SPATIAL AND TEMPORAL PARTICIPATION IN RECREATIONAL FISHING

by

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Buffering inland fisheries against large-scale changes in ecosystem function, climate regimes, and societal valuations of natural resources requires progressive management approaches that incorporate fish and angler dynamics at large spatial and temporal scales. Current paradigms of inland fishery management generally utilize waterbody-specific, fish-centric frameworks designed to regulate fish populations directly, and anglers indirectly, through fish stock enhancement and harvest regulation. In reality, anglers are the most manageable component of a fishery but management of anglers requires explicit consideration of their behavior (e.g., spatial and temporal patterns of participant use), which, unlike fish populations, operates at a scale larger than a single waterbody. Therefore, a first step in creating a resilient and sustainable recreational fishery requires gaining a thorough understanding of angler behavior so that managers can anticipate current and future management needs. In this dissertation, I used three techniques to describe angler behavior in a region (19 reservoirs) during a 4-year period. Anglers make decisions about where to go fishing using a large amount of information. One piece of information available to them is posts to social media websites. I provided a means to evaluate fishing effort on individual-waterbody and regional scales from posts to an online fishing social network; potentially reducing the need for intensive creel surveys. Anglers also make decisions about how far to drive to

participate in angling. I used kernel-density estimation to describe the spatial area of influence of reservoirs; differences in area of influence are likely related to access and amenities, fish community, and angler preferences. Finally, network analysis provided a social-ecological perspective to angler behavior and an explicit link between anglers and the reservoirs that they chose to fish. This angler-reservoir interaction is important to understand for angler recruitment and retention and potential changes in the regional fishery due to management actions. In combination, these techniques provide natural resource agencies with the tools needed for fisheries management agencies to ensure resilient and sustainable inland recreational fishing.

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Chapter 1: Introduction to Salt Valley Angler Survey

Fisheries management has a long history of angler surveys, beginning in the 1920s and 1930s in the United States of America (Clark 1934; Needham 1937). However, throughout the last century most surveys have focused on the potential catch and harvest of fish species by anglers (Cook and Younk 1998; evidenced by the current and historical name of many surveys (i.e., creel surveys), named after a woven basket used to keep or hold harvested fish. Economic-focused surveys joined the fisheries management world during the 1960s (e.g., Crutchfield 1962) and signified a switch from fish-focused surveys to human-focused surveys. Furthermore, angler surveys have evolved to encompass surveys aimed at understanding the fisheries clientele, anglers, and what they desire from fisheries (e.g., Fedler and Ditton 1994). This new field that aims to understand the angler and how they interact with the resource is often termed human dimensions.

Historically, fisheries management agencies have not placed emphasis on human-dimensions studies designed to understand anglers and their motives (Voiland and Duttweiler 1984; Brown 1987). Areas of research such as conservation biology (Jacobson and Duff 1998) and wildlife biology (Decker et al. 1992) have also not historically placed emphasis on understanding participants. There is still a disconnect between fishery management and human dimensions although human-dimensions research is now available and becoming more mainstream (Hunt et al. 2013). Most fishery managers put more importance on information about angler support of management actions, angler attitudes and angler satisfaction than on angler motivations, market information and demographics of anglers (Wilde et al. 1996). More recently, state management agencies are realizing the need for understanding their clientele and managing for their future. For example, the Nebraska Game and Parks Commission (NGPC) recently adopted a 20-year plan directing Commission employees to work towards recruitment, development, and retention of hunter and angler populations in Nebraska (NGPC 2008). Recruitment and retention of anglers is imperative for natural resource agencies to maintain funding, as a majority of their funding comes directly from participants through license sales.

Angler retention (i.e., continuation of license purchases from year to year) varies temporally, spatially, and demographically. Reasons for angler drop-out or failure to purchase a fishing license include lack of time, angling partners, social interaction, and angling access (Fedler and Ditton 2001; Sutton et al. 2009). However, most anglers would begin fishing again if these personal and structural constraints were removed (Fedler and Ditton 2001). Efforts by managers to increase angling participation from lapsed anglers should focus on increasing interest in angling, increasing knowledge of angling regulations, and reducing time required for participation (Sutton et al. 2009).

Demographics of anglers affect both rates and motives of participation in angling. Location (proximity to water), employment status (full-time vs. unemployed), primary residence (urban vs. rural), education level, and household size are all important factors that affect rates of angling participation among the general population (Fedler 2000; Arlinghaus 2006). Age also influences angling participation; in general, changes in participation patterns correlate with life changes (e.g., drop in angling participation at time of starting full-time college or career; Fedler 2000; Arlinghaus 2006). Angler gender is also important in determining angler demographic subgroups because males are more likely to participate in fishing (USFWS 2006) and females are more likely to harvest the fish they catch (Schroeder et al. 2006). Angler experience (e.g., number of years angling), investment (e.g., amount of money invested in angling gear), and consumptive habits (e.g., catch-and-release vs. harvest angling) are important in determining angler subgroups to be used for analysis of motives (Chipman and Helfrich 1988).

We have some knowledge of why anglers may or may not participate in angling during a particular year, yet we do not understand what affects anglers' decisions to participate at a certain water body on any given day. Questions that should be asked to further our knowledge of angler behavior include:

- Why do anglers choose to participate in fishing on a certain day?
- Why do anglers select one water body over another?
- Does the choice of water body change seasonally?
- Do anglers fish elsewhere if their preferred water body is not available (i.e., closed for renovation)?
- Do anglers continue to fish for a certain species or switch species throughout the year? Across years?

Answers to these questions and a thorough understanding of angler behavior are needed to understand the effects of management actions on angler participation and harvest.

One management action that may negatively, or positively, affect angler participation within a region is reservoir renovations. Renovations often include closing reservoirs for a short period (1-4 years) to renovate fish habitat and restructure the fish community. Actions may close water bodies preferred by anglers and force anglers to make a decision on if, and where to fish on any given day. The set of substitute sites from which they chose to fish on any given day is a list of water bodies with characteristics that are suitable to their desires and type of fishing (e.g., species present, location and type of fishing available).

Recognition of this concept of a set of substitute sites from which anglers choose to fish leads to a need for a change in management practices. Most inland fisheries management is done on a fishery-by-fishery basis (i.e., water bodies are managed independently from one another within a region). However, this management practice seems unlikely to create the types of fishing experiences that anglers prefer. A new practice in which water bodies are managed with consideration of other water bodies within the region is needed; i.e., a regional-fishery management approach (Martin and Pope 2011). A regional fishery is defined as a complex social-ecological system consisting of a set of water bodies, the fish that inhabit the water bodies, and society that has an overarching influence on the fish and water bodies. This practice does not eliminate water-body specific management and specifically allows for creation of different fisheries for different angler groups (e.g., high-density centrarchid fishery for urban angling within a city and a low-density trophy percid fishery in a rural area for avid anglers).

Though the current focus is water-body specific regulations for fishing, there is a growing realization that watershed-level issues affect each water body (Lester et al. 2003) and that mobility of anglers influences each water body within a region (Carpenter and Brock 2004; Kaufman et al. 2009). Socio-ecological models have shown that these large-scale relationships are diverse and complicated (Carpenter and Brock 2004), and that a single-focus management approach leads to greater variability in fish-population response than does an adaptive management approach (Carpenter and Gunderson 2001). Several models have been developed to examine regional-level effects on anglers and fish populations in response to restricting effort on some lakes to reduce harvest (Cox et al. 2003), however, these models did not explicitly assess angler movement and assumed an ideal-free distribution (Fretwell and Lucas 1970) in which anglers disperse effort to equalize catch rates across the region. Assumptions on angler behavior limit the applicability of these models on larger, more complex systems in which all lakes are not identical.

Choice of fishing site by anglers is driven by a combination of six factors: travel costs, fishing quality, environmental quality, facility development, encounters with other anglers, and regulations (Hunt 2005) given a list of available sites. These factors combine to form a ranking of fishing sites for each individual angler that serves as their set of substitute sites. A listing of available sites along with the dynamics of day-to-day fishing conditions leads to variation in where an angler chooses to fish on any given day.

Models to describe angler choice among sites have traditionally used either gravity models or choice models to assess angler preferences for fishing sites. Gravity models assume that fishing site choice is negatively affected by distance from anglers' residence and positively affected by quality of fishing sites (e.g., Freund and Wilson 1973); however, they do not assume any behavioral theory. This deficiency led to the adoption of choice models using random utility theory (Train 2009). Choice models allow for the prediction of how changes in site quality may affect use at other sites and its effects on the economic value of an area. Random utility theory assumes that anglers will select one fishing site over the other available choices to maximize their greatest utility, or benefit (Cascetta 2009). This angling utility is a measure that is made up of both an unobserved portion and an observable portion that can be modeled.

Hunt (2005) defined two different methods researchers have used to define the observable portion of fishing utility. The revealed preference method uses actual fishing site choice patterns reported by anglers during either an interview or survey. The stated preference method uses hypothetical situations during an interview or survey to develop a ranking of fishing site characteristics that drive angler fishing site choices. Most studies to date have used a revealed preference method, however, a combination of these two methods using actual behavior and model parameters would be beneficial (Earnhart 2001; Hunt 2005). A more robust method may include using a stated preference model to predict angler behavior then validation of that model using revealed preference data (e.g., Wallmo and Gentner 2008) or an observational method that removes any biases associated with angler's answers and just relies on their true behavior.

Other fishing site choice models have used multinomial-logit choice models to force angler substitutions into a defined set of substitute fishing sites (Hunt 2005). This method does not account for variation among anglers in what they perceive as a valid set of substitute water bodies. One way to account for this is to use a generalized extreme values or generalized nested-logit model (Hunt et al. 2004), which is a more flexible model that allows for asymmetrical substitutability. These models are likely more realistic than making the assumption that all anglers are choosing fishing sites in the same manner.

The theory of recreational specialization (Bryan 1977; Ditton et al. 1992) provides a method to evaluate angler types and therefore create angler groups to use for substitution modeling. Angler typology based on fishing preferences, fishing skill, and type of fishing pursued have been beneficial in describing angler attitudes and behavior (e.g., Connelly et al. 2001; Salz and Loomis 2005). The use of angler groups derived from typology and demographics allows for a more accurate assessment of angler substitution practices.

There is an abundance of studies and literature about spatial substitution of fishing effort among both species and water bodies (e.g., Jakus et al. 1997; Sutton and Ditton 2005; Hyun and Ditton 2006; Hunt et al. 2007; Beville and Kerr 2009). However, these studies are all based on a "snapshot" view of angler substitution and behavior. These snapshot views are usually based on aggregated angler substitution responses across an entire year or fishing season.

Angler behavior likely changes throughout the year (sometimes on a day-to-day basis) and an understanding of these dynamics is necessary to understand the long-term effects of management actions such as reservoir closures. The only study using a spatio-temporal model to describe angler behavior and participation was a weekly-substitution approach employed to study the economic valuation of salmon fishing at multiple sites in southeastern Alaska (Carson et al. 2009).

Given the social-ecological nature of angler movement and choice of reservoir, a more appropriate modeling choice may be in the form of network analysis (Wasserman and Faust 1994). Traditional network analysis, derived from graph theory, has focused on the connections and relationships between actors, typically people, within a group; thus, has been termed social network analysis and has been used since the 1930s (Scott 1988). Network theory may have started in sociology, but has been used in many disciplines ranging from friendships derived from mobile-phone records (Eagle et al. 2009), disease-transmission patterns (Christley et al. 2005), brain synapses (Rubinov and Sporns 2010), ecological food-webs (Krause et al. 2003), plant-pollinator communities (Bosch et al. 2009), and many more. This diversity in application reveals the robustness of this network analysis as a tool to examine the structure of complex systems. Resilience of social-ecological systems has been proposed as one particular metric that may be particularly suited to studying with network analysis (Janssen et al. 2006).

One of the earliest works in network analysis regarded how anglers interacted in relation to the villages that they belonged (Barnes 1954). This type of network, termed a bipartite network, contains two types of nodes, one for each type of actor. In the analysis of a bipartite network, the connections between each type of actors are modeled. In the case of the regional fishery, the water-bodies represent one set of nodes and anglers represent another set of nodes that are used to connect water-bodies together. A one-mode projection, or a projection of just the reservoirs, can be made in which the number of anglers connecting any two reservoirs represents the edge between those reservoirs. This bipartite network can be used to gain important, network-level information on the regional fishery that is not available with other modeling techniques. Although this technique is static (i.e., no explicit temporal modeling), insights can be drawn from examining changes in network structure after virtually removing nodes and reassessing network attributes (Callaway et al. 2000). Neural network models, a similar tool to social network models, have similar predictive power to those of choice models like the discrete choice models historically used to model reservoir choice (Hensher and Ton 2000).

These models of angler substitution and movement among regional fisheries should serve as a first step in designing further models to examine effects of angler movements on the fish communities themselves. For instance, the base network built using a network theory approach could then be used to model fishing effort changes when a reservoir is closed for renovation. These changes in fishing effort, given angler substitution patterns, would allow for modeling of catch and harvest at substitute water-bodies.

Goals

My research has two primary goals: 1) understand spatial and temporal patterns in angler participation and 2) understand angler behavior in response to regulation changes among water bodies.

Objectives

1) Document current angler participation in water bodies of the Salt Valley watershed in southeastern Nebraska.
2) Describe differences in participation levels among angler groups (both demographic and specialization) in the Salt Valley watershed.
3) Develop spatio-temporal models to describe spatial (water-bodies) and temporal (monthly) patterns in angler participation within the Salt Valley watershed.
4) Document water-body substitution groups within the Salt Valley watershed and describe differences in substitution groups among anglers.

Hypotheses

Objective 1

$H_{o1\text{-}1}$: Angling effort is constant across all water bodies within the Salt Valley watershed.

$H_{A1\text{-}1a}$: Angling effort increases linearly with water body size.

$H_{A1\text{-}1b}$: Angling effort increases exponentially with water body size.

$H_{A1\text{-}1c}$: Angling effort within predicted water body substitution groups is constant.

$H_{A1\text{-}1d}$: Angling effort decreases with linear distance from population center (i.e., Lincoln, NE).

Objective 2

$H_{o2\text{-}1}$: Angling effort is constant across all angler groups within the Salt Valley watershed.

$H_{A2\text{-}1a}$: Angling effort increases with angler age within the Salt Valley watershed.

$H_{A2\text{-}1b}$: Angling effort is greater for males than females within the Salt Valley watershed.

$H_{A2\text{-}1c}$: Angling effort is greater for more experienced anglers within the Salt Valley watershed.

Objective 3

$H_{o3\text{-}1}$: Anglers select substitute water bodies at random when access to preferred water body is prevented.

$H_{A3\text{-}1a}$: Anglers select substitute water bodies based on public information on fish community, regulations, and boating access (i.e., information available to the public can be used to predict angler substitute sites).

$H_{A3\text{-}1b}$: Anglers select substitute water bodies based on information gained from other anglers (i.e., word-of-mouth information transfer about quality of fishing).

$H_{A3\text{-}1c}$: Anglers select substitute water bodies based on tradition and past fishing experiences (i.e., angler substitute sites are chosen on an individual level and cannot be predicted using available information).

$H_{A3\text{-}1d}$: Anglers do not select substitute water bodies and participate in non-angling recreational activity when access to preferred water body is prevented.

$H_{A3\text{-}1e}$: Anglers do not select substitute water bodies and participate in non-recreational activity when access to preferred water body is prevented.

Objective 4

$H_{o4\text{-}1}$: All anglers exhibit the same pattern of substitute water-bodies when access to preferred water body is prevented.

$H_{A4\text{-}1a}$: Anglers pattern of substitute water-bodies varies with angler experience (i.e., years fished, days fished in prior year, etc.).

$H_{A4\text{-}1b}$: Anglers pattern of substitute water-bodies varies with location of residence (i.e., urban vs. rural anglers; e.g., Schramm and Dennis 1993).

$H_{A4\text{-}1c}$: Anglers pattern of substitute water-bodies varies with fishing goals (i.e., species-targeted fishing vs. "anything" fishing).

Study Area

Salt Valley Watershed—The Salt Valley watershed is located in the southeastern portion of Nebraska (Figure 1-1). Salt Creek drains this watershed in a southeast to northwest direction and empties into the Platte River near Ashland, Nebraska. Portions of this watershed are highly developed (i.e., Lincoln, Nebraska) and other portions remain rural. The rural areas are primarily row-crop agriculture and pastureland.

Bluestem Lake—Bluestem Lake is an 132-ha flood-control reservoir located 4 km west of Sprague, Nebraska. The fish community consists of bluegill *Lepomis macrochirus,* largemouth bass *Micropterus salmoides*, walleye *Sander vitreus*, crappie *Pomoxis annularis* and *P. nigromaculatus,* flathead catfish *Pylodictis olivaris,* channel catfish *Ictalurus punctatus,* and common carp *Cyprinus carpio carpio*. All species are managed with statewide regulations.

Bowling Lake—Bowling Lake is a 4.8-ha reservoir located in Lincoln, Nebraska. Bowling Lake is owned by the city of Lincoln and was renovated in 2007 and restocked. The fish community consists of bluegill, largemouth bass, and channel catfish. Bowling is also stocked with rainbow trout *Oncorhynchus mykiss* every winter for increased angler opportunities. Largemouth bass are managed as a catch-and-release fishery, channel catfish are managed with a daily bag limit of three fish and panfish are collectively managed with a daily bag limit of 10 fish. Bowling Lake was not included in April-May

2009 sampling because it was dry because of problems with the water pump. Bowling Lake is closed to all activity from 11 p.m. to 5 a.m. daily.

Branched Oak Lake—Branched Oak Lake is a 728-ha flood-control reservoir located 0.8 km west and 6.4 km north of Malcolm, Nebraska. The fish community consists of bluegill, largemouth bass, walleye, crappie, flathead catfish, channel catfish, blue catfish *Ictalurus furcatus*, common carp, hybrid striped bass *Morone chrysops x saxatilis*, and white perch *Morone americana*. Most species are managed under statewide regulations. Walleye are managed with a one fish over 558-mm restriction, crappie are managed with a minimum length limit of 254 mm, and hybrid striped bass and flathead catfish are managed as a catch-and-release trophy fishery.

Conestoga Lake—Conestoga Lake is a 93-ha flood-control reservoir located 2.4 km north of Denton, Nebraska. The fish community consists of bluegill, largemouth bass, walleye, crappie, flathead catfish, channel catfish, common carp, hybrid striped bass, and freshwater drum *Aplodinotus grunniens*. All species are managed with statewide regulations.

Cottontail Lake—Cottontail Lake is an 11.7-ha flood-control reservoir located 0.8 km north of Martell, Nebraska. Cottontail Lake is owned by the Lower Platte South Natural Resources District (LPSNRD) and was renovated in 2006 and restocked. The fish community consists of bluegill, largemouth bass, and channel catfish. Largemouth bass are managed with a minimum length limit of 533 mm, channel catfish are managed with a daily bag limit of three fish, and panfish are collectively managed with a daily bag limit of 10 fish.

East/West Twin Lake—East and West Twin Lake combined is a 109-ha flood-control reservoir located 4 km north and 0.8 km west of Pleasant Dale, Nebraska. The fish community consists of bluegill, largemouth bass, walleye, muskellunge *Esox masquinongy*, crappie, channel catfish, bullhead *Ameiurus sp.*, and common carp. All species are managed with statewide regulations. West Twin Lake was not assessed in this study due to difficulty in access.

Holmes Lake—Holmes Lake is a 40-ha flood-control reservoir located in Lincoln, Nebraska. Holmes is owned by the city of Lincoln and was renovated in 2004 and restocked. The fish community consists of bluegill, largemouth bass, walleye, and channel catfish. The south basin of Holmes Lake is also stocked with rainbow trout every winter for increased angler opportunities. Largemouth bass are managed as a catch-and-release fishery, channel catfish are managed with a daily bag limit of three fish, panfish are collectively managed with a daily bag limit of 10 fish, and there is a no live bait regulation.   Holmes Lake is closed to all activity from 11 p.m. to 5 a.m. daily.

Killdeer Lake—Killdeer Lake is an 8-ha flood-control reservoir located 4 km north of Martell, Nebraska. The fish community consists of bluegill, largemouth bass, crappie, channel catfish, and bullhead. All species are managed with statewide regulations.

Meadowlark Lake—Meadowlark Lake is a 22-ha flood-control reservoir located 9 km west and 1.6 km north of Agnew, Nebraska. Meadowlark Lake is owned by the LPSNRD and was renovated in 2007 and restocked. The fish community consists of bluegill, largemouth bass, crappie, and channel catfish. Largemouth bass are managed with a minimum length limit of 533 mm, channel catfish are managed with a daily bag limit of three fish, panfish are collectively managed with a daily bag limit of 10 fish, and there is a no live bait regulation.

Merganser Lake—Merganser Lake is 17-ha flood-control reservoir located 1.2 km north and 1.6 km east of Kramer, Nebraska. Merganser Lake is owned by the LPSNRD. The fish community consists of bluegill, largemouth bass, channel catfish, and bullhead. Largemouth bass are managed with a minimum length limit of 533 mm and all other species are managed with statewide regulations.

Olive Creek Lake—Olive Creek Lake is a 71-ha flood-control reservoir located 3.2 km east and 1.6 km south of Kramer, Nebraska. The fish community consists of bluegill, largemouth bass, and channel catfish. Largemouth bass are managed with a 533-mm minimum length limit, sunfish are collectively managed with minimum length limit of 203 mm, and there is a no live bait regulation.

Pawnee Lake—Pawnee Lake is a 300-ha flood-control reservoir located 3.2 km north and 2.4 km west of Emerald, Nebraska. The fish community consists of bluegill, largemouth bass, sauger *Sander canadensis*, walleye, white bass *Morone chrysops*, crappie, flathead catfish, channel catfish, common carp, freshwater drum, and white perch. Panfish are collectively managed with a daily bag limit of 10 fish and all other species are managed with statewide regulations.

Red Cedar Lake—Red Cedar Lake is a 20-ha reservoir flood-control reservoir located 9 km north and 3.2 km west of Valparaiso, Nebraska. Red Cedar Lake is owned by the LPSNRD. The fish community consists of bluegill, largemouth bass, crappie, flathead catfish, and channel catfish. All species are managed with statewide regulations.

Stagecoach Lake—Stagecoach Lake is a 79-ha flood-control reservoir located 2.4 km south and 0.8 km west of Hickman, Nebraska. The fish community consists of bluegill, largemouth bass, walleye, crappie, channel catfish, common carp, and hybrid striped bass. Largemouth bass are managed with a minimum length limit of 533 mm and hybrid striped bass are managed with a daily bag limit of three fish and only one fish over 457 mm is allowed. All other species are managed with statewide regulations.

Timber Point Lake—Timber Point Lake is an 11-ha flood-control reservoir located 1.6 km south and 3.2 km east of Brainard, Nebraska. Timber Point Lake is owned by the LPSNRD and was renovated in 2005 and restocked. The fish community consists of bluegill, largemouth bass, muskellunge, crappie, and channel catfish. Largemouth bass are managed with a minimum length limit of 533 mm and all other species are managed with statewide regulations.

Wagon Train Lake—Wagon Train Lake is an 127-ha flood-control reservoir located 3.2 km east of Hickman, Nebraska. The fish community consists of bluegill, redear sunfish *Lepomis microlophus,* largemouth bass, walleye, muskellunge, and channel catfish. Largemouth bass are managed with a minimum length limit of 533 mm and muskellunge are managed with a minimum length limit of 1,016 mm. All other species are managed with statewide regulations.

Wild Plum Lake—Wild Plum Lake is a 6-ha flood-control reservoir located 2.4 km north and 0.8 km west of Kramer, Nebraska. Wild Plum Lake is owned by the LPSNRD. The fish community consists of bluegill, largemouth bass, and channel catfish. All species are managed with statewide regulations.

Wildwood Lake—Wildwood Lake is a 42-ha flood-control reservoir located 1.6 km west and 2.4 km north of Agnew, Nebraska. Wildwood Lake is owned by the LPSNRD and was renovated in 2003 and restocked. The fish community consists of bluegill, largemouth bass, walleye, and channel catfish. Largemouth bass and channel catfish are managed as a total catch-and-release fishery and panfish are collectively managed with a 203-mm minimum length limit. All other species are managed with statewide regulations.

Yankee Hill—Yankee Hill Lake is an 84-ha flood-control reservoir located 4 km east and 1.6 km south of Denton, Nebraska. Yankee Hill Lake was renovated in 2007 and restocked. The fish community consists of bluegill, largemouth bass, walleye, and channel catfish. Largemouth bass are managed with a 533-mm minimum length limit, panfish are collectively managed with a daily bag limit of eight fish, and there is a no live bait regulation. All other species are managed with statewide regulations.

Creel Methods

Sampling Frame—The sampling frame consisted of 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. The sampling frame included three eight-hour shifts (00:00-08:00 [early], 08:00-16:00 [mid], and 16:00-24:00 [late]) per day.

The sampling frame included 19 reservoirs (listed above; Figure 1-1) in the Salt Valley watershed. These 19 reservoirs were grouped based on surface area and fish community into five similar groups (Table 1-1). From each group, two reservoirs were selected randomly to sample each year (Table 1-2) with the exception of Branched Oak Lake, which was sampled each year.

Sample selection—Creel survey days and times were chosen following a stratified multi-stage probability sampling regime (Malvestuto 1996). Each group of lakes received the same sampling effort each month consisting of twelve samples. These samples were split evenly into six categories (weekday-early, weekday-mid, weekday-late, weekend-early, weekend-mid, and weekend-late). Weekday sample days were selected from all non-holiday Monday-Friday days within each month and weekend sample days were selected from all Saturday-Sunday days plus all federal holidays within each month. All available sampling periods within each month were assigned a random date from within the available sampling frame.

Each creel technician was assigned to two samples from each sampling category listed above (e.g., weekend-early) for a total of twelve samples per month. Two creel technicians were assigned to 2 reservoirs and randomly assigned creel periods on those reservoirs. Deviations from randomly assigned creel periods (i.e., technicians switched shifts due to vacations or sickness and maintained random schedule of samples on reservoirs) were allowed because of logistical constraints and were recorded as a non-random creel.

Two pressure-count times per water body were randomly chosen within the sampling period. Creel technicians moved between reservoirs within each pair in order to attain these pressure counts at the randomly assigned times. Angler interviews were conducted when creel technicians were not conducting pressure counts and only conducted at the end of the angler's fishing trip.

Pressure counts were also conducted at each of the 19 reservoirs regardless of whether or not they are included in that year's full creel surveys. These water bodies were sampled twice per month during each of the six divisions discussed above for a total of 12 samples per month. During each sample period, a bus-route method was used to conduct pressure counts at each reservoir (Figure 1-2). To randomize bus-route samples, a random start direction, start reservoir, and start time (within the first 2 hours of the sampling period) were selected for each sample. Hedgefield Lake was added to the pressure-count route in 2011 following re-opening after renovation, but was not included in full creel surveys.

Inclement weather (i.e., blizzard-like conditions or icy roads) sometimes prevented sampling from occurring during winter. Data missed during inclement weather during the low-use season (e.g., winter in Nebraska) typically account for a small proportion of the total data collected (Spiller et al., 1988). Therefore, during times of inclement weather, pressure counts were assumed to be zero and were not rescheduled.

On-site Creel Survey—On-site creel surveys consisted of a roving count to estimate effort with access-point interviews to estimate harvest. Roving counts were conducted from vehicles or high point observations. Pressure counts (effort) included angling effort and other water-based recreational effort (e.g., water skiing, pleasure boating, etc.; Figure 1-3).

Creel technicians intercepted anglers at access points upon completion of their fishing trip and conducted interviews to gather information on fishing effort, catch and harvest. Interviews contained questions on method of angling (boat, bank or ice), type of fishing license, angling behavior, quality of fishing experience, zip code and patterns of angling participation (Figure 1-4). Further questions addressed angler turnover rate (i.e., whether an angler has been interviewed within the last month or last 6 months). Species and angler-reported length of released fish and species and the length and weight of all harvested fish were recorded at the end of the interview (Figure 1-5).

Return-Mail Survey—Anglers that participated in the on-site creel surveys were asked if they were willing to participate in an additional return-mail survey during 2010-2012. This survey was completed at home and returned in a postage-paid envelope (e.g., Ditton and Hunt 2001). Concerns over recall bias with traditional angler mail surveys (e.g., Osborn and Matlock 2010) were minimal given the short time expected for survey return.

This return-mail survey included detailed questions on angler demographics, angler behavior and motivations for picking substitute sites (Figures 1-6 and 1-7). Questions examining angling success and enjoyment of the potential substitute sites within the Salt Valley watershed used a five-point Likert-type scale (Likert 1932; Clason and Dormody 1994). The return-mail survey also included questions about bait preferences (i.e., live vs. dead, species preference, etc.), boat usage, preferences on fishing private or public water bodies, and fish identification skills (Figures 1-6 and 1-7).

Pre-sampling Substitute Site Classification—Water bodies can be classified into distinct groups based on watershed factors, fish-community data, and water-body size using statistical tests (Schupp 1992; Cross and McInerny 1995). Pre-sampling substitute site groups were created using data available to the general angling public from the NGPC website and the 2009 NGPC Fishing Guide.

A subjective, lake classification was conducted using only water-body size and presence of fish species. This classification was done subjectively by grouping waterbodies that had similar fish species composition and water body size. Although analyzed subjectively, fish species present were consistent across water body groups indicating that this simple classification also provided a clear grouping of reservoirs (Table 1-1).

Data Analysis—Total angling effort was calculated for all 20 (original 19 plus Hedgefield Lake added in 2011 and 2012) water bodies using a daily estimator by strata sampled with traditional creel analysis techniques from bus-route pressure count surveys (Pollock 1994). Effort and harvest were calculated by weekend and weekday and then combined to determine monthly estimates for each water body. Angler catch and harvest from the completed-trip interviews were calculated using the ratio-of-means estimator (i.e., mean catch from interviews divided by mean effort; Pollock et al. 1994, Pollock et al. 1997). Annual estimates are reported in Appendices A through D. Estimates were calculated by month to decrease bias (Rasmussen et al. 1998). Estimates of effort, catch, and harvest are reported by reservoir and month in Appendices E through H.

Dissertation Overview

This dissertation focuses on spatial and temporal participation of anglers in the Salt Valley regional fishery of southeastern Nebraska. In this dissertation, I use three cutting-edge ideas to determine spatial and temporal participation and distribution of anglers and explore potential management implications of regulation changes in the regional fishery. I begin by addressing the use of an online fishing forum to predict fishing effort both within a reservoir temporally and among reservoirs within a regional fishery (Chapter 2). Next I examine the spatial influence of individual reservoirs within the regional fishery by adopting kernel-density methods to examine the different spatial distribution of angler home origins for reservoirs (Chapter 3). In the final research chapter, I use network analysis to understand the interactions among reservoirs, and anglers, in the regional fishery and draw conclusions on the resilience of the Salt Valley regional fishery to disturbances (Chapter 4). Finally, I conclude with implications and recommendations for fisheries management and at a broader scale, natural resources management.

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Table 1-1. Delineation of sampling groups for on-site creel survey by surface area (hectares) and fish type present. An "X" indicates fish species present in that reservoir. Fish types listed are bluegill (BLG), largemouth bass (LMB), walleye (WAE), crappie (CRP), flathead catfish (FHC), channel catfish (CCF), hybrid striped bass (HSB).

Group	Reservoir	Surface area	BLG	LMB	WAE	CRP	FHC	CCF	HSB
1	Bowling	4.9	X	X				X	
	Wild Plum	6.5	X	X				X	
	Killdeer	8.1	X	X		X		X	
	Timber Point	11.3	X	X		X		X	
	Cottontail	11.7	X	X				X	
	Merganser	16.6	X	X				X	
	Red Cedar	20.2	X	X		X	X	X	
	Meadowlark	22.3	X	X		X		X	
2	Holmes	40.5	X	X	X			X	
	Wildwood	41.7	X	X	X			X	
	Olive Creek	70.8	X	X				X	
	Stagecoach	78.9	X	X	X	X		X	X
3	Yankee Hill	84.2	X	X	X			X	
	Conestoga	93.1	X	X	X	X	X	X	X
	East/West Twin	109.3	X	X	X	X		X	
	Wagon Train	127.5	X	X	X			X	
	Bluestem	131.9	X	X	X	X	X	X	
	Pawnee	299.5	X	X	X	X	X	X	
4	Branched Oak	728.4	X	X	X	X	X	X	X

Table 1-2. Salt Valley reservoir angler surveys completed during 2009 – 2012. An "X" indicates that water body was surveyed January through December of that year, except for 2009 when surveying was conducted April through December.

Group	Reservoir	2009	2010	2011	2012
1	Bowling				
	Wild Plum			X	
	Killdeer				X
	Timber Point	X			
	Cottontail		X		
	Merganser		X	X	
	Red Cedar	X			
	Meadowlark				X
2	Holmes	X		X	
	Wildwood		X	X	X
	Olive Creek				X
	Stagecoach	X	X		
3	Yankee Hill			X	
	Conestoga	X			
	East Twin				
	Wagon Train			X	X
	Bluestem		X		X
	Pawnee	X	X		
4	Branched Oak	X	X	X	X

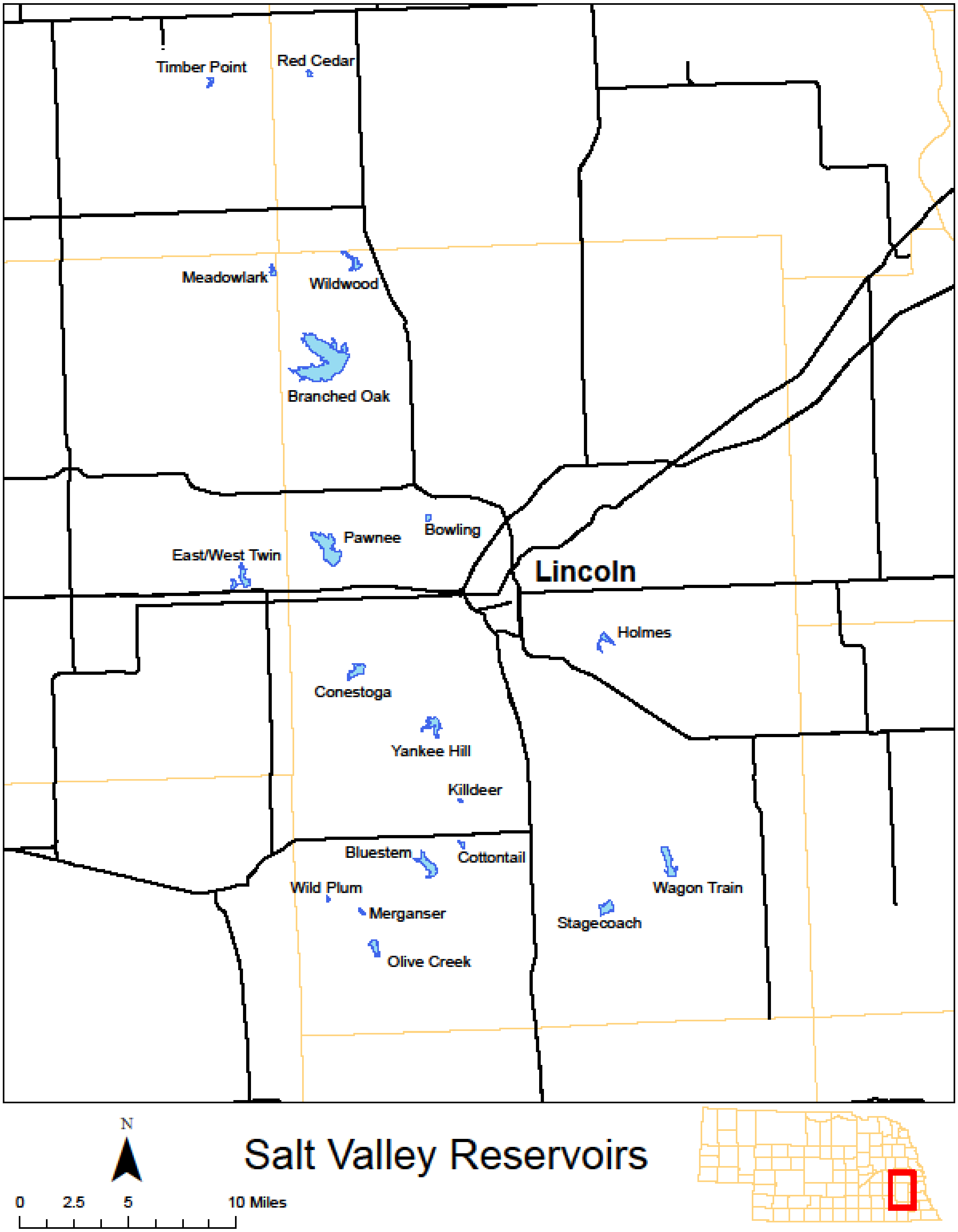


Figure 1-1. Map of 19 study reservoirs in the Salt Valley watershed of southeastern Nebraska.

Figure 1-2. Map of bus-route creel survey for study reservoirs in the Salt Valley watershed of southeastern Nebraska.

Salt Valley Creel Day Information

Date _________ Reservoir ________________ Creel Tech _______ Randomly assigned? Y or N

Pressure Counts

Time	Reservoir	# bank anglers	# bank non-anglers	# boats on water	# of boat anglers	# of non-anglers on boat	Water temp (C)	Effect of weather (circle one)	Ice conditions (circle one)	Vegetation coverage? (circle one)	Comments
								Positive None Negative	Safe Marginal Unsafe None	None Scarce Abundant Excessive	
								Positive None Negative	Safe Marginal Unsafe None	None Scarce Abundant Excessive	
								Positive None Negative	Safe Marginal Unsafe None	None Scarce Abundant Excessive	
								Positive None Negative	Safe Marginal Unsafe None	None Scarce Abundant Excessive	

Figure 1-3. Datasheet for conducting pressure counts at reservoirs during a creel shift.

Salt Valley Angler Interview

Date _________

Reservoir ________________ Section _____

Creel Tech _______

Random ? YES OR NO

Angler Interview Interview # ______

How many anglers in party? ________

What type of angler? BOAT BANK ICE

ICE ONLY # lines out _______

Ice shack Y N

What time did you begin fishing? _______ Time of interview (end fishing)? ________

Angling effort (time elapsed) ________

What type of fishing license do you have? __________ (annual, resident, etc.)

What was the primary species that you targeted today? ________

Did you catch most of your primary species on bait or artificial lures? BAIT or LURE

If bait, what type? __________ What type of hook? _________

If lure, what type did you catch most target fish on? ___________

What depth of water did you fish to capture most of your targeted species? ______

Did you use electronics while fishing today? Y N If so, what type? __________________

How satisfied are you with your fishing experiences at this reservoir? VS S N D VD

What is your ZIP code? __ __ __ __ __

Have you been interviewed by a creel technician within....

Last month? YES or NO

Last 6 months? YES or NO

Have you participated in this return-mail survey in the past 6 months? YES or NO

What was the last water body on which you used your boat? _____________

When was this? ____________

Reservoirs are often closed for many reasons (including rehabilitation projects, blue-green algae blooms, road closures, etc.). If this reservoir would have been closed today, would you have fished elsewhere today? YES or NO

If yes, where would you have fished today? __________

If no, what would have you done today? _____________

Figure 1-4. Datasheet (front side) for conducting interviews in the Salt Valley angler survey project.

Harvest Information - Record length (mm) and weight (g) on first five fish, lengths on next five, and then count the remaining fish.

Species	L - 1	W - 1	L - 2	W - 2	L - 3	W -3	L - 4	W - 4	L - 5	W -5	L - 6	L - 7	L - 8	L - 9	L - 10	Count

Catch and Release Information – Record all reported lengths of caught and released fish.

Species	<5 (<125)	5 (125)	6 (150)	7 (175)	8 (200)	9 (230)	10 (255)	11 (280)	12 (305)	13 (330)	14 (355)	15 (380)	16 (405)	17 (430)	18 (455)	19 (480)	20 (510)	21 (530)	22 (560)	23 (585)	24 (610)	25 (635)	26 (660)	27 (685)	28 (710)	29-32 (735-815)	33-36 (840-915)	>36 (>915)

Figure 1-5. Datasheet (back side) for conducting interviews and recording catch and harvest in the Salt Valley angler survey project.

12. Where do you obtain your **live** bait? *Select all that apply.*

Live fish (minnows, etc)
- Bait shop
- Where you are fishing
- Another lake/stream
- Breed at home
- Other (*Specify*) ____________

Other live bait (worms, etc.)
- Bait shop
- Where you are fishing
- Another lake/stream
- Collected at home
- Breed at home
- Other (*Specify*) ____________

13. What do you believe is the **greatest** threat over the next 5 years to your fishing enjoyment in the Salt Valley reservoirs? *Please limit answer to ONE threat.*

____

____

Personal Background Information

Your answers are strictly confidential.

14. What is your home **ZIP** code? _ _ _ _ _

15. What is **your** gender? Male Female

16. What year were **you** born? _ _ _ _

17. What is **your** race? *Select all that apply.*

- White
- Spanish, Hispanic, or Latino
- American Indian
- Black or African American
- Chinese
- Vietnamese
- Japanese
- Korean
- Other (specify) ____________________

19. What is **your** current occupation? *Select all that apply.*

- Self-employed
- Retired
- Employed Full-time
- Student
- Employed Part-time
- Homemaker
- Not Employed

20. What is the highest level you completed in school? *Select one.*

- Completed grade school
- Some high school
- Completed high school
- Some vocational school
- Some college
- Completed 2-year college
- Completed 4-year college
- Some graduate school
- Completed graduate school

21. What is your current **household** income? *Select one:*

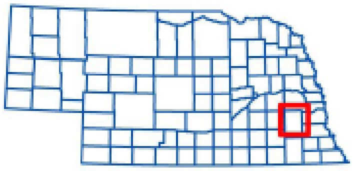
- Under $20,000
- $20,000 - $30,000
- $30,001 - $50,000
- $50,001 - $70,000
- $70,001 - $100,000
- $100,001 - $150,000
- $150,001 – $200,000
- $200,001 - $250,000
- Over $250,001

***THANK YOU** for your time and participation!*

Please **RETURN** to:
Angler Survey
School of Natural Resources
University of Nebraska-Lincoln
118 Hardin Hall
Lincoln, NE 68583-0984

If you have suggestions or comments concerning the Salt Valley reservoirs, please share them here or on an attached sheet.

