TRACKING BLUE CATFISH: QUANTIFYING SYSTEM-WIDE DISTRIBUTION OF A MOBILE FISH PREDATOR THROUGHOUT A LARGE HETEROGENEOUS RESERVOIR

by

KAYLA M. GERBER

B.S., Winona State University, 2011

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Division of Biology
College of Arts and Sciences

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2015

Approved by:

Major Professor
Martha E. Mather

Copyright

Abstract

A flexible distribution is an adaptive response that allows animals to take advantage of spatial variation in the fluctuation of resources. Distribution of mobile organisms is complex so multi-metric patterns derived from dynamic distribution trajectories must be deconstructed into simpler components for both individuals and populations. Tagging and tracking fish is a very useful approach for addressing these fisheries research questions, but methodological challenges impede its effectiveness as a research tool. Here, I developed and evaluated a high-retention, high-survival tagging methodology for catfish. Then, I integrated multiple distribution metrics to identify if sites within an ecosystem function differently for mobile predators. Finally, I determined if distinct groups of individuals existed, based on distributional patterns. In the appendices, I test sources of variation in system-wide detections (i.e., season, diel period, size, and release location) and provide additional details on methods and interpretation of the results. To address these objectives, I tracked 123 acoustically tagged (VEMCO V9-V13) Blue Catfish (*Ictalurus furcatus* mean: 505.3 mm TL; SE: 12.3 mm; range: 300-1090 mm) from June through November, 2012-2013, in Milford Reservoir, KS. Across the five months, 85.4-100.0% of the tagged Blue Catfish were detected at least once a month by an array of 20 stationary receivers (VR2W), a detection rate much higher than rates reported in the literature for catfish (38%). Blue Catfish were consistently aggregated in the northern portion of the middle region of Milford Reservoir. Using three metrics (population proportion, residence time, and movements), I found four types of functional sites that included locations with (i) large, active aggregations, (ii) exploratory/transitory functions, (iii) small, sedentary aggregations, and (iv) low use. I also found that tagged Blue Catfish clustered into three groups of individuals based on distribution. These included (1) seasonal movers, (2) consistent aggregations across seasons, and (3) fish

exhibiting site fidelity to Madison Creek. Sites with different functions and groups of individual fish were related but not the same. My approach to looking at multiple responses, functions of sites, and individual groupings provided new insights into fish ecology that can advance fisheries management of mobile predators.

Table of Contents

List of Figures

List of Tables

Acknowledgements

This project was funded with Dingell-Johnson Sport Fish Restoration Act monies through the Kansas Department of Wildlife, Parks, and Tourism. The project was administered by the Kansas Cooperative Fish and Wildlife Research Unit as a joint effort between Kansas State University, the U.S. Geological Survey, U.S. Fish and Wildlife Service, the Kansas Department of Wildlife, Parks, and Tourism (KDWPT), and the Wildlife Management Institute. I am grateful to everyone from KDWPT that made this project possible. I especially would like to thank Keith Sexson, Joe Kramer, Doug Nygren, and Tom Mosher for leadership that resulted in a successful collaboration. I would also like to thank Jason Goeckler, John Reinke, Ron Marteney, Ely Sprenkle, and Daric Schneidewind. A special thanks goes out to my major advisor and committee members Martha Mather, David Haukos, Alice Boyle, and Joe Smith for all of their comments, feedback, and guidance throughout the development of the project. I would like to thank Jack Finn for his help with the network analysis. I would also like to thank all of my friends who have been there to provide moral support and stories of success and failure; especially, Zach Peterson, who shared in all of the successes (data collection) and failures (boats not working and flat/blown tires) encountered out in the field. Last but not least I would like to thank my family Chris & Monica Gerber, Kristine Gerber, and Mitchell Gerber who have supported my decision to move eight hours away from home for graduate school. Not only have they supported me over the past three years but they have provided support and encouragement my whole life. I would not have been able to accomplish what I have without them. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government. This research was conducted under the auspices of Kansas State University IACUC Protocols #3151 and 3151.1.

Chapter 1 - A High-Retention, High-Survival Methodology for Surgically Implanting Telemetry Tags in Fish

Abstract

Tagging and tracking fish is useful for addressing fisheries research questions, but methodological challenges impede its effectiveness as a research tool. A review of tagging studies revealed that Blue Catfish (*Ictalurus furcatus*) and Channel Catfish (*I. punctatus*) have high tag loss through expulsion, egestion, and mortality (mean catfish tag loss= **62%**, range = **0-100%**). I tested how incision location, antibiotics, and surgery time affected survival and tag retention of 70 hatchery-raised Channel Catfish [184-260 mm (TL)] in Milford Hatchery, KS over 12 weeks to understand why catfish do not retain their tags. I also acoustically tagged and tracked 123 Blue Catfish in Milford Reservoir, KS, in 2012 and 2013. For these field data, I used five data diagnostic metrics to evaluate detections to understand patterns of tag loss and mortality. Mortality and tag expulsion rates of the hatchery-reared Channel Catfish that I tagged were greatest in the first two weeks. A ventral incision resulted in a greater tag loss rate than a lateral incision. Over five months for both 2012 and 2013, I observed **85.4-100%** survival/retention in my field tagged Blue Catfish, a detection rate greater than rates reported in the literature for catfish (**38%**). In summary, pre-tagging preparation, extreme care during tagging to reduce stress, and a lateral incision contributed to my high-retention methodology for tagging catfish. Preventative measures (antibiotics and salt bath) likely reduced tag loss and mortality in the field. Multiple detection data diagnostics provided a useful and novel perspective on patterns of retention and mortality in tagged fish. Both of these aspects of tagging methodology can benefit fisheries research and management.

Introduction

Fish tagging and tracking can provide substantial insights into distributional patterns. Knowing fish location is useful for many questions related to research and management (Hubert 1999; Millspaugh and Marzluff 2001). Understanding distribution patterns is a challenge for effective fisheries ecology and conservation, this information gap can be addressed with tagging and tracking (e.g., Alldredge et al. 2011). With the development of smaller and lighter transmitters and other technological advances (Knaepkens et al. 2005; Metcalfe 2006; Hitt and Angermeier 2008; Albanese et al. 2009), biotelemetry or tagging and tracking has become one of the most popular methods to study fish in their natural environment (Bridger and Booth 2003). As a consequence, in recent years the number of fish tagging studies has increased dramatically (Fig. 1.1). However, methodological obstacles related to tagging and tagging data diagnostics impede the successful use of this new technology for fisheries ecology and management. Here, I seek to provide a high-retention, high-survival tagging methodology and identify data assessment techniques that can be used to evaluate the quality of tagging data. My methodology can be applied to all species that are large enough (body size >2% tag weight) and most ecosystems. As a proof of concept, I evaluate my methodology on two species that have been shown to be difficult to tag, Blue and Channel Catfish.

Lack of detections is a problem for telemetry studies which can negate scientific advances that might result from tracking research. Changes in timing and location of detections are the essential pieces of information that radio or acoustically tagged fish provide relative to distribution. Identifying why tagged fish are undetected in the field is difficult. Lack of detections can occur when a tagged fish: (1) naturally leaves the detection array temporarily or permanently; (2) dies from natural causes; (3) dies from tagging or handling associated with tagging; or (4) loses its tag via egestion (mouth or anus) or ejection (incision site). Lack of

detections from each of these sources has different implications for data interpretation. The mechanism that causes a tagged fish to be undetected [natural (1-2 above) vs tag-related (3-4 above)] is usually unknown in the field. The last two patterns of non-detections are caused by poor tagging methodology and can raise serious questions about the quality of the resulting tracking data. A good tagging methodology and a thoughtful plan for critically evaluating the detection of tagged fish can reduce some of the uncertainty related to tagging.

A rigorous and standardized tagging methodology can reduce tag-related mortality and tag loss. Surgically implanting acoustic tags within the coelomic cavity of a fish is generally regarded as the most appropriate method for long-term biotelemetry applications (Jepsen et al. 2002; Bridger and Booth 2003; Brown et al. 2011; Cooke et al. 2011; Theim et al. 2011). However, the surgical implantation of acoustic tags has the potential to cause infection, alter behavior, and ultimately lead to mortality (Bridger and Booth 2003; Cooke et al. 2011). To ensure that data generated from tagged fish are relevant to untagged conspecifics, fish tracking research requires synthesis and refinement (Cooke et al. 2011). In particular, methodologies for tagging fish need to be developed and evaluated to understand if tagged fish are not detected because they are absent from an array (natural patterns of interest), whether they died as a result of tagging (methodological problems), or whether they lost their tags (methodological problems).

A sound tagging methodology and rigorous evaluation is important for all fish tracking studies. Tagging methodologies have been developed or evaluated for many species (e.g., Chinook Salmon, *Oncorhynchus tshawytscha,* Panther et al. 2011; Rainbow Trout, *Oncorhynchus mykiss*, Ivasauskas et al. 2012; Shortnose Sturgeon, *Acipenser brevirostrum*, and Atlantic Sturgeon, *A. oxyrhynchus oxyrhychus*, Crossman et al. 2013). Tag retention of non-ictalurid fish (% tags retained) is variable but can be high [**65%** & **75%** (Ivasauskas et al. 2012);

13% & **94%** (Crossman et al. 2013); **96%** (Panther et al. 2011)]. However, only a limited number of studies have developed or evaluated tagging methodologies for recreationally-important catfish species (Blue Catfish; e.g., Holbrook et al. 2012; Bodine and Fleming 2013 and Channel Catfish, e.g., Summerfelt and Mosier 1984; Marty and Summerfelt 1986, 1990). Tag retention for ictalurid catfish is usually low [Blue Catfish: **47%** (Holbrook et al. 2012); **0%** (Bodine and Fleming 2013); Channel Catfish: **29%** (Summerfelt and Mosier 1984); **30%** (Marty and Summerfelt 1986); Table 1.1]. Catfish tag loss occurs via ejection (i.e., loss through incision site or egestion; Summerfelt and Mosier 1984; Marty and Summerfelt 1986) as tags have been found outside of previously tagged catfish. Even though new methods are being developed and evaluated (Bodine and Fleming 2013), a high-survival, high-retention methodology for tagging catfish has still not been identified. As catfish continue to increase in popularity as a sportfish, the inability to tag and track catfish will escalate as a research and management problem.

I developed and evaluated a tagging and tracking methodology for Blue Catfish and Channel Catfish. Specifically, I asked three questions: (1) Does my tagging methodology result in high-survival and high-retention of surgically implanted tags over a 10-day period (short-term stress) and five months (over two seasons: summer and fall)?, (2) What data diagnostic metrics help evaluate the success of tagging relative to retention and survival over both the first ten days and the duration of the field study?, and (3) Using a hatchery study, which aspects of my tagging methodology (incision location, antibiotics, surgery time) affected catfish tag loss and survival?

Methods

Overview

I tagged Blue Catfish (BC) and Channel Catfish (CC) four times over three years (2012-2014) in two settings (Milford Hatchery and Milford Reservoir, KS, 39°08'42"N, 96°56'54"W;

Table 1.2). These trials served three purposes: (1) practice tagging techniques (2012, BC, Milford Hatchery); (2, 3) evaluate field distributions of catfish (2012 & 2013, BC, Milford Reservoir) across ten days and five months; and (4) test three components of my tagging protocol (incision location, antibiotics, surgery time; 2014, CC, Milford Hatchery). I used the same tagging protocol (described below) for all evaluations.

2012 – Blue Catfish, Milford Hatchery, Technique Practice and Evaluation

After reviewing the literature, developing a surgical protocol, and practicing incision and suturing techniques in the laboratory, I tested my tagging protocol on live hatchery-raised Blue Catfish (estimated range: 150-250 mm TL) at Milford Hatchery, KS (Table 1.2). Each of four individual taggers on my team sequentially tagged five catfish, following the procedures in my written protocol (described below). Tagged catfish were then held and observed in a hatchery tank for seven days. At the end of the week, tag placement was evaluated through euthanasia and dissection. This qualitative evaluation was an opportunity to standardize, test, and improve the tagging technique.

2012, 2013 – Blue Catfish, Milford Reservoir, Field Evaluation of Distribution

For my test of distributional patterns of Blue Catfish in Milford Reservoir, KS, I targeted 400-600 mm TL in both 2012 and 2013. This size range was the most commonly available size of Blue Catfish in Milford Reservoir (John Reinke, KDWPT, personal communication; Appendix A; Fig. A.1). In 2012, the average fish size tagged was 487 mm TL [range: 383-1020 mm total length (TL); SE: 14.5; n = 48; 88% 400-600 mm TL; Table A.1]. In 2013, I added smaller and larger fish to the study (Table A.2). This resulted in an average size of tagged Blue Catfish in 2013 of 517 mm TL (range: 343-1090 mm TL; SE: 17.8, n = 75; 71% 400-600 mm TL). Tagged fish were tracked with a lake-wide stationary receiver array (described elsewhere;

Appendix B). The upper river receiver (receiver 1 – outside of the reservoir) and the upper within-reservoir receiver (receiver 2 – inside of the reservoir) formed a two-tier gate to detect upriver egress from the reservoir. The southernmost receiver in the reservoir (receiver 19 – inside of the reservoir) and the receiver below the dam (receiver 20 – outside of the reservoir) formed another two-tier gate to detect downriver egress. More detail on array design and receiver range test can be found elsewhere (Appendix B). Although my goal was to tag the most common size range, actual sizes of fish I tagged depended on what fish sizes were captured through electrofishing.

Tagging Methodology

I used an 8-step tagging procedure that included: 1-pre-field preparations; 2-preparation at the tagging location; 3-minimal stress fish collection; 4-anesthesia; 5-tagging with surgeon and anesthesiologist; 6-antibiotics after surgery; 7-salt bath recovery; and 8-minimal stress release (Figs. 1.2 & 1.3). The same procedures were used for all field and hatchery tagging for both catfish species.

1. Pre-Field Preparations

Preparation before field work was essential to minimize fish stress. Existing literature on tagging studies was reviewed and summarized to determine what tagging techniques were used. I also contacted authors via email who had published on catfish tagging for additional insights. As with most research facilities, I was required to submit an Institutional Animal Care and Use Committee (IACUC) protocol #3151 and #3151.1 for which a university veterinarian provided useful advice on anesthetic and surgical techniques.

In addition to the literature and technical expert consultations, practicing incisions and suturing was essential. Many useful print and online video tutorials on surgical techniques exist

and provided a good starting point. Practice was perhaps the most important component of my protocol. Incision and suturing were practiced on inanimate objects (oranges and bananas) and dead fish were also added as a new dimension. An important component of my technique, however, was tagging live hatchery fish prior to field tagging (Figs. 1.2 and 1.3-1). Tagging of hatchery fish was followed by an evaluation of survival, healing, and tag placement in the hatchery for seven days.

2. Preparation at the Tagging Location

For field sampling, I used jon boats, beached adjacent to the collection area, as mobile surgical stations. This minimized the time fish were confined during transport before surgery. This setup also allowed me to release fish near the location where they were captured, which was essential. For tagging in the field, workspace was limited, so I pre-planned all steps for fish processing to make sure that a two-person surgical team could easily transfer fish from a holding tank (volume: 76 L; diameter: 41 cm), to the anesthesia tank (volume: 10 L), to the surgery board, to a recovery tank (volume: 76 L; diameter: 41 cm), then to the reservoir for release (Figs. 1.2 and 1.3-2). I chose to use two operating teams in two separate jon boats with a shared salt bath recovery tank to process my fish quota more rapidly. I monitored temperatures in each holding and recovery tank and compared it to ambient lake temperatures. When tank temperatures exceeded reservoir temperature I changed the water. Patio umbrellas were placed over the holding and recovery tanks to provide shade for the fish. For my hatchery study, I used a very similar inside set-up.

3. Minimal Stress Fish Collection

Blue Catfish were captured for tagging using boat electrofishing (1 stationary boat, 2 capture boats) with low pulse DC current (15 pulses/s, 3-5 amps) (Bodine and Shoup 2010; Figs.

1.2 and 1.3-3). Fish were held on electrofishing boats post-sampling in large aerated live wells. I tagged 5-10 catfish at a time so that catfish were held on board < 60 minutes post-capture. This step in my protocol allowed me to tag fish of predetermined size from known locations that were captured with minimal stress and held in low stress conditions for a relatively short time per surgery.

4. Anesthesia, 5. Tagging with Surgeon and Anesthesiologist

Individual fish were anesthetized one at a time with Aqui-S 30 mg-L in a single fish tank until they lost orientation (2012: average: 2 min. 16 sec., SE: 12 sec.; 2013: average: 2 min. 30 sec., SE: 7 sec.; 2014: average: 2 min. 42 sec., SE: 3 sec.; Fig. 1.3-4). During the tagging of a fish, two people processed the fish. One acted as the surgeon and never moved from the surgical station. The other acted as the anesthesiologist and moved the fish from a holding tank, to the anesthesia tank, to the surgery board, to the recovery tank. The anesthesiologist also constantly applied ambient water (with Aqui-S if needed) to the fish skin and gills during surgery and made sure the fish remained in the optimal position for a quick and stress-free surgery. In 2012, for field tagging, I used VEMCO V9 tags (length: 29-47 mm, weight in air: 4.7-6.4 g, weight in water: 2.9-3.5 g). In 2013, I added VEMCO V13-1H tags (length: 36-48 mm, weight in air: 11-13 g, weight in water: 6-6.5 g). Tags were less than 2% of the body weight of all tagged fish (Bridger and Booth 2003).

After anesthesia, fish were weighed (hanging scale with a cradle of soft mesh) and measured on a wet measuring board. A 15-30 mm lateral incision was made below the pectoral fin about ¾ of the way to the tip of the fin (15-20 mm incision for 300-700 mm TL Blue Catfish; 20-30 mm incision for >700 mm TL Blue Catfish; Figs. 1.2 and 1.3-5). I used surgical scalpels of size 12 for fish < 700 mm TL and 22 for fish > 700 mm TL. As catfish intestines are very

close to a thin body wall, I was careful to make the incision into the fish body wall in increments so that only skin and muscle, not intestines, were cut. A tag sterilized with betadine or alcohol was carefully inserted into the body cavity. The incision was closed with 2-4 simple interrupted sutures (Ethicon, braided, coated Vicryl, 3-0, FS-1, 24 mm 3/8 c reverse cutting for fish > 700 mm TL; Ethicon, braided, coated Vicryl, 3-0, FS-2, 19 mm 3/8 c, reverse cutting for fish < 700 mm TL). Surgery time was relatively short (2012: average: 2 min. 38 sec., SE: 7 sec.; 2013: average: 2 min. 54 sec., SE: 5 sec; 2014: average: 1 min. 54 sec., SE: 1 sec.). Multiple sutures ensured that the incision would remain closed if a single suture failed.

6. Antibiotics after Surgery, 7. Salt Bath Recovery, 8. Minimal Stress Release

After surgery all fish received an intramuscular injection of antibiotic (Liquamycin: 0.1 mg/kg per fish; Figs. 1.2 and 1.3-6), then were allowed to recover in an individual tank (volume: 76 L; diameter: 41 cm) with oxygenated, ambient water until the fish was upright and swimming (Recovery times 2012: average: 5 min. 7 sec., SE: 24 sec.; 2013: average: 7 min. 14 sec., SE: 13 sec.; 2014: average: 6 min. 30 sec., SE: 11 sec.). Tagged fish were then transferred to a larger community recovery tank (volume: 1,380 L) with a 0.05% salt solution to aid in slime coat recovery (Figs. 1.2 and 1.3-7). After at least 15 minutes in a salt bath, fish were individually captured with a soft mesh trout net, placed in the lake close to where they were captured, and allowed to voluntarily swim away (Figs. 1.2 and 1.3-8).

Metrics for Evaluation of the Data and Tagging Methodology from the Field

The fate of tagged fish in the field is unknown unless fish are actively detected at different locations with some frequency. If fish are alive post tagging and retain their tags, they should be repeatedly detected at different receivers. I examined post-tagging detection data for Blue Catfish in five ways. First, I plotted detections (presence-absence) for the first ten days

when post-tagging mortality and tag loss to acute stress was most likely to occur (Baras et al. 1999; Jepsen et al. 2002). This abacus type of plot is very common for tagging studies but typically combines multiple locations. I used this metric for the first ten days, but weekly detections can also be plotted for the entire study. I assumed that fish that were detected in multiple time periods were alive and retained their tags.

Second, even if tags are repeatedly detected, tagged fish could die and lodge next to a receiver, so I summarized the total number of receivers visited by each fish in the first ten days and for the entire study period. This was a quick evaluation of whether fish that were detected actively moved among receivers. I assumed that if fish were detected at >1 receiver they were alive and retained their tags.

Third, in the event that the above-described multiple receiver visitation diagnostic is not convincing enough, I constructed a "miniature" plot of distribution for each individual fish that summarized all daily detection events at each receiver (Y-axis) over the entire study period (X-axis). A single plot was used to assess if fish regularly changed position over both the first ten days and the entire study period. In this chapter, I showed this third metric only for fish detected at ≤1 receivers during the first ten days. In Appendix C, I show miniatures for all fish across both years. If fish were alive, mobile, and retained their tags, I predict they would be detected at many different receivers throughout the study.

Fourth, I plotted the number of fish detected per month (%) across the first five months of the study for both years. This is a common diagnostic in tagging studies although tagging studies do not often redetect a large number of their tagged fish. The greater the number of fish detected across the first five months meant that there was evidence of a high-retention and survival methodology.

Finally, I determined if any fish could have left the reservoir system by examining the two-tier gate receivers located at the causeway (receiver 2), upstream of the reservoir (receiver 1), at the dam (receiver 19), and downstream of the reservoir (receiver 20; Fig. B.1). This egress diagnostic must interpreted with other diagnostics. For example, if tagged fish are regularly detected throughout the system they did not leave the system. For fish to leave the system, they need to be detected at receiver 1 (2012 – upstream of the reservoir) or receiver 20 (2012 and 2013, downstream of the reservoir). Potentially, tagged fish last detected at receiver 2 in 2013 could have left the system. Fish detections at receiver 1 and 2 can be compared to assess the probability that a fish last detected at receiver 2 left the system.

2014 – Channel Catfish, Milford Hatchery, Evaluation

In 2014, I tested how three factors (incision location, antibiotics, and surgery time) affected tag loss for 70, age-0, hatchery-reared channel catfish (Table 1.2). I tested these three factors by creating five treatments with different combinations of incision location (lateral or ventral), antibiotics (antibiotics or no antibiotics), surgery time [short (2 min.) or long (8 min.)], and a control. Each of the five treatments contained 14 fish (size range: 184-260 mm TL). Treatment 1 was the treatment I described above for my field tagging [lateral incision, antibiotics, quick surgery time (2-3 min)]. Treatment 2 was similar to treatment 1 but used a ventral incision (ventral incision, antibiotics, quick surgery time). Treatment 3 used a lateral incision, no antibiotics, and a quick surgery time. Treatment 4 used alternative options to treatment 1 [ventral incision, no antibiotics, longer surgery time (about 8 min)]. Treatment 5 was a control in which tagging was simulated but no fish were tagged.

Before the hatchery experiment tagging, all dummy VEMCO V6 tags (length: 16.5 mm, weight in air: 1 g) were engraved with a number. Post-tagging, all fish were Floy tagged. I

recorded treatment, VEMCO dummy tag number, and Floy tag number so I could link tag loss to a treatment. I held all 70 fish in a single (4 m X 4 m) compartment of a hatchery raceway for 12 weeks. I took pictures and recorded general fish condition, which included incision condition (suture present, redness at incision, redness at suture insertions, and healing of the incision), Floy tag number, and Floy tag insertion condition, for each fish on a weekly basis. Each week, the bottom of the hatchery compartment visually and manually searched four times (two times each by two people) to recapture ejected tags. At the end of 12 weeks, I euthanized all fish with an overdose of Aqui-S, measured and weighed fish, recovered tags, and photographed tag position within the body cavity. To summarize data, I plotted tag loss and survival data by treatment. I used a Chi square test to test if tag loss was distributed equally across all treatments overall and for the fish that lost their tags ('chisq.test' function; 'stats' package; R Core Team 2013).

Results

2012 – Blue Catfish, Milford Hatchery, Technique Practice and Evaluation

During the initial trials in which the protocols for tagging were tested and evaluated, all tagged fish survived seven days (data not shown). All tags remained within the body cavity and the incisions healed well. Based on this result, few changes were made to the field protocol.

2012, 2013 – Blue Catfish, Milford Hatchery, Technique Practice and Evaluation

For the field tagging of Blue Catfish, tagged fish suffered little short-term tag loss. Using the first data evaluation metric, in 2012, all but one of the 48 tagged fish were detected at least once in the first ten days by the stationary receivers (black squares per row=detection per fish; Fig. 1.4). Seventy three percent of tagged fish were detected for five or more days during any of the first ten days. In 2013, all 75 tagged fish were detected at least once in the first ten days (Fig.

1.5). Ninety six percent of all fish tagged in 2013 were detected for five or more days within any of the first ten days post-tagging.

In 2012, tagged fish were detected at an average of five receivers (range: 0-12, SE: 0.37; Table 1.3) for the first ten days and an average of 12 receivers (range: 3-18, SE: 0.51; Table 1.3) over the entire field season. In 2013, fish were detected at an average of nine receivers (range: 2-13, SE: 0.33; Table 1.4) in the first ten days and an average of 13 receivers (range: 5-18, SE: 0.42; Table 1.4) over the entire field season.

In 2012, only four tagged fish (1, 8, 27, and 38) were detected at ≤ 1 receivers in the first ten days (Table 1.3). Only one fish was detected on the day it was tagged and released and never detected again (Fig. 1.6C), but the other three fish were detected multiple times at multiple receivers after the first ten days (Fig. 1.6A, B, D). No tagged fish, in 2013, were detected at ≤ 1 receiver.

In 2012, 96% of the fish were detected in early July and August (Fig. 1.7). About 92% of the fish were detected in September and October. In November, 90% of the tagged Blue Catfish continued to be detected. In 2013, 100% of the fish were detected in June and about 91% of the fish tagged were detected in July (Fig. 1.7). From August through October, > 85% of the tagged fish were detected.

In both 2012 and 2013, no fish left Milford Reservoir downstream through the dam (receiver 20; Fig. 1.8). In 2012, no fish left Milford Reservoir upstream through upstream egress (receiver 1; Fig. 1.8). However, because of the vandalized upstream receiver (receiver 1) in August 2013, I relied on the inner gate (receiver 2) to detect potential upstream egress. In order for a fish to leave Milford through the upper exit, it must pass receiver 2. In 2013, 59 fish were observed at the upstream reservoir receiver two, only five of the 59 fish were last detected there

(receiver 2; Fig. 1.8; Table 1.5). For comparison, fish detections at receivers 2 and 1 in 2012 shows that fish detected at receiver 2 (17 fish) do not leave the reservoir via receiver 1 (0 fish). Of the five fish detected at receiver 2 in 2013, two of these fish were not detected subsequently because receivers were removed when the field season ended in June 2014 (Fig. 1.9A, B). The remaining three fish traversed frequently between receiver 2 and other receivers in the reservoir. I determined that these repeated movements back and forth through the upper reservoir (i.e., repeating vertical bands of detections; Fig. 1.9C, D, E) were unlike the quick unidirectional movement (i.e., one single vertical line) that would be expected for long-distance, unidirectional upstream migrants. Although unlikely, ≤5 fish could have left upstream of the reservoir in 2013. In summary, using these five metrics I determined if a fish possibly died, lost its tag, or left the reservoir system.

2014 – Channel Catfish, Milford Hatchery, Tagging Experiment

Age-0 channel catfish from Milford Hatchery suffered little tag loss or mortality in any treatment during the 12-week study. No mortality occurred in treatment 1 (my field methodology), treatment 3 (no antibiotics), and the control (Treatment 5) (Fig. 1.10). Fish in treatment 2 (ventral incision) had a mortality of 21% while those in treatment 4 had a mortality of 7%. Differences in survival were marginally significant ($P = 0.07$, $\alpha = 0.05$; Fig. 1.10) among treatments 1, 3, 5 (lowest mortality, $n = 0$ died) and treatment 2 (highest mortality, $n = 3$ died).

All tag loss occurred within the first two weeks (Fig. 1.11). Treatment 1, the treatment I used for field tagging, had no tag loss (Fig. 1.12), treatments 2 and 3 had an overall tag loss of 21% (3 individuals in each treatment lost tags), and treatment 4 had an overall tag loss of 29% (4 individuals lost their tags). My tagging methodology (treatment 1) had a significantly lower tag loss than treatment 4 ($P = 0.0455$, $\alpha = 0.05$).

Discussion

Tag Retention in the Hatchery

My tagging methodology had high-survival and high-retention in the hatchery, exceeded retention of other catfish studies, and was greater than or similar to retention rates of other species. My tag retention exceeded that of most existing Blue and Channel Catfish tag evaluations. In the hatchery trial of Channel Catfish tagging, my methodology (Treatment 1) resulted in **100%** survival and **100%** tag retention. In an early study on catfish tag retention of internally implanted tags, Marty and Summerfelt (1986) found that 84 of 120 Channel Catfish expelled their tags in 18-23 days after being tagged (**30%** retention) with traditional (non-anchored) implantation methods. In response to this tag ejection, complex internal anchoring procedures were developed that had better, but still low, tag retention rates (Siegwarth and Pitlo 1999). However, this anchored implantation technique can be physiologically stressful to tagged fish. For example, in preparation for using ultrasonic telemetry on Blue Catfish in Lake Texoma, TX, Lee (2009) used both traditional and anchored attachment methods (n=5 fish per attachment method; 530-838 mm TL). After 120 days in a hatchery pond, all fish retained their tags but **90%** died from both methods combined and seven of the mortalities occurred between 25-48 days. Thus, my tag retention rate exceeded that of most existing Blue Catfish tag evaluations.

My results (**100%** retention) in the hatchery were similar or exceeded tag retention rates observed in other fish species (**13%-100%**) in an experimental setting. In a recent study on the effects of surgically implanted tags in Bighead Carp, *Hypophthalmichthys noblis*, Luo et al. (2015) also found that all fish retained their tags (**100%** retention) by the end of the study period (56 days). In hatchery/laboratory experiments, Shortnose Sturgeon and Chinook Salmon also had very high retention rates (**96%** Panther et al. 2011; **94%** Crossman et al. 2013). Experimental

studies on Steelhead/Rainbow Trout had lower retention rates than what I found (**65% & 75%** Ivasauskas et al. 2012; **80%** Sandstrom et al. 2013). Only one study, using Atlantic Sturgeon had a tag retention similar to other catfish studies (**13%** Crossman et al. 2013).

Tag Retention in the Field

My tag retention in the field, as measured by detections of individual Blue Catfish, was also high and exceeded tag retentions of most existing catfish tagging studies. I repeatedly detected **85%** of the tagged Blue Catfish in Milford Reservoir through five months across two years. Other Blue Catfish telemetry studies did not detect as many of their tagged fish. In Lake Norman, NC, after 120 days only 15 of 29 (**52%**) Blue Catfish (500-900 mm TL) with externally attached radio tags were detected throughout the rest of the study (Grist 2002). In Lake Texoma, TX, only 28 of 50 (**56%**) tagged Blue Catfish (636-1305 mm TL) were successfully tracked (Lee 2009). In the lower Missouri River, 24 of 80 (**30%**) acoustically tagged Blue Catfish (569-1260 mm TL) were included in the movement data set because a large number of tagged fish were missing (Garrett and Rabeni 2011). Finally, a field evaluation of 50 Blue Catfish (600-995 mm TL) in Lake Buchanan, TX, found that **40%** of all tagged fish were detected at six months and only **19%** at 12 months (Bodine and Fleming 2013).

When compared to field telemetry studies of other species, my study had similar or greater detections rates than those in other reservoir systems and higher detection rates than those in rivers and oceans. For Grass Carp, *Ctenopharyngodon idella*, (369-813 mm TL and 586-688 mm TL) and Northern Pike, *Esox lucius*, (520-720 mm TL and 530-770 mm TL), **67-100%** were tracked for 7-12 months in reservoirs/lakes (Chilton and Poarch 1997; Jepsen et al. 2001). For the ocean fish, Blackspot Seabream, *Pagellus bogaraveo*, (270-420 mm FL) and Bigeye Scad, *Selar crumenophthalmus*, (average ± SD = 180 ± 12 mm), **0-43%** of the fish remained by the

end of each of the studies (Afonso et al. 2012; Capello et al. 2012). Studies in river systems also had low detection rates, **0%** of Trout Cod, *Maccullochella macquariensis,* remained by the end of a seven month study (Ebner et al. 2007), and in the Mokelumne River, CA, although 301 of 330 (**91%**) hatchery-origin and 51 of 137 (**37%**) natural-origin Rainbow Trout were successfully tracked during migration (Del Real et al. 2012).

Existing literature demonstrates that Blue and Channel Catfish are extraordinarily challenging to tag successfully (i.e., ensure high-survival and high-retention). My methodology, using Blue Catfish, had greater survival and tag-retention than any other catfish study and was as great or greater than survival and retention for other fish species. Consequently, our methodology can be applied to catfish as well as other species.

Testing Factors of Tag Retention

My tagging methodology probably had high retention because of (1) preparation and practice, (2) incision location, and (3) use of multiple prophylactic practices (antibiotics, salt bath, minimal holding time). My protocol emphasized preparation, practice, and organization before the tagging event. I was able to hold fish for a shorter time period (capture-release: approx. 1 hr.), operate on them quickly (2-3 min.), keep them wet at all times, and allow them to recover in tanks of adequate size (volume: 76 and 1,380 L) with acceptable water temperature and dissolved oxygen. Overall, this allowed me to process fish quickly with minimal stress. Two disadvantages of my methods were that I was less flexible on where I tagged fish (I needed to remain close to the capture location) and my approach required more personnel because I had two surgery teams (two people each), 1-2 people to record data and an electrofishing crew (9 people). Despite this investment in personal time, preparation, practice, and organization allowed me to collect data from most of my tags making this methodology very cost effective overall.

Others have also emphasized the need for the level of organization and preparation I have demonstrated (Jepsen et al. 2002; Mulcahy 2003; Wagner and Cooke 2005; Cooke et al. 2011).

A lateral incision reduced my tag loss in the hatchery. In my hatchery trials, I found that incisions did not fully heal for at least a week and during that time, gravity may result in tag loss through a ventral incision. Others have also tested incision location using other methods with different results. A Chinook Salmon study tested three incision locations (ventral, lateral, and lateral-diagonal) and found that the two lateral incision locations were less likely to reopen over time (Panther et al. 2011). For Grass Carp, a ventral incision was less likely to puncture ovaries and was easier for the surgeon than a lateral incision, but effectiveness of incision location was inconclusive because a *Flexibactor columnaris* outbreak killed **72%** of their lateral incision treatment group (Schramm and Black 1984). A recent study on Spotted Seatrout (250-600 mm TL) also tested two different ventral incision placements (midline and off-midline) (Robillard et al. 2015) and found that the midline treatment had **65%** tag retention, the off-midline had **70%** tag retention, and overall, 49 of 66 fish (**74%** survival) survived the study. My protocol, using a lateral incision, did not reopen, did not puncture organs, and resulted in greater retention in a controlled hatchery test.

Quantifying procedures that reduce mortality is difficult because of the nonlinear nature of the mortality response. Because of the investment in the tagging-tracking process and the serious consequences of tag loss and tag-related mortality, I advocate incorporating as many prophylactic measures in tagging protocols as possible. The effect of antibiotics was not definitive in my hatchery evaluation. However, antibiotics may have aided in the survival and healing of my field caught fish. Isely et al. (2002) also tested the use of an antibiotic and found that gentamicin sulfate (0.5 mg/kg), a long-acting antibiotic, was effective in preventing initial

post-surgery infection (average = 14 days); however, there was no effect on cumulative mortality. Even if antibiotics do not have an effect on cumulative mortality, the prevention of post-surgery infection is important because all of the tag loss and the majority of the mortality occurred in my hatchery study during the first two weeks.

An array of data diagnostics are needed to evaluate tag loss and mortality in the field. Unless tagged fish are detected, whether they died, were stressed, or were behaving normally but out of the receiver array or study area is unknown. Lack of detections, can raise questions about the quality of the data on tagged fish that are detected. I specifically looked at the first ten days because during this time the incision was healing, sutures were lost, and the probability was highest for tag loss (Baras et al. 1999; Deters et al. 2012). Examining an abacus plot is useful and is common to many tagging studies. Percent or numbers detected is commonly used to determine tag loss/mortality over the entire study period (Grist 2002; Lee 2009; Garrett and Rabeni 2011, Bodine and Fleming 2013). Other studies have also focused on how fish move out of the system or great distances (Fisher et al. 1999; Garrett 2010). Most studies do not examine multiple metrics to evaluate the quality of tagging data as I have. A regular record of detections (abacus), the total number of receivers at which each fish was detected, the miniature detection plots, percent detections throughout the study, and egress at ten days and for the entire study were all useful in evaluating the success of tagging. I recommend the use of all five of these, novel and rarely used, metrics in future tagging studies.

Summary

I have provided information on how I tagged fish and evaluated my tagging process to guide future tagging studies on an array of species in a variety of systems. My tagging was quite successful because I invested time and money in organization, preparation, and training. Because

of the monetary and labor investment in a tagging program, I strongly recommend this amount of preparation. The tagging protocol that I describe should be directly applicable to other fish species including but not limited to catfish. In future, telemetry studies that require surgical implantation of telemetry tags researchers and managers should also take precautionary steps (e.g., antibiotics, salt bath) to ensure the best possible outcome of tag implantation (i.e., high-retention and low mortality). Substantial implications for fisheries ecology and management accrue from a good tagging database (discussed elsewhere – Chapter 2).

References

Afonso, P., G. Graca, G. Berke, and J. Fontes. 2012. First observations on seamount habitat use of Blackspot seabream (*Pagellus bogaraveo*) using acoustic telemetry. Journal of Experimental Marine Biology and Ecology 436: 1-10.

Albanese, B., P.L. Angermeier, and J.T. Peterson. 2009. Does mobility explain variation in colonisation and population recovery among stream fishes? Freshwater Biology 54(7): 1444-1460.

Alldredge, P., M. Gutierrez, D. Duvernell, J. Schaefer, P. Brunkow, and W. Matamoros. 2011. Variability in movement dynamics of topminnow (*Fundulus notatus* and *F. olivaceus*) populations. Ecology of Freshwater Fish 20(4): 513-521.

Baras, E., L. Westerloppe, C. Melard, J.C. Philippart, and V. Benech. 1999. Evaluation of implantation procedures for PIT-Tagging juvenile Nile tilapia. North American Journal of Aquaculture 61(3): 246-251.

Bodine, K. A. and D. E. Shoup. 2010. Capture efficiency of Blue Catfish electrofishing and the effects of temperature, habitat, and reservoir location on electrofishing-derived length structure indices and relative abundance. North American Journal of Fisheries Management 30(2): 613-621.

Bodine, K. A. and B. P. Fleming. 2013. Evaluation of an alternative technique for attaching external transmitters to Blue Catfish. North American Journal of Fisheries Management 33(5): 950-955.

Bridger, C. J. and R. K. Booth. 2003. The effects of biotelemetry transmitter presence and attachment procedures on fish physiology and behavior. Reviews in Fisheries Science 11(1): 13-34.

Brown, R. S., M.B. Eppard, K.J. Murchie, J.L. Nielson, and S.J. Cooke. 2011. An introduction to the practical and ethical perspectives on the need to advance and standardize the

intracoelomic surgical implantation of electronic tags in fish. Reviews in Fish Biology and Fisheries 21(1): 1-9.

Capello, M., M. Soria, P. Cotel, G. Potin, L. Dagorn, and P. Freon. 2012. The heterogeneous spatial and temporal patterns of behavior of small pelagic fish in an array of Fish Aggregating Devices (FADs). Journal of Experimental Marine Biology and Ecology 430: 56-62.

Chilton, E. W. and S. M. Poarch. 1997. Distribution and movement behavior of radio-tagged grass carp in two Texas reservoirs. Transactions of the American Fisheries Society 126(3): 467-476.

Cooke, S. J., C.M. Woodley, M.B. Eppard, R.S. Brown, and J.L. Nielson. 2011. Advancing the surgical implantation of electronic tags in fish: a gap analysis and research agenda based on a review of trends in intracoelomic tagging effects studies. Reviews in Fish Biology and Fisheries 21(1): 127-151.

Crossman, J. A., K.L. Hammell, and M.K. Litvak. 2013. Experimental examination of surgical procedures for implanting sonic transmitters in juvenile Shortnose Sturgeon and Atlantic Sturgeon. North American Journal of Fisheries Management 33(3): 549-556.

Del Real, S. C., M. Workman, and J. Merz. 2012. Migration characteristics of hatchery and natural-origin *Oncorhynchus mykiss* from the lower Mokelumne River, California. Environmental Biology of Fishes 94(2): 363-375.

Deters, K. A., R.S. Brown, J.W. Boyd, M.B. Eppard, and A.G. Seaburg. 2012. Optimal suturing technique and number of sutures for surgical implantation of acoustic transmitters in juvenile salmonids. Transactions of the American Fisheries Society 141(1): 1-10.

Ebner, B. C., J.D. Thiem, and M. Lintermans. 2007. Fate of 2 year-old, hatchery-reared Trout Cod *Maccullochella macquariensis* (Percichthyidae) stocked into two upland rivers. Journal of Fish Biology 71(1): 182-199.

Fischer, S.A., S. Eder, and E.D. Aragon. 1999. Movements and habitat use of Channel Catfish and Blue Catfish in a small impoundment in Missouri. Pages 239-255 *in* E.R. Irwin, W.A. Hubert, C.F. Rabeni, H.L. Schramm, and T. Coon, editors. Catfish 2000: Proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Garrett, D.L. 2010. Movement, habitat use, and spawning characteristics of Flathead and Blue Catfish on the lower Missouri River and tributaries. Doctoral Dissertation, University of Missouri, Columbia, Missouri.

Garrett, D.L., and C.F. Rabeni. 2011. Intra-annual movement and migration of Flathead Catfish and Blue Catfish in the lower Missouri River and tributaries. Pages 495-509 *in* P. H. Michaletz and V. H. Travnichek, editors. Conservation, ecology, and management of catfish: the second international symposium. American Fisheries Society, Symposium 77, Bethesda, Maryland.

Grist, J.D. 2002. Analysis of a Blue Catfish population in a southeastern reservoir: Lake Norman, North Carolina. Master's Thesis. Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Hitt, N. P. and P. L. Angermeier. 2008. Evidence for fish dispersal from spatial analysis of stream network topology. Journal of the North American Benthological Society 27(2): 304-320.

Holbrook, S. C., W.D. Byars, S.D. Lamprecht, and J.K. Leitner. 2012. Retention and physiological effects of surgically implanted telemetry transmitters in Blue Catfish. North American Journal of Fisheries Management 32(2): 276-281.

Hubert, W. A. 1999. Biology and management of Channel Catfish. Pages 3-22 *in* E. R. Irwin, W. A. Hubert, C. F. Rabeni, H. L. Schramm, Jr., and T. Coon, editors. Catfish 2000: proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Isely, J. J., S.P. Young, T.A. Jones, and J.J. Schaffler. 2002. Effects of antenna placement and antibiotic treatment on loss of simulated transmitters and mortality in hybrid Striped Bass. North American Journal of Fisheries Management 22(1): 204-207.

Ivasauskas, T. J., P.W. Bettoli, and T. Holt. 2012. Effects of suture material and ultrasonic transmitter size on survival, growth, wound healing, and tag expulsion in Rainbow Trout. Transactions of the American Fisheries Society 141(1): 100-106.

Jepsen, N., S. Beck, C. Skov, and A. Koed. 2001. Behavior of Pike (*Esox lucius* L.) > 50 cm in a turbid reservoir and in a clearwater lake. Ecology of Freshwater Fish 10(1): 26-34.

Jepsen, N., A. Koed, E.B. Thorstad, and E. Baras. 2002. Surgical implantation of telemetry transmitters in fish: how much have we learned? Hydrobiologia 483(1-3): 239-248.

Knaepkens, G., K. Baekelandt, and M. Eens. 2005. Assessment of the movement behaviour of the Bullhead (*Cottus gobio*), an endangered European freshwater fish. Animal Biology 55(3): 219-226.

Lee, Corey. 2009. Annual movement patterns of adult Blue Catfish in a large reservoir using ultrasonic telemetry. Master's Thesis. University of Oklahoma, Norman, Oklahoma.

Luo, H. W., X.B. Duan, S. Wang, S.P. Liu, and D.Q. Chen. 2015. Effects of surgically implanted dummy ultrasonic transmitters on growth, survival and transmitter retention of Bighead Carp *Hypophthalmichthys nobilis*. Environmental Biology of Fishes 98(4): 1131-1139.

Marty, G. D. and R. C. Summerfelt. 1986. Pathways and mechanisms for expulsion of surgically implanted dummy transmitters from Channel Catfish. Transactions of the American Fisheries Society 115(4): 577-589.

Marty, G. D. and R. C. Summerfelt. 1990. Wound-healing in Channel Catfish by epithelialization and contraction of granulation-tissue. Transactions of the American Fisheries Society 119(1): 145-150.

Metcalfe, J. D. 2006. Fish population structuring in the North Sea: understanding processes and mechanisms from studies of the movements of adults. Journal of Fish Biology 69: 48-65.

Millspaugh, J. and Marzluff, editors. 2001. Radio tracking and animal populations. Academic Press, San Diego, California.

Mulcahy, D. M. 2003. Surgical implantation of transmitters into fish. Ilar Journal 44(4): 295-306.

Panther, J. L., R.S. Brown, G.L. Gaulke, K.A. Deters, C.M. Woodley, and M.B. Eppard. 2011. Influence of incision location on transmitter loss, healing, survival, growth, and suture retention of juvenile Chinook Salmon. Transactions of the American Fisheries Society 140(6): 1492-1503.

Robillard, M. M. R., L.M. Payne, R.R. Vega, and G.W. Stunz. 2015. Best practices for surgically implanting acoustic transmitters in Spotted Seatrout. Transactions of the American Fisheries Society 144(1): 81-88.

Sandstrom, P., A.J. Ammann, C. Michel, G. Singer, E.D. Chapman, S. Lindley, R.B. MacFarlane, and A.P. Klimley. 2013. Growth, survival, and tag retention of Steelhead Trout (*Oncorhynchus mykiss*) and its application to survival estimates. Environmental Biology of Fishes 96(2-3): 145-164.

Schramm, H. L., Jr. and D. J. Black. 1984. Anesthesia and surgical procedures for implanting radio transmitters into Grass Carp. Progressive Fish-Culturist 46(3): 185-190.

Siegwarth G. L. and J. M Pitlo, Jr. 1999. A modified procedure for surgically implanting radio transmitters in Channel Catfish. Pages 287-292 *in* E. R. Irwin, W. A. Hubert, C. F. Rabeni, H. L. Schramm, Jr., and T. Coon, editors. Catfish 2000: Proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Summerfelt, R. C. and D. Mosier. 1984. Transintestinal expulsion of surgically implanted dummy transmitters by Channel Catfish. Transactions of the American Fisheries Society 113(6): 760-766.

Thiem, J. D., M.K. Taylor, S.H. McConnachie, T.R. Binder, and S.J. Cooke. 2011. Trends in the reporting of tagging procedures for fish telemetry studies that have used surgical implantation of transmitters: a call for more complete reporting. Reviews in Fish Biology and Fisheries 21(1): 117-126.

Wagner, G. N. and S. J. Cooke. 2005. Methodological approaches and opinions of researchers involved in the surgical implantation of telemetry transmitters in fish. Journal of Aquatic Animal Health 17(2): 160-169.

Table 1.1. Summary of experimental catfish tagging studies. Length of study (days), percent tag retention, and percent mortality are shown. The average across all studies is shown at the bottom.

Catfish Study	Length of Study	Percent Tag Retention	Percent Tag Loss	Percent Mortality
Summerfelt and Mosier (1984)	117 days	29%	71%	16%
Marty and Summerfelt (1986)	23 days	30%	70%	13%
Marty and Summerfelt (1990)	93 days	6%	94%	0%
Lee (2009)	120 days	100%	0%	90%
Holbrook et al. (2012)	244 days	47%	53%	0%
Bodine and Fleming (2013)	182 days	0%	100%	13%
Average	130 days	38%	62%	22%

Table 1.2. Summary of evaluation procedures used to develop and evaluate tagging protocols for catfish including study year, species (BC = Blue Catfish, CC = Channel Catfish), size range (mm TL), location, tag type (size mm), number of fish used, average surgery time (s), and evaluation methods.

Study Year	Species	Size Range (mm TL)	Location	Tag Type (Size mm)	No. Fish	Average Surgery Time (s)	Evaluation
2012	BC	150-250*	Hatchery	V9 (29 mm)	20	NA	Euthanize and Dissect
2012	BC	383-1020	Reservoir	V9 (29 mm)	48	158	Detections 10 days 5 months
2013	BC	343-1090	Reservoir	V9 (29 mm) V13 (36 mm)	75	174	Detections 10 days 5 months
2014	CC	184-260	Hatchery	V6 (16.5 mm)	70	114	Response Tag Loss Mortality Growth Treatment Incision Antibiotics Surgery Time

Table 1.3. The total number of receivers at which individual Blue Catfish were detected in 2012 during the first ten days and the entire study and the average number of receivers for all fish in Milford Reservoir, KS. Boxes indicate ≤1 receiver.

	Number of Receivers	
Fish	Ten Days	Entire Study
1	1	12
2	6	12
3	2	13
4	7	10
5	7	16
6	5	13
7	5	9
8	0	13
9	5	12
10	2	16
11	2	16
12	3	15
13	4	6
14	7	14
15	6	13
16	12	18
17	8	14
18	11	16
19	2	10
20	4	13
21	3	12
22	2	3
23	3	10
24	4	14
25	2	14
26	3	15
27	1	3
28	4	15
29	4	12

	Number of Receivers	
Fish	Ten Days	Entire Study
30	5	8
31	7	11
32	6	11
33	4	6
34	4	11
35	3	10
36	4	4
37	7	15
38	1	10
39	4	13
40	5	17
41	5	15
42	2	15
43	11	15
44	4	15
45	3	15
46	7	15
47	6	12
48	6	17
Average	5	12

Table 1.4. The total number of receivers at which Blue Catfish were detected in 2013 during the first ten days and the entire study and the average number of receivers for all fish in Milford Reservoir, KS.

	Number of Receivers	
Fish	Ten Days	Entire Study
1	8	9
2	11	12
3	12	15
4	12	13
5	10	10
6	8	12
7	9	9
8	4	16
9	13	13
10	11	13
11	6	7
12	10	14
13	11	13
14	9	9
15	10	15
16	9	18
17	8	14
18	8	13
19	12	13
20	10	14
21	10	16
22	12	13
23	7	14
24	12	14
25	11	15
26	11	16
27	11	16
28	8	15
29	13	13

	Number of Receivers	
Fish	Ten Days	Entire Study
30	9	9
31	11	13
32	3	15
33	12	16
34	12	13
35	13	17
36	12	14
37	10	13
38	5	11
39	10	14
40	11	11
41	2	5
42	10	14
43	6	10
44	5	12
45	7	16
46	5	16
47	7	10
48	11	12
49	7	12
50	6	9
51	6	6
52	5	13
53	5	12
54	5	9
55	5	9
56	10	16
57	11	11
58	4	7
59	5	10
60	5	11
61	10	14
62	9	11
63	11	11
64	9	11
65	8	17

	Number of Receivers	
Fish	Ten Days	Entire Study
66	12	14
67	12	13
68	11	11
69	11	17
70	12	15
71	6	12
72	4	17
73	5	5
74	12	16
75	5	11
Average	9	13

Table 1.5. Date and receiver number of the last detection for each tagged Blue Catfish in Milford Reservoir, KS in 2013. Boxes indicate fish last detected at receiver 2 for further examination of possible egress.

