that did not differentiate individual lakes.

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1. Introduction

There are many spatial aspects that must be considered when designing a creel survey. Spatial layout and waterbody size can affect a clerk's ability to interview and accurately count anglers, which would affect the accuracy and precision of estimates of effort and catch. Numerous researchers have investigated the complexities associated with conducting creel surveys on large (>10,000 ha) waterbodies (e.g., Soupier et al., 2006; McGlennon and Kinloch, 1997; Smucker et al., 2010). Large waterbodies, which are best sampled using a "bus route" approach (Robson and Jones, 1989;

Jones and Robson, 1991) and aerial counts of anglers (Smucker et al., 2010), are often difficult to sample because numerous access points exist over a large area. Further, large waterbodies can be spatially heterogeneous such that catch rates of targeted fish species and angling effort are not uniform throughout the waterbody, requiring spatial stratification of the waterbody (Pollock et al., 1994; Soupier et al., 2006) to accurately estimate effort and catch.

Although less studied, small (<100 ha) waterbodies can also be difficult to survey, particularly when there are multiple waterbodies being assessed within a small geographic area. Trip length tends to be relatively short (i.e., hours) at small waterbodies (Pierce and Bindman, 1994) and thus the chance encounter with anglers can be small and inconsistent (i.e., dominated on weekends and holidays). Small public waterbodies can exist within a matrix of other waterbodies and given the proximity and short trips, anglers may move between several waterbodies on a single trip (Martin and Pope,

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Fig. 1. Map of the Fremont lakes in Dodge County, Nebraska.

2011; Martin, 2013). Further, depending on the proximity of small, public waterbodies to urban centers, there can be large variation in effort (i.e., many counts with zeros on weekdays and many counts with large numbers on weekends) that can lead to complications when calculating effort estimates (Taylor et al., 2011).

The aim of this study was to quantify angling effort and catch across a spatially complex system of small lakes. Fremont Lakes State Park (41° 26.060'N, 96° 31.966'W; Fig. 1) (hereafter Fremont lakes) is located about two miles west of the city of Fremont, Nebraska (2011 population 26,456) and includes 19 small sandpit lakes that cover a total surface area of 265 ha. Given the proximity of the lakes to each other, travel-cost differences among lakes are negligible (i.e., <US\$ 1.50 [2013 IRS mileage rate, US GSA, 2013]) and anglers can potentially move between several lakes on a single day. Of particular concern in this system is the ability to differentiate fish caught and harvested (i.e., retained by the angler) among lakes during a single day. We sought to calculate at each of the 19 Fremont lakes: (1) angling effort (hours of angling), (2) catch-per-unit effort (CPUE; $N_{\text{fish}} \text{ hr}^{-1}$), (3) associations of CPUE and angling effort among lakes, and (4) movement patterns of anglers among lakes.

2. Methods

2.1. Study area

Fremont lakes, which ranged in area from 0.6 to 20.8 ha, were formed when groundwater filled depressions were created by sand-pit mining. These lakes shared common characteristics of being small, shallow (<5 m), groundwater fed, and irregularly shaped. Lakes were relatively close together; the greatest straight-line distance between any two lakes was 4.38 km (Fig. 1). Within the complex of lakes, anglers can fish for black bullhead *Ameiurus melas*, bluegill *Lepomis macrochirus*, common carp *Cyprinus carpio*, channel catfish *Ictalurus punctatus*, black crappie *Pomoxis nigromaculatus*, white crappie *P. annularis*, largemouth bass *Micropterus salmoides*, muskellunge *Esox masquinongy*, rainbow trout *Oncorhynchus mykiss*, and hybrid striped bass *Morone chrysops* × *M. saxatilis*. Individual lakes have been managed for different fish communities and angling opportunities. For example, catchable-size bullhead were stocked into lake 3, muskellunge were stocked into lakes 2, 8, and 20, and rainbow trout were stocked into lake 2. Further, electric-powered and non-powered boats were allowed on all lakes, whereas gas-powered boats were only allowed on lakes 15 and 20.

2.2. Angler surveys and effort counts

The angler survey for the Fremont lakes system was designed to collect standard creel information on time and date of interview, party size, angling duration (calculated by subtracting start time

from interview time), most sought fish species, harvested fish, and released fish. We asked anglers to itemize the time spent and the numbers and sizes of species caught (harvested + release) among the lakes visited during that day.