2010 Angler Survey



Salt Valley Project

Dear Angler,

I am conducting a survey to help the Nebraska Game and Parks Commission learn more about recreational use of reservoirs within the Salt Valley watershed.

Your participation is voluntary and you may decline to respond to any or all questions. Your responses will be held confidential. This survey should take approximately 10 minutes to complete.

Please direct your questions to Dr. Kevin Pope (402-472-7028). Project information and updates are available at http://snr.unl.edu/necoopunit/creel.html.

I appreciate your participation with this survey.

Sincerely,

Luke

Figure 1-6. Example of return-mail survey (front) for the Salt Valley angler survey project.

Instructions: Fill in blanks or shade in circles for each question.

1. How long have **you** had a fishing license?
   ________ YEARS

2. How would **you** rate your fishing skills? *Select one on a scale from amateur (1) to very skilled (5).*

   Amateur — *Average* — *Very skilled*
   ① ② ③ ④ ⑤

3. How many days did **you** fish within the last 12 months?
   In Nebraska ________ DAYS
   Outside Nebraska ________ DAYS

4. Which type of water do you fish more often?
   Select one: ① Public (NGPC & NRD reservoirs, etc.)
   ② Private (farm ponds, etc.)

5. *Please answer both questions for each reservoir in the Salt Valley watershed.*

Reservoir	How many **days** did you fish this reservoir in the last 12 months?	How **likely** are you to fish this reservoir in the next 12 months? *Not likely* (1)	(2)	(3)	(4)	*Likely* (5)
Bowling	________	①	②	③	④	⑤
Wild Plum	________	①	②	③	④	⑤
Killdeer	________	①	②	③	④	⑤
Timber Point	________	①	②	③	④	⑤
Cottontail	________	①	②	③	④	⑤
Merganser	________	①	②	③	④	⑤
Red Cedar	________	①	②	③	④	⑤
Meadowlark	________	①	②	③	④	⑤
Holmes	________	①	②	③	④	⑤
Wildwood	________	①	②	③	④	⑤
Olive Creek	________	①	②	③	④	⑤
Stagecoach	________	①	②	③	④	⑤
Yankee Hill	________	①	②	③	④	⑤
Conestoga	________	①	②	③	④	⑤
East/West Twin	________	①	②	③	④	⑤
Wagon Train	________	①	②	③	④	⑤
Bluestem	________	①	②	③	④	⑤
Pawnee	________	①	②	③	④	⑤
Branched Oak	________	①	②	③	④	⑤

6. Where was your last fishing trip **outside** the Salt Valley watershed?
   State ______ Fishing location ________________

7. How satisfied are you with your fishing experiences at Cottontail Reservoir? *Select one on a scale from very dissatisfied (1) to very satisfied (5).*

   Very dissatisfied — *Very satisfied*
   ① ② ③ ④ ⑤

8. How important are each of the following factors to you when selecting a reservoir to fish in the Salt Valley watershed? *Select one on a scale from not important (1) to very important (5).*

Not Important (1)	(2)	(3)	(4)	*Very Important* (5)	Factor
①	②	③	④	⑤	Type of fish present
①	②	③	④	⑤	Water quality
①	②	③	④	⑤	Camping facilities
①	②	③	④	⑤	Boating access
①	②	③	④	⑤	Length limits in effect
①	②	③	④	⑤	Bag limits in effect
①	②	③	④	⑤	Catch fish to eat
①	②	③	④	⑤	Catch a trophy fish
①	②	③	④	⑤	Solitude (not many people)
①	②	③	④	⑤	Previous catch of fish
①	②	③	④	⑤	Previous experience
①	②	③	④	⑤	Fishing reports – internet, tv, radio
①	②	③	④	⑤	Fishing reports – word of mouth
①	②	③	④	⑤	Marina facilities
①	②	③	④	⑤	Beauty of area
①	②	③	④	⑤	Other (*Specify*) ____________________

9. What type of fish identification guide do you carry with you while fishing? *Select all that apply:*
   ① Common Fishes of Nebraska
   ② Nebraska Fishing Guide
   ③ National Audubon Society Field Guide to Fishes
   ④ Other (*Specify*) ________________
   ⑤ I *NEVER* carry a fish identification guide

10. How confident are you in your ability to correctly identify the following fish? *Select one on a scale from not confident (1) to extremely confident (5).*

Not	*A little*	*Somewhat*	*Very*	*Extremely*	Fish
①	②	③	④	⑤	Walleye
①	②	③	④	⑤	Sauger
①	②	③	④	⑤	White crappie
①	②	③	④	⑤	Black crappie
①	②	③	④	⑤	Channel catfish
①	②	③	④	⑤	Flathead catfish
①	②	③	④	⑤	Blue catfish
①	②	③	④	⑤	White bass
①	②	③	④	⑤	Hybrid striped bass (wiper)
①	②	③	④	⑤	White perch
①	②	③	④	⑤	Bluegill
①	②	③	④	⑤	Redear sunfish
①	②	③	④	⑤	Green sunfish

11. How often did you use each type of bait within the last 12 months?

	Bait	*None*	*Some*	*Half*	*Most*	*Always*
	Artificial lures	①	②	③	④	⑤
Live fish	Minnows	①	②	③	④	⑤
Live fish	Goldfish	①	②	③	④	⑤
Live fish	Bluegill	①	②	③	④	⑤
Live fish	White Perch	①	②	③	④	⑤
Live fish	Other fish	①	②	③	④	⑤
	Dead fish/cutbait	①	②	③	④	⑤
	Crickets/grasshoppers	①	②	③	④	⑤
	Crayfish/crawdads	①	②	③	④	⑤
	Nightcrawlers	①	②	③	④	⑤
	Leeches	①	②	③	④	⑤
	Salamanders/frogs	①	②	③	④	⑤
	Waxworms	①	②	③	④	⑤
	Other (*Specify*) ____________	①	②	③	④	⑤

Survey CONTINUES on back.

Figure 1-7. Example of return-mail survey (back) for the Salt Valley angler survey project.

Chapter 2: Using angler posted information to an online social network to assess fishing effort

Introduction

Policies emphasizing ecosystem management (Christensen et al. 1996; MSFCMRA 2006) and social-ecological systems (Berkes and Folke 1998) have created the need for new tools to assess system-wide change. Fisheries management, for example, has evolved from individual water-body to watershed-scale management (Carpenter and Brock 2004; Martin and Pope 2011) creating a need (Pollock et al. 1994) to simultaneously gather information within and across interacting water-bodies. Traditional creel surveys are difficult to implement on multiple individual water-bodies within a region because they are expensive and logistically difficult to conduct (Lester et al. 2003). Furthermore, among-water body variation in amenities, fish communities, and other recreational opportunities prevents the expansion of results from a subset of single water-bodies to all water-bodies in a region.

There is a need to develop a method to assess fishing effort across multiple water-bodies that is both cost-effective and easy to implement. Possible methods to collect effort-only data on a regional, or larger, scale include mail and telephone surveys (Brown 1991; Weithman 1991), aerial surveys (Volstad et al. 2006), and bus-route count surveys (Jones and Robson 1991). Although no information on catch or harvest would be collected in these surveys, effort is correlated to the harvest of fish (Michaletz and Stanovick 2005). Mail and telephone surveys allow data to be gathered efficiently across multiple water-bodies, but these surveys are subject to recall bias (Osborn and Matlock 2010) and operate on a time-scale that is too course to pick up short-term changes in regional fishing pressure. Alternatively, the growing use of the internet by anglers has created a possible method of tracking fishing effort with minimal cost and time.

Angler-related online social networks (OSN; e.g., Nebraska Fish and Game Association, www.nefga.org) create a community feel among anglers within a region, and often lead to the development of friendships and fishing partners outside of the online world (Ridings and Gefen 2004; Tang 2010). The use of these fishing forums has grown during the past decade and patterns of internet search volume for terms such as “fishing forums” and “fishing” mimic seasonal trends observed in fishing participation (Martin et al. 2012). Anglers use these OSN as a way of relaying fishing conditions, often discussing where to go fishing and relaying stories of past catches. Posts on OSN can be read by anyone with internet access, often leading to a more complete sharing of information across the angling population than previously achieved through traditional word-of-mouth exchange.

Angler posts about water-bodies to OSN provide a unique medium to test hypotheses on the temporal and spatial distribution of fishing pressure. These reviews provide an account of user’s demand for recreational opportunities. Within the Salt Valley regional fishery in southeastern Nebraska, we examined the relationship between the number of posts to a fishing forum mentioning a reservoir and the observed fishing effort at that reservoir. We hypothesized that this forum provides a relative index of monthly effort on individual reservoirs as well as a relative index of effort across multiple reservoirs.

Methods

Study site—The Salt Valley watershed in southeastern Nebraska, USA includes 19 flood-control reservoirs that range 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*, black crappie *Pomoxis nigromaculatus* and white crappie *Pomoxis annularis*, 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 hours per hectare. Two of the 19 reservoirs are located within the city limits of Lincoln, Nebraska, a city of 250,000 people. Travel time between these 19 reservoirs has a maximum travel time of approximately 60 minutes between any two reservoirs.

Online Social Network Data—Data on posts to the online social network were gathered from the Nebraska Fish and Game Association (NEFGA) Forum (www.nefga.org). The NEFGA forum had 4,964 members and 264,214 fishing-related posts as of January 28, 2013. We searched all posts from May to September during 2009 and 2010 to the NEFGA fishing forum for all references to each of the 19 reservoirs on April 1, 2011. All references to each reservoir were summed by month to provide a monthly estimate of online activity for that reservoir.

Angler Effort Data—Data on angler effort were collected using a bus-route roving count at all 19 reservoirs during 2009 and 2010. Survey days and times were chosen following a stratified multi-stage probability-sampling regime (Malvestuto 1996). Days were stratified by day-type with two strata: weekday and weekend days (all weekend days plus federal holidays). Each day was further stratified into three, eight-hour shifts (00:00-08:00 [early], 08:00-16:00 [mid], and 16:00-24:00 [late]) per day. Two samples from each of the 6 day-type-period strata were randomly selected each month (i.e., two weekday-early, two weekend early, etc.) for a total of 12 samples per month. A random start direction, start reservoir, and start time (within the first two hours of period) was selected for each sample period. Creel clerks were instructed to complete the loop around all 19 reservoirs as quickly as possible to ensure comparable numbers of anglers across reservoirs.

Monthly estimates of effort and associated variance were calculated using equations provided by Malvestuto et al. (1978). The basic process of the extrapolations is as follows. First, fishing pressure for each survey day was calculated by multiplying the angler count by the number of hours in the survey period (i.e., 8 hours) adjusted by the probability of the daily period (i.e., 0.33). The mean daily pressure for each stratum (weekday and weekend/holiday) was then calculated for the month and these two mean values are weighted by the proportion of the day types per month and summed. This daily pressure estimate was then multiplied by the number of days per month to calculate monthly pressure.

Data Analysis— All reservoirs with less than a maximum of four posts to the online forum in a month were removed from further analyses, resulting in 13 reservoirs for analyses. Reservoirs with fewer than 4 maximum monthly posts had little variation in posts and could not meaningfully correlate with effort. Non-parametric correlation (i.e., Spearman's rank correlation) was used to analyze the association between monthly angler posts to the NEFGA forum and monthly angler effort on both individual reservoir and regional scales in R v2.15.2 (R Development Core Team 2012). Individual reservoir correlations were used to determine reservoir-specific associations between posts and effort. We assumed a significance level of 0.05 for this assessment. Non-parametric correlation was also used to determine regional-scale associations by examining the correlation between monthly posts and effort across all reservoirs.

Results

The total number of posts to the NEFGA forum for the 19 reservoirs in the Salt Valley regional fishery was 1,234 between May and September during 2009 and 2010. The mean ± SE number of posts per month about an individual reservoir ranged from 0.2 ± 0.1 to 23.0 ± 3.4 posts (Table 2-1). The two reservoirs with the greatest number of posts were Holmes Lake, the largest urban reservoir, and Branched Oak Reservoir, the largest reservoir in the region. Smaller reservoirs (surface area range 4-40 ha), excluding urban reservoirs, in the region had few posts except following events such as a large fish being caught and reported.

The total angler effort observed at the 19 reservoirs in the Salt Valley regional fishery was 810,221 hours between May and September during 2009 and 2010. The mean ± SE angler effort observed per month ranged from 258 ± 87 to 14,207 ± 2,684 hours (Table 2-1). The reservoir with the greatest angler effort was Holmes Lake, the largest urban reservoir. Small reservoirs (<40 ha, with the exception of Bowling Lake) had little angling effort.

Six reservoirs were removed from the analysis because they had less than a maximum of four posts per month and could not meaningfully be correlated to observed fishing effort. Reservoir-specific correlations between posts to the NEFGA forum and monthly fishing effort (log number of hours) were significantly positive in 5 of the 13 remaining reservoirs (Table 2-2). The other 7 reservoirs exhibited no significant relationship between angling effort and the number of posts to the NEFGA forum. Temporal trends in both number of posts and angler effort follow similar seasonal patterns with the peak number of posts coming one month prior to peak fishing effort (Figure 2-1). The association between posts and fishing effort (log number of hours) was significantly positive on a regional-scale as well ($r = 0.82$, $P<0.001$; Figure 2-2).

Discussion

The NEFGA forum is used by anglers within the Salt Valley region of Nebraska to gather and exchange information on fishing resources within the region. The close proximity of these 19 reservoirs to a population center created a unique regional fishery. Angler participation in the NEFGA forum provided an opportunity to use this online social network to predict angling effort on regional and individual reservoir scales. Anglers' posts about individual reservoirs vary from general questions about where to fish, reporting of fishing conditions, and reporting of extreme catches, either of large fish, multiple fish, or no fish. This sharing of information in an online format leads to faster and more complete sharing across the angling community than was previously available given only word-of-mouth transfer of information (Hampton and Wellman 2003).

On the individual-reservoir scale, the monthly number of posts to the NEFGA forum was positively related to the observed angler effort at five out of 13 of the reservoirs. On these reservoirs, angler posts to the online fishing forum could be used to examine trends in angler effort. The remaining reservoirs, with no significant relationship between angler effort and posts, were included in both posts seeking specific information about that individual reservoir and posts with general questions asked about multiple reservoirs. These large, broad scale questions that encompassed multiple reservoirs likely altered the effect of posts on angling effort on any one reservoir. Further, tools to efficiently classify a thread of posts as either positive or negative about a reservoir would be helpful in determining the relationship to pressure at an individual water body (e.g., Ye et al. 2009). Although not addressed in this study, further research into the effects of repeated posters, or individual people who post repeatedly about the same topic, should be analysed to determine if they play a role in determining the observed relationships.

Perhaps of more importance to managers, the number of posts to the NEFGA forum was related to the amount of angler effort on a regional scale. This provides a relative index of angler effort across the region with reservoirs receiving the most angler effort also receiving the greatest number of posts. This method provided a quick and easy way to index effort across the reservoirs in this region by searching the online social network and calculating a monthly number of posts per reservoirs. This allows managers to look across an entire regional fishery and determine where anglers are spending their effort. Furthermore, the trends observed across the region in posts closely mimicked seasonal trends observed in actual effort. This seasonal trend lends credibility to the use of this online tool for following fishing effort temporally.

This method shows a simple way to analyze social-ecological systems on multiple scales with minimal effort and expense. Participation data are often the most difficult and time-consuming type of data to collect on a social-ecological system and are often subject to interviewer bias. Relying on angler-reported data allows managers to gain some knowledge on angler behavior, and use of the water bodies they manage, and potential exists to monitor participation on larger spatial and temporal scales than currently feasible given historic approaches and budgetary constraints. Monitoring participation at larger spatial and temporal scales, regional rather than individual reservoir, is important for understanding how reservoirs interact with each other and how anglers perceive the whole set of reservoirs as a regional fishery. Additionally, other information of interest for managers could be gleaned from these forums as well. Information on what species anglers are targeting, violations observed by anglers, and anglers' general perceptions of reservoirs amenities, fish communities, and access are available within these forum posts. This information would likely require sampling at a larger spatial scale, perhaps regional, to gain a large enough sample size to be useful. The greatest potential influence on management comes from the ability to monitor, in near real-time, changes in fisheries that are not usually visible until a creel or standardized fish sampling is conducted.

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Table 2-1. Surface area (ha), mean monthly effort (angler hours ± SE) and mean number of posts to the Nebraska Fish and Game Association Fishing Forum discussing each reservoir per month for the 13 reservoirs in the Salt Valley regional fishery of Nebraska during April-September 2009 and 2010.

Reservoir	Surface Area	Mean ± SE Effort			Mean ± SE Posts		
Bowling	4.9	2133.3	±	375.3	2.8	±	0.5
Meadowlark	22.3	715.3	±	176.3	1.2	±	0.3
Holmes	40.5	14207.0	±	2684.6	23.0	±	3.4
Wildwood	41.7	4335.8	±	619.5	6.2	±	1.2
Olive Creek	70.8	3095.3	±	472.1	4.0	±	0.4
Stagecoach	78.9	5212.7	±	1050.6	9.3	±	1.5
Yankee Hill	84.2	3005.4	±	492.9	4.2	±	0.7
Conestoga	93.1	4557.9	±	663.4	3.6	±	0.5
East Twin	109.3	3082.9	±	690.2	1.8	±	0.5
Wagon Train	127.5	8196.4	±	1204.9	13.3	±	1.9
Bluestem	131.9	1221.4	±	246.2	1.8	±	0.4
Pawnee	299.5	7340.6	±	1021.0	11.8	±	1.7
Branched Oak	728.4	7992.1	±	1540.7	16.4	±	1.1

Table 2-2. Results of individual lake correlations between monthly estimated effort from bus-route pressure count and posts on the online social forum at reservoirs of the Salt Valley regional fishery during April-September 2009 and 2010.

Reservoir	R	*P*
Bluestem	0.48	0.11
Bowling	-0.05	0.88
Branched Oak	0.47	0.13
Conestoga	0.03	0.93
East Twin	0.08	0.79
Holmes	0.61	0.03
Meadowlark	0.59	0.04
Olive Creek	0.74	<0.01
Pawnee	0.48	0.11
Stagecoach	0.65	0.02
Wagon Train	0.44	0.15
Wildwood	0.76	<0.01
Yankee Hill	0.38	0.22

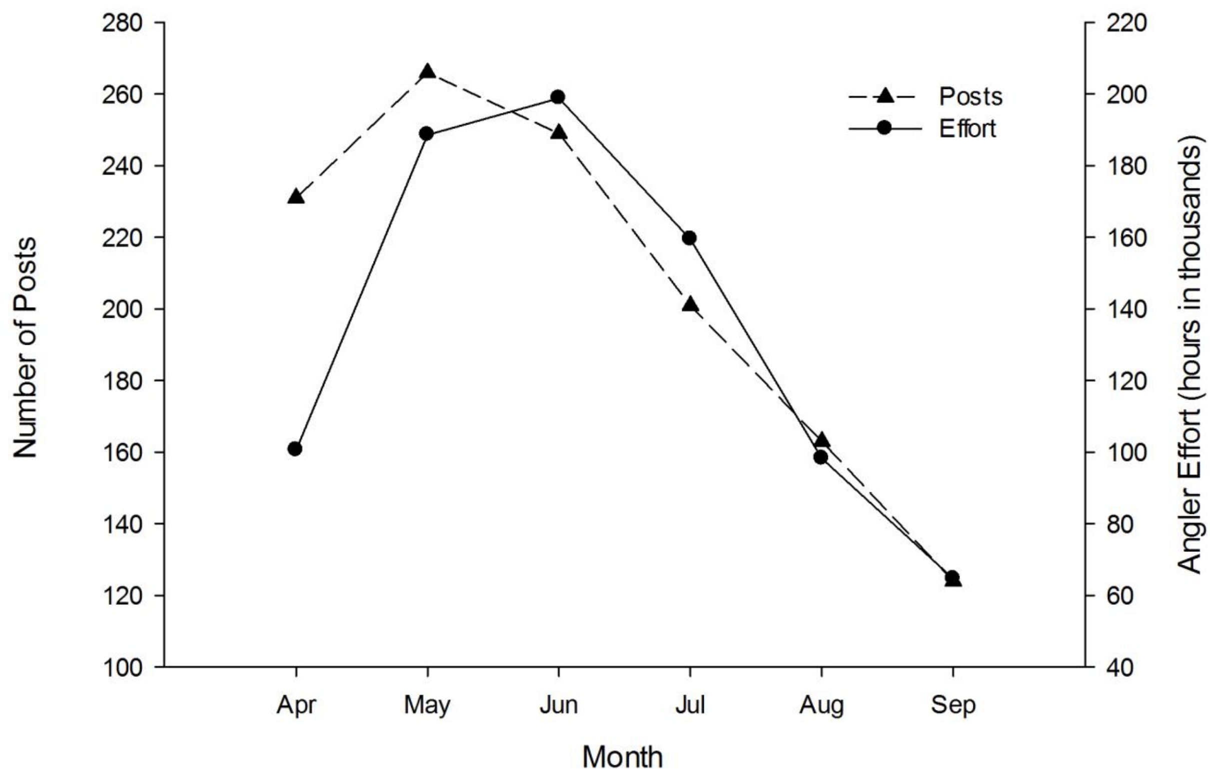

Figure 2-1. Temporal trends in total number of posts to the online social network and total angler effort (in thousands of hours) in the Salt Valley region of Nebraska April-September 2009 and 2010.

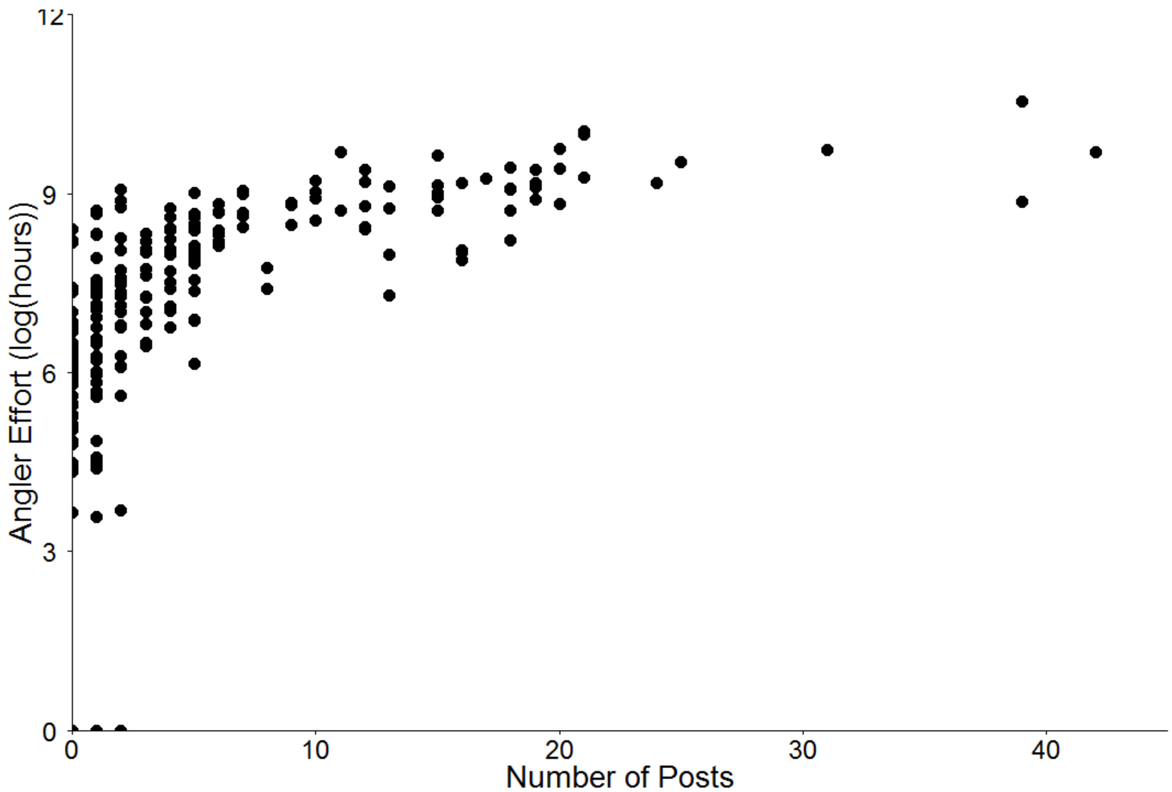

Figure 2-2. The association between number of posts on the online social network to angler effort per month (log number of hours) for the 13 reservoirs in the Salt Valley region of Nebraska during April-September 2009 and 2010 (r = 0.82, < 0.001)

Chapter 3. Area of Influence of Reservoirs within the Salt Valley Regional fishery of Nebraska

Introduction

Site-selection research is common in recreational fisheries (Jakus et al. 1997; Schramm et al. 2003; Sutton and Ditton 2005; Carlin et al. 2012; Aas and Onstad 2013; De Freitas et al. 2013). However, angler groups vary in characteristics and their site-selection behavior. For example, urban and rural anglers differ in general demographic variables as well as travel distances to participate in angling (Arlinghaus and Mehner 2004). Angler motivations, like harvest orientation, also create differences in angler behavior (Beardmore et al. 2011) that likely affect site selection.

One major component of site selection research has been travel distance, and many of the traditional means of analyzing site selection were based on a travel cost function using gravity models (e.g., Freund and Wilson 1973). 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 a cost to participate in the activity at that given location. There are three components that need to be addressed when examining how travel distance affects site selection: the availability of fishing opportunities, potential angling population, and preferences of anglers (Cole and Ward 1994).

Defining spatial demand for fishing is difficult, especially in situations where availability of sites for fishing varies temporally. There are two parts to defining the spatial demand for fishing within a given spatial area. First, anglers are only willing to travel so far on a single-day trip for fishing. Willingness-to-travel varies among anglers based on many factors, many of which affect those site-selection decisions discussed above. Furthermore, anglers traveling long distances on vacation for fishing are often willing to travel more than anglers on day trips because the cost-per-hour of fishing (or cost-per-potential-fish) per mile traveled becomes less as you stay for more days on a vacation. This could be a potential temporal confounding factor in systems where anglers are traveling long distances to fish. Second, spatial demand is determined both by anglers currently using the lake and those that are not using the lake but may use the lake in the future. Potential angler population needs to be derived using population data for the study area as well.

Angler surveys have generally collected coarse-level spatial data on angler point of origination; often collecting just angler home state, or home county and state. This coarse-level spatial data has limited spatial analysis of angler participation. Collecting data on angler point of origination to the Zone Improvement Plan (ZIP) code allows for finer-scale spatial data to be collected and analyzed, leading to new and exciting results from our angler surveys. Furthermore, the addition of population data from the U.S. Census allows us to make further assessments of fishing opportunities in relation to potential angler density. Understanding the spatial demand for angling, as well as the current spatial area of influence for fishing at different lakes, is especially important given the recent push toward angler recruitment and retention across the United States of America.

One technique that may be used to analyze angler spatial data is kernel density estimation (Worton 1989; Seaman and Powell 1996). This technique has been used in the wildlife literature for many years, but has not been adopted widely in fisheries (see

Vokoun 2003 for example of univariate kernel density home range analysis). However, kernel density estimation is not just restricted to home range analysis. Kernel density estimation has been used to determine the best placement of new hospitals to distribute customer usage (Donthu and Rust 1989), distribution of traffic accidents (Xie and Yan 2008), and distribution of crime hot spots (Wang et al. 2013).

My objective is to define the area of influence for reservoirs of the Salt Valley regional fishery in southeastern Nebraska, USA, using kernel-density estimation. I will use angler survey data conducted from in-person interviews conducted at these reservoirs. The spatial area of influence for a reservoir and potential overlap with other reservoirs (i.e., competing for anglers) is important to understand for fishery managers in terms of recruitment of anglers. Areas of the region that are not sending anglers to any reservoirs may be of interest for heightened recruitment efforts; whereas areas of the region that are sending anglers to every reservoir may be seen as areas to lessen recruitment efforts.

Methods

Study area – The Salt Valley regional fishery is located in the southeastern portion of Nebraska (Figure 3-1) in the Salt Creek watershed. Portions of this watershed are highly developed (i.e., Lincoln and Omaha, Nebraska) and other portions 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 hours per hectare.

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. Seven reservoirs were randomly selected to be included in the full creel survey each year (Table 1-2).

Creel survey days (N=12 per month) and times were chosen following a stratified multi-stage probability-sampling regime (Malvestuto 1996). Sample days each month were split evenly into six categories (weekday-early [00:00-08:00], weekday-mid[08:00-16:00], weekday-late[16:00-24:00], weekend-early, weekend-mid, and weekend-late). Weekday sample days were selected from all non-holiday 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 anglers at the completion of their trips at access points and conducted interviews to gather information on fishing effort, catch and harvest. Interviews contained questions on method of angling (boat, bank or ice), type of fishing license, angling behavior, quality of fishing experience, home location (i.e., Zone Improvement Plan [ZIP]), and patterns of angling participation (e.g., substitute fishing site).

Analysis – All analyses were conducted using R v15.2 (R Core Team 2012). Driving distances were calculated for all angler parties using the *taRifx.geo* package (Friedman

2012) using Bing Maps (Microsoft 2013). 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 an ANOVA with day type and lake.

Spatial error associated with angler home ZIP code was reduced by taking a bootstrapping approach and randomly assigning anglers to a smaller spatial scale (i.e., census blocks) within the ZIP code. Census blocks are related to population size, with the number of census blocks in a ZIP code increasing as population increases. To accomplish this, each angler was taken and a random census block from the list of available census blocks within the 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 repeated 1,000 times to reduce any error associated with random assignment and the means of the resulting kernel density estimates (see below) were taken for each cell.

Kernel utilization distributions (Worton 1989) were calculated using the kernelUD function in the adehabitatHR package (Calenge 2006) in R. A bivariate normal kernel was used which places a bivariate normal kernel over each observed point and uses the smoothing parameter, h, to controls the width of the bivariate normal kernel. I set h at the *ad hoc* level, “href”, after trials of different h levels including LCSV and other subjectively chosen values (Silverman 1986). There are other choices for kernel functions, however, choice of kernel function does not greatly affect estimates of the utilization distribution (Silverman 1986). The extent, or spatial range to estimate the utilization distribution was set at 0.5, which indicates that I estimated kernel density values 0.5 x the range of coordinates, past the observed range (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 utilization across the region for each lake.

Area of influence (hectares) was calculated for the 10, 50, and 95% utilization distributions for each reservoir. Variation of kernel density estimates were calculated using a bootstrap approach (Kernohan et al. 2001). Angler ZIP code locations were bootstrapped from the original dataset for each reservoir with 50% of each reservoirs samples being drawn on each iteration with replacement. 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. Reservoirs with less than 25 anglers, Killdeer and Red Cedar, were excluded from variance calculation.

Results

A total of 3,739 parties were interviewed across the 4-year survey period. 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. Driving distance varied among reservoirs with the urban reservoir, Holmes Lake, having the smallest driving distance (12.9 ± 0.6 km; Figure 3-2). Most other reservoirs median travel distance is approximately the distance between the population center, Lincoln, and the reservoir. Travel distance varied between anglers fishing on weekday (33.5 ± 0.57) or weekend days (36.5 ± 0.54; $F_{1,3705}$=18.308, P<0.001) and varied among reservoirs ($F_{16,3705}$=70.95, P<0.001; Figure 3-2). However, the interaction between day type and reservoir was not significant ($F_{16,3705}$=1.07, P=0.37). Differences in travel distance by day type did differ significantly for Red Cedar Lake (Figure 3-2).

Kernel density estimates across all reservoirs ranged from 0.0 – 6.33 x 10^{-9} anglers*m^{-2} with a mean of 1.35 x 10^{-11} anglers*m^{-2}. However, kernel density estimates from the 1,000 iterations varied little with a mean ± SE coefficient of variation across iterations of 1.90 ± 0.01 anglers*m^{-2}. Further analysis was completed on one iteration of the kernel density for simplicity.

Areas of influence ranged from 1,210 ± 22 to 52,500 ± NA ha for 10% utilization distribution, 11,277 ± 70 to 340,800 ± NA ha for 50% utilization distribution and 79,494 ± 812 to 1,276,800 ± NA ha for 95% utilization distribution (Table 3-1; Figure 3-3). Standard errors could not be calculated for reservoirs with sample size of less than 25 anglers. Sixteen of the seventeen reservoirs area of influence included Lincoln, Nebraska whereas only twelve of the seventeen reservoirs included Omaha, Nebraska, an area of much greater population just to the northeast (Figure 3-3). In general, the 10% utilization distribution was centered on Lincoln, Nebraska. The smallest reservoir area of influence was for Holmes Lake, the urban reservoir in the regional fishery, whereas the largest area of influence was for Red Cedar Reservoir. Area of influence was unrelated to surface area (Spearman's correlation, S = 768, $P = 0.82$) or number of parties interviewed at a reservoir (Spearman's correlation, S = 938, P = 0.56; Figure 3-4).

Discussion

The spatial use of a regional fishery is an important first step in understanding what anglers' desire from the fishery resources within an area. Revealed preferences of anglers, through actual use of reservoirs, is an effective means of examining and comparing the current angler base of reservoirs across a regional fishery. I 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 and the angling population. These differences among reservoirs are important for managers to understand in terms of where anglers are coming from to fish reservoirs and the importance of maintaining a diversity of different types of reservoirs in a regional fishery.

Anglers travel a certain distance to a reservoir to fish on a given day and this distance likely plays a major part in making daily decisions on where to go fishing. Anglers in the Salt Valley do vary in travel distance among different reservoirs with the urban reservoir, Holmes Lake, not surprisingly having the smallest travel distance.

Outside of the urban reservoir, most reservoirs had a median travel distance of between 25 and 40 km, the distance between those reservoirs and Lincoln, Nebraska. However, travel distance alone does not allow us to determine if these reservoirs are drawing anglers from primarily Lincoln, or the entire area within the radius of that 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 reservoirs differentially across the regional fishery. In general, reservoirs further away from the urban center had larger areas of influence, whereas reservoirs, such as Holmes Lake, inside Lincoln, had small areas of influence. Furthermore, area of influence did not increase as the number of observations (i.e., anglers interviewed) increased as has been suggested (Seaman et al. 1999). There appears to be a distinction between reservoirs that draw from Omaha, Nebraska, and those that do not. Omaha is the largest city in Nebraska and is located on the eastern edge of my 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 (Chapter 2).

Defining the spatial use of fishing in the Salt Valley regional fishery allows fishery managers to visualize specific areas of the regional fishery that anglers are coming from for each reservoir. Using the area-of-influence as a pre- and post-assessment of angling participation, would allow managers to examine not only a numerical increase in angling participation following renovations, stockings, or changes in regulations, but allows for determination of changes in the spatial draw of anglers to the lake. Furthermore, this spatial analysis technique allows for determination of areas within the regional fishery that may be underused from a fishery perspective, with no anglers coming from those areas with low kernel densities. 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 is driven by population and demographic factors of potential anglers.

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Table 3-1. Area-of-influence size for reservoirs of the Salt Valley regional fishery from kernel density estimates of 10%, 50% and 95% utilization distributions and N is sample size of anglers included in area-of-influence estimates. Standard errors calculated by bootstrapping approach described in text; (.) indicates no standard error calculated because of small sample size (n < 25).

Reservoir	N	10% ± SE		50% ± SE		95% ± SE	
WP	30	19,613	(286)	148,501	(1,935)	665,958	(8,573)
KD	16	3,200	(.)	22,400	(.)	110,400	(.)
CT	59	2,690	(33)	24,248	(240)	127,701	(1,147)
TP	55	40,803	(387)	310,776	(2,374)	1,243,966	(6,601)
RC	7	52,500	(.)	340,800	(.)	1,276,800	(.)
MG	37	9,350	(187)	75,590	(1,407)	421,075	(7,569)
ML	29	12,325	(254)	100,157	(2,003)	537,707	(9,170)
HO	494	1,210	(22)	11,277	(70)	79,494	(812)
WW	482	6,163	(33)	54,946	(266)	624,317	(2,712)
OC	195	7,456	(50)	69,408	(448)	430,157	(2,171)
ST	254	4,008	(31)	35,014	(224)	314,270	(2,482)
CO	93	4,475	(65)	36,274	(465)	321,531	(5,318)
YH	196	3,741	(37)	30,701	(251)	273,626	(3,166)
BS	31	14,952	(256)	113,589	(1,887)	617,726	(10,015)
WT	254	4,366	(24)	38,878	(157)	531,339	(2,699)
PA	201	6,771	(58)	55,661	(469)	681,781	(5,669)
BO	814	6,501	(24)	57,563	(209)	771,019	(2,447)

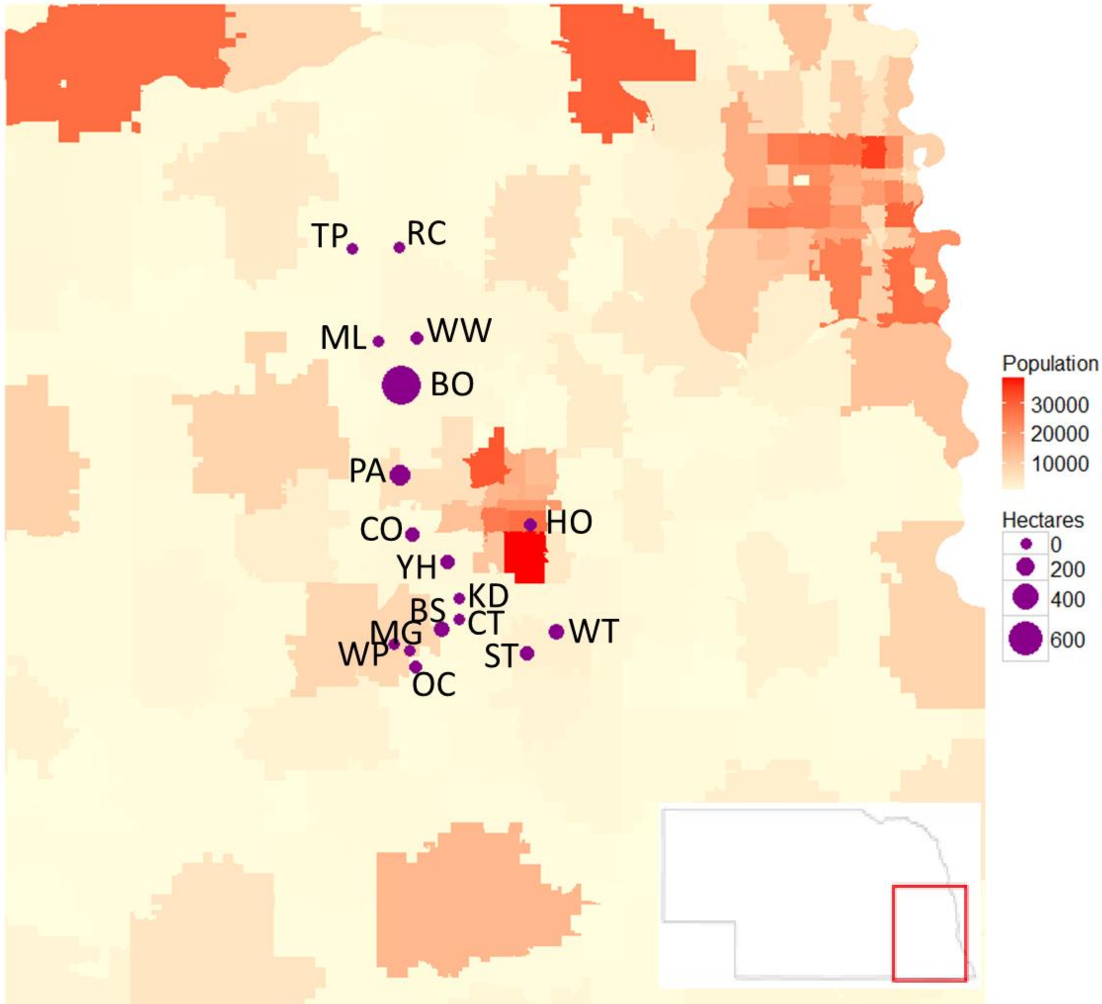

Figure 3-1. Map of Salt Valley regional fishery with population density based on ZIP code for the Salt Valley region. Population density of ZIP code based on data from 2010 United States Census. Reservoir two-letter codes represent: BO = Branched Oak Lake, BS = Bluestem Lake, CO= Conestoga Lake, CT = 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.