Fish	Date	Receiver
1	July 21, 2013	6
2	Dec. 21, 2013	4
3	Dec. 4, 2013	8
4	Nov.25, 2013	8
5	June 21, 2013	6
6	Nov. 17, 2013	8
7	June 17, 2013	4
8	Nov. 9, 2013	18
9	Nov. 7, 2013	13
10	Nov. 9, 2013	15
11	Dec. 11, 2013	4
12	June 9, 2014	2
13	June 18, 2014	8
14	June 18, 2014	10
15	June 18, 2014	8
16	June 18, 2014	7
17	June 18, 2014	8
18	June 1, 2014	5
19	June 6, 2014	5
20	May 20, 2014	8
21	April 13, 2014	8
22	June 16, 2014	10
23	June 16, 2014	10
24	June 18, 2014	10
25	June 17, 2014	10
26	June 18, 2014	10
27	April 18, 2014	10
28	June 15, 2014	7
29	June 11, 2014	10

Fish	Date	Receiver
30	April 11, 2014	8
31	June 18, 2014	8
32	Feb. 26, 2014	8
33	May 30, 2014	5
34	June 19, 2014	4
35	June 8, 2014	5
36	May 8, 2014	8
37	June 15, 2014	5
38	June 15, 2014	8
39	April 9, 2014	5
40	June 22, 2013	15
41	July 20, 2013	14
42	June 7, 2014	5
43	Aug. 30, 2013	4
44	June 20, 2014	4
45	June 19, 2014	7
46	June 17, 2014	8
47	June 21, 2014	4
48	June 21, 2014	4
49	June 10, 2014	5
50	June 21, 2014	4
51	April 27, 2014	5
52	June 19, 2014	8
53	June 20, 2014	5
54	June 20, 2014	4
55	June 21, 2014	4
56	June 8, 2014	2
57	April 20, 2014	5
58	July 28, 2014	6
59	June 20, 2014	5
60	Jan. 1, 2014	7
61	June 20, 2014	8
62	Feb. 29, 2014	2
63	Feb. 28, 2014	5
64	Feb. 25, 2014	4
65	Nov. 9, 2013	14

Fish	Date	Receiver
66	Oct. 2, 2013	13
67	Feb. 29, 2014	2
68	June 16, 2013	3
69	Nov. 9, 2013	17
70	Nov. 9, 2013	15
71	Feb. 27, 2014	5
72	Feb. 30, 2014	4
73	June 19, 2013	3
74	Nov. 12, 2013	7
75	Feb. 30, 2014	2

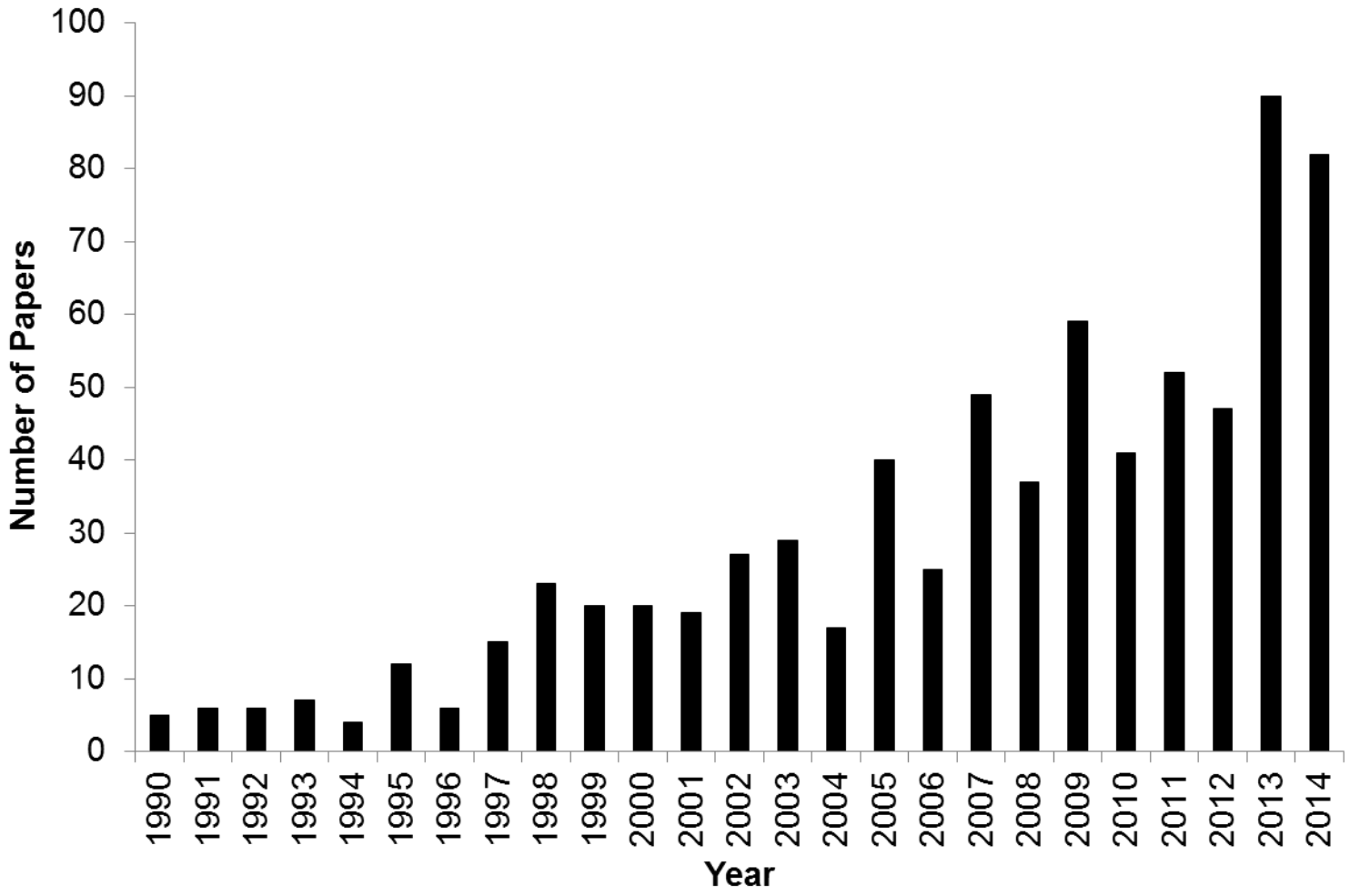


Figure 1.1. Results of a Web of Science literature search on the key words "fish" and "movement" and "radio tag" or "acoustic tag" is shown. The results are sorted by calendar year.

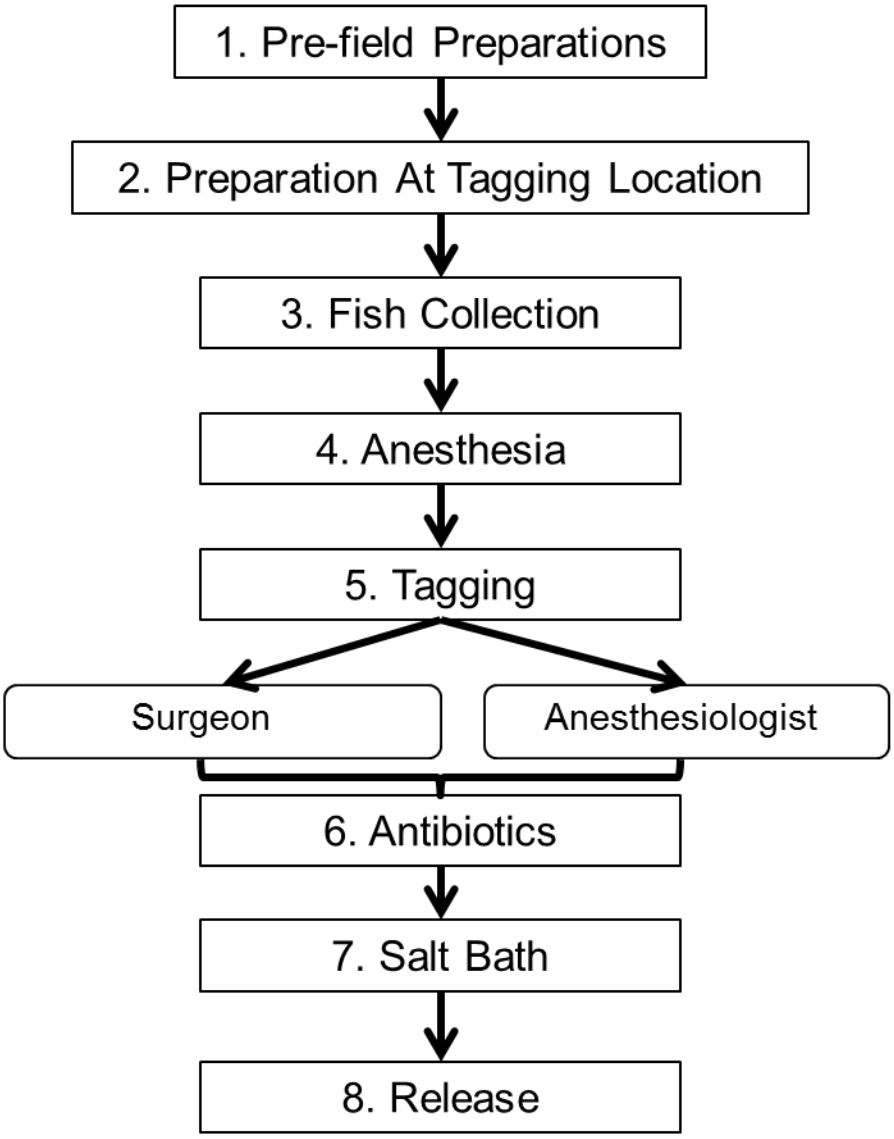


Figure 1.2. Shown is a flowchart that described the eight steps in my tagging protocol. Each step is described in greater detail in the text.

Figure 1.3. A picture montage that depicts the eight steps in my tagging protocol. (1) pre-field preparations, (2) preparation at tagging location, (3) fish collection, (4) anesthesia, (5) tagging, (6) antibiotics, (7) salt bath, and (8) release. Each step is described in greater detail in the text.

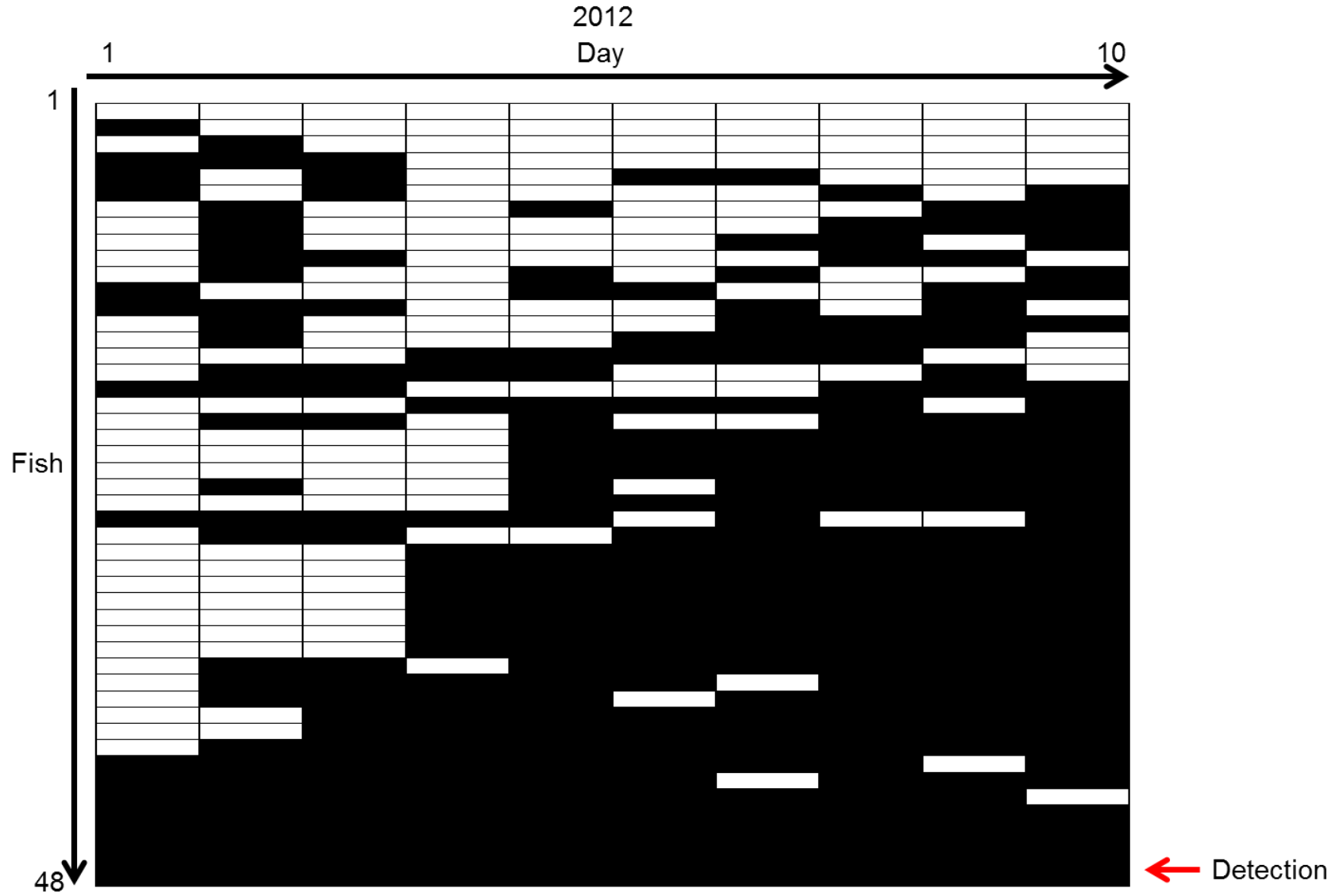


Figure 1.4. Daily detections used to evaluate Blue Catfish first ten days after tagging in Milford Reservoir, KS in 2012. On the X-axis are the first ten days. On the Y-axis is fish number. A filled square indicated that a fish was detected by at least one stationary receiver.

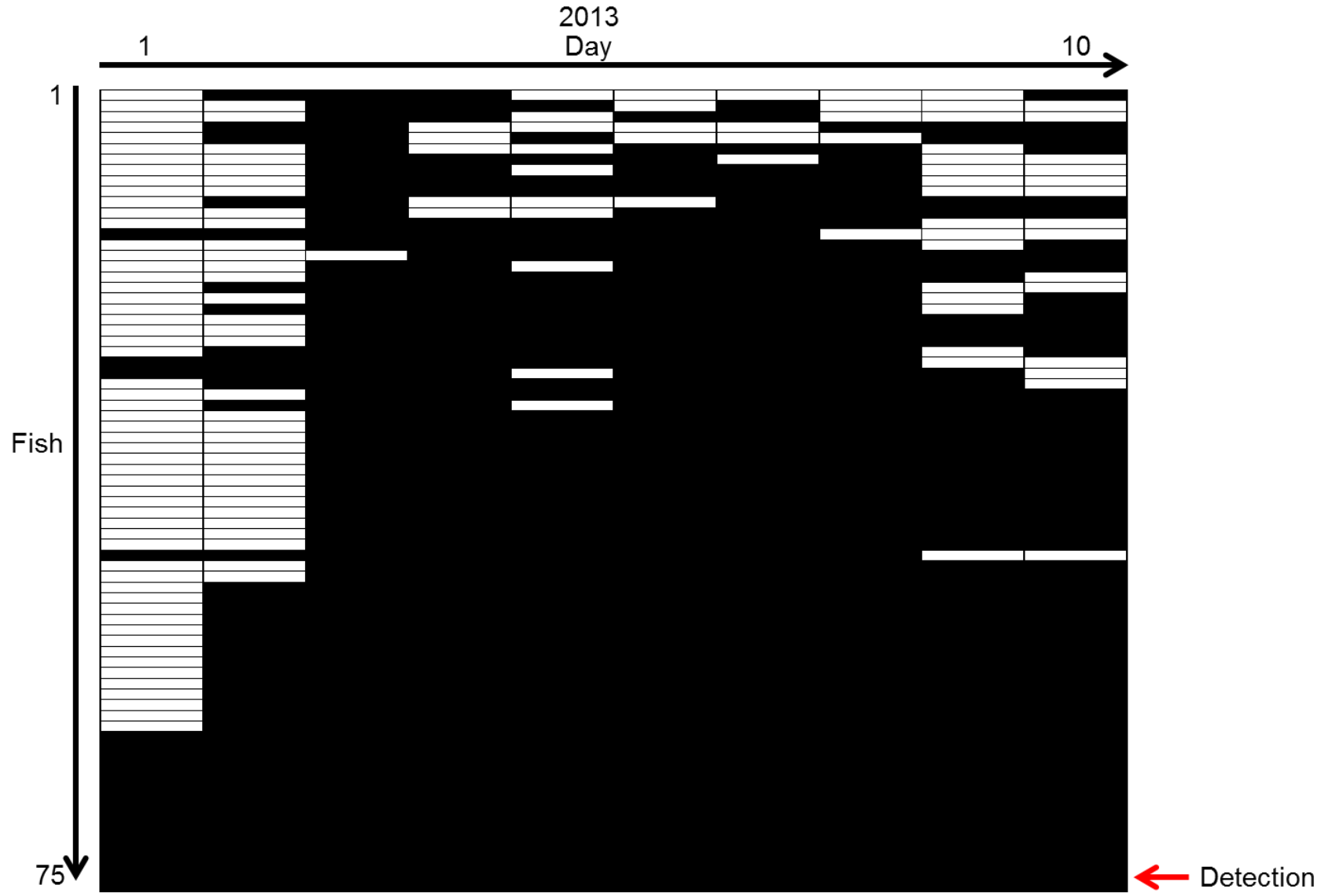


Figure 1.5. Daily detections used to evaluate Blue Catfish first ten days after tagging in Milford Reservoir, KS in 2013. On the X-axis are the first ten days. On the Y-axis is fish number. A filled square indicates that a fish was detected by at least one stationary receiver.

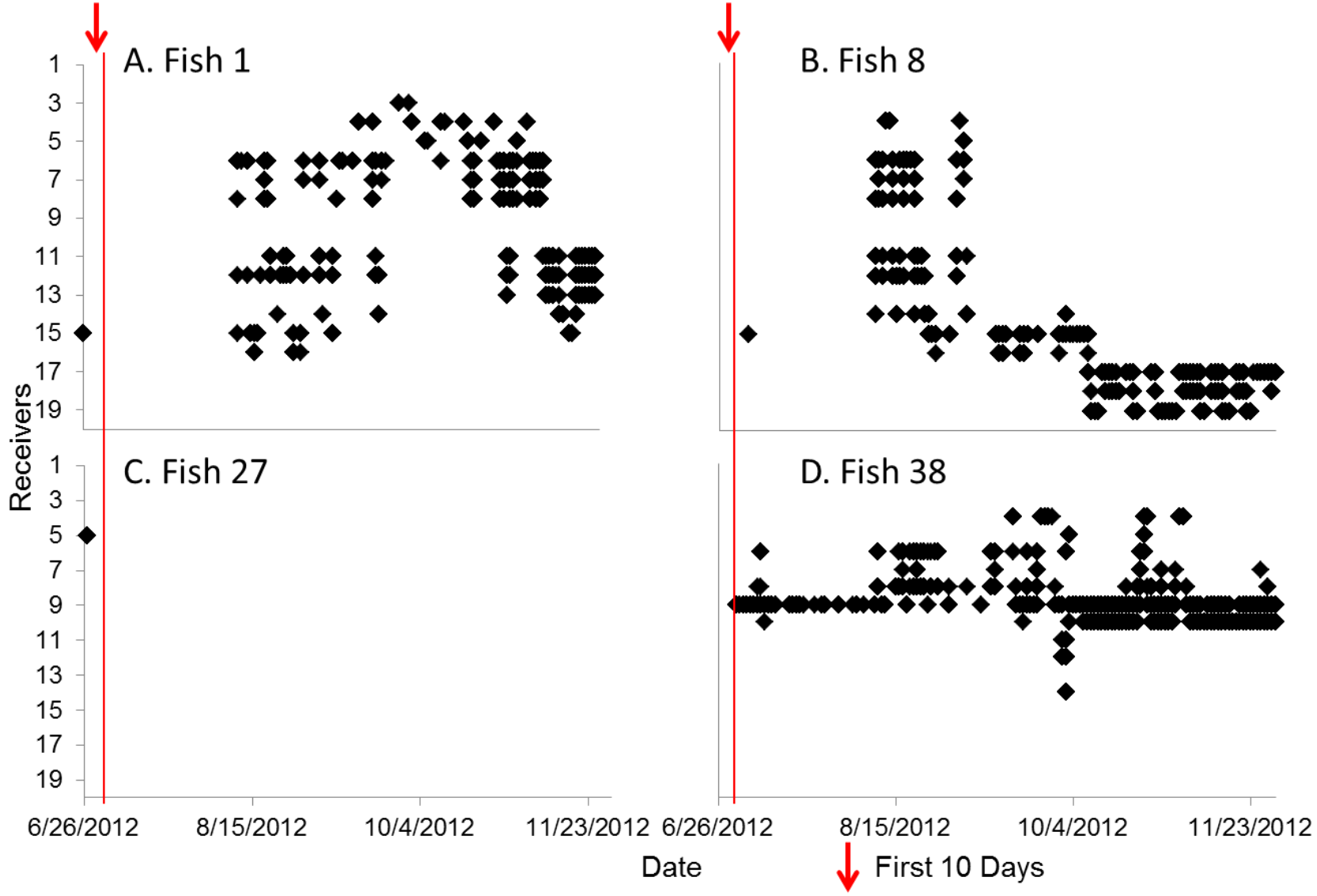


Figure 1.6. All daily detections of four Blue Catfish [fish 1 (A), 8 (B), 27 (C), and 38 (D)] that were detected at ≤ 1 receivers during the first ten days in Milford Reservoir, KS in 2012. On the X-axis is date. On the Y-axis is receivers 1-20. The line and arrows indicate the first ten days.

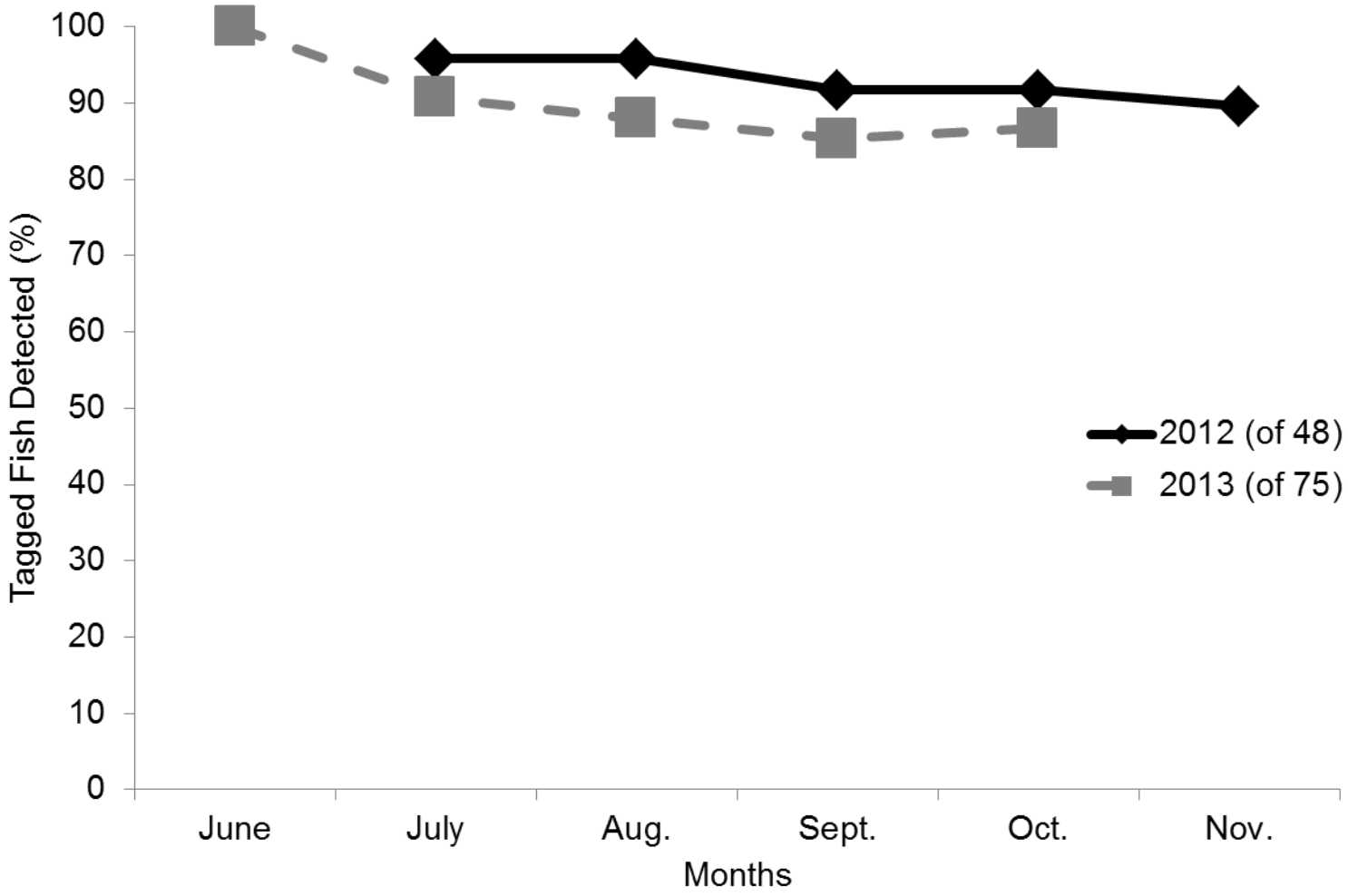


Figure 1.7. Monthly detections of Blue Catfish in Milford Reservoir, KS in 2012 and 2013. The X-axis is month and the Y-axis is tagged fish detected (%). Forty-eight fish were tagged in 2012 and 75 were tagged in 2013. 2012 starts at less than 100% because June has been removed. Detection rate is substantially greater than previous catfish studies.

Receiver	Numbers of Fish		Number of Fish Last Seen
	2012	2013	
1	0	-	-
2	17	59	5
19	13	10	-
20	0	0	-

Figure 1.8. Shown on the left is a map of Milford Reservoir, KS with two-tier gates to detect egress from the reservoir. Receiver 1 was located in the Republican River above the reservoir and receiver 2 was the northern most in-reservoir receiver deployed to detect upriver egress. Receiver 20 was located in the Republican River below the dam and receiver 19 was the southernmost in-reservoir receiver deployed to detect egress through the dam. Shown on the right is a table that lists the number of fish detected at receivers 1, 2, 19, and 20 throughout the five month study period as well as the number that were last detected at receiver 2. For egress to occur in 2012, fish must be detected at receivers 1 or 20. For egress to occur in 2013, fish must be detected at receiver 20 or last seen at receiver 2. Most fish detected at receiver 2 (17 in 2012) do not leave the

system (0 at receiver 1 in 2012) so detections at receiver 2 represent a maximum number of fish that could possibly have left the system.

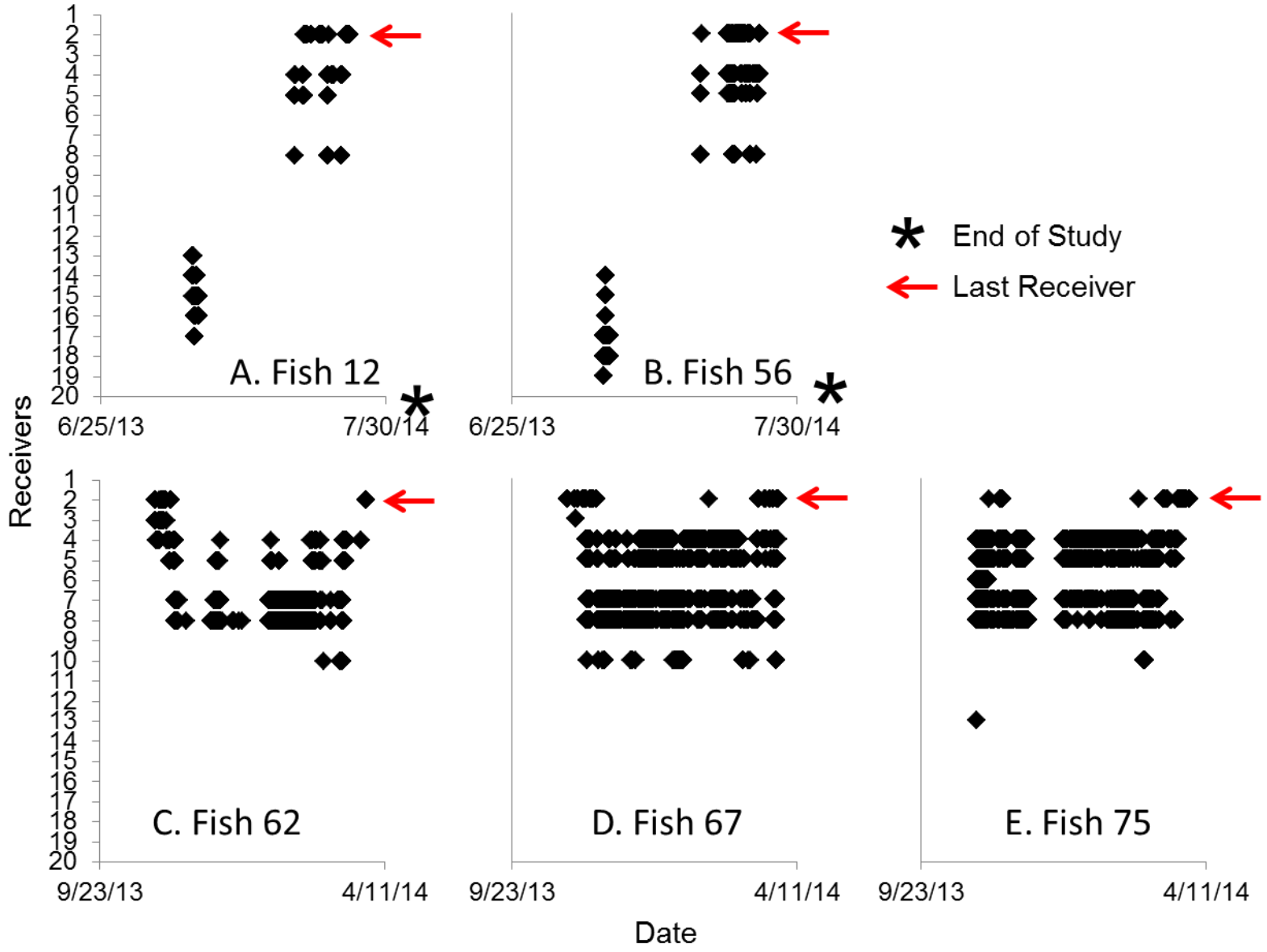


Figure 1.9. All daily detections for five Blue Catfish [fish 12 (A), 56 (B), 62 (C), 67 (D), and 75 (E)] that were last detected at receiver 2 in Milford Reservoir, KS in 2013. On the X-axis is the date and the Y-axis are receivers 1-20. The last detection/receiver is indicated by the arrow and the asterisk by the X-axis indicates the fish that were last detected at receiver 2 because the study ended (A, B). My judgement from the movement patterns is that no fish left the system in 2013.

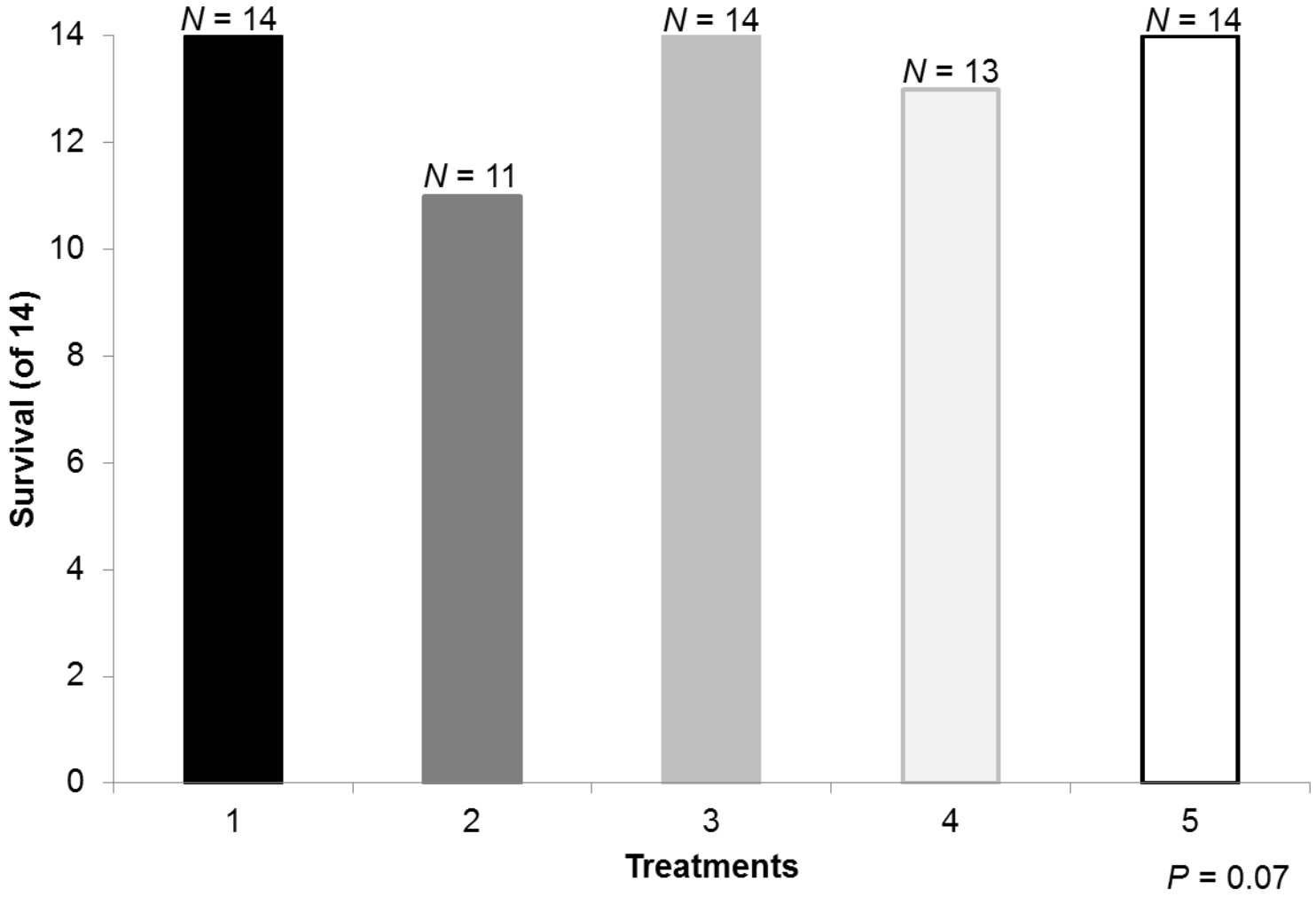
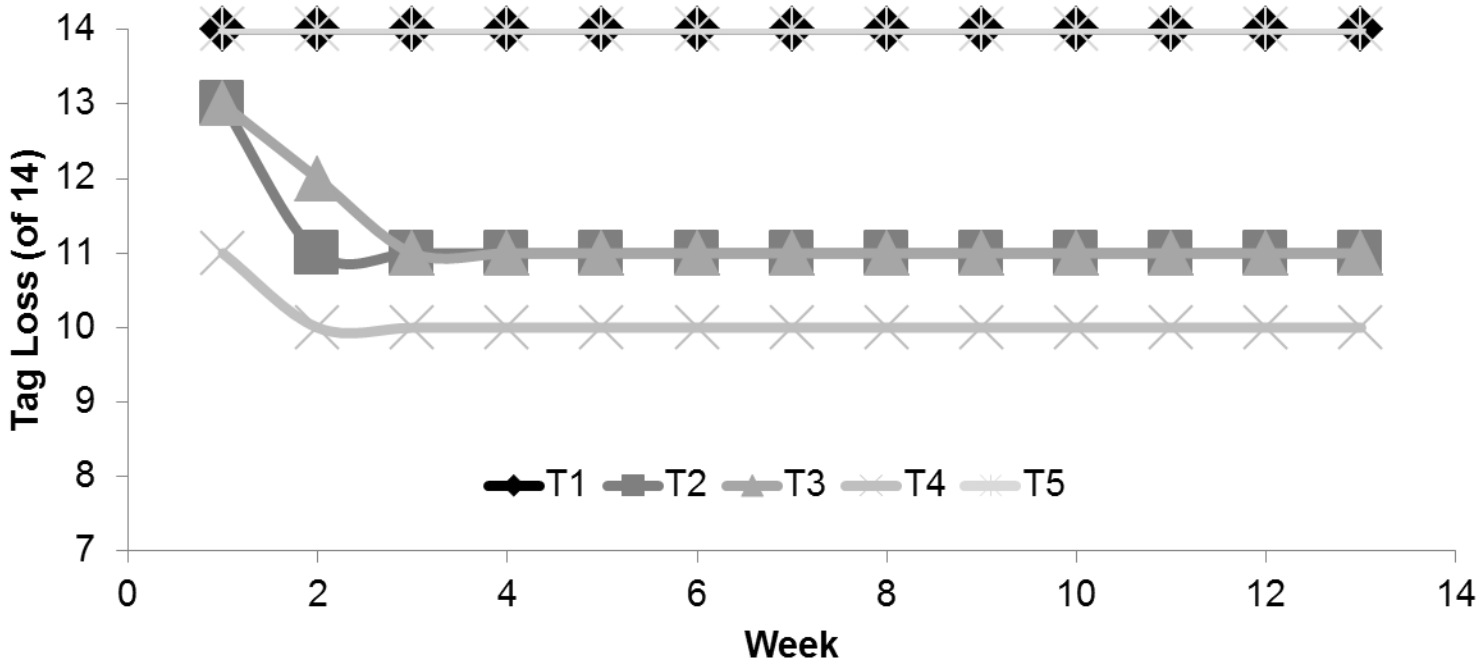


Figure 1.10. Survival of hatchery-reared Channel Catfish 12 weeks after tagging. The X-axis is treatment and the Y-axis is number of fish that survived (i.e., survival). Number of fish remaining alive are shown above bars. My five treatments contained 14 fish each that were given different combinations of incision location, antibiotics, and surgery time. Treatment 1 was the treatment I used for my field tagging [lateral incision, antibiotics, quick surgery time (2-3 min.)]. Treatment 2 was similar to treatment 1 but used a ventral incision (ventral incision, antibiotics, quick surgery time). Treatment 3 used a lateral incision but no antibiotics (lateral incision, no antibiotics, quick surgery time). Treatment 4 used alternative options to treatment 1 [ventral incision, no antibiotics, longer surgery time (about 8 min.)]. Treatment 5 was a control in which tagging was simulated but no fish were tagged. Survival is marginally significant ($P = 0.07$; $\alpha = 0.05$) between treatments with no mortality [Trt 1 (my field treatment), 3, 5] and treatment 2.



Treatment	1	2	3	4	5
Incision	Lateral	Ventral	Lateral	Ventral	NA
Antibiotic	Yes	Yes	No	No	NA
Surgery Time	Short	Short	Short	Long	NA

Figure 1.11. Tag loss by hatchery-reared Channel Catfish through time for five treatments. The X-axis is week and the Y-axis is number of fish that lost their tags (i.e., tag loss). The details of the treatments 1-5 are also shown above. Statistical differences are discussed in text and on Fig. 1.12.

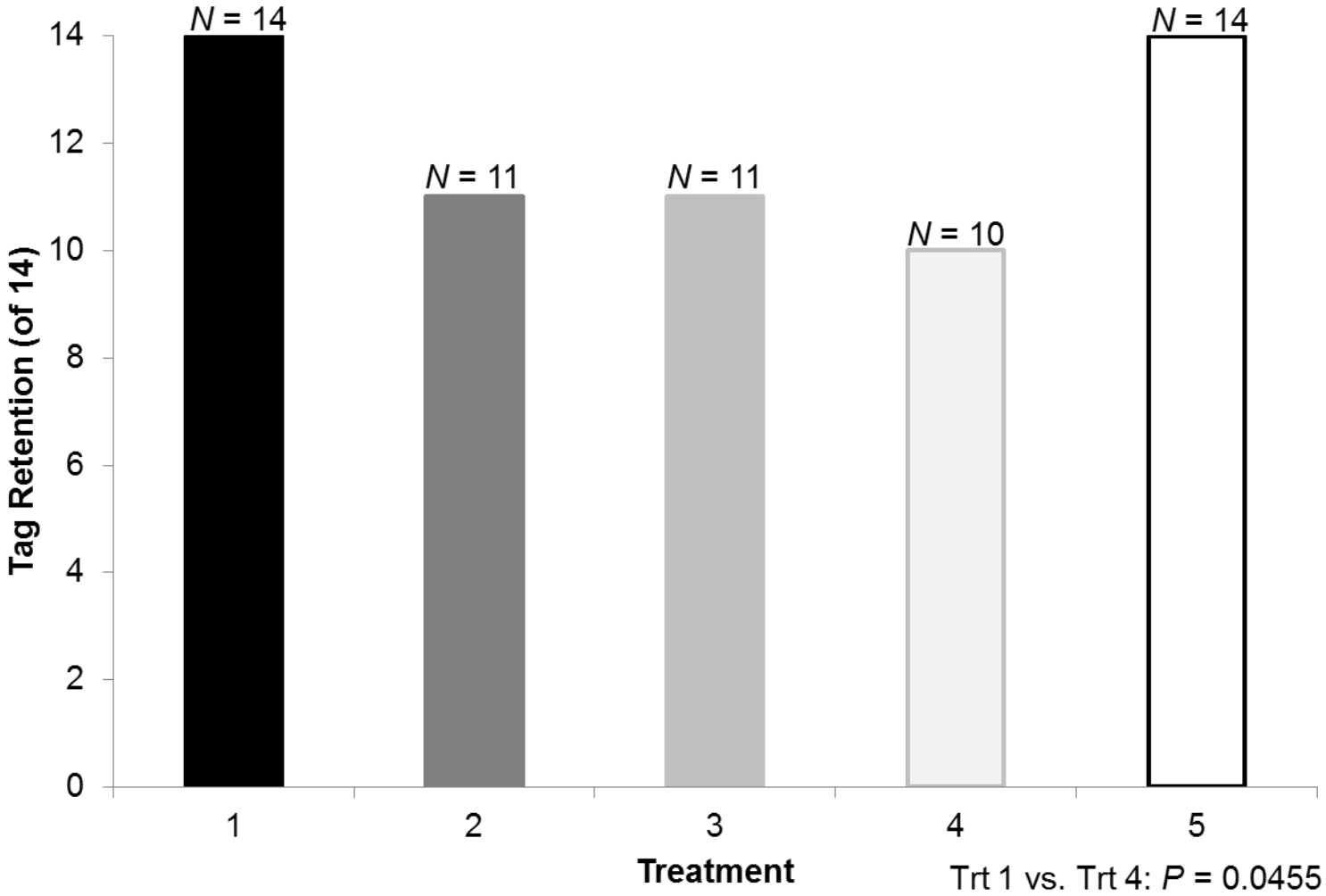


Figure 1.12. Tag retention of hatchery-reared Channel Catfish. The X-axis is treatment and the Y-axis is number of fish that retained their tags (i.e., tag retention). Number of fish retaining tags are shown above bars. My five treatments contained 14 fish each that were given different combinations of incision location, antibiotics, and surgery time. Treatment 1 was the treatment I used for my field tagging [lateral incision, antibiotics, quick surgery time (2-3 min.)]. Treatment 2 was similar to treatment 1 but used a ventral incision (ventral incision, antibiotics, quick surgery time). Treatment 3 used a lateral incision but no antibiotics (lateral incision, no antibiotics, quick surgery time). Treatment 4 used alternative options to treatment 1 [ventral incision, no antibiotics, longer surgery time (about 8 min.)]. Treatment 5 was a control in which tagging was simulated but no fish were tagged. Treatments 1 (my field treatment) and 4 were significantly different ($P = 0.0455$; $\alpha = 0.05$).

Chapter 2 - Identifying Functional Sites Used by Different Groups of Individual Mobile Predators

Abstract

A flexible distribution is an adaptive response that allows animals to take advantage of spatial variation in the fluctuation of resources. Distribution of mobile organisms is complex so multi-metric patterns derived from dynamic distribution trajectories must be deconstructed into simpler components for both individuals and populations. I integrated multiple distribution metrics to identify if sites within an ecosystem function differently for mobile predators. Then, I determined if distinct groups of individuals existed, based on distributional patterns. To address these objectives, I tracked 123 acoustically tagged (VEMCO V9-V13) Blue Catfish (*Ictalurus furcatus* mean: 505.3 mm TL; SE: 12.3 mm; range: 300-1090 mm) from June through November, 2012-2013, in Milford Reservoir, KS. Across the five months, 85.4-100.0% of the tagged fish were detected at least once a month by an array of 20 stationary receivers (VR2W). Using three metrics (population proportion, residence time, and movements), I found four distributional patterns across sites that included locations with (i) large, active aggregations, (ii) exploratory/transitory functions, (iii) small, sedentary aggregations, and (iv) low use. I also found that tagged Blue Catfish clustered into three groups of individuals based on their distribution: (1) seasonal movers, (2) consistent aggregations across seasons, and (3) fish exhibiting site fidelity to Madison Creek. Sites with different functions and groups of individual fish were related but not the same. Distribution plays an important role in fish ecology and fisheries management. My approach to looking at multiple responses, functions of sites, and individual fish groupings provided new insights into this research area that can advance fisheries management of mobile predators.

Introduction

Flexibility in distribution is essential to the life history and ecological niche of many taxa and is an adaptive response that allows animals to take advantage of spatial variation in the fluctuation of resources (Baker 1978; Gross et al. 1988). However, mobility adds complexity to quantifying distribution. Although many fish species change distributions for spawning, foraging, and overwintering (Garcia-Berthou 1999; Weller and Winter 2001; Tripp et al. 2011), little is known about geographically-localized distribution patterns within an ecosystem or the extent of individual (or group) variation within and across geographic areas (Cadrin and Secor 2009). Until recently, researchers and managers had limited methodological options for quantifying distributions of mobile organisms. The lack of information on the distribution and movement of mobile fish has been an obstacle for both research and management. Blue Catfish, *Ictalurus furcatus*, is a model organism for addressing how tradeoffs of residency and mobility affect distribution through functional sites, aggregations, and individual groups. Here, I use acoustic telemetry and stationary receivers to assess how multiple responses or metrics can guide the analysis of complex distributional data of Blue Catfish (Q1: Fig. 2.1), test how these population responses inform function of specific locations within the reservoir (Q2: Fig. 2.1), and identify if individual fish group within a large heterogeneous reservoir (Q3: Fig. 2.1).

Knowing distribution is important for research and management. Animals are not distributed evenly throughout their environments but instead display spatially and temporally heterogeneous patterns (Albanese et al. 2004; Planque et al. 2011; Scheiner and Willig 2011). This uneven distribution can have both benefits and adverse consequences for individuals, populations, and communities. Thus, understanding variation in distribution is foundational for research and management (Kennedy and Gray 1993; Jackson et al. 2001; Metcalfe 2006; Roberts

and Angermeier 2007). For example, knowing fish distribution is important for stock assessments and collection of biological samples (e.g., diets, scales, otoliths). Without knowing where fish are located, effective sampling for survival, recruitment, growth, and other research and management objectives will be ineffective and inefficient (Hansen et al. 2008; Planque et al. 2011). Past distributional data have been collected at only a few times a year (i.e., monthly or annual sampling) at a few locations within a system (Hardiman et al. 2004; Hanson and Curry 2005; Crockett et al. 2006; Bhagat and Ruetz 2011). Even in tracking studies, relatively few fish are detected regularly at a limited number of locations (1-3 stationary locations) and often for a small subset of possible times (Weller and Winter 2001; Zamora and Moreno-Amich 2002; Vehanen and Johansson 2006). Consequently, most existing fish distributional data are limited and give a very incomplete view of where fish spend their time.

Electronic tags allow for quantification of animal distributions (Hobson 1999; Metcalfe 2006). Because existing distributional data are so limited in space and time, most fish ecology and fish management studies have not encountered the complexity of mobile organism distribution for individuals. However, real-time, whole-lake trajectories illustrate the complexity of distribution (e.g., Q1, fish A-C; Fig. 2.1). These trajectories are complex and difficult to understand, quantify, and compare as a whole. Thus, multi-metric patterns from trajectories must be deconstructed into simpler components for both individuals and populations. For individuals, distribution can be described using presence/absence, residence time, and number of movements. For populations, distribution can be described using unique individuals/proportion of population, mean residence time, and mean movements. To quantify distribution of Blue Catfish, I integrated the three responses at the population level (Q1; Fig.2.1).

Fish use different locations for different purposes. These different locations can be used for spawning, feeding, and transitional areas, with some locations rarely used. Spawning sites are often locations that many fish travel to and reside for a short time period (Irving and Modde 2000; Stancill et al. 2002; Warner et al. 2009). In comparison, feeding locations may be locations where fish spend a lot of time (e.g., site fidelity) and at which predators may or may not move around a lot (Garcia-Berthou 1999; Farrugia et al. 2011; Huuskonen et al. 2012). Exploratory/transitional areas are locations that fish move through but don't spend much time (e.g., migration paths, forays from focal location; Booth et al. 2013; Chapman et al. 2015). Other locations are rarely used (e.g., where predators are, open water habitats; Jones and Stuart 2009; Riha et al. 2015). The use of locations with different functions may shift annually and seasonally (e.g., from spawning locations to summer locations to over-winter locations) or with resources (Garcia-Berthou 1999; Weller and Winter 2001; Tripp et al. 2011). Using multiple fish distribution responses (e.g., population proportion, residence time, and movements), I determined how sites within a system are used by fish (e.g., how sites function for such purposes as spawning, feeding, transitional, gathering, or low use; Q2; Fig. 2.1).

Fish of the same size and age have historically been thought to behave similarly even though behavioral and distributional differences related to size are well documented (Minns 1995; Kramer and Chapman 1999). However, an increasing number of studies show that not all fish of the same size behave the same (Jepsen et al. 2001; Vokoun and Rabeni 2005). For example, two distributional groups have been displayed by fish (1) broad-use and (2) localized use (Jepsen et al. 2001; Martin et al. 2009; Tripp et al. 2011). The broad-use fish distribute and move throughout the system while the localized use fish remain in one area (i.e., site fidelity). Contingents or groups of acoustically-tagged individuals that behave as distinct groups (e.g.,

Pautzke et al. 2010) are being documented with increasing frequency. Here, I determined if individual Blue Catfish form distinct groups (Q3; Fig. 2.1).