A stratified multi-stage probability sampling regime (Malvestuto, 1996) was used to determine days of interviews. Twenty days were surveyed each month and stratified by day-type with 14 weekday days and 6 weekend and holiday days per month. Each creel day was further stratified into two survey periods (sunrise to 1330 [morning], and 1330 to sunset [afternoon]). During each survey shift, creel clerks conducted instantaneous counts to estimate daily effort and interviews to estimate daily catch and harvest (Malvestuto, 1996). Boat anglers were interviewed at boat ramps (primarily completed trips) and bank anglers were interviewed by roving (Pollock et al., 1994) the banks (completed and incomplete trips). During the interview process, harvested fish were enumerated and identified by creel clerks and numbers and species of released fish were recorded as specified by the angler. One angler, the representative of the party, completed the survey per interview; thus, all data were collected at the party level. Given the number of lakes, two creel clerks worked each creel shift. One creel clerk would count the number of bank and boat anglers on the northern lakes (lakes 1, 2, 3, 4, 5, 6, and 8) while the other clerk would count the number of bank and boat anglers on the southern lakes (lakes 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, and 20). During the survey shift, there were two instantaneous counts conducted at each lake. For each count conducted, creel clerks would begin counts at a predetermined randomly selected time at a randomly selected lake (within the northern and southern groups of lakes) and move in a randomly selected direction (i.e., clockwise or counter clockwise) until all lakes had received a count. All counts were completed in less than an hour from the start time. The mean number of anglers during the two counts of each lake was used to calculate a lake-specific daily effort (Pierce and Bindman, 1994; Malvestuto, 1996). Angler surveys were conducted from 01 April to 31 October 2011.

2.3. Numerical analysis

Monthly estimates and associated variances were calculated following methods described by Malvestuto et al. (1978), Malvestuto (1996), Pollock et al. (1994), and Pollock et al. (1997). The basic process of the extrapolations is as follows. First, angling effort for each survey day was calculated by multiplying the mean angler count by the number of hours in the survey period adjusted by the proportion of the daily period (i.e., 0.5 or half of the total hours within a day). The mean daily effort for each stratum (weekday and weekend [including US Federal holidays]) was then calculated for each month and these two mean values were weighted by the proportion of the day types per month and summed to get the effort on a typical day during the month. This estimate was then multiplied

by the number of days per month to calculate the total monthly effort. The daily catch per unit effort (CPUE) for each survey day was calculated by dividing the total catch for surveyed anglers that day by the total recorded trip lengths of surveyed anglers that day. The catch for that day was then calculated by multiplying the daily CPUE by daily effort (effort of period extrapolated out to the day). The mean daily catch for each stratum (weekday and weekend) was then calculated for the month, and these two mean values were weighted by the proportion of the day types per month and summed, and this daily catch estimate was then multiplied by the number of days per month to obtain an estimate of monthly catch. The same process of extrapolation was applied to harvest data to estimate monthly harvest. Significant differences in trip time for boat and bank anglers among sites was assessed using a one-way ANOVA and Tukey's pair-wise comparisons.

Non-metric multidimensional scaling (NMDS) analysis was used to explore the patterns in species-specific CPUE among the Fremont lakes. We used the “metaMDS” function with Bray-Curtis distance measure in the *vegan* package (Oksanen et al., 2011) to perform the ordination. Fitted surfaces of total effort (i.e., contour plots) were added to the ordination model using the “ordisurf” function in the *vegan* package, which uses thin-plate splines in a generalized additive model (GAM; Wood, 2003; Marra, 2011) to fit values of variables in ordination space. This allowed us to examine the interplay between angling effort and the community of catchable fish among the Fremont lakes. All analyses were completed using R v2.15.2 (R Development Core Team, 2012).

We sought to determine movement patterns of anglers that visited multiple lakes on a single day. We calculated the number of connections between each of the lakes, where one connection was the movement of one party from one lake to another. We then used linear regression to relate the number of connections for a given lake to total effort (hours), total number of fish caught, caught-while-sought catch rates (CWS CPUE), and the distance (midpoint to midpoint) to the nearest lake. Distances (m) between midpoints of lakes were calculated using coordinates from a GIS shapefile of Nebraska lakes.