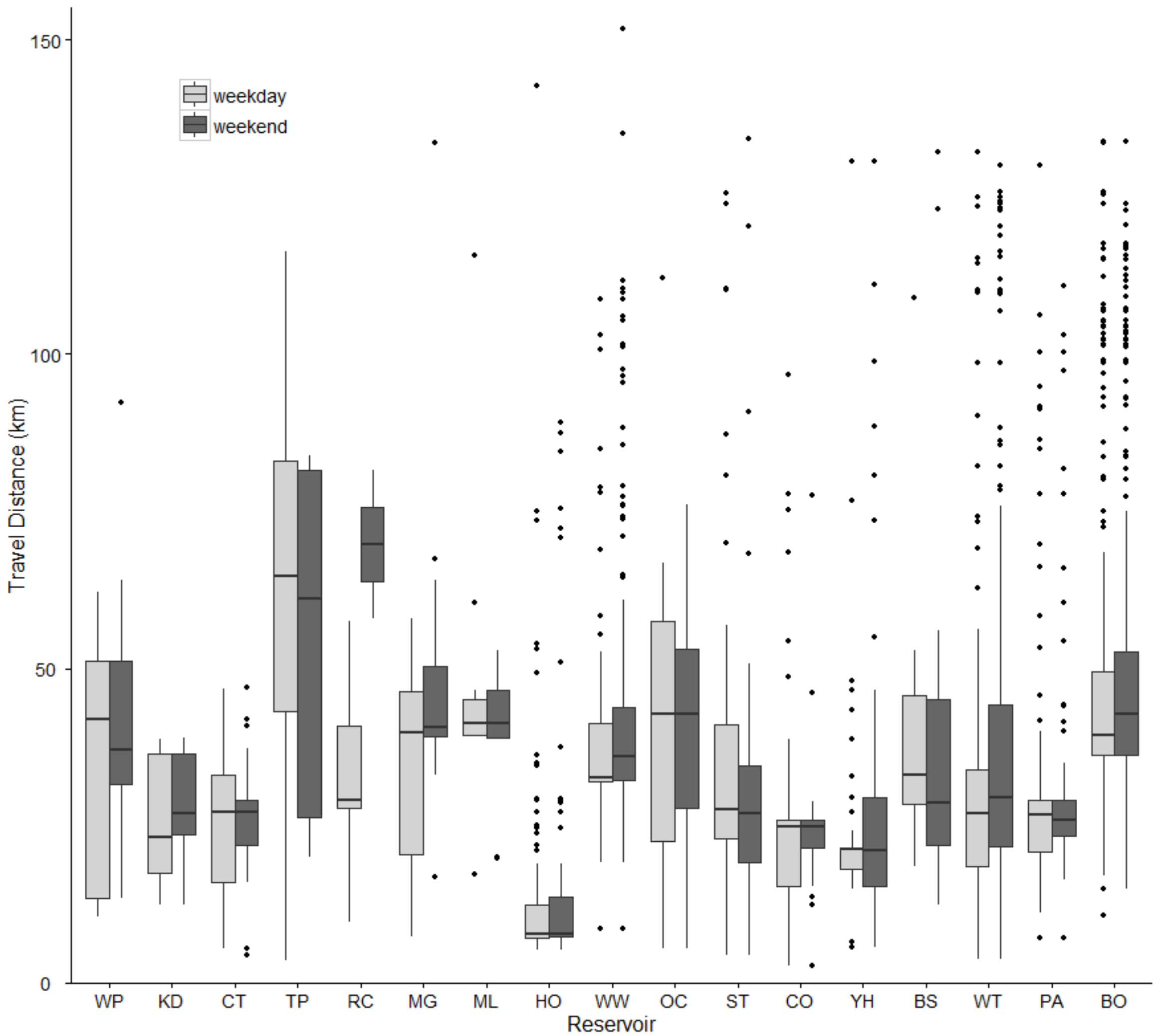

Figure 3-2. Box plot of driving distance traveled for anglers fishing reservoirs on weekends (dark gray) and weekdays (light gray) from home ZIP code of angler to geographical coordinates of reservoir in the Salt Valley regional fishery. Horizontal black lines represent median, boxes represent range from 25th to 75th percentile, whiskers extend from the box to highest or lowest value within 1.5 × IQR (interquartile range), points represent outliers.

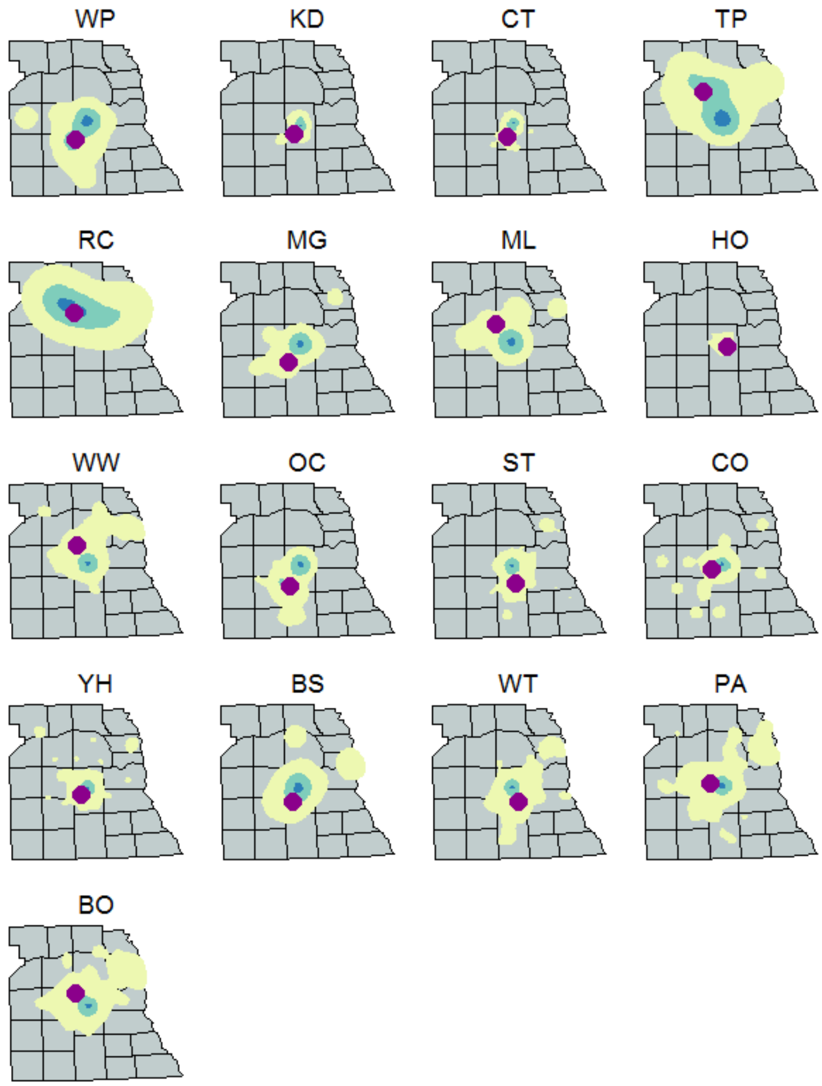

Figure 3-3. Area-of-influence of Salt Valley reservoirs. Red point represents location of reservoir and polygons represent 10% (darkest blue), 50% (light blue), 95% (yellow) area of influence of reservoirs based on kernel utilization distribution estimates.

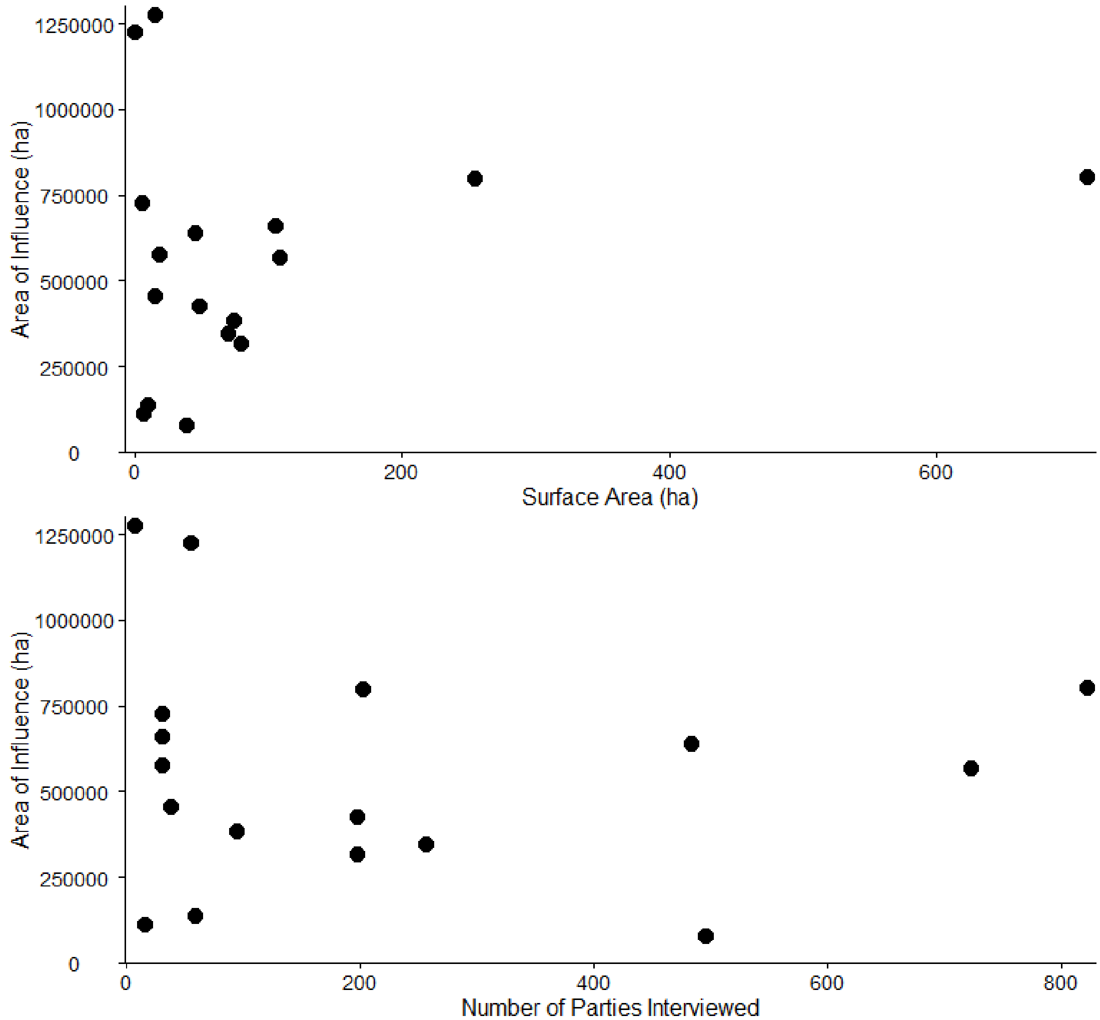

Figure 3-4. Relationship between area-of-influence (ha) estimates and reservoir surface area (ha; top) and number of parties interviewed at each reservoir (bottom) at reservoirs of the Salt Valley regional fishery.

Chapter 4: Network analysis of a regional fishery: implications for recruitment and retention of anglers

Introduction

Models to describe angler choice of fishing location and movement among water bodies have developed from simple, gravity models (e.g., Freund and Wilson 1973) to complex, multinomial-logit choice or generalized nested-logit models (e.g., Hunt 2005; Hunt et al. 2004). These more complex models used random utility theory (Train 2009), to describe the process in which anglers chose fishing sites to maximize their greatest utility (Cascetta 2009), or benefit. Site-selection models were further refined with the use of recreational-specialization theory to evaluate angler types and create angler groups for use in site-selection models (e.g., Connelly et al. 2001; Salz and Loomis 2005).

One limitation of previous modeling techniques is in the ability to determine the underlying structure of the social-ecological system (Berkes et al. 2000). There are likely multiple angler groups, such as groups defined by angler skill (e.g., recreational specialization; Bryan 1977), and multiple water-body groups, such as groups defined by fish communities. Both angler groups and water-body groups likely interact with each other creating a complex social-ecological system. Without a thorough understanding of the structure of the complete social-ecological system, it is difficult to draw conclusions on potential changes to the system and its resilience. These changes are of particular importance when looking at how to recruit or retain anglers on a regional scale.

A possible modeling technique that combines the desirable attributes of the previously described modeling techniques and allows for a unique understanding of the underlying structure of a social-ecological system is network analysis. Network analysis, derived from graph theory, has been used to describe friendships derived from mobile-phone records (Eagle et al. 2009), disease-transmission patterns (Christley et al. 2005), brain synapses (Rubinov and Sporns 2010), ecological food-webs (Krause et al. 2003), and plant-pollinator communities (Bosch et al. 2009). Network analysis allows for the explicit linking of nodes (i.e., objects of interest) by weighted edges (i.e., strength of association) to gain an understanding of the importance of different linkages among nodes within the social-ecological system. Resilience of social-ecological systems has been proposed as one particular metric that may be particularly suited for study with network analysis (Janssen et al. 2006).

Changes in the regional fishery (Martin and Pope 2011), or available waterbodies for anglers to choose, result in changes in network structure and the social-ecological system. The resilience of a regional fishery is dependent on the set of water-body options that anglers can choose from. A resilient regional fishery would be one that has a set of diverse waterbody options to choose from but maintains redundancy within those options, in case of failure of fish populations.

The human-and-waterbody interaction is of particular interest as a social-ecological network for fisheries management, especially control of invasive species (Johnson et al. 2001) and prevention of overharvest (Carpenter and Brock 2004). The direct linkages between waterbodies and anglers provides management a tool for understanding potential pathways for invasive species spread, through angler boat movement, and secondary effects of overharvest of fish communities. For example, if one waterbody is overharvested or endures a fish kill, managers may be able to proactively manage for increased harvest at nearby waterbodies or substitute sites and reduce either bag limits before overharvest becomes a concern. A basic understanding of network structure of a regional fishery will further our knowledge of angler dynamics and lead to better fisheries management. My objectives are to (a) explore how water bodies interact with one another through angler use (i.e., define groups within the regional fishery), (b) explore how anglers group themselves across the region in terms of patterns of angling participation, and (c) determine how resilient a regional fishery is to disturbance through removals of reservoirs.

Methods

Data Collection—Interviews were conducted in-person (Figures 1-4 and 1-5) at 19 reservoirs in the Salt Valley region of southeastern Nebraska during 2009-2012 (Figure 1-1). Seven reservoirs were sampled per year (Table 1-2), two from each of a pre-defined classification scheme based on reservoir size and fish community (Table 1-1). One participant from the angling party, the representative of the party, answered all in-person survey questions. To collect in-depth information on angler use patterns within the Salt Valley, all individual anglers, not only the representative who completed the in-person survey, surveyed during 2010-2012 were asked to participate in a return-mail survey (Figures 1-6 and 1-7). Return, postage-paid envelopes were provided to anglers to increase survey return rates (Armstrong and Lusk 1987). Questions included on the return-mail survey addressed visitation to the 19 reservoirs in the Salt Valley in the past 12 months (Question 5 on survey), self-reported skill (Question 2), demographics (Questions 14-21), recreational specialization (Questions 1-3), and motivations for selecting a reservoir (Question 8).

Network Analysis— Network analysis was completed using the igraph package in R (Csardi and Nepusz 2006; R Core Team 2012). All plots used a force-directed layout (Fruchterman and Reingold 1991) unless otherwise noted as a spatial layout. Force-directed layouts assign forces among the set of edges and nodes and place nodes to minimize energy, resulting in a graph with edges of uniform length and nodes with weaker connections being placed further apart.

A weighted, bipartite matrix was created using angler return-mail survey data on visitation to Salt Valley reservoirs. Surveys were combined across years for analysis. In this bipartite matrix, anglers were listed in rows and reservoirs were listed in columns resulting in an 897 × 19 matrix. If a particular angler visited a reservoir, the corresponding cell indicated the number of days that reservoir was visited in the past 12 months. If an angler did not visit a reservoir, the corresponding cell received a zero. A bipartite projection of this matrix was completed in iGraph, which results in two matrices; an 897 × 897 angler matrix and a 19 × 19 reservoir matrix. Further analysis was completed on the reservoir matrix only. Within this reservoir matrix, cells represent a measure of how often these reservoirs were visited by the same anglers.

The graph representation of this reservoir matrix represents reservoirs as nodes, and reservoirs visited by the same angler parties were connected by edges. Edges were weighted by the number of angler parties that connected those reservoirs. We first used a modularity-based community detection algorithm (Newman 2004) to determine whether discrete communities of nodes, or groups of tightly connected reservoirs, existed within this reservoir co-visitation network. The fast-and-greedy algorithm maximizes modularity; modularity is defined as the fraction of edges that fall within groups minus the expected fraction of edges within groups if edges were distributed at random among nodes (Newman 2006). Modularity ranges from -0.5 to 1 and positive values indicate that the number of edges within a group is greater than the expected number.

Due to large sample size and lack of variation in node degree, a bootstrapping method was used on the original 897 × 19 network (Lusseau et al. 2008). Bootstrapping allows for some variation to be derived from the original dataset, given that there are no other data from which to derive variation. The original bipartite matrix (897 × 19) was resampled with replacement by row to create a new matrix with the same dimensions (897 × 19) as the original matrix. This resampling was repeated 1,000 times to create individual bipartite matrices. Each bootstrapped matrix was then ran through a bipartite projection in iGraph to obtain the 19 × 19 reservoir matrix, and community detection was used on each bootstrapped iteration using the fast-and-greedy algorithm (Clauset et al. 2004). Membership of each reservoir into community subgroups was saved during each iteration and combined to make a 1,000 × 19 matrix of community membership. This new matrix was then used to create a 19 × 19 square adjacency matrix by calculating a probability of each pair of reservoirs being connected. This probability was calculated as the proportion of 1,000 iterations in which the pair of reservoirs was in the same community.

The resulting matrix based off of community membership was used for all further reservoir analyses. Degree, the number of other nodes each node is connected to was calculated for all reservoirs (Wasserman and Faust 1994). Community detection of this resulting network was also calculated using the fast-and-greedy algorithm. The spatial structure of the regional fishery communities was examined by plotting reservoirs in their correct geographic location. Reservoir latitude and longitude were added as vertex attributes and a new geographic layout was created. Other attributes of the regional fishery such as reservoir size were included as an attribute matrix. Reservoir size and fish community were used *a priori* to create a hypothesis of reservoir grouping and resulted in four groups (Table 1-1). These reservoir groups were used to test substitution patterns (H_o: anglers are more likely to substitute for another reservoir within the same group); thus, reservoirs in the same *a priori* group should be in the same community.

Angler Communities—Differences in angler behavior and reservoir selection among anglers was tested using a combination of cluster analysis to create similar clusters of anglers and network analysis to describe the relationship among the Salt Valley reservoirs within each angler cluster. Data from the return-mail survey questions aimed at determining recreational specialization (Bryan 1977; Chipman and Helfrich 1988; Fisher 1997) were used for k-means cluster analysis using the PAM function in the cluster package in R (Maechler et al. 2013). The three variables used to cluster anglers into group were 1) total number of days fished in the last 12 months, 2) self-reported angler skill level ranging from unskilled to very skilled measured by a 5-point Likert scale (Likert 1932), and 3) a measure of importance of fishing to the anglers lives. This last measure was calculated as a self-reported number of years holding a fishing license divided by the adjusted-angler’s age (adjusted by subtracting 16 years because no license is needed until age 16 in Nebraska). A dissimilarity matrix based on Gower’s distance was used for cluster analysis because angler skill was measured on an ordinal scale and treated as a factor variable (Gower 1971). The number of clusters was determined from the iteration with the greatest average silhouette width after running iterations ranging from 2 to 20 clusters (Rousseeuw 1987). A larger silhouette width indicates a better fit of the clustering algorithm, and is used as a measure of fit.

Angler cluster assignment was then assigned to the original 897 × 19 matrix and subset to create matrices for each angler group. These angler-group matrices were then each ran through a bipartite projection to get a resulting 19 × 19 matrix and created a network of reservoir nodes and edges describing the angling participation patterns of each angler cluster. The fast-and-greedy algorithm was used to detect communities for each reservoir network based on angler clusters. Network-level metrics such as degree distribution, density, number of communities, and modularity were calculated for each angler cluster.

Reservoir Removal—Resilience of the regional fishery to disturbance was tested by topological removal of reservoirs from the network and analyzing network measures such as modularity. Every possible combination of reservoirs was selected and removed from the network from 1 reservoir per iteration to 18 reservoirs per iteration (i.e., only one reservoir remaining in the network). For example, at the removal level of 5 reservoirs, 11,628 combinations of reservoirs were possible to be removed from the set of 19 reservoirs. As each combination was removed, the resulting 897 × 14 (in the case of 5 reservoirs being removed) matrix would be subjected to bipartite projection, and the reservoir matrix (19 × 19) was graphed and subjected to community detection using the fast-and-greedy algorithm. Modularity at each iteration was calculated after community detection. Further analysis looked at the number of communities and mean community size at each level of removals to examine effects of reservoir removal.

Results

A total of 897 usable return-mail surveys was received (21% return rate) from January 2010-December 2012. Surveys were combined across years. Of the returned surveys, anglers reported 35.9 ± 44.1 days fishing the 19 reservoirs of the Salt Valley during the last 12 months with a total of 32,249 days reported. Anglers visited 4.6 ± 0.9 reservoirs in the past 12 months with a range from 1 to 15 reservoirs. Of the Salt Valley reservoirs, Wagon Train Lake received the greatest number of reported fishing days followed by Holmes and Branched Oak lakes (Figure 4-1). Visitation by individual anglers at individual reservoirs ranged from 0 to 250 days fishing in the last 12 months, with the mean ± SE ranging from 0.07 ± 0.02 at Red Cedar Lake to 5.3 ± 0.6 days at Holmes Lake.

Reservoir Network—The observed network of reservoirs had 19 nodes with 171 edges (Figure 4-2). The density of the observed network was 1.0, indicating an edge occurred between every pair of nodes, i.e., at least one angler visited every combination of reservoirs. Therefore, the degree of each node was 18, indicating a complete network, with little variation between nodes. No distinct communities were found among the reservoirs using community detection algorithms.

After bootstrapping the observed network, the resulting network based on probability of group membership had 19 nodes with 135 edges (Figure 4-3). The group of reservoirs most centrally located on the graph were Bluestem, Bowling, Meadowlark, Olive Creek, Red Cedar, and Timber Point; indicating these reservoirs were of most importance to connecting all reservoirs together. The density, or proportion of possible edges that actually exist, of the bootstrapped network was 0.789 and degree ranged from 9 to 18 (Table 4-1). Community detection of the bootstrapped network revealed two separate communities within the regional fishery (Figure 4-4), indicating that anglers of the Salt Valley regional fishery use these two groups of reservoirs differently. Furthermore, those six centrally located reservoirs mentioned in Figure 4-3 were still centrally located and belonged to two groups. Bluestem and Olive Creek were located within the larger community of reservoirs, but were located closer to the smaller community of reservoirs, indicating that these two reservoirs were connectors between the two communities. Modularity of the bootstrapped network was 0.32 using the fast-and-greedy algorithm, signifying a greater number of edges within groups than would be expected at random. There was no spatial component to the delineation of these two communities, with each community stretching from across the entire Salt Valley regional fishery (Figure 4-5). The two communities of the regional fishery did differ by reservoir surface area; with a small (<50 ha) and large (>50 ha) reservoir community (Figure 4-6). The community of small reservoirs matched our *a priori* hypothesized group of small water-bodies (Table 1-1).

Angler Communities—Cluster analysis of the angler community based on recreational specialization data found four clusters that described the most variation in this dataset. Fifty-nine observations were removed because anglers did not answer all questions related to recreational specialization. The four-cluster solution described 16% of the variation in the angler dataset with two components (Figure 4-7). The four clusters differed in the total number of days fished in the last 12 months (Kruskal-Wallis, X^2 = 167.7, df = 3, P < 0.001), self-reported skill level (Kruskal-Wallis, X^2 = 823.0, df = 3, P < 0.001) and proportion of years with license (Kruskal-Wallis, X^2 = 122, df,= 3, P < 0.001; Figure 4-8). In general, as the number of days spent fishing increased, so did angler self-reported skill and the proportion of years holding a license (Figure 4-8). Angler cluster one represents anglers (N = 70) that fish few days per year (18.4 ± 1.6), have low angling skill, and buy a fishing license once every two years. Angler cluster two represents anglers (N = 317) that fish more often than cluster one (38.6 ± 2.3 days), have average angling skill, and buy a fishing license three out of every four years. Angler cluster three represents anglers (N = 312) that fish more often (56.7 ± 2.7 days), are skilled anglers, and buy a fishing license nine out of every 10 years. Angler cluster four represents anglers (N = 139) that fish the most (87.6 ± 5.5 days), are very skilled anglers, and buy a license every year.

Reservoir networks of angler clusters differed in structure and function. Density of reservoir networks ranged from 0.71 for angler cluster one to 1.0 for angler cluster three (Table 4-2). The number of reservoir communities ranged from 2 to 3 with modularity ranging from 0.01 to 0.09 using the fast-and-greedy community-detection algorithm (Table 4-2). Furthermore, reservoir networks for different angler clusters varied in degree distribution, reflecting number of reservoirs used by individual anglers (Figure 4-9). The larger variation in node degree of angler group 1 indicates that this group behaves differently and there is not much overlap between reservoirs. Reservoir groups varied among angler clusters with angler clusters two and four being similar to the overall network structure of the regional fishery, using data from all anglers combined (Figures 4-10 – 4-13). The resulting networks from these two angler clusters had two reservoir communities: a community of small (<50 ha) and a community of larger (>50 ha) reservoirs (Figures 4-11 and 4-13) although modularity was low indicating a weak division into communities. The network of angler cluster one had three reservoir communities and appears to be driven by spatial location within the regional fishery (Figure 4-10) with a group of southern reservoirs, group of northern reservoirs, group of middle latitude reservoirs. The large number of red lines, or connections between reservoir groups, indicates the low modularity and relative weak strength of this community detection. The network of angler cluster three had three reservoir communities and appears to have an interaction effect between reservoir size and spatial location (Figure 4-12); with a southern, northern, and middle reservoir groups.

Reservoir Removal—Removal of reservoirs form the regional fishery by topological removal resulted in a reduction in modularity. Modularity decreased as reservoirs were removed from the regional fishery (Figures 4-14). Perhaps of more importance, modularity never increased as reservoirs were removed, as predicted *a priori*. I predicted that as reservoirs were removed from the system, the behavior of the system that the network would be broken up into more discrete communities of reservoirs, but this was not the case. The range of modularity spread to almost zero after removal of 5 reservoirs from the regional fishery (Figure 4-15), indicating that anglers now saw the regional fishery as one group of reservoirs. The number of reservoir communities from community detection in the regional fishery did not decrease until 10 reservoirs were removed (Figure 4-16). The mean size of reservoir community and number of reservoirs in community both decreased rapidly as expected (Figure 4-17).

Discussion

Network analysis is a useful tool to describe fishing participation across a regional fishery. Anglers make choices among fishing locations on a daily basis and these decisions have an effect on that angler's future decisions among fishing locations. Often fishery managers do not think that changes at one reservoir will affect anglers at another reservoir, but there are often more subtle changes, due to crowding or overfishing, that can have large, cumulative effects (Carpenter and Brock 2004). The explicit connections shown in network analysis between fishing locations allow researchers and managers to examine potential consequences of any action with a region.

The regional network of the Salt Valley regional fishery consists of two distinct reservoir groups based on angler use patterns. These two groups are defined by reservoir size and indicate that anglers see separate, qualitatively different fishing experiences on small and larger reservoirs. This is likely driven by a combination of angler access, access regulations (i.e., no Nebraska Game and Parks Commission park permit needed to access 7 out of 8 reservoirs in the small reservoir community whereas park permit required in 9 out of 11 reservoirs in the large reservoir community), and fish community. However, these factors are all highly correlated and the current study cannot determine which factors are the most important. It is important to note which reservoirs are centrally located within the force-directed graphs (Figure 4-4). Reservoirs such as Bluestem, Olive Creek, Red Cedar, and Timber Point play an important role in connecting these reservoir groups. From a management viewpoint, these reservoirs are traffic gateways between the two groups and are of greater risk for invasive species.

The reservoir classification based on angler use patterns differs from our *a priori* classification of reservoirs based on fish community and reservoir size (Table 1-1). This social-reservoir classification contains two reservoir groups, whereas the ecological reservoir classification contains four groups. This dissimilarity indicates that anglers do not see differences among reservoirs in the same way that biologists and researchers typically do. However, the small reservoir group (reservoirs with largemouth bass, bluegill, and channel catfish and reservoirs <30 ha) from the ecological classification and the smaller reservoir group from the social classification are identical. From a social-ecological system perspective, the social reservoir classification encompasses variability in angler choice and is likely a better reservoir classification system to base regional management objectives.

The angling community of the Salt Valley regional fishery is comprised of four distinct clusters, ranging from less active, unskilled anglers to highly active, very skilled anglers. Reservoir use patterns and the resulting network community of these four angler clusters differ as well. Specifically, angler clusters one and three differ from the overall pattern of two reservoir communities based on reservoir size. These two clusters have different reservoir network communities and appear to have a strong spatial component that affects decisions of where to fish, whereas the overall community did not show any spatial influence. A thorough understanding of the behavior of angler cluster one, the less skilled anglers, is important to understand for angler recruitment and retention. This cluster, in particular, has a strong spatial factor to the network community that drives decisions to choose fish at reservoirs that are closer to home. Differences in angler behavior across this gradient of recreational specialization are important to understand for angler recruitment and retention. Anglers that are less active and unskilled are more likely to stop angling if angling access at their favorite reservoir whereas anglers that are highly active and very skilled are likely to keep angling at another location. Further research into the differences how different anglers across this spectrum of angling specialization is needed and should address other distributions of anglers such as a probability distribution around some mean angler skill, as opposed to the clustering technique used here.

The Salt Valley regional fishery is highly resilient to disturbances that would remove reservoirs from the system. Reservoir removals have little effect on existing network structure unless removing greater than 5 reservoirs at one time. The change in structure as reservoirs are removed is highly dependent on which reservoirs are removed, but reservoirs removed that affect resilience are counter to what we initially hypothesized. We initially hypothesized that the reservoirs that would be most important to maintaining resilience would be those larger reservoirs that have greater fishing effort, as these reservoirs are likely visited by more anglers. However, reservoirs that reduce modularity (i.e., reduce resilience) faster than other reservoirs are some of the smaller reservoirs that have the least fishing pressure in the region. This is likely because these reservoirs are used as an exploratory trip for most anglers, and are therefore used by many anglers in the regional fishery, but for few days. Although not tested, the resiliency of the angler cluster one network is likely less than the overall Salt Valley network because of the greater dependency on spatial location and smaller reservoir community size.

An understanding of the network structure of a regional fishery is needed for knowing what anglers will do in response to manmade disturbances, such as reservoir renovations or regulation changes. However, it is also important for understanding the potential implications of invasive species spread or overharvest. Invasive species are likely to spread from an infected reservoir to other reservoirs that have strong angler use connections with the infected reservoir. Similarly, knowing angler movement patterns and preferences can help predict what anglers will do when populations of popular fish species decline, or harvest regulations become limiting (e.g., Beard et al. 2003). Anglers are likely to move to the next reservoir with the strongest connection that also has a good population of species of interest to continue harvest. Proactive management of regional fisheries, after gaining an understanding of angler behavior, can lead to changes in regulations and prevent invasive species spread or overharvest of sportfishes. One assumption that needs to be addressed when addressing the topological removal of reservoirs to measure resilience is that angler behavior remains the same given that the choice of reservoirs has changed. In this case, I just removed data from the dataset that I had of angler behavior, there was no measure of what direct effects certain reservoir removals would have on this regional fishery. For a more complete understanding of regional fishery resilience, a thorough survey of anglers on the substitutability of reservoirs under different removal scenarios is needed.

The application of network theory to user participation has widespread applications in natural resources management. Natural resource agencies are interested in increasing recruitment and retention of hunters and anglers to secure funding and a user base for the future; however, without an understanding of current behavior, and what to expect these new hunters and anglers to do, this is a difficult task. Network analysis allows natural resource agencies to gain a better understanding of current user behavior. The techniques of network theory can be used to determine where and what is the best placement of new properties for participation or if current locations are getting used in amounts that equal their maintenance costs (i.e., is the return-on-investment enough to keep properties). A thorough understanding of our user base in natural resources will allow natural resource management agencies to better manage for and serve our constituents.

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Table 4-1. Node-level metrics of bootstrapped matrix for the reservoirs of the Salt Valley regional fishery. Code is the two-letter code that reservoirs are referred to throughout remaining figures, degree is the number of other nodes that each reservoir is connected to.

Reservoir	Code	Degree
Branched Oak Lake	BO	14
Bluestem Lake	BS	18
Bowling Lake	BW	18
Conestoga Lake	CO	14
Cottontail Lake	CT	8
East Twin Lake	TW	14
Holmes Lake	HO	14
Killdeer Lake	KD	8
Merganser Lake	MG	8
Meadowlark Lake	ML	18
Olive Creek Lake	OC	14
Pawnee Lake	PA	14
Red Cedar Lake	RC	18
Stagecoach Lake	ST	14
Timber Point Lake	TP	18
Wild Plum Lake	WP	8
Wagon Train Lake	WT	14
Wildwood Lake	WW	14
Yankee Hill Lake	YH	14

Table 4-2. Network-level metrics of reservoir networks based on angler clusters defined by cluster analysis in the Salt Valley regional fishery. Density is the proportion of possible edges that occur within the network. Communities are the number of communities found using the fast-and-greedy community detection algorithm. Modularity is a measure of the number of edges contained within groups compared to the number expected within groups by random.

Cluster	Density	Communities	Modularity
1	0.71	3	0.09
2	0.98	2	0.01
3	1.00	3	0.02
4	0.99	2	0.02

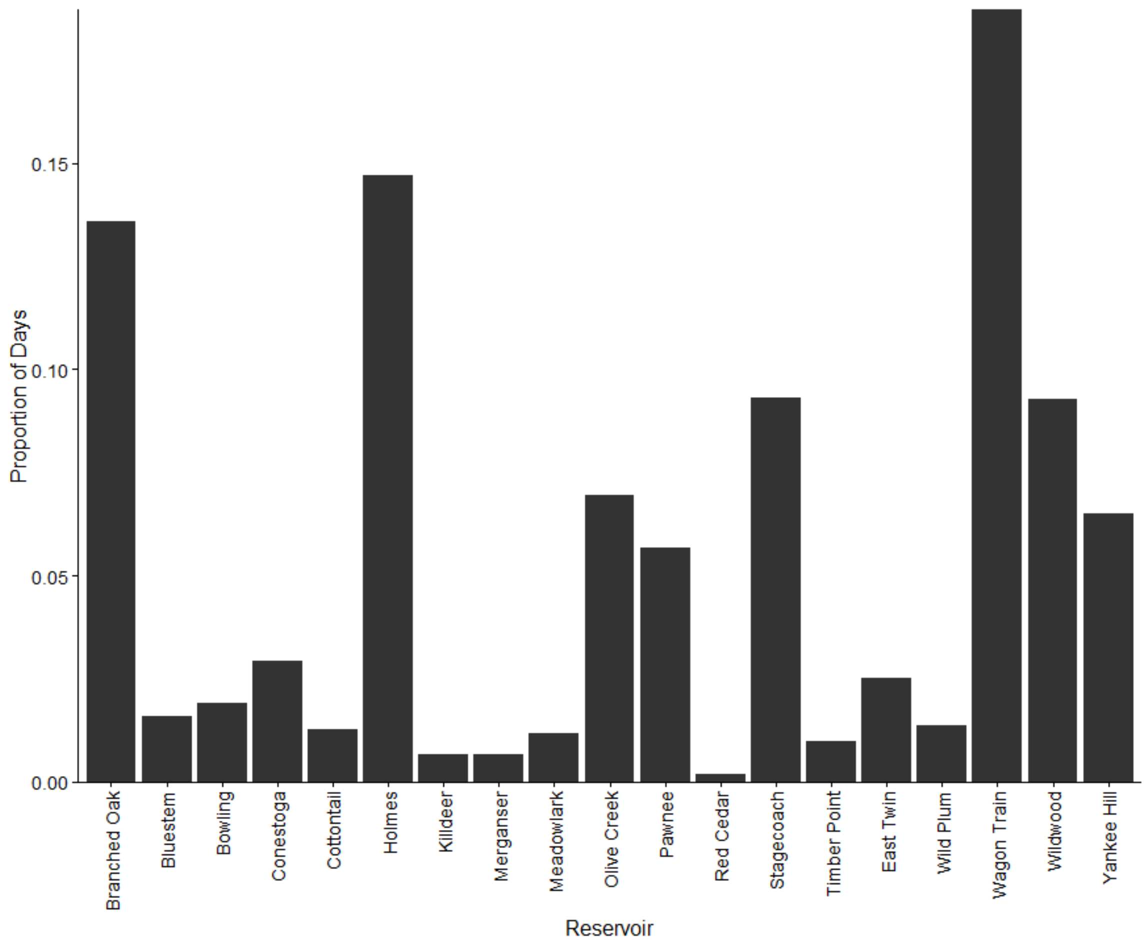

Figure 4-1. Proportion of reported days that anglers fished in the Salt Valley regional fishery in the past 12 months at each of the 19 Salt Valley reservoirs.

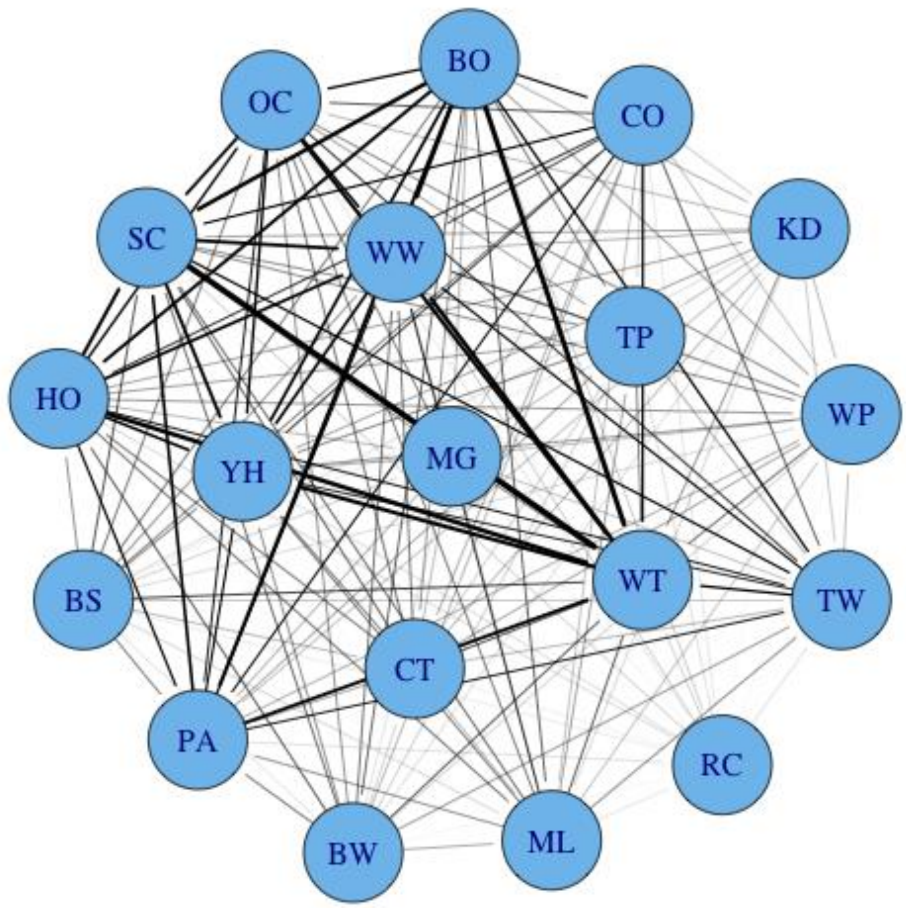

Figure 4-2. Reservoir projection of observed Salt Valley regional fishery network using Fruchterman-Reingold layout. Nodes (circles) represent reservoirs and edges (lines) represent a weighted measure of association among those reservoirs (i.e., strength of substitutability between reservoirs).

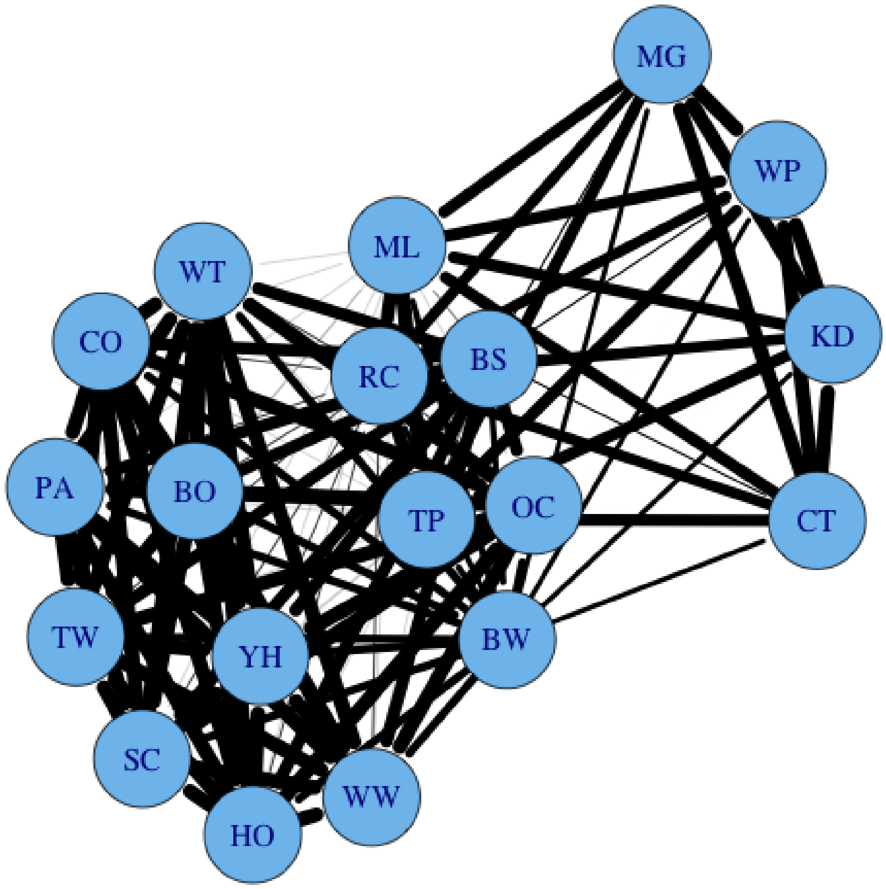

Figure 4-3. Salt Valley regional fishery network after bootstrapping technique using Fruchterman-Reingold layout. Nodes (circles) represent reservoirs and edges (lines) connecting two reservoirs represent weighted measure of association between those two reservoirs (i.e., probability of being in the same community in bootstrapping iterations using fast-and-greedy community-detection algorithm).