Variation in distribution and movement across systems reinforces the need to compare patterns across catfish populations (Kwak et al. 2011). Smaller scale (e.g., daily, seasonal, non-breeding periods, ontogenetic, and habitat shifts; Werner and Gilliam 1984; Albanese et al. 2004; Roberts and Angermeier 2007; Albanese et al. 2009) as well as long-distance migrations (Hobson 1999; Borcherding et al. 2002; Roberts and Angermeier 2007) alter organismal distribution. As with most animals, patterns of catfish distribution may vary across seasons (Lagler 1961; Pflieger 1997; Graham 1999; Timmons 1999; Fischer et al. 1999; Grist 2002; Garrett 2010). Examples exist of individual Blue Catfish moving upstream in the spring and summer (Lagler 1961; Graham 1999) in reservoirs (Timmons 1999; Grist 2002) and rivers (Garrett 2010). Blue Catfish also can redistribute downstream in the fall and winter (Lagler 1961; Pflieger 1997; Graham 1999) in reservoirs (Grist 2002) and rivers (Garrett 2010), including downstream emigration out of reservoirs (Graham and DeiSanti 1999). Local conditions also can influence how Blue Catfish distribute relative to deeper water offshore (Pflieger 1997; Edds et al. 2002), changing temperature, high discharge (Garrett 2010; Tripp et al. 2011), and other variables (Peterson 2015). What researchers and managers do not know is where Blue Catfish are located, what proportion of the population changes distribution, how long Blue Catfish stay in one place or move and the degree of individual variation. Consequently, I asked what responses best quantify Blue Catfish distribution (Q1), if sites within a single ecosystem, Milford Reservoir, function differently relative to Blue Catfish (Q2), and if groups of individuals use the reservoir differently, based on one distributional response (residence time) (Q3; Fig. 2.1).

Methods

Study System

Milford Reservoir (39°08'42"N, 96°56'54"W) is an impoundment of the Republican River located in the Lower Republican watershed 17.6 km above the confluence with the Smoky Hill River (Dickinson, Clay, and Geary counties, KS) (Fig. 2.2). Milford Reservoir was formed from a flood control dam (earth and rock with a spillway) that was built by the U.S. Army Corps of Engineers in 1967 (Layher and Boles 1980). Milford Reservoir is the largest reservoir in Kansas, has a surface area of 6,555 ha, has 262 km of shoreline dominated by limestone cobble and boulders, has an average depth of 6.7 m, and a maximum depth of 19.8 m (Goeckler et al. 2003).

I divided Milford Reservoir into four regions that included an arm of the reservoir (Madison Creek: centerline length 2 km; surface area 1.14 km^2) and three similarly-sized main reservoir regions. These regional divisions were based on centerline length and area (Upper region: centerline length 8 rkm; surface area 17.27 km^2, Middle region: centerline length 8 rkm; surface area 13.23 km^2, Lower region: centerline length 8 rkm; surface area 15.19 km^2; Fig. 2.2). The upper region is the shallowest region (average depth: 5.70 m; range: 2.90-8.26 km), is closest to the river inflow, and had a similar width as the lower region (average width: 2.58 km; range: 1.30-3.79 km). The middle region had four major tributaries (including the Madison Creek tributary), intermediate depths (average depth: 10.30 m; range: 7.62-13.76 m), and on average was the narrowest region of the reservoir (average width: 1.65 km; range: 1.22-2.14 km). The lower region contained the dam and outflow, had the greatest depths (average depth: 14.20 m; range: 9.02-17.80 m), and was a similar width to the upper region (average width: 2.54 km; range: 1.80-3.14 km). The last region is the major tributary, Madison Creek. This tributary has an

average depth of 7.1 m (range: 1.7-9.9 m) and average width of 0.49 km (range: 0.40-0.53 km). I use the regions as ways to describe the results and not as quantitative tests of location.

Fish Tagging (Number, Size, Timing)

In both 2012 and 2013, I targeted Blue Catfish that were similar to the most abundant size of Blue Catfish in Milford Reservoir (Fig. A.1). Blue Catfish were collected at locations identified as aggregations in preliminary sampling because tagging and releasing fish at random or regular locations throughout the reservoir would not have been logistically realistic. At Causeway, Madison Creek, and School Creek (Fig. C.1), 15-17 fish (2012) and 22-27 fish (2013) were tagged at each location on three sequential days. Fish were released in the same location where they were caught and tagged within two hours. Specifically, on 26-28 June, 2012, I internally implanted 48 Blue Catfish with VEMCO V9 (*n*=48) acoustic tags (mean fish size = 487 mm TL, range 383-1020, SE 14.5, 88% 400-600 mm TL; Table A.1). On 3-5 June, 2013, I internally implanted 75 Blue Catfish with VEMCO V9 (*n*=11) and V13 (*n*=64) tags (mean fish size = 517 mm TL, range 343-1090, SE 17.8, *n*=75, 71% 400-600 mm TL; Table A.2). Fish were collected using boat electrofishing (1 stationary boat, 2 capture boats) with low pulse DC current (Bodine and Shoup 2010). Individual fish were anesthetized one at a time with Aqui-S 30 mg-L until they lost orientation. A 15-30 mm lateral incision was made below the pectoral fin about ¾ of the way to the tip of the fin. A sterile tag was carefully inserted into the body cavity and the incision was closed with 2-4 sutures. After surgery all fish received an intramuscular injection of Liquamycin (0.1 mg/kg). Upon recovery, tagged fish were transferred to a community tank with a 0.05% salt solution before all fish were released. Tagging procedures are described in detail elsewhere (Chapter 1).

Receiver Placement

In 2012 and 2013, I tracked tagged Blue Catfish with a multiple stationary receiver array. I collected data using VEMCO (VR2W-69kHz) receivers, which received coded pings from tags each time a tagged fish came within range (i.e., 70% detection within 600 m of the receiver; Appendix B). In both years, receivers were deployed in the same locations although receiver losses in 2013 altered the array between years. In 2012 and 2013, the receivers were located at 18 locations within the reservoir and two locations adjacent to the reservoir exits (Fig. 2.3A, B). In 2013, four receivers (receivers 11, 12, 16, and 17) were lost due to vandalism or boating conflicts. In both years, for data analysis, I used data from one of three-receivers used as gates in the middle region of the reservoir. Specifically, I removed four receivers (2012 receivers: 7, 8, 11, 13; 2013 receivers: 7, 8, 11, 12) to eliminate range overlap and obtain a more even distribution of receivers. In 2013, receivers 11 and 12 were removed from analysis because they were lost during the course of the study (receiver 11 in September and receiver 12 in August). Thus, in 2012, of the 18 receivers located within the reservoir, 14 receivers were used for data analysis, and in 2013, 12 receivers were used for data analysis.

Data Format

Each receiver was downloaded monthly using a laptop with VEMCO's VUE software. Each individual tag detection was recorded as a single data line including date, time, and fish tag number. After field data downloads were complete, data from all receivers were retrieved from VUE, combined in Microsoft ACCESS and EXCEL.

Many methodological questions and sources of variation were addressed to assess quality of telemetry data and are discussed in detail elsewhere (Appendix D-I). To assess capture-tag-release location, residence time at each receiver location was calculated for the three release

locations effects to identify whether fish tagged at each receiver location spent more time at the receivers near where they were caught and released (Appendix D). I tested differences across diel periods using mean residence time (h) and mean number of movements using a Kruskal-Wallis test followed by a post-hoc Mann Whitney U multiple comparisons test with a Bonferroni adjustment (Appendix E). I also tested if total residence time and total movements differed across fish size using a linear regression to determine if fish size could have influenced the distribution patterns (Appendix F). Fish size and release location were compared across the cluster results of a non-hierarchical PAM (partitioning around medoids) cluster analysis on the 2012 residence time (Appendix G). Other null distributions were compared to the even distribution using a Chi-square analysis (Appendix H). I tested differences across seasons in 2013 using a Kruskal-Wallis test followed by a post-hoc Mann Whitney U multiple comparisons test with a Bonferroni adjustment (Appendix I).

Responses

Numbers of unique individuals, residence time, and numbers of movements are three metrics that I used to quantify the complex distribution of individual tagged fish (Fig. 2.1). The variable "unique individuals" was defined as the number of individuals present at a location. This response was calculated by counting fish for each receiver location only once. After an individual fish was recorded at a specific receiver, it was not included in future counts even if it was again detected at that location. Unique individuals provided some insight about whether individual fish were using distinct regions of the reservoir. The variable "population proportion" was defined as the percent of the total number of tagged fish detected at a location. This response was calculated as the total number of unique individuals divided by the total number of tagged fish. Population proportion identified if a specific location was widely used by many fish or just

frequented by a small group of individuals. Because unique individuals and population proportion are similar responses, here I only show the population proportion response.

Residence time is not commonly reported in fish tracking studies as it is only possible with an extensive array of stationary receivers. For fixed receivers that record data 24 h day in the same location, residence time is the preferred response that often replaces home range, which typically requires detections at random not fixed locations. Residence time quantified how much time each animal spent at each location. To calculate residence time, raw detection data from VUE were transformed into residence times for each fish at each receiver location using VTrack (R 2.15.2 software; R Core Team; Campbell et al. 2012). This program was used to quantify residence time at each site. Residence time is initialized at each site once a tagged fish is detected twice and terminates when a tagged fish was not detected for 1 hour or it is detected at another location. Residence time was used to distinguish whether a fish favored a location (large residence time) or was passing through (small residence time).

Movement is often used in telemetry studies because it provides information on how active a fish is and whether it remained sedentary or moved often. Movements among receivers were calculated as the number of times each fish came or went from a receiver location. The number of movements were calculated by summing the total number of movements for all fish to and from each receiver location. These movements were then scaled by the total amount of time (i.e., hours) that the study lasted.

Sites

Spatial distribution of Blue Catfish within Milford Reservoir was quantified using maps of all three metrics (population proportion, mean residence time, and mean movements) for the entire study period of 2012 (July-November) and 2013 (June-October). For maps of all three

responses, the size of the map symbol was proportional to response size. The maps displayed general spatial patterns that allowed me to compare the three fish responses and analyze location specific trends (e.g., seasonal). Mean residence time and mean movement distribution patterns were tested against an even distribution using a Chi-square analysis with 2000 Monte Carlo simulations ('chisq.test' function, 'stats' package, R). For mean residence time, an even distribution was defined as an equal amount of time spent at each receiver. The Chi-square analysis for residence time evaluated if fish spent more time, less time, or the expected amount of time at each receiver location. For mean movements, an even distribution was defined as an equal number of movements at each receiver location. The Chi-square analysis for movement evaluated if fish moved more, moved less, or moved the expected amount at each receiver location. Other null distributions (clusters at the upper, middle, and lower regions) were also tested using Chi-square analysis and revealed similar patterns of aggregation (Appendix H).

Year

To determine if the yearly trends were different, residence time was compared at individual receivers. I compared years using a Kruskal-Wallis nonparametric ANOVA (Analysis of Variance) ('kruskal.test' function, 'stats' package, R) followed by a post-hoc Mann Whitney U multiple comparisons test with a Bonferroni adjustment ('pairwise.wilcox.test' function, 'stats' package, R). Because comparisons across years were made at 12 receivers, I made a Bonferroni correction of 0.05/12 and used a critical alpha for across year comparisons of 0.004. In this chapter, I focus on 2012, similar patterns for 2013 are summarized in Appendix I.

Season

I tested if mean residence time and mean movements differed across months. Residence time and movements for July, August, September, October, and November were calculated for

each fish. Because each month was approximately the same duration, residence time (in hours) was compared for the entire monthly period. For movements, the number of total movements per day were compared across months. For both residence time and movements, differences among months were tested with a Kruskal-Wallis nonparametric ANOVA ('kruskal.test' function, 'stats' package, R) followed by a post-hoc Mann Whitney U multiple comparisons test with a Bonferroni adjustment ('pairwise.wilcox.test' function, 'stats' package, R). Individual fish were treated as replicates. Because comparisons across months were made at 14 receivers, I made a Bonferroni correction of 0.05/14, which resulted in a critical alpha of 0.004 for comparisons. Seasonal trends in 2013 were similar to 2012 and are summarized in Appendix I.

Groups of Individuals

I tested whether groups existed in the spatial data using two approaches; cluster analysis and network analysis. I used separate cluster analyses on residence time for all months combined and by month to identify if groups existed within the larger dataset. All fish were used for initial cluster analyses, but the final clusters only included fish that had residence times >25% of the maximum residence time. The cluster analysis did reveal clusters of 1 fish, but these were never considered alone. They were always grouped with other clusters of fish in the simplifications to create a larger group of fish. Because of this the simplifications of the clusters does not have the same number of fish across the months. Residence time data (total hours per month) was used to create a Euclidean distance matrix for the cluster analysis. The non-hierarchical method PAM (partitioning around medoids) the PAM function in R ('cluster' package, R) was used to determine if there were groups of fish present throughout the reservoir. The optimal number of clusters was determined by maximizing the average silhouette width and assessed using silhouette plots (Kaufman and Rousseeuw 1990) and Jaccard bootstrap mean values obtained

from the bootstrap method ('clusterboot' function, 'fpc' package, R). Jaccard bootstrap mean values >0.60 indicated cluster patterns (Hennig 2008). For synthesis of the 2012 clusters, I combined all monthly clusters into three general movement patterns. The 2012 synthesis combined the voluminous original cluster data (Appendix J) into synthesis clusters. The 2013 clusters (Appendix K) were similar.

A network analysis was also used to quantify fish groups based on residence time data (total hours per month) using the Fast-Greedy modularity optimization algorithm ('fastgreedy.community' function, 'igraph' package, R). This method is a hierarchical agglomerative method that optimizes modularity (Clauset et al. 2004; Finn et al. 2014). The results of the network analysis were viewed using a 'bipartite' graph that had two nodes (i.e., fish and receivers; Dale and Fortin 2010; Finn et al. 2014).

Results

Overview

In July-November, 2012, 48 tagged fish were detected a total of 1,139,402 times with an average of 24,243 detections per fish (range: 493-83,190, SE: 2,796.7). Seventy three percent of tagged fish were detected for five or more days during the first ten days and in November 90% of the tagged fish continued to be detected (Chapter 1). Overall, fish spent on average 181.7 hours (range: 9.2-393.4 hr, SE: 16.4) at receiver locations during 2012. Fish moved on average 167 times (range: 1-943, SE: 33.6) among receiver locations. In 2012, tagged fish were detected at an average of 12 receivers (range: 3-18, SE: 0.51) over the entire first field season. In November, 43 of the 48 (90%) tagged fish continued to be detected.

In June-October, 2013, 75 tagged fish were detected a total of 2,044,881 times with an average of 27,265 detections per fish (range: 233-109,205, SE: 2,473.9). Ninety six percent of all

fish tagged in 2013 were detected for five or more days within the first ten days post-tagging and throughout the study 85% of the tagged fish were detected. Overall fish spent on average 191.6 hours (range: 2.5-415.9 hr, SE: 13.9) at receiver locations during 2013. Fish moved on average 245 times (range: 1-1,307, SE: 28.1) between receiver locations in 2013. In 2013, fish were detected at an average of 13 receivers (range: 5-18, SE: 0.42) over the entire field season. In October, 64 of the 75 (85%) tagged fish continued to be detected.

Population-level Responses

I focused on population responses while individual level responses were examined in Appendix L. The three population responses (population proportion, mean residence time, mean movements) provided a wealth of diverse information that described different but complementary facets of Blue Catfish distribution in Milford Reservoir (Fig. 2.4). All of these population level responses revealed concentrations of Blue Catfish at specific locations within Milford Reservoir (population proportion - Fig. 2.4A, D), where tagged fish spent their time (residence time - Fig. 2.4B, E), and how much tagged fish moved (movements - Fig. 2.4C, F). In both years, a greater proportion of tagged fish were aggregated in the southern end of the upper region and throughout the middle region of the reservoir with fewer fish detected at the extremes of the reservoir (Fig. 2.4A, D). Specifically, in 2012, 81-88% of the population was detected in the southern end of the upper region and 94-98% were detected in the northern end of the middle region of the reservoir (2012 receivers: 4-6, 12, 14). In 2013, 93-99% of the fish were detected in the southern end of the upper region and 96-99% were detected in the northern end of the middle region of the reservoir at receivers: 4-6, 13 (Fig. 2.4A, D).

For mean residence time, fish spent the most time at locations located within the southern end of the upper region and northern end of the middle region (2012 receivers: 6, 9, 10, 12 and

2013 receivers: 4, 6, 9, 10; Fig. 2.4B, E). Across both years, tagged fish spent 16-61 hours at five receivers (receivers: 4, 6, 9, 10, and 12). Three of the five high residence time locations were shared across years (receivers: 6, 9, 10; Fig. 2.4B, E). Within the upper and middle regions, small differences existed in the exact locations where fish aggregated based on population proportion and mean residence time. Specifically, more fish were detected for longer periods of time in the northern end of the middle region of the reservoir in 2012 (receivers: 6, 12; Fig. 2.4A, B) and in the southern end of the upper region of the reservoir in 2013 (receivers 4, 6; Fig. 2.4D, E). Thus, between years, a shift occurred between receivers 4 (2013) and 12 (2012) (Fig. 2.4B, E).

With mean movements for both years (Fig. 2.4C, F), another facet of Blue Catfish distribution emerged. In 2012, the highest number of movements were in the middle region and northern end of the lower region (receivers: 12, 14, 15, 16; Fig. 2.4C). Whereas in 2013, the greatest number of movements at the southern end of the upper region and northern end of the middle region (receivers: 4-6, 13; Fig. 2.4F). For both years, the lowest number of movements were at the extreme ends of the reservoir (receivers: 2, 3, 18, 19; Fig. 2.4C, F).

The patterns of mean residence time and mean movements in both years were statistically different from an even distribution ($P<0.001$; $\alpha = 0.05$; Fig. 2.5A, B). More tagged fish spent more time and moved more at certain locations than would be expected if tagged fish used all areas equally. In 2012, fish spent more time at receivers 6, 9, 10, and 12 (Fig. 2.5A) and had the highest number of movements at receivers 6, 12, 14, 15, and 16 (Fig. 2.5A). In 2013, fish spent more time at receivers 4 and 6 (Fig. 2.5B) and had the greatest number of movements at receivers 4, 6, 9, 10, and 13 (Fig. 2.5B). Thus, by combining responses, sites can be shown to function differently.

Year

Patterns of distribution were similar across years. No differences in years existed for receivers 5, 6, 9, 10, 12/13, and 19 (Fig. 2.6D-H, L). Statistically significant differences between years that were too small (≤0.078 hr or 4.68 min.; Table 2.1) to be ecologically meaningful occurred at receivers 2, 3, 14, 15, and 18 (Fig. 2.6A, B, I, J, K). An ecologically meaningful and statistically significant yearly difference occurred at receiver 4 in the upper region (Fig. 2.6C) as fish shifted their distribution within the sites (receivers 4, 6, and 12/13) where a large aggregation occurred. Because residence time among the receivers between the years were similar, here I will focus on 2012. (2013 results are shown in Appendix I.)

Season

Monthly trends in fish distribution using mean residence time provided more insights into patterns of aggregation. In 2012, use of the upper region (receivers 2, 3, 4, 5) was variable across months, but not significantly different using the Bonferroni corrected critical alpha of 0.004 (Fig. 2.7A). No statistically significant monthly differences existed at receivers in the Madison Creek arm (receivers: 9 & 10; Fig. 2.7B) or at the middle region (receivers: 6 & 12; Fig. 2.7C). Only at locations in the southern end of the middle region (receivers: 14 & 15) and lower region (receivers: 16-19) were significantly different across months (Fig. 2.7C, D). For these southern middle and lower region receivers, residence times were greater in the fall. In general, seasonal changes reflected increases in residence in the lower region locations in the fall as a select group of fish in the upper and middle regions moved south in the fall.

Similar monthly changes were observed with 2012 mean number of movements. Mean movements were variable across months in the upper region of the reservoir (receiver 2-5). Although marginally significant ($P = 0.004$), movements at receiver 2 in the upper region of the

reservoir were quantitatively too small (average: 0.02-0.17 movements/hour) to be ecologically meaningful (Fig. 2.8A). However, across months differences were not significant at receivers 3-5 using a Bonferroni corrected critical alpha (0.05/14 = 0.004). No significant seasonal differences in movements occurred in northern Madison Creek (receiver: 10; Fig. 2.8B) and receivers in the middle region (receivers: 6 & 12; Fig. 2.8C). However, in southern Madison (receiver: 9; Fig. 2.8B), southern end of the middle region (receivers: 14 & 15; Fig. 2.8C) and lower region of the reservoir (receivers: 16-19; Fig. 2.8D), movements increased in the fall. In summary, as with residence time, numbers of movements reflects a southern movement of some individuals in the fall.

Groups of Individuals

Three types of distributional groups were identified by combining statistical clusters of individual fish across seasons (Appendix J). Within groups, individuals were distributed similarly, but differences in distribution existed across groups. The first type of distribution included fish that were seasonal movers (Fig. 2.9; *n* = July: 27, August: 26, September: 20, October: 24, November: 19). In July and August, these were fish that spent most of their time in the southern end of the upper region and northern end of the middle region (receivers: 4, 6, 12; Fig. 2.9A, B). In September, six clusters of fish emerged that were spread throughout the southern end of the upper region, the middle region, and northern end of the lower region (receivers: 4, 5, 6, 12, 14, 15, and 16; Fig. 2.9C). In October and November, these clusters merged into one cluster of fish that consistently spent more time in the southern end of the middle region and the lower region (receivers: 6, 12, 14-19; Fig. 2.9D, E).

The second type of distribution group included fish that do not make seasonal movements but remained in a consistent aggregation within the middle region (Fig. 2.10; *n* = July: 2, August:

5, September: 9, October: 3, November: 8). This distribution group was composed of a single cluster in July and August (Fig. 2.10A, B). This group remained in the southern end of the upper region and northern end of the middle region across all months (receivers: 4-6, 12, 14; Fig. 2.10C-E).

The third type of distribution group included the Madison Creek site fidelity fish (Fig. 2.11; *n* = July: 2, August: 0, September: 2, October: 4, November: 4). These fish stayed near the Madison Creek receivers (9, 10) in July (Fig. 2.11A), September (Fig. 2.11B), October (Fig. 2.11C), and November (Fig. 2.11D). These synthesis groups were derived from the original monthly clusters, which are presented here as an appendix but are not interpreted separately (Appendix J). A clusters were defined using the 2013 data (Appendix K), which showed similar distributional patterns. Cluster patterns were not different for fish size (Appendix G) because capture-tag-release locations reflected the reservoir-wide aggregation patterns (i.e., they were caught-tagged-released where they were aggregated for logistic reasons). Some groups were related to release locations (group 3 – Site fidelity to Madison) and others were not (Appendix G). This trend reflected natural aggregation patterns of these mobile predators.

In addition to a cluster analysis, a network analysis was run. As an example of network analysis results, in November, five groupings of fish and receivers (Fig. 2.12) emerged. The purple grouping of fish (Fig. 2.12), associated with receivers 9 & 10, were the Madison Creek fish from the cluster analysis. The red grouping of fish (Fig. 2.12), associated with receivers 4-6, were fish that do not make seasonal movements and spent time in the lower end of the upper region and upper end of the middle region. The three blue groupings of fish (Fig. 2.12) together comprised my final cluster of fish that were seasonal migrants.

Discussion

Overview

Understanding patterns of organismal distribution is fundamental in ecology (Roshier et al. 2008; Planque et al. 2011; Scheiner and Willig 2011) and fisheries, biology, and management (Pet et al. 2005; Espinoza et al. 2014; Specziar and Turcsanyi 2014). Ecological and fisheries researchers ask many questions about animal location including questions about seasonal shifts (Hardiman et al. 2004), modeling bioenergetics feedbacks (Nestler et al. 2002), fish population size (Crockett et al. 2006; Pierce et al. 2011), identity of fish assemblages (Bhagat and Ruetz 2011), and patterns of fish production (Baldwin et al. 2000). The answers to these questions often have fisheries management implications by providing data for stocking strategies (Baldwin et al. 2000; Hardiman et al. 2004), a comparison of future fish community structure (Bhagat and Ruetz 2011), controlling population size (Crockett et al. 2006), exploitation rates (Pierce et al. 2011), managing habitats (Nestler et al. 2002). Even though organismal distribution is a foundation for most ecological and fisheries questions, existing data on whole system animal distributions poorly describes patterns.

Historically, however, data on distribution have been spatially and temporally limited. For example, using gill-nets, fyke-nets, and hydroacoustics, fisheries researchers have sampled lakes/reservoirs for periods of once per month (Baldwin et al. 2000; Hardiman et al. 2004), multiple times a month (Nestler et al. 2002; Pierce et al. 2011), and multiple times a year (Crockett et al. 2006; Bhagat and Ruetz 2011). Spatial coverage is also limited using traditional sampling, with some researchers sampling ten or more sites (Baldwin et al. 2000) but most researchers sampling ten sites or fewer (Nestler et al. 2002; Hardiman et al. 2004; Crockett et al. 2006; Bhagat and Ruetz 2011; Pierce et al. 2011).

Even with contemporary tracking technology that can collect more extensive data sets, spatial and temporal coverage of fish use of the lake/reservoir ecosystem for research that seeks to quantify distributional patterns is limited. For example, in three recent tracking studies, 4-16 fish were tracked for 28 days-2 years using 1-3 stationary receivers or manual tracking (Weller and Winter 2001; Zamora and Moreno-Amich 2002; Vehanen and Johansson 2006). Consequently, tracking data, like data from traditional sampling gears, only quantify distribution over a relatively small number of individuals, times, and locations.

As a result of these limited spatial and temporal data sets, researchers have not frequently seen the full distributional complexity that is present in whole system analysis of many mobile individuals. As such, both ecologists and fisheries biologists often do not even recognize the scope of the problem with quantifying distribution and thus have developed limited tools for this problem. My extensive Blue Catfish tracking data set included 12-14 continuously recording acoustic receivers over five months per year, range coverage of 13.6-15.8 km^2 (21-24% of the reservoir), 123 fish tagged across two years, over one million detections, 85% tag retention over five months each year. As such, my spatially and temporally detailed dataset provides a novel opportunity to define and compare multiple distributional responses, identify how sites may differ in function, and assess if individual fish group.

Distributional Metrics

My three population distributional responses (e.g., population proportion, mean residence time, mean movements) tell important but different pieces of the story of where mobile fish predators are located. Together, these responses tell a more comprehensive story about the function of sites than individual responses alone. For example, if I had only quantified population proportion, I would only know locations where the fish were located or absent.

Population proportion provides important information but it does not reveal if a popular location is where individual fish spent a lot of time or if it was a transitory location through which fish were constantly passing on their way to somewhere else. Residence time revealed if fish were spending a lot or a little time at a location (i.e., residing there or passing through). However, trends in residence time could be caused by many or a few fish being present at a location. Thus, together population proportion and residence time revealed patterns that neither response alone revealed. For example, locations can have large numbers of fish staying for a long time (aggregations of many individuals), large numbers of fish staying briefly (transition areas of low residence), small numbers of fish staying a long time (aggregations of a small group of site specific individuals), or small numbers of fish staying briefly (low use areas). Aggregations (both large and small) can be characterized by lots of movements in which animals return to a central location (central place foraging; Rosenberg and McKelvey 1999) or little movement (site fidelity; Switzer 1993). Thus, population proportion and residence time suggest the amount of movement. But numbers of movements are needed to provide information about how much an individual fish is moving to and from a location.

Combining all three response variables (population proportion, residence time, and movements) provided insights about how sites within the reservoir function. For example, I found four types of sites: (1) areas with aggregation of a large number of individuals that moved but returned to the aggregation locations, (2) exploratory/transitory locations, (3) locations with an aggregation of a few individuals that did not move much, and (4) low use locations. The first distributional pattern occurred when there were a high number of individuals, high residence times, and high movements. This pattern was present in the southern end of the upper region and northern end of the middle region (2012 receivers: 6, 12; 2013 receivers: 4, 6) and may have

represented a type of central place foraging in which fish went out from but returned to the same location on a regular basis.

The exploratory/transitory distributional locations were characterized by a large number of individuals, short residence time, and low to moderate movements. Sites in the upper region were probably used for exploration (2012 receivers: 4, 5; 2013 receivers: 2, 3) and select sites in the middle region may have been transitory or a way from getting from here to there (2012 receivers: 14, 15; 2013 receivers: 13, 14).

The third distributional pattern for sites was characterized by few individuals, long residence times, and low movements. For example, a small group of fish that were regularly detected in Madison Creek (receivers: 9, 10) exhibited site fidelity to this location (Switzer 1993). The final distributional pattern, low use, was present in the remaining locations of the reservoir (i.e., upper and lower; 2012 receivers: 2, 3, 16-19 and 2013 receivers: 15, 18, 19) and was characterized by low numbers of individuals, low residence time, and low movements. Consequently, lake-wide distributional patterns emerged, in which locations with large active aggregations were surrounded by exploratory/transitory sites with low use areas at the perimeter.

Few studies have examined, interpreted, and integrated multiple responses although most other tracking studies have used one or two responses similar to those I used. When a subset (n = 17) of the most recent tracking literature is examined as a whole, three categories of responses related to spatial distribution are common. These three general categories mirror my three responses described above. The first category includes any type of movement response (e.g., mean movements, movement distance per day, extent of movement; Gerig et al. 2014; Kim et al. 2014). The second category is time/space use which includes responses that quantify the amount of time a fish spends somewhere or the amount of space it uses (e.g., mean residence time,

utilization distribution, home range; Acuna-Marrero et al. 2014; Bass et al. 2014). The third category includes counts (e.g., population proportion, detections; Currey et al. 2014; Gerig et al. 2014). Of the 17 papers reviewed five studies only used one response (Acuna-Marrero et al. 2014; Bass et al. 2014; Cole and Bettoli 2014; Cook et al. 2014; Herrala et al. 2014). None of the studies paired responses from the movement and time/space use categories together. Only two studies paired responses from the time/space use and counts categories together (Currey et al. 2014; Lowerre-Barbieri et al. 2014). While the rest of the studies (n = 9) paired responses from the movement and counts categories together (Eiler et al. 2014; Gerig et al. 2014). Thus, my approach of combining responses provides an innovative way to explore space use by mobile organisms that could be widely used in the fish tracking community.

Fish Aggregations

My spatially explicit, reservoir-wide dataset demonstrated unambiguously that tagged Blue Catfish consistently aggregated in the northern end of the middle region of the reservoir. The distributional pattern revealed by the two different responses (e.g., population proportion and mean residence time) was similar. Specifically, for all months and both years, more fish were present and individual fish spent more time in the northern end of the middle region. The concentration of fish and elevated residence were not in the wide (average = 2.54 km) and deep (average = 14.20 m) lower region or the wide (average = 2.48 km) and shallow (average = 5.70 m) upper region, but focused on the middle region that had the narrowest width (average = 1.65 km) and an average depth (10.30 m) between the other two regions. The irregular distribution of organisms commonly occurs as a result of most sampling. In addition, many fish aggregate during short periods to spawn (Meyer et al. 2007; Grabowski and Jennings 2009; Hennen and

Brown 2014). System-wide aggregations of non-spawning fish that are consistent across years and months have rarely been documented (Kennedy et al. 2015).

Groups of Individuals

My study is one of the first to document distributional groups for freshwater fish of the same size. I identified three groups of individuals based on distributional patterns. Specifically, the first group of seasonal movers was composed of fish that used the northern end of the middle region in the summer then shifted to locations in the lower region and the southern end of the middle region in the fall. Not all seasonal movers moved south to the same geographic extent.

Seasonal changes in fish distribution are well described in the fish literature. Studies on Blue Catfish have observed seasonal shifts, especially in the fall and spring. In impoundments, Blue Catfish have been observed moving into deeper areas in the fall (Fischer et al. 1999) and in large rivers they move into the open river or downstream in the fall (Garrett and Rabeni 2011; Tripp et al. 2011). Studies on other species of fish have also found that there are seasonal changes in fish distribution. Other predator species (e.g., Muskellunge, *Esox masquinongy*, Northern Pike, *Esox lucius*, and Largemouth Bass, *Micropterus salmoides*) also displayed movements into deeper water habitats in the fall for overwintering (Vehanen and Johansson 2006; Hanson et al. 2008; Gillis et al. 2010). Here, these seasonal movements are integrated into patterns of distribution. Not all fish move the same amount and not all fish make a seasonal shift.

The second group of fish was composed of consistently aggregated fish that used the northern end of the middle region throughout the study period (i.e., these fish did not move south in the fall). The last group of fish used the Madison Creek region and also did not move south in the fall.

Other studies are starting to find distributional groups in their data. In freshwater river-systems, fish have displayed two distributional groups (1) non-movers and (2) movers. The non-movers stayed in the river (i.e., site fidelity) while the movers moved into a lake, tributary, or open river (Jepsen et al. 2001; Vehanen and Johansson 2006; Tripp et al. 2011). This may be a general pattern for predators as contingents (i.e., groups) of acoustically-tagged individuals have been documented in coastal systems (e.g., Flounder, DeCelles and Cadrin 2010; Striped Bass, Pautzke et al. 2010; Green Sturgeon, Lindley et al. 2011; Common Snook, Lowerre-Barbieri 2014). As the incidence of these patterns increase, likely more sophisticated tools for analyzing and simplifying these data will emerge (e.g., network analyses).

Management Implications

My research on distribution has three major management implications. First, I have provided information on where Blue Catfish are located in Milford Reservoir. Existing data on distribution are very limited and knowing distribution is critical for all management and research activities. My spatially explicit approach suggests that fish are aggregated in consistent locations within and between years. If managers can identify the occurrence of these Blue Catfish aggregations in other reservoirs they should be able to better assess the stock and more effectively collect biological samples (e.g., diet, aging structures). To find these aggregations, managers might implement an extensive survey in which they systematically sample the entire reservoir to identify aggregations. One of the top things that anglers often want to know is where fish are located and fishermen often have ‘secret spots’ where they have determined the fish to be located. So, if management agencies know where fish are aggregated they could create their own outreach maps for anglers.

Second, the number of empirical studies on Blue Catfish distribution, movement, and habitat are increasing. However, at present, each one represents an isolated data point because of system-specific difference in morphometry, bathymetry, habitat, and researcher-specific methodological differences across studies. Researchers and managers would benefit from a standardized synthesis of what is actually known about Blue Catfish distribution and movements across a wide range of states and ecological systems.

Finally, some management utility may arise from the awareness that discrete groups of same-sized fish can differ in their distribution. These results are novel in the field of freshwater fish biology and management. However, knowledge of this pattern could be useful in the future. For example, awareness of the Blue Catfish in Milford Reservoir that remain within Madison Creek could influence habitat management, restoration, and planning.

References

Acuna-Marrero, D., J. Jimenez, F. Smith, P.F. Doherty, A. Heam, J.R. Green, J. Paredes-Jarrin, and P. Salinas-de-Leon. 2014. Whale Shark (*Rhincodon typus*) seasonal presence, residence time and habitat use at Darwin Island, Galapagos Marine Reserve. PLoS ONE 9(12): e115946.

Albanese, B., P.L. Angermeier, and S. Dorai-Raj. 2004. Ecological correlates of fish movement in a network of Virginia streams. Canadian Journal of Fisheries and Aquatic Sciences 61(6): 857-869.

Albanese, B., P.L. Angermeier, and J.T. Peterson. 2009. Does mobility explain variation in colonisation and population recovery among stream fishes? Freshwater Biology 54(7): 1444-1460.

Baldwin, C. M., D.A. Beauchamp, and J.J. Van Tassell. 2000. Bioenergetic assessment of temporal food supply and consumption demand by salmonids in the Strawberry Reservoir food web. Transactions of the American Fisheries Society 129(2): 429-450.

Baker R. R. 1978. The evolutionary ecology of animal migration. Holmes and Meier Publishers, New York, New York.

Bass, A. L., T.O. Haugen, and L.A. Vollestad. 2014. Distribution and movement of European Grayling in a subarctic lake revealed by acoustic telemetry. Ecology of Freshwater Fish 23(2): 149-160.

Bhagat, Y. and C. R. Ruetz. 2011. Temporal and fine-scale spatial variation in fish assemblage structure in a drowned river mouth system of Lake Michigan. Transactions of the American Fisheries Society 140(6): 1429-1440.

Booth, M. T., N.G. Hairston, and A.S. Flecker. 2013. How mobile are fish populations? Diel movement, population turnover, and site fidelity in suckers. Canadian Journal of Fisheries Aquatic Science 70: 1-12.

Borcherding, J., M. Bauerfeld, D. Hintzen, and D. Neumann. 2002. Lateral migrations of fishes between floodplain lakes and their drainage channels at the Lower Rhine: diel and seasonal aspects. Journal of Fish Biology 61(5): 1154-1170.

Bridger, C. J. and R. K. Booth. 2003. The effects of biotelemetry transmitter presence and attachment procedures on fish physiology and behavior. Reviews in Fisheries Science 11(1): 13-34.

Cadrin, S.X., and D.H. Secor. 2009. Accounting for spatial population structure in stock assessment: past, present, and future. Pages 405-426 *in* R. Rothschild, R., editor. Future of fisheries science in North America. Bethesda, Maryland.

Campbell, H.A., Watts, M.E., Dwyer, R.G., Franklin, C.E. 2012. V-Track: software for analysing and visualising animal movement from acoustic telemetry detections. Marine and Freshwater Research, 63:815–820.

Chapman, E. D., A.R. Hearn, G.P. Singer, W.N. Brostoff, P.E. LaCivita, and A.P. Klimley. 2015. Movements of Steelhead (*Oncorhynchus mykiss*) smolts migrating through the San Francisco Bay Estuary. Environmental Biology of Fishes 98(4): 1069-1080.

Clauset, A., M.E.J. Newman, and C. Moore. 2004. Finding community structure in very large networks. Physical Review E 70(6).

Cole, A. J. and P. W. Bettoli. 2014. Thermal ecology of subadult and adult Muskellunge in a thermally enriched reservoir. Fisheries Management and Ecology 21(5): 410-420.

Cook, A. M., R.G. Bradford. 2014. Hydroacoustic tracking of the endangered Atlantic Whitefish (*Coregonus huntsmani*); comparative analysis from wild and hatchery reared populations. Environmental Biology of Fishes 97(8): 955-964.

Cooke, S. J., C.M. Woodley, M.B. Eppard, R.S. Brown, and J.L. Nielson. 2011. Advancing the surgical implantation of electronic tags in fish: a gap analysis and research agenda based on a review of trends in intracoelomic tagging effects studies. Reviews in Fish Biology and Fisheries 21(1): 127-151.

Crockett, H. J., B.M. Johnson, P.J. Martinez, and D. Brauch. 2006. Modeling target strength distributions to improve hydroacoustic estimation of Lake Trout population size. Transactions of the American Fisheries Society 135(4): 1095-1108.

Currey, L. M., M.R. Heupel, C.A. Simpfendorfer, and A.J. Williams. 2014. Sedentary or mobile? Variability in space and depth use of an exploited coral reef fish. Marine Biology 161(9): 2155-2166.

Dale, M. R. T. and M. J. Fortin. 2010. From graphs to spatial graphs. Annual Review of Ecology, Evolution, and Systematics 41: 21-38.

DeCelles, G. R. and S. X. Cadrin. 2010. Movement patterns of Winter Flounder (*Pseudopleuronectes americanus*) in the southern Gulf of Maine: observations with the use of passive acoustic telemetry. Fishery Bulletin 108(4): 408-419.

Edds, D. R., W.J. Matthews, and F.P. Gelwick. 2002. Resource use by large catfishes in a reservoir: is there evidence for interactive segregation and innate differences? Journal of Fish Biology 60(3): 739-750.

Eiler, J. H., M.M. Masuda, T.R. Spencer, R.J. Driscoll, and C.B. Schreck. 2014. Distribution, stock composition and timing, and tagging response of wild Chinook Salmon returning to a large, free-flowing river basin. Transactions of the American Fisheries Society 143(6): 1476-1507.

Espinoza, M., M. Cappo, M.R. Heupel, A.J. Tobin, and C.A. Simpfendorfer. 2014. Quantifying shark distribution patterns and species-habitat associations: implications of marine park zoning. Plos One 9(9).

Farrugia, T. J., M. Espinoza, and C.G. Lowe. 2011. Abundance, habitat use and movement patterns of the Shovelnose Guitarfish (*Rhinobatos productus*) in a restored southern California estuary. Marine and Freshwater Research 62(6): 648-657.

Finn, J. T., J.W. Brownscombe, C.R. Haak, S.J. Cooke, R. Cormier, T. Gagne, and A.J. Danylchuk. 2014. Applying network methods to acoustic telemetry data: modeling the movements of tropical marine fishes. Ecological Modelling 293: 139-149.

Fischer, S.A., S. Eder, and E.D. Aragon. 1999. Movements and habitat use of Channel Catfish and Blue Catfish in a small impoundment in Missouri. Pages 239-255 *in* E.R. Irwin, W.A. Hubert, C.F. Rabeni, H.L. Schramm, and T. Coon, editors. Catfish 2000: Proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, MD.

Garcia-Berthou, E. 1999. Spatial heterogeneity in Roach (*Rutilus rutilus*) diet among contrasting basins within a lake. Archiv Fur Hydrobiologie 146(2): 239-256.

Garrett, D. L. 2010. Movement, habitat use, and spawning characteristics of Flathead and Blue Catfish on the lower Missouri River and tributaries. Doctoral Dissertation, University of Missouri, Columbia, Missouri.

Garrett, D.L., and C.F. Rabeni. 2011. Intra-annual movement and migration of Flathead Catfish and Blue Catfish in the lower Missouri River and tributaries. Pages 495-509 *in* P. H. Michaletz and V. H. Travnichek, editors. Conservation, ecology, and management of catfish: the second international symposium. American Fisheries Society, Symposium 77, Bethesda, Maryland.

Gerig, B., M.J. Dodrill, and W.E. Pine. 2014. Habitat selection and movement of adult Humpback Chub in the Colorado River in Grand Canyon, Arizona, during an experimental steady flow release. North American Journal of Fisheries Management 34(1): 39-48.

Gillis, N. C., T. Rapp, C.T. Hasler, H. Wachelka, and S.J. Cooke. 2010. Spatial ecology of adult Muskellunge (*Esox masquinongy*) in the urban Ottawa reach of the historic Rideau Canal, Canada. Aquatic Living Resources 23(2): 225-230.

Goeckler, J.M., M.C. Quist, J.A. Reinke and C.S. Guy. 2003. Population characteristics and evidence of natural reproduction of Blue Catfish in Milford Reservoir, Kansas. Transactions of the Kansas Academy of Science 106:149-154.

Grabowski, T. B. and C. A. Jennings. 2009. Post-release movements and habitat use of Robust Redhorse transplanted to the Ocmulgee River, Georgia. Aquatic Conservation-Marine and Freshwater Ecosystems 19(2): 170-177.

Graham, K. 1999. Biology and management of Blue Catfish. Pages 37-49 *in* E.R. Irwin, W.A. Hubert, C.F. Rabeni, H.L. Schramm, Jr. and T. Coon, editors. Catfish 2000: proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Graham, K., and K. DeiSanti. 1999. The population and fishery of Blue Catfish and Channel Catfish in the Harry S Truman Dam tailwater, Missouri. Pages 361–376 *in* E.R. Irwin, W.A. Hubert, C.F. Rabeni, H.L. Schramm, Jr. and T. Coon, editors. Catfish 2000: proceedings of the international Ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Grist, J. D. 2002. Analysis of a Blue Catfish population in a southeastern reservoir: Lake Norman, North Carolina. Master's Thesis. Virginia Polytechnic Institute and State University. Blacksburg, Virginia.

Gross, M. R., R.M. Coleman, and R.M. McDowell. 1988. Aquatic productivity and the evolution of diadromous fish migration. Science 239(4845): 1291-1293.

Hansen, M. J., N.J. Horner, M. Liter, M.P. Peterson, and M.A. Maiolic. 2008. Dynamics of an increasing Lake Trout population in Lake Pend Oreille, Idaho. North American Journal of Fisheries Management 28(4): 1160-1171.

Hanson, K. C., C.T. Hasler, S.J. Cooke, C.D. Suski, and D.P. Philipp. 2008. Intersexual variation in the seasonal behaviour and depth distribution of a freshwater temperate fish, the

Largemouth Bass. Canadian Journal of Zoology-Revue Canadienne De Zoologie 86(8): 801-811.

Hanson, S. D. and R. A. Curry. 2005. Effects of size structure on trophic interactions between age-0 Smallmouth Bass and juvenile anadromous Alewives. Transactions of the American Fisheries Society 134(2): 356-368.

Hardiman, J. M., B.M. Johnson, and P.J. Martinez. 2004. Do predators influence the distribution of age-0 Kokanee in a Colorado reservoir? Transactions of the American Fisheries Society 133(6): 1366-1378.

Hennen, M. J. and M. L. Brown. 2014. Movement and spatial distribution of Common Carp in a South Dakota glacial lake system: implications for management and Removal. North American Journal of Fisheries Management 34(6): 1270-1281.

Hennig, C. 2008. Dissolution point and isolation robustness: robustness criteria for general cluster analysis methods. Journal of Multivariate Analysis 99, 1154-1176.

Herrala, J. R., P.T. Kroboth, N.M. Kuntz, and H.L. Schramm. 2014. Habitat use and selection by adult Pallid Sturgeon in the lower Mississippi River. Transactions of the American Fisheries Society 143(1): 153-163.

Hobson, K. A. 1999. Tracing origins and migration of wildlife using stable isotopes: a review. Oecologia 120(3): 314-326.

Huuskonen, H., H. Haakana, A. Leskela, and J. Piironen. 2012. Seasonal movements and habitat use of River Whitefish (*Coregonus lavaretus*) in the Koitajoki River (Finland), as determined by Carlin tagging and acoustic telemetry. Aquatic Ecology 46(3): 325-334.

Irving, D. B. and T. Modde. 2000. Home-range fidelity and use of historic habitat by adult Colorado Pikeminnow (*Ptychocheilus lucius*) in the White River, Colorado and Utah. Western North American Naturalist 60(1): 16-25.

Jackson, D. A., P.R. Peres-Neto, and J.D. Olden. 2001. What controls who is where in freshwater fish communities - the roles of biotic, abiotic, and spatial factors. Canadian Journal of Fisheries and Aquatic Sciences 58(1): 157-170.

Jepsen, N., S. Beck, C. Skov, and A. Koed. 2001. Behavior of Pike (*Esox lucius L.*) > 50 cm in a turbid reservoir and in a clearwater lake. Ecology of Freshwater Fish 10(1): 26-34.

Jones, M. J. and I. G. Stuart. 2009. Lateral movement of Common Carp (*Cyprinus carpio L.*) in a large lowland river and floodplain. Ecology of Freshwater Fish 18(1): 72-82.

Kaufman, L. and P.J. Rousseeuw. 1990. Partitioning around medoids (program pam). Pages 68-125 *in* John Wiley & Sons, Inc., editors. Finding groups in data: an introduction to cluster analysis, John Wiley & Sons, Inc., Hoboken, New Jersey.

Kennedy, M. and R. D. Gray. 1993. Can ecological theory predict the distribution of foraging animals - a critical analysis of experiments on the ideal free distribution. Oikos 68(1): 158-166.

Kennedy, C.G., M.E. Mather, J.M. Smith, J.T. Finn, and L.A. Deegan. 2015. Discontinuities concentrate mobile predators: implications for organism-environment interactions at a seascape scale. Ecosphere. In Press.

Kim, J. H., J.D. Yoon, W.M. Heo, D.S. Kim, C. Kim, and M.H. Jang. 2014. Movement patterns of three freshwater fish species after upstream transportation by fishway in the Jangheung Dam. Paddy and Water Environment 12: S141-S148.

Kramer, D. L. and M. R. Chapman. 1999. Implications of fish home range size and relocation for marine reserve function. Environmental Biology of Fishes 55(1-2): 65-79.

Kwak, T.J., M.T. Porath, P.H. Michaeletz, and V.H. Travnichek. 2011. Catfish Science: Status and Trends in the 21st Century. American Fisheries Society Symposium 77:755–780.

Lagler, K.F. 1961. Freshwater fishery biology. William C. Brown Company/McGraw-Hill, Dubuque, Iowa.

Layher, W.G. and R.J. Boles. 1980. Food habits of the Flathead Catfish, *Pylodictis olivaris* (Rafinesque), in relation to length and season in a large Kansas reservoir. Transactions of the Kansas Academy of Sciences 83: 200-214.

Lindley, S. T., D.L. Erickson, M.L. Moser, G. Williams, O.P. Langness, B.W. McCovey, M. Belchik, D. Vogel, W. Pinnix, J.T. Kelly, J.C. Heublein, and A.P. Klimley. 2011. Electronic tagging of Green Sturgeon reveals population structure and movement among estuaries. Transactions of the American Fisheries Society 140(1): 108-122.

Lowerre-Barbieri, S., D. Villegas-Rios, S. Walters, J. Bickford, W. Cooper, R. Muller, and A. Trotter. 2014. Spawning site selection and contingent behavior in Common Snook, *Centropomus undecimalis*. Plos One 9(7).

Martin, D. R., L.A. Powell, and K.L. Pope. 2009. Spring home ranges of White Bass in irrigation reservoirs of the Republican River Basin, Nebraska. Ecology of Freshwater Fish 18(4): 514-519.

Metcalfe, J. D. 2006. Fish population structuring in the North Sea: understanding processes and mechanisms from studies of the movements of adults. Journal of Fish Biology 69: 48-65.

Meyer, C. G., K.N. Holland, and Y.P. Papastamatiou. 2007. Seasonal and diel movements of Giant Trevally *Caranx ignobilis* at remote Hawaiian atolls: implications for the design of Marine Protected Areas. Marine Ecology Progress Series 333: 13-25.

Minns, C. K. 1995. Allometry of home-range size in lake and river fishes. Canadian Journal of Fisheries and Aquatic Sciences 52(7): 1499-1508.

Nestler, J. M., R.A. Goodwin, T.M. Cole, D. Degan, and D. Dennerline. 2002. Simulating movement patterns of Blueback Herring in a stratified southern impoundment. Transactions of the American Fisheries Society 131(1): 55-69.

Pautzke, S. M., M.E. Mather, J.T. Finn, L.A. Deegan, and R.M. Muth. 2010. Seasonal use of a New England estuary by foraging contingents of migratory Striped Bass. Transactions of the American Fisheries Society 139(1): 257-269.

Pet, J. S., P.J. Mous, A.H. Muljadi, Y.J. Sadovy, and L. Squire. 2005. Aggregations of *Plectropomus areolatus* and *Epinephelus fuscoguttatus* (groupers, Serranidae) in the Komodo National Park, Indonesia: monitoring and implications for management. Environmental Biology of Fishes 74(2): 209-218.

Peterson, Z. 2015. Quantifying patterns and select correlates of spatially and temporally explicit distribution of a fish predator (Blue Catfish, *Ictalurus furcatus*) throughout a large reservoir ecosystem. Master's Thesis. Kansas State University, Manhattan, Kansas.