3. Results

There were 2,050 anglers from 1,138 parties interviewed at the Fremont lakes from 1 April 2011 to 31 October 2011. Few parties

Table 1

The surface area (ha), number of interviews, and mean with standard error (SE) trip length (hours) by bank anglers at the Fremont lakes, Nebraska, during 1 April to 31 October 2011. Groups of lakes with significantly different trip lengths are designated with letters.

Fremont lake	Surface area	Interviews	Trip length	SE	
1	5.1	85	1.52	0.14	bc
2	6.4	203	1.56	0.09	bc
3	1.3	82	1.75	0.15	bc
4	2.6	20	1.12	0.16	c
5	4.8	68	1.69	0.13	bc
6	1.1	0	–	–	
8	5.1	2	7.75	6.75	a
9	4.3	29	1.67	0.16	bc
10	14.8	29	2.54	0.39	b
11	2.5	33	1.33	0.14	bc
12	2.9	4	1.05	0.37	c
13	1.9	5	1.33	0.25	bc
14	2.1	1	0.67	–	c
15	21.7	178	2.46	0.16	b
16	5.4	48	1.81	0.24	bc
17	2.3	77	1.26	0.11	c
18	4.5	14	1.24	0.18	c
19	1.6	3	0.75	0.27	c
20	18.9	66	2.11	0.21	bc

(<0.5%) refused to complete the survey. The highest and lowest percentage of interviews were completed at Lake 2 (20%) and Lake 6 (0%; no interviews), respectively. Trip length for bank anglers was significantly different among the Fremont lakes ($F_{17,929} = 6.01$, $P < 0.0001$) and ranged (mean $\pm$ SE) from 7.75 ± 6.75 h (Fremont lake 8) to 0.75 ± 0.27 h (Fremont lake 19) (Table 1). Trip length (3.22 ± 0.13 h) for boat anglers was not significantly different among the Fremont lakes ($F_{15,169} = 3.81$, $P = 0.11$). The most sought fishes, as indexed by number of lakes on which effort was exerted, were anything (17 of 19 lakes), largemouth bass (15 of 19 lakes), and channel catfish (13 of 19 lakes) (Fig. 2).

There were $34,654 \pm 1,520$ fish caught and $7,172 \pm 613$ fish harvested among all the Fremont lakes from 1 April 2011 to 31 October 2011. Bluegill ($N = 10,292$), largemouth bass ($N = 8,360$) and crappie ($N = 6,591$) were the most caught fish, whereas crappie ($N = 2,784$), bluegill ($N = 1,166$), and channel catfish ($N = 1,158$) were the most harvested. Catch rates varied among species across the Fremont lakes, with bluegill, crappie, and largemouth bass caught the most frequently across the lakes (Table 2). Bluegill catch rates

Fig. 2. Angling effort $\pm$ SE (hours) for the Fremont lakes, Nebraska, during 1 April to 31 October 2011, with a breakdown of effort targeted toward specific species.

Table 2

Mean $\pm$ SE catch per unit effort of fishes caught in the Fremont lakes, Nebraska, during 1 April to 31 October 2011. A dash (–) indicates the species was not caught in the lake. Catch per unit effort is the number of fish per angler per hour of angling.