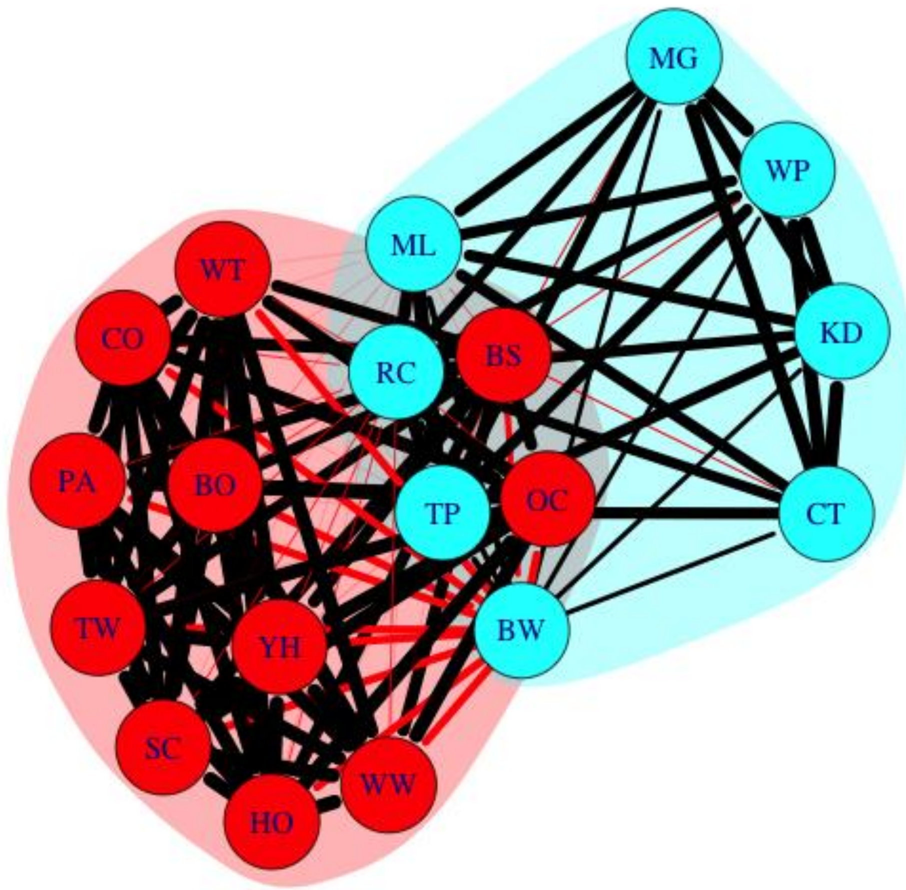

Figure 4-4. Group membership in the Salt Valley regional fishery bootstrapped network using the fast-and-greedy community-detection algorithm. Nodes (circles) represent reservoirs and edges (lines) connecting two reservoirs represent weighted measure of association between those two reservoirs. Red and blue nodes indicate two distinct groups of reservoirs. Black edges are those connecting two reservoirs within the same group, red edges are those connecting two reservoirs in different groups.

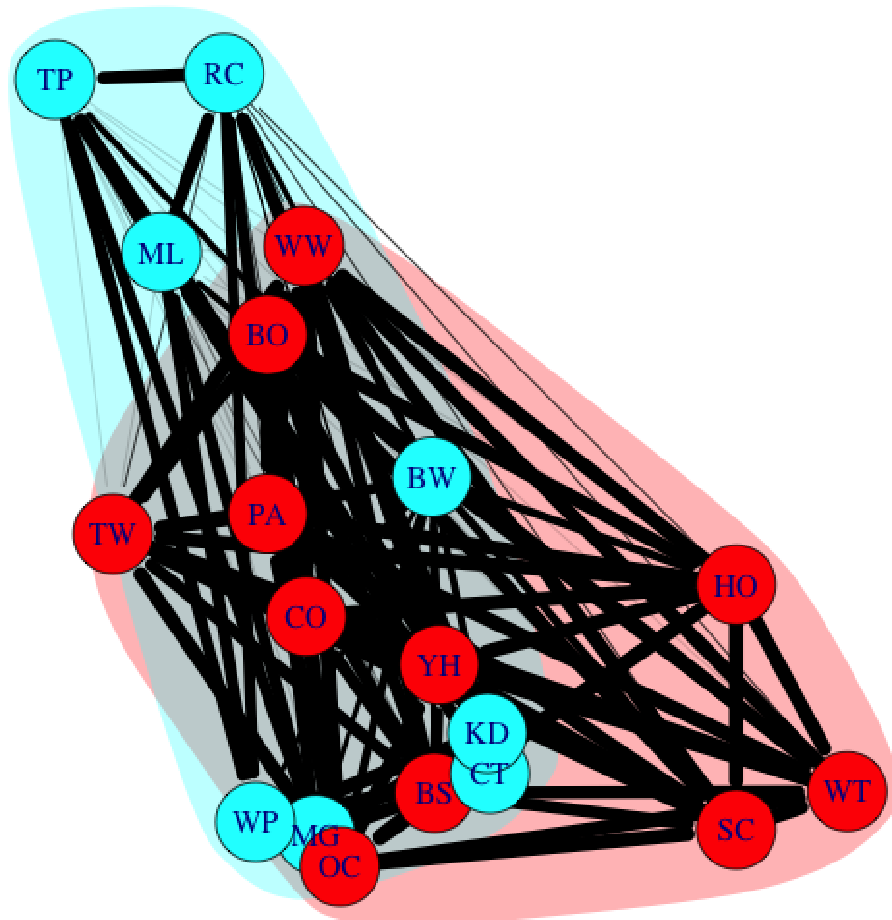

Figure 4-5. Spatial layout of the Salt Valley regional fishery bootstrapped network with communities defined by the fast-and-greedy community-detection algorithm. Nodes (circles) represent reservoirs and edges (lines) connecting two reservoirs represent weighted measure of association between those two reservoirs. Red and blue nodes indicate two distinct groups of reservoirs. Black edges are those connecting two reservoirs within the same group, red edges are those connecting two reservoirs in different groups.

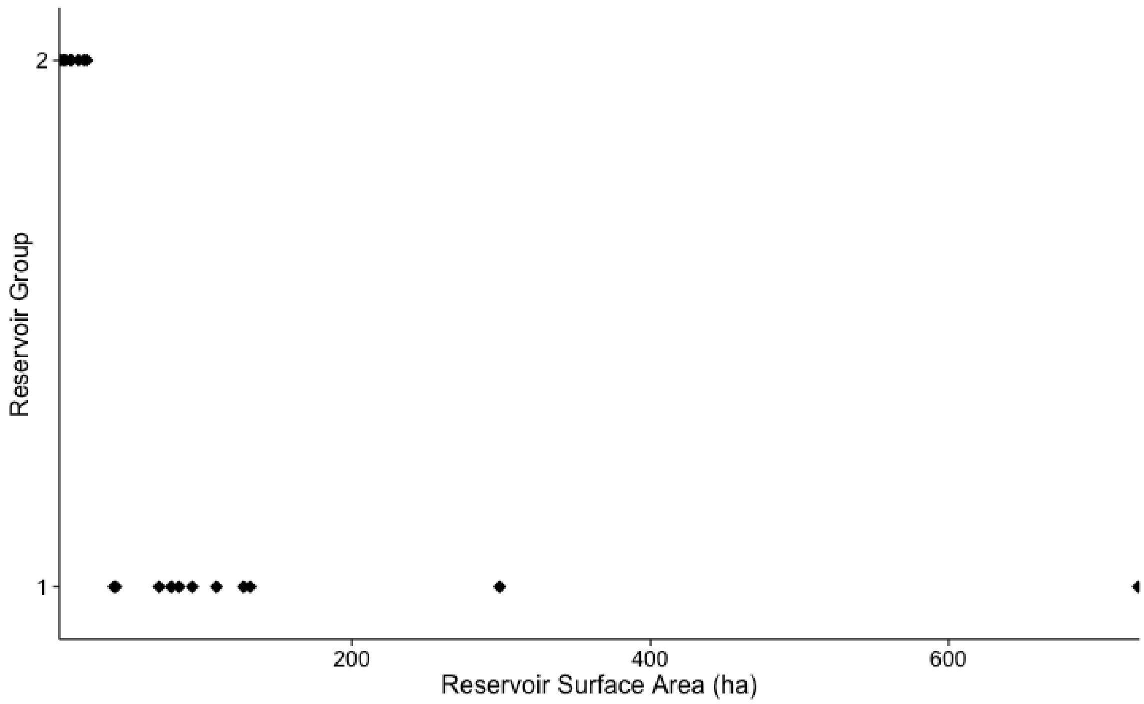

Figure 4-6. Group membership of reservoirs in the Salt Valley regional fishery as a function of reservoir size (surface hectares of water). Reservoir group 1 corresponds to red nodes in Figure 4-4 and reservoir group 2 corresponds to blue nodes in Figure 4-4.

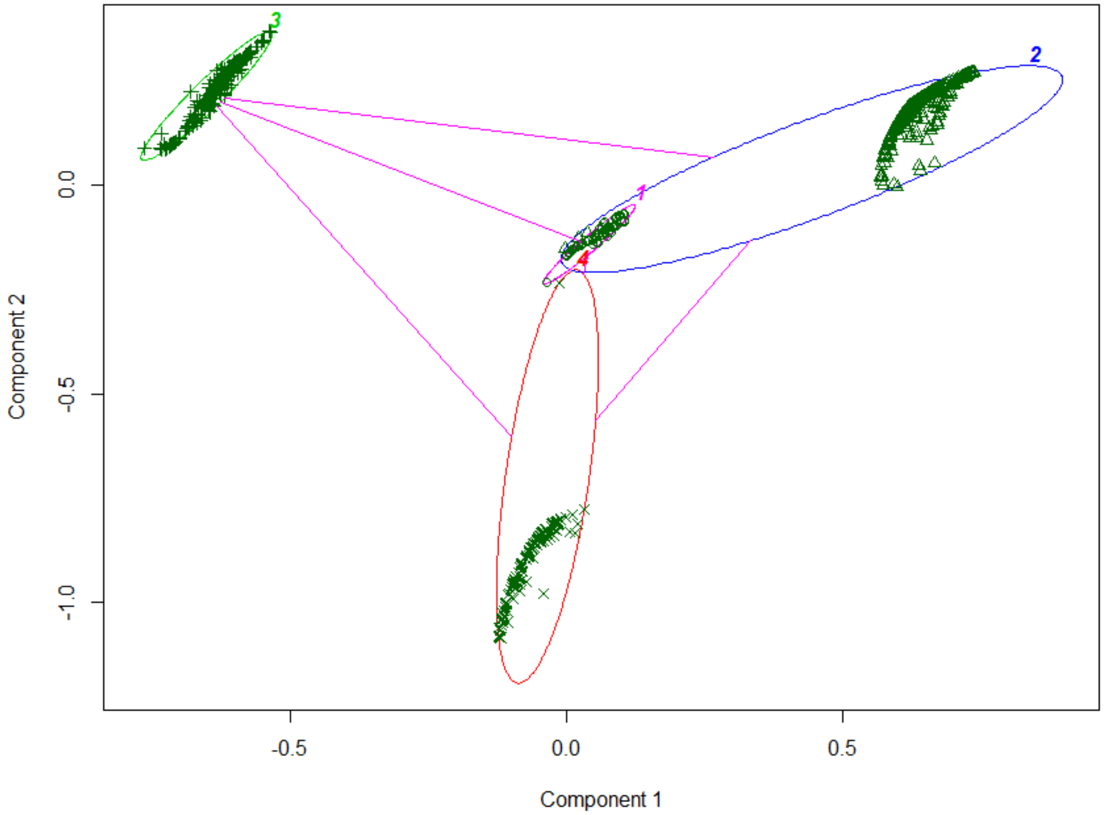

Figure 4-7. Cluster analysis of anglers in the Salt Valley regional fishery based on recreational specialization. Four-cluster solution explains 15.9% of variability in data.

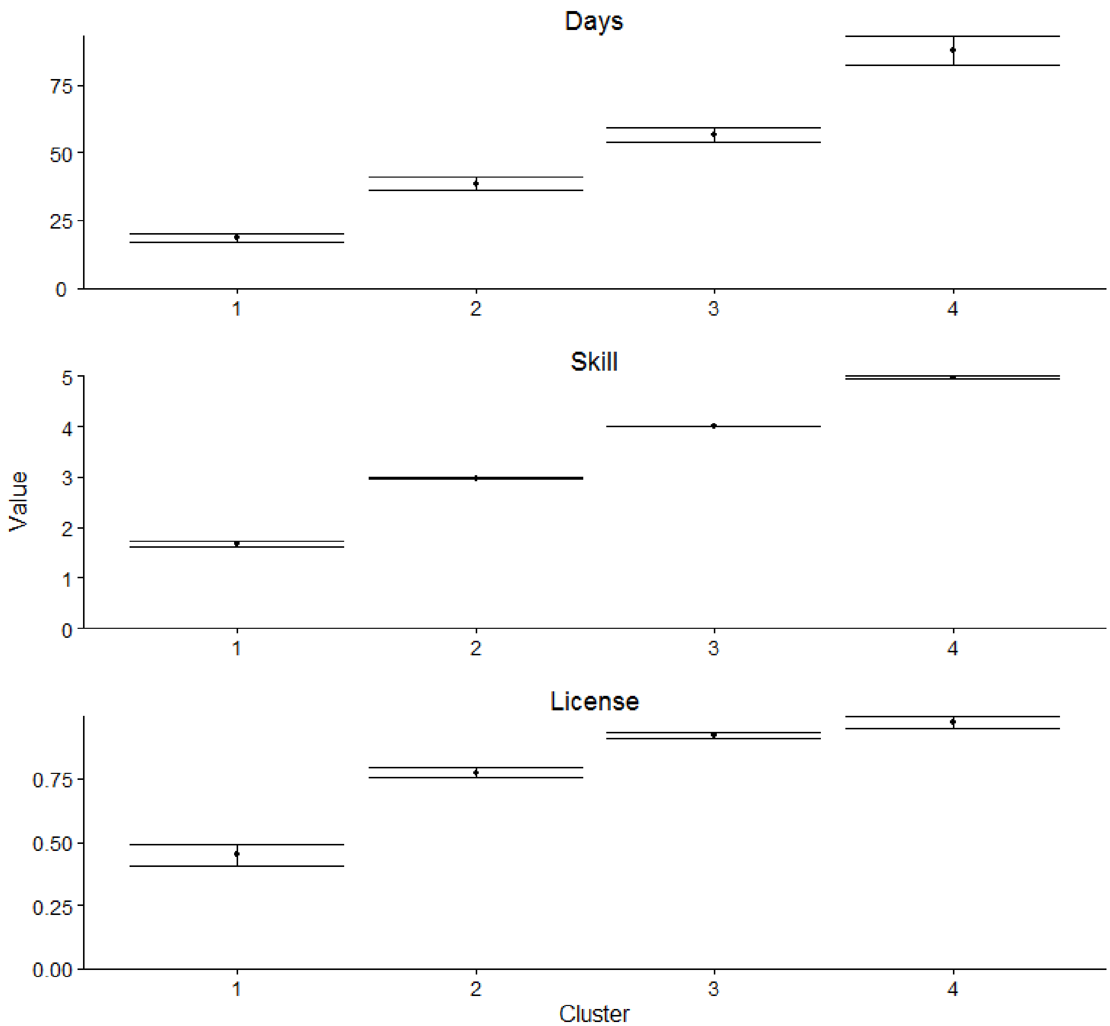

Figure 4-8. Recreational specialization of angler cluster defined by cluster analysis in the Salt Valley regional fishery. Days (mean ± SE) are the total number of days reported fishing by anglers answering the return-mail survey, skill (mean ± SE) is the self-reported skill on a 5-point Likert scale from 1 (amateur) to 5 (very skilled), and license is a measure of importance of fishing to anglers' lives, calculated as a self-reported number of years (mean ± SE) holding a fishing license divided by the angler's age (subtracting 16 years no license is needed until age 16 in Nebraska).

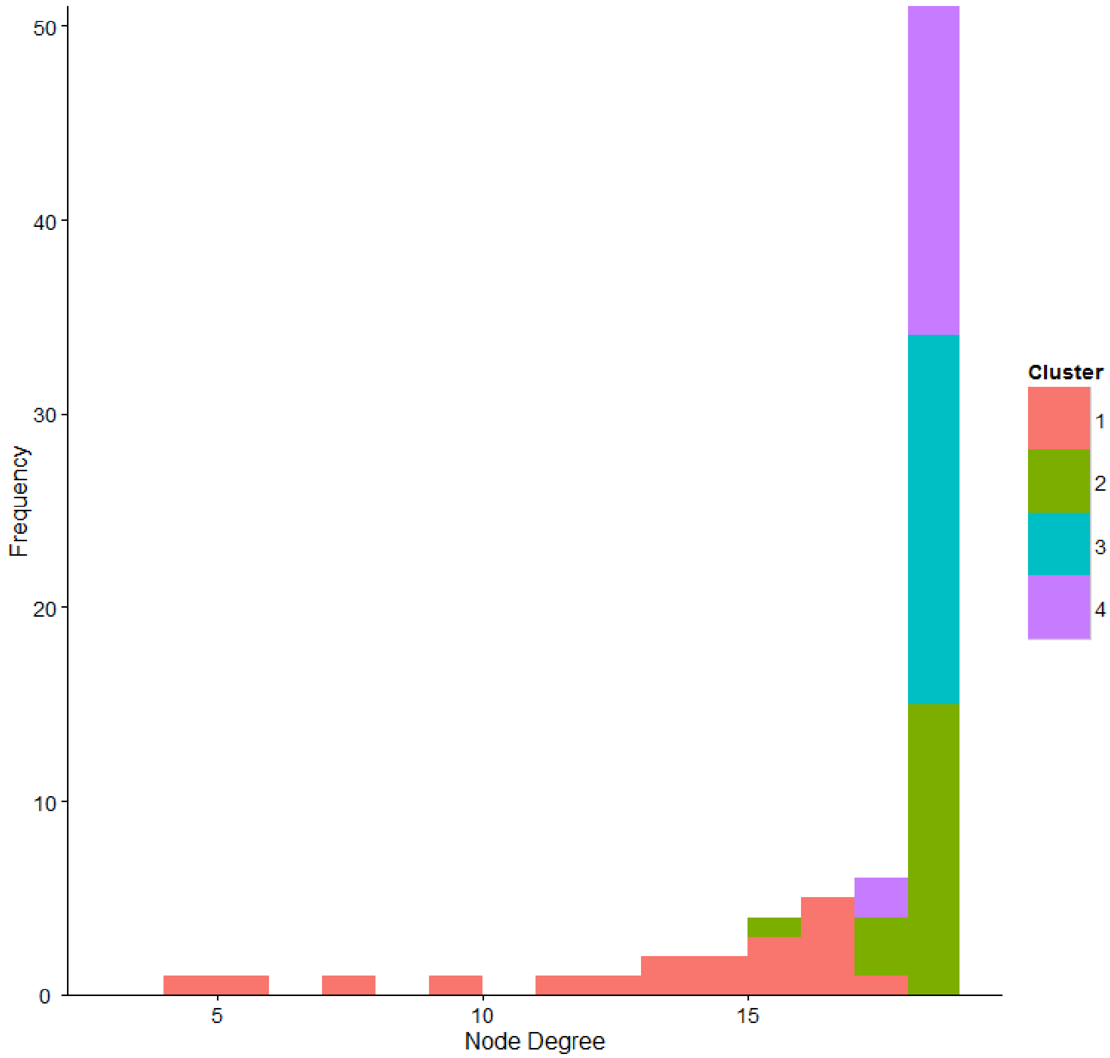

Figure 4-9. Degree distribution of lakes in networks of individual angler clusters of the Salt Valley regional fishery. Angler clusters were derived using cluster analysis based on recreational specialization.

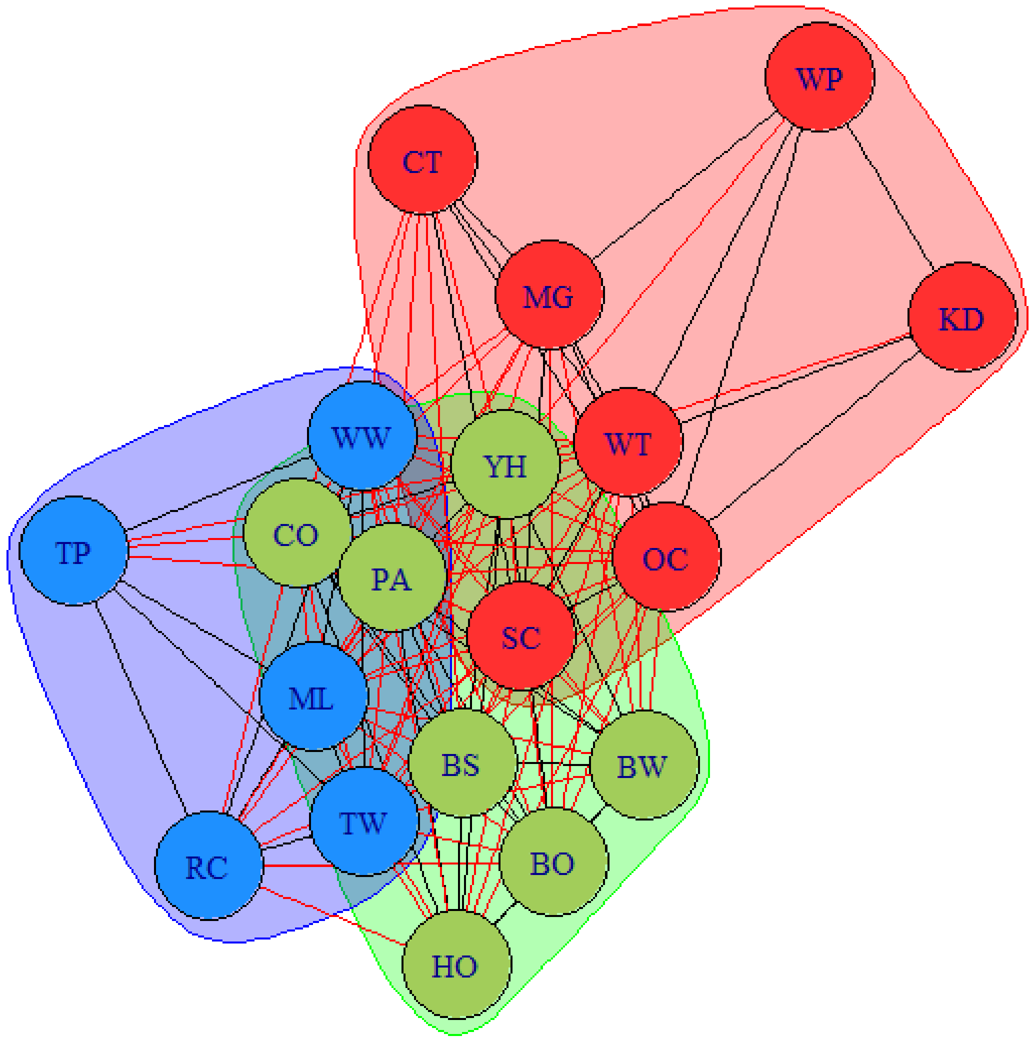

Figure 4-10. Reservoir network for angler cluster one of the Salt Valley regional fishery. Community detection determined by the fast-and-greedy algorithm. Nodes (circles) represent reservoirs and edges (lines) connecting two reservoirs represent weighted measure of association between those two reservoirs. Red, blue, and green nodes indicate three distinct groups of reservoirs. Black edges are those connecting two reservoirs within the same group, red edges are those connecting two reservoirs in different groups.

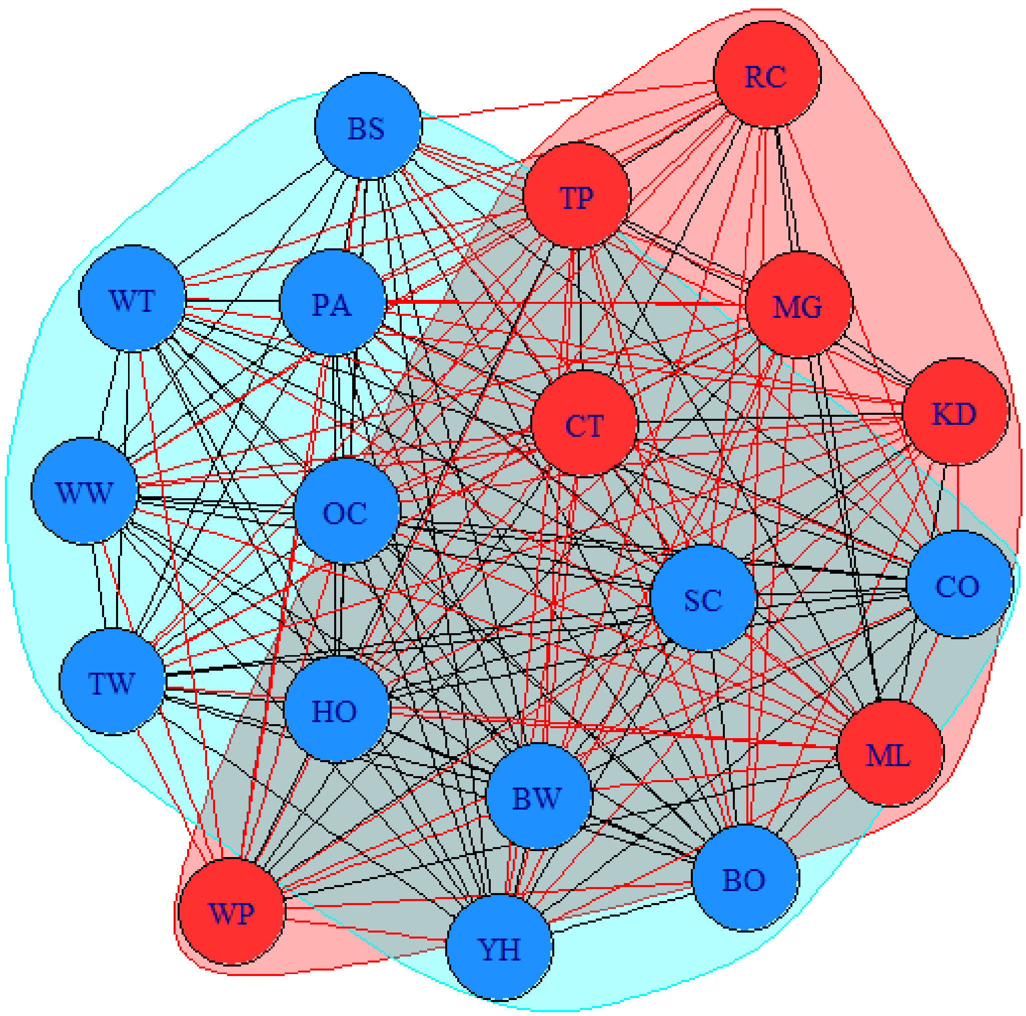

Figure 4-11. Reservoir network for angler cluster two of the Salt Valley regional fishery. Community detection determined by the fast-and-greedy algorithm. Nodes (circles) represent reservoirs and edges (lines) connecting two reservoirs represent weighted measure of association between those two reservoirs. Red and blue nodes indicate two distinct groups of reservoirs. Black edges are those connecting two reservoirs within the same group, red edges are those connecting two reservoirs in different groups.

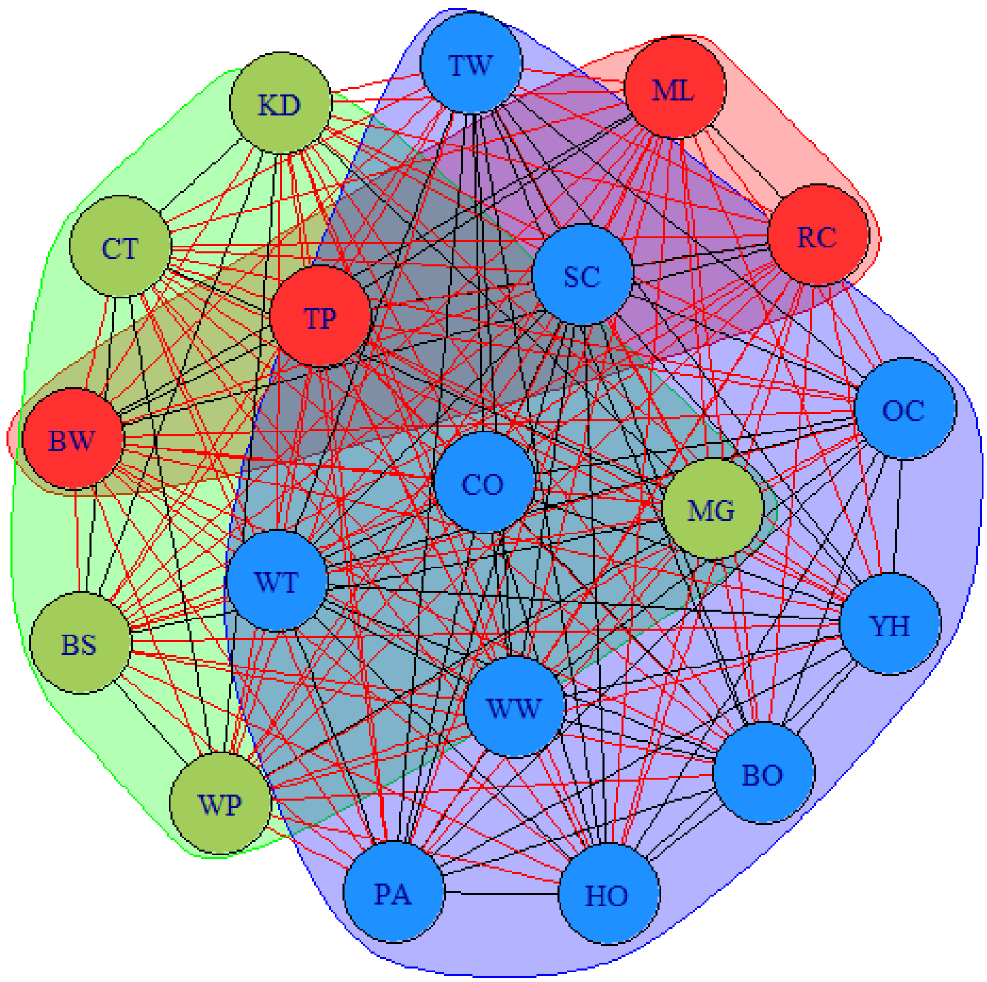

Figure 4-12. Reservoir network for angler cluster three of the Salt Valley regional fishery. Community detection determined by the fast-and-greedy algorithm. Nodes (circles) represent reservoirs and edges (lines) connecting two reservoirs represent weighted measure of association between those two reservoirs. Red, blue, and green nodes indicate three distinct groups of reservoirs. Black edges are those connecting two reservoirs within the same group, red edges are those connecting two reservoirs in different groups.

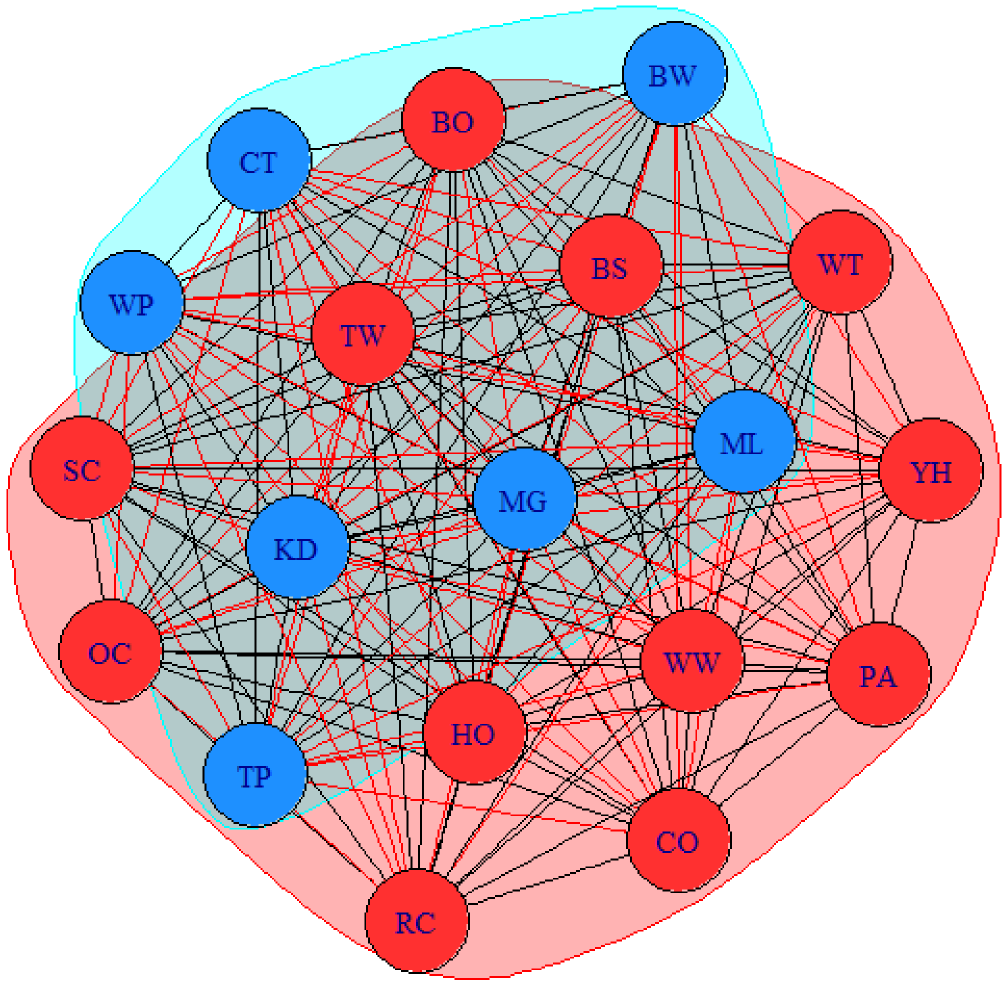

Figure 4-13. Reservoir network for angler cluster four of the Salt Valley regional fishery. Community detection determined by the fast-and-greedy algorithm. Nodes (circles) represent reservoirs and edges (lines) connecting two reservoirs represent weighted measure of association between those two reservoirs. Red and blue nodes indicate two distinct groups of reservoirs. Black edges are those connecting two reservoirs within the same group, red edges are those connecting two reservoirs in different groups.

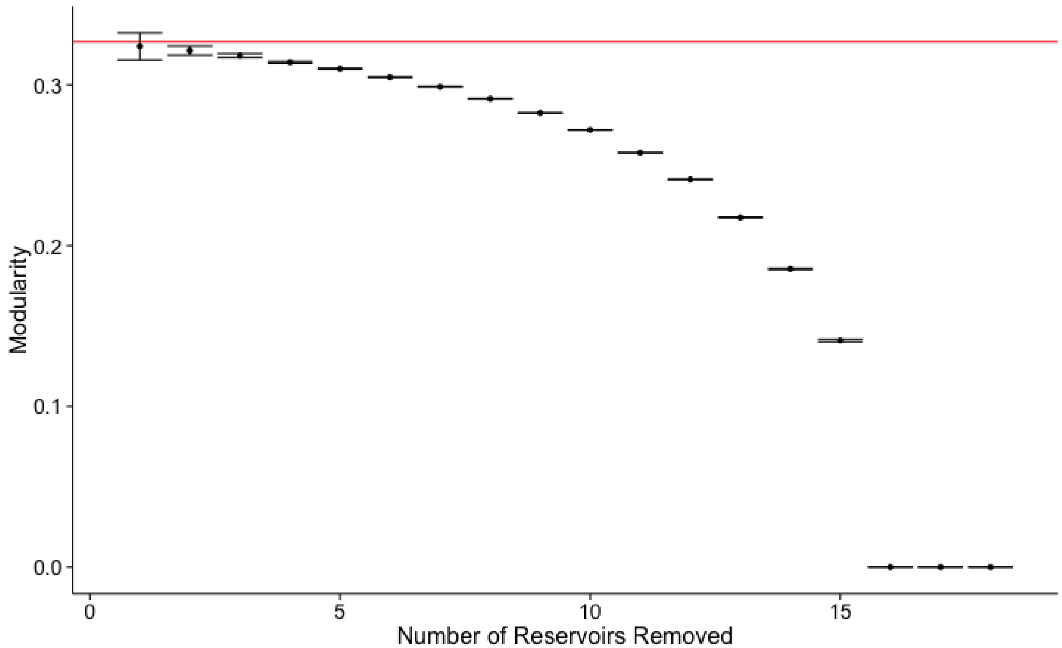

Figure 4-14. Modularity (mean ± SE) for each level of node removal experiment in the network of the Salt Valley regional fishery. Red line indicates modularity of full observed network.

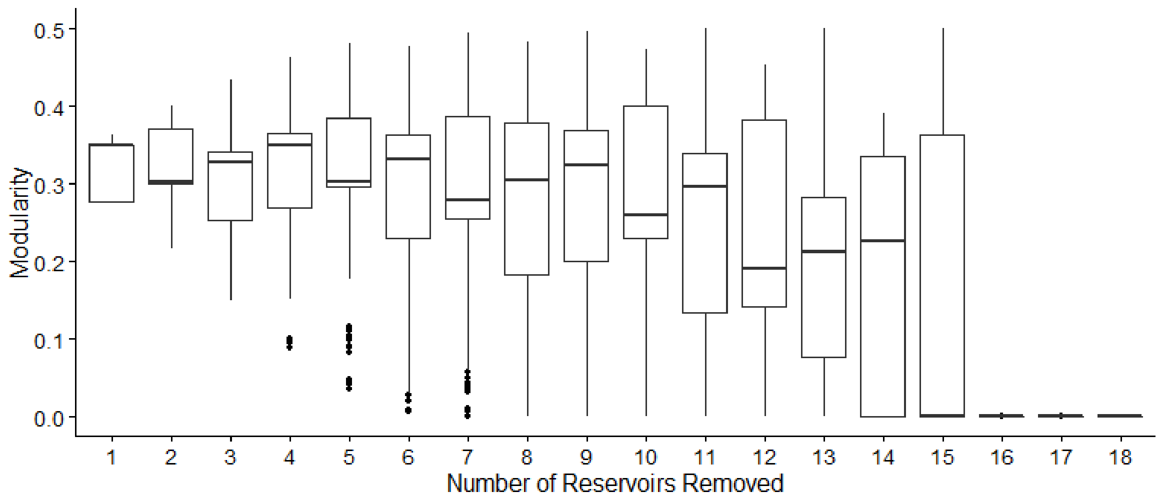

Figure 4-15. Distribution of modularity for each level of node removal experiment in the network of the Salt Valley regional fishery. Horizontal black lines represent median, boxes represent range from 25th to 75th percentile, whiskers extend from the box to highest or lowest value within 1.5 × IQR (interquartile range), points represent outliers.

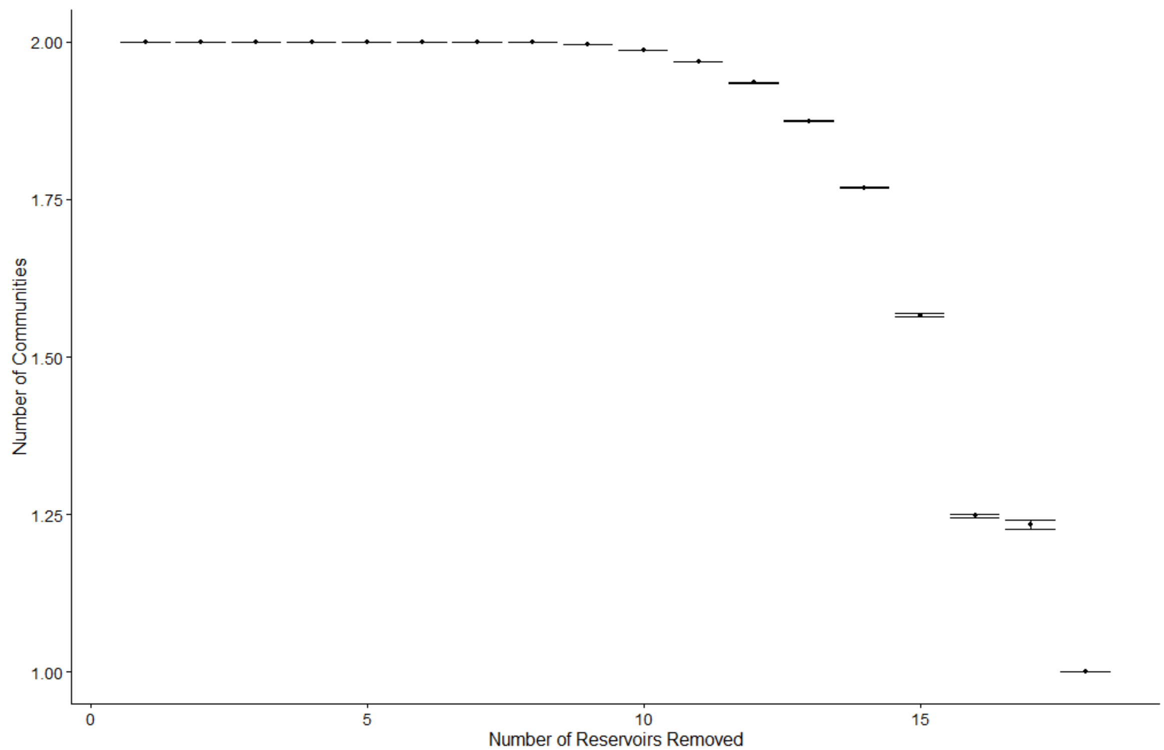

Figure 4-16. Number of communities (mean ± SE) for each level of node level removal experiment in the network of the Salt Valley regional fishery.