Pflieger, W.L. 1997. The fishes of Missouri. Missouri Department of Conservation, Jefferson City, Missouri.

Pierce, L. L., B.D.S Graeb, D.W. Willis, J.S. Sorensen, and M.A. Pegg. 2011. Stocking success of Paddlefish in Lake Francis Case, South Dakota: population characteristics and sport fishery potential. Transactions of the American Fisheries Society 140(5): 1359-1369.

Planque, B., C. Loots, P. Petitgas, U. Lindstrom, and S. Vaz. 2011. Understanding what controls the spatial distribution of fish populations using a multi-model approach. Fisheries Oceanography 20(1): 1-17.

Riha, M., D. Ricard, M. Vasek, M. Prchalova, T. Mrkvicka, T. Juza, M. Cech, V. Drastik, M. Muska, M. Kratochvil, J. Peterka, M. Tuser, J. Sed'a, P. Blabolil, M. Blaha, J. Wanzenbock, and J. Kubecka. 2015. Patterns in diel habitat use of fish covering the littoral and pelagic zones in a reservoir. Hydrobiologia 747(1): 111-131.

Roberts, J. H. and P. L. Angermeier. 2007. Spatiotemporal variability of stream habitat and movement of three species of fish. Oecologia 151(3): 417-430.

Rosenberg, D. K. and K. S. McKelvey. 1999. Estimation of habitat selection for central-place foraging animals. Journal of Wildlife Management 63(3): 1028-1038.

Roshier, D. A., V.A.J. Doerr, and E.D. Doerr. 2008. Animal movement in dynamic landscapes: interaction between behavioural strategies and resource distributions. Oecologia 156(2): 465-477.

Scheiner, S.M. and M.R. Willig. 2011. A general theory of ecology. Pages 3-18 *in* S.M. Scheiner and M.R. Willig, editors, The theory of ecology. The University of Chicago Press, Chicago, Illinois.

Specziar, A. and B. Turcsanyi. 2014. Effect of stocking strategy on distribution and recapture rate of Common Carp *Cyprinus carpio L*., in a large and shallow temperate lake: implications for recreational put-and-take fisheries management. Journal of Applied Ichthyology 30(5): 887-894.

Stancill, W., G.R. Jordan, and C.P. Paukert. 2002. Seasonal migration patterns and site fidelity of adult Paddlefish in Lake Francis Case, Missouri River. North American Journal of Fisheries Management 22(3): 815-824.

Switzer, P. V. 1993. Site fidelity in predictable and unpredictable habitats. Evolutionary Ecology 7(6): 533-555.

Timmons, T.J. 1999. Movement and exploitation of Blue and Channel Catfish in Kentucky Lake. Pages 187– 191 *in* E.R. Irwin, W.A. Hubert, C.F. Rabeni, H.L. Schramm, Jr. and T. Coon, editors. Catfish 2000: proceedings of the international Ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Tripp, S. J., M. J. Hill, H. A. Calkins, R. C. Brooks, D. P. Herzog, D. E. Ostendorf, R. A. Hrabik, and J. E. Garvey. 2011. Blue Catfish movement in the upper Mississippi River. Pages 511-519 *in* P. H. Michaletz and V. H. Travnichek, editors. Conservation, ecology, and management of catfish: the second international symposium. American Fisheries Society, Symposium 77, Bethesda, Maryland.

Vehanen, T., P. Hyvarinen, K. Johansson, and T. Laaksonen. 2006. Patterns of movement of adult Northern Pike (*Esox lucius L*.) in a regulated river. Ecology of Freshwater Fish 15(2): 154-160.

Vokoun, J. C. and C. E. Rabeni. 2005. Variation in an annual movement cycle of Flathead Catfish within and between two Missouri watersheds. North American Journal of Fisheries Management 25(2): 563-572.

Warner, D. M., R.M. Claramunt, J. Janssen, D.J. Jude, and N. Wattrus. 2009. Acoustic estimates of abundance and distribution of spawning Lake Trout on Sheboygan Reef in Lake Michigan. Journal of Great Lakes Research 35(1): 147-153.

Weller, R. R. and J. D. Winter. 2001. Seasonal variation in home range size and habitat use of Flathead Catfish in Buffalo Springs Lake, Texas. North American Journal of Fisheries Management 21(4): 792-800.

Werner, E. E. and J. F. Gilliam. 1984. The ontogenetic niche and species interactions in size structured populations. Annual Review of Ecology and Systematics 15: 393-425.

Zamora, L. and R. Moreno-Amich. 2002. Quantifying the activity and movement of Perch in a temperate lake by integrating acoustic telemetry and a geographic information system. Hydrobiologia 483(1-3): 209-218.

Table 2.1. Average residence time (h) fish spent at receivers in Milford Reservoir, KS in 2012 and 2013. The differences in the average residence time (h) between the two years.

Receiver	2012	2013	Mean Difference (h)
R2	0.0051	0.0206	0.0155
R3	0.029	0.031	0.001
R14	0.078	0.045	0.033
R15	0.076	0.062	0.014
R18	0.0189	0.0034	0.0155

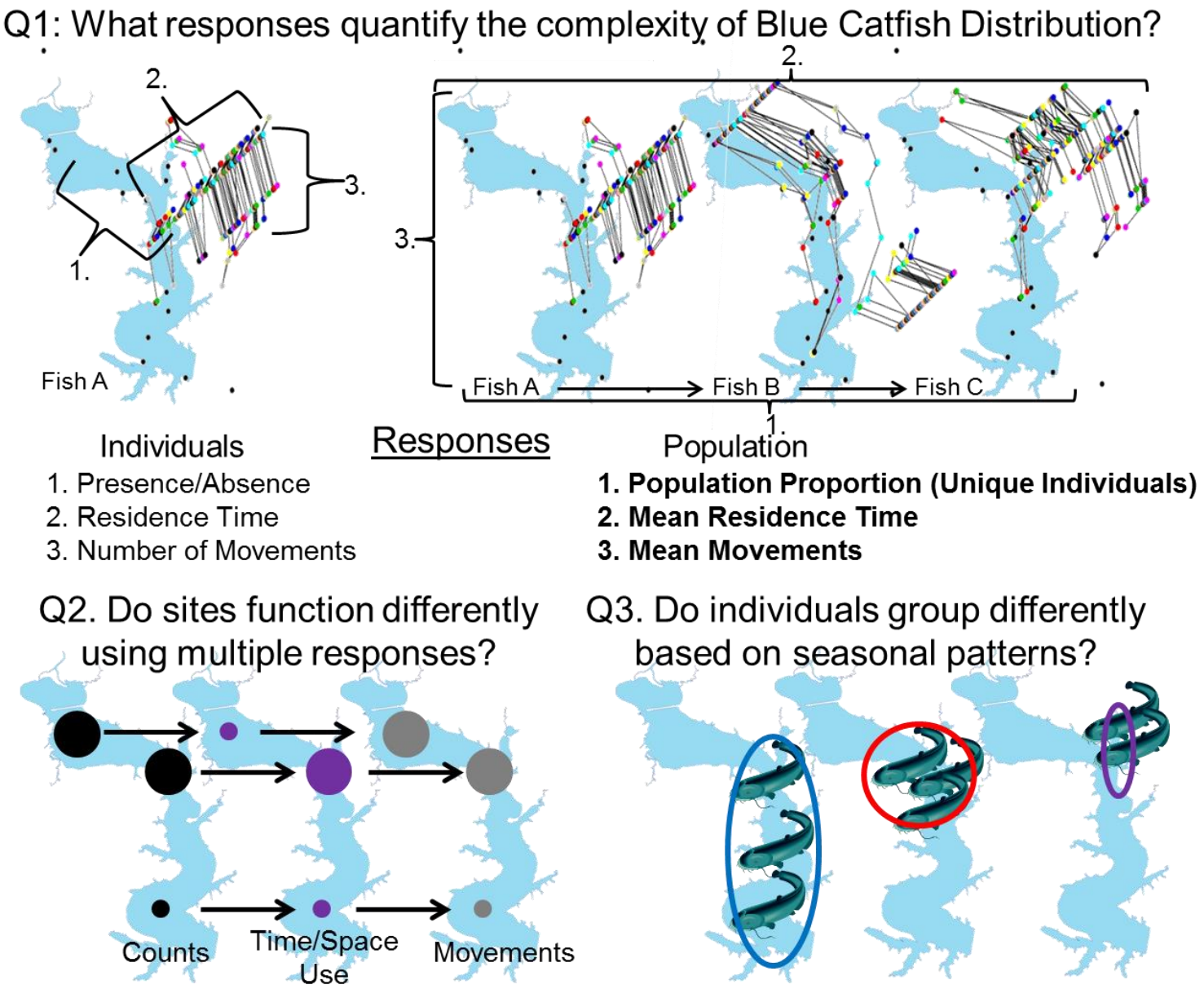


Figure 2.1. Conceptual diagram of the complexity of distribution. A total of six responses are shown three for individuals (1. presence/absence, 2. residence time, 3. number of movements) and three for populations (1. population proportion, 2. mean residence time, 3. mean movements). Also shown are my three research questions.

Region	Receivers
Upper	2, 3, 4, & 5
Madison	9 & 10
Middle	6, 12/13, 14, & 15
Lower	16, 17, 18, & 19

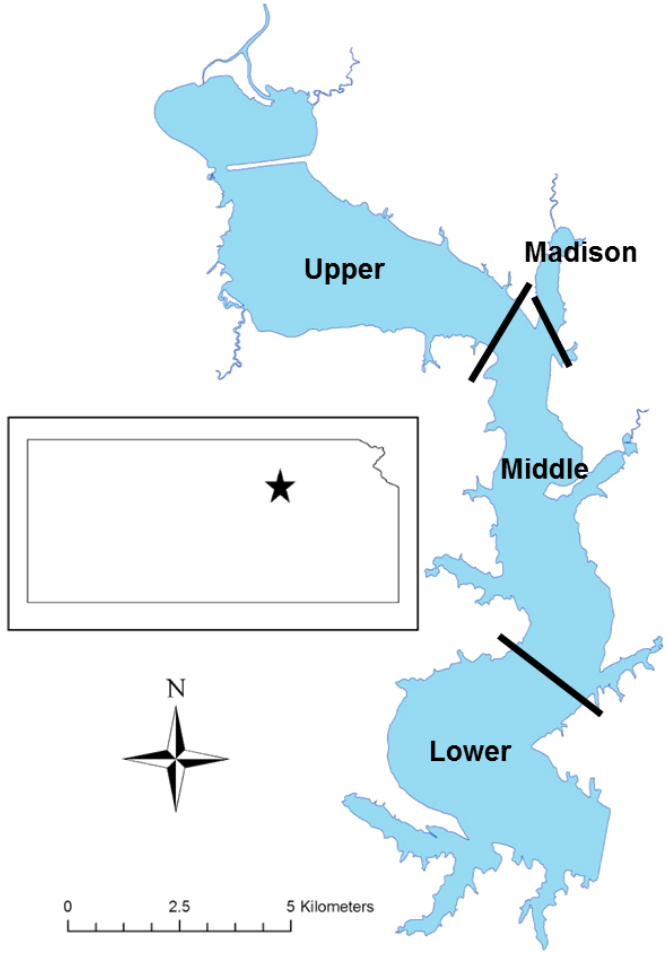


Figure 2.2. My study site, Milford Reservoir, KS, is an impoundment split into four regions on the Republican River in northeastern Kansas. The four regions are upper (receivers 2-5), middle (receivers 6, 12/13, 14, and 15), lower (receivers 16-19), and Madison Creek (receivers 9 and 10).

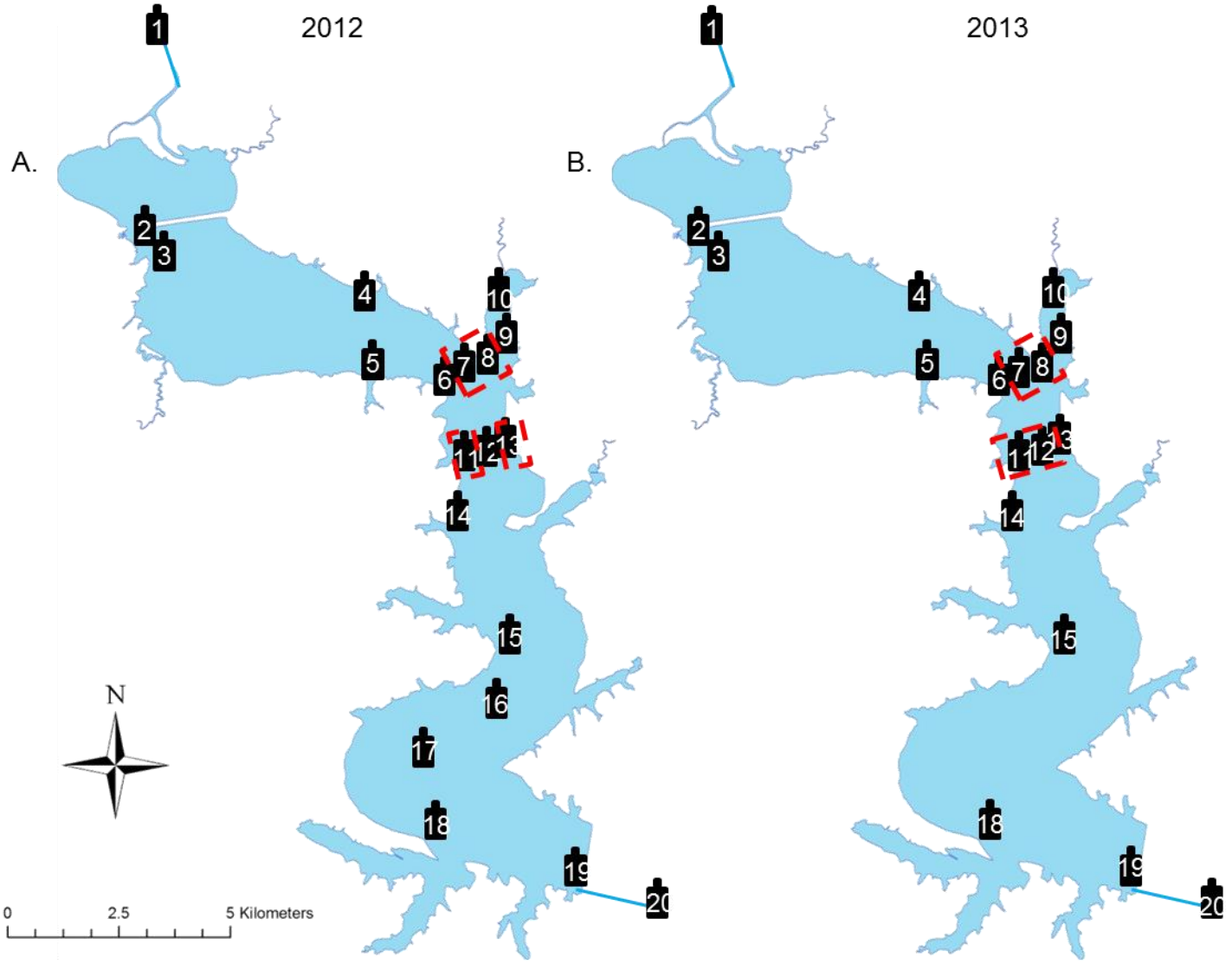


Figure 2.3. Distribution of 20 stationary acoustic receivers within Milford Reservoir, KS, is shown for (A) 2012 and (B) 2013. (A) Receivers 7, 8, 11, and 13 were removed for data analysis in 2012 to eliminate overlap and provide a more even distribution (dashed boxes indicate the location of the receivers that were removed). (B) Receivers 7, 8, 11, and 12 were removed for data analysis in 2013 for the same reason (dashed boxes indicate the location of the receivers that were removed). As a result in 2012 and 2013, we used 14 and 12 receivers for data analysis respectively.

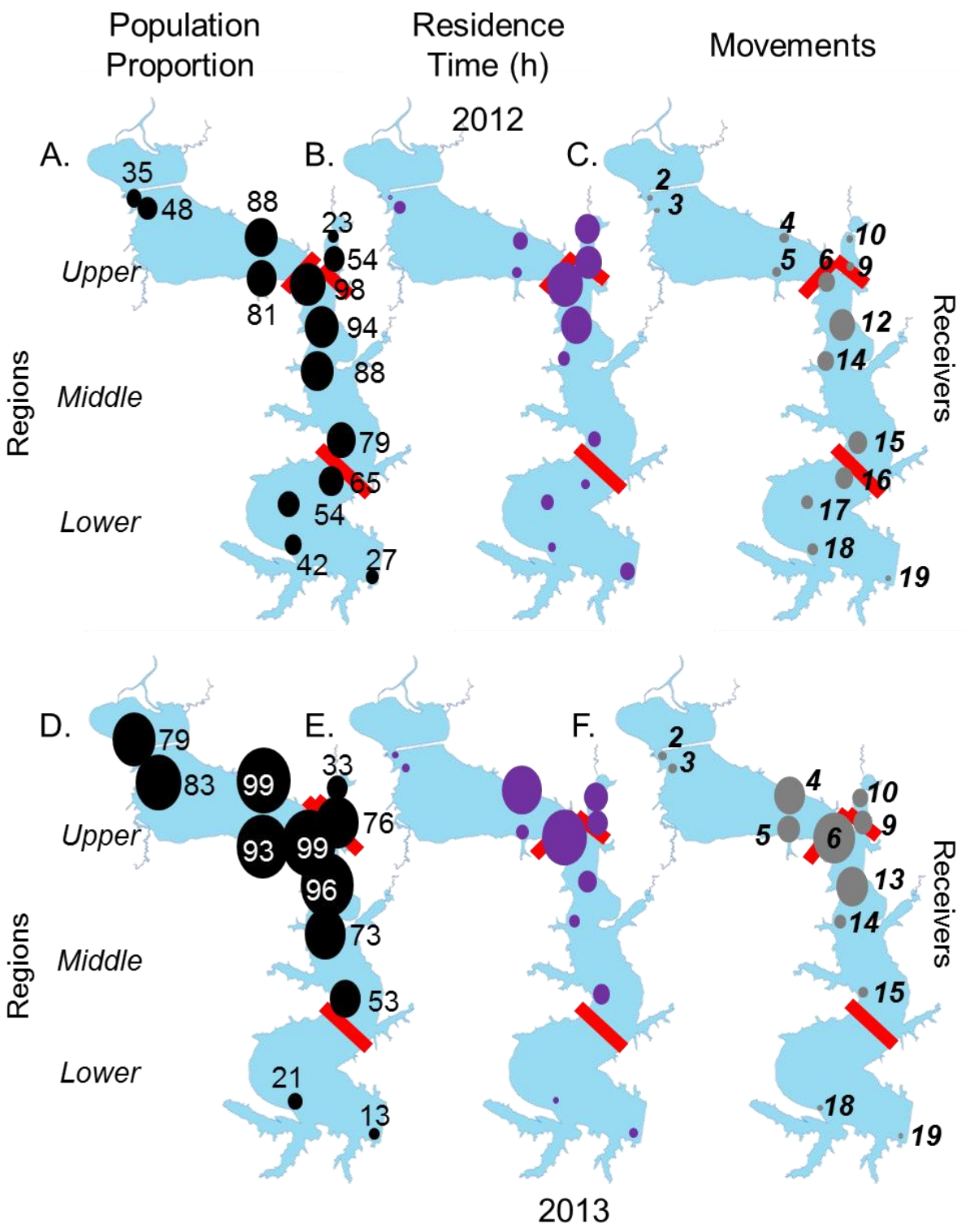


Figure 2.4. The spatial distribution of population proportion, residence time (h), and movements in Milford Reservoir, KS for 2012 (A, B, and C) and 2013 (D, E, and F) is shown for 48 and 75 tagged Blue Catfish at 14 and 12 receivers, respectively. The black dots represent population proportion and the size of the dot is proportional to the total

number of fish detected. The purple dots represent residence time and the size of the dot is proportional to the average amount of time all fish spent at a location. The gray dots represent movement and the size of the dot is proportional to the average number of movements all fish made at a location. Regions are indicated on the left. Receiver numbers are shown in bold italics in C, F and are relevant to all panels.

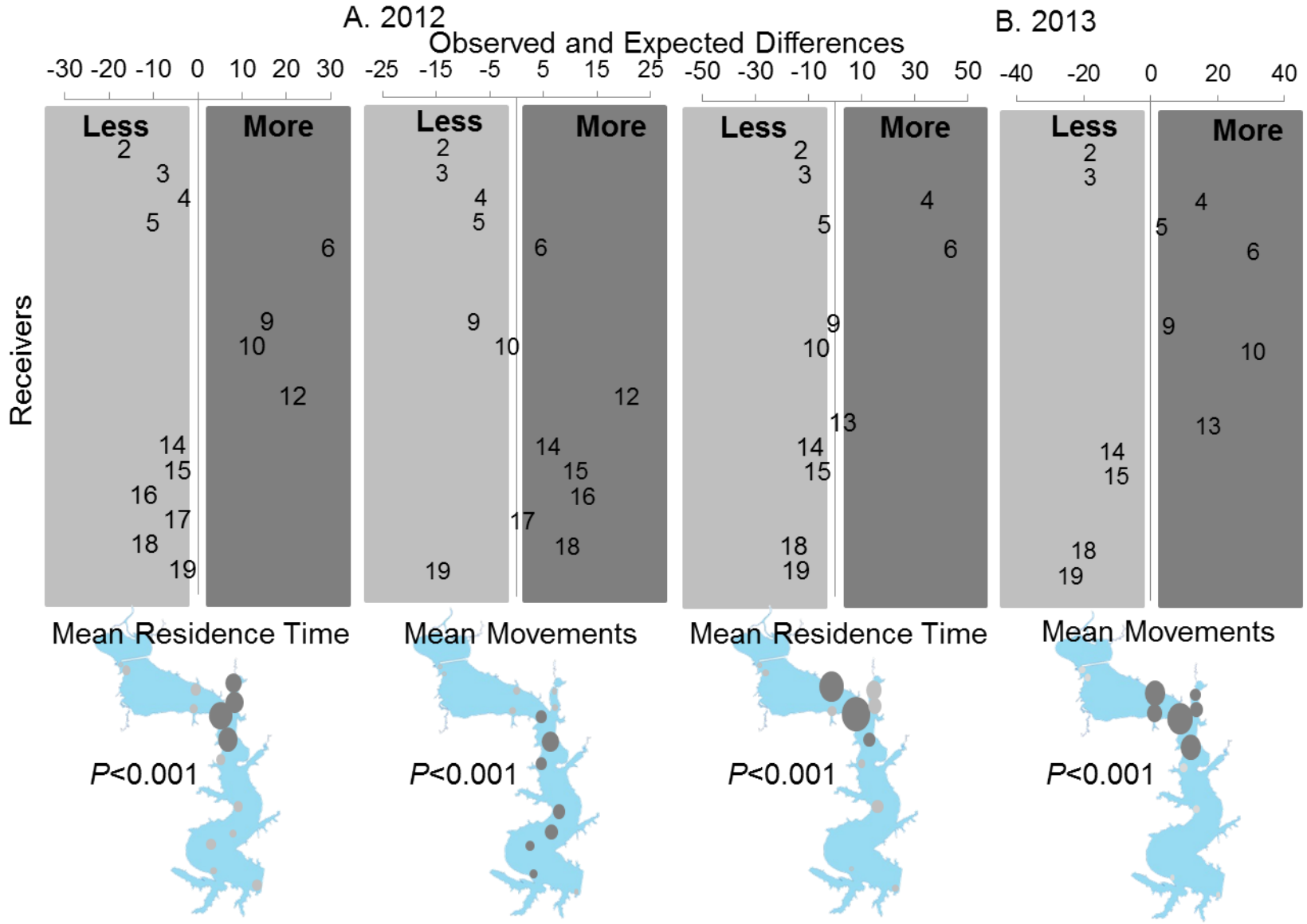


Figure 2.5. Results of a Chi-square analysis that identified at which receivers fish spent more time than expected and receivers at which fish spent less time than expected in 2012 (A) and 2013 (B) in Milford Reservoir, KS. Expected for residence time is based on an even distribution (i.e., same amount of time at all receiver locations). Also shown are results that identify at which receivers fish moved more than expected and at which receiver fish moved less than expected in 2012 (A) and 2013 (B) based

on an even distribution (i.e., same amount of movements at all receiver locations). On the maps dark gray dots indicated locations of more time/movements than expected and light gray dots represent locations of less time/movements than expected.

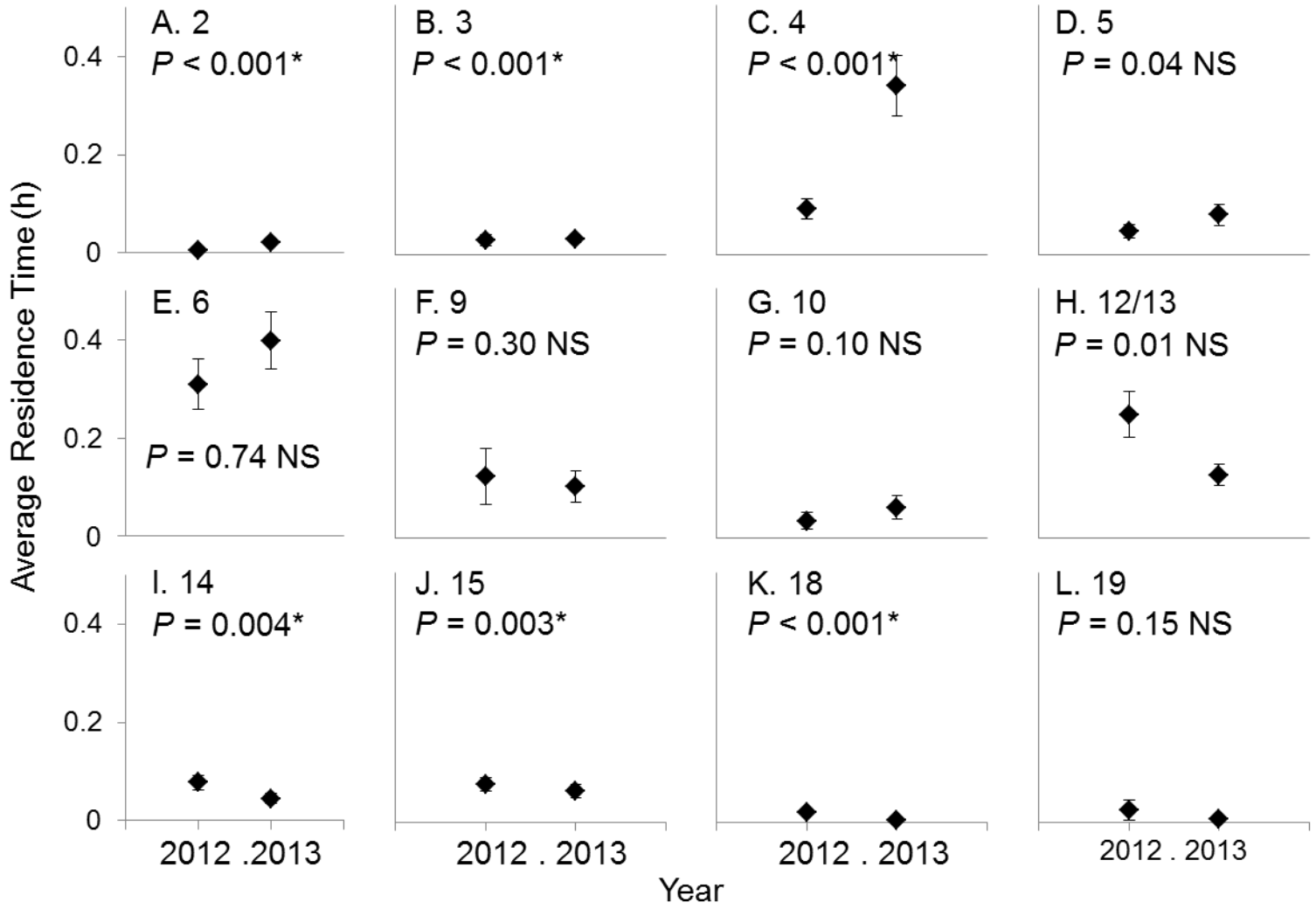


Figure 2.6. Comparison of average residence time (h) across two years (2012 and 2013) at all receiver locations in Milford Reservoir, KS. On the X-axis is the two years and on the Y-axis is average residence time (h). Only receivers present in both years were compared. Also shown are the results of a Kruskal-Wallis nonparametric ANOVA that tested the effect of year. Bonferroni corrected critical alpha *P*<0.004 (0.05/12) was used to determine significance.

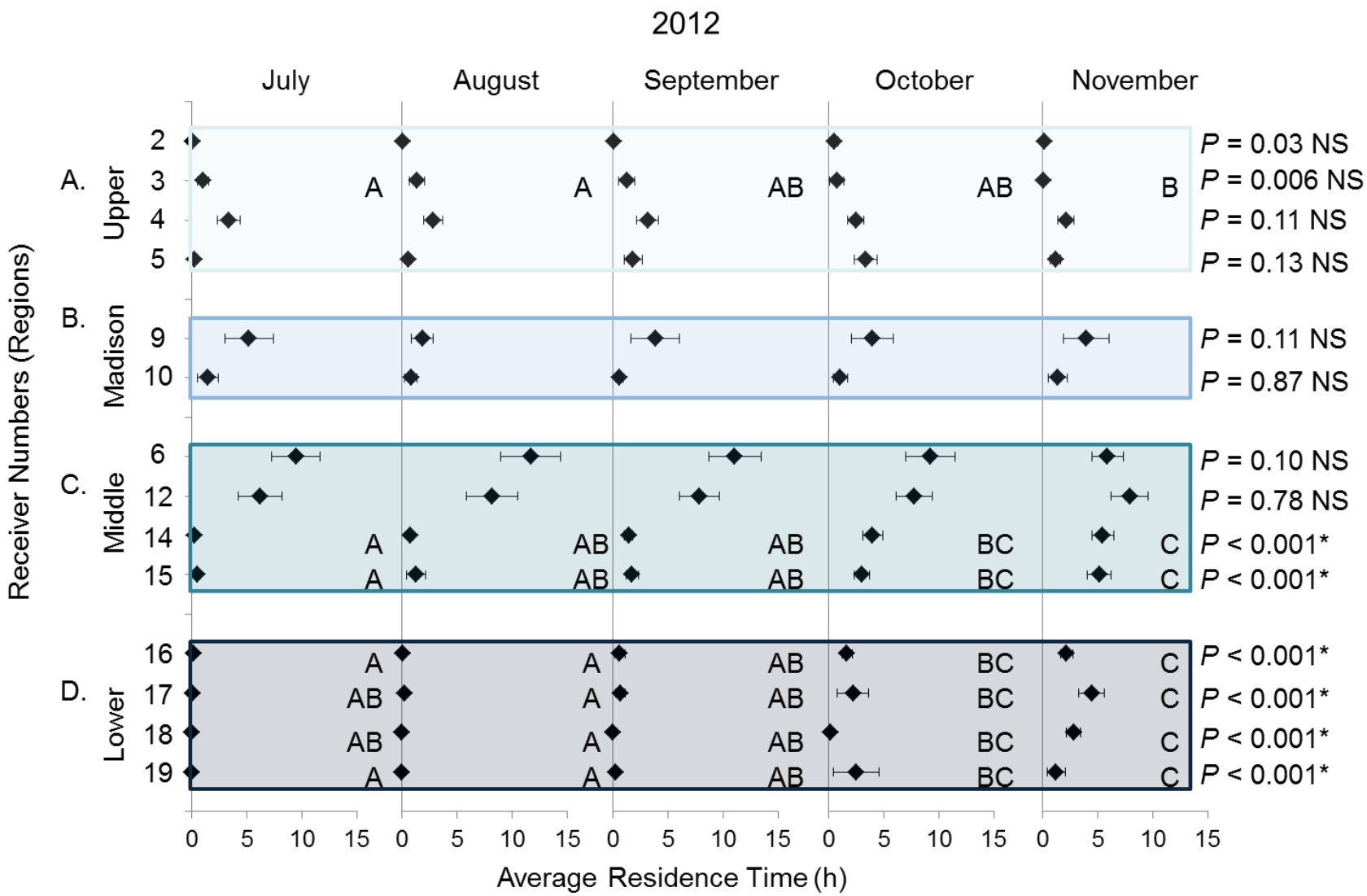


Figure 2.7. Average and SE plots depicting monthly changes in average residence time (h) in Milford Reservoir, KS in 2012. The X-axis is average residence time (h) for each month and the Y-axis is receiver. Y-axes are standardized to compare across months. The boxes across the graphs indicate the regions of the reservoir: (A) Upper, (B) Madison, (C) Middle, and (D) Lower. Also shown are the results of a Kruskal-Wallis nonparametric ANOVA and a post-hoc Mann Whitney U multiple comparisons with a Bonferroni correction that tested the effect of month. Bonferroni corrected critical alpha *P*<0.004 (0.05/14) was used to determine significance.

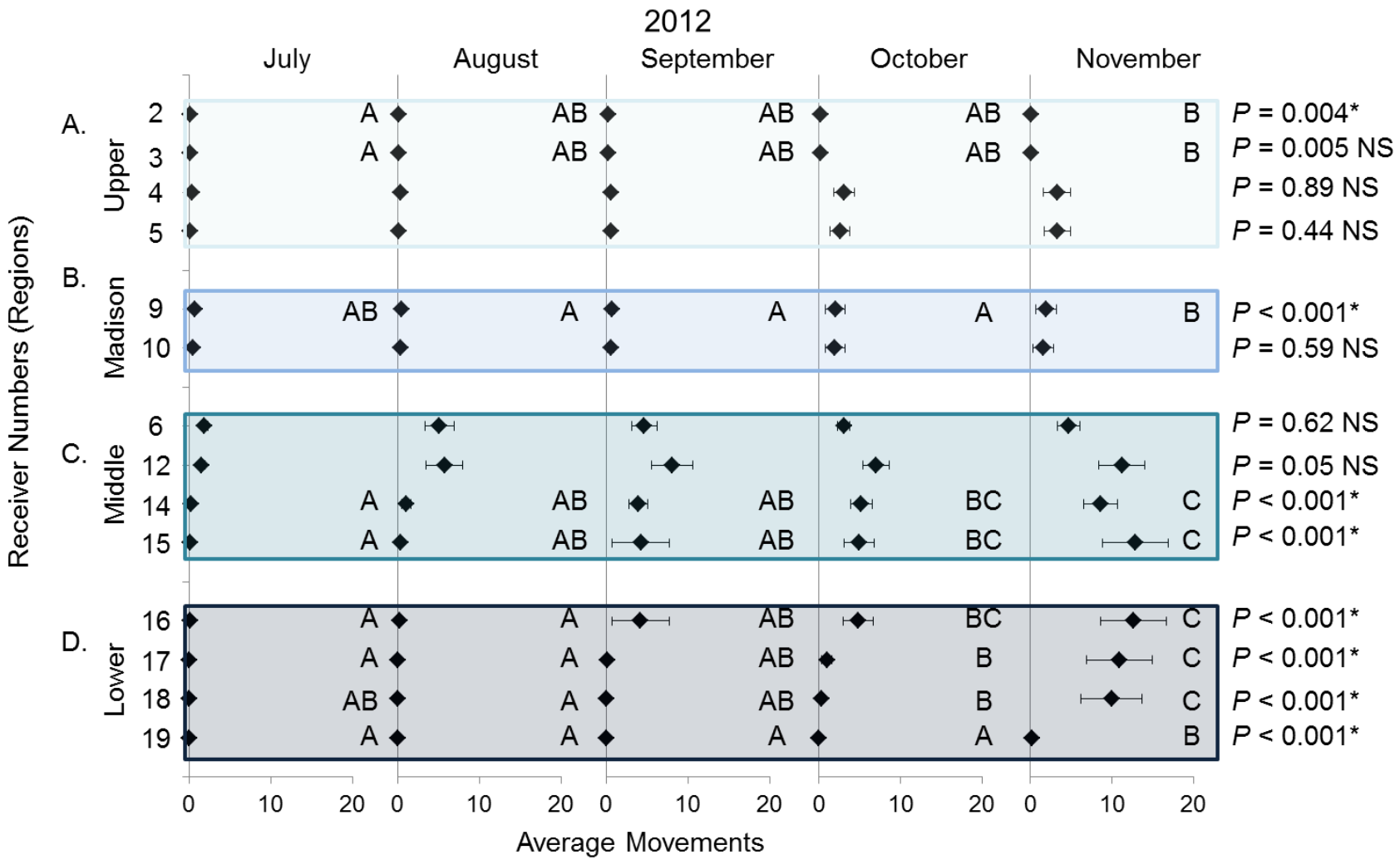


Figure 2.8. Average and SE plots depicting monthly changes in average movements in Milford Reservoir, KS in 2012. The X-axis is average movements for each month and the Y-axis is receiver. Y-axes are standardized to compare across months. The boxes across the graphs indicate the regions of the reservoir: (A) Upper, (B) Madison, (C) Middle, and (D) Lower. Also shown are the results of a Kruskal-Wallis nonparametric ANOVA and a post-hoc Mann Whitney U multiple comparisons with a Bonferroni correction that tested the effect of month. Bonferroni corrected critical alpha *P*<0.004 (0.05/14) was used to determine significance.

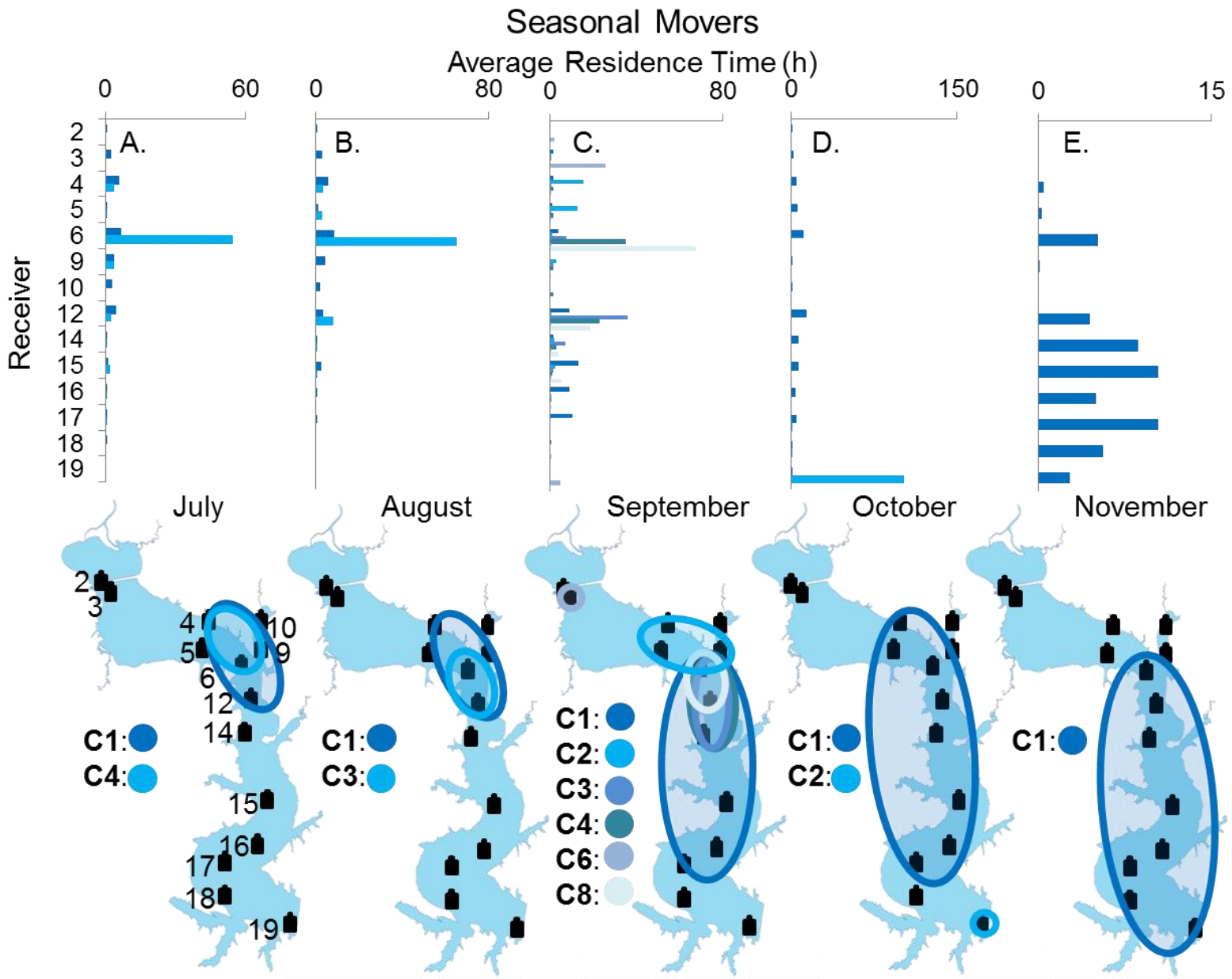


Figure 2.9. Maps and bar plots of the seasonal movers distributional pattern in Milford Reservoir, KS in 2012 from the monthly cluster analyses for (A) July, (B) August, (C) September, (D) October, and (E) November. The X-axis of the bar plots is average residence time (h) and the Y-axis is receiver number. On the maps the black squares represent the receiver

locations. The circles represent the clusters, the size and location of the circles represent where the fish were located during each month. *n* = July: 27, August: 26, September: 20, October: 24, November: 19.

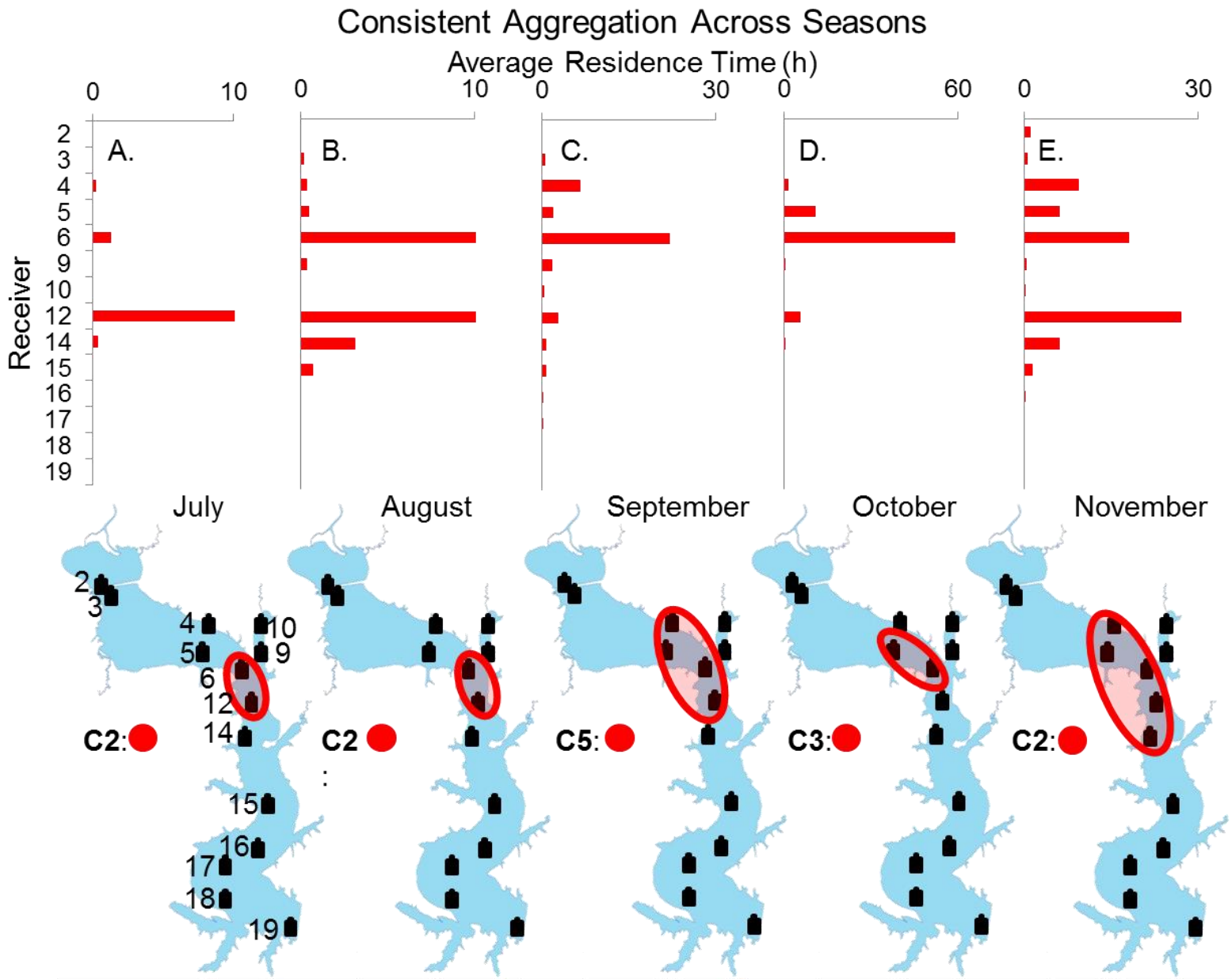


Figure 2.10. Maps and bar plots of the consistent aggregation distributional pattern in Milford Reservoir, KS, 2012 from the monthly cluster analyses for (A) July, (B) August, (C) September, (D) October, and (E) November. The X-axis of the bar plots is average residence time (h) and the Y-axis is receiver number. On the maps the black squares represent the receiver

locations. The circles represent the clusters, the size and location of the circles represent where the fish were located during each month. *n* = July: 2, August: 5, September: 9, October: 3, November: 8.

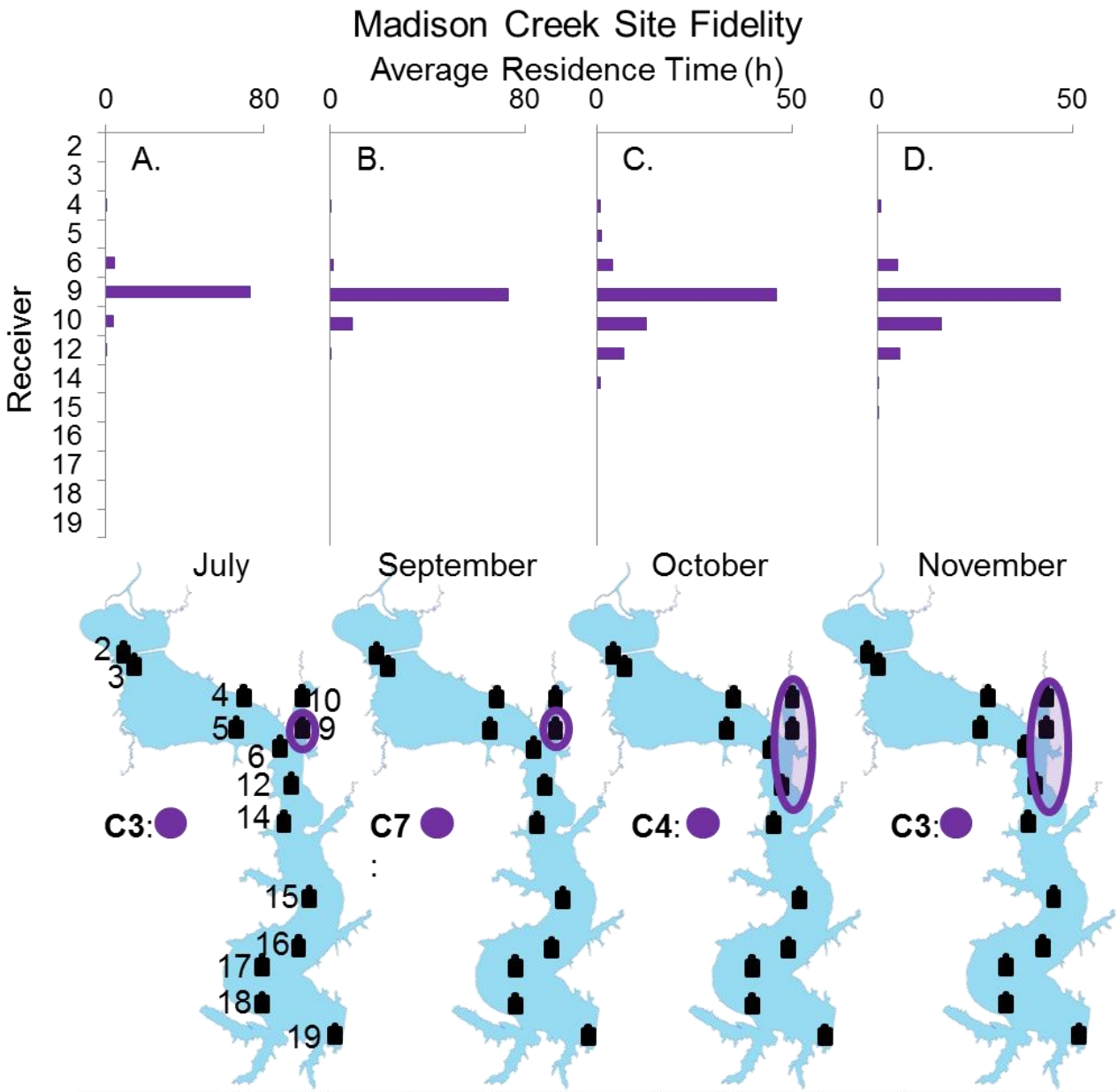


Figure 2.11. Maps and bar plots of the Madison Creek site fidelity distributional pattern in Milford Reservoir, KS, 2012 from the monthly cluster analyses (A) July, (B) August, (C) September, (D) October, and (E) November. The X-axis of the bar plots is average residence time (h) and the Y-axis is receiver number. On the maps the black squares represent the receiver

locations. The circles represent the clusters, the size and location of the circles represent where the fish were located during each month. *n* = July: 2, August: 0, September: 2, October: 4, November: 4.