Lake	Bluegill	Buffalo	Bullhead	Channel catfish	Common carp	Crappie	Largemouth bass	Rainbow trout	Yellow perch
1	0.13 $\pm$ 0.04	–	–	0.06 $\pm$ 0.03	–	0.11 $\pm$ 0.11	0.20 $\pm$ 0.07	–	–
2	0.16 $\pm$ 0.08	–	–	0.13 $\pm$ 0.05	–	0.21 $\pm$ 0.15	0.13 $\pm$ 0.05	0.41 $\pm$ 0.15	–
3	0.18 $\pm$ 0.07	–	0.46 $\pm$ 0.16	0.02 $\pm$ 0.01	–	0.01 $\pm$ 0.01	0.14 $\pm$ 0.06	–	–
4	0.34 $\pm$ 0.12	–	–	–	–	0.03 $\pm$ 0.03	0.10 $\pm$ 0.08	–	–
5	0.19 $\pm$ 0.08	–	–	0.04 $\pm$ 0.02	–	0.18 $\pm$ 0.09	0.18 $\pm$ 0.06	–	–
6	–	–	–	–	–	–	–	–	–
8	0.01 $\pm$ 0.01	–	–	–	–	0.04 $\pm$ 0.04	0.04 $\pm$ 0.04	–	–
9	0.15 $\pm$ 0.11	–	–	0.05 $\pm$ 0.05	0.04 $\pm$ 0.03	0.00 $\pm$ 0.00	0.02 $\pm$ 0.02	–	–
10	0.03 $\pm$ 0.03	–	–	0.07 $\pm$ 0.03	0.00 $\pm$ 0.00	–	0.02 $\pm$ 0.02	–	–
11	0.84 $\pm$ 0.32	–	–	0.12 $\pm$ 0.05	–	0.45 $\pm$ 0.25	0.11 $\pm$ 0.04	–	–
12	–	–	–	–	–	0.01 $\pm$ 0.01	0.01 $\pm$ 0.01	–	–
13	0.03 $\pm$ 0.04	–	0.00 $\pm$ 0.00	–	–	–	–	–	–
14	0.12 $\pm$ 0.14	–	–	–	–	0.08 $\pm$ 0.10	0.01 $\pm$ 0.00	–	–
15	0.03 $\pm$ 0.02	0.01 $\pm$ 0.00	0.00 $\pm$ 0.00	0.27 $\pm$ 0.06	0.03 $\pm$ 0.02	0.01 $\pm$ 0.01	0.01 $\pm$ 0.01	–	–
16	0.16 $\pm$ 0.08	0.00 $\pm$ 0.01	0.00 $\pm$ 0.00	0.05 $\pm$ 0.04	0.01 $\pm$ 0.01	0.42 $\pm$ 0.48	0.02 $\pm$ 0.02	–	0.04 $\pm$ 0.03
17	0.69 $\pm$ 0.40	–	–	0.04 $\pm$ 0.05	–	0.65 $\pm$ 0.33	0.06 $\pm$ 0.03	–	–
18	0.02 $\pm$ 0.02	–	–	0.01 $\pm$ 0.00	–	0.37 $\pm$ 0.12	0.17 $\pm$ 0.07	–	–
19	0.21 $\pm$ 0.22	–	–	–	–	–	–	–	–
20	0.24 $\pm$ 0.09	–	–	0.04 $\pm$ 0.02	–	0.17 $\pm$ 0.10	0.54 $\pm$ 0.13	–	0.00 $\pm$ 0.00

ranged from 0.02 ± 0.02 fish/angler/h to 0.84 ± 0.32 fish/angler/h, crappie catch rates ranged from 0.01 ± 0.01 fish/angler/h to 0.65 ± 0.33 fish/angler/h, and largemouth bass catch rates ranged from 0.01 ± 0.01 fish/angler/h to 0.54 ± 0.13 fish/angler/h, depending on the lake. Lakes with specialized stocking programs for black bullhead (lake 3) and rainbow trout (lake 2) had greater catch rates of the respective species than lakes without the specialized stockings (Table 2). The lowest catch rates among the species caught were bigmouth buffalo *Ictiobus cyprinellus*, common carp, and yellow perch *Perca flavescens*, all of which were only caught in a small subset (i.e., 2) of lakes.

There was a separation of Fremont lakes in multivariate space based on patterns in species-specific CPUE among lakes (Fig. 3). A two-dimensional solution was the best fit for the NMDS ordination of catch rates, which yielded a final stress of 0.1279. Ordination of the sites by NMDS in relation to the GAM contour of total effort indicated a non-linear gradient (Fig. 3) with a separation among two types of sportfish (i.e., fish caught via rod and reel) communities in the Fremont lakes, each with similar angling effort. For example, Fremont lake 20 had high catch rates of bluegill, crappie, and largemouth bass and high levels of angling effort, whereas

Fremont lake 15 had high catch rates of channel catfish, common carp, and bigmouth buffalo and similarly high levels of angling effort.