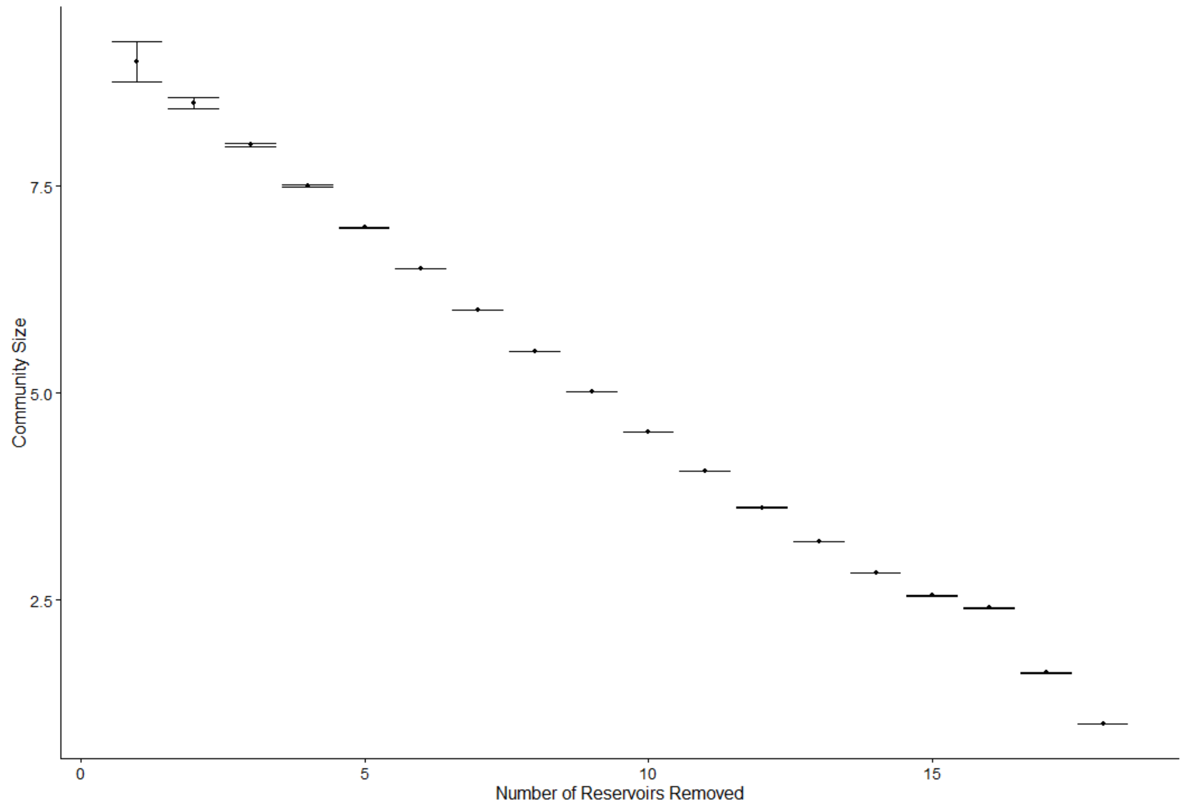

Figure 4-17. Community size (mean ± SE) for each level of node level removal experiment in the network of the Salt Valley regional fishery.

Chapter 5: Conclusions and Recommendations

Buffering inland fisheries against large-scale changes in ecosystem function, climate regimes, and societal valuations of natural resources requires progressive management approaches that incorporate mechanisms of fish and angler population dynamics at a large spatial and temporal scale. Current paradigms of inland fishery management (e.g., trophy-fishery management, catch-and-release, put-and-take fishery management) generally utilize waterbody-specific, fish-centric frameworks that intend to regulate anglers indirectly through management of fish populations through stocking and regulation. Explicitly managing anglers requires consideration of their behavior (e.g., spatial and temporal patterns of participant use), which, unlike fish populations, operates at a scale larger than a single waterbody (Carpenter and Brock 2004; Martin and Pope 2011). Therefore, a first step in creating a resilient and sustainable fishery requires gaining a thorough understanding of angler behavior so that managers can anticipate current and future management needs. As a result of these management information needs, I conclude this dissertation with a summary of my research and propose management and research recommendations to create a more holistic, fishery management framework.

Conclusions and Management Recommendations—A thorough understanding of participant behavior begins with understanding how participants are currently using the social-ecological system. I add to the knowledge of participant behavior in a social-ecological system by using three unique methods. The second chapter of my dissertation focuses on how information from an online social network devoted to fishing can be used to predict fishing effort. Posts to the social network correlated to fishing effort within a reservoir, indicating that posts may be used as a predictor of fishing effort across months within a reservoir. Furthermore, posts were correlated to effort across reservoirs, indicating that posts may be used as a relative index of fishing effort across a region. This use of a free, online tool to assess fishing effort could greatly reduce time and effort required by management agencies to collect angler effort data.

The third chapter of my dissertation describes areas of use for reservoirs using home-range analyses techniques. Understanding the potential area from which a reservoir draws anglers has implications for recruitment of anglers as well as potential enforcement of regulations. The area-of-influence of a reservoir is not related to reservoir size or number of parties interviewed, thus suggesting that other factors such as access, fish community, and angler preferences drive differences in size of area-of-influence. This method could be adopted by natural resource agencies to understand where participants are coming from to use reservoirs for fishing, grasslands for hunting, and parks for camping.

The fourth chapter of my dissertation uses a new method to examine angler participation across multiple reservoirs. Traditionally these studies have used models that do not explicitly allow modeling of the anglers and reservoirs. Network analysis describes both the anglers and the reservoirs they visit, thus giving a complete picture of the social-ecological system. The reservoir network in the Salt Valley is composed of two communities, large and small reservoirs, whereas the angler network of is composed of four communities that vary in skill and avidity. This angler-reservoir interaction is important to understand for angler recruitment and retention and potential changes in the regional fishery due to management actions.

Based on the results and lessons learned from my dissertation research, below is a bulleted list of management recommendations for natural resource agencies to follow for fisheries management presented in order of importance. These are written with a focus on the Fisheries Division of the Nebraska Game and Parks Commission (NGPC), but could be adopted to fit many other natural resource management agencies as well.

- Determine what regional fisheries exist within the state of Nebraska.
    - Adopt a two-tiered approach for determining what regional fisheries exist within the state. First, the Delphi method (Dalkey and Helmer 1963), a method that uses a series of structured interviews and summaries to elucidate the consensus response, should be used to create an interactive process in which fishery managers from across the state discuss and determine boundaries based on expert knowledge. Second, an in-depth set of questions examining spatial participation of anglers should be added to the next Nebraska Statewide Angler Survey to determine boundaries based on angler behavior.
    - Regional fisheries are scale-dependent, both temporally and spatially, and appropriate scales for management should be defined and considered when defining regional fisheries.
- Determine what angler groups exist within the state of Nebraska.
    - The four angler groups described by recreational specialization within the relatively urban Salt Valley region are likely not encompassing of all

angler groups across the state of Nebraska as angling participation varies across an urban-rural gradient (Arlinghaus et al. 2008).

- Further, angler groups may be better described and distinguished using data not collected in the current survey. Species and waterbody-type preferences may predict angler groups in a more relevant way than typical classification using demographics or recreational specialization (Connelly et al. 2013).

- Develop quantifiable management objectives at the regional scale.
  - Management personnel must set quantifiable objectives at the regional scale for evaluation purposes.
  - Management objectives should include both short- (5-year) and long-term (25-year) objectives for the region.
  - In regions with frequent reservoir renovations, such as the Salt Valley and the Fremont Lakes regions, management plans should account for the limited lifespan of reservoir renovations by including a long-term plan of renovations that aims to maintain a diversity of fishing opportunities within the region.
- Develop waterbody-specific management objectives to develop and maintain a diverse group of anglers and water-bodies throughout the region.
  - The regional fishery is best when a diverse group of fishing opportunities exists to maximize the number of anglers that are happy with current fishing opportunities in the region.

  - Management should consider the entire region when setting waterbody-specific management objectives and strive to maintain diversity.
- Management should set quantifiable management objectives and determine most appropriate evaluation tool.
  - Some water-bodies may best be managed to meet a minimum level of fishing effort (e.g., Branched Oak Lake has a current management objective to increase angling effort by 20,000 hours over current levels). Other water-bodies may best be managed to meet a minimum level of catch per unit effort for target species (e.g., Harlan County Reservoir has a management objective to maintain catch rates of walleye at 0.21 fish per angler per hour).
  - Evaluation of these two management objectives requires data from creel surveys; yet require a different amount of effort to collect this data. The management objective that requires data on angler effort can be collected using a regional approach, similar to the bus-route pressure count I used in the Salt Valley, to collect data on multiple reservoirs using the same technician. Conversely, the management objective that requires data on catch rates has to be collected on a waterbody-specific approach, decreasing the number of water-bodies sampled or increasing costs to the agency to gather data.
  - This tradeoff between effort and catch data is inherent in the way creel data are collected and analyzed. Management should be aware of this and

if effort data is sufficient for their management objectives, a regional effort-only approach should be adopted.

- Changes in access should not be changed at more than 5 reservoirs in the Salt Valley at one time.
    - The resilience of the system, quantified by network modularity, greatly declines after removal of 5 reservoirs. Thus, any changes that limit angling participation, through changes in access, on reservoirs should be kept to less than 5 reservoirs at one time.
    - Furthermore, given spatial context of substitute sites for less skilled, potentially newly recruited anglers (angler cluster 1 from Chapter 4), it is imperative that management does not change access on multiple reservoirs in close proximity.
- Develop management objectives for distribution of angler demographics and skill levels among different reservoirs.
    - Reservoirs should differ in the distribution of angler demographics (i.e., gender, age, income, etc.) as well as angler skill and specialization (e.g., angler clusters in Chapter 4).
    - Urban reservoirs, such as Holmes and Bowling Lakes, are desirable as places for less skilled, newly recruited anglers to fish potentially due to ease of access. These reservoirs should be managed to maintain this diversity of anglers by creating high catch rates of species such as bluegill and largemouth bass.

   - More remote Salt Valley reservoirs, such as Wildwood Lake, are currently managed with a special regulation to create a trophy fishery and, if desired, should be managed to satisfy highly skilled group of anglers.

Conclusions and Research Recommendations—Angler behavior on a regional scale is not well understood and further research is needed to understand the intricacies of the angler-reservoir interaction on a larger spatial- and temporal-scale. Future research into angler behavior on a regional scale should use methods developed by this project. Specifically, methods to collect fishing effort data on a regional scale using a bus-route design (i.e., drive route around all reservoirs and count anglers during one survey period) proved to be effective at characterizing the regional fishery. I would also recommend continuing collection of data on substitute sites and angler home Zone Improvement Plan (ZIP) code. These data are invaluable for determining the effects of potential management actions on a regional scale.

This dissertation research opened the door to many further questions on angler behavior at the individual waterbody, regional, and state levels. Below I provide a bulleted list of recommendations for future research into angler behavior presented in the order I believe should be addressed.

- Conduct survey of Nebraska Game and Parks Commission fishery management personnel to determine the value of angler surveys to management decisions.
   - Currently, it is unclear to what extent management personnel use creel survey data. A survey of management personnel would allow research to

be focused on what management finds most useful in day-to-day management of fishery resources. For example, do managers put more weight on information about fishing effort or catch rates when making management decisions? If managers use effort data, and have associated management objectives relative to fishing effort, a regional scale approach collecting only effort data would be more effective than intensive creel surveys.

- Examine further benefits of using social media as a tool to gather data on fisheries to reduce costs of associated creel surveys.
    - Anglers use the Internet and social media to gather and exchange information on fishing (Martin et al. 2012). Specifically, the use of angler forums has increased drastically over the past decade. Natural resource agencies should be using social media to their advantage in marketing, understanding their clientele, and gathering data. However, further questions need to be addressed.
        - What are limitations of using angler-posted information as surrogate for fishing effort?
        - What are effects of repeated posts by the same user on estimates of monthly fishing effort?
        - Can sentiment analysis be used to define positive or negative posts about reservoirs and create a fine-scale temporal association between posts and effort on a larger reservoir like Branched Oak Lake?

        - Can angler-posted information be used as a means to look at catch rates, or catch rates of large fish?
        - Is social media an effective way to survey anglers on potential management actions and increase trust in the management agency?

- Examine remote-sensing technology to efficiently collect angler effort, and potentially catch rates, at low-visitation waterbodies.
    - Costs of conducting intensive surveys at low-visitation waterbodies, such as Red Cedar, Merganser, and Wild Plum Lakes, is often deemed unnecessary and therefore creel surveys are not conducted due to logistical and budgetary constraints. Remote-sensing technology, such as time-lapse photography, should be tested to determine if they can be used to accurately assess angler effort. Furthermore, standard protocols for using these technologies and analyzing associated data needs to be developed.
- Repeat regional angler survey approach in the Papio watershed in Omaha, Nebraska to determine differences between Salt Valley and a more urban Papio watershed. Based on data collected in the Salt Valley, we believe the following adjustments should be made to increase data-quality and can be made without compromising our ability to make comparisons between regions:
    - Sampling should be conducted at one reservoir per creel shift. For the Salt Valley project, creel technicians were assigned two reservoirs per shift, with the exception of Branched Oak Lake, and split time between these two reservoirs. Although this allowed us to almost double the number of lakes sampled in a year, the number of individual anglers surveyed was

decreased because of missed time for interviews that was devoted to travel between reservoirs.

- Increase number of pressure counts per survey period to four to capture variability in fishing effort throughout an 8-hour period. The addition of two more pressure counts, to four total, would allow for the variation in effort within a day to be accounted and carried through calculations of monthly effort estimates. However, if at a minimum two counts are scheduled and completed within a survey period, this is still an improvement over the standard of one count period with no associated variation.
- Reducing the number of strata within day from three 8-hour periods to two approximately 9-hour periods encompassing sunrise to three-hour post-sunset. Reducing strata to two would allow for an increase in the number of days sampled per month (thereby increasing statistical power) in each strata with the same total effort by creel technicians.
- Reduce sampling months for intensive creel surveys to April to November instead of year-round. Continue bus-route pressure-count route year-round to estimate pressure. The majority of fishing effort in eastern Nebraska occurs during the spring-fall months. Ice fishing does not contribute a large portion of angler harvest or effort in these systems, therefore, I recommend only conducting bus-route pressure counts year-round to monitor ice-fishing.

- Use an adaptive management approach to research effects of changing regulations and stocking strategies on angler behavior and participation (Martin and Pope 2011).
    - Determining an effective way to lure anglers from one waterbody to another through management actions, such as either creating more or less restrictive regulations, is imperative for preventing undesirable effects of changes within a regional fishery.

The research in this dissertation laid the groundwork for better management of our fishery, and wildlife, resources. The methods developed here are not limited to only anglers, but should be applied to hunters, wildlife watchers, and park users. For example, a regional look at hunter participation across private lands enrolled in the Conservation Reserve Program and Wildlife Management Areas is currently underway in southwestern Nebraska using many of the same methods as this angler survey project. Further research into the dynamics of user participation across the whole of natural resources management is needed to understand and better serve our clientele.

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Appendix A. Summary of creel survey effort and number of counts and interviews conducted.

Table A-1. Number of days in survey period, days surveyed, counts conducted, and parties interviewed during the Salt Valley Angler Survey project during 1 April through 31 December in 2009 and 1 January through 31 December 2010, 2011, and 2012.

Year	Days in survey period	Days surveyed	Counts conducted	Parties interviewed
		Bluestem		
2010	365	134	286	14
2012	365	134	286	15
		Branched Oak		
2009	275	88	182	177
2010	365	128	282	318
2011	365	133	286	174
2012	365	136	285	193
		Conestoga		
2009	275	96	197	96
		Cottontail		
2010	365	135	288	61
		Holmes		
2009	275	89	190	176
2011	365	186	447	339
		Killdeer		
2012	365	135	287	18
		Meadowlark		
2012	365	129	280	32

Year	Days in survey period	Days surveyed	Counts conducted	Parties interviewed
		Merganser		
2010	365	135	288	20
2011	365	134	283	19
		Olive Creek		
2012	365	184	451	203
		Pawnee		
2009	275	95	196	95
2010	365	133	284	115
		Red Cedar		
2009	275	86	177	7
		Stagecoach		
2009	275	86	189	84
2010	365	134	286	177
		Timber Point		
2009	275	86	175	59
		Wagon Train		
2011	365	130	278	220
2012	365	188	453	516
		Wild Plum		
2011	365	134	284	32
		Wildwood		
2010	365	133	284	157
2011	365	131	284	143
2012	365	130	280	207
		Yankee Hill		
2011	365	184	450	201

Appendix B. Summary of annual estimates of number of anglers fishing Salt Valley lakes during 2009-2012.

Table B-1. Total number of anglers (SE), bank anglers (SE), and boat anglers (SE) for the Salt Valley lakes during 1 April through 31 December in 2009 and 1 January through 31 December 2010, 2011, and 2012.

Year	Total anglers		Bank anglers		Boat anglers	
			Bluestem			
2010	2,126	(264)	1,718	(235)	407	(70)
2012	3,304	(462)	2,758	(401)	545	(115)
			Branched Oak			
2009	13,900	(1,217)	7,978	(856)	5,922	(644)
2010	10,802	(837)	5,941	(522)	4,861	(453)
2011	14,340	(1,213)	7,213	(652)	7,126	(709)
2012	13,277	(1,126)	6,603	(568)	6,673	(771)
			Conestoga			
2009	5,554	(500)	3,799	(355)	1,755	(218)
			Cottontail			
2010	1,418	(175)	956	(126)	461	(99)
			Holmes			
2009	32,891	(2,989)	30,426	(2,856)	2,464	(310)
2011	27,443	(1,327)	25,374	(1,255)	2,069	(195)
			Killdeer			
2012	1,100	(184)	925	(165)	176	56
			Meadowlark			
2012	1,786	(219)	1,212	(189)	574	(79)
			Merganser			
2010	865	(151)	668	(128)	196	(64)
2011	502	(96)	441	(91)	62	(20)
			Olive Creek			
2012	6,230	(424)	3,687	(307)	2,543	(204)

Year	Total anglers		Bank anglers		Boat anglers	
			Pawnee			
2009	11,508	(1,525)	9,190	(1,434)	2,318	(225)
2010	10,959	(1,053)	8,971	(933)	1,988	(291)
			Red Cedar			
2009	654	(.)	510	(.)	144	(.)
			Stagecoach			
2009	6,791	(658)	4,907	(467)	1,883	(344)
2010	8,299	(715)	6,162	(595)	2,137	(231)
			Timber Point			
2009	1,714	(.)	574	(.)	1,130	(.)
			Wagon Train			
2011	17,393	(1,260)	11,134	(845)	6,260	(573)
2012	20,168	(1,144)	12,670	(775)	7,469	(452)
			Wild Plum			
2011	846	(131)	461	(89)	386	(95)
			Wildwood			
2010	6,584	(512)	3,161	(290)	3,422	(328)
2011	8,112	(612)	3,923	(333)	4,189	(413)
2012	8,778	(670)	4,235	(456)	4,543	(394)
			Yankee Hill			
2011	4,951	(276)	2,705	(209)	2,246	(137)

Appendix C. Summary of annual estimates of angling effort for Salt Valley lakes during 2009-2012.

Table C-1. Total angling effort (SE; hours), bank angling effort (SE), and boat angling effort (SE) for the Salt Valley lakes during 1 April through 31 December in 2009 and 1 January through 31 December 2010, 2011, and 2012.

Year	Total Effort		Bank Effort		Boat Effort	
			Bluestem			
2010	4,717	(586)	3,813	(524)	904	(156)
2012	8,685	(1,214)	7,251	(1,053)	1,434	(302)
			Branched Oak			
2009	57,513	(5,036)	33,010	(3,552)	24,503	(2,663)
2010	43,412	(3,366)	23,876	(2,098)	19,536	(1,821)
2011	55,284	(4,678)	27,810	(2,515)	27,474	(2,733)
2012	55,476	(4,703)	27,592	(2,371)	27,885	(3,222)
			Conestoga			
2009	19,532	(1,758)	13,360	(1,248)	6,172	(768)
			Cottontail			
2010	3,969	(490)	2,678	(354)	1,290	(278)
			Holmes			
2009	70,139	(6,375)	64,884	(6,092)	5,255	(661)
2011	60,709	(2,936)	56,133	(2,776)	4,576	(432)
			Killdeer			
2012	2,465	(412)	2,071	(370)	393	(125)
			Meadowlark			
2012	5,911	(724)	4,011	(625)	1,900	(262)
			Merganser			
2010	2,110	(368)	1,630	(313)	480	(158)
2011	1,407	(269)	1,234	(254)	172	(58)
			Olive Creek			
2012	20,787	(1,415)	12,302	(1,024)	8,485	(680)

Year	Total Effort		Bank Effort		Boat Effort	
			Pawnee			
2009	36,326	(4,815)	29,009	(4,525)	7,317	(710)
2010	33,532	(3,222)	27,448	(2,854)	6,084	(890)
			Red Cedar			
2009	2,334	(.)	1,820	(.)	514	(.)
			Stagecoach			
2009	26,746	(2,590)	19,328	(1,841)	7,418	(1,355)
2010	28,460	(2,455)	21,161	(2,042)	7,329	(794)
			Timber Point			
2009	6,272	(.)	2,139	(.)	4,133	(.)
			Wagon Train			
2011	69,761	(5,054)	44,655	(3,391)	25,106	(2,297)
2012	80,972	(4,593)	50,987	(3,111)	29,985	(1,816)
			Wild Plum			
2011	2,283	(353)	1,243	(240)	1,040	(257)
			Wildwood			
2010	25,849	(2,009)	12,412	(1,138)	13,437	(1,287)
2011	28,786	(2,172)	13,922	(1,182)	14,864	(1,467)
2012	33,170	(2,632)	16,003	(1,722)	17,166	(1,489)
			Yankee Hill			
2011	15,691	(876)	8,572	(661)	7,118	(435)

Appendix D. Summary of annual estimates of catch and harvest for Salt Valley lakes surveyed 2009-2012.

Table D-1. Total catch (SE), harvest (SE), and catch per unit effort (SE) and harvest per unit effort (SE) by seeking anglers for the Salt Valley lakes during 1 April through 31 December in 2009 and 1 January through 31 December 2010, 2011, and 2012. Species codes are: BCF = blue catfish, BHD = bullhead species, BLG = bluegill, CCF = channel catfish, CCP = common carp, CRP = crappie (black and white combined), GSF = green sunfish, HSB = hybrid striped bass, LMB = largemouth bass, RBT = rainbow trout, WHB = white bass, and WHP = white perch.

Species	Catch		Harvest		CPUE		HPUE	
			Bluestem – 2010					
CCF	223	(108)	0	(0)	0.00	(0.00)	0.00	(0.00)
LMB	54	(26)	0	(0)	0.01	(0.00)	0.00	(0.00)
TOTAL	288	(118)	0	(0)	0.01	(0.01)	0.00	(0.00)
			Bluestem – 2012					
BLG	1,176	(454)	83	(32)	0.01	(0.00)	0.00	(0.00)
LMB	222	(1550	0	(0)	0.00	(0.00)	0.00	(0.00)
TOTAL	1,537	(547)	147	(57)	0.41	(0.05)	0.02	(0.01)
			Branched Oak – 2009					
BLG	5,502	(908)	0	(0)	0.00	(0.00)	0.00	(0.00)
CCF	3,448	(848)	1,007	(454)	0.10	(0.03)	0.06	(0.00)
CRP	11,183	(4,432)	1,314	(480)	0.93	(0.11)	0.06	(0.01)
HSB	3,955	(2,112)	0	(0)	0.04	(0.03)	0.00	(0.00)
TOTAL	28,166	(2,986)	2,719	(725)	0.52	(0.17)	0.00	(0.00)
			Branched Oak – 2010					
CCF	2,449	(498)	542	(176)	0.00	(0.00)	0.00	(0.00)
CRP	16,303	(3,212)	2,289	(1,262)	1.42	(0.34)	0.27	(0.22)
WHP	4,906	(1,233)	429	(187)	0.00	(0.00)	0.00	(0.00)
TOTAL	29,655	(3,800)	4,482	(1,300)	0.73	(0.15)	0.03	(0.08)
			Branched Oak – 2011					
CRP	90,543	(61,615)	3,611	(1,233)	1.91	(1.16)	0.30	0.14
LMB	6,134	(1,861)	39	(26)	0.57	(0.10)	0.00	0.00
WHP	8,974	(2,358)	1,891	(1,063)	0.00	(0.00)	0.00	0.00
TOTAL	113,094	(61,612)	6,680	(1,917)	1.28	(0.19)	0.27	0.06

Species	Catch		Harvest		CPUE		HPUE	
			Branched Oak – 2012					
CRP	25,529	(8,285)	5,150	(1,478)	0.79	(0.36)	0.22	(0.12)
WHP	23,915	(16,042)	19,369	(16,017)	0.79	(0.00)	0.79	(0.00)
TOTAL	61,020	(18,414)	26,914	(16,116)	0.76	(0.13)	0.12	(0.04)
			Conestoga – 2009					
BCF	410	(247)	8	(5)	0.00	(0.00)	0.00	(0.00)
BLG	3140	(845)	416	(311)	0.36	(0.00)	0.36	(0.00)
CCF	1800	(350)	267	(136)	0.09	(0.00)	0.00	(0.00)
CCP	1391	(596)	185	(77)	.	(0.18)	0.01	(0.01)
LMB	513	(125)	23	(21)	0.09	(0.00)	0.00	(0.00)
TOTAL	7,752	(1,502)	921	(366)	0.63	(0.21)	0.02	(0.02)
			Cottontail - 2010					
BLG	3,529	(741)	474	(207)	0.14	(0.00)	0.00	(0.00)
CCF	452	(294)	417	(293)	0.20	(0.00)	0.20	(0.00)
GSF	1,008	(337)	74	(55)	0.00	(0.00)	0.00	(0.00)
LMB	2,209	(552)	0	(0)	0.94	(0.25)	0.00	(0.00)
TOTAL	7,638	(1,548)	964	(368)	2.11	0.21)	0.13	(0.12)
			Holmes - 2009					
BLG	47,157	(9,502)	2,007	(825)	1.38	(0.13)	0.06	(0.01)
LMB	11,144	(2,437)	25	(18)	0.98	(0.54)	0.00	(0.00)
TOTAL	64,493	(10,898)	2,398	(817)	1.63	(0.74)	0.06	(0.07)
			Holmes – 2011					
BLG	37,516	(3,859)	3,965	(777)	2.17	(0.25)	0.28	(0.11)
CRP	14,027	(2,782)	101	(32)	2.00	(0.44)	0.00	(0.00)
GSF	5,487	(1,598)	3,658	(1,470)	0.00	(0.00)	0.00	(0.00)
LMB	14,855	(2,361)	25	(13)	0.90	(0.16)	0.00	(0.00)
RBT	6,161	(1,202)	3,163	(733)	0.26	(0.06)	0.09	(0.04)
TOTAL	81,780	(6,723)	11,785	(2,159)	1.70	(0.42)	0.18	(0.13)
			Killdeer – 2012					
BLG	905	(758)	2	(1)	0.00	(0.00)	0.00	(0.00)
CRP	2,430	(1,537)	49	(33)	0.11	(0.00)	0.00	(0.08)
LMB	716	(259)	0	(0)	0.47	(0.09)	0.09	(0.00)
TOTAL	4,280	(2,323)	52	(34)	0.80	(0.00)	0.00	(0.00)
			Meadowlark – 2012					
BLG	3,020	(1,614)	1,094	(962)	1.55	(0.00)	0.79	(0.00)
LMB	915	(296)	0	(0)	0.21	(0.05)	0.00	(0.00)
TOTAL	4,242	(1,658)	1,105	(962)	0.20	(0.00)	0.00	(0.00)
			Merganser – 2010					
BLG	970	(348)	0	(0)	0.24	(0.00)	0.00	(0.00)
CRP	120	(78)	0	(0)	0.00	(0.00)	0.00	(0.00)
LMB	494	(158)	0	(0)	0.47	(0.00)	0.00	(0.00)
TOTAL	1,631	(434)	0	(0)	0.65	(0.02)	0.00	(0.00)
			Merganser - 2011					
BLG	706	(505)	0	(0)	0.00	(0.00)	0.00	(0.00)
CRP	88	(39)	0	(0)	0.02	(0.00)	0.00	(0.00)
LMB	261	(120)	0	(0)	0.15	(0.00)	0.00	(0.00)
TOTAL	1,122	(562)	39	(18)	0.77	(0.00)	0.00	(0.00)

Species	Catch		Harvest		CPUE		HPUE	
Olive Creek - 2012								
BLG	11,915	(1,396)	1,738	(567)	3.78	(0.34)	0.02	(0.00)
LMB	14,183	(2,505)	0	(0)	1.41	(0.19)	0.00	(0.00)
TOTAL	27,816	(3,083)	2,244	(578)	1.39	(0.27)	0.10	(0.03)
Pawnee - 2009								
BLG	899	(525)	0	(0)	0.68	(0.00)	0.00	(0.00)
CCP	1,025	(495)	429	(196)	0.04	(0.02)	0.02	(0.01)
CRP	1,536	(570)	0	(0)	0.08	(0.00)	0.00	(0.00)
LMB	1,207	(764)	0	(0)	0.04	(0.00)	0.00	(0.00)
WHB	484	(259)	0	(0)	0.00	(0.00)	0.00	(0.00)
WHP	2,550	(1,201)	1,170	(998)	0.16	(0.09)	0.00	(0.00)
TOTAL	9,316	(2,098)	1,689	(1,018)	0.51	(0.24)	0.05	(0.05)
Pawnee - 2010								
BLG	1,241	(317)	42	(26)	0.11	(0.00)	0.00	(0.00)
CCP	718	(283)	712	(283)	0.30	(0.02)	0.30	(0.02)
CRP	2,011	(992)	1,183	(988)	0.50	(0.43)	0.09	(0.09)
WHB	1,329	(576)	0	(0)	0.02	(0.00)	0.00	(0.00)
WHP	7,503	(2,270)	3,500	(1,533)	1.41	(0.00)	1.34	(0.00)
TOTAL	14,159	(2,670)	5,665	(1,841)	0.14	(0.06)	0.01	(0.01)
Red Cedar - 2009								
BLG	57	(.)	0	(.)	0.00	(0.00)	0.00	(0.00)
CCF	1	(.)	7	(.)	0.00	(0.00)	0.00	(0.00)
LMB	31	(.)	0	(.)	0.00	(0.00)	0.00	(0.00)
TOTAL	95	(.)	7	(.)	0.09	(0.03)	0.00	(0.00)
Stagecoach - 2009								
CCF	2,065	(643)	893	(406)	0.04	(0.02)	0.01	(0.00)
CRP	5,931	(2,345)	891	(513)	0.15	(0.08)	0.01	(0.02)
LMB	1,631	(715)	0	(0)	0.19	(0.01)	0.00	(0.00)
TOTAL	10,013	(2,920)	1,775	(621)	0.18	(0.11)	0.02	(0.02)
Stagecoach - 2010								
BLG	2,438	(637)	137	(92)	0.18	(0.06)	0.00	(0.00)
CCF	3,216	(548)	548	(175)	0.01	(0.02)	0.00	(0.00)
CRP	7,245	(1,490)	3,136	(1,038)	0.56	(0.16)	0.27	(0.14)
LMB	1,055	(245)	0	(0)	0.17	(0.05)	0.00	(0.00)
TOTAL	16,334	(2,273)	4,499	(1,225)	0.64	(0.06)	0.01	(0.00)
Timber Point - 2009								
BLG	5,057	(.)	11	(.)	1.34	(0.00)	0.00	0.00
LMB	2,974	(.)	0	(.)	0.92	(0.10)	0.00	0.00
TOTAL	8,130	(.)	11	(.)	1.65	(0.21)	0.01	0.01
Wagon Train - 2011								
BLG	10,766	(2,340)	1,145	(743)	0.32	(0.00)	0.00	(0.00)
CCF	5,075	(1,482)	2,087	(662)	0.98	(0.65)	0.42	(0.26)
CRP	43,464	(10,244)	11,777	(2,375)	2.25	(0.23)	0.56	(0.12)
LMB	6,169	(1,293)	35	(26)	0.39	(0.20)	0.00	(0.00)
TOTAL	67,454	(10,938)	15,382	(2,709)	0.70	(0.18)	0.16	(0.11)

Species	Catch		Harvest		CPUE		HPUE	
			Wagon Train – 2012					
BLG	10,644	(1,823)	987	(226)	0.79	(0.04)	0.05	(0.00)
CCF	5,948	(732)	2,328	(458)	0.16	(0.01)	0.11	(0.01)
CRP	35,076	(6,992)	2,160	(606)	2.43	(0.64)	0.19	(0.05)
LMB	7,583	(899)	0	(0)	0.40	(0.06)	0.00	(0.00)
TOTAL	63,867	(8,724)	5,874	(793)	0.82	(0.15)	0.04	(0.03)
			Wild Plum - 2011					
BLG	1,596	(525)	99	(72)	0.67	(0.00)	0.12	(0.00)
CRP	1,224	(853)	222	(142)	1.97	(0.00)	0.19	(0.00)
LMB	1,337	(667)	119	(101)	0.46	(0.04)	0.00	(0.00)
TOTAL	4,258	(1,427)	469	(221)	1.17	(0.00)	0.19	(0.00)
			Wildwood - 2010					
BLG	36,619	(13,594)	17	12	0.97	(0.01)	0.00	(0.00)
CRP	20,318	(13,380)	755	420	2.69	(0.04)	0.10	(0.03)
LMB	14,322	(6,765)	0	0	0.45	(0.21)	0.00	(0.00)
TOTAL	74,381	(33,503)	772	423	2.14	(0.41)	0.00	(0.00)
			Wildwood - 2011					
BLG	25,422	(5,763)	5,332	(1,694)	0.63	(0.00)	0.13	(0.00)
CRP	13,680	(5,694)	3,741	(1,370)	1.22	(0.12)	0.21	(0.10)
LMB	8,020	(1,540)	2	(1)	0.68	(0.11)	0.00	(0.00)
TOTAL	49,230	(9,123)	9,107	(2,387)	1.60	(0.62)	0.03	(0.01)
			Wildwood - 2012					
BLG	20,345	(4,291)	2,613	(1,169)	0.90	(0.04)	0.45	(0.00)
CRP	30,593	(8,860)	7,546	(3,598)	2.19	(0.48)	0.80	(0.60)
LMB	8,415	(1,414)	0	(0)	0.46	(0.05)	0.00	(0.00)
TOTAL	61,238	(11,440)	10,211	(3,776)	2.20	(0.24)	0.02	(0.02)
			Yankee Hill - 2011					
BLG	4,931	(669)	344	(240)	0.86	(0.10)	0.33	(0.09)
BHD	3,759	(716)	429	(136)	0.13	(0.00)	0.13	(0.00)
LMB	9,800	(1,316)	0	(0)	1.14	(0.12)	0.00	(0.00)
TOTAL	21,060	(1,847)	1,131	(287)	2.01	(0.13)	0.02	(0.01)

Appendix E. Monthly angling effort at Salt Valley reservoirs sampled during 2009-2012.

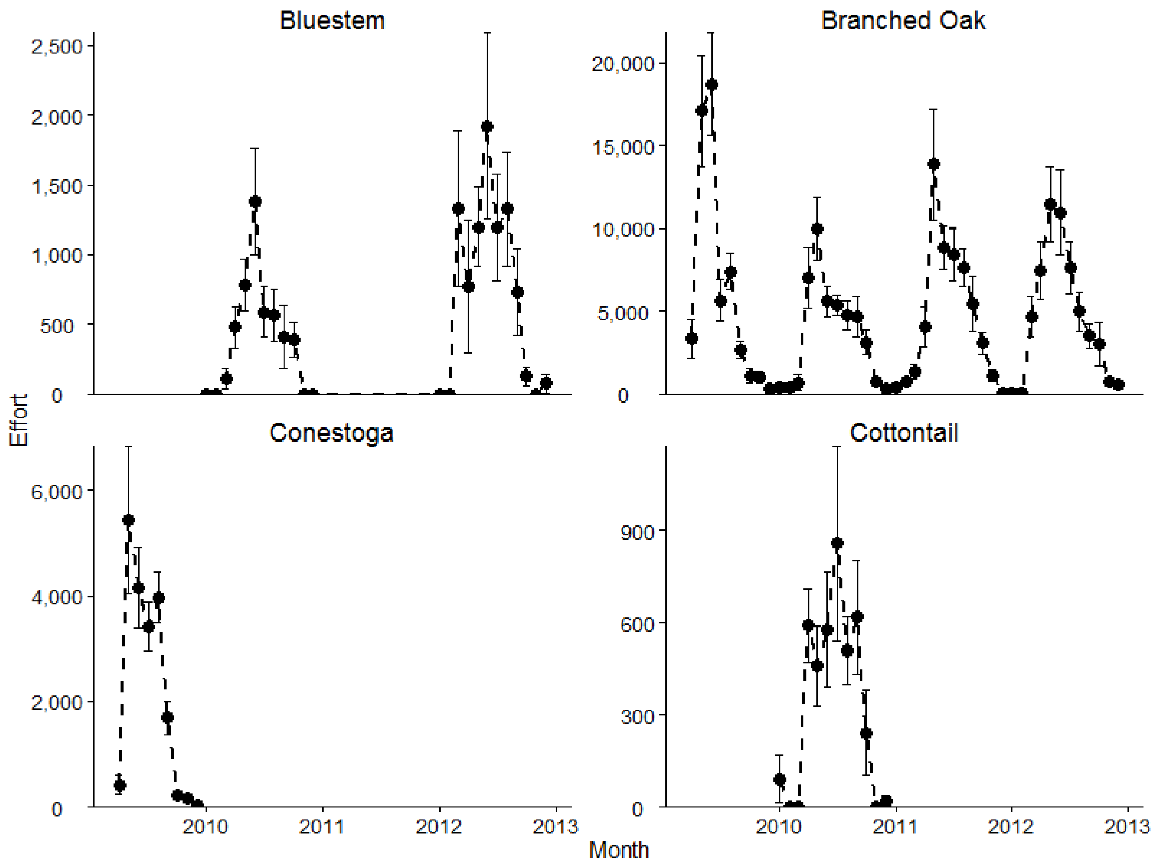

Figure E-1. Monthly fishing effort (mean ± SE) at Bluestem, Branched Oak, Conestoga, and Cottontail reservoirs.

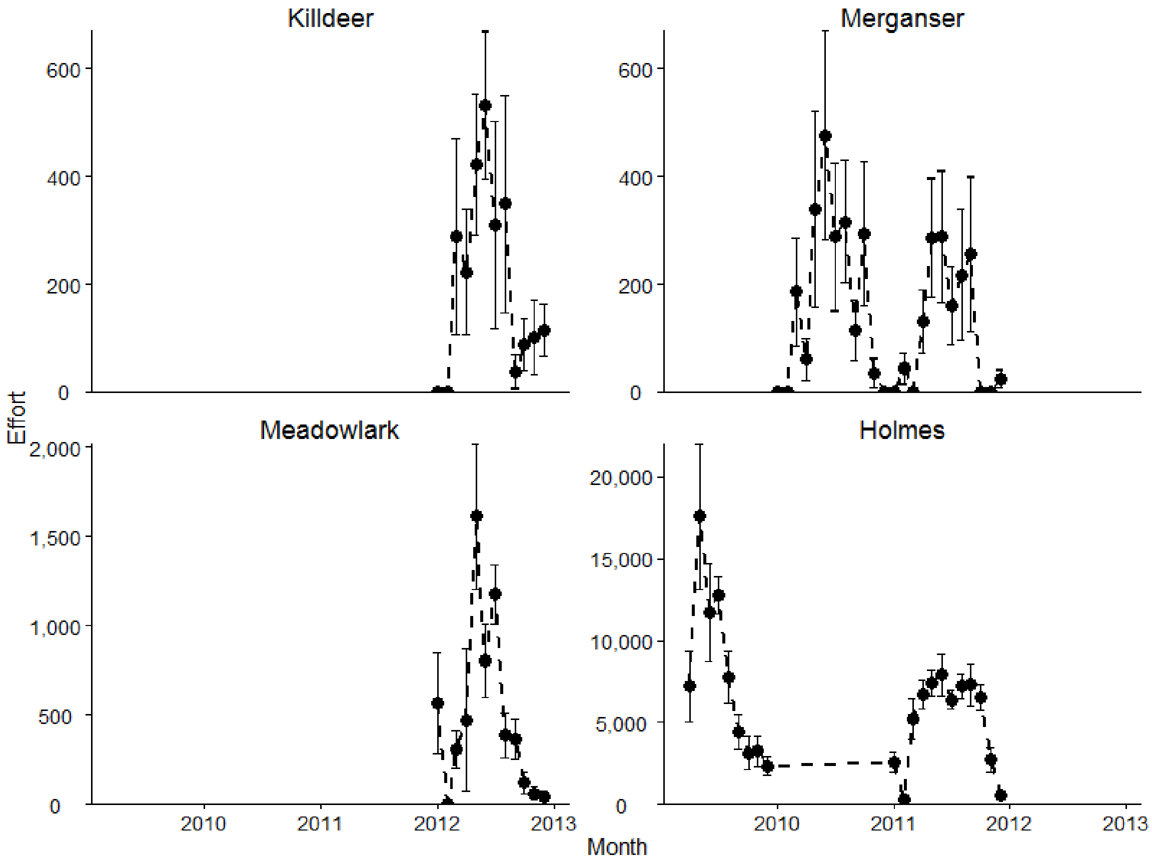

Figure E-2. Monthly fishing effort (mean ± SE) at Killdeer, Merganser, Meadowlark, and Holmes reservoirs.

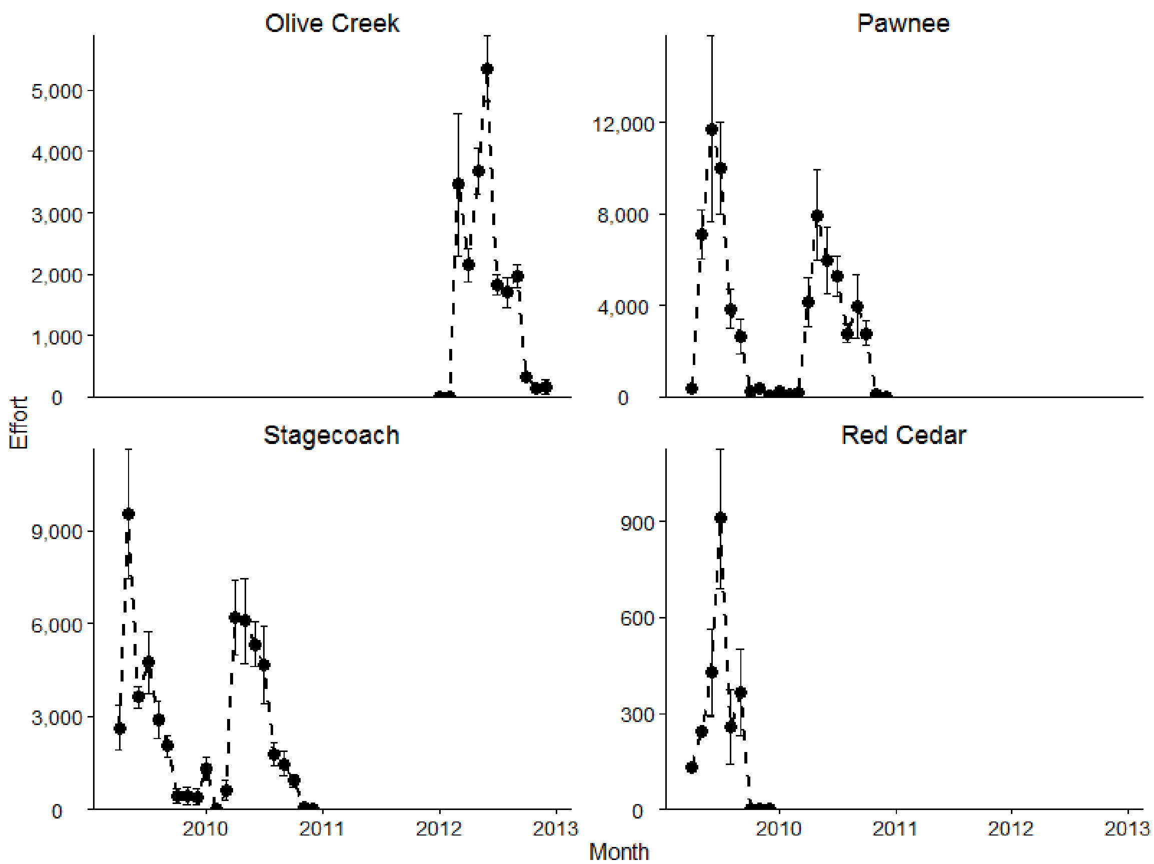

Figure E-3. Monthly fishing effort (mean ± SE) at Olive Creek, Pawnee, Stagecoach, and Red Cedar reservoirs.