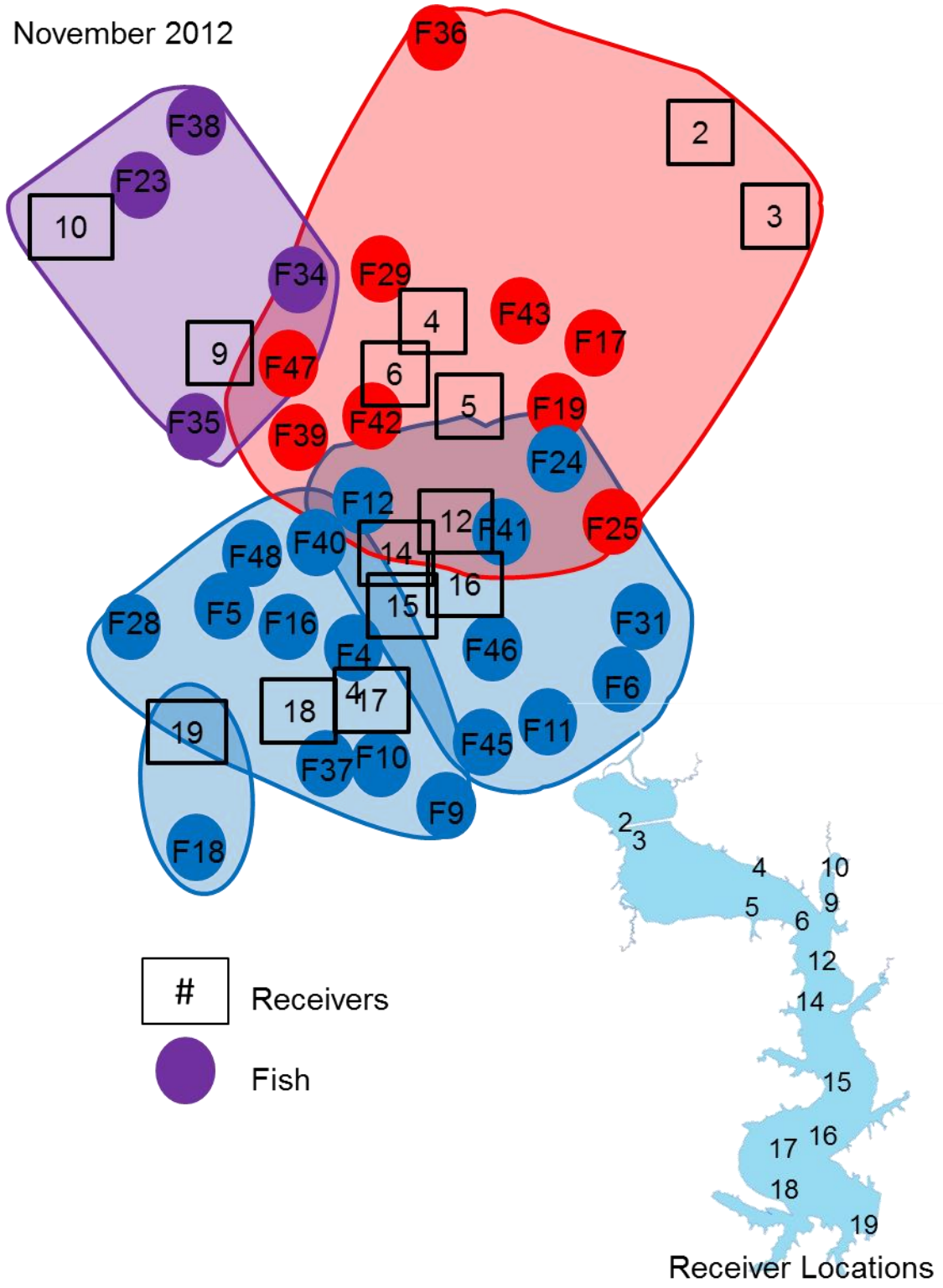


Figure 2.12. Network analysis of the residence time (h) for the month of November in Milford Reservoir, KS, 2012. The small colored circles represent individual fish and the squares represent the receivers. The large colored shapes represent the groups of fish and the three colors coordinate with the colors from the three cluster simplifications.

Appendix A - Fish Sizes Tagged

What sizes of fish were tagged and why?

In both 2012 and 2013, I targeted Blue Catfish that were similar to the most abundant size class of Blue Catfish in Milford Reservoir, based on 2012 KDWPT field survey conducted before fish tagging (Fig. A.1). In 2012, the average fish size tagged was 487 mm TL (range 383-1020, SE 14.5, *n*=48; Table A.1). In 2013, we added a limited number of smaller and larger fish to the study (Table A.2) resulting in an average size of tagged Blue Catfish in 2013 of 517 mm TL (range 343-1090, SE 17.8, *n*=75). The sizes tagged depended on fish size distribution in Milford Reservoir (i.e., what sizes were available) and what sizes KDWPT biologists were able to capture for tagging.

Table A.1. Length (mm), weight (kg), and release location for Blue Catfish tagged in Milford Reservoir, KS in 2012.

Fish	Length (mm)	Weight (kg)	Release Location
1	430	0.66	School
2	480	0.88	School
3	430	0.56	School
4	480	0.82	School
5	430	0.72	School
6	500	1.05	School
7	489	0.97	School
8	434	0.64	School
9	512	1.26	School
10	384	0.41	School
11	411	0.73	School
12	452	0.77	School
13	490	1.12	School
14	510	1.09	School
15	420	0.66	Causeway
16	506	0.99	School
17	490	1.15	School
18	751	4.4	School
19	392	0.51	Causeway
20	383	0.43	Causeway
21	518	1.27	Causeway
22	484	1.1	Causeway
23	615	2.5	Madison
24	419	0.58	Causeway
25	516	1.08	Causeway
26	451	0.81	Causeway
27	471	1.01	Causeway
28	408	0.52	Causeway
29	419	0.63	Causeway

Fish	Length (mm)	Weight (kg)	Release Location
30	407	0.68	Madison
31	485	0.96	Madison
32	401	0.54	Madison
33	515	1.2	Madison
34	466	0.81	Madison
35	542	1.33	Madison
36	1020	9.52	Madison
37	487	0.88	Madison
38	489	2.01	Madison
39	439	0.67	Causeway
40	487	1	Causeway
41	531	1.41	Causeway
42	436	0.68	Causeway
43	573	1.8	Causeway
44	504	1	Madison
45	480	1.21	Madison
46	421	0.6	Madison
47	532	1.33	Madison
48	469	1.01	Madison

Table A.2. Length (mm), weight (kg), and release location for Blue Catfish tagged in Milford Reservoir, KS in 2013.

Fish	Length (mm)	Weight (kg)	Release Location
1	370	0.44	Madison
2	377	0.64	Madison
3	372	0.36	School
4	392	0.57	Madison
5	396	0.47	Madison
6	361	0.35	Madison
7	369	0.35	Causeway
8	343	0.22	Causeway
9	393	0.41	School
10	375	0.43	School
11	369	0.33	Causeway
12	515	1.13	Madison
13	506	1.12	Madison
14	550	1.71	Madison
15	531	1.2	Madison
16	445	0.77	Madison
17	511	1.02	Madison
18	1030	17.9	School
19	451	0.74	School
20	591	1.91	School
21	403	0.53	School
22	505	1.04	Madison
23	470	0.98	Madison
24	425	0.94	Madison
25	820	6.59	Madison
26	413	0.6	Madison
27	440	0.74	Madison
28	405	0.54	Madison
29	472	0.85	Madison

Fish	Length (mm)	Weight (kg)	Release Location
30	446	0.66	Madison
31	443	0.68	Madison
32	438	0.68	School
33	449	0.77	School
34	519	1.44	Causeway
35	513	1.09	School
36	455	0.71	School
37	430	0.56	School
38	490	1.2	School
39	415	0.51	School
40	530	1.35	School
41	450	0.87	School
42	735	4.77	School
43	765	5.9	Causeway
44	514	1.3	Causeway
45	845	8.6	Causeway
46	526	1.36	Causeway
47	705	4.54	Causeway
48	421	0.61	Causeway
49	421	0.63	Causeway
50	460	0.72	Causeway
51	440	0.82	Causeway
52	513	1.26	Causeway
53	423	0.67	Causeway
54	508	1.14	Causeway
55	521	1.22	Causeway
56	1090	20.4	Causeway
57	429	0.72	Causeway
58	900	9.54	Causeway
59	400	0.53	Causeway
60	513	1.27	Causeway
61	1000	15.4	Causeway
62	510	1.56	Madison
63	555	1.86	Madison
64	505	1.36	Madison
65	540	1.08	School

Fish	Length (mm)	Weight (kg)	Release Location
66	530	1.15	School
67	489	1.12	Madison
68	495	0.96	Madison
69	467	0.71	School
70	466	0.79	School
71	625	2.47	Causeway
72	730	5.68	Causeway
73	537	1.43	Causeway
74	510	1.13	School
75	528	1.26	Causeway

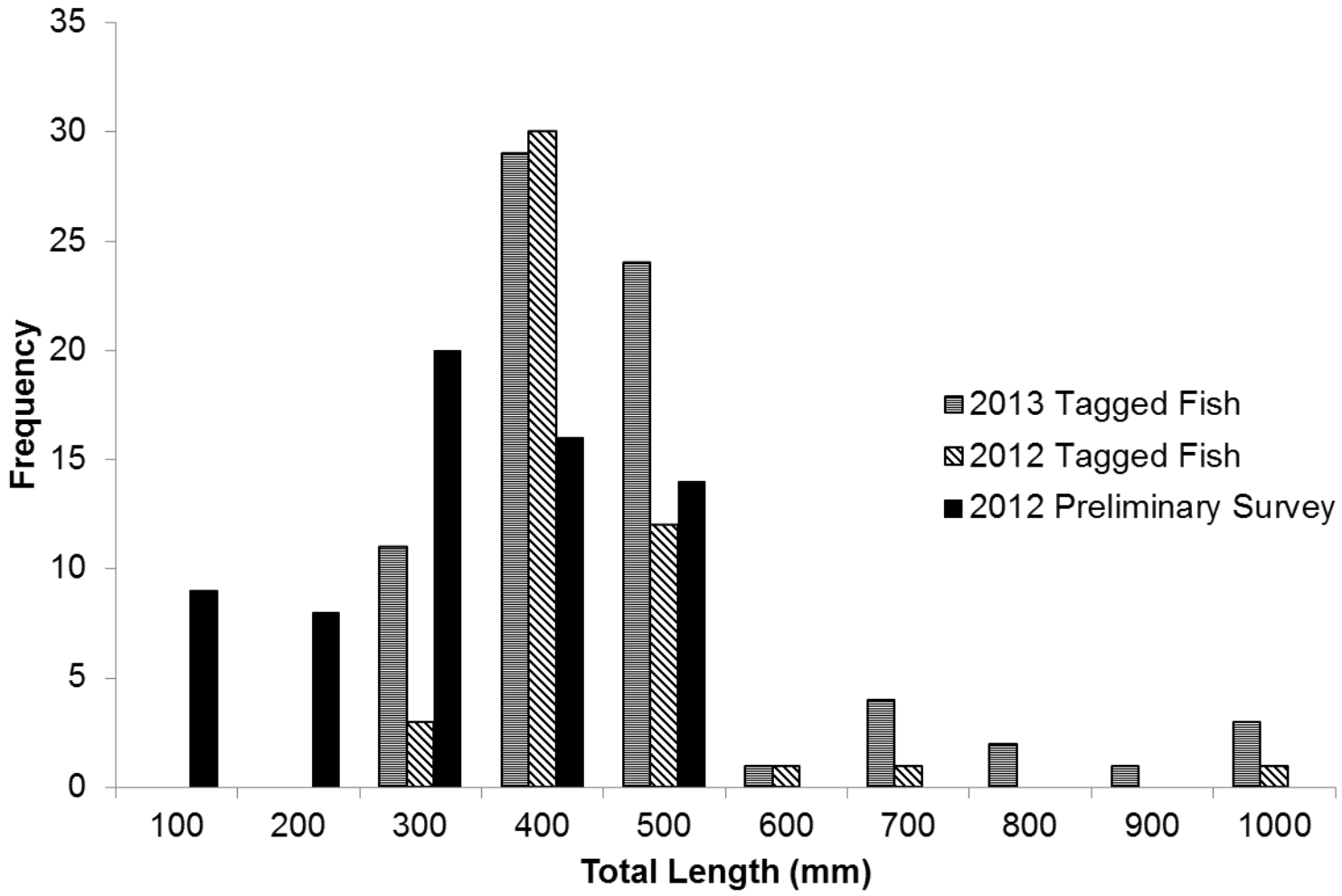


Figure A.1. Length-frequency distribution of the 2012 KDWPT survey (black bars), 2012 tagged fish (hashed bars), and 2013 tagged fish (gray bars) in Milford Reservoir, KS. On the X-axis is fish length (mm) and the Y-axis is frequency. Sizes of fish tagged depended on underlying fish distribution and the sizes of fish that KDWPT biologists were able to capture for tagging.

Appendix B - Receiver Array Design and Range Test

How do you set up an array and what are the ranges of the receivers?

Even if fish retain their tags, they may not be detected by receivers, so thoughtful design and evaluation (e.g., array setup and range tests) are also essential to an effective tracking study. Array design is based off of the study objectives which will define the layout (Heupel et al. 2006). Gate systems and regular/irregular grid systems are popular in array designs (Heupel et al. 2006). Gates are often used to detect directed animal movements such as migrations (Huuskonen et al. 2012; Renfelds et al. 2013; Chapman et al. 2015) and grid systems are used to determine animal distribution within a defined area (Farrugia et al. 2011; Alos and Cabanellas-Reboredo 2012; Currey et al. 2014). Detection ranges of receiver arrays are important for understanding whether the data collected represents an accurate estimate of a fish's space use (Klimley et al. 1998; Welsh et al. 2012). Detection ranges are often just assumed based on manufacturer specifications (Welsh et al. 2012; Kessel et al. 2014); when tested by researchers they can deviate within different aquatic habitats (Heupel et al. 2006) and across temporal and spatial scales (Simpfendorfer et al. 2008; Payne et al. 2010).

Receiver Array Design

In 2012, I deployed receivers in June (Table B.1); receivers were located at 18 locations within the reservoir and two locations adjacent to the reservoir exits (Fig. B.1A). The upper river receiver (receiver 1) and the upper within-reservoir receiver (receiver 2) formed a two-tier gate to detect upriver egress from the reservoir. The southernmost receiver in the reservoir (receiver 19) and the receiver below the dam (receiver 20) formed another two tier gate to detect downriver egress. I also had two 3-stationary receiver gate arrays (receivers 6-8, 11-13) across the middle of the reservoir (i.e., the limited width allowed complete coverage of the entire

section as confirmed by range tests) to detect any fish that moved through the middle region of the reservoir. In 2012, for data analysis, I removed data from 2 of the 3 receivers in these gates (receivers 7, 8, 11, and 13) to obtain a more even distribution of receivers (Fig. B.1A - dashed squares indicate receivers that were removed). Thus, in 2012, of the 18 within reservoir receivers, 14 were used for data analysis.

In 2013, I deployed receivers similarly (May-November 2013; Table C.1). However, receiver 1 was vandalized in August, 2013. Receivers 16 & 17 were lost due to vandalism or boating conflicts. Gate receiver 13 replaced gate receiver 12 because receiver 12 was lost. When both receiver 12 and 13 were present (June and July), in 2013, detections were similar (June: receiver 12: 24,354 & receiver 13: 24,010; July: receiver 12: 36,861 & receiver 13: 36,890) and the number of fish detected was similar (June: receiver 12: 63 & receiver 13: 67; July: receiver 12: 50 & receiver 13: 52) across the two receivers demonstrating that exchanging these receivers did not affect the results. In 2013, I also removed data from 2 of the 3 gate receivers (receivers 7,8, 11, and 12) (Fig. B.1B - dashed squares indicate receivers that were removed). Thus, in 2013, of the 18 within reservoir receivers, 12 were used for data analysis.

Range Test

I conducted range tests using two methods. Both tests provided information on the distance at which a tag can be detected under field conditions. First, I conducted a range test using the methods provided by the receiver manufacturer, VEMCO. For this, I deployed an array of receivers in an 800 m straight line, separated by 100 m intervals. Two test tags (V9-2H: 69kHz, 30 sec.; V13-1H: 69kHz, 30 sec.) were located at the first receiver (0 m). Receivers at 100-800 m were constantly exposed to the repetitive pinging of these tags over a week. Adequate

data were collected at each receiver to get a probability of detection at 100 m intervals. These range test data were processed using VEMCO software.

I also conducted a second set of range tests at three receiver locations within Milford Reservoir. These three receiver sites were chosen because they have similar bathymetry (e.g., water depth), so I could get an estimate of range variation associated with individual sites. For this range test, I drove a boat in four cardinal directions (N, S, E, W) from a centrally-deployed receiver for up to 1,000 m (or until we encountered the shore). At 100 m intervals, I submerged the test tags in the water for a count of five detection pings, determined using a manual tracker. From this design, I could determine distances that a tag was detected in four different directions. Data for the second range test was processed using Excel.

Range Test Results

Both V9 and V13 tags were detected over 80% of the time at distances from 0-300 m (Fig. B.2). Percent detections decreased to about 75% between 300-500 m. Detections declined to 70% at 600 m from the tag (Fig. B.2). VEMCO recommends selecting a receiver range that corresponds to at least 70% of the detections, so I used 600 m as a radius from this range test.

In the second range test, individual detection radii varied from 300-650 m (average 462.5 m) for receiver 4 (Fig. B.3A). Individual detection radii varied from 500-1,000 m (average 775 m) for receiver 7 (Fig. B.3B). Individual detection radii varied from 700-900 m (average 825 m) for receiver 12 (Fig. B.3C). Overall, the average range radius in this second range test (average 687 m) was similar to the range found in the VEMCO recommended range test (average 600 m). Underwater receivers never detect all tag detections because of the physics affecting the signal as it moves through the ambient medium. Complex bathymetry and other sources of interference also affect detections. This is why tags are rarely detected 100% of the time and why the tag

manufacturer states that a 70% or above detection rate is acceptable. These processes are mathematically very complex and usually not considered by biologists. However, because every tag is not detected during every 120 second emission cycle, responsible researchers rarely use a single fish detection in an analysis (i.e., when residence times were calculated for the Blue Catfish a fish had to be detected at least two times for a residence time to be counted). Because the tags I used emit a full tag sequence every 60-120 seconds, tagged Blue Catfish would need to swim 1.2 km (two times the detection radius) in less than 1-2 minutes to not be detected. Lack of detections and signal strength were not used in analyses because these trends can be affected by many factors.

Summary

Receiver array setup and range tests are also essential to an effective tagging evaluation and research study. My receiver array detected fish throughout the lake. Detection ranges of receiver arrays are important for understanding whether the data collected represents an accurate estimate of a fish's space use (Klimley et al. 1998; Welsh et al. 2012). Detection ranges are often just assumed based on manufacturer specifications (Welsh et al. 2012; Kessel et al. 2014); when tested by researchers they can deviate within different aquatic habitats (Heupel et al. 2006) and across temporal and spatial scales (Simpfendorfer et al. 2008; Payne et al. 2010). Our two range evaluation methods provided similar range estimates which enhanced our confidence in the range at which our tags could be detected. My stationary array was designed to detect lake-wide patterns by covering the whole extent of Milford Reservoir from the causeway to the dam. One of the deficiencies of the array was that small-scale movements were not detected because of the large detection diameter of the receivers (1,200 m) and the wide spacing between receivers.

The impetus for my field study was to understand broad-scale distributional patterns throughout an entire reservoir. Receiver sites were designed to identify lake-wide aggregations, not heterogeneity or frequent distribution changes within localized areas. When my field study was initiated, little information existed about Blue Catfish distribution in Milford Reservoir. Hence, an extensive sampling design with many samples across the reservoir was required. Given the state of the knowledge when I initiated this study, I simply would not have known where to place receivers to detect Blue Catfish. Conducting an extensive and intensive design simultaneously is logistically unfeasible. Thus, the design I describe here (broad spatial scale, low resolution) was well suited for our question and likely would be useful for initial studies in other systems.

References

Alos, J. and M. Cabanellas-Reboredo. 2012. Experimental acoustic telemetry experiment reveals strong site fidelity during the sexual resting period of wild Brown Meagre, Sciaena umbra. Journal of Applied Ichthyology 28(4): 606-611.

Chapman, E. D., A.R. Hearn, G.P. Singer, W.N. Brostoff, P.E. LaCivita, and A.P. Klimley. 2015. Movements of Steelhead (*Oncorhynchus mykiss*) smolts migrating through the San Francisco Bay Estuary. Environmental Biology of Fishes 98(4): 1069-1080.

Currey, L. M., M.R. Heupel, C.A. Simpfendorfer, and A.J. Williams. 2014. Sedentary or mobile? Variability in space and depth use of an exploited coral reef fish. Marine Biology 161(9): 2155-2166.

Farrugia, T. J., M. Espinoza, and C.G. Lowe. 2011. Abundance, habitat use and movement patterns of the Shovelnose Guitarfish (*Rhinobatos productus*) in a restored southern California estuary. Marine and Freshwater Research 62(6): 648-657.

Heupel, M. R., J.M. Semmens, and A.J. Hobday. 2006. Automated acoustic tracking of aquatic animals: scales, design and deployment of listening station arrays. Marine and Freshwater Research 57(1): 1-13.

Huuskonen, H., H. Haakana, A. Laskela, and J. Piironen. 2012. Seasonal movements and habitat use of River Whitefish (*Coregonus lavaretus*) in the Koitajoki River (Finland), as determined by Carlin tagging and acoustic telemetry. Aquatic Ecology 46(3): 325-334.

Kessel, S. T., S.J. Cooke, M.R. Heupel, N.E. Hussey, C.A. Simpfendorfer, S. Vagle, and A.T. Fisk. 2014. A review of detection range testing in aquatic passive acoustic telemetry studies. Reviews in Fish Biology and Fisheries 24(1): 199-218.

Klimley, A. P., F. Voegeli, S.C. Beavers, and B.J. Le Boeuf. 1998. Automated listening stations for tagged marine fishes. Marine Technology Society Journal 32(1): 94-101.

Payne, N. L., B.M. Gillanders, D.M. Webber, and J.M. Semmens. 2010. Interpreting diel activity patterns from acoustic telemetry: the need for controls. Marine Ecology Progress Series 419: 295-301.

Reinfelds, I. V., C.T. Walsh, D.E. Van Der Meulen. 2013. Magnitude, frequency and duration of instream flows to stimulate and facilitate catadromous fish migrations: Australian bass (*Macquaria Novemaculeata perciformes, percichthyidae*). River Research and Applications 29(4): 512-527.

Simpfendorfer, C. A., M.R. Heupel, and A.B. Collins. 2008. Variation in the performance of acoustic receivers and its implication for positioning algorithms in a riverine setting. Canadian Journal of Fisheries and Aquatic Sciences 65(3): 482-492.

Welsh, J. Q., R.J. Fox, D.M. Webber, and D.R. Bellwood. 2012. Performance of remote acoustic receivers within a coral reef habitat: implications for array design. Coral Reefs 31(3): 693-702.

Table B.1. Summary of deployment and removal of receivers in Milford Reservoir, KS in 2012 and 2013. Included is date of receiver deployment, date of receiver removal, and for 2013 the date the receiver went missing.

Receiver	2012 Deployment	2012 Removal	2013 Deployment	2013 Removal	2013 Missing
1	June 20, 2012	Dec. 2012	May 16, 2013	NA	Aug. 2013
2	June 20, 2012	NA	May 16, 2013	June 2014	
3	June 20, 2012	Mar. 2013	May 16, 2013	NA	
4	June 20, 2012	July 2013	May 16, 2013	June 2014	
5	June 20, 2012	Mar. 2013	May 16, 2013	June 2014	
6	June 20, 2012	Mar. 2013	May 16, 2013	NA	
7	June 20, 2012	Mar. 2013	May 16, 2013	June 2014	
8	June 20, 2012	Mar. 2013	May 16, 2013	June 2014	
9	June 20, 2012	Mar. 2013	May 16, 2013	NA	
10	June 20, 2012	Mar. 2013	May 16, 2013	June 2014	
11	June 20, 2012	Jan. 2013	May 16, 2013	NA	Sep. 2013
12	June 20, 2012	Mar. 2013	May 16, 2013	NA	Aug. 2013
13	June 20, 2012	NA	May 16, 2013	NA	
14	June 20, 2012	Jan. 2013	May 16, 2013	NA	
15	June 20, 2012	Jan. 2013	May 16, 2013	NA	
16	June 20, 2012	Jan. 2013	May 16, 2013	NA	Sep. 2013
17	June 20, 2012	Jan. 2013	May 16, 2013	NA	June & Sep. 2013
18	June 20, 2012	Jan. 2013	May 16, 2013	NA	
19	June 20, 2012	Jan. 2013	May 16, 2013	NA	
20	June 20, 2012	Dec. 2012	May 16, 2013	NA	

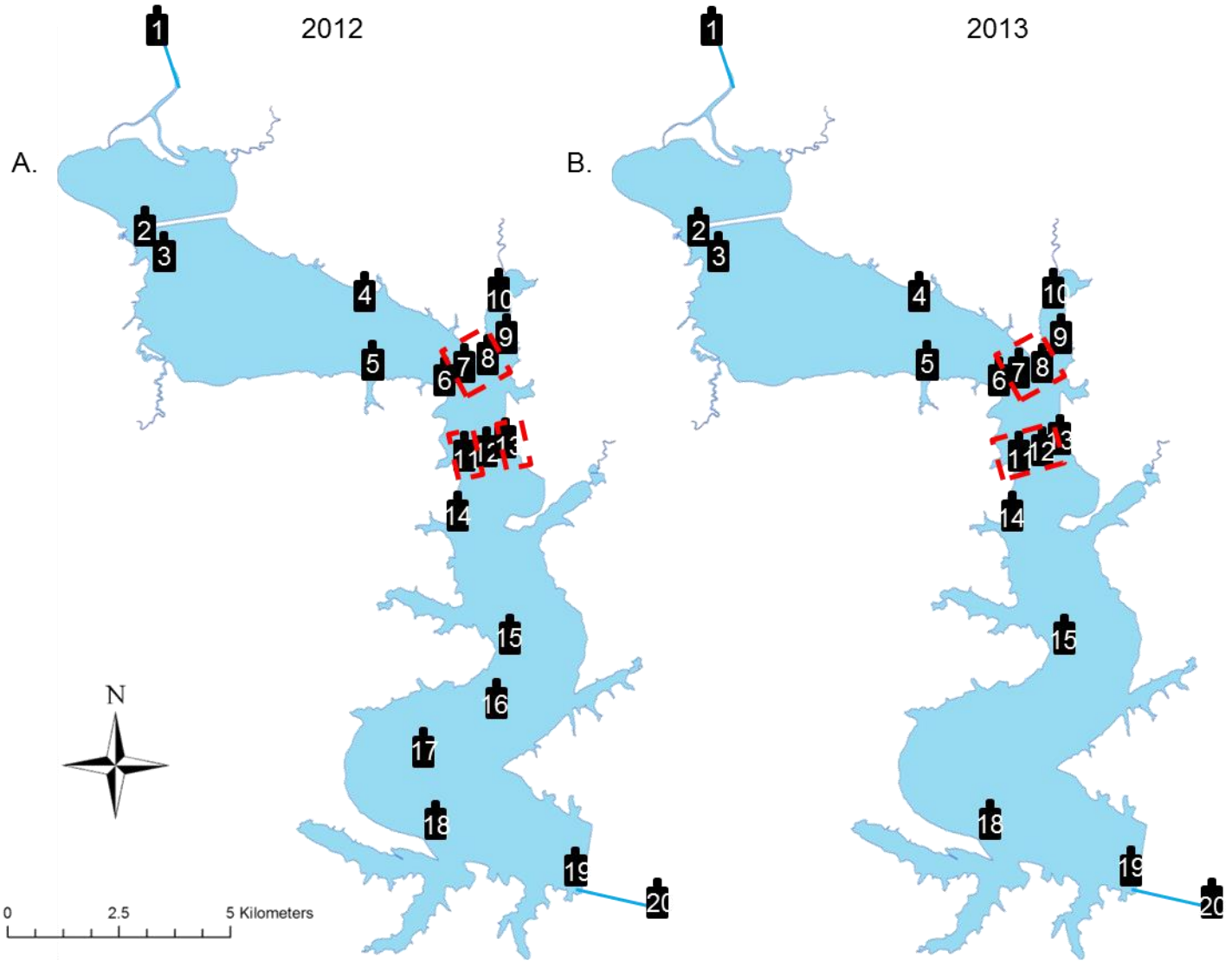


Figure B.1. Distribution of 20 stationary acoustic receivers within Milford Reservoir, KS is shown for (A) 2012 and (B) 2013. (A) Receivers 7, 8, 11, and 13 were removed for data analysis in 2012 to provide a more even distribution (dashed boxes indicate the location of the receivers that were removed). (B) Receivers 7, 8, 11, and 12 were removed for data analysis in 2013 for the same reason (dashed boxes indicate the location of the receivers that were removed). As a result in 2012 and 2013, we used 14 and 12 receivers for data analysis respectively.

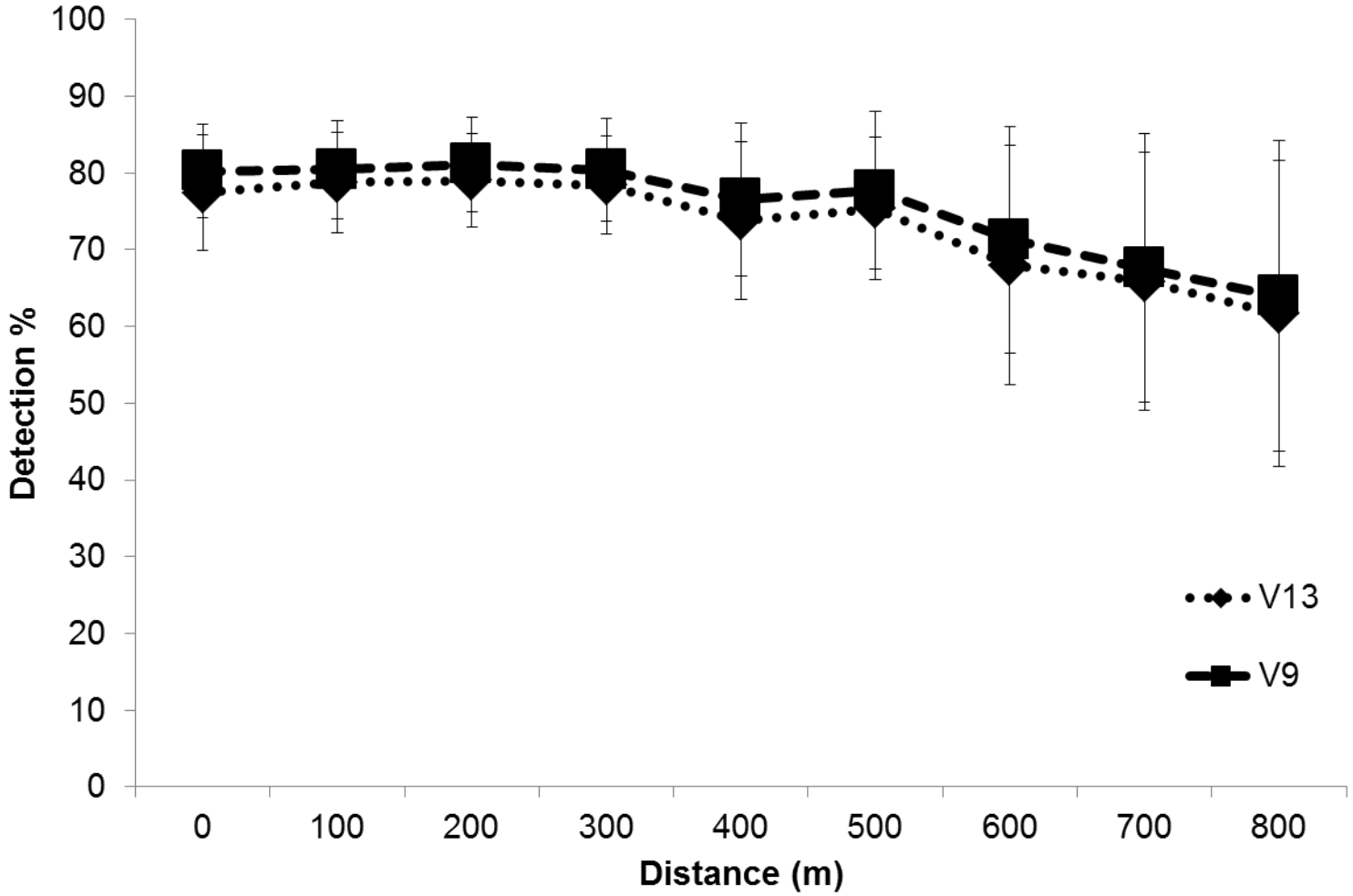
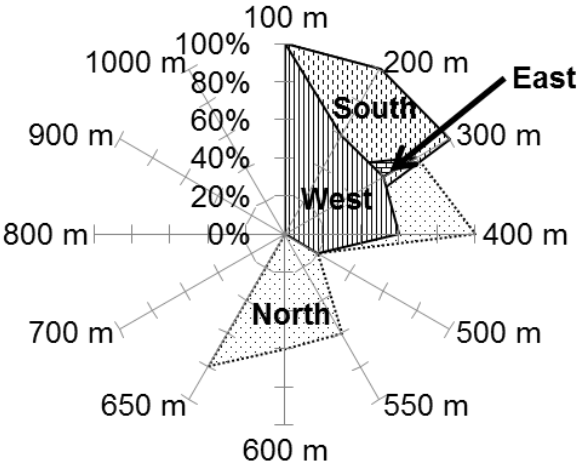
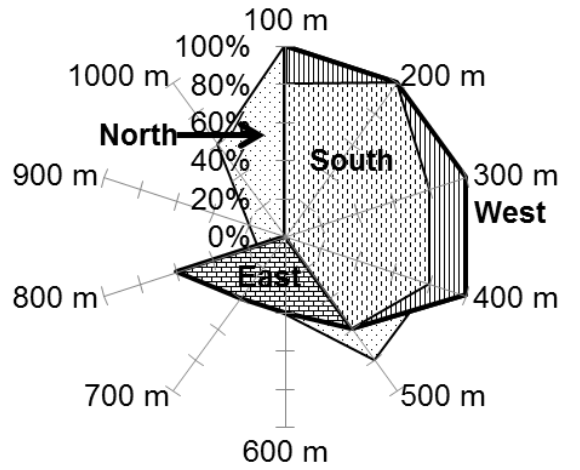


Figure B.2. Results of a VEMCO range test in Milford Reservoir, KS in 2013. The X-axis is distance from tags at 0 m and the Y-axis is detection percent. VEMCO states that 70% is the least amount of detection required for an accurate range.



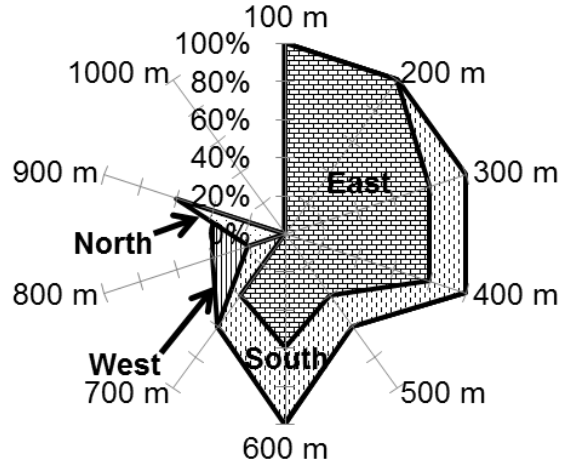
A. Receiver 4

	Range (m)
Average	462.5
Minimum	300
Maximum	650



B. Receiver 7

	Range (m)
Average	775
Minimum	500
Maximum	1000



C. Receiver 12

	Range (m)
Average	825
Minimum	700
Maximum	900

Figure B.3. Results of a range test using the four cardinal directions (N,S,E,W) in Milford Reservoir, KS in 2014. Each of the four directions are shown on the plots which represent three different locations in the reservoir (A-C). Tables summarize average, minimum, and maximum range (m).

Appendix C - All Fish Miniatures 2012 & 2013

Did fish regularly change position?

I constructed a “miniature” plot of distribution for each individual fish that summarized all daily detection events at each receiver (Y-axis) over the entire study period (X-axis). A single plot included both the first ten days and the entire study period.

Any change on Y-axis (receiver location) through time (X-axis) indicated active movement by tagged fish. A lost tag near the receiver or a dead fish near the receiver would be represented as a continuous horizontal line. All tagged fish show active movement.

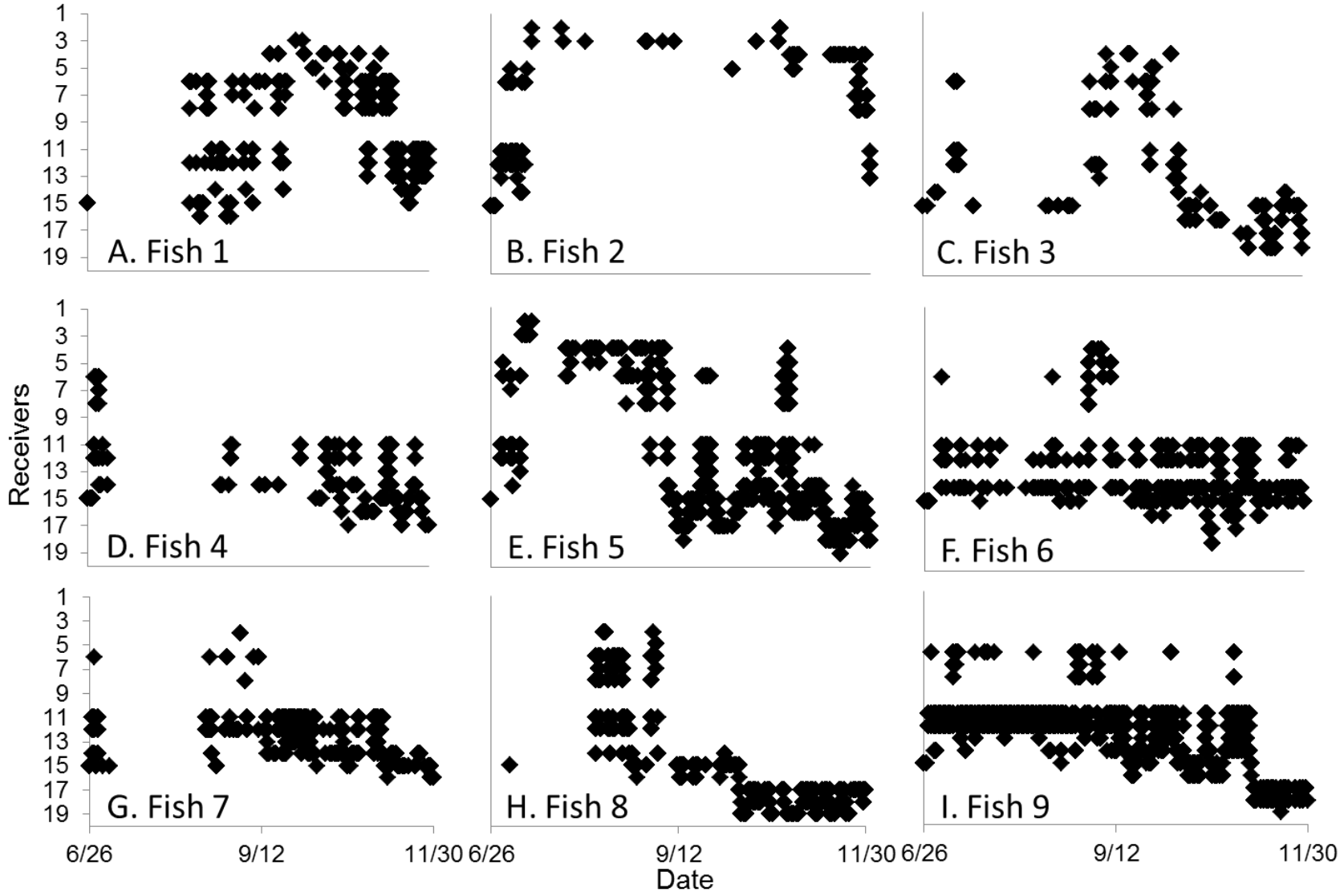


Figure C.1. All daily detections of eight Blue Catfish (A-I) in Milford Reservoir, KS in June 26 – November 30, 2012. On the X-axis is date. On the Y-axis is receivers 1-20. The dots on the plots represent detections through time from left to right.

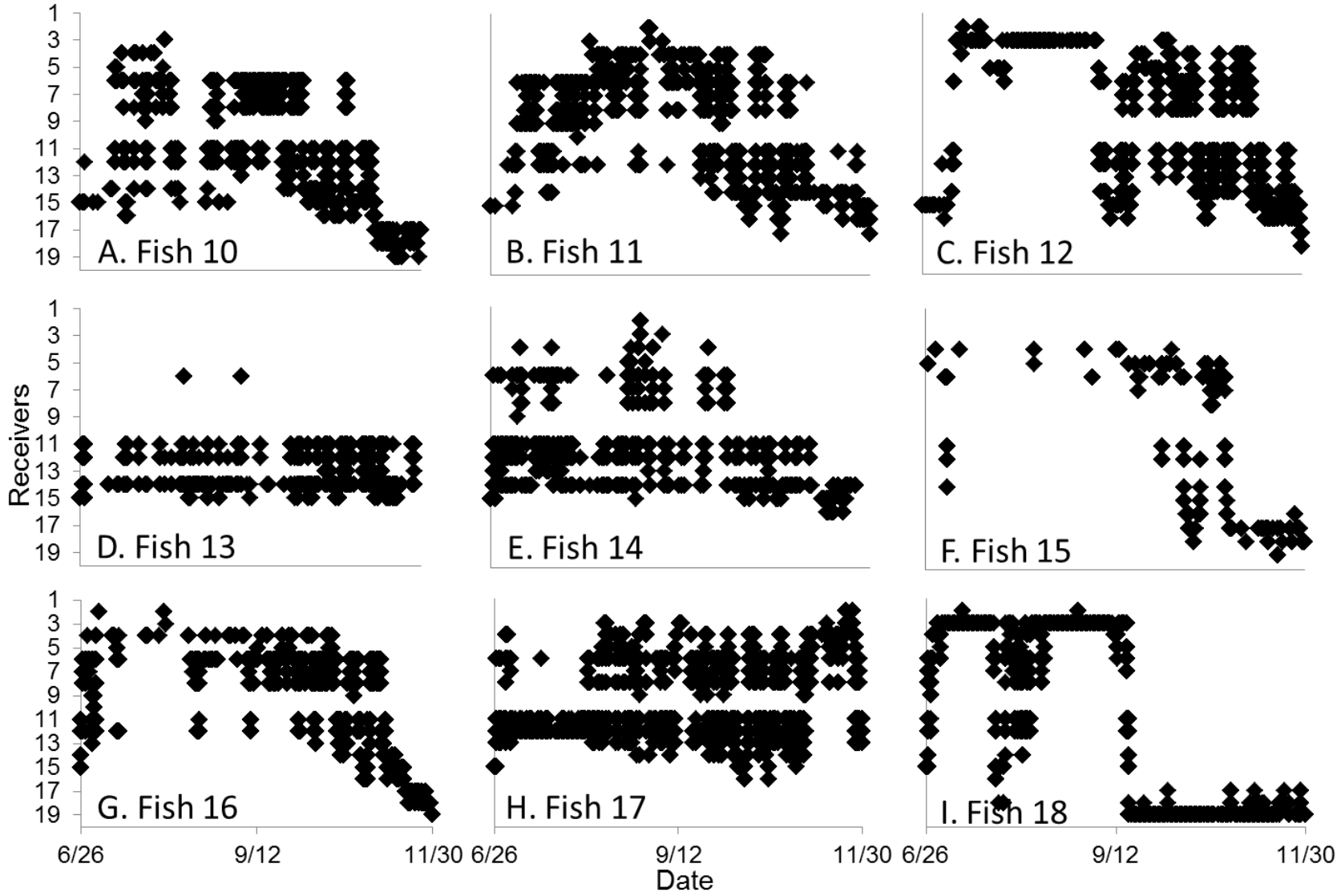


Figure C.2. All daily detections of eight Blue Catfish (A-I) in Milford Reservoir, KS in June 26 – November 30, 2012. On the X-axis is date. On the Y-axis is receivers 1-20. The dots on the plots represent detections through time from left to right.

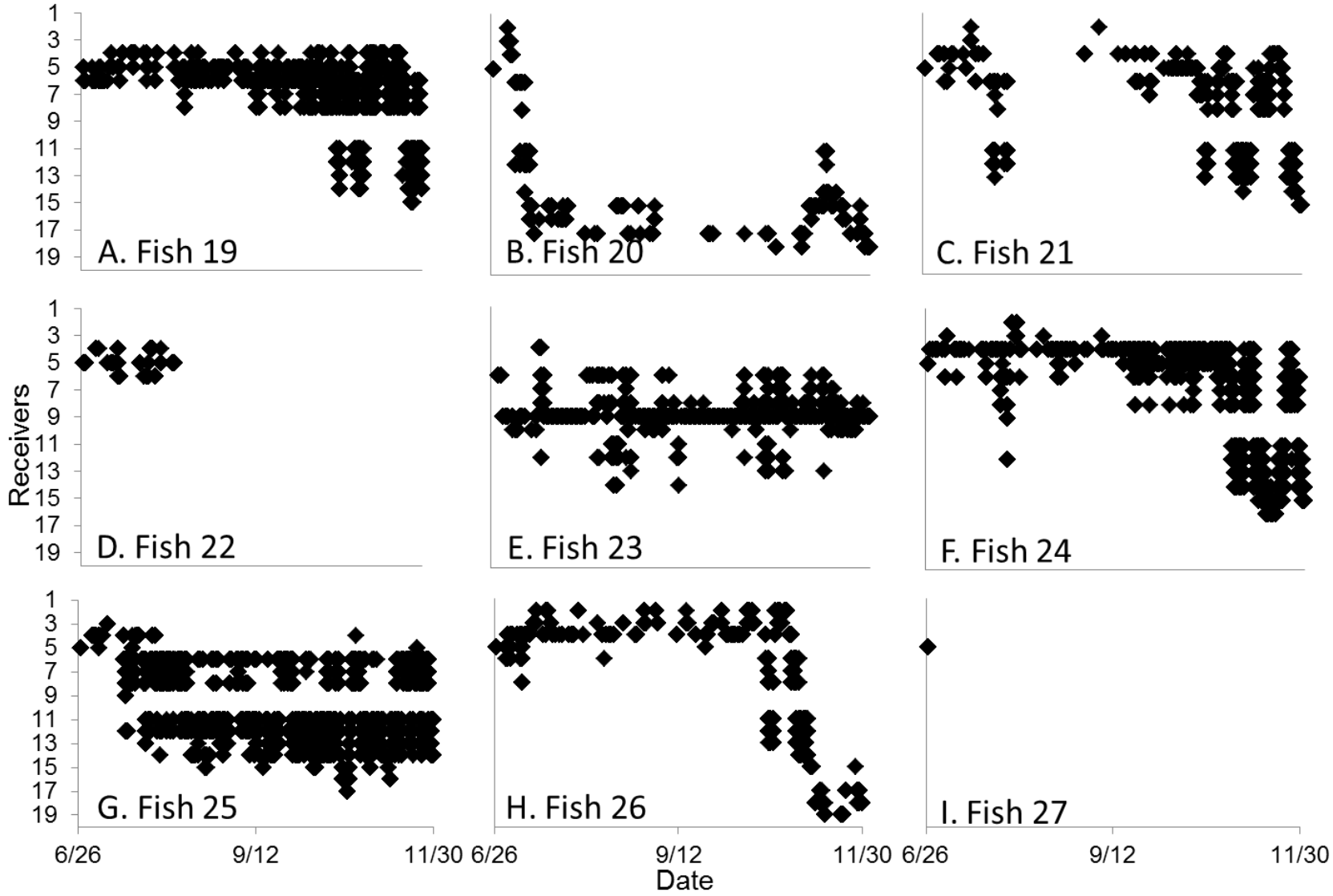


Figure C.3. All daily detections of eight Blue Catfish (A-I) in Milford Reservoir, KS in June 26 – November 30, 2012. On the X-axis is date. On the Y-axis is receivers 1-20. The dots on the plots represent detections through time from left to right.

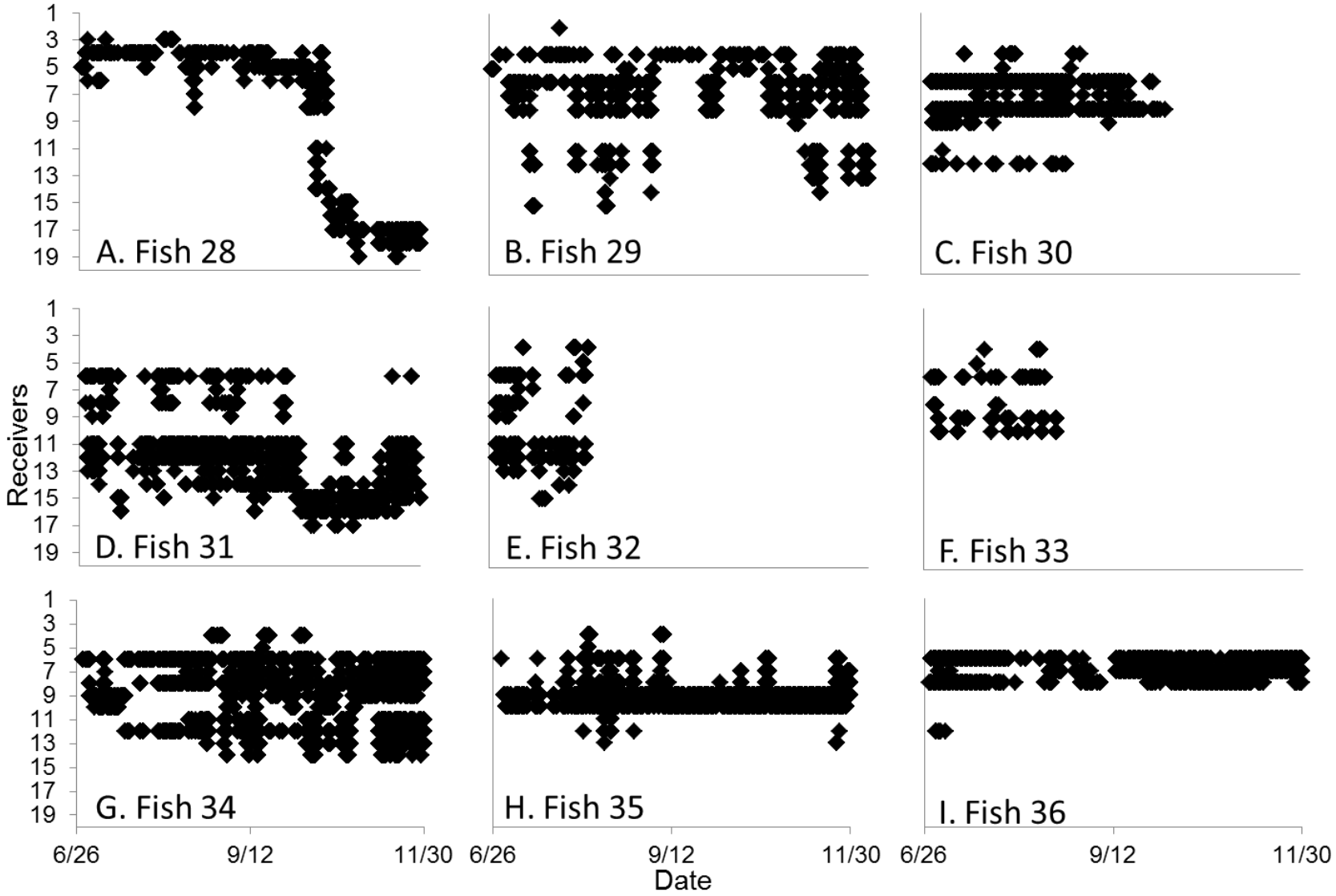


Figure C.4. All daily detections of eight Blue Catfish (A-I) in Milford Reservoir, KS in June 26 – November 30, 2012. On the X-axis is date. On the Y-axis is receivers 1-20. The dots on the plots represent detections through time from left to right.