Of the 1,138 parties interviewed, 77 (7%) indicated that they had visited multiple lakes during a single day. There was no significant difference in the party size of anglers making multiple lake visits (mean $\pm$ SE, 2.04 ± 0.17) versus single lake visits (1.81 ± 0.03) (t test, $t = 1.3756$, $df = 208.367$, $P = 0.170$). Further, there was no significant difference in the number of multiple lake visits versus the single lake visits during weekday and weekend ($\chi^2 = 0.0016$, $df = 1$, $P = 0.969$). Of the 77 parties that visited multiple lakes, 67 (87%) were bank anglers and 10 (13%) were boat anglers, which was not significantly different than the single-visit party types ($\chi^2 = 0.5858$, $df = 1$, $P = 0.444$). Overall, the greatest numbers of multiple-lake angler parties were observed in July and September ($N = 17$ and 14 , respectively), whereas the fewest numbers were observed in April and June ($N = 6$ and 5 , respectively). The greatest numbers of single-lake angler parties were observed in June and July ($N = 207$ and 170 , respectively), whereas the fewest numbers were observed in September and October ($N = 99$ and 94 , respectively). Anglers that moved among multiple lakes were primarily seeking largemouth bass (28%), anything (24%), and channel catfish (22%), which did not differ from the overall composition of anglers at Fremont lakes. Further, 58% of the parties that moved did not catch any fish at their first location, and 18% of parties that moved and did not catch any fish at their first location changed the species they were seeking at the next lake.

Most of the lake-to-lake movement occurred within the northern set of lakes for both bank and boat anglers (66 and 60%, respectively). Overall, Fremont lakes 2, 5, and 20 had the greatest number of lake-to-lake connections, each with nine (Fig. 4). In contrast, Fremont lakes 6, 13, and 19 had no lake-to-lake connections (i.e., no multi-lake angler parties fished these lakes). There was a positive relationship between the number of connections and total effort among the Fremont lakes ($r^2 = 0.63$; $F_{1,17} = 28.42$; $P < 0.0001$) (Fig. 5). Likewise, there was a positive relationship between the number of connections and total number of fish caught at the Fremont lakes ($r^2 = 0.55$; $F_{1,17} = 21.01$; $P = 0.0003$). There was no significant relationship between the number of connections and mean caught-while-sought CPUE at the Fremont lakes ($r^2 = 0.14$; $F_{1,17} = 2.711$; $P = 0.118$). There was a weak negative relationship between distance to nearest lake and the number of connections ($r^2 = 0.04$; $F_{1,17} = 16.230$; $P < 0.0001$), primarily indicating a lack of movement between distant lakes (e.g., lake 8 to lake 14).

Fig. 3. A non-metric multidimensional scaling (NMDS) ordination and the General Additive Model (GAM) fitted contours of total effort (hours) for the Fremont lakes, Nebraska, during 1 April to 31 October 2011.

Fig. 4. The total effort (hours; 1 April 31–October 2011) at the Fremont lakes, Nebraska and the number of connections between lakes for those anglers that visited multiple lakes during a single day. The width of the line represents the total number of parties that moved between lakes (i.e., more parties = greater width).

4. Discussion

Angling effort at the Fremont lakes was not uniform among lakes. Fremont lakes 20, 2, and 15 (ordered most to least) accounted for nearly 49% of all the effort at the lake complex during 2011. Despite these lakes accounting for most of the angling effort in the Fremont lakes, there was an interesting separation in the communities of catchable fish. At one end of the spectrum there were lakes associated with greater CPUE of bluegill, crappie, and largemouth bass (i.e., lakes 2 and 20), and at the other end of the spectrum there were lakes with greater CPUE of bigmouth buffalo, channel catfish, and common carp (i.e., lake 15). Compositions of angler catches at these waterbodies were similar to compositions observed during standardized sampling of the fish communities at Fremont lakes by Nebraska Game and Parks Commission (P. Chvala, personal communication). The greater angler efforts on Fremont lakes 2, 15, and 20 were associated with anglers seeking specific species, whereas the lesser efforts on the other lakes were more associated with anglers seeking anything. In general, anglers treated the Fremont lakes system as multiple separate lakes, tending to spend most of their time angling at lakes with the greatest sportfish CPUE. Given the relationship observed between effort and sportfish CPUE,

it appears that angling effort could be less centralized and more spread out by improving the sportfish communities (i.e., increasing the CPUE of commonly targeted species through stocking and habitat restoration) in the lakes at the edges of the Fremont lakes complex. For example, Fremont lake 8 has anglers seeking crappie but the crappie CPUE is at the lower end of the range observed at the Fremont lakes, thus a stocking program with an emphasis on crappie at this waterbody could potentially be a relatively easy approach in increasing angler usage at a relatively low-use lake.