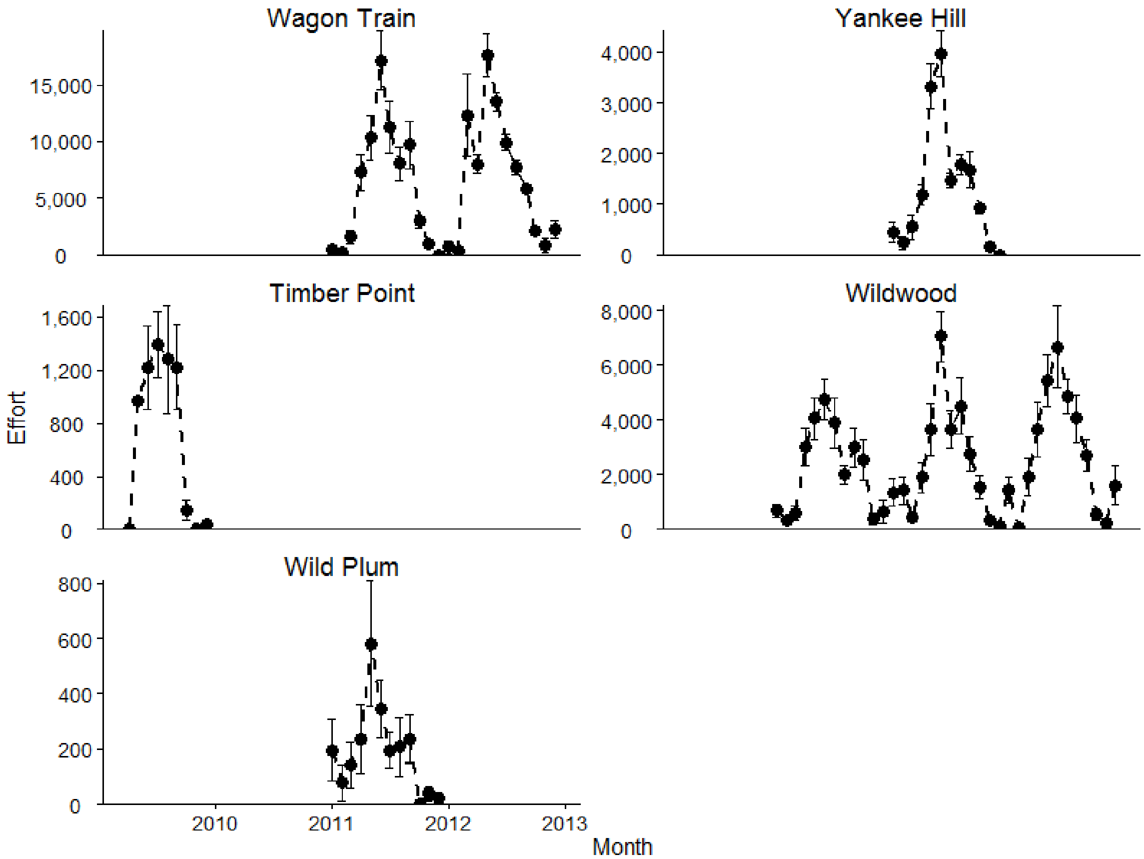

Figure E-4. Monthly fishing effort (mean ± SE) at Wagon Train, Yankee Hill, Timber Point, Wildwood, and Wild Plum reservoirs.

Appendix F. Monthly estimates of catch for Salt Valley lakes surveyed 2009-2012.

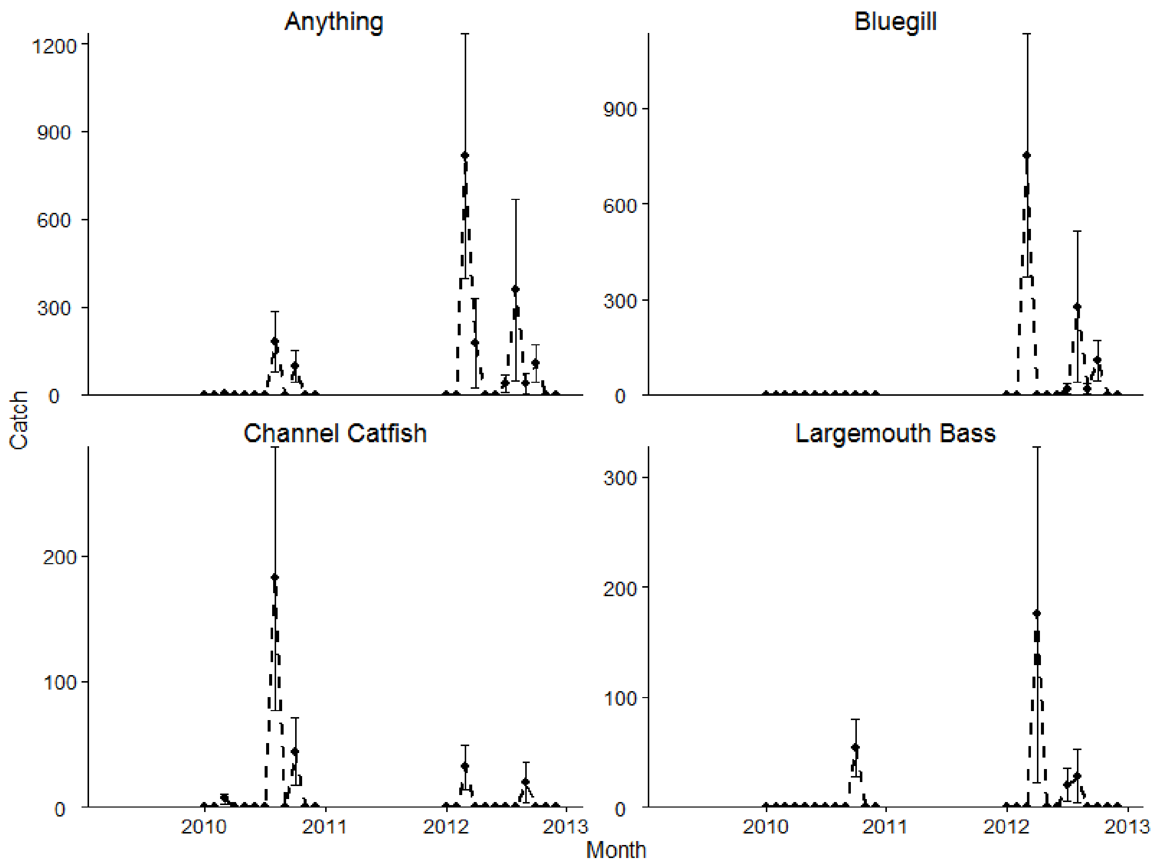

Figure F-1. Monthly catch (mean ± SE) of species comprising greater than 5% of catch in any one year at Bluestem Lake.

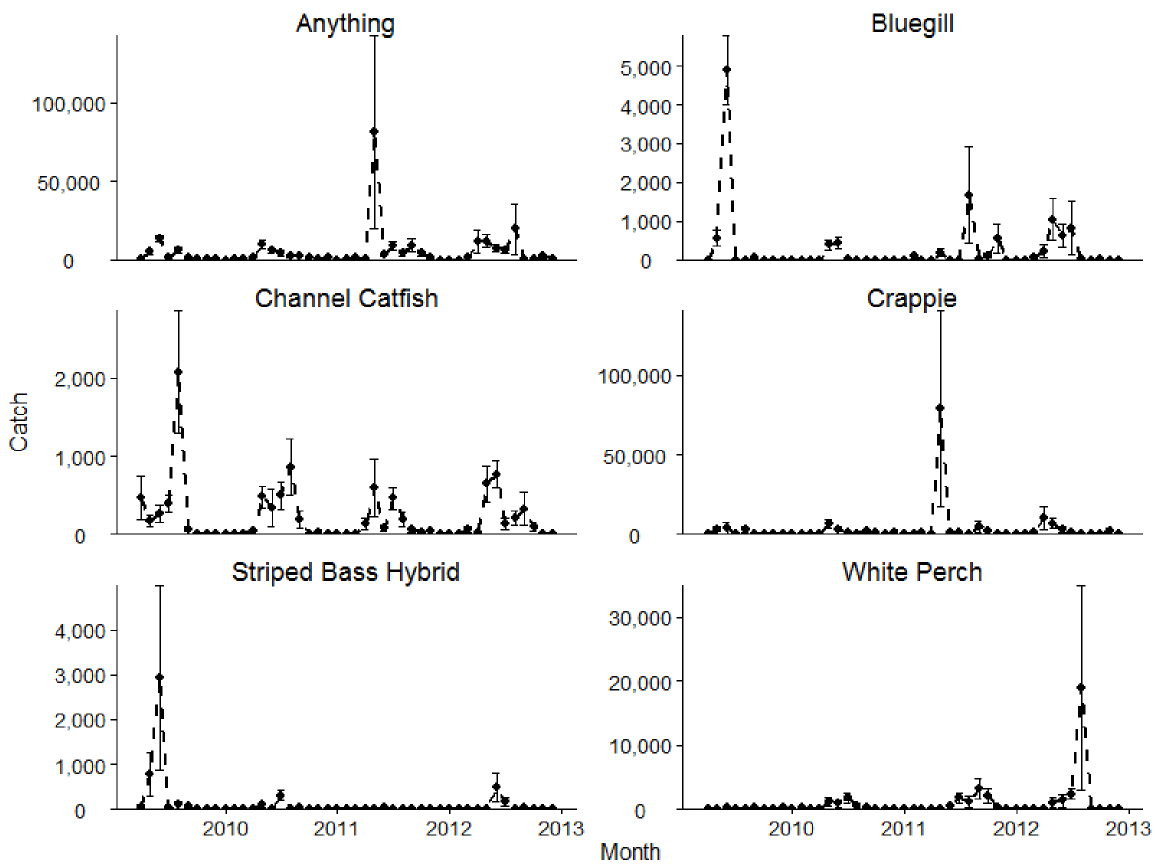

Figure F-2. Monthly catch (mean ± SE) of species comprising greater than 5% of catch in any one year at Branched Oak Lake. Anything represents total catch of fish.

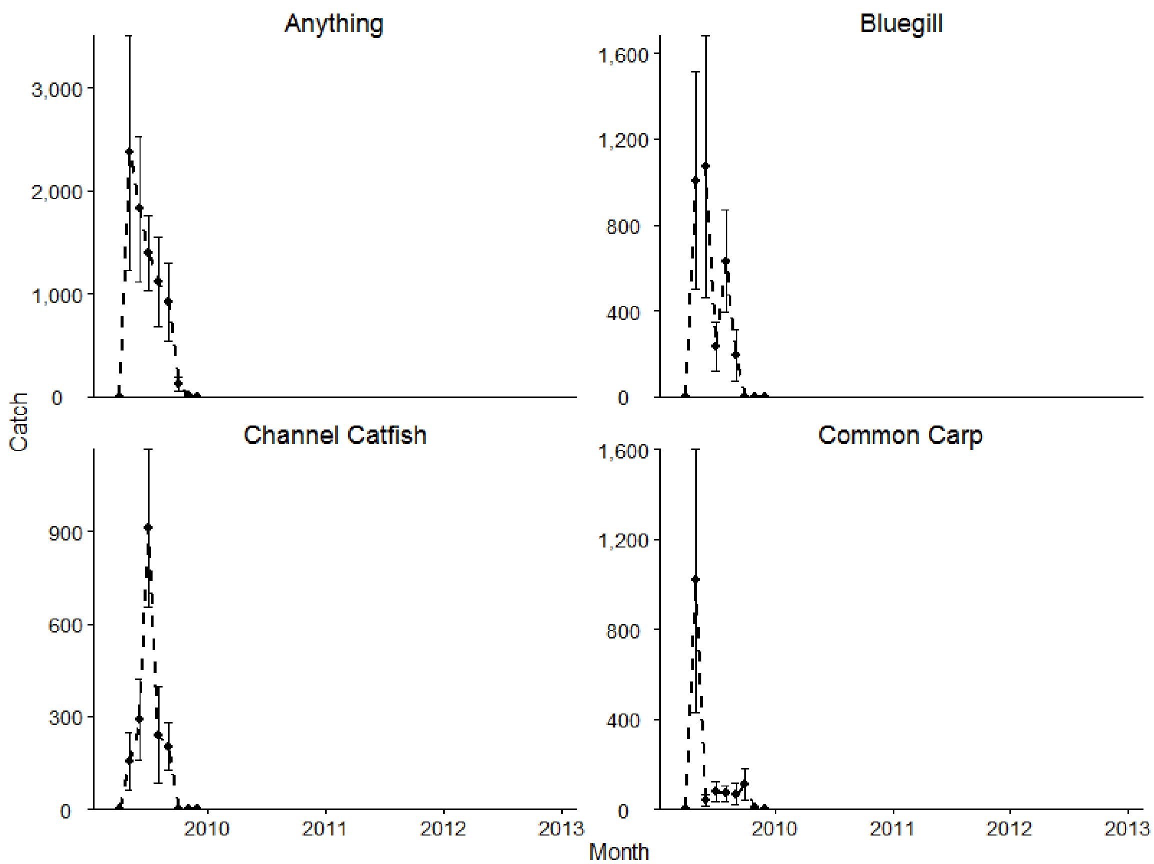

Figure F-3. Monthly catch (mean ± SE) of species comprising greater than 5% of catch in any one year at Conestoga Lake. Anything represents total catch of fish.

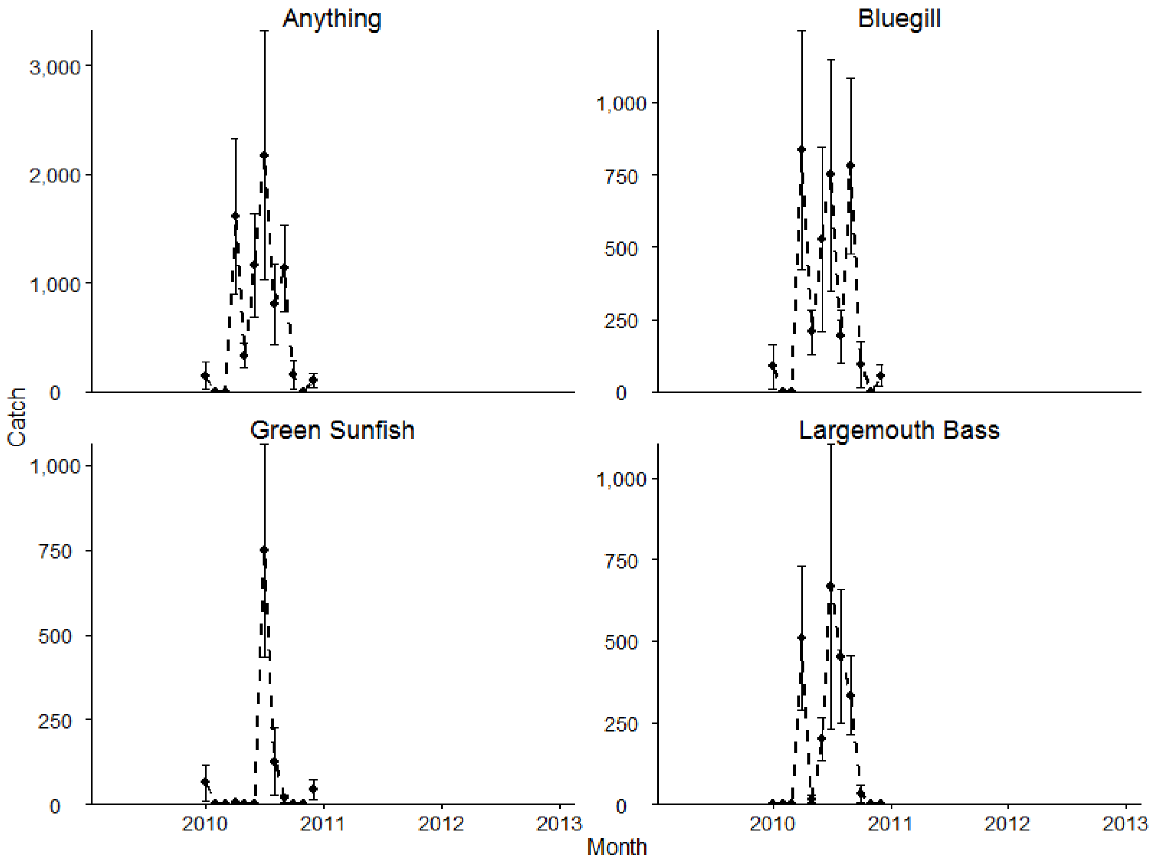

Figure F-4. Monthly catch (mean ± SE) of species comprising greater than 5% of catch in any one year at Cottontail Lake. Anything represents total catch of fish.

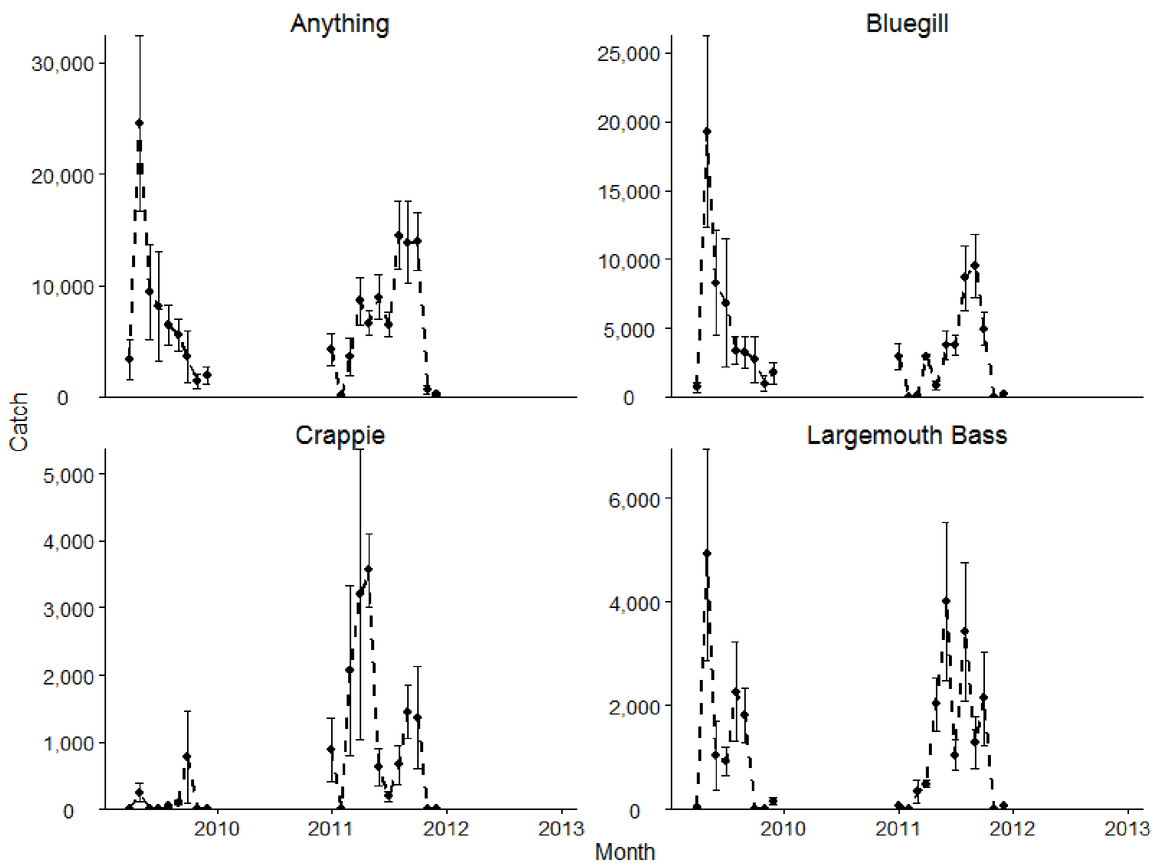

Figure F-5. Monthly catch (mean ± SE) of species comprising greater than 5% of catch in any one year at Holmes Lake. Anything represents total catch of fish.

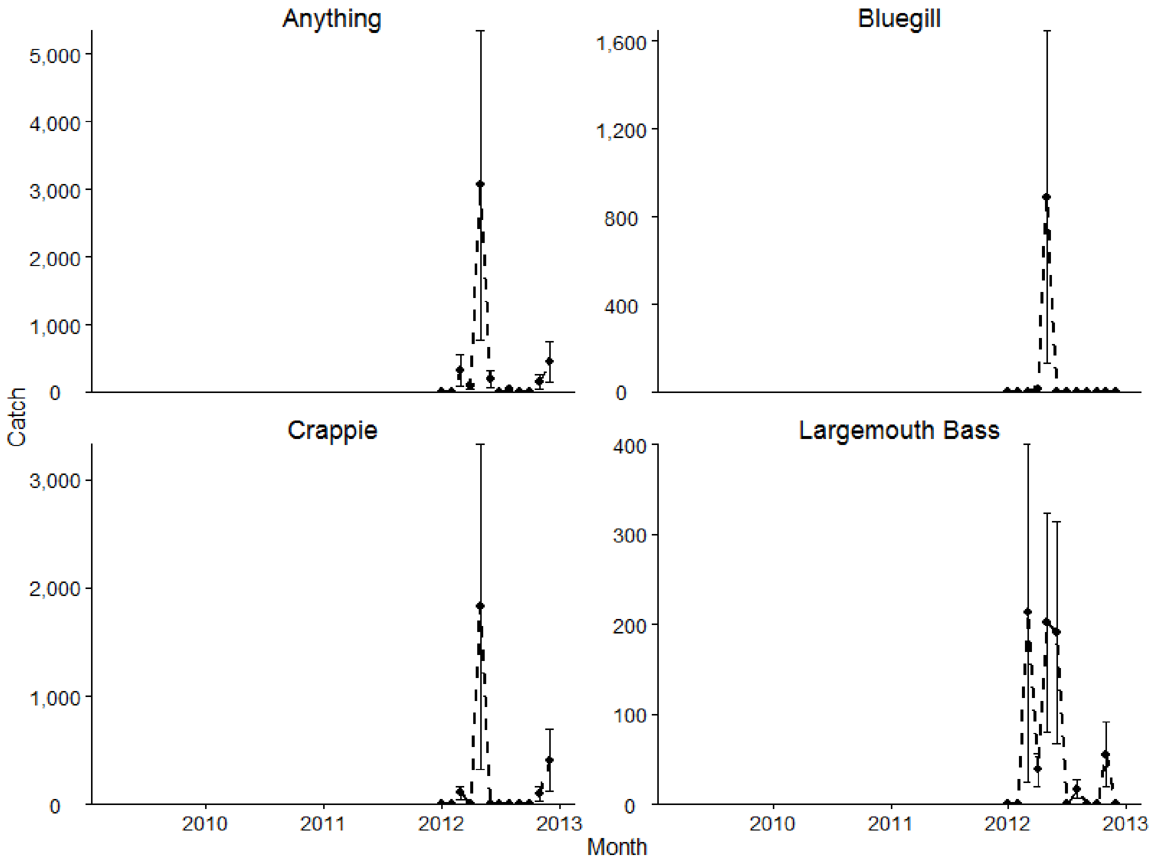

Figure F-6. Monthly catch (mean ± SE) of species comprising greater than 5% of catch in any one year at Killdeer Lake. Anything represents total catch of fish.

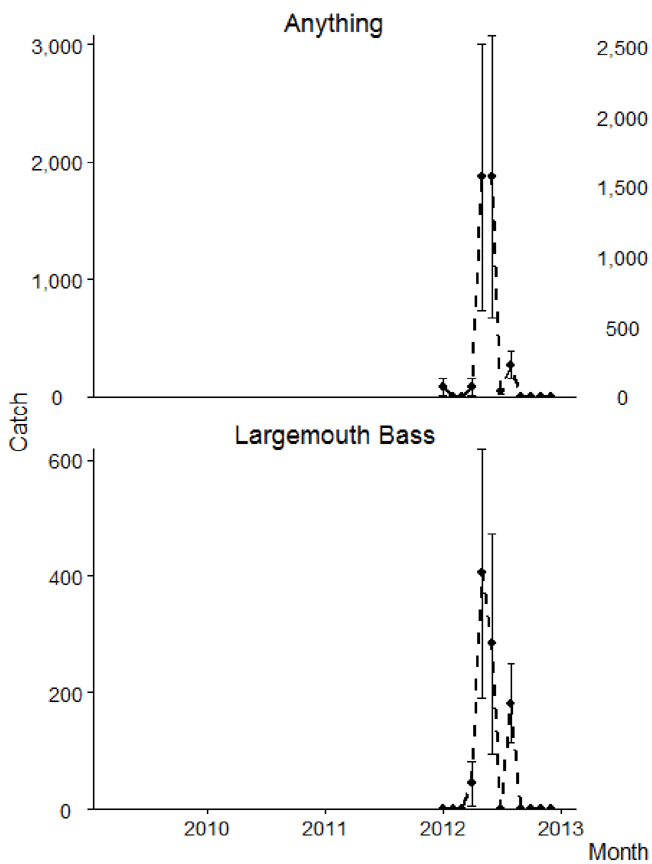

Figure F-7. Monthly catch (mean ± SE) of species comprising greater than 5% of catch in any one year at Meadowlark Lake. Anything represents total catch of fish.

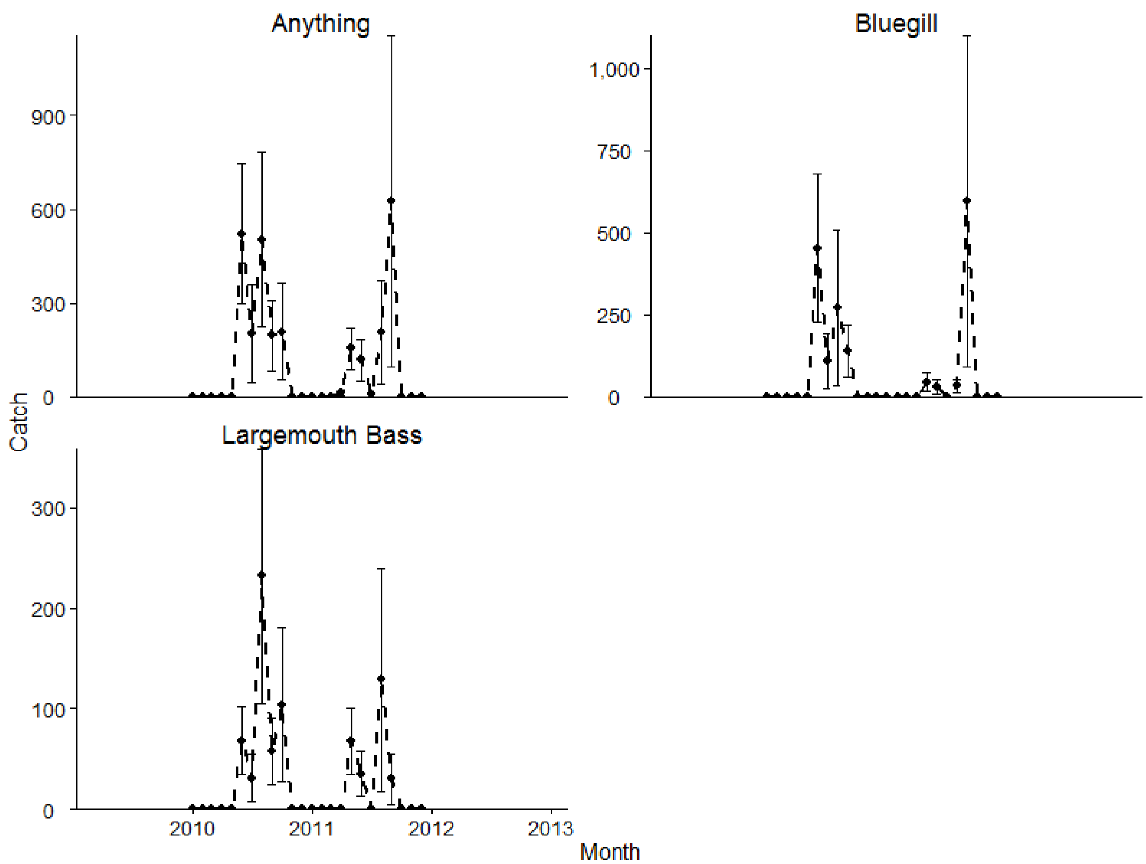

Figure F-8. Monthly catch (mean ± SE) of species comprising greater than 5% of catch in any one year at Merganser Lake. Anything represents total catch of fish.

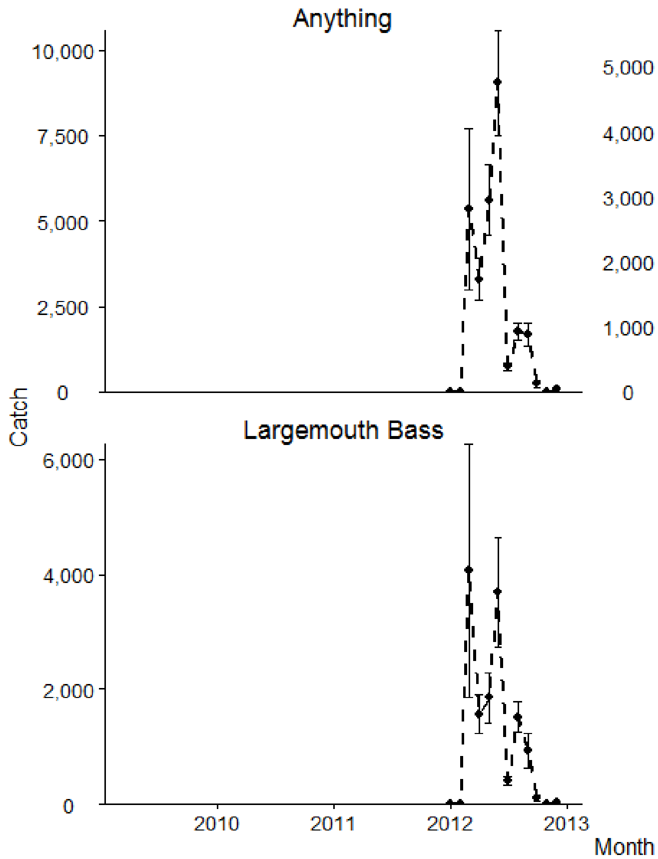

Figure F-9. Monthly catch (mean ± SE) of species comprising greater than 5% of catch in any one year at Olive Creek Lake. Anything represents total catch of fish.

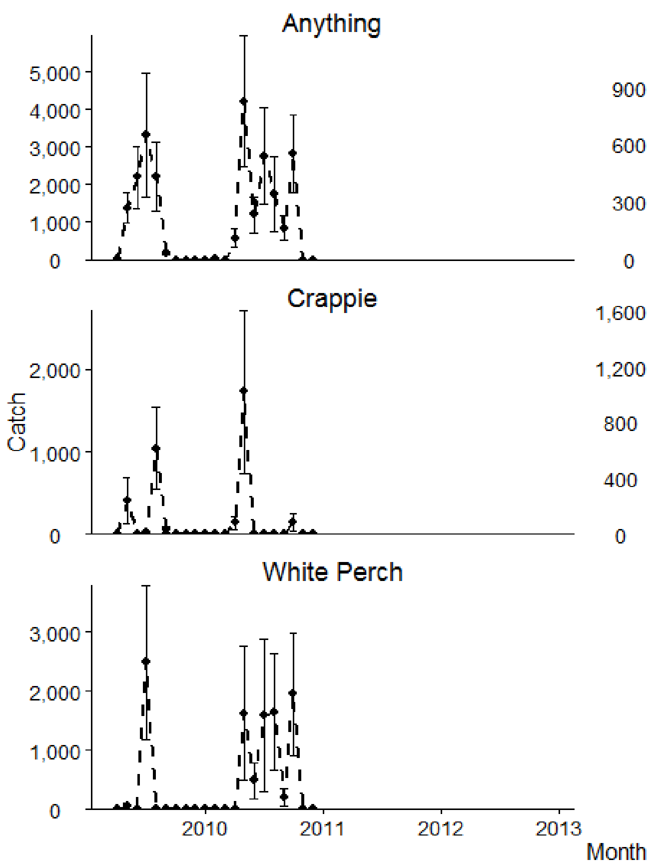

Figure F-10. Monthly catch (mean ± SE) of species comprising greater than 5% of catch in any one year at Pawnee Lake. Anything represents total catch of fish.

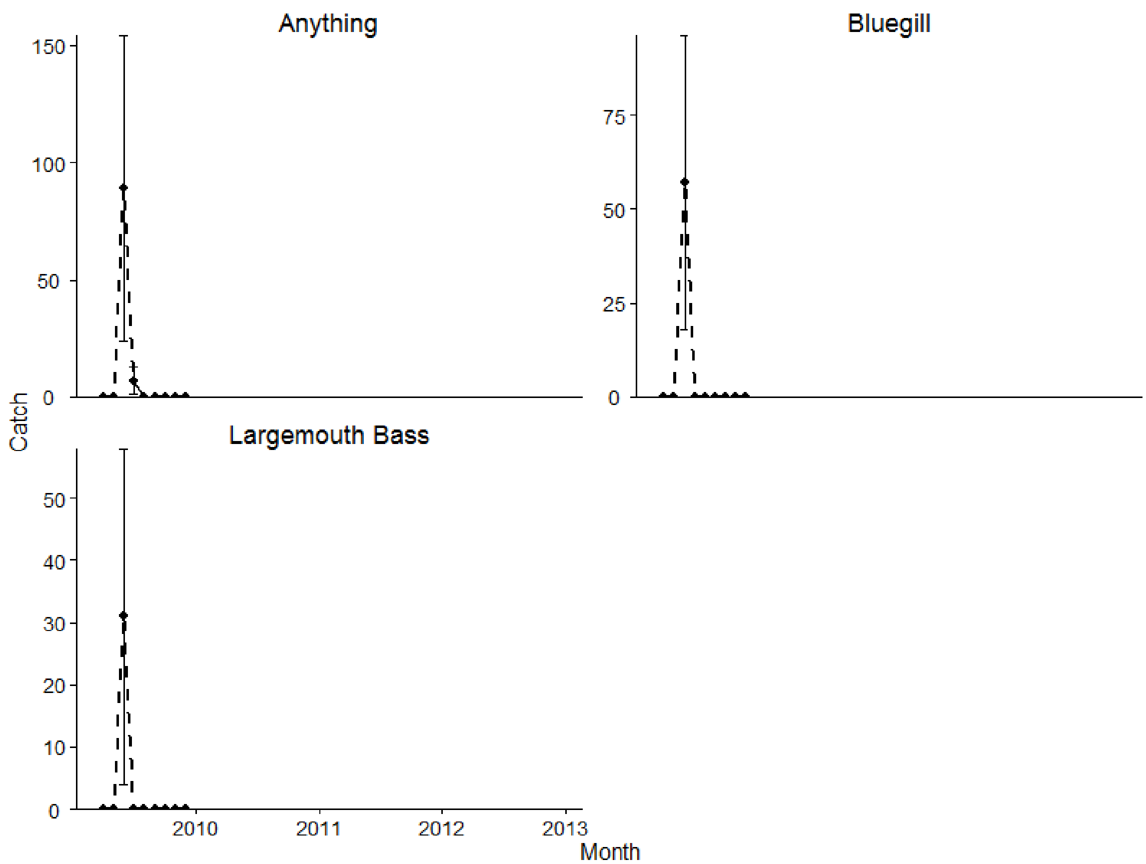

Figure F-10. Monthly catch (mean ± SE) of species comprising greater than 5% of catch in any one year at Red Cedar Lake. Anything represents total catch of fish.

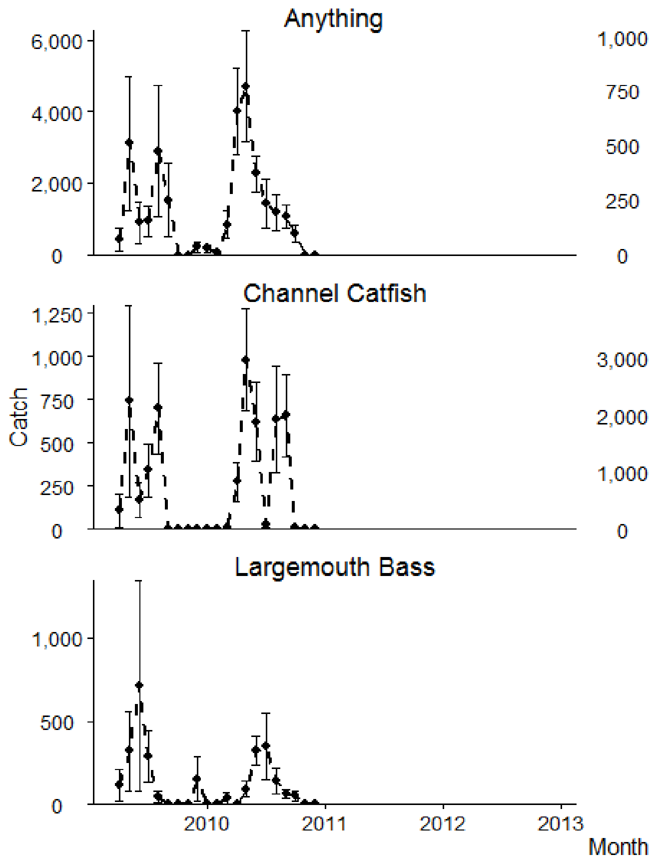

Figure F-11. Monthly catch (mean ± SE) of species comprising greater than 5% of catch in any one year at Stagecoach Lake. Anything represents total catch of fish.

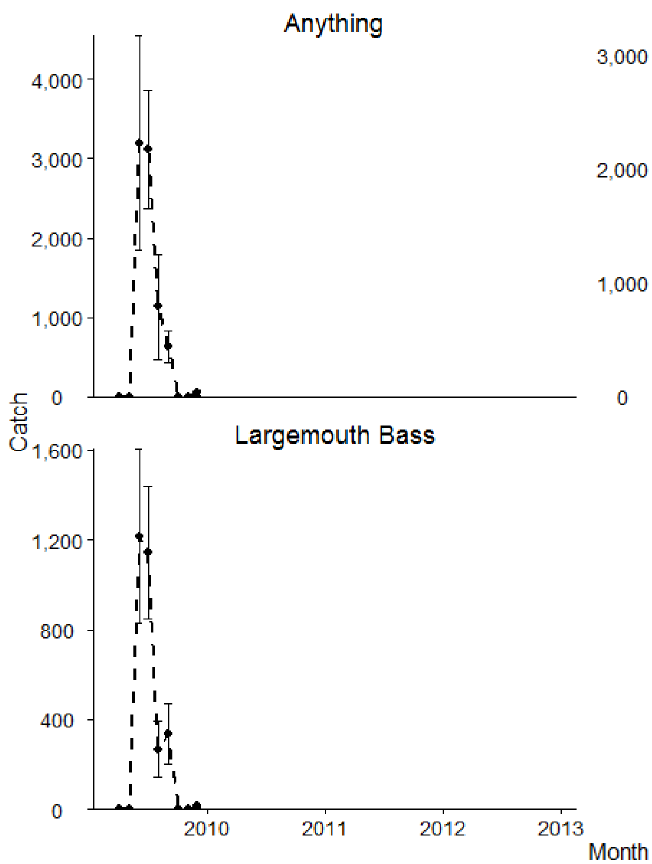

Figure F-12. Monthly catch (mean ± SE) of species comprising greater than 5% of catch in any one year at Timber Point Lake. Anything represents total catch of fish.