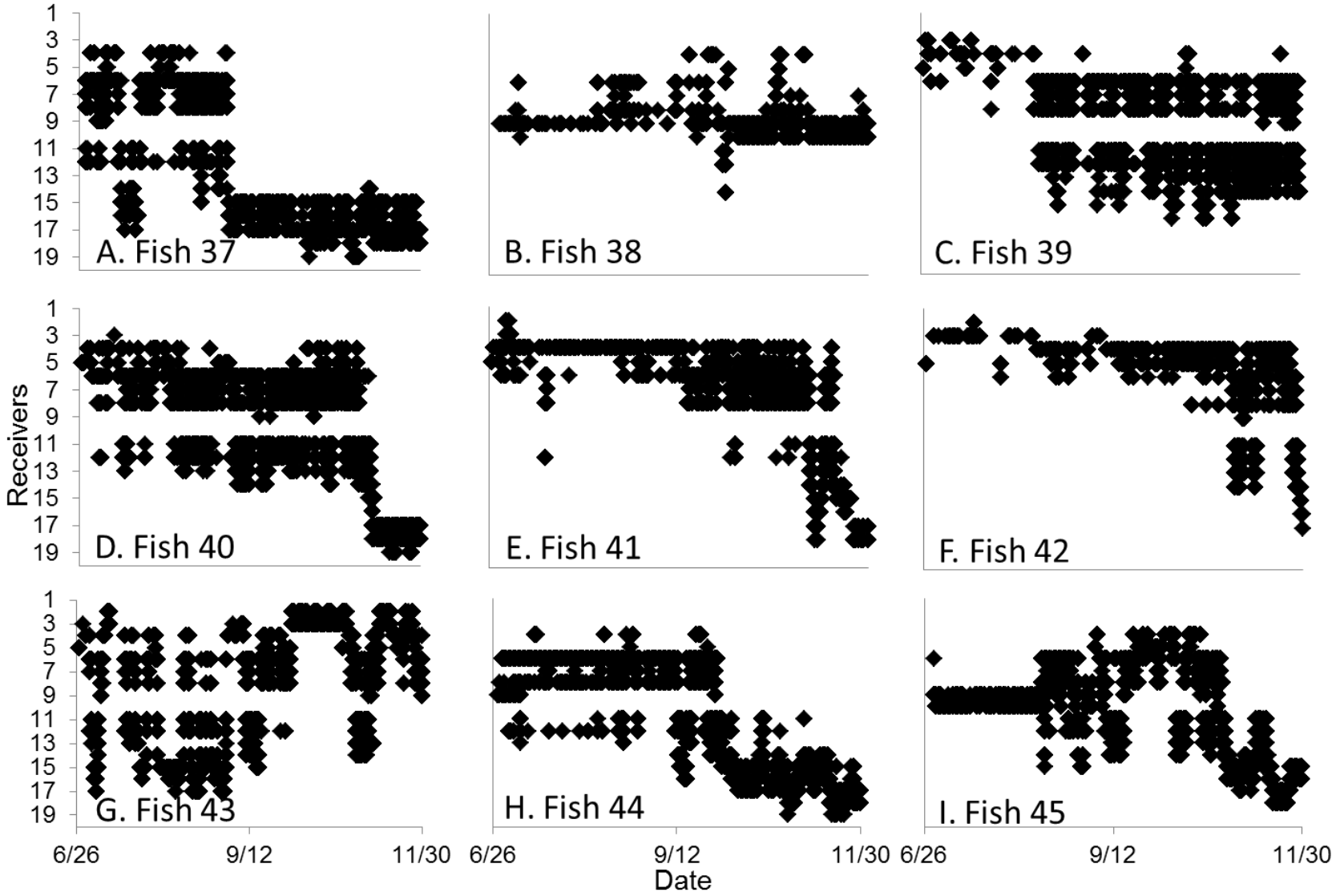


Figure C.5. All daily detections of eight Blue Catfish (A-I) in Milford Reservoir, KS in June 26 – November 30, 2012. On the X-axis is date. On the Y-axis is receivers 1-20. The dots on the plots represent detections through time from left to right.

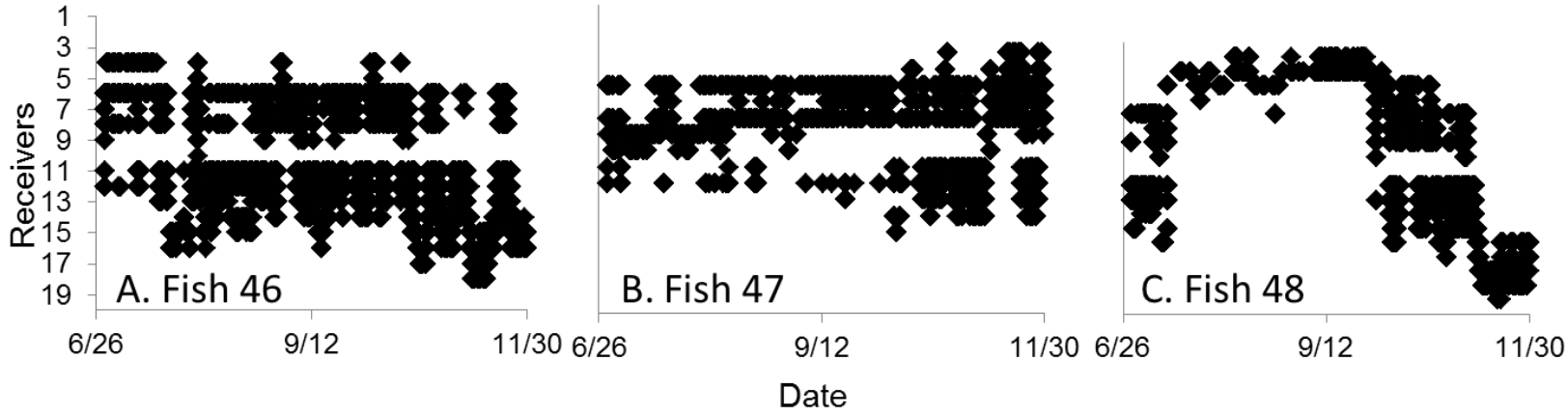


Figure C.6. All daily detections of eight Blue Catfish (A-C) in Milford Reservoir, KS in June 26 – November 30, 2012. On the X-axis is date. On the Y-axis is receivers 1-20. The dots on the plots represent detections through time from left to right.

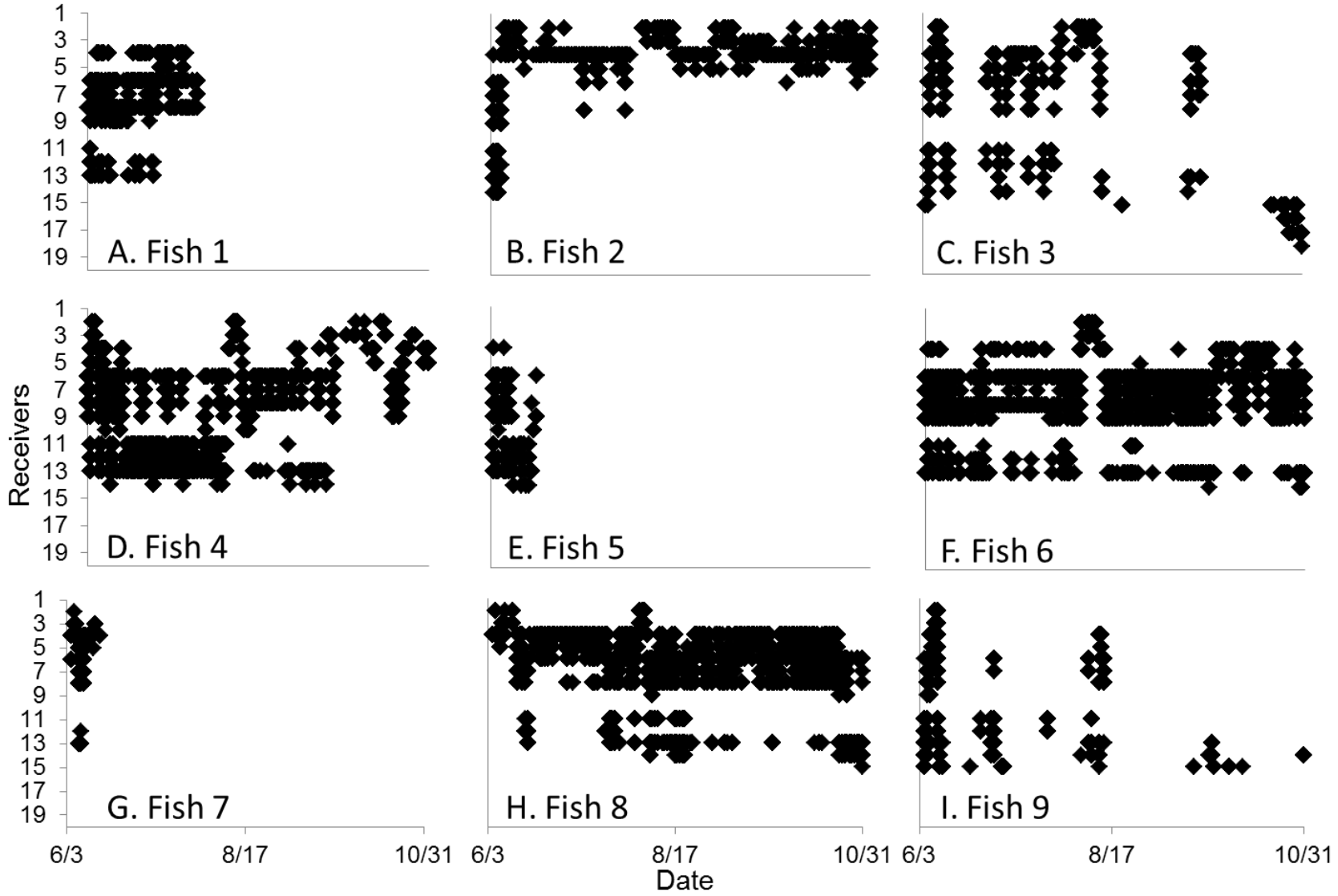


Figure C.7. All daily detections of eight Blue Catfish (A-I) in Milford Reservoir, KS in June 3 – October 31, 2013. On the X-axis is date. On the Y-axis is receivers 1-20. The dots on the plots represent detections through time from left to right.

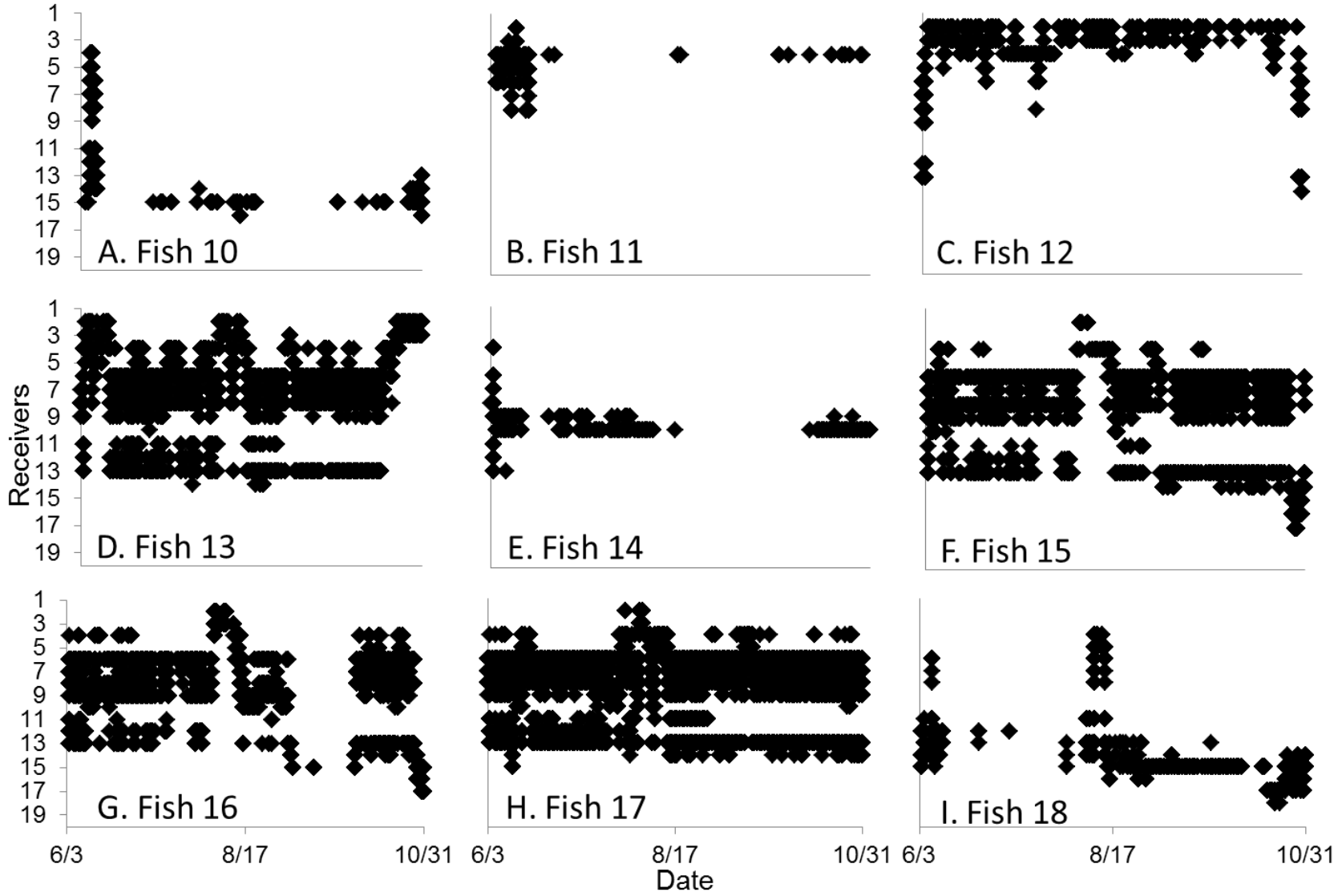


Figure C.8. All daily detections of eight Blue Catfish (A-I) in Milford Reservoir, KS in June 3 – October 31, 2013. On the X-axis is date. On the Y-axis is receivers 1-20. The dots on the plots represent detections through time from left to right.

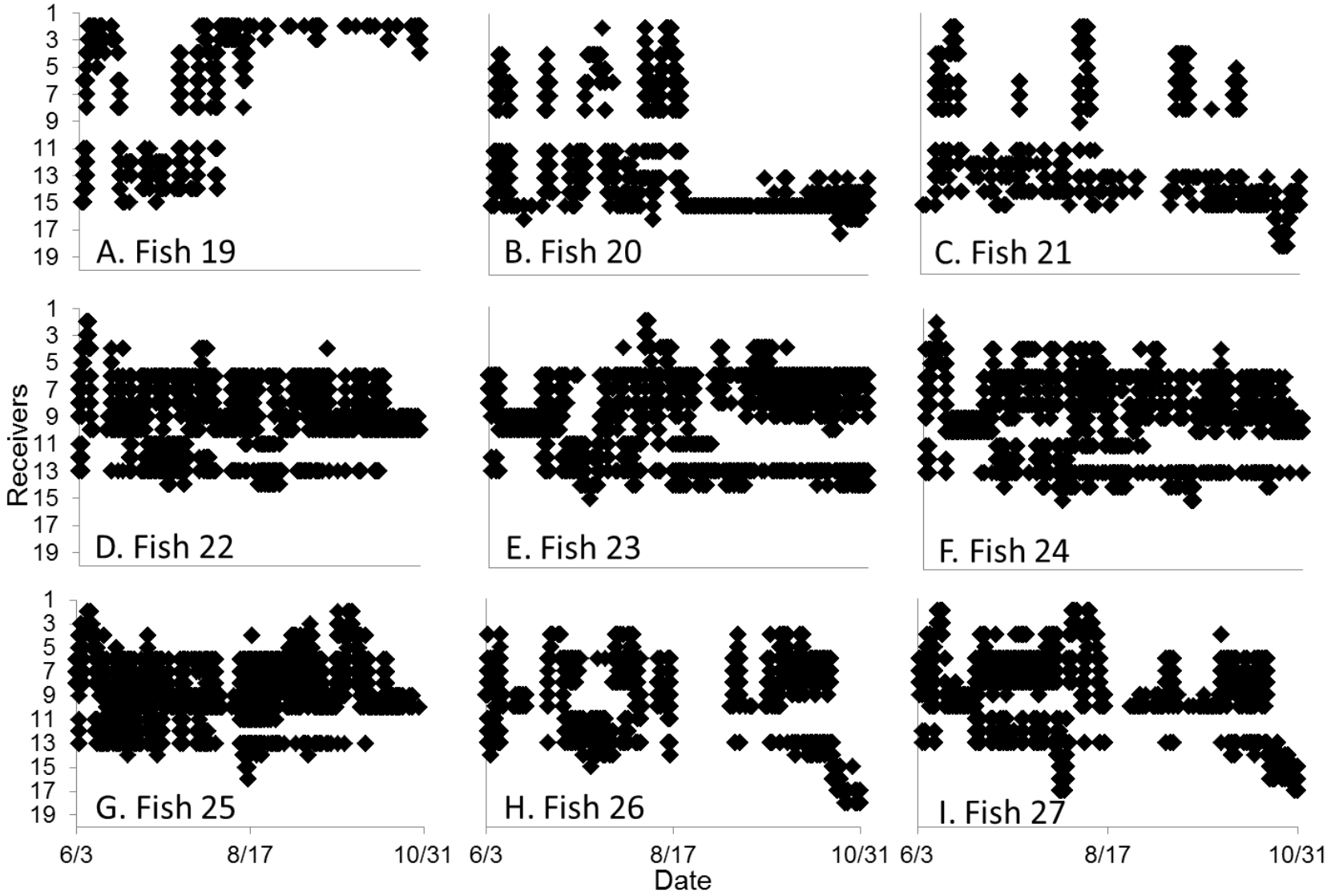


Figure C.9. All daily detections of eight Blue Catfish (A-I) in Milford Reservoir, KS in June 3 – October 31, 2013. On the X-axis is date. On the Y-axis is receivers 1-20. The dots on the plots represent detections through time from left to right.

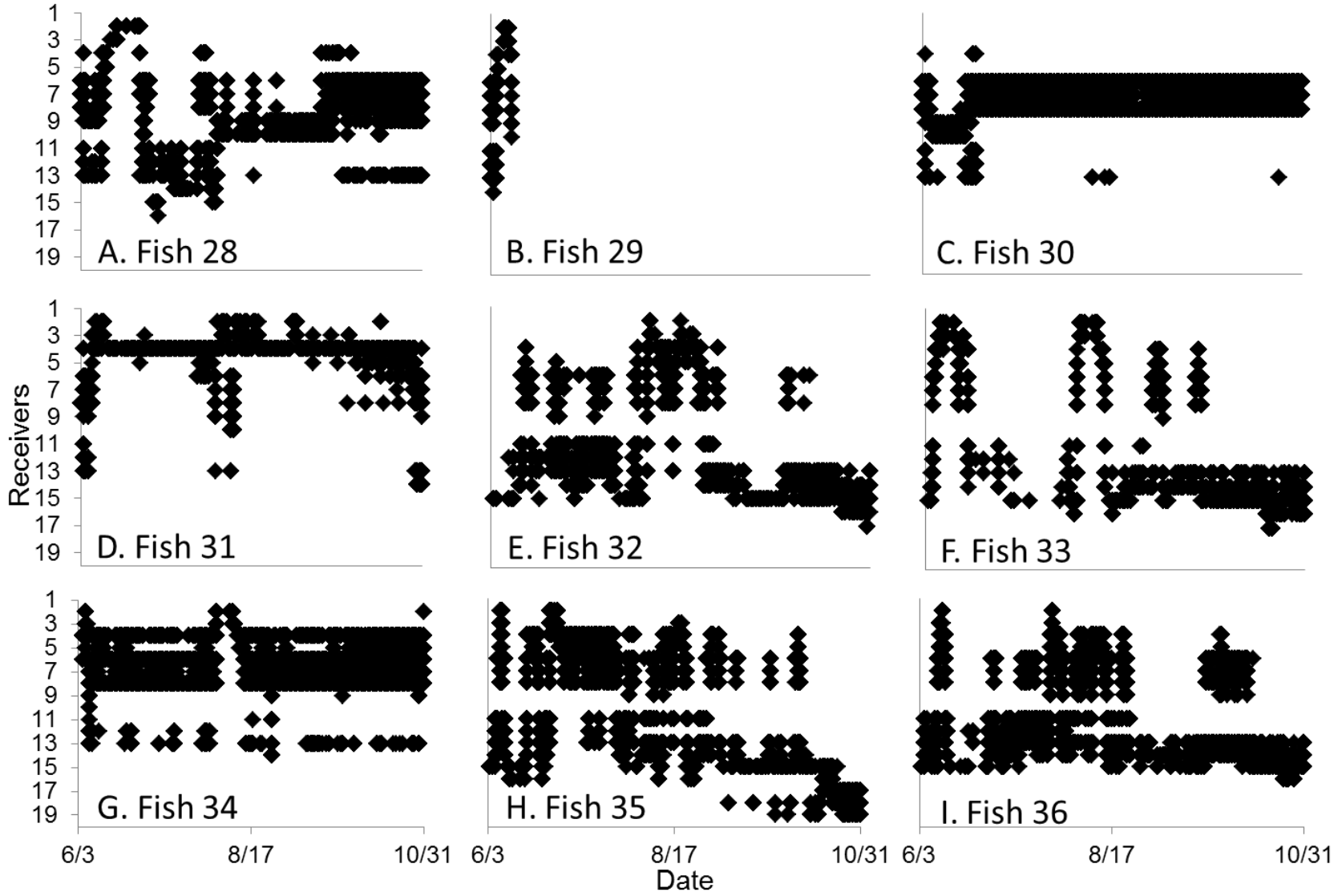


Figure C.10. All daily detections of eight Blue Catfish (A-I) in Milford Reservoir, KS in June 3 – October 31, 2013. On the X-axis is date. On the Y-axis is receivers 1-20. The dots on the plots represent detections through time from left to right.

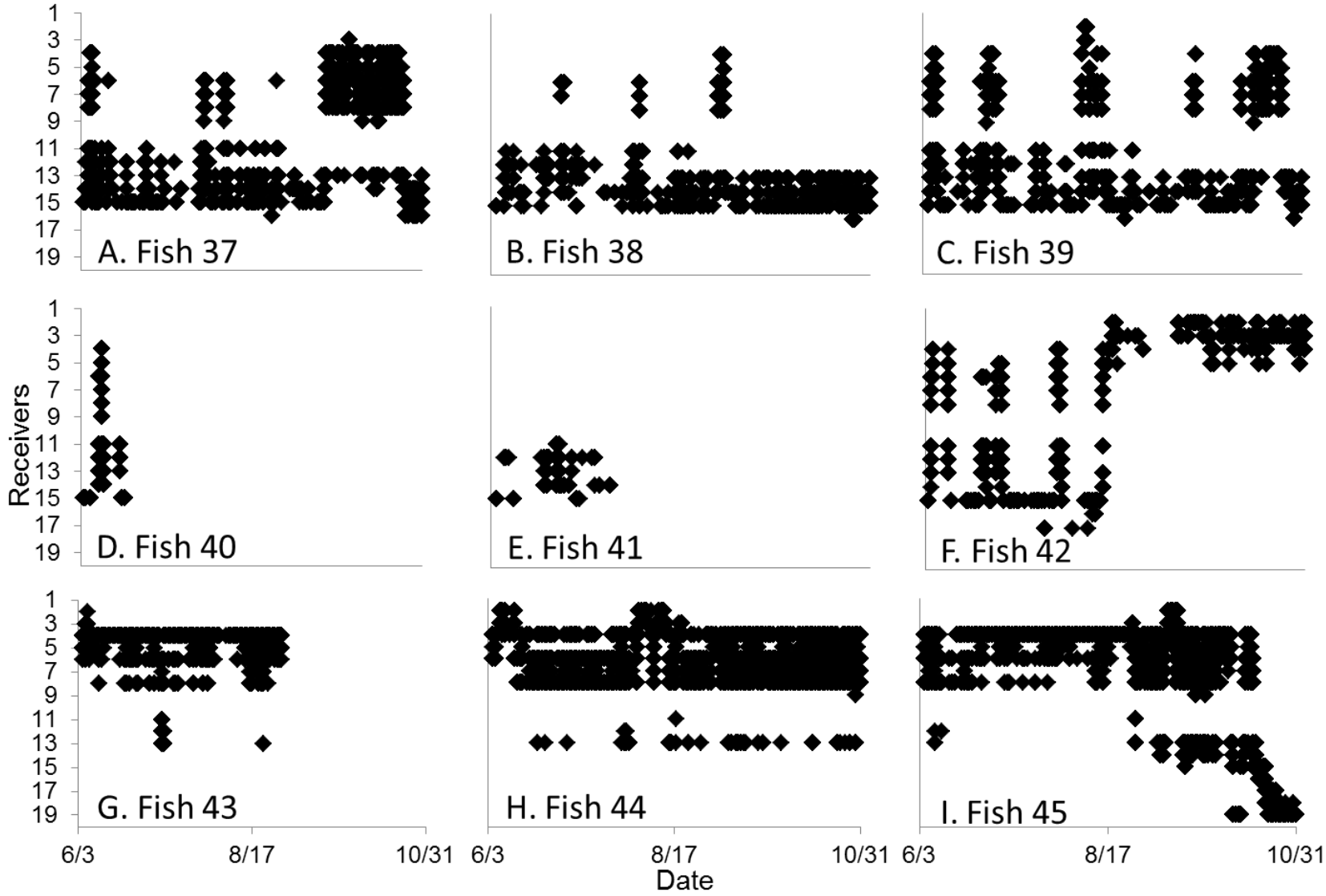


Figure C.11. All daily detections of eight Blue Catfish (A-I) in Milford Reservoir, KS in June 3 – October 31, 2013. On the X-axis is date. On the Y-axis is receivers 1-20. The dots on the plots represent detections through time from left to right.

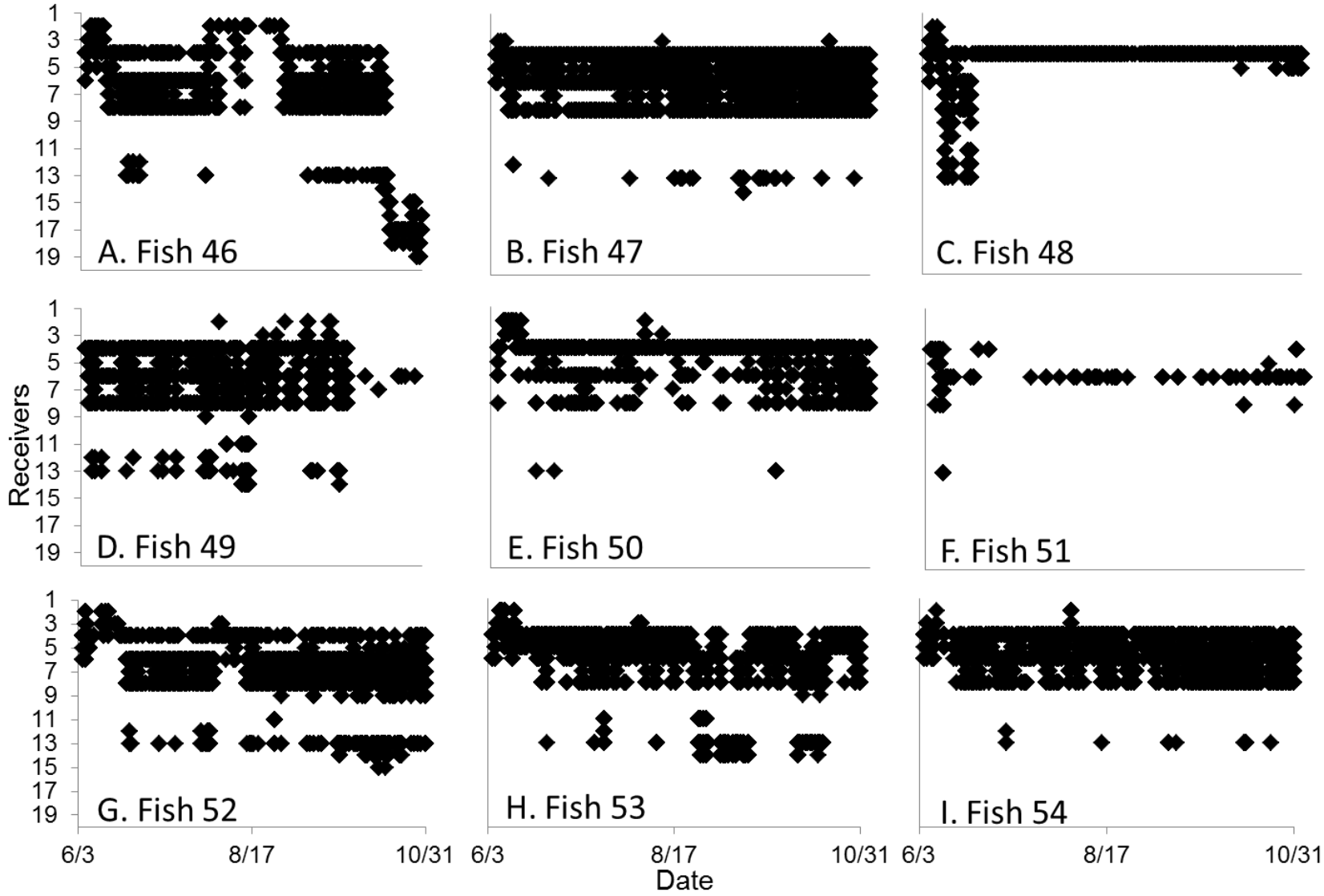


Figure C.12. All daily detections of eight Blue Catfish (A-I) in Milford Reservoir, KS in June 3 – October 31, 2013. On the X-axis is date. On the Y-axis is receivers 1-20. The dots on the plots represent detections through time from left to right.

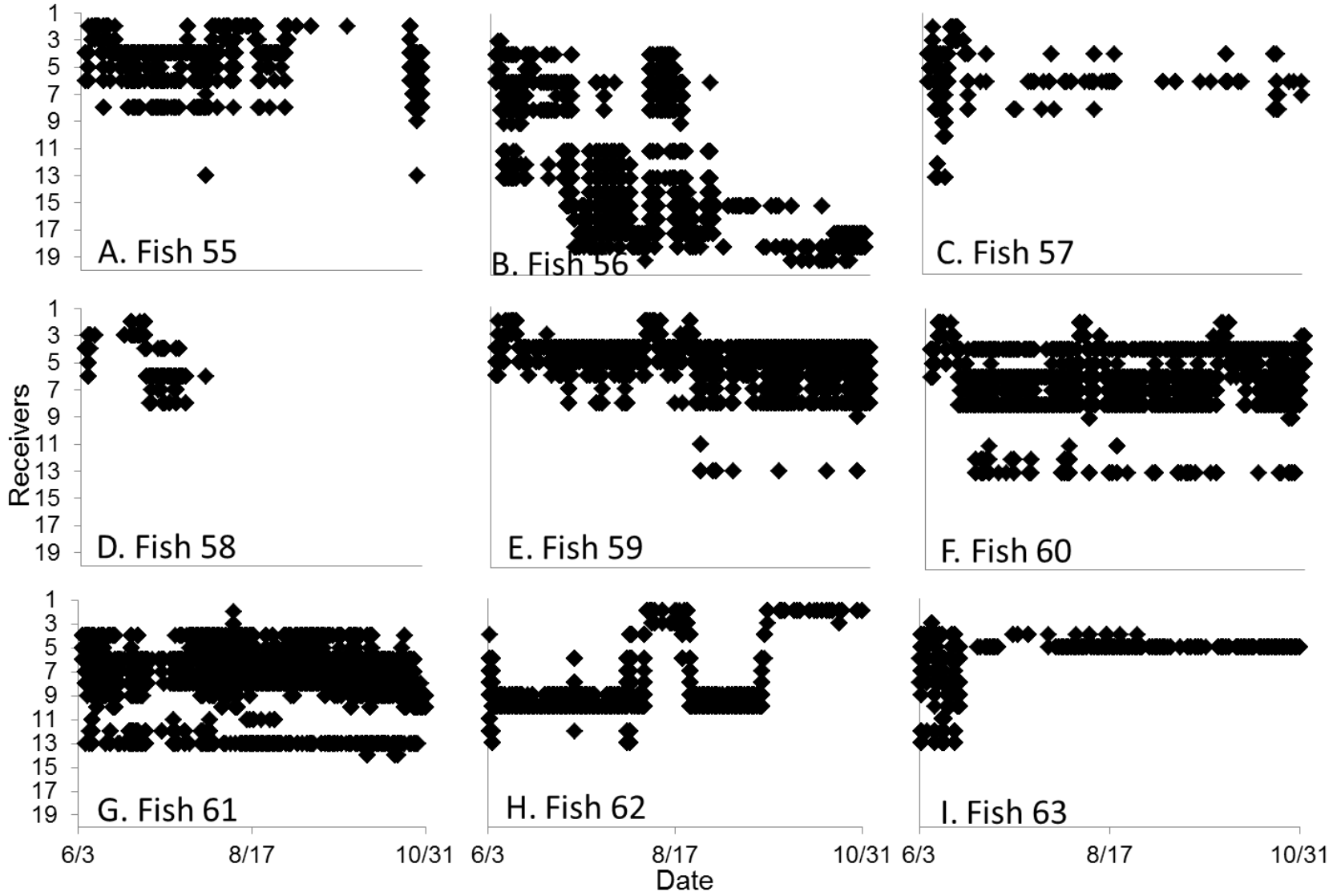


Figure C.13. All daily detections of eight Blue Catfish (A-I) in Milford Reservoir, KS in June 3 – October 31, 2013. On the X-axis is date. On the Y-axis is receivers 1-20. The dots on the plots represent detections through time from left to right.

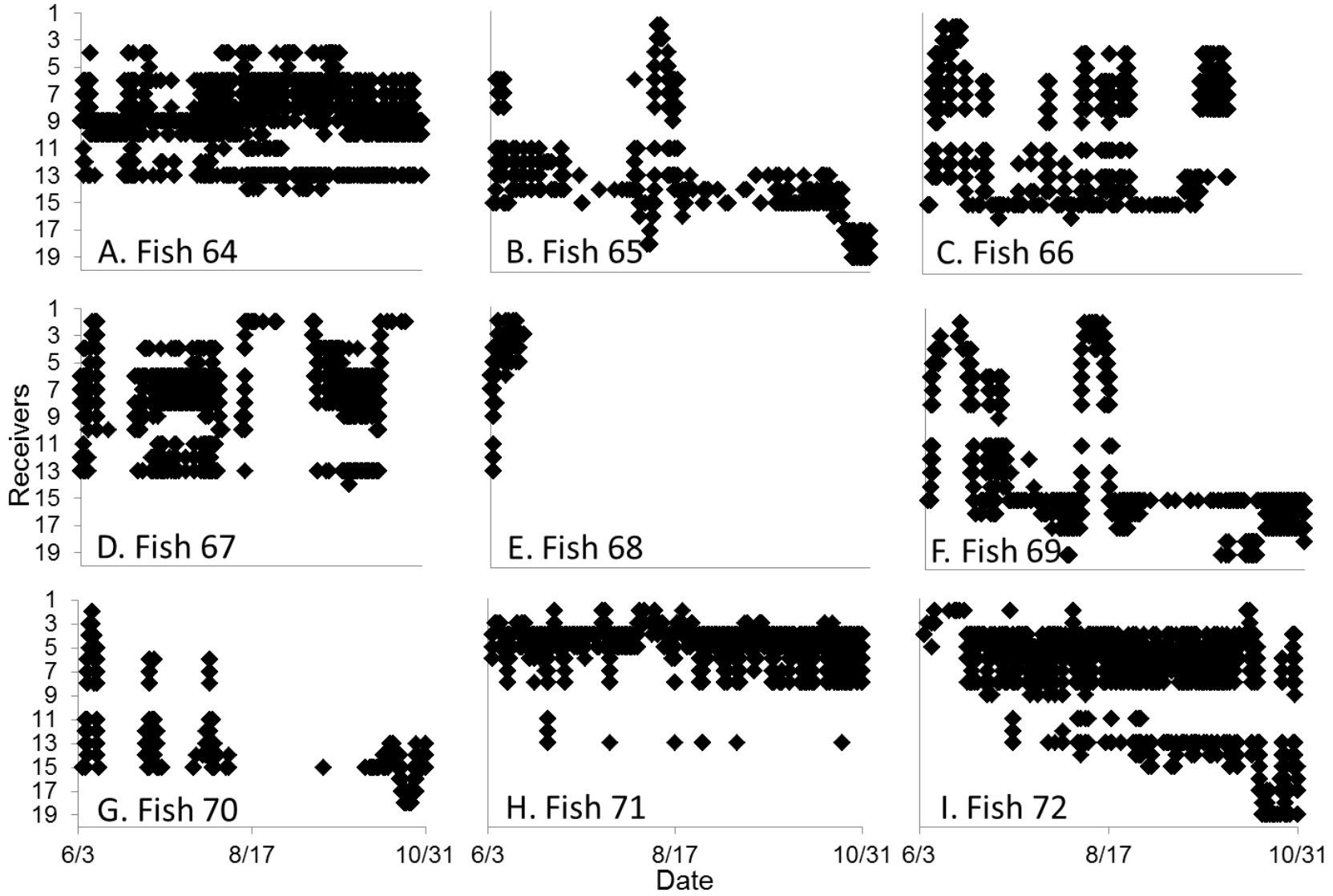


Figure C.14. All daily detections of eight Blue Catfish (A-I) in Milford Reservoir, KS in June 3 – October 31, 2013. On the X-axis is date. On the Y-axis is receivers 1-20. The dots on the plots represent detections through time from left to right.

Figure C.15. All daily detections of eight Blue Catfish (A-I) in Milford Reservoir, KS in June 3 – October 31, 2013. On the X-axis is date. On the Y-axis is receivers 1-20. The dots on the plots represent detections through time from left to right.

Appendix D - Release Location

Does capture-release location influence where fish are?

Methods

To assess the role of capture-tag-release location, residence time at each receiver location was calculated for the three release locations (Causeway, Madison, and School; Fig. D.1) to identify whether fish tagged at each receiver location spent more time at the receivers near where they were caught and released. First, I also identified whether fish tagged at each location visited different receivers or if all tagged fish visited the same set of receivers regardless of where they were initially caught and released. Second, I used a Kruskal-Wallis test with a post-hoc Mann Whitney U multiple comparisons test to test whether release location affected distribution. A Bonferroni corrected critical alpha of 0.004 was used to judge significance (i.e., no trend with $P > 0.004$ was considered significant to control comparison wide error rate).

Results

In both 2012 and 2013, tagged fish visited a wide range of receivers and spent substantial time at a wide range of receivers regardless of where they were captured, tagged, and released (Tables D.1 and D.2; Figs. D.2 and D.3). In general, regard tagged Blue Catfish spent more time near the receivers where they were originally captured, tagged, and released, but in 2012, the only significant trend was that fish released at the Madison site (near receiver 9; Fig. D.2F) spent significantly more time at the Madison site and the locations near the Madison site (receiver 10; Fig. D.2G). In 2013, tagged Blue Catfish that were captured, tagged, and released at the Causeway site (near receiver 4; Fig. D.3C) spent significantly more time at the Causeway site than fish released at the other two locations. In 2013, tagged Blue Catfish that were captured, tagged, and released at the Madison site (near receiver 9; Fig. D.3F) spent significantly more

time at the Madison site and the locations near the Madison site (receivers 10 & 13; Fig. D.3G, H). In 2013, tagged Blue Catfish that were captured, tagged, and released at the School site (near receiver 15; Fig. D.3J) spent significantly more time at the School site and receiver 14 (Fig. D.3I) than fish released at the other two locations. These trends for both years were not surprising since the fish were aggregated at the Causeway (receivers 4 and 5), Madison (receiver 9), and School (receiver 15) sites when they were captured and continued to stay in those aggregations after they were tagged and released.

Table D.1. All of the receivers each fish visited (indicated by an X) and the total number of receivers that a fish visited over the entire study in Milford Reservoir, KS in 2012. Each table represents a tagging location (Causeway, Madison, and School) and the darkened column is the nearest receiver to each tagging location.

	Fish	Receivers														Total
		2	3	4	5	6	9	10	12	14	15	16	17	18	19	
Causeway	15			X	X	X			X	X	X	X	X	X	X	10
	19			X	X	X			X	X	X					6
	20	X	X	X		X			X	X	X	X	X	X		10
	21	X	X	X	X	X			X	X	X					8
	22			X	X	X										3
	24	X	X	X	X	X	X		X	X	X	X				10
	25		X	X	X	X	X		X	X	X	X	X			10
	26	X	X	X	X	X			X	X	X		X	X	X	11
	27		X													1
	28		X	X	X	X			X	X	X	X	X	X	X	11
	29	X		X	X	X	X		X	X	X					8
	39		X	X	X	X	X		X	X	X	X				9
	40		X	X	X	X	X	X	X	X	X	X	X	X	X	13
	41	X	X	X	X	X			X	X	X	X	X	X		11
	42	X	X	X	X	X	X		X	X	X	X	X			11
	43	X	X	X	X	X	X		X	X	X	X	X			11
Madison	23			X		X	X	X	X	X						6
	30			X	X	X	X		X							5
	31					X	X		X	X	X	X	X			7
	32			X	X	X	X		X	X	X					7
	33			X	X	X	X	X								5
	34			X	X	X	X	X	X	X						7
	35			X	X	X	X	X	X							6
	36					X			X							2
	37			X	X	X	X		X	X	X	X	X	X	X	11
	38			X	X	X	X	X	X	X						7
	44			X	X	X	X		X	X	X	X	X	X	X	11
	45			X	X	X	X	X	X	X	X	X	X	X		11
	46			X	X	X	X	X	X	X	X	X	X	X		11
	47			X	X	X	X	X	X	X	X					8
	48	X	X	X	X	X	X		X	X	X	X	X	X	X	13

	Fish	Receivers														Total
		2	3	4	5	6	9	10	12	14	15	16	17	18	19	
School	1		X	X	X	X			X	X	X	X				8
	2	X	X	X	X	X			X	X						7
	3			X	X	X			X	X	X	X	X	X		9
	4					X			X	X	X	X	X			6
	5	X	X	X	X	X			X	X	X	X	X	X	X	12
	6			X	X	X			X	X	X	X	X	X		9
	7			X		X			X	X	X	X				6
	8			X	X	X			X	X	X	X	X	X	X	10
	9					X			X	X	X	X	X	X	X	8
	10		X	X	X	X	X		X	X	X	X	X	X	X	12
	11	X	X	X	X	X	X	X	X	X	X	X	X			12
	12	X	X	X	X	X			X	X	X	X	X	X		11
	13					X			X	X	X					4
	14	X	X	X	X	X	X		X	X	X	X				10
	16	X	X	X	X	X	X	X	X	X	X	X	X	X	X	14
	17	X	X	X	X	X	X		X	X	X	X				10
	18	X	X	X	X	X			X	X	X	X	X	X	X	12

Table D.2. All of the receivers each fish visited (indicated by an X) and the total number of receivers each fish visited over the entire study in Milford Reservoir, KS in 2013. Each table represents a tagging location (Causeway, Madison, and School) and the darkened column is the closest receiver.

	Fish	Receivers												Total
		2	3	4	5	6	9	10	13	14	15	18	19	
Causeway	7	X	X	X	X	X			X					6
	8	X	X	X	X	X	X		X	X	X	X		10
	11	X	X	X	X	X								5
	34	X	X	X	X	X	X	X	X	X				9
	43	X	X	X	X	X			X					6
	44	X	X	X	X	X	X		X	X				8
	45	X	X	X	X	X			X	X	X	X	X	10
	46	X	X	X	X	X	X		X	X	X	X	X	11
	47		X	X	X	X	X		X	X				7
	48	X	X	X	X	X	X	X	X					8
	49	X	X	X	X	X	X		X	X				8
	50	X	X	X	X	X	X		X					7
	51			X	X	X			X					4
	52	X	X	X	X	X	X		X	X	X			9
	53	X	X	X	X	X	X		X	X				8
	54	X	X	X	X	X			X					6
	55	X	X	X	X	X	X		X					7
	56		X	X	X	X	X		X	X	X	X	X	10
	57	X	X	X	X	X	X	X	X					8
	58	X	X	X	X	X								5
	59	X	X	X	X	X	X		X					7
	60	X	X	X	X	X	X		X					7
	61	X	X	X	X	X	X	X	X	X	X			10
	71	X	X	X	X	X			X	X	X			8
	72	X	X	X	X	X	X		X	X	X	X	X	11
	73	X	X	X	X	X								5
	75	X	X	X	X	X	X		X					7
Madison	1			X	X	X	X		X					5
	2	X	X	X	X	X	X		X	X				8
	4	X	X	X	X	X	X	X	X	X				9
	5			X		X	X	X	X	X				6
	6	X	X	X	X	X	X		X	X				8

	Fish	Receivers												Total
		2	3	4	5	6	9	10	13	14	15	18	19	
Madison	12	X	X	X	X	X	X		X	X	X			9
	13	X	X	X	X	X	X	X	X	X				9
	14			X		X	X	X	X					5
	15	X		X	X	X	X	X	X	X	X			9
	16	X	X	X	X	X	X	X	X	X	X	X	X	12
	17	X	X	X	X	X	X	X	X	X	X			10
	22	X	X	X	X	X	X	X	X	X				9
	23	X	X	X	X	X	X	X	X	X	X			10
	24	X	X	X	X	X	X	X	X	X	X			10
	25	X	X	X	X	X	X	X	X	X	X			10
	26			X	X	X	X	X	X	X	X	X	X	10
	27	X	X	X	X	X	X	X	X	X	X			10
	28	X	X	X	X	X	X	X	X	X	X			10
	29	X	X	X	X	X	X	X	X	X				9
	30			X		X	X	X	X					5
	31	X	X	X	X	X	X	X	X	X				9
	62	X	X	X		X	X	X	X					7
	63		X	X	X	X	X	X	X					7
	64			X	X	X	X	X	X	X				7
	67	X	X	X	X	X	X	X	X	X				9
	68	X	X	X	X	X	X		X					7
School	3	X	X	X	X	X			X	X	X	X		9
	9	X	X	X	X	X	X		X	X	X			9
	10			X	X	X	X		X	X	X			7
	18			X	X	X			X	X	X	X		7
	19	X	X	X	X	X			X	X	X			8
	20	X	X	X	X	X			X	X	X			8
	21	X	X	X	X	X	X		X	X	X	X		10
	32	X	X	X	X	X	X		X	X	X			9
	33	X	X	X	X	X	X		X	X	X	X		10
	35	X	X	X	X	X	X		X	X	X	X	X	11
	36	X	X	X	X	X	X		X	X	X			9
	37		X	X	X	X	X		X	X	X			8
	38			X	X	X			X	X	X			6
	39	X	X	X	X	X	X		X	X	X			9

	Fish	Receivers												Total
		2	3	4	5	6	9	10	13	14	15	18	19	
School	40			X	X	X	X		X	X	X			7
	41								X	X	X			3
	42	X	X	X	X	X			X	X	X			8
	65	X	X	X	X	X	X		X	X	X	X	X	11
	66	X	X	X	X	X	X		X	X	X			9
	69	X	X	X	X	X	X		X	X	X	X	X	11
	70	X	X	X	X	X			X	X	X	X		9
	74	X	X	X	X	X			X	X	X	X	X	10

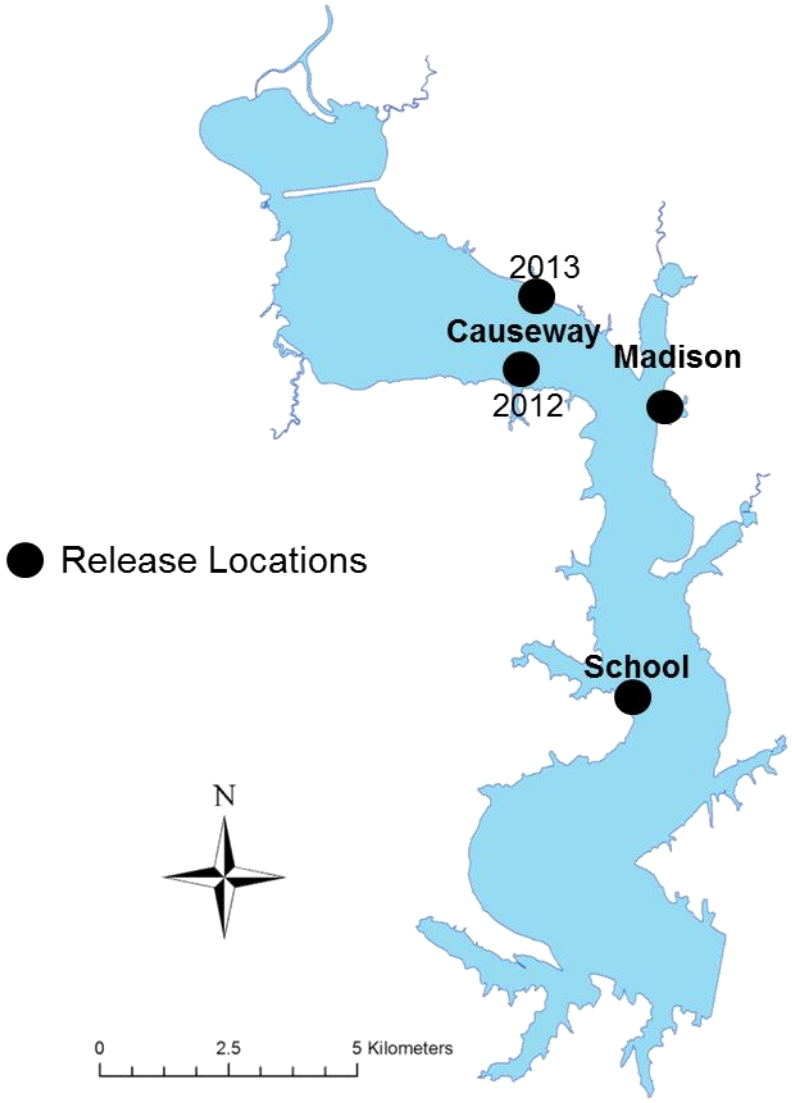


Figure D.1. Map of Milford Reservoir, KS that has the three release locations (indicated by black circles).