It is often assumed that anglers are highly mobile and are responsive to spatial (among waterbodies) and temporal (among years) differences in fish abundances (Johnson and Carpenter, 1994; Carpenter and Brock, 2004; Post, et al., 2008). We expected 20–25% of angler parties to move among the lakes during a single trip, but the percentage of angling parties that moved among lakes during a single day was less than expected. Overall, 1 in 15 angler parties moved among lakes during a single day. Further, anglers that moved among lakes did not differ in general characteristics assessed from the overall composition of anglers at Fremont lakes. The factors involved in the decision to move from one lake to another was unclear, although it may be related to catch as a majority of the parties that moved did not catch any fish at their first location. However, catch

Fig. 5. The relationship between the number of lake-to-lake connections with total effort (hours), total number of fish caught, caught-while-sought catch rates (number of fish per angler per hour of angling), and the distance (m) to the nearest lake's midpoint at the Fremont lakes, Nebraska, during 1 April to 31 October 2011. The dashed lines represent the predicted linear relationships (lines are only presented for significant relationships).

is often not the primary motivation for angling (Driver and Knopf, 1976; Fedler and Ditton, 1994) and the decision to move to another lake may be related to other noncatch-related factors (Johnson and Carpenter, 1994; Hunt, 2005; Post et al., 2008; Johnston et al., 2010; Hunt et al., 2011). For example, Johnston et al. (2011) observed that trout anglers were not attracted to high-catch-rate fisheries and they suggested that angler behaviour is complex and may be strongly influenced by harvest regulations. In our study, regulations were not a confounding factor as all lakes within the Fremont Lake complex had identical harvest regulations and we observed that angling effort tended to be concentrated on lakes with relatively greater CPUE, probably driven by either previous experience angling at the Fremont lakes or through word of mouth. Anglers that did move among lakes may have simply been exploring other possibilities within the Fremont lakes. It is clear that further research is needed to understand the factors involved in the decision to stop angling and move to another lake, an understanding that is important for actively managing a spatially complex system of small lakes.

The number of connections to other lakes appeared to be related to CPUE; lakes with elevated CPUE tended to have the greatest amount of effort. Similarly, these lakes with the greatest catch and CPUE tended to have the most connections to other Fremont lakes. Although the lakes with the greatest connections had a lot of effort, there was no pattern in the direction of the movement. For example, there were 13 parties that moved from lake 2 to another lake and another 13 parties that moved from other lakes to lake 2. There appeared to be a relationship between the connections and distance between lakes, such that close lakes tended to have more connections than distant lakes. It is difficult to determine if this was due to the proximity of the lakes or if it was due to fishery quality (lakes at the periphery of the complex had low catch rates), although there was no relationship between the number of connections at a lake and the CWS CPUE.

Using a survey design that allowed separation of catch and harvest at the individual-lake level revealed angler-use patterns that would have been missed if the whole system was surveyed as a single unit. For example, a coarser survey design would have provided angling effort and a CPUE for the entire complex and we would have missed that relationship between angling effort and CPUE at the individual lake, which has implications on how angling effort could be managed in this system of lakes (Martin and Pope, 2010) and increase the resiliency of the fishery (Post, 2013). Furthermore, the creel survey used in this study revealed that anglers rarely move among lakes during a single trip; that is when an angler decides to fish at a given lake they stay at that lake during the fishing trip. Surveying anglers at the lake level and assessing catch and harvest from each additional lake did come at a cost. The coarser survey design could use a single clerk to conduct interviews and conduct counts as interviews and counts are combined across lakes, whereas the finer survey design required the use of two clerks to sufficiently intercept anglers at the individual lakes (particularly those with short trips) and conduct angler counts at the individual lake. Asking anglers additional questions about which lakes they fished and where fish were caught did not seem to bother the anglers as the participation rate in the survey was high (>99.5%), and similar to participation rates from standardized creel surveys used elsewhere in Nebraska (Chizinski, unpublished data). The level of detail we were able to obtain by partitioning angler effort and catch with this survey has implications for all spatially complex systems (i.e., region of small waterbodies or a very large waterbody). The greater resolution in angler use and catch throughout the system can reveal previously unknown patterns and offer opportunities for more effective management strategies. Knowing effort and catch rates at specific lakes helps target future management (e.g., fish renovations and alum treatments) at those particular lakes.

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