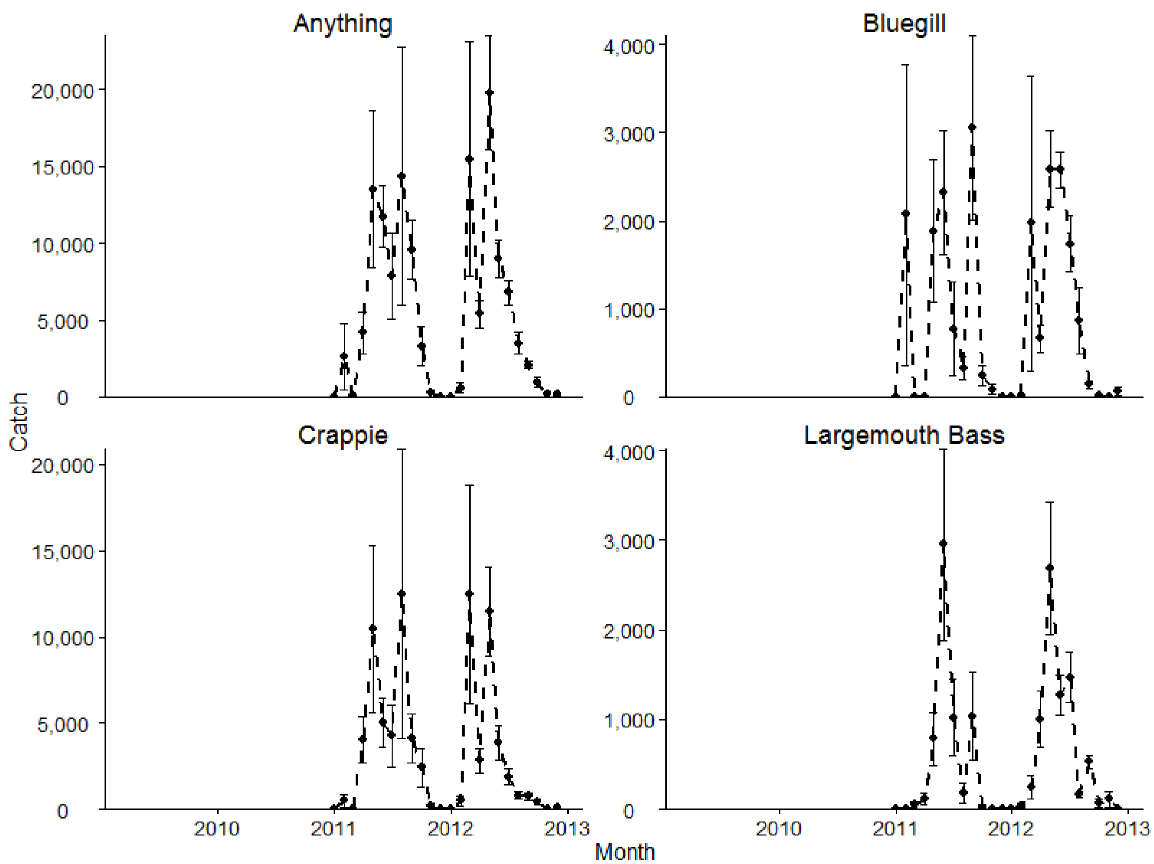

Figure F-13. Monthly catch (mean ± SE) of species comprising greater than 5% of catch in any one year at Wagon Train Lake. Anything represents total catch of fish.

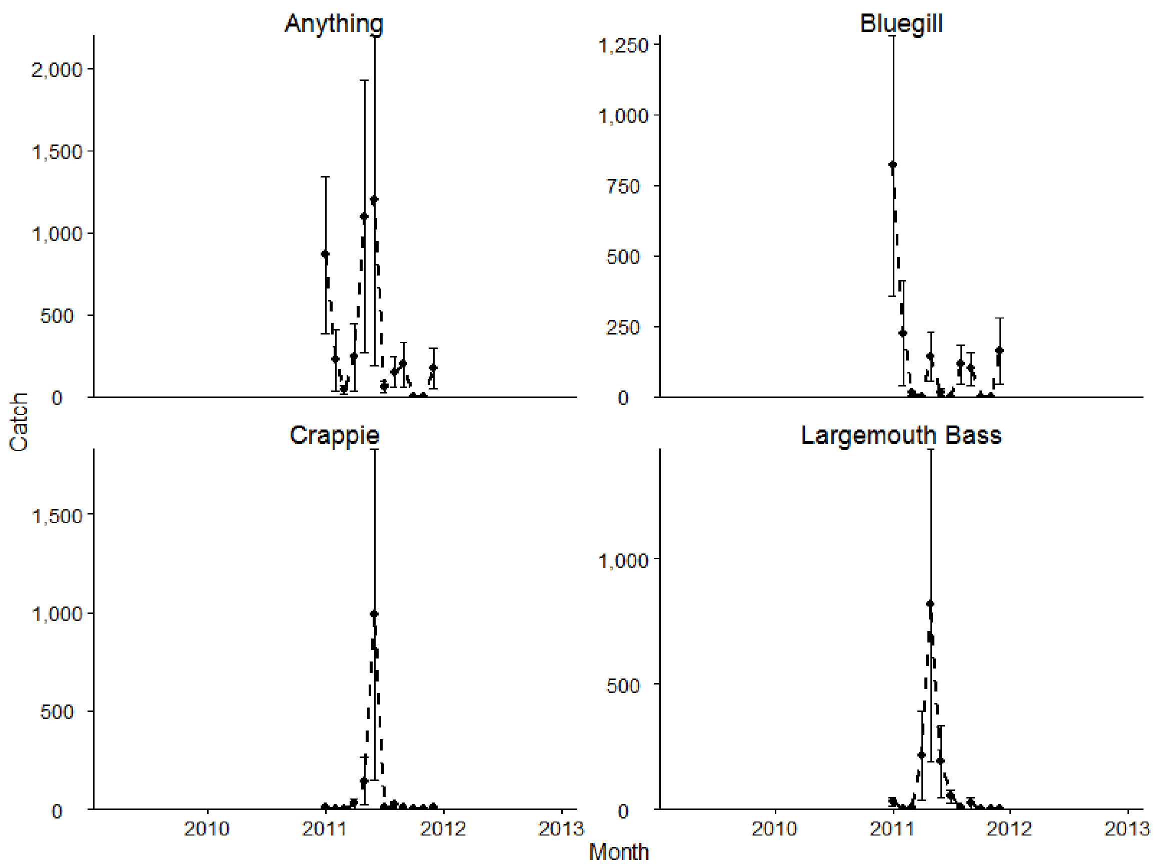

Figure F-14. Monthly catch (mean ± SE) of species comprising greater than 5% of catch in any one year at Wild Plum Lake. Anything represents total catch of fish.

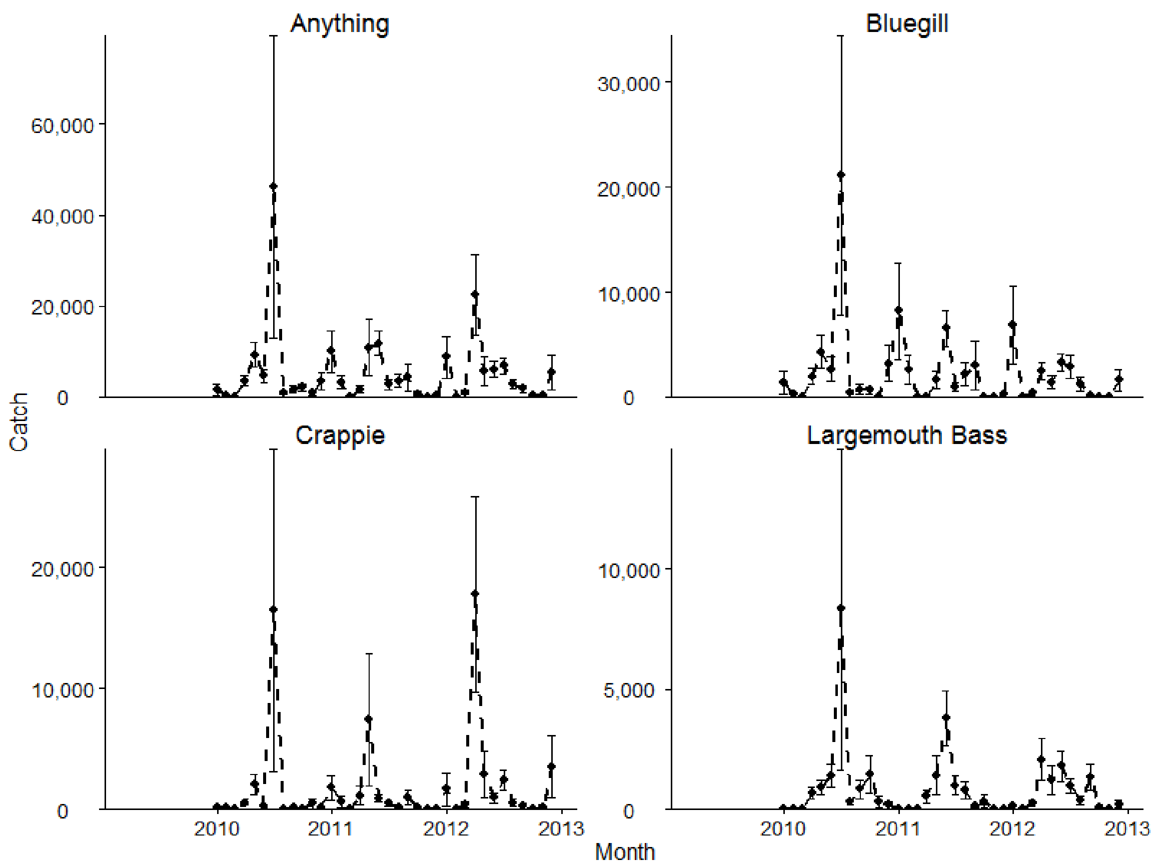

Figure F-15. Monthly catch (mean ± SE) of species comprising greater than 5% of catch in any one year at Wildwood Lake. Anything represents total catch of fish.

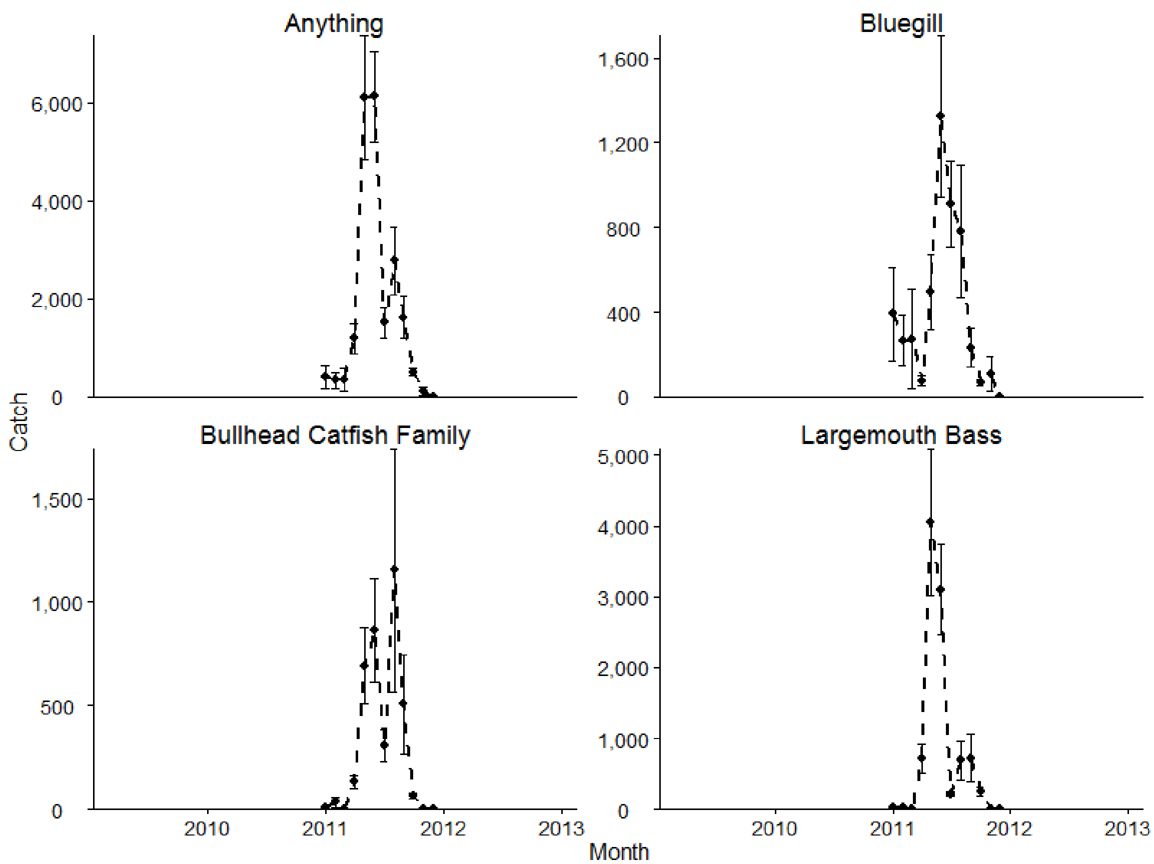

Figure F-16. Monthly catch (mean ± SE) of species comprising greater than 5% of catch in any one year at Yankee HIll Lake. Anything represents total catch of fish.

Appendix G. Monthly estimates of harvest for Salt Valley lakes surveyed 2009-2012.

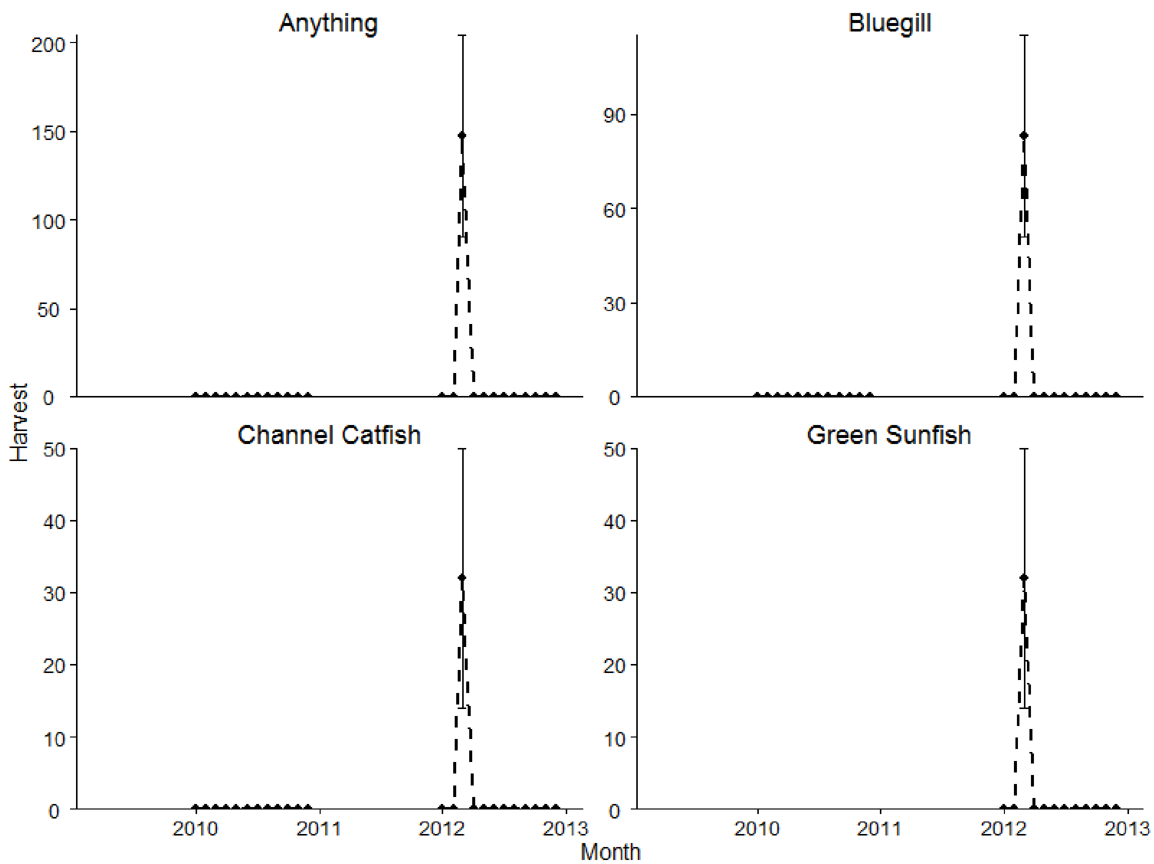

Figure G-1. Monthly harvest (mean ± SE) of species comprising greater than 5% of harvest in any one year at Bluestem Lake. Anything represents total harvest of fish.

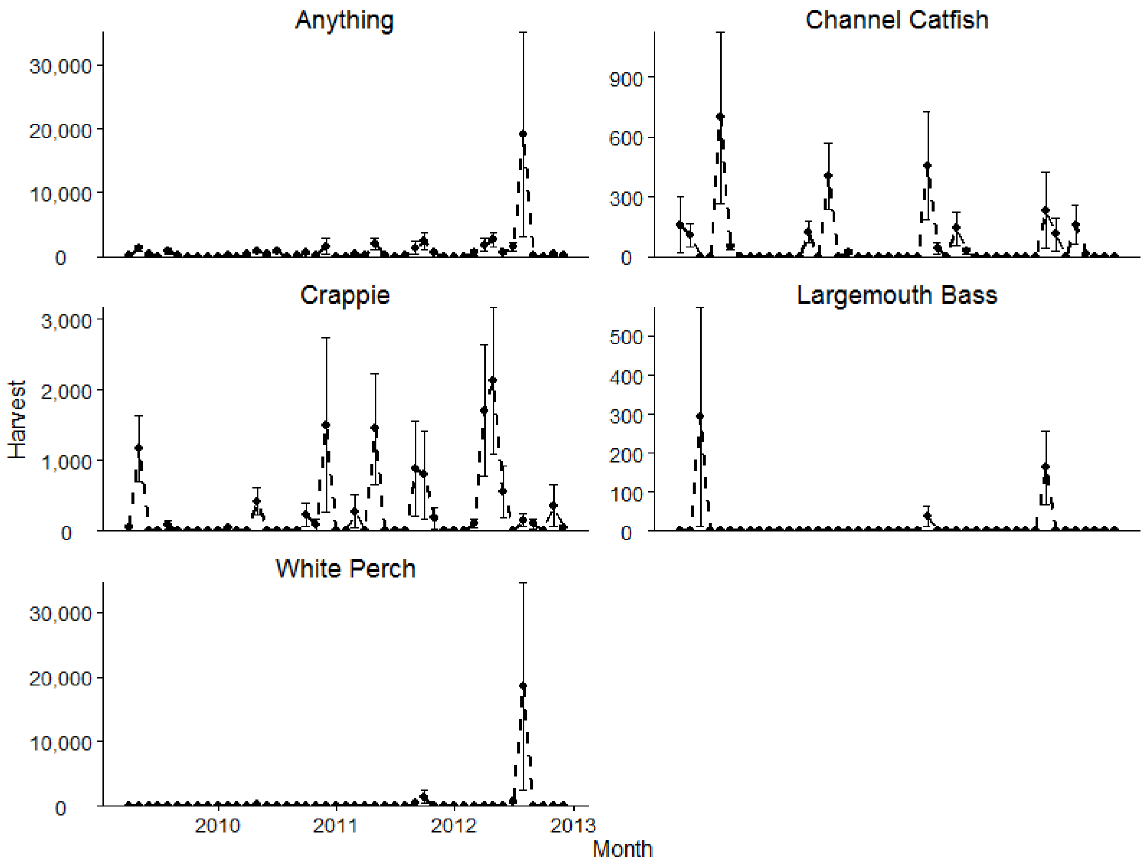

Figure G-2. Monthly harvest (mean ± SE) of species comprising greater than 5% of harvest in any one year at Branched Oak Lake. Anything represents total harvest of fish.

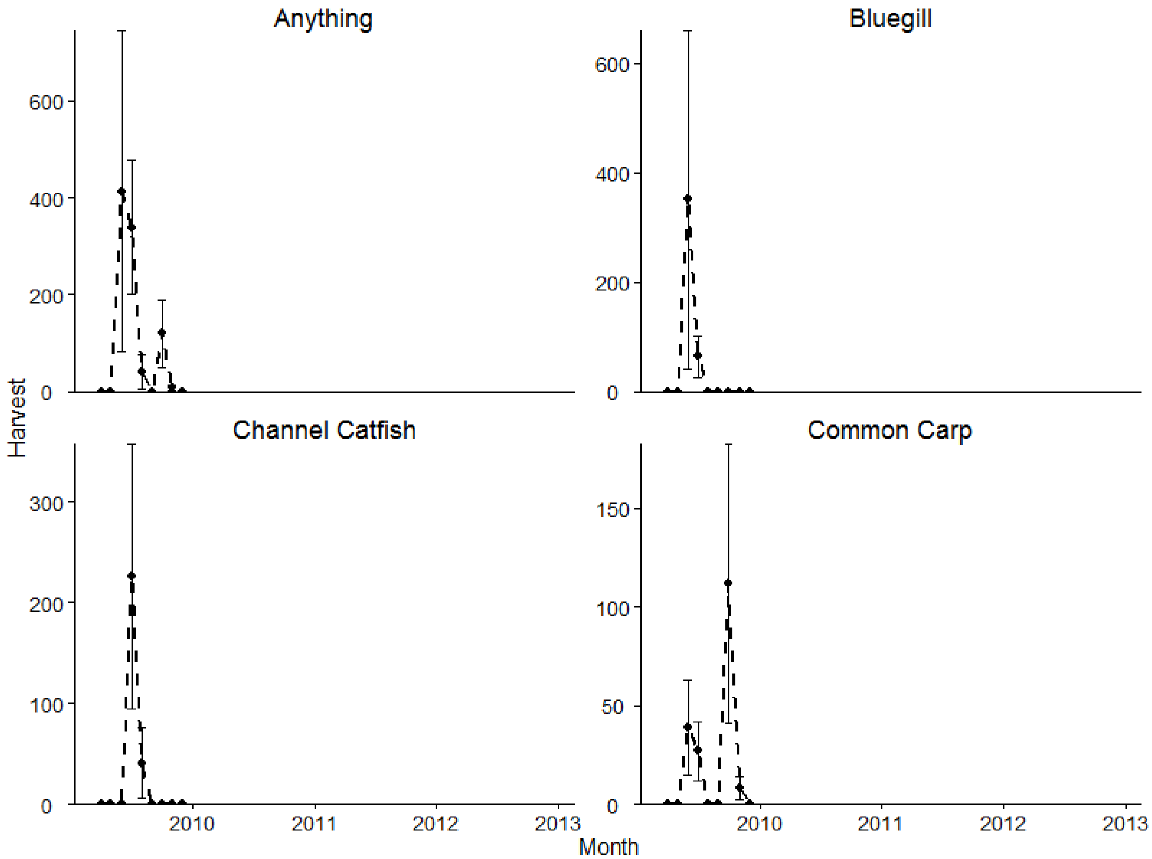

Figure G-3. Monthly harvest (mean ± SE) of species comprising greater than 5% of harvest in any one year at Conestoga Lake. Anything represents total harvest of fish.

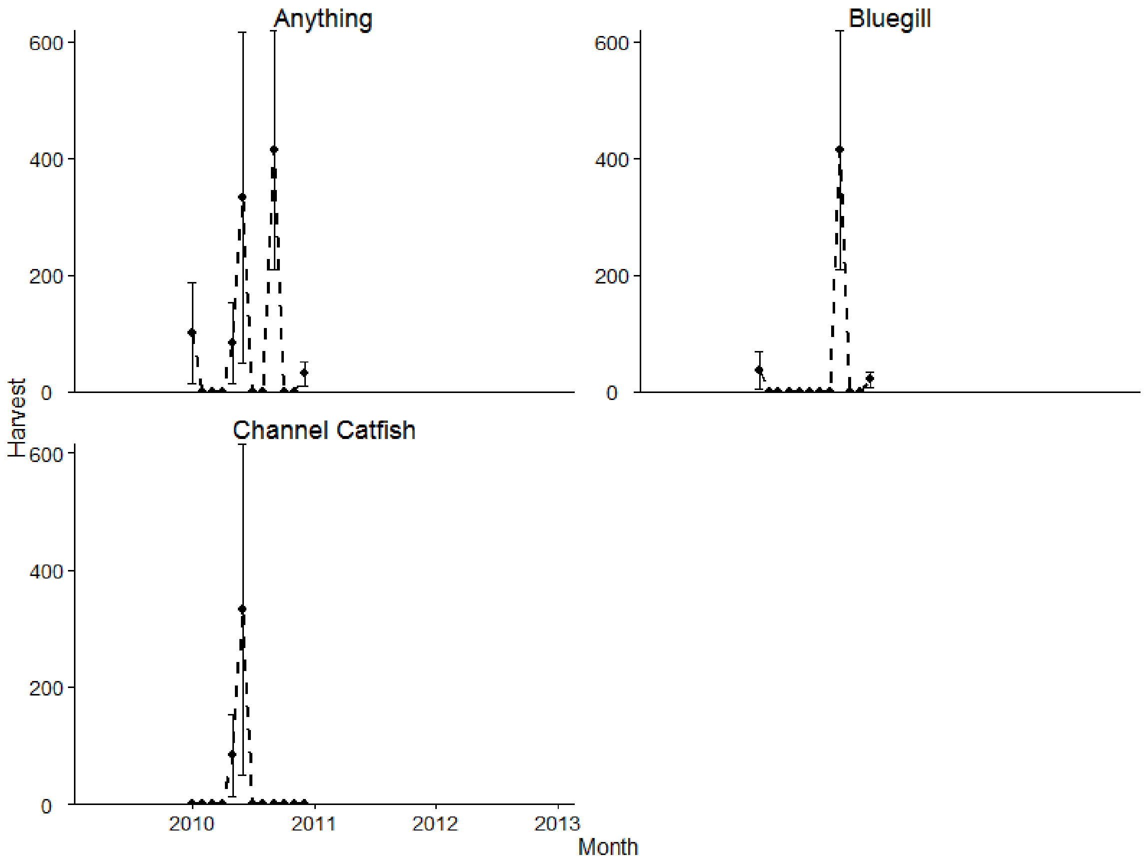

Figure G-4. Monthly harvest (mean ± SE) of species comprising greater than 5% of harvest in any one year at Cottontail Lake. Anything represents total harvest of fish.

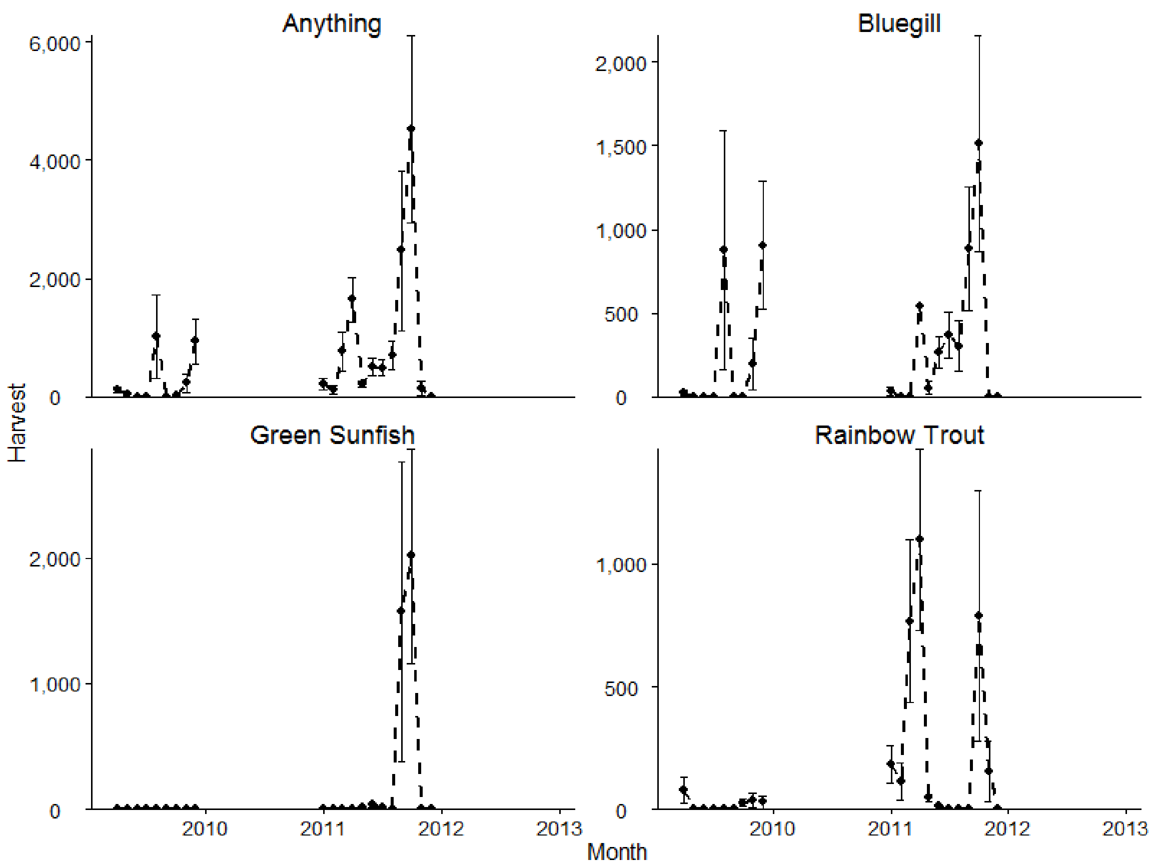

Figure G-5. Monthly harvest (mean ± SE) of species comprising greater than 5% of harvest in any one year at Holmes Lake. Anything represents total harvest of fish.

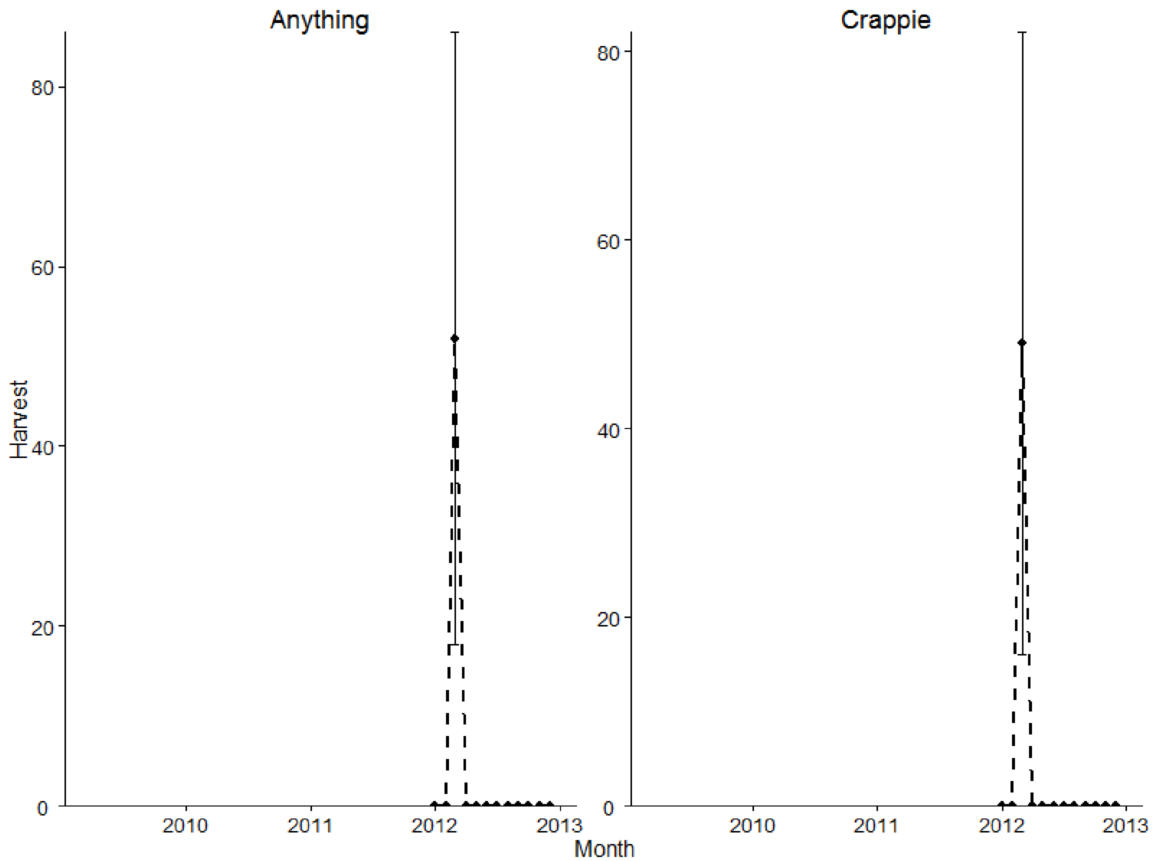

Figure G-6. Monthly harvest (mean ± SE) of species comprising greater than 5% of harvest in any one year at Killdeer Lake. Anything represents total harvest of fish.

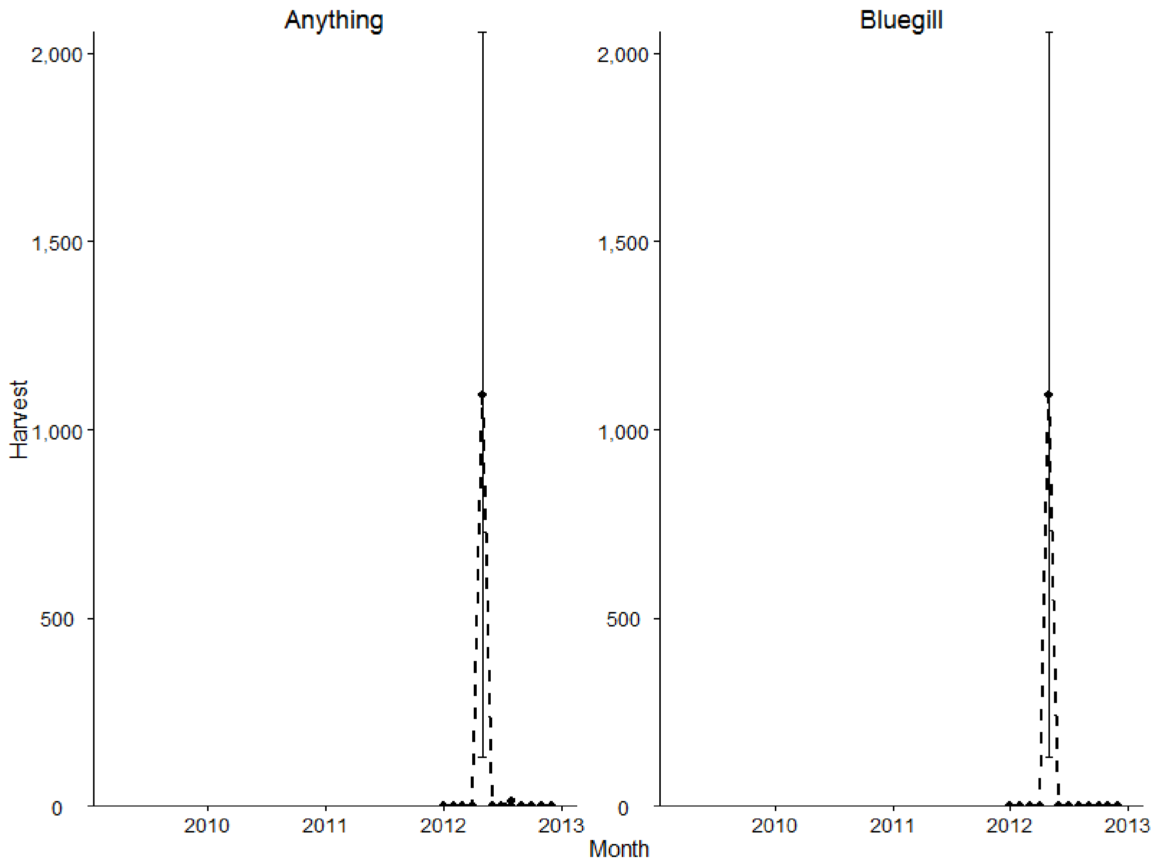

Figure G-7. Monthly harvest (mean ± SE) of species comprising greater than 5% of harvest in any one year at Meadowlark Lake. Anything represents total harvest of fish.

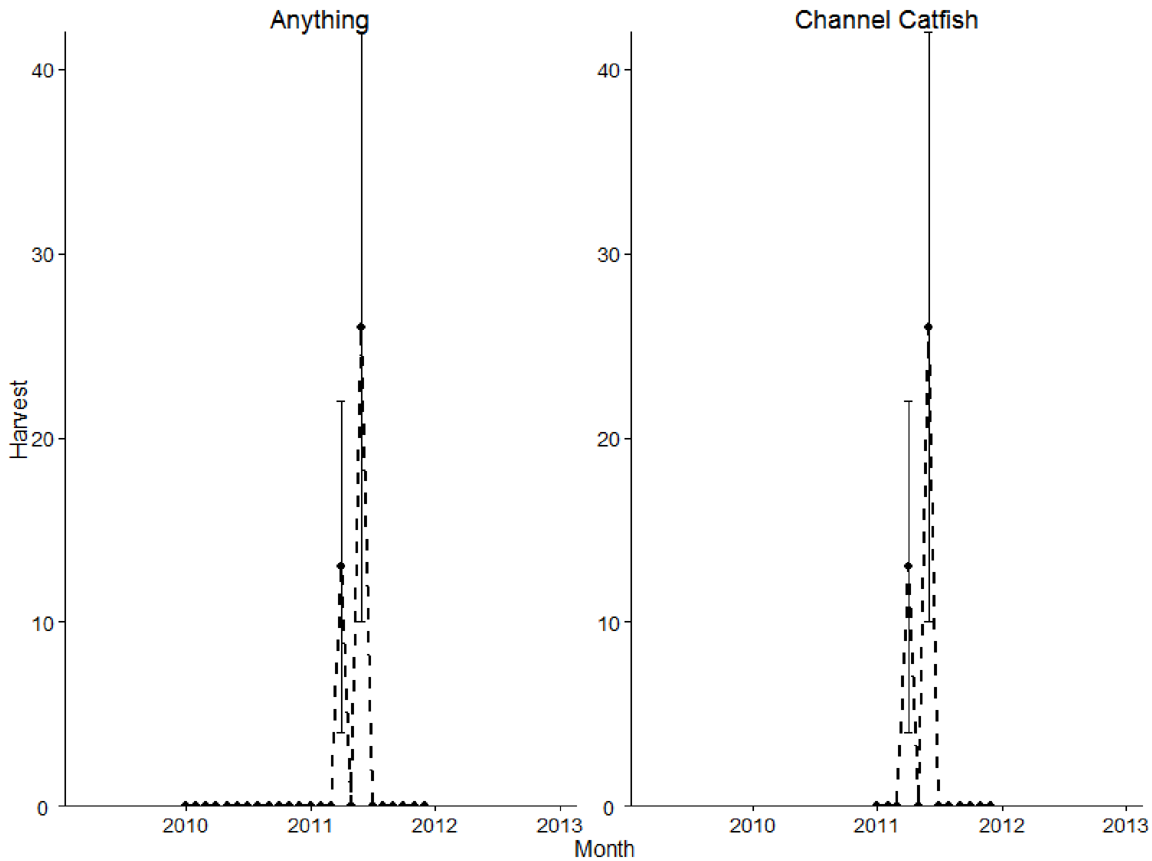

Figure G-8. Monthly harvest (mean ± SE) of species comprising greater than 5% of harvest in any one year at Merganser Lake. Anything represents total harvest of fish.

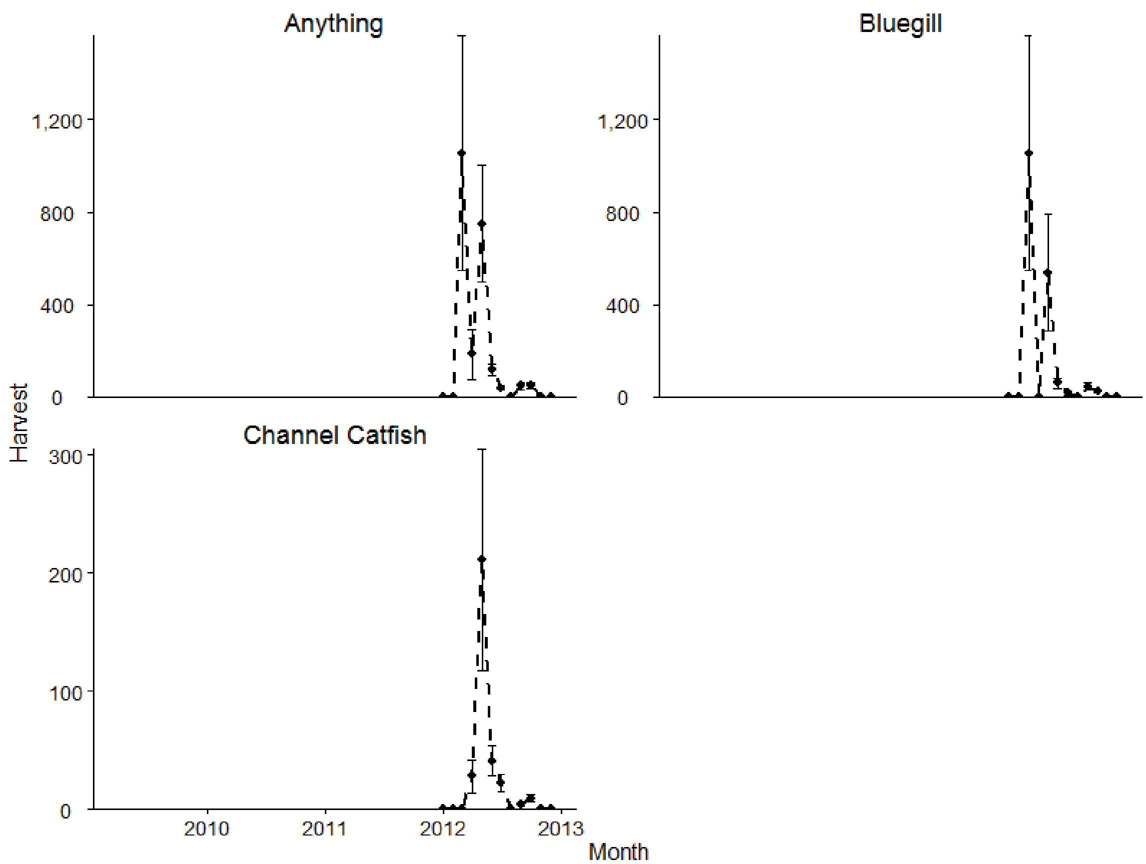

Figure G-9. Monthly harvest (mean ± SE) of species comprising greater than 5% of harvest in any one year at Olive Creek Lake. Anything represents total harvest of fish.