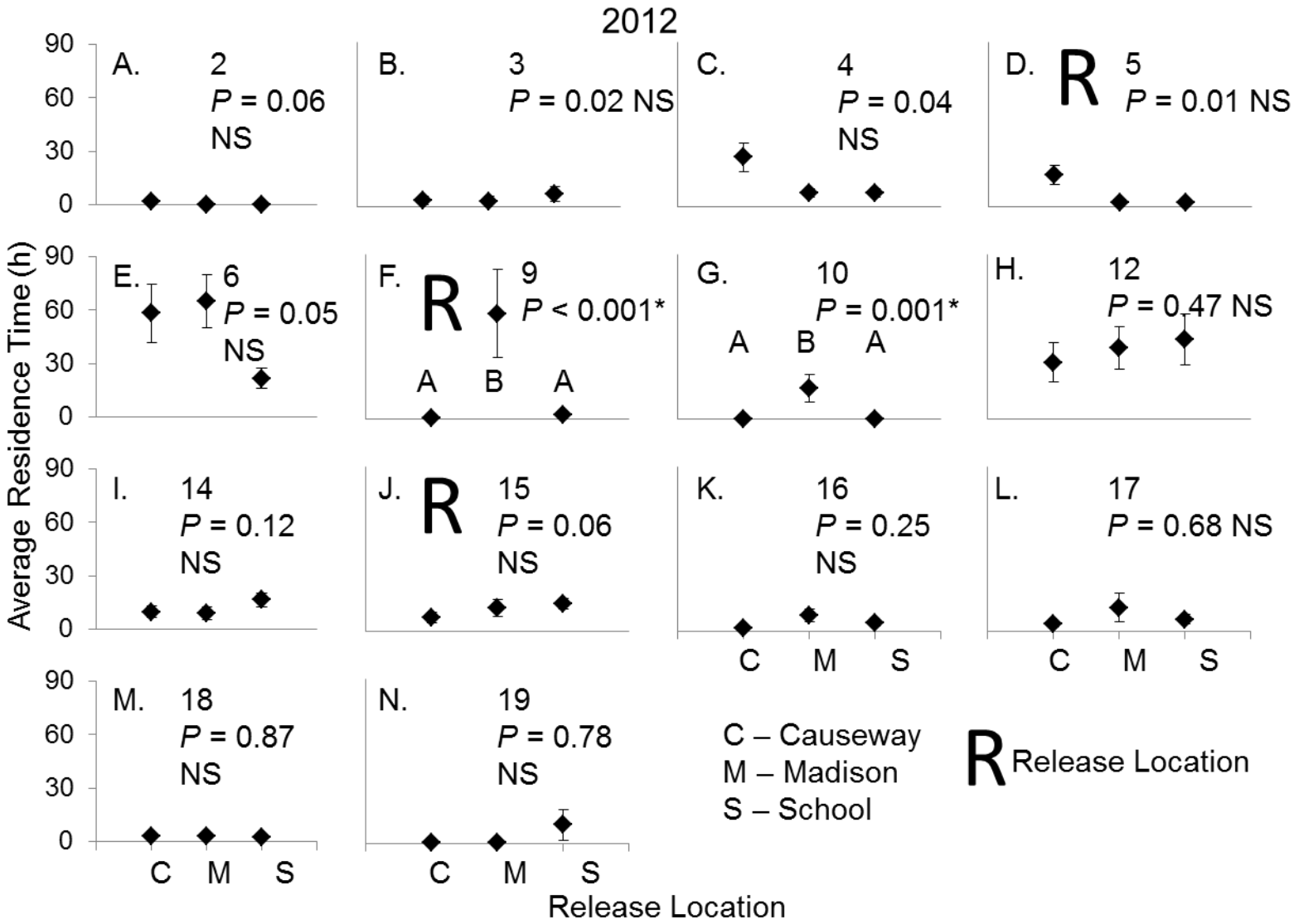


Figure D.2. Average and SE plots depicting release location differences using average residence time (h) in Milford Reservoir, KS in 2012. The X-axis if the release locations Causeway (C), Madison (M), and School (S). The Y-axis is the average residence time (h). Y-axes are standardized to compare across months. Capital R's indicate receivers closest to release location. Also shown are the results of a Kruskal-Wallis nonparametric ANOVA and post-hoc Mann Whitney U multiple comparisons with Bonferroni corrections that test release locations. Bonferroni corrected critical alpha P<0.004 was considered significant.

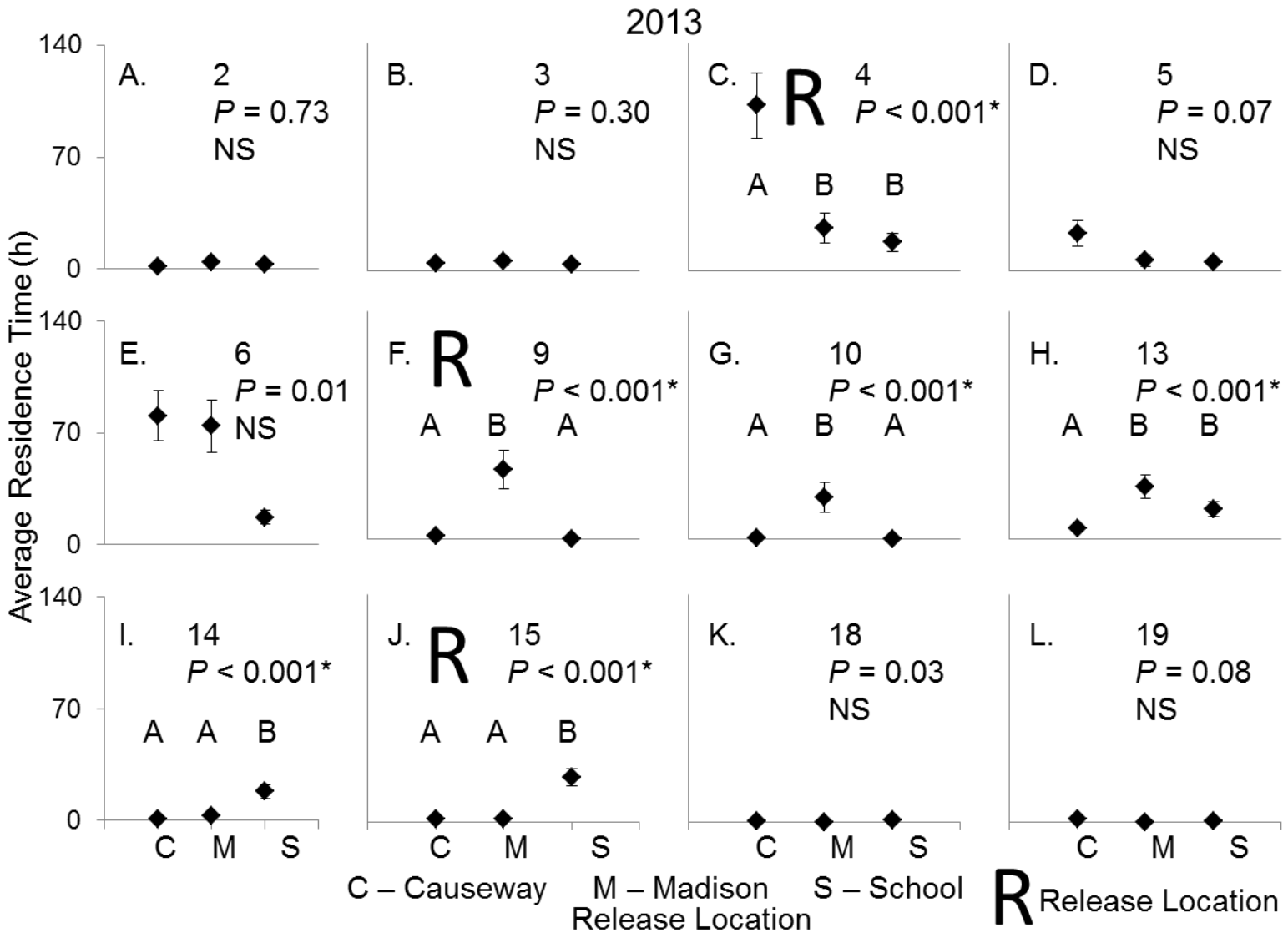


Figure D.3. Average and SE plots depicting release location differences using average residence time (h) in Milford Reservoir, KS in 2013. The X-axis if the release locations Causeway (C), Madison (M), and School (S). The Y-axis is the average residence time (h). Y-axes are standardized to compare across months. Capital R's indicate receivers closest to release location. Also

shown are the results of a Kruskal-Wallis nonparametric ANOVA and post-hoc Mann Whitney U multiple comparisons with Bonferroni corrections that test release locations. Bonferroni corrected critical alpha P<0.004 was considered significant.

Appendix E - Diel Period

Are there differences between diel periods?

Methods

To examine trends identified by the spatial patterns in greater detail, I tested if mean residence time and mean movements differed across diel periods for both 2012 and 2013. Residence times and movements were calculated for four daily time periods: (a) dawn (a 2 hour period centered around sunrise), (b) day (length in h), (c) dusk (a 2 h period centered around sunset), and (d) night (length in h). The daily time periods were calculated from a table of sunrise and sunset times retrieved from the United States Naval Observatory (USNO) website (http://aa.usno.navy.mil/data/docs/RS_OneYear.php). Hourly residence time and hourly movements were compared with a Kruskal-Wallis test followed by a post-hoc Mann Whitney U multiple comparisons test with a Bonferroni adjustment. A Bonferroni corrected critical alpha (0.004) was used to determine significance.

Results

At each receiver location there were no significant differences in the mean residence time across diel periods (e.g., dawn, day, dusk, and night) for 2012 and 2013 (Fig. E.1A-N & E.2A-L). Significant differences in mean movements between diel periods were detected for receiver 10 in 2012 (Fig. E.3G) but the differences in the number of movements were small and variable. No significant differences in movement were detected in 2013 (Fig. E.4A-L),

Discussion

The distribution of Blue Catfish in Milford Reservoir did not differ across diel periods. Differences in diel distribution of fish and other organisms has been a topic of interest in fish

ecology and fish management for decades. A study that tracked radio tagged Brown Trout found that the fish were more active at dusk (Ovidio et al. 2002). Booth et al. (2013) tracked Sonora and Desert Suckers and found that they moved into shallow habitats in the evening. Pikeperch displayed higher activity at dusk (Poulet et al. 2005). It is often common knowledge for anglers to fish during certain diel periods which has had influences on the questions that we ask as scientists. I found no significant difference between diel periods (i.e., dawn, day, dusk, night) when using residence time, but I found isolated differences between diel periods when using movements. Variable trends were seen in the diel periods between years when using movements. Our data on residence time collected reservoir-wide, 24 hours a day for 123 fish over five months provides some of the most credible evidence available that differential distribution did not occur among the diel periods.

References

Booth, M. T., N.G. Hairston, and A.S. Flecker. 2013. How mobile are fish populations? Diel movement, population turnover, and site fidelity in suckers. Canadian Journal of Aquatic Science 70: 1-12.

Ovidio, M., E. Baras, D. Goffaux, F. Giroux, and J.C. Philippart. 2002. Seasonal variations of activity pattern of Brown Trout (*Salmo trutta*) in a small stream, as determined by radio-telemetry. Hydrobiologia 470(1-3): 195-202.

Poulet, N., C. Arzel, S. Messad, S. Lek, and C. Argillier. 2005. Diel activity of adult Pikeperch *Sander lucioperca* (L.) in a drainage canal in the Mediterranean basin during spring. Hydrobiologia 543: 79-90.

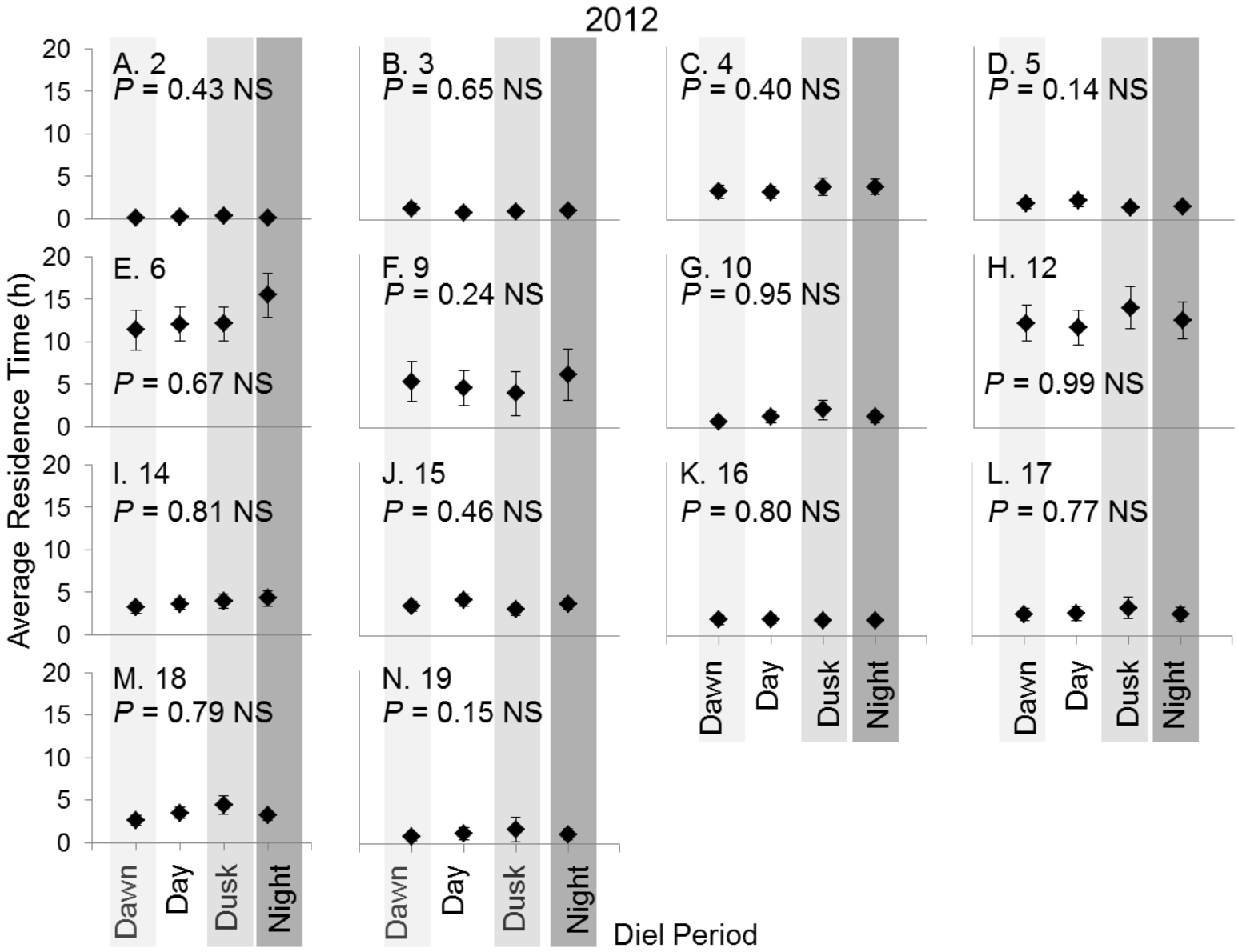


Figure E.1. Average and SE plots depicting diel changes in average residence time (h) in Milford Reservoir, KS in 2012. The X-axis is each diel period (dawn, day, dusk, night; also indicated by the bars across plots) and the Y-axis is average residence time (h). Y-axes are standardized to compare across months. Also shown are the results of a Kruskal-Wallis nonparametric

ANOVA and a post-hoc Mann Whitney U multiple comparisons with a Bonferroni correction that tested the effect of month. A Bonferroni corrected critical alpha, P<0.004, was used to determine significance.

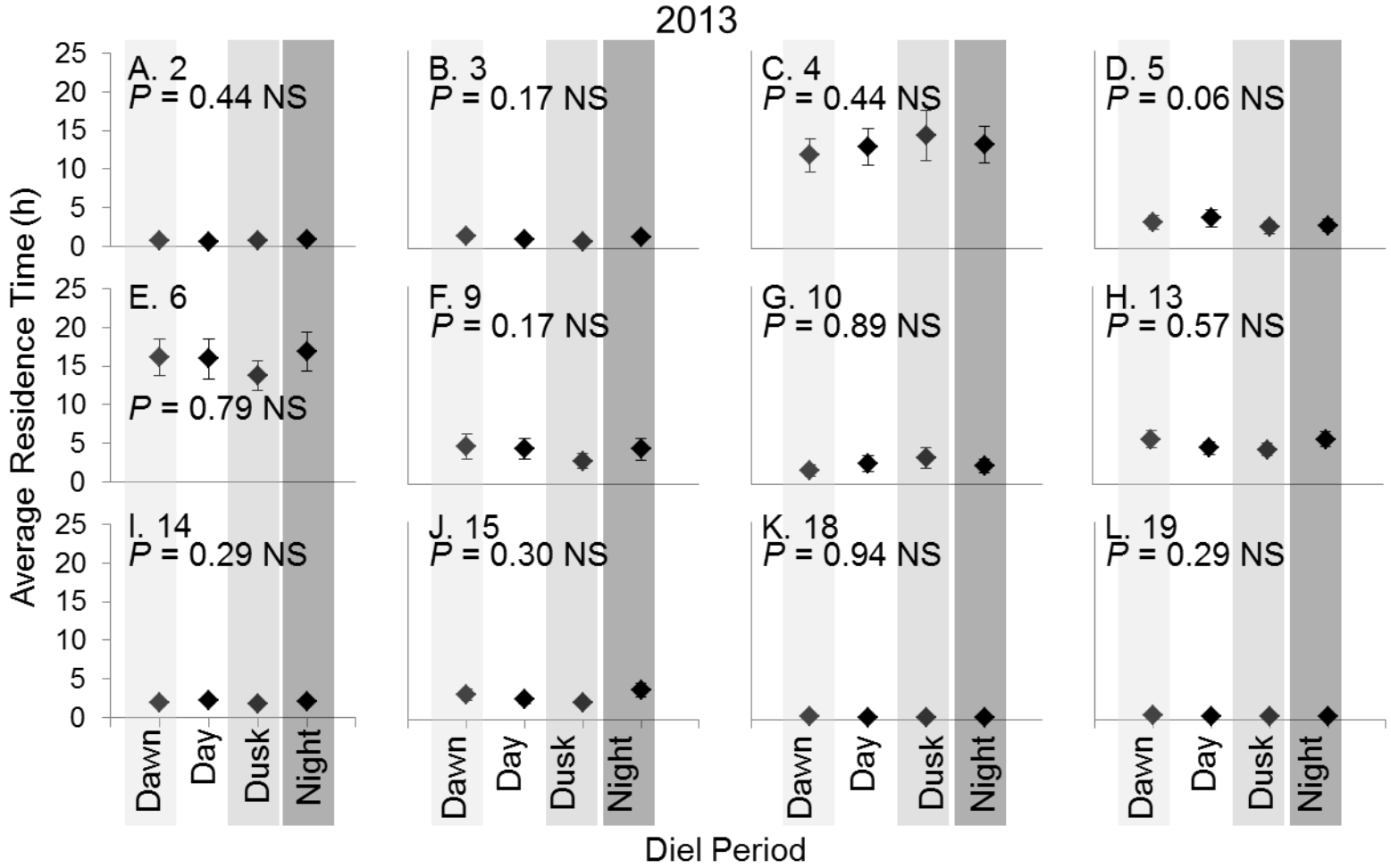


Figure E.2. Average and SE plots depicting diel changes in average residence time (h) in Milford Reservoir, KS in 2013. The X-axis is each diel period (dawn, day, dusk, night; indicated by the bars across plots) and the Y-axis is average residence time (h). Y-axes are standardized to compare across months. Also shown are the results of a Kruskal-Wallis nonparametric ANOVA and a post-hoc Mann Whitney U multiple comparisons with a Bonferroni correction that tested the effect of month. A Bonferroni corrected critical alpha, P<0.004, was considered significant.

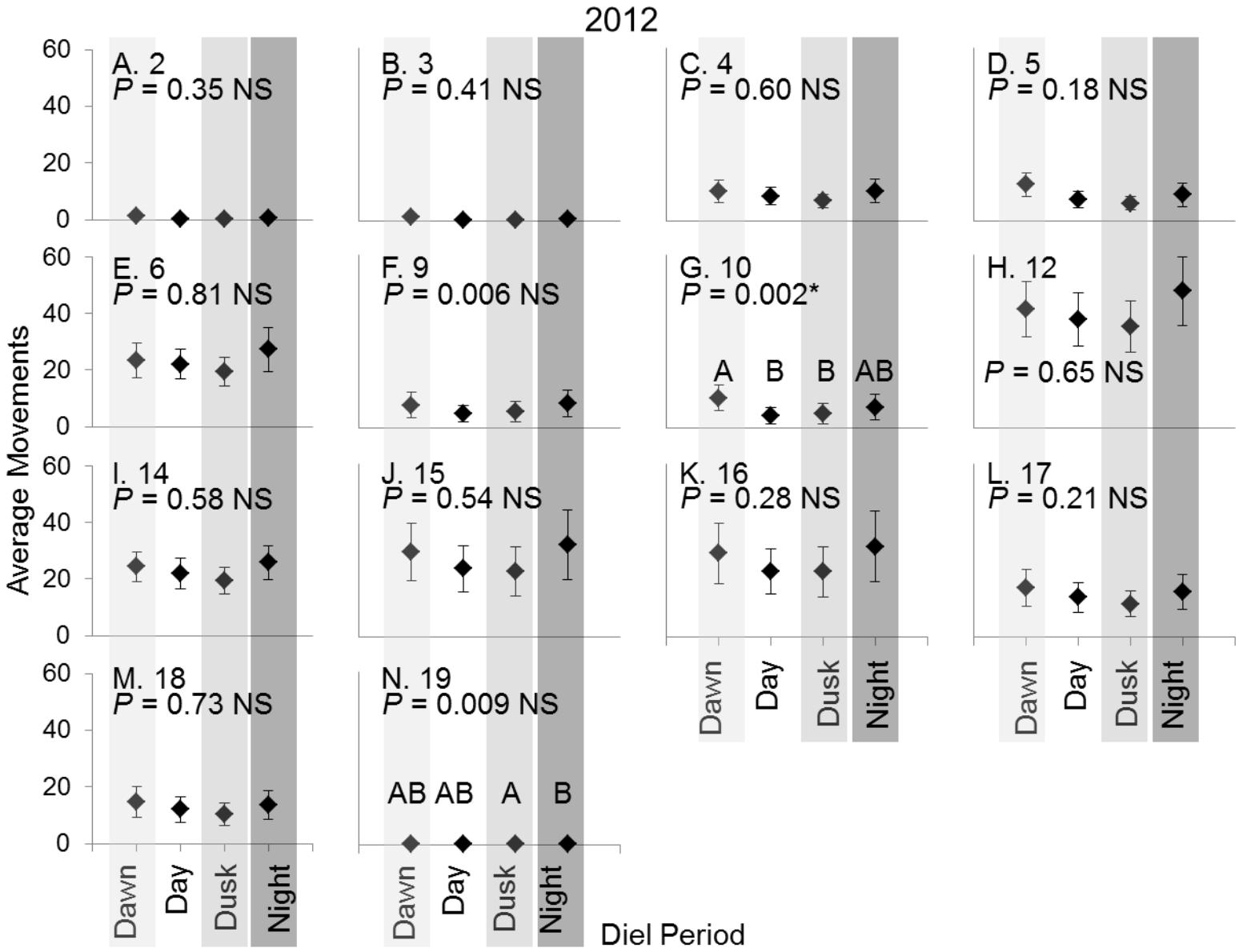


Figure E.3. Average and SE plots depicting diel changes in average movements in Milford Reservoir, KS in 2012. The X-axis is each diel period (dawn, day, dusk, night; indicated by the bars across plots) and the Y-axis is average movements. Y-axes are standardized to compare across months. Also shown are the results of a Kruskal-Wallis nonparametric ANOVA and a post-

hoc Mann Whitney U multiple comparisons with a Bonferroni correction that tested the effect of month. Bonferroni corrected critical alpha of P<0.004 was considered significant.

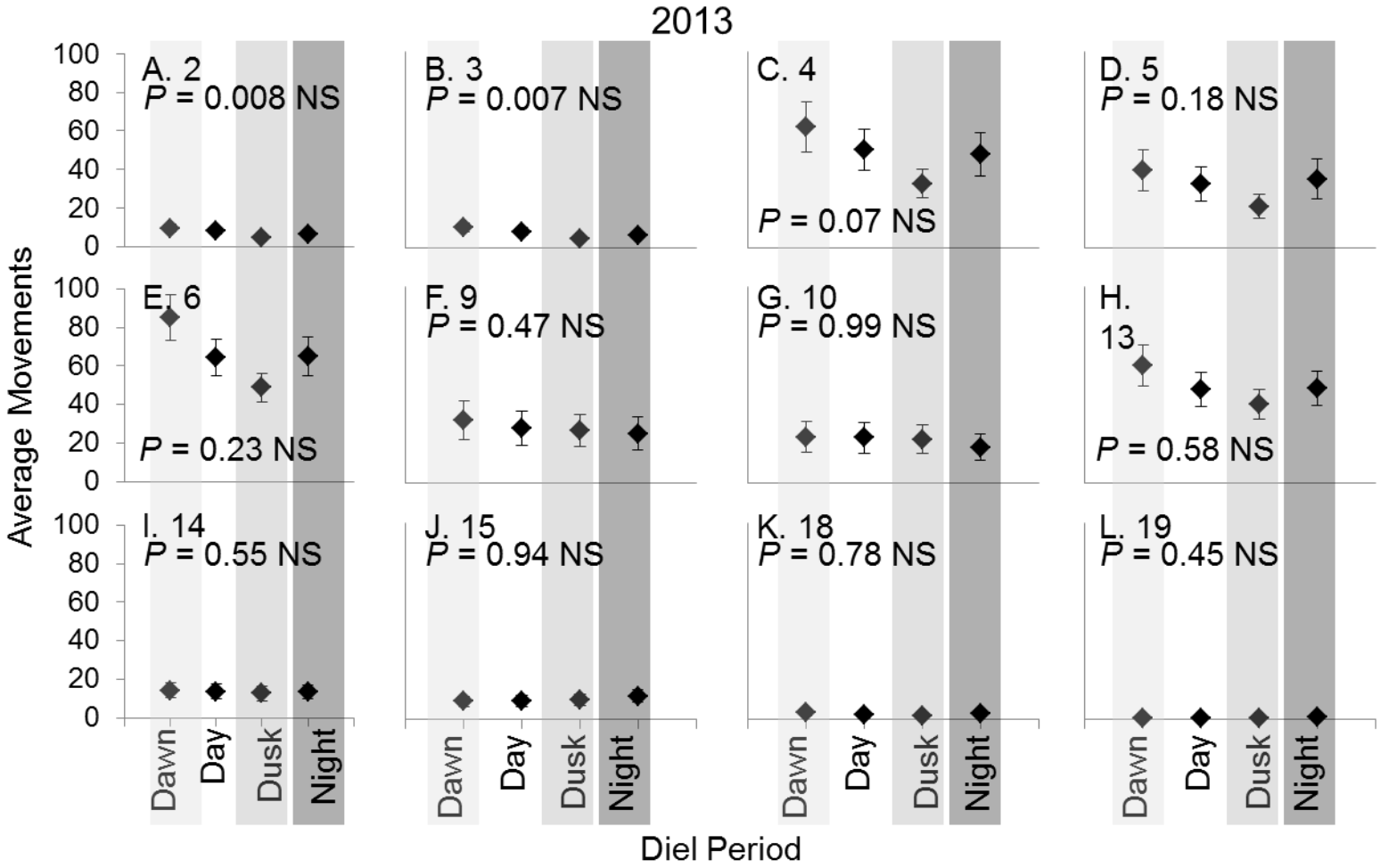


Figure E.4. Average and SE plots depicting diel changes in average movements in Milford Reservoir, KS in 2013. The X-axis is each diel period (dawn, day, dusk, night; indicated by the bars across plots) and the Y-axis is average movements. Y-axes are standardized to compare across months. Also shown are the results of a Kruskal-Wallis nonparametric ANOVA and a post-hoc Mann Whitney U multiple comparisons with a Bonferroni correction that tested the effect of month. Bonferroni corrected critical alpha of P<0.004 was considered significant.

Appendix F - Fish Size

Does fish size influence residence time and number of movements?

Methods

I also tested if total residence time and total movements differed across fish size. A linear regression between fish total length (mm TL; treatment or X) and residence time (response or Y) ('lm' function, 'stats' package, R) was used to test for differences between fish sizes.

Results

Fish of the same size were highly variable. Total residence time and total number of movements were tested across fish sizes to determine if the distribution of larger fish was different. Neither residence time ($P>0.05$; Fig. F.1A, B) nor number of movements ($P>0.05$; Fig. F.1C, D) differed by fish size. Fish of the same size were highly variable.

Discussion

I did not observe any difference in distribution and movement related to the size of the Blue Catfish. Most of the fish I tracked were a common size range (400-600 mm TL). Because Blue Catfish are reputed to spawn at 420-480 mm (Graham and DeiSanti 1999), most of the fish I tagged were a single ecological group, mature adults.

References

Graham, K., and K. DeiSanti. 1999. The population and fishery of Blue Catfish and Channel Catfish in the Harry S Truman Dam tailwater, Missouri. Pages 361–376 *in* E.R. Irwin, W.A. Hubert, C.F. Rabeni, H.L. Schramm, Jr. and T. Coon, editors. Catfish 2000: proceedings of the international Ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

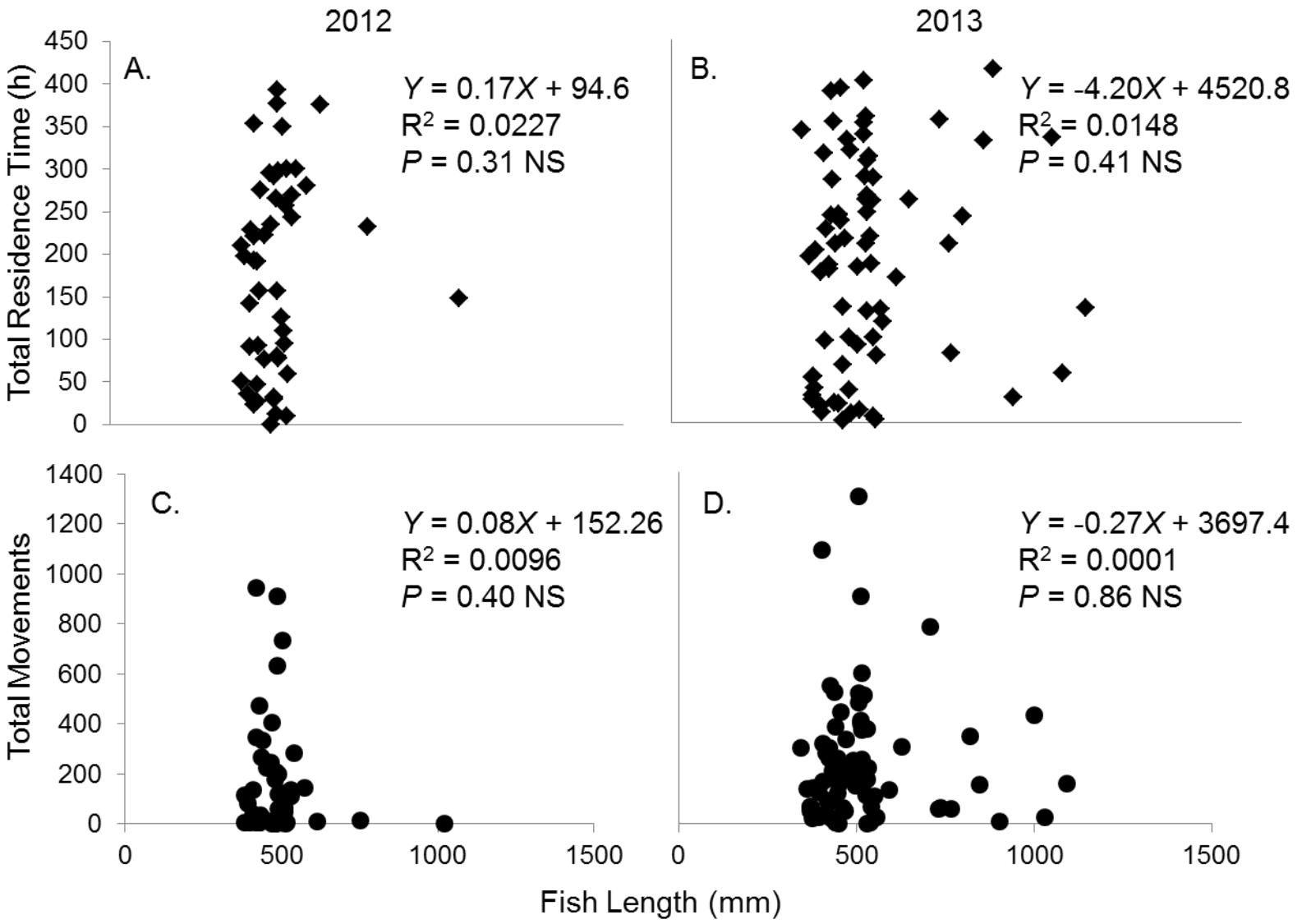


Figure F.1. Total residence time (h) and total movements across fish size in Milford Reservoir, KS in 2012 (A,C) and 2013 (B,D). The X-axis is fish length (mm) and the Y-axis is total residence time (h) (A,B) and total movements (C,D). Y-axes are

standardized to compare across years. Also shown are the results of a linear regression between fish total length (treatment) and residence time (response).

Appendix G - 2012 Fish Size and Release Location by Fish Group

Does the cluster analysis group fish by size and release location?

Fish size and release location were determined for the three groups of fish from the cluster simplifications. Neither larger fish nor smaller fish group together (Table F.1). The seasonal mover group (Group 1; Table G.1) was composed of fish from all three tagging locations (*n* = Causeway: 4, Madison: 7, School: 8). The consistently aggregated across seasons group (Group 2; Table G.1) was composed mostly of fish tagged at the Causeway location (*n* = 6). The Madison Creek group (Group 3; Table G.1) was composed of fish tagged at the Madison location (*n* = 4). In 2012, the majority of the fish that I tagged were within the targeted 400-600 mm size range. Only four fish were not within the size range (one smaller and three larger). These fish were spread between the three groups of fish, with two in the seasonal mover group and one a piece in the consistently aggregated across seasons and Madison Creek groups.

Table G.1. Comparing fish length (mm) and release locations for the 2012 final cluster simplifications in Milford Reservoir, KS in 2012.

Fish	Length (mm)	Release Location	Group
5	430	School	1
6	500	School	1
9	512	School	1
10	384	School	1
11	411	School	1
12	452	School	1
16	506	School	1
18	751	School	1
24	419	Causeway	1
28	408	Causeway	1
31	485	Madison	1
36	1020	Madison	1
37	487	Madison	1
40	487	Causeway	1
41	531	Causeway	1
44	504	Madison	1
45	480	Madison	1
46	421	Madison	1
48	469	Madison	1
17	490	School	2
19	392	Causeway	2
25	516	Causeway	2
29	419	Causeway	2
39	439	Causeway	2
42	436	Causeway	2
43	573	Causeway	2
47	532	Madison	2
23	615	Madison	3
34	466	Madison	3
35	542	Madison	3
38	489	Madison	3

Appendix H - Null Distributions

Do other null distributions provide different answers?

Other null hypotheses were tested in addition to an even distribution (e.g. hyp. 1: upper, hyp. 2: middle, and hyp. 3: lower) for both years (Fig. H.1 & H.2). Each null hypothesis was significant ($P < 0.001$) but there was a high degree of similarity between each hypothesis and the even distribution.

2012

Region	Receiver	Hyp. 1	Hyp. 2	Hyp. 3	Even
Upper	2	-30.66	-14.17	-10.87	-16.52
Upper	3	-21.94	-5.45	-2.16	-7.81
Upper	4	-17.1	-0.6	2.69	-2.96
Upper	5	-24.21	-7.71	-4.42	-10.07
Middle	6	35.16	26.37	35.16	29.51
Middle	9	21.52	12.72	21.52	15.87
Middle	10	17.87	9.07	17.87	12.22
Middle	12	27.24	18.44	27.24	21.58
Middle	14	0.08	-8.72	0.08	-5.58
Middle	15	1.14	-7.65	1.14	-4.51
Lower	16	-6.42	-9.72	-26.21	-12.08
Lower	17	1.24	-2.06	-18.55	-4.42
Lower	18	-6.42	-9.54	-26.03	-11.89
Lower	19	2.31	-0.98	-17.47	-3.34

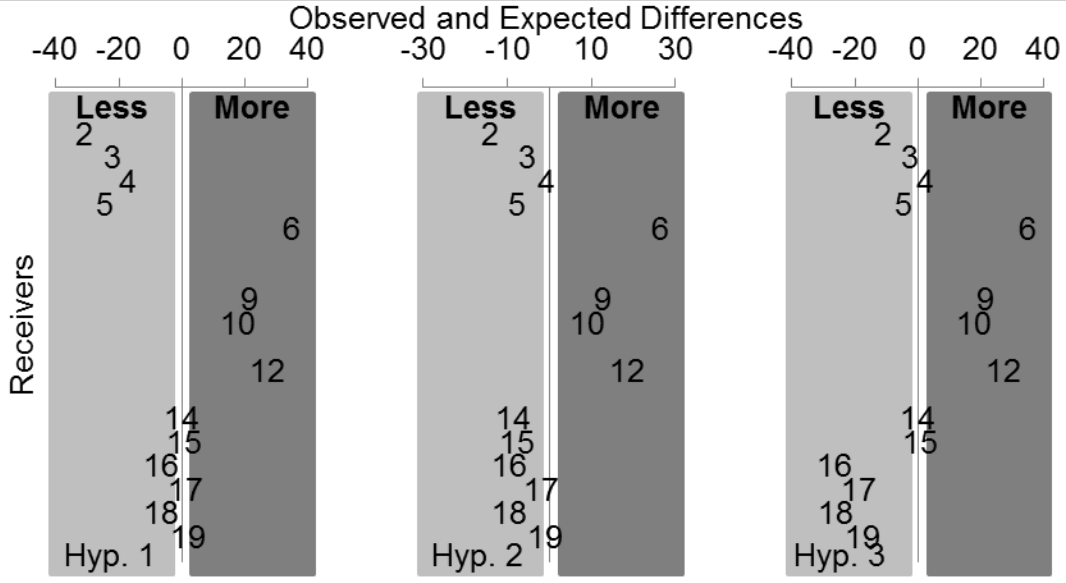


Figure H.1. Null distribution hypotheses 1, 2, and 3 compared to an even distribution in Milford Reservoir, KS in 2012. In the table, Observed and expected differences are listed

for each hypothesis and the even distribution. Also listed are the receivers and regions of the reservoir. In the plots, the X-axis is observed and expected differences and the Y-axis is receivers. The receivers within the light portion of the plot are locations where fish spent less time than expected and receivers within the dark portion are locations where fish spent more time than expected.

2013					
Region	Receiver	Hyp. 1	Hyp. 2	Hyp. 3	Even
Upper	2	-20.86	-4.28	-6.49	-12.88
Upper	3	-19.24	-2.65	-4.86	-11.25
Upper	4	26.94	43.53	41.31	34.93
Upper	5	-11.92	4.67	2.46	-3.93
Middle	6	47.77	37.63	50.17	43.78
Middle	9	3.6	-6.53	6	-0.39
Middle	10	-2.9	-13.03	-0.5	-6.89
Middle	13	6.94	-3.19	9.34	2.95
Middle	14	-5.28	-15.42	-2.89	-9.27
Middle	15	-2.64	-12.77	-0.24	-6.63
Lower	18	-11.46	-14.23	-47.4	-15.46
Lower	19	-10.96	-13.73	-46.9	-14.96

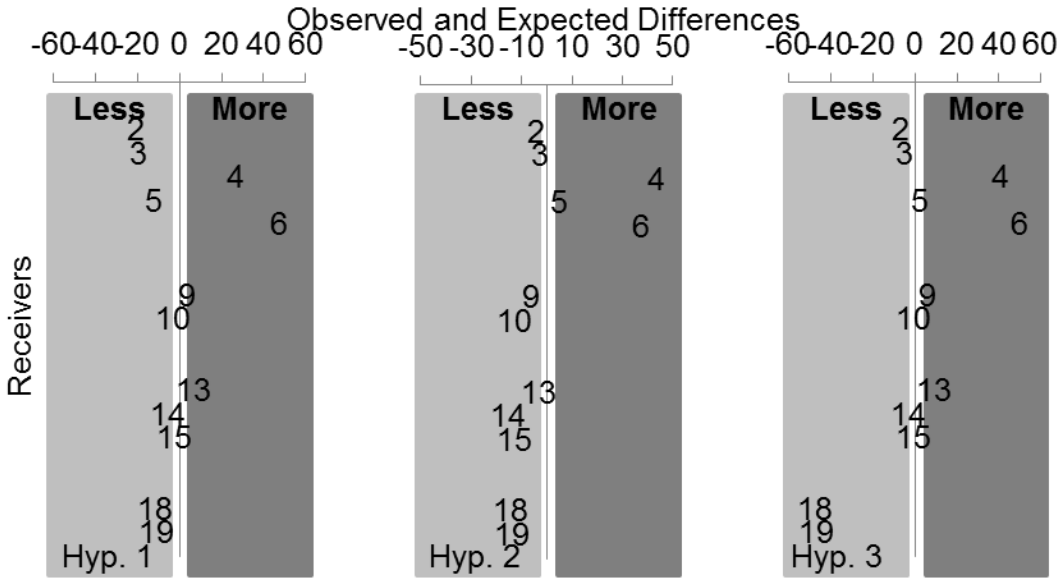


Figure H.2. Null distribution hypotheses 1, 2, and 3 compared to an even distribution in Milford Reservoir, KS in 2013. In the table, Observed and expected differences are listed

for each hypothesis and the even distribution. Also listed are the receivers and regions of the reservoir. In the plots, the X-axis is observed and expected differences and the Y-axis is receivers. The receivers within the light portion of the plot are locations where fish spent less time than expected and receivers within the dark portion are locations where fish spent more time than expected.

Appendix I - 2013

In 2013, does fish distribution change across seasons?

2013 - Seasonal

In 2013, as observed in 2012, seasonal changes reflected decreases in residence time in the upper region locations and increases in residence in the lower region locations in the fall as fish in the upper and middle regions moved south. Use of the upper region (receivers 2, 3, 4, 5) was variable across months. Receivers 2 and 3 in the upper region of the reservoir were significantly different across months when using a Bonferroni corrected critical alpha of 0.05/12 or 0.004 (Fig. I.1A). The receivers in the upper region showed a trend of decreasing residence times later in the year (i.e., October and November). All receivers in the lower region were significantly different across months (receivers 18 and 19; Fig. I.1D). For these southern receivers, residence times were higher in the fall. These patterns were the result of a select group of tagged fish moving southward, to various degrees, in Milford Reservoir in the fall.

Monthly changes were also observed with mean movement data, but data was more variable. Mean movements were highly variable in the upper region of the reservoir (receiver 2-5). Although statistically significant when using a Bonferroni corrected critical alpha of 0.004, movements in the upper region of the reservoir were quantitatively small or inconsistent across months (receivers: 2-4; Fig. I.2A). In the upper end of the middle region and the lower region of the reservoir (receivers: 6, 18, and 19; $P<0.01$; Fig. I.2C, D) movements increased in the fall.

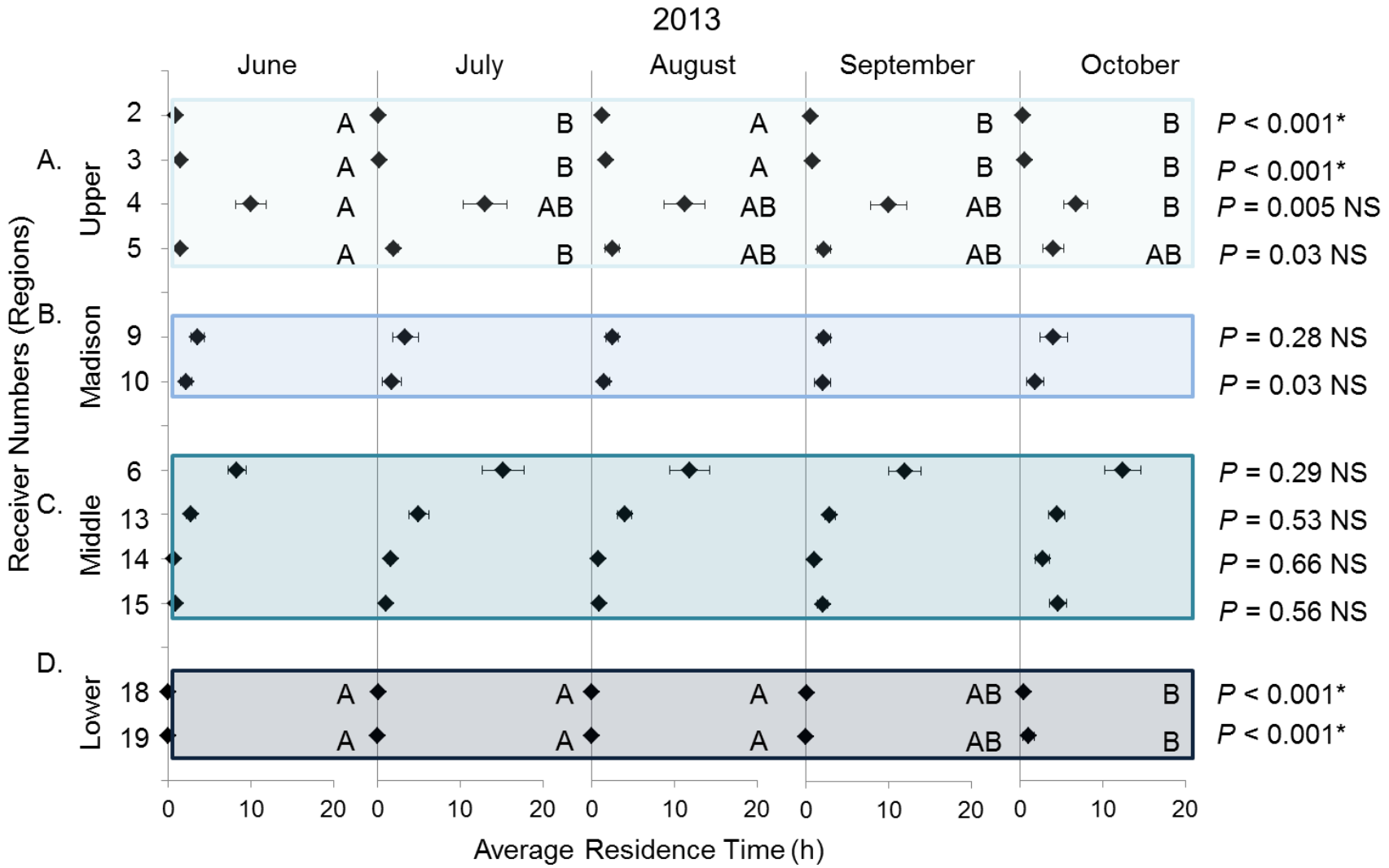


Figure I.1. Average and SE plots depicting monthly changes in average residence time (h) in Milford Reservoir, KS in 2013. The X-axis is average residence time (h) for each month and the Y-axis is receiver. Y-axes are standardized to compare across months. The boxes across the graphs indicate the regions of the reservoir: (A) Upper, (B) Madison, (C) Middle, and (D)

Lower. Also shown are the results of a Kruskal-Wallis nonparametric ANOVA and a post-hoc Mann Whitney U multiple comparisons with a Bonferroni correction that tested the effect of month. Bonferroni corrected critical alpha P<0.004 was considered significant.

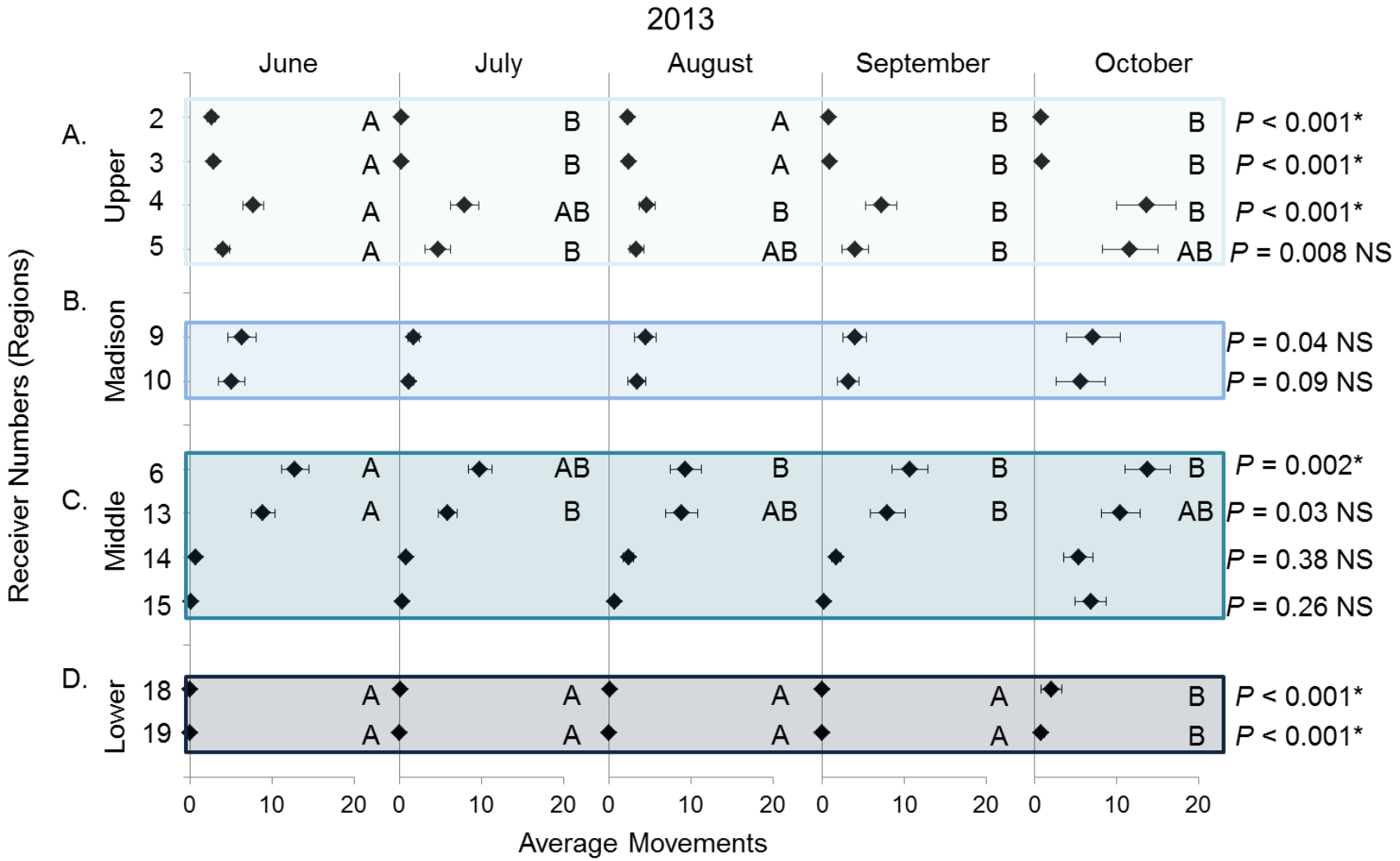


Figure I.2. Average and SE plots depicting monthly changes in average movements in Milford Reservoir, KS in 2013. The X-axis is average movements for each month and the Y-axis is receiver. Y-axes are standardized to compare across months. The boxes across the graphs indicate the regions of the reservoir: (A) Upper, (B) Madison, (C) Middle, and (D) Lower. Also shown

are the results of a Kruskal-Wallis nonparametric ANOVA and a post-hoc Mann Whitney U multiple comparisons with a Bonferroni correction that tested the effect of month. Bonferroni corrected critical alpha P<0.004 was considered significant.