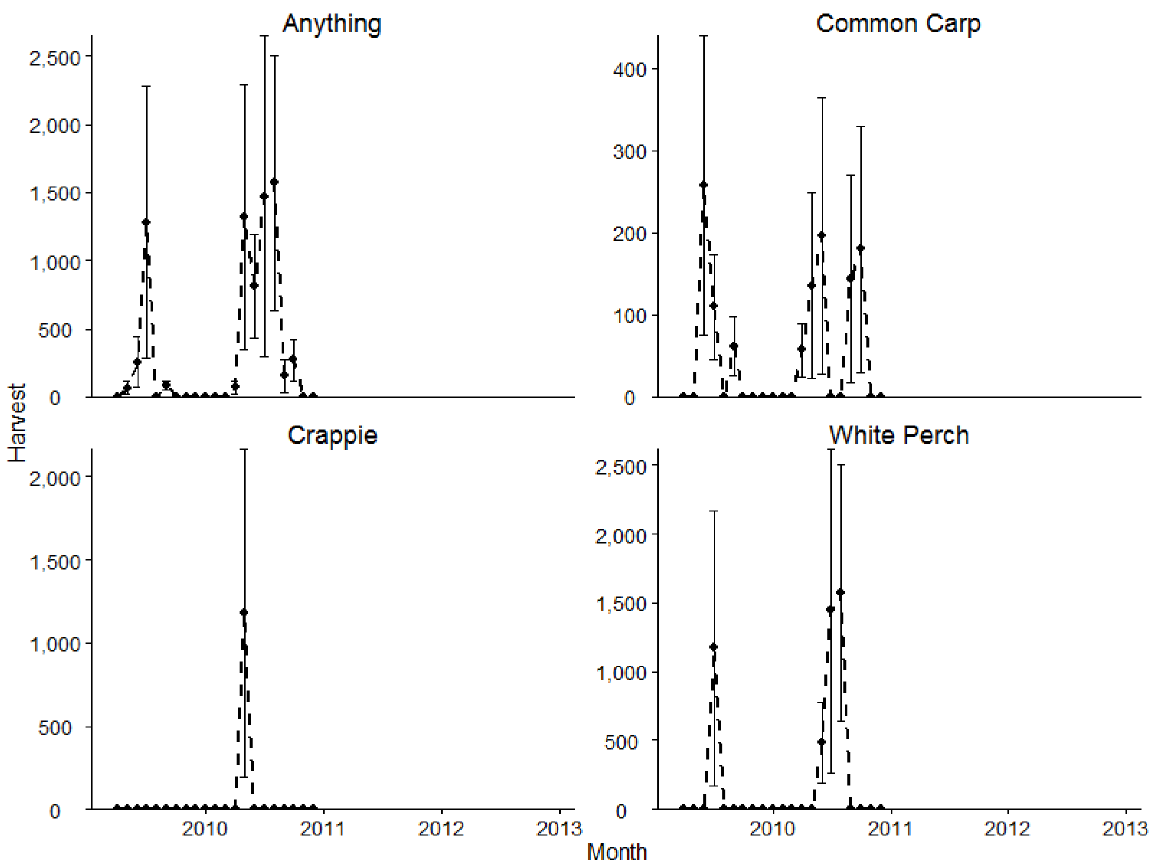

Figure G-10. Monthly harvest (mean ± SE) of species comprising greater than 5% of harvest in any one year at Pawnee Lake. Anything represents total harvest of fish.

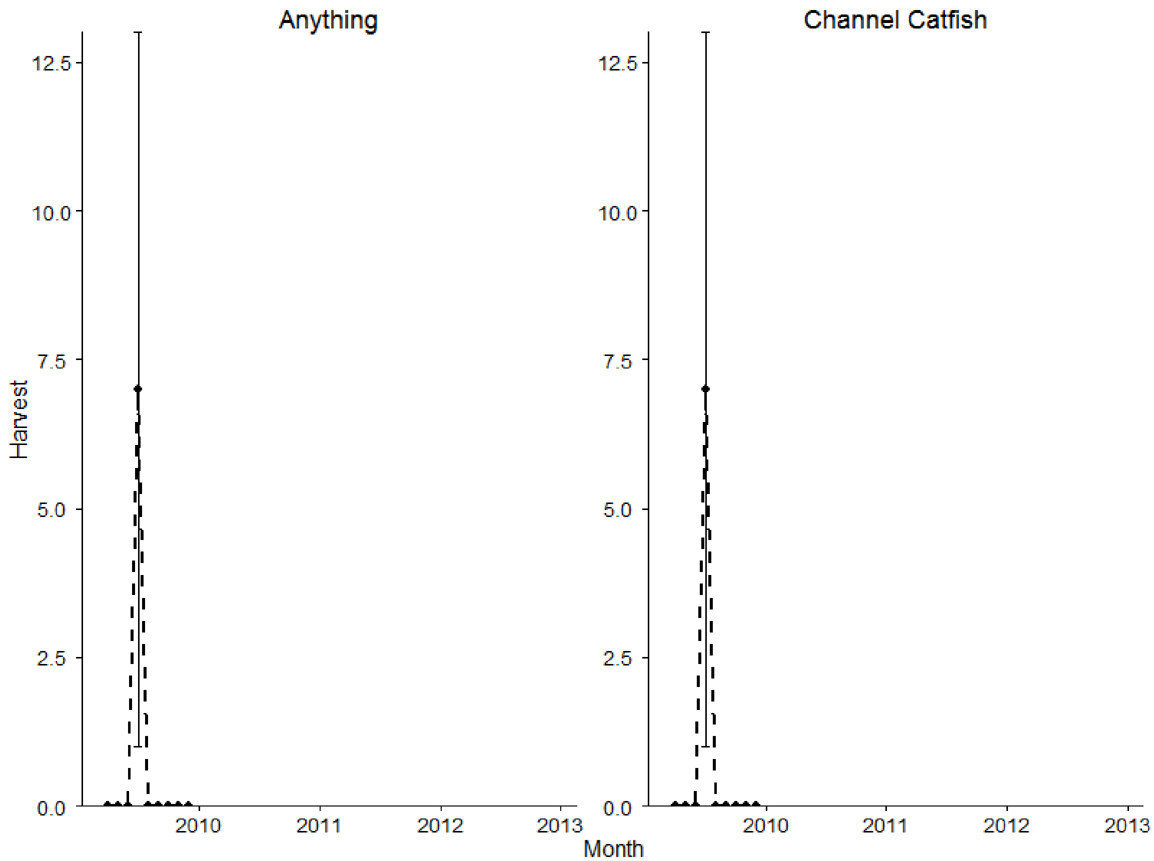

Figure G-11. Monthly harvest (mean ± SE) of species comprising greater than 5% of harvest in any one year at Red Cedar Lake. Anything represents total harvest of fish.

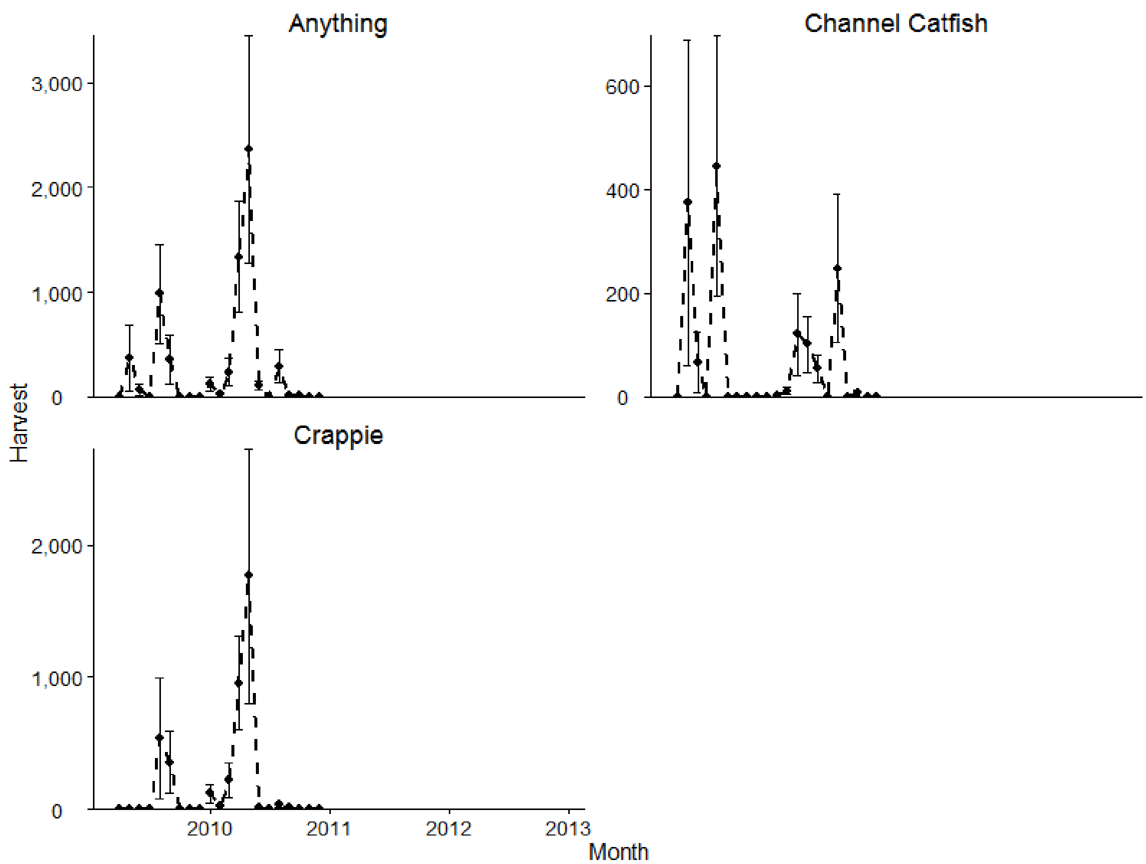

Figure G-12. Monthly harvest (mean ± SE) of species comprising greater than 5% of harvest in any one year at Stagecoach Lake. Anything represents total harvest of fish.

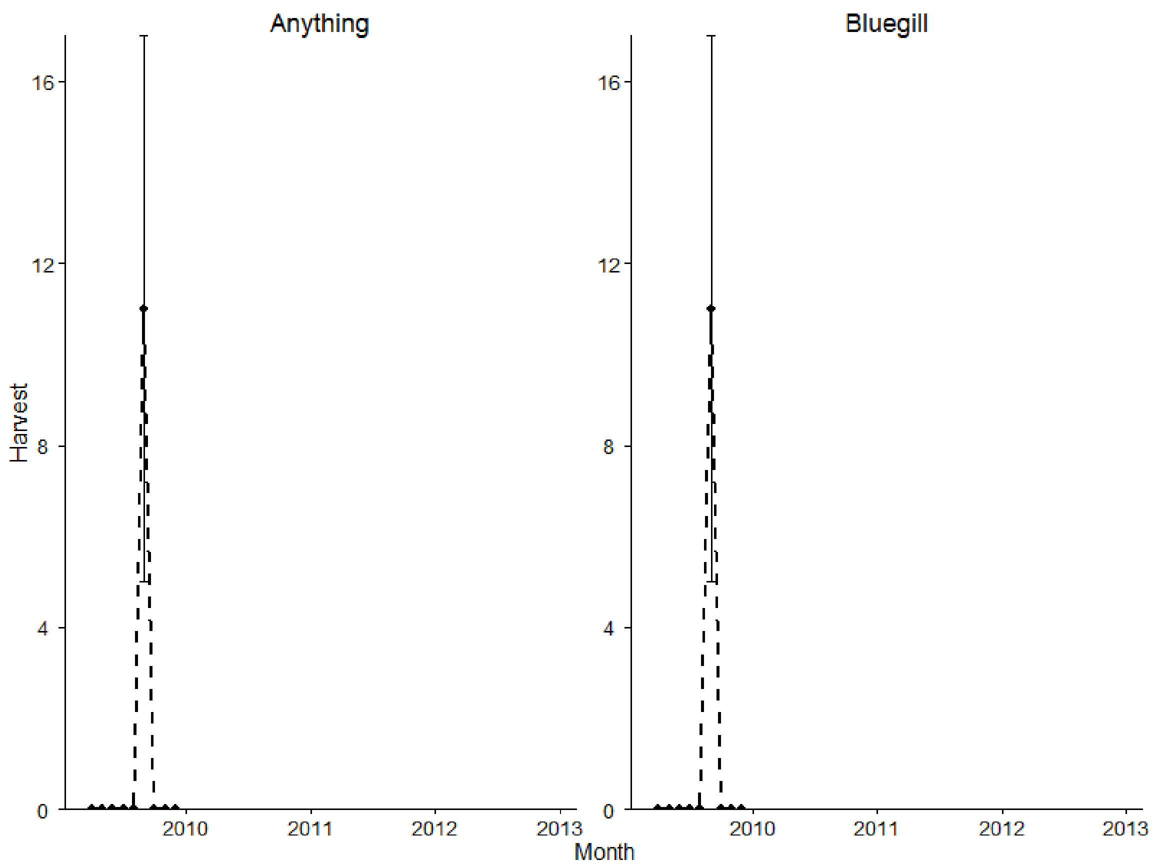

Figure G-13. Monthly harvest (mean ± SE) of species comprising greater than 5% of harvest in any one year at Timber Point Lake. Anything represents total harvest of fish.

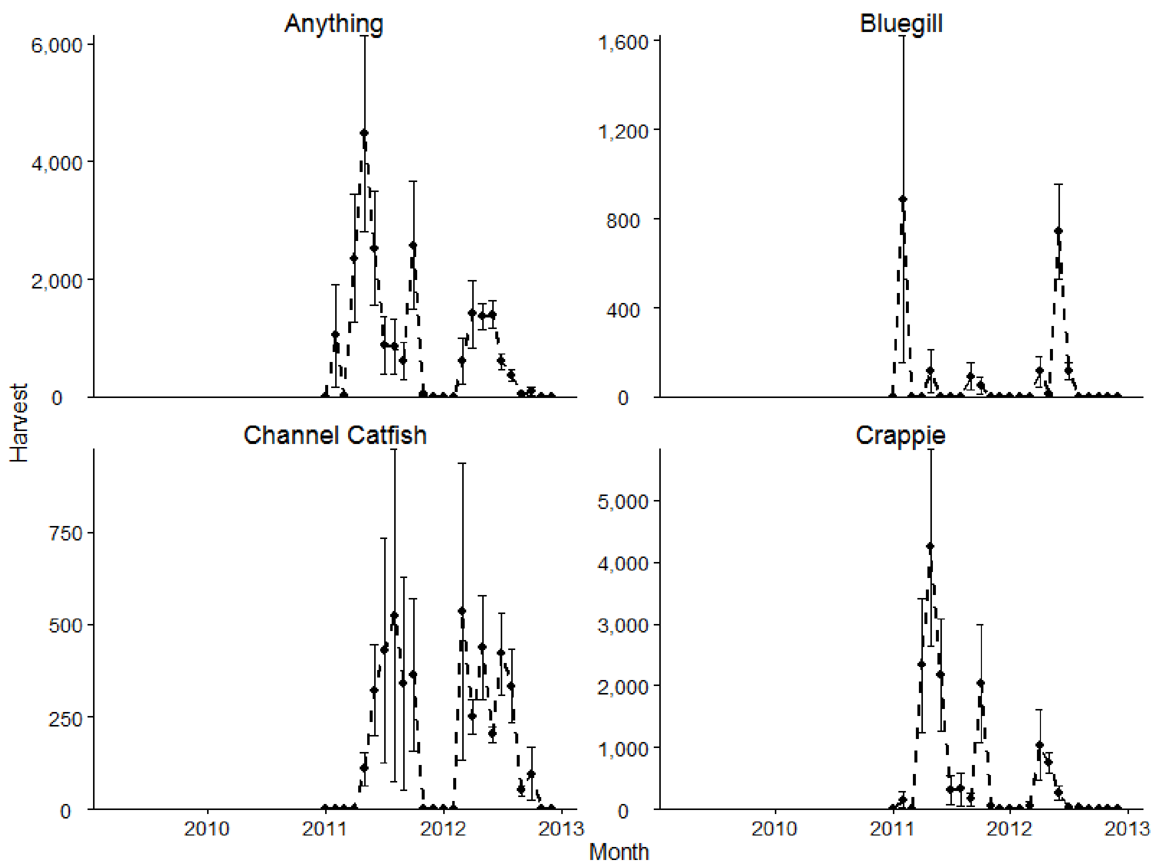

Figure G-14. Monthly harvest (mean ± SE) of species comprising greater than 5% of harvest in any one year at Wagon Train Lake. Anything represents total harvest of fish.

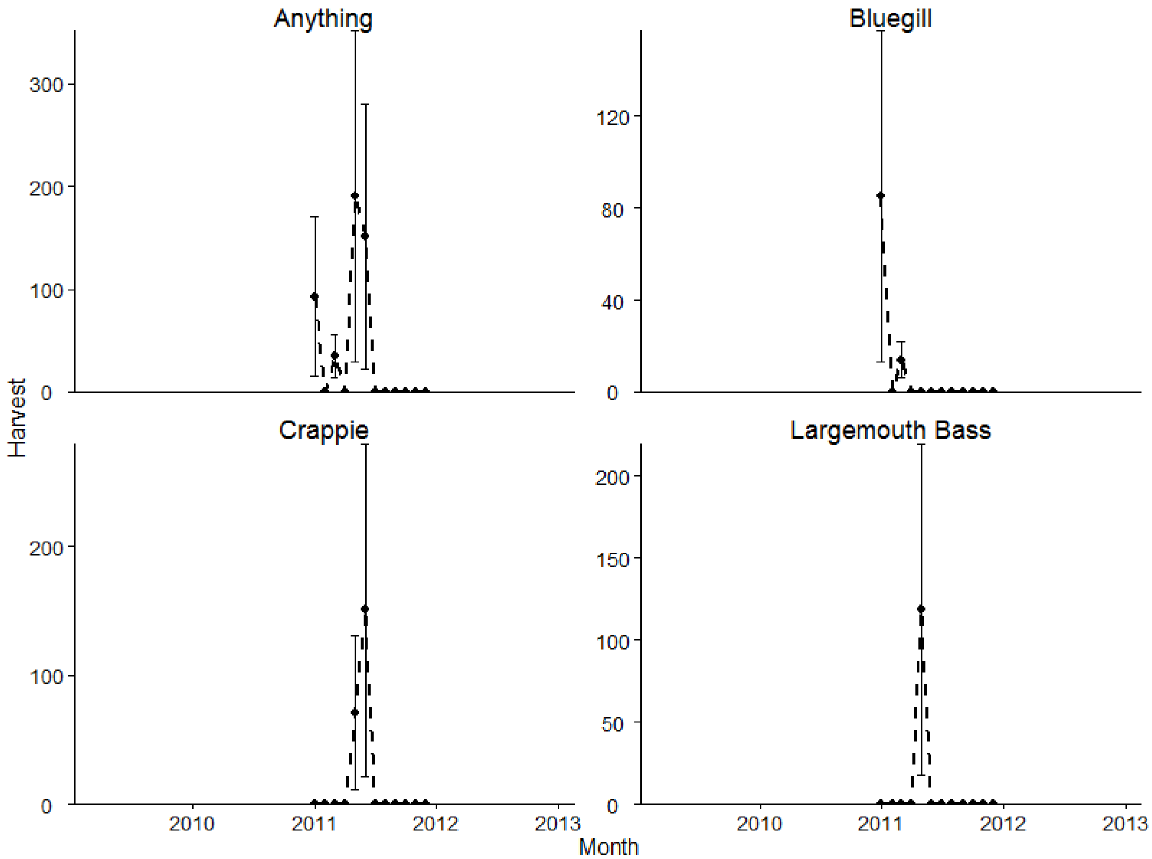

Figure G-15. Monthly harvest (mean ± SE) of species comprising greater than 5% of harvest in any one year at Wild Plum Lake. Anything represents total harvest of fish.

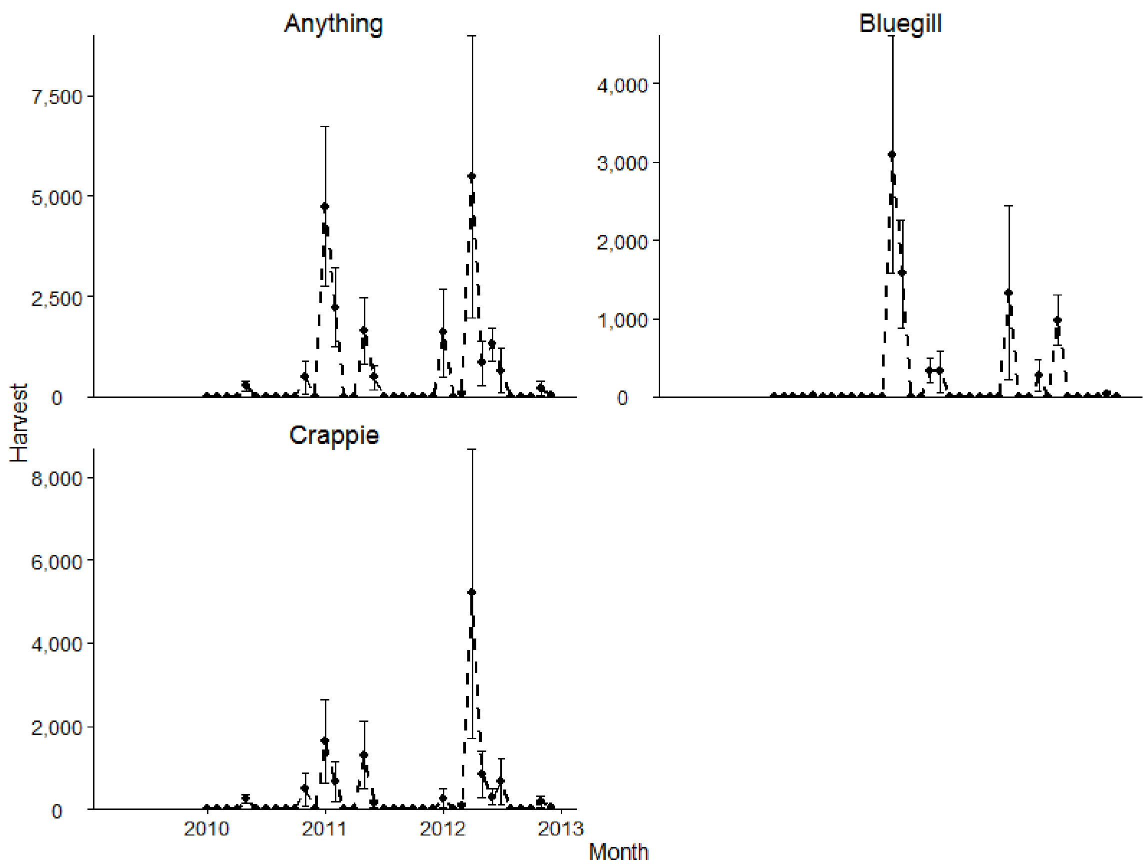

Figure G-16. Monthly harvest (mean ± SE) of species comprising greater than 5% of harvest in any one year at Wildwood Lake. Anything represents total harvest of fish.

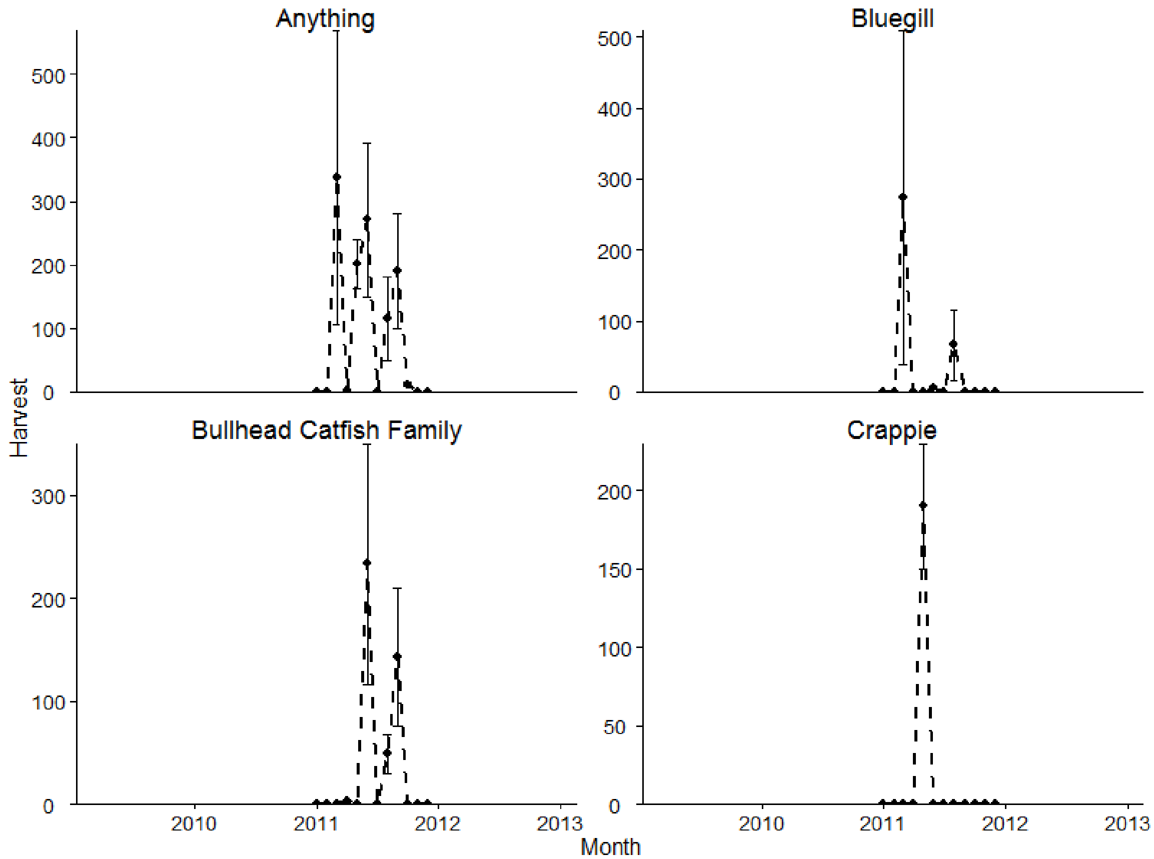

Figure G-17. Monthly harvest (mean ± SE) of species comprising greater than 5% of harvest in any one year at Yankee Hill Lake. Anything represents total harvest of fish.

Appendix H. Monthly fishing effort estimated from bus-route pressure counts at all Salt Valley reservoirs during 2009-2012.

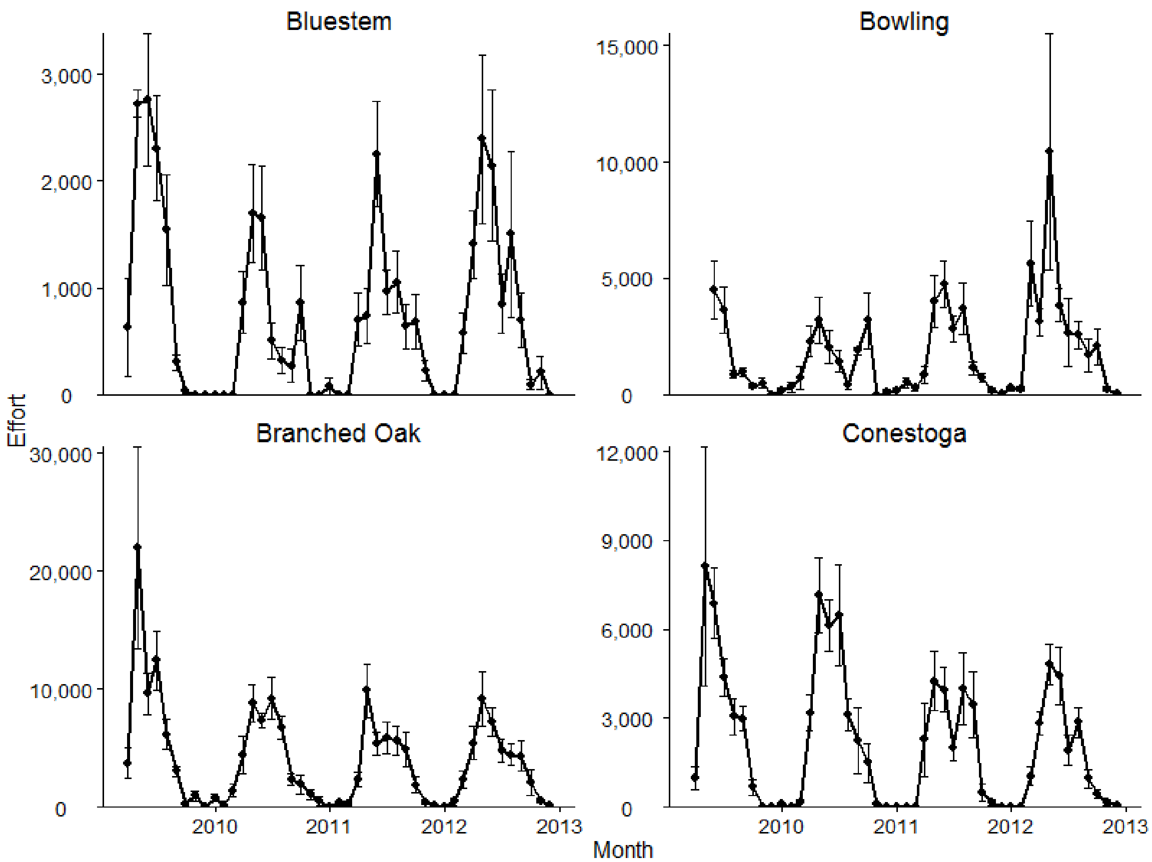

Figure H-1. Monthly fishing effort (mean ± SE) estimated from bus-route pressure counts at Bluestem, Bowling, Branched Oak, and Conestoga reservoirs during 2009-2012.

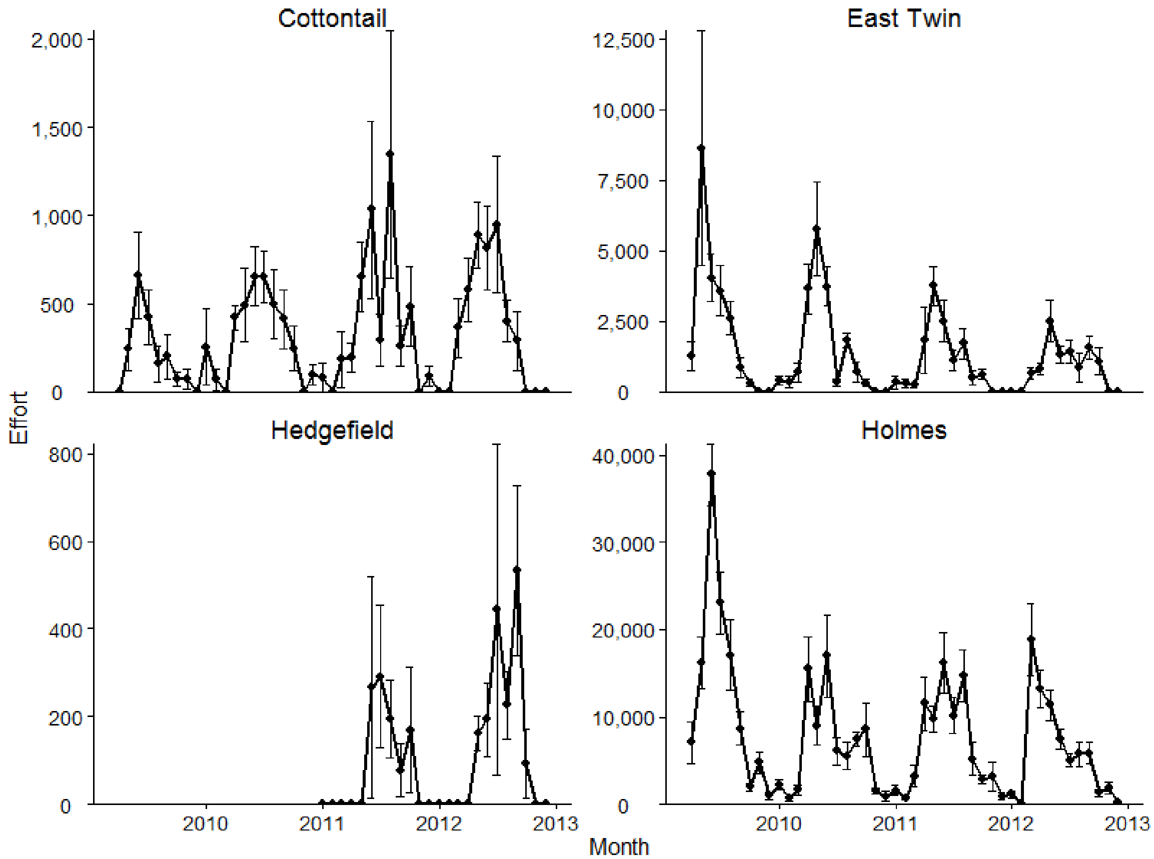

Figure H-2. Monthly fishing effort (mean ± SE) estimated from bus-route pressure counts at Cottontail, East Twin, Hedgefield, and Holmes reservoirs during 2009-2012.

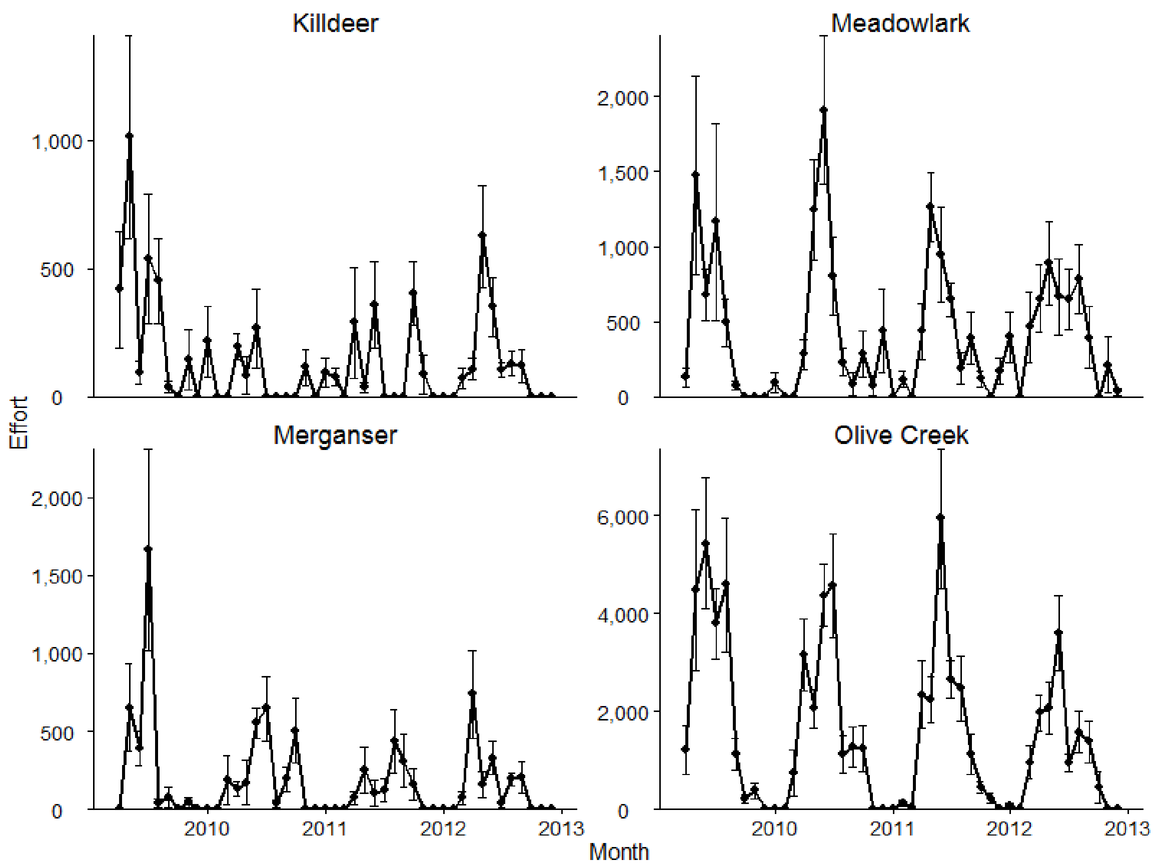

Figure H-3. Monthly fishing effort (mean ± SE) estimated from bus-route pressure counts at Killdeer, Meadowlark, Merganser, and Olive Creek reservoirs during 2009-2012.

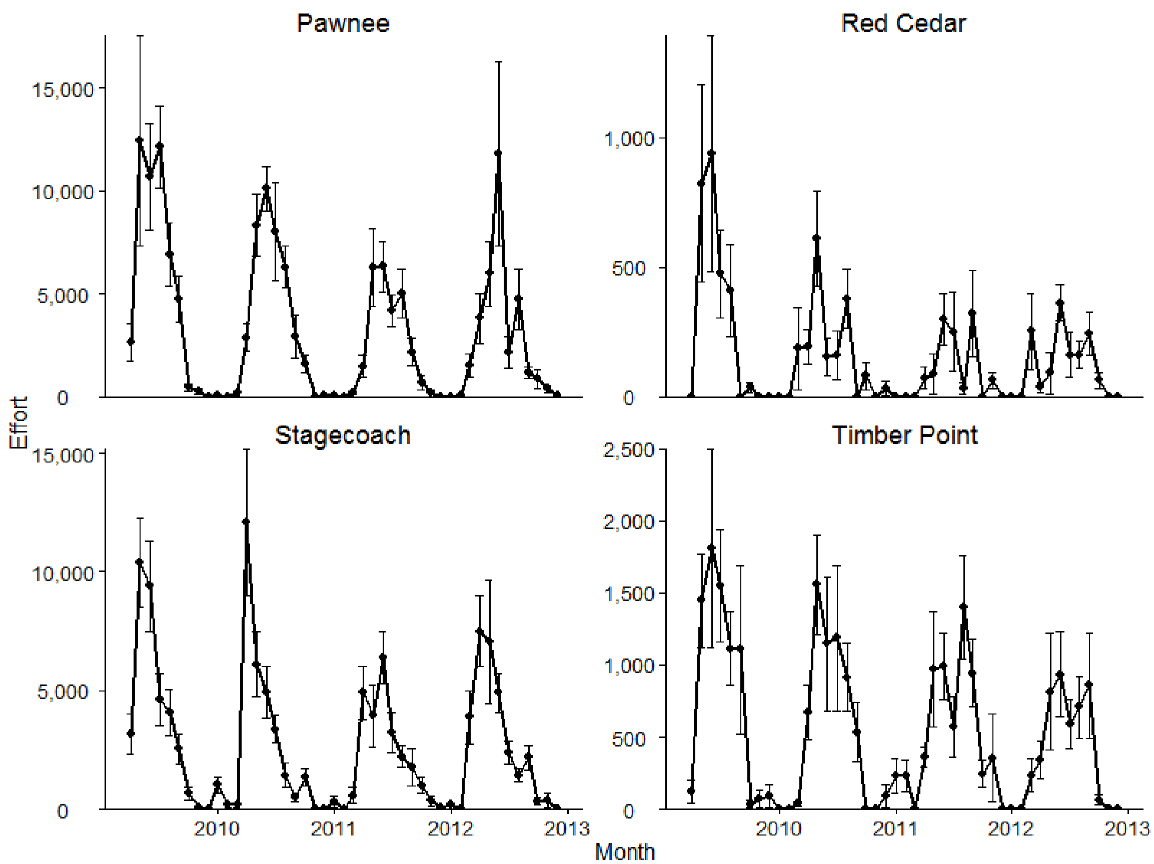

Figure H-4. Monthly fishing effort (mean ± SE) estimated from bus-route pressure counts at Pawnee, Red Cedar, Stagecoach, and Timber Point reservoirs during 2009-2012.

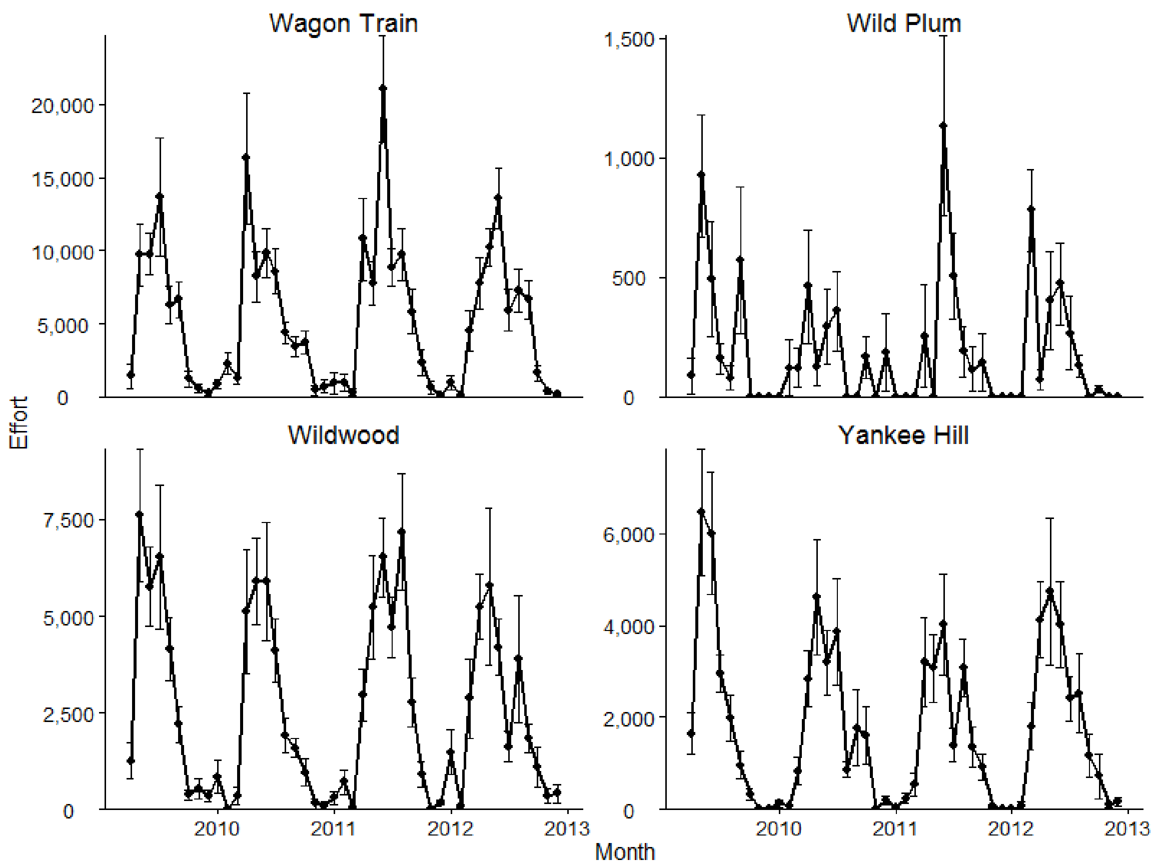

Figure H-5. Monthly fishing effort (mean ± SE) estimated from bus-route pressure counts at Wagon Train, Wild Plum,. Wildwood, and Yankee Hill reservoirs during 2009-2012.