Appendix J - 2012 Cluster Analyses by Month

Do fish group together?

Clusters of fish were formed using residence time (h) for each individual month for 2012. In July, this resulted in four clusters (Fig. J.1-4). In August, this resulted in three clusters (Fig. J.5-8). In September, this resulted in eight clusters (Fig. J.9-12). In October, this resulted in four clusters (Fig. J.13-16). In November, this resulted in three clusters (Fig. J.17-20).

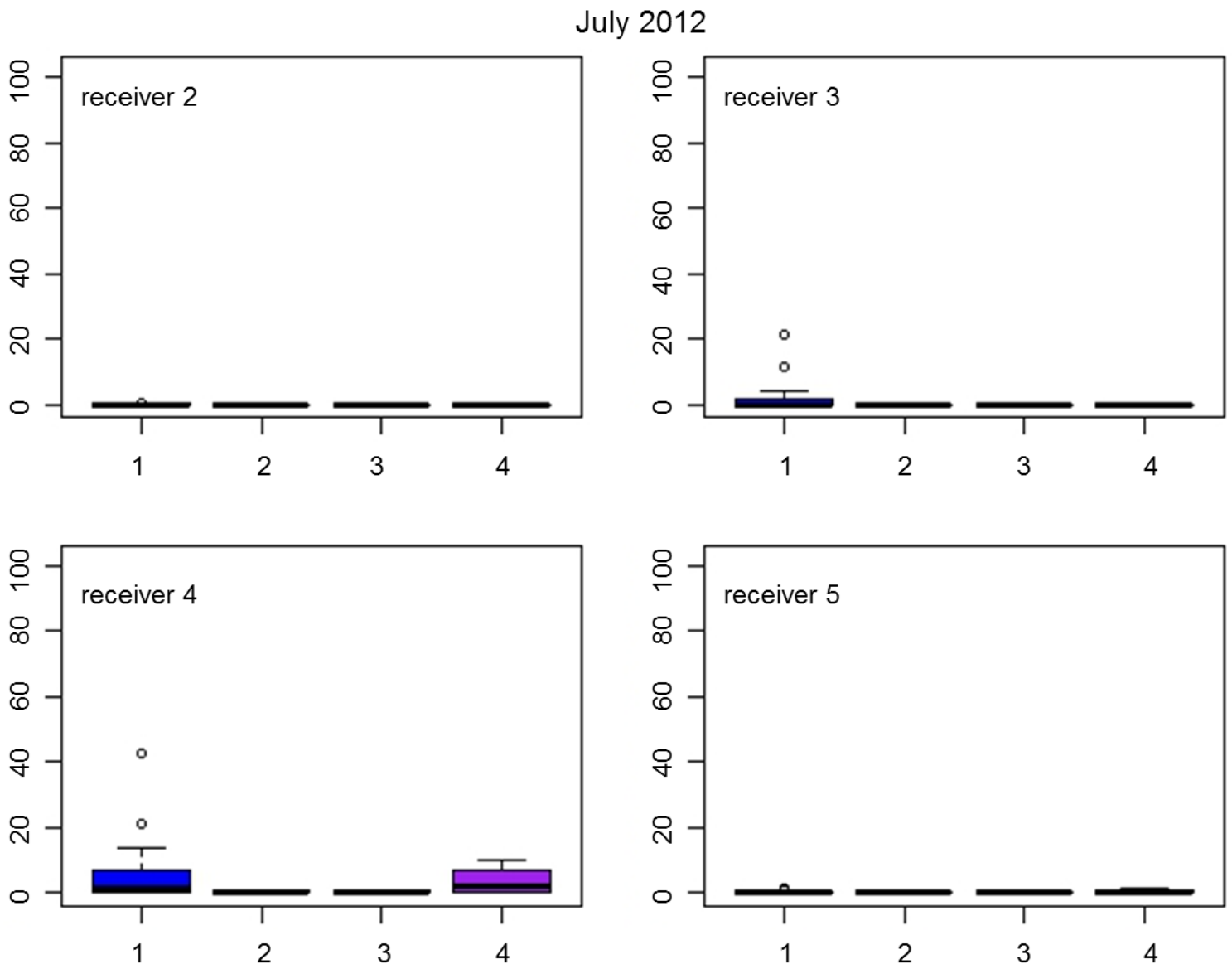


Figure J.1. Boxplots of residence times for receivers 2-5 in Milford Reservoir, KS in July, 2012. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

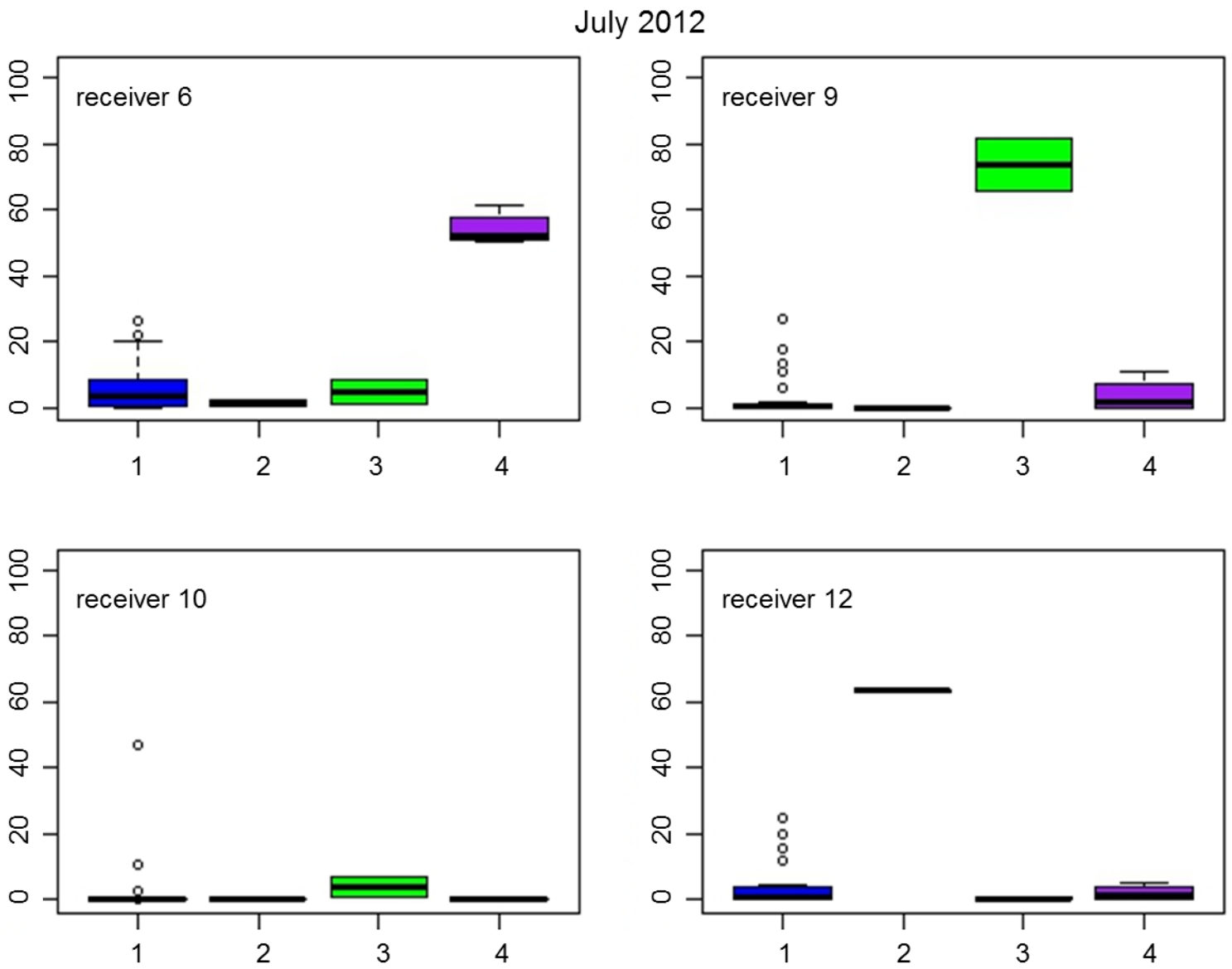


Figure J.2. Boxplots of residence times for receivers 6-12 in Milford Reservoir, KS in July, 2012. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

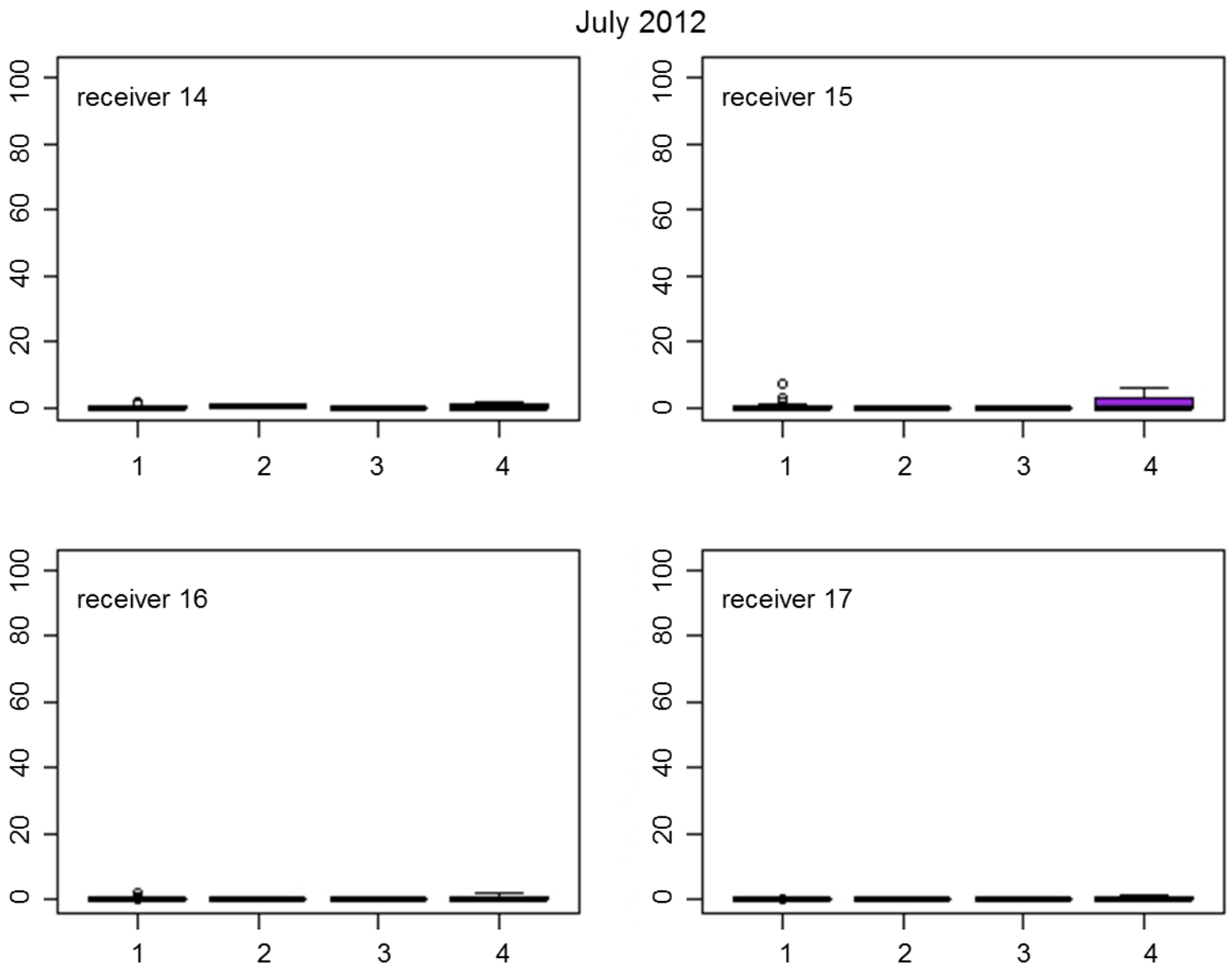


Figure J.3. Boxplots of residence times for receivers 14-17 in Milford Reservoir in KS, July, 2012. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

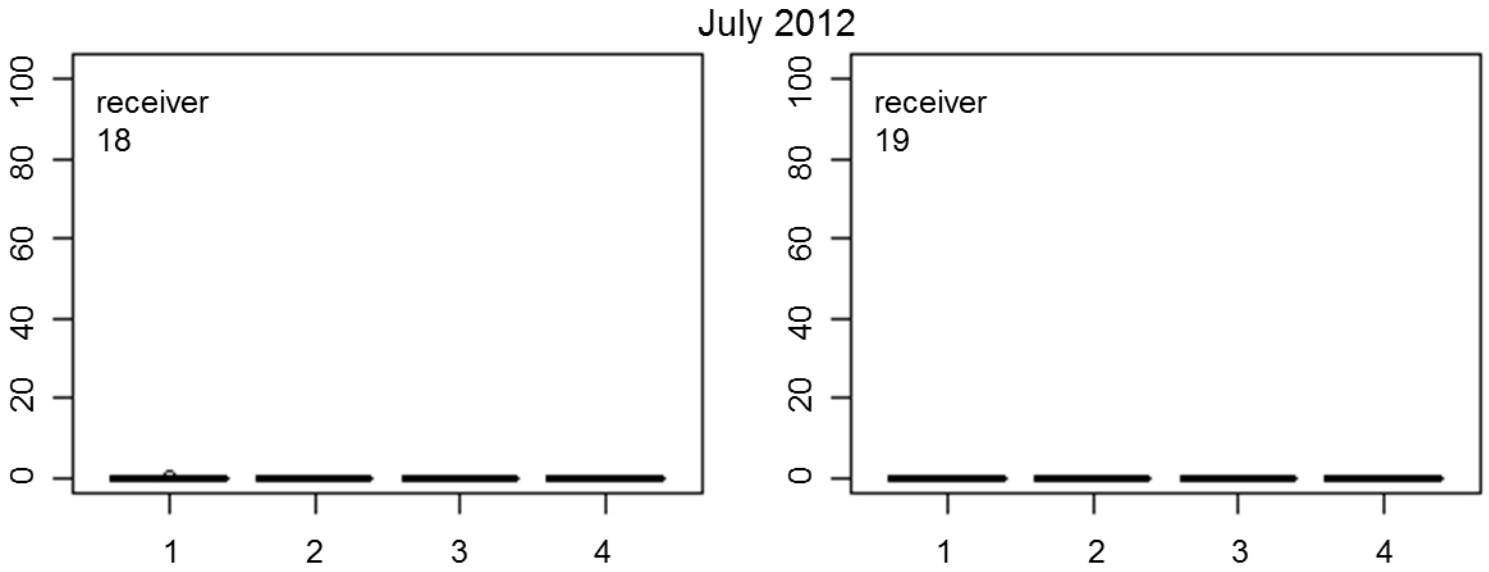


Figure J.4. Boxplots of residence times for receivers 18 & 19 in Milford Reservoir, KS in July, 2012. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

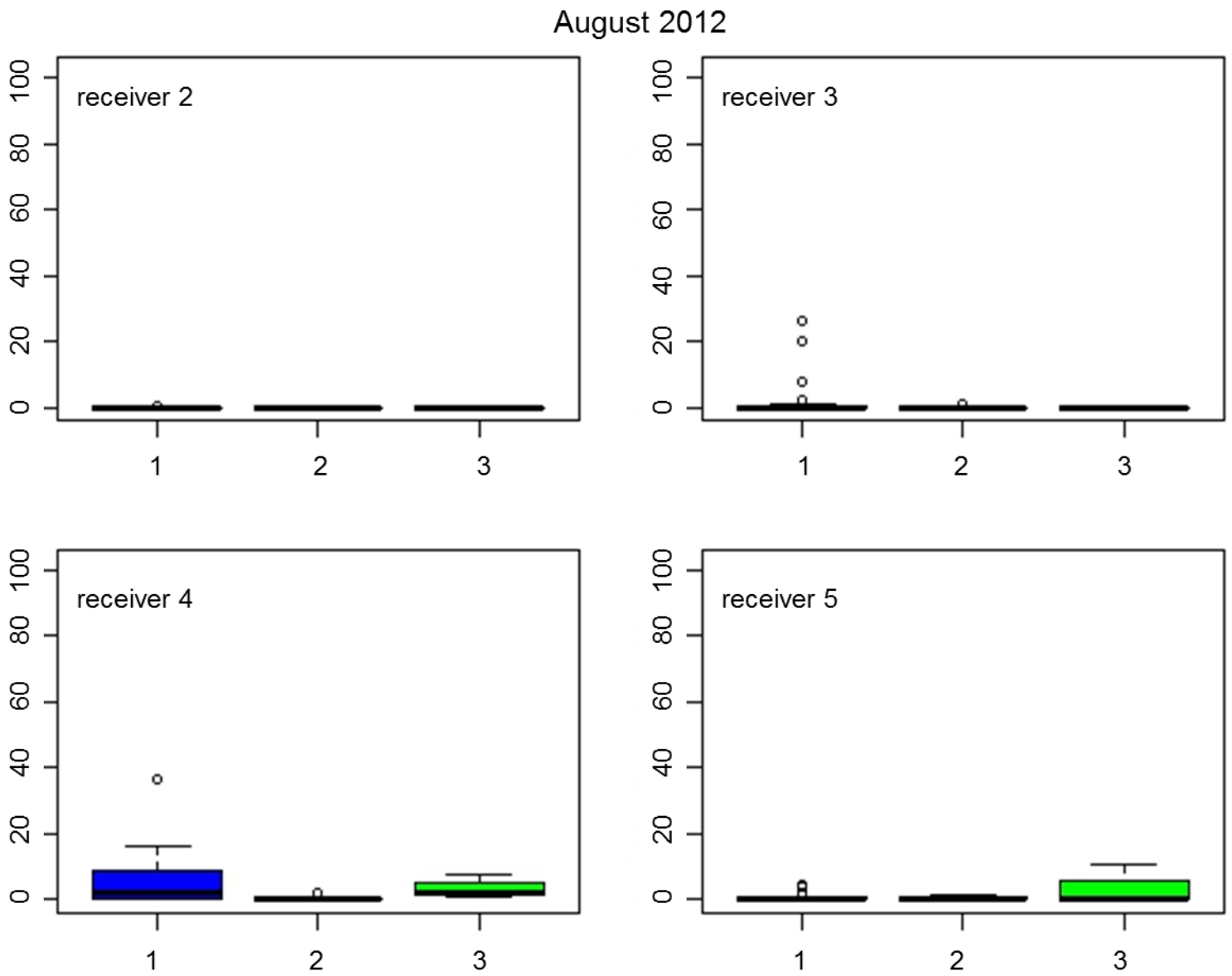


Figure J.5. Boxplots of residence times for receivers 2-5 in Milford Reservoir, KS in August, 2012. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

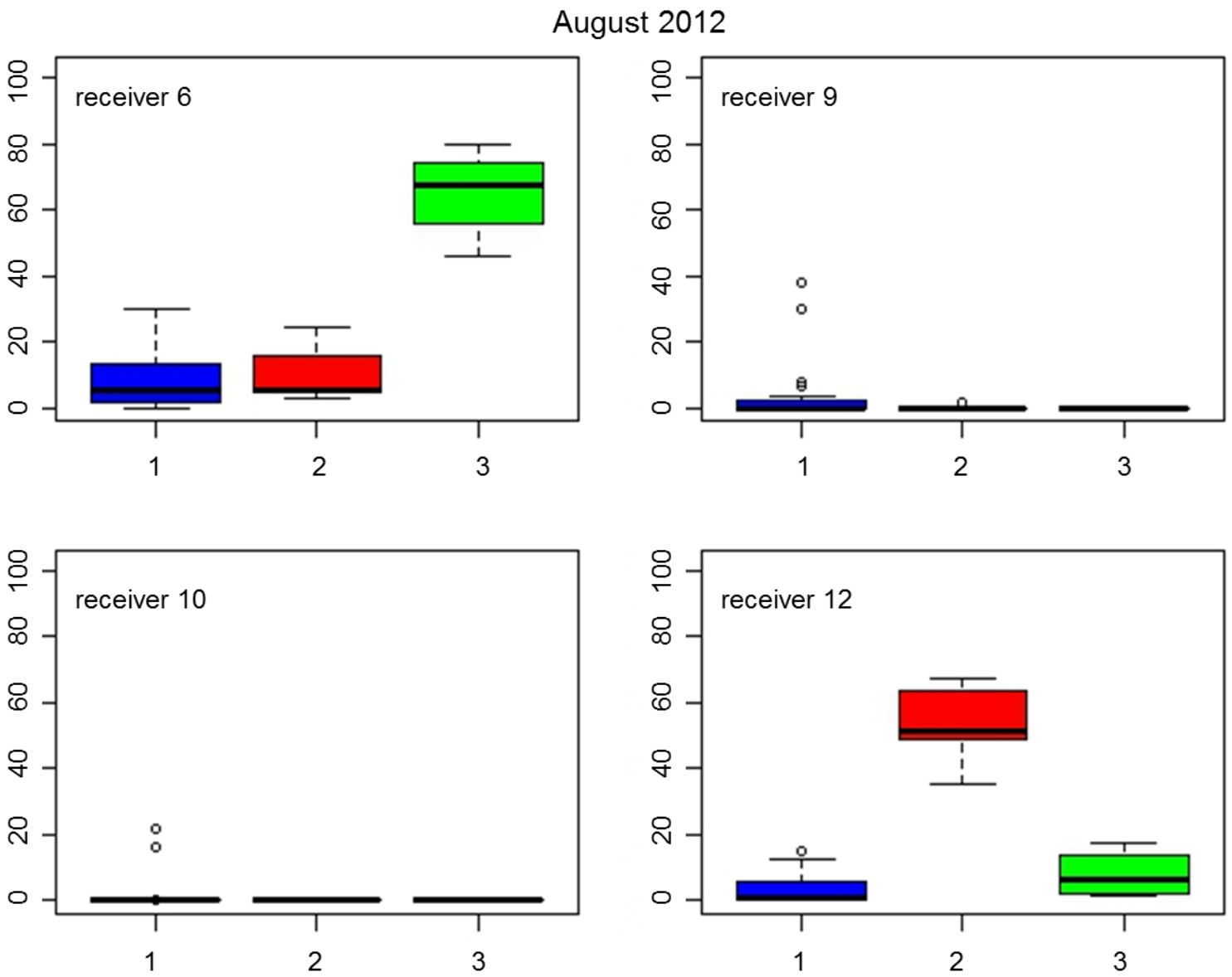


Figure J.6. Boxplots of residence times for receivers 6-12 in Milford Reservoir, KS in August, 2012. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

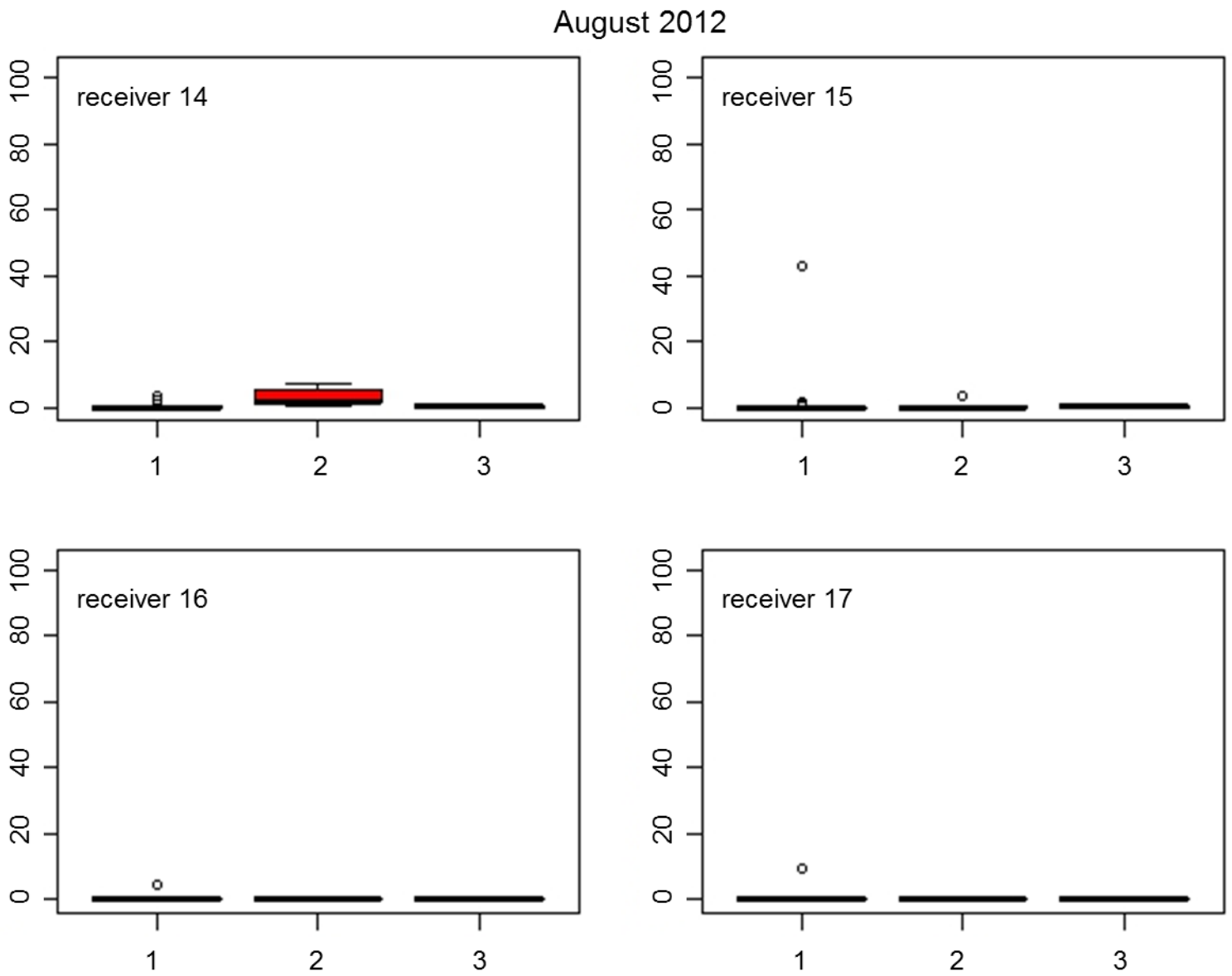


Figure J.7. Boxplots of residence times for receivers 14-17 in Milford Reservoir, KS in August, 2012. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

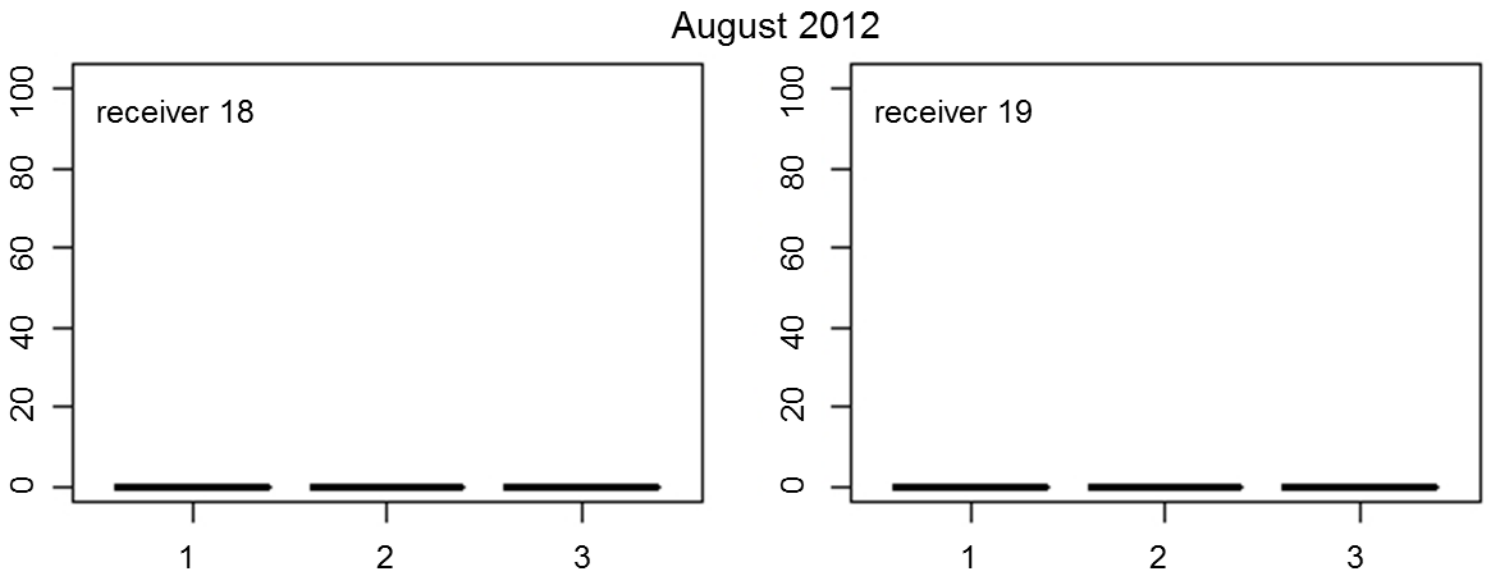


Figure J.8. Boxplots of residence times for receivers 18 & 19 in Milford Reservoir, KS in August, 2012. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

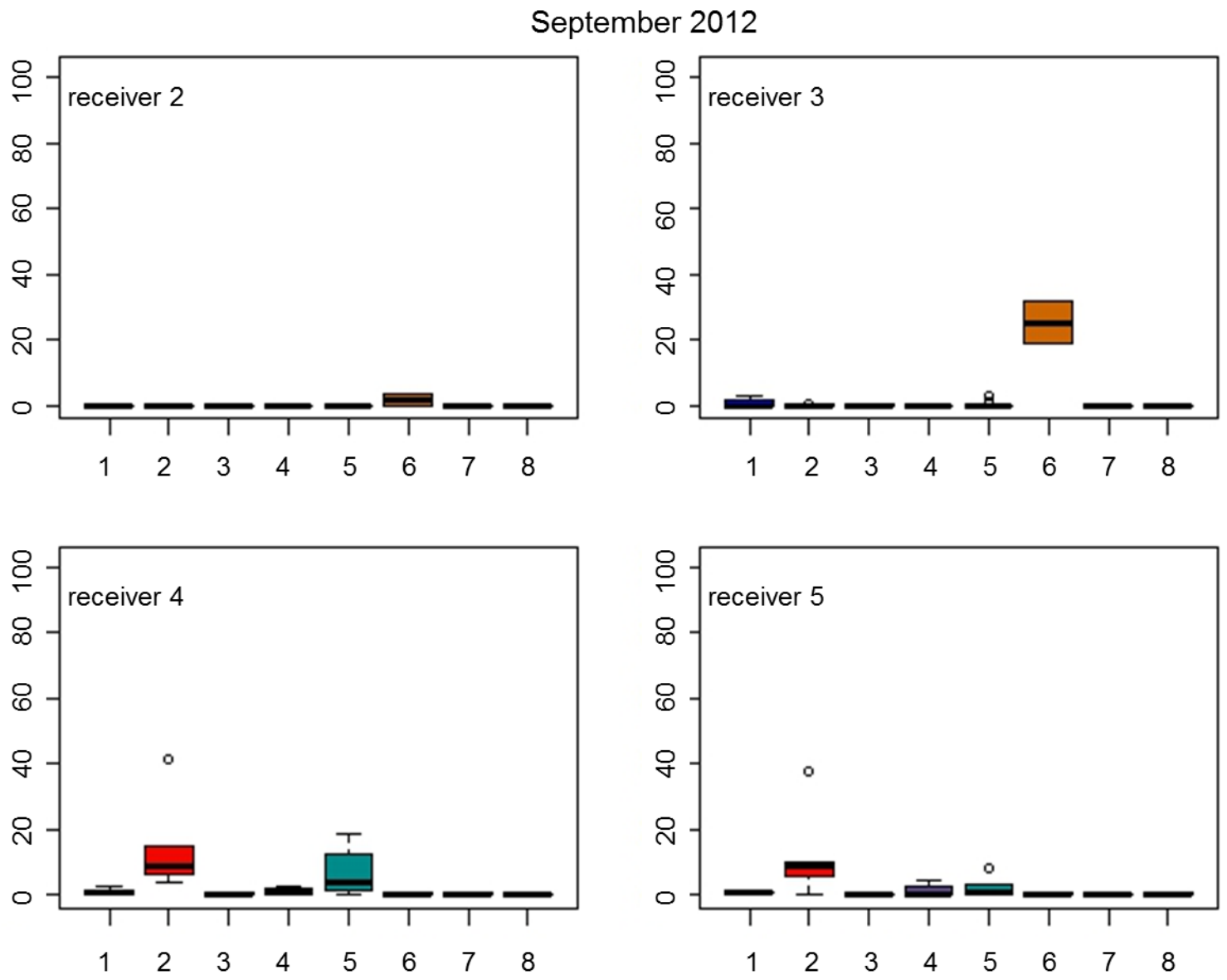


Figure J.9. Boxplots of residence times for receivers 2-5 in Milford Reservoir, KS in September, 2012. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

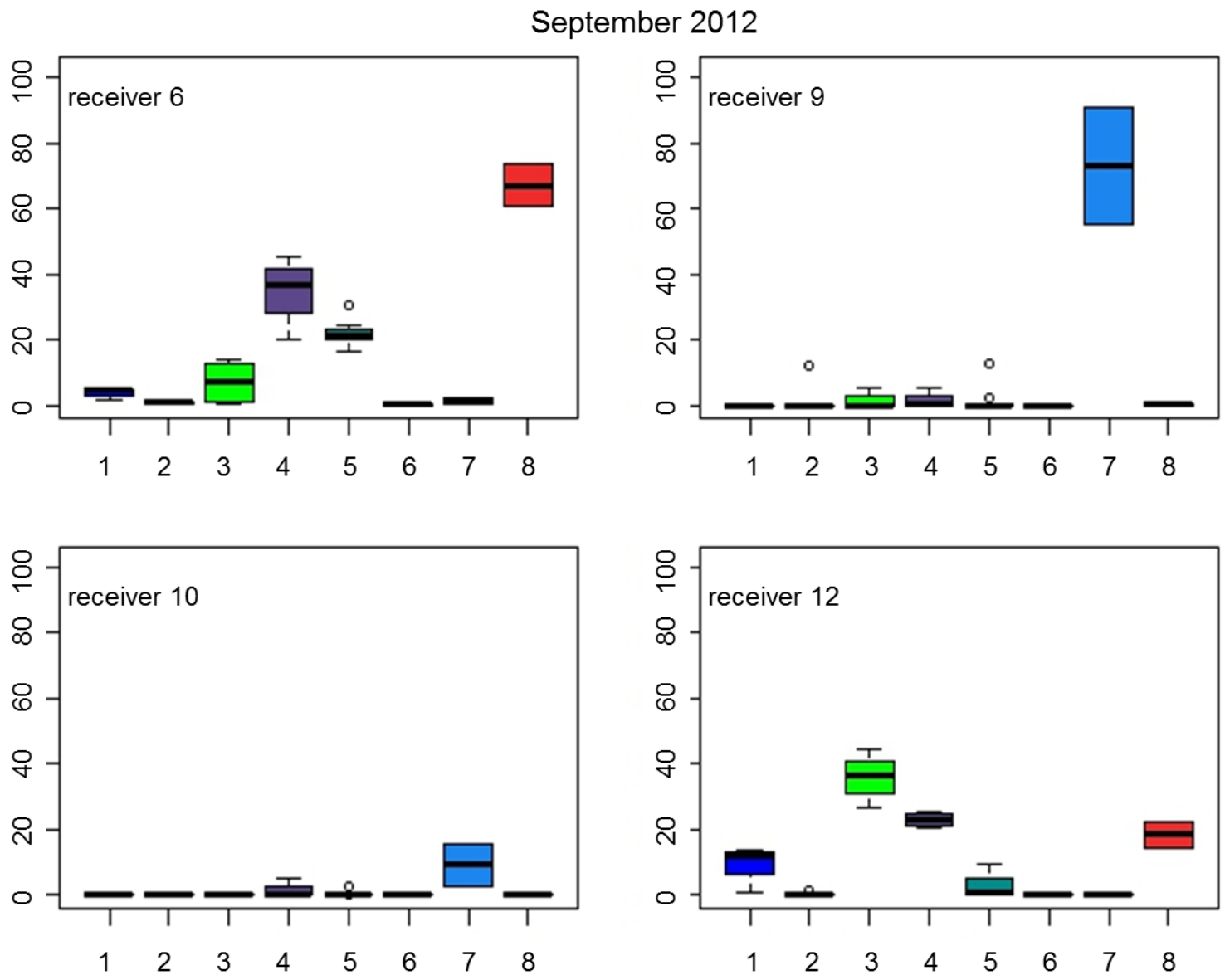


Figure J.10. Boxplots of residence times for receivers 6-12 in Milford Reservoir, KS in September, 2012. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

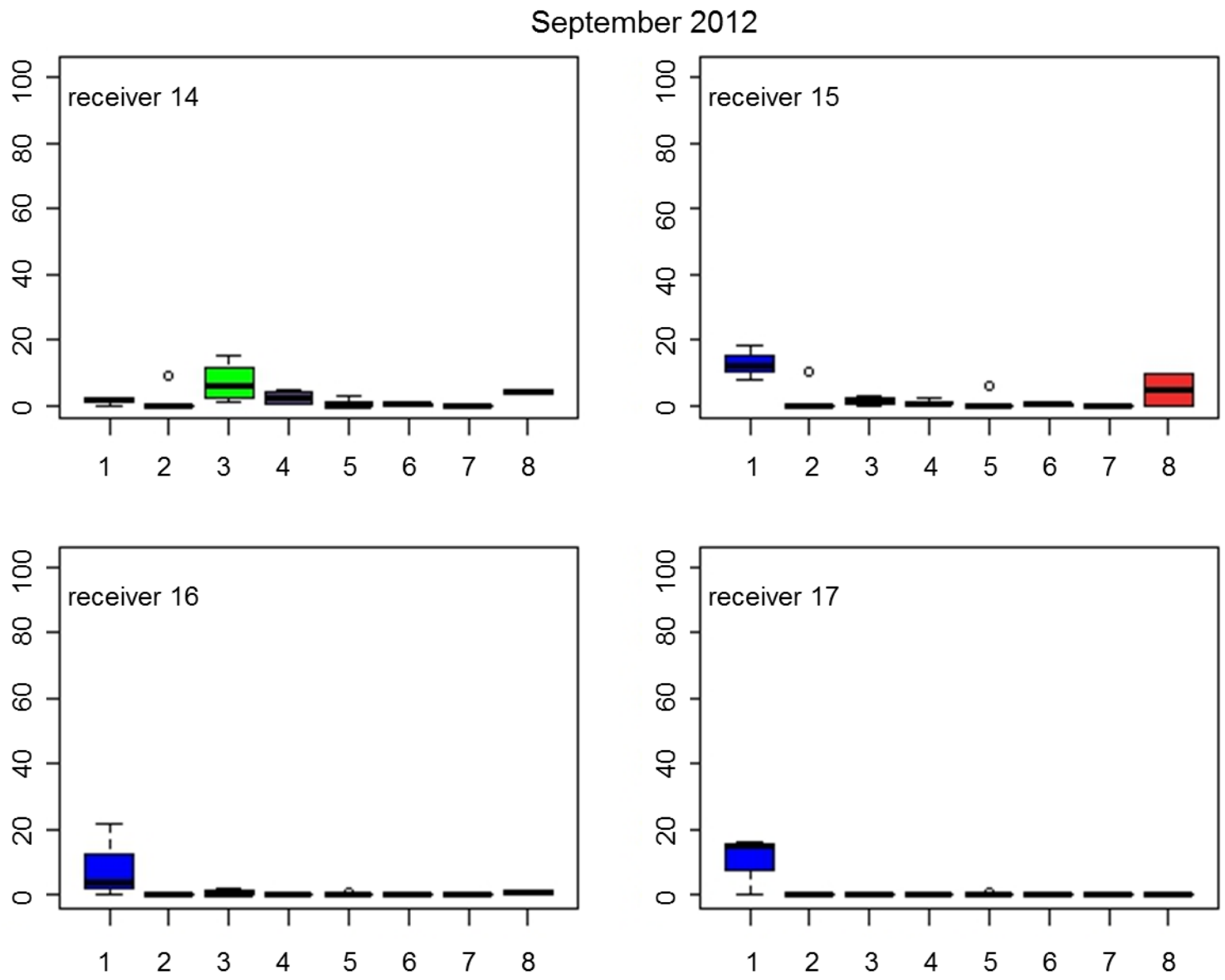


Figure J.11. Boxplots of residence times for receivers 14-17 in Milford Reservoir, KS in September, 2012. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

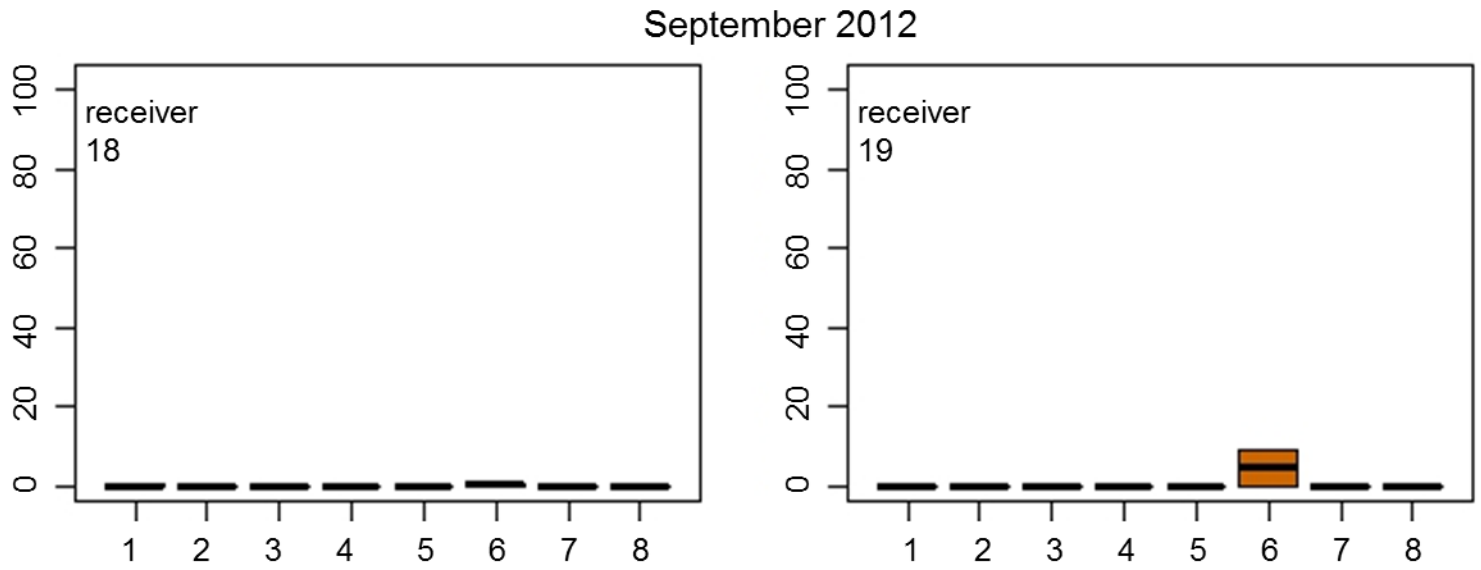


Figure J.12. Boxplots of residence times for receivers 18 & 19 in Milford Reservoir, KS in September, 2012. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

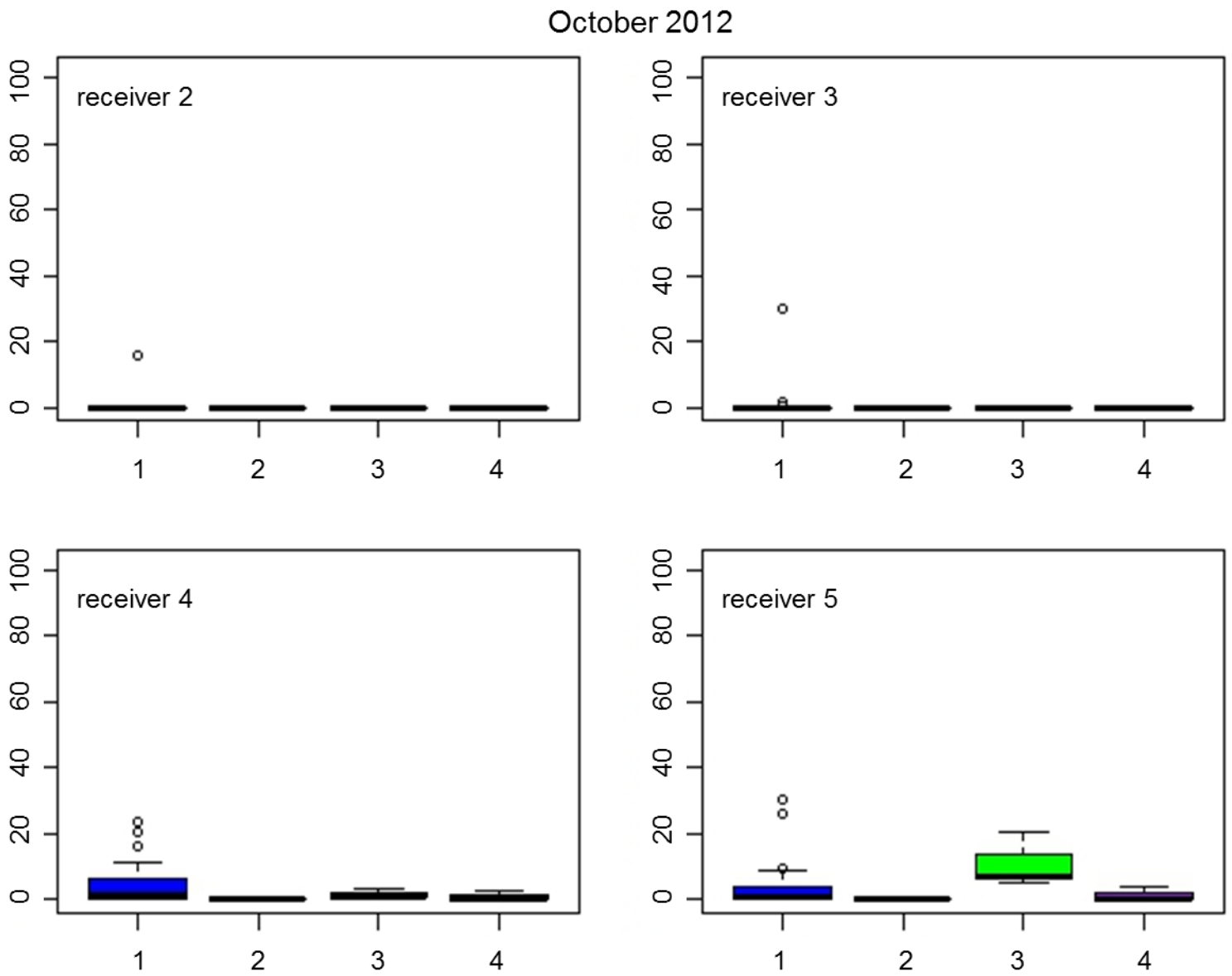


Figure J.13. Boxplots of residence times for receivers 2-5 in Milford Reservoir, KS, October in 2012. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

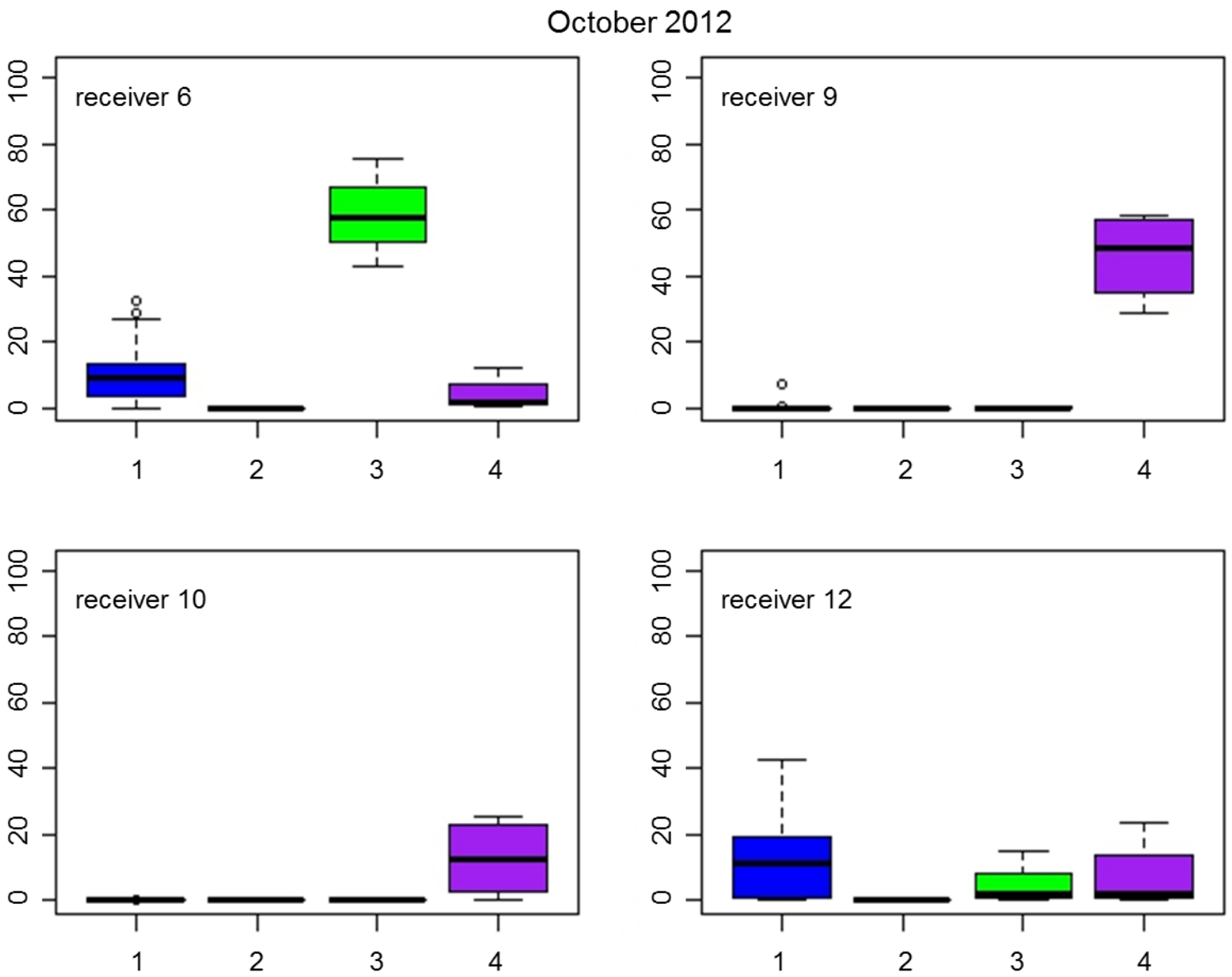


Figure J.14. Boxplots of residence times for receivers 6-12 in Milford Reservoir, KS in October, 2012. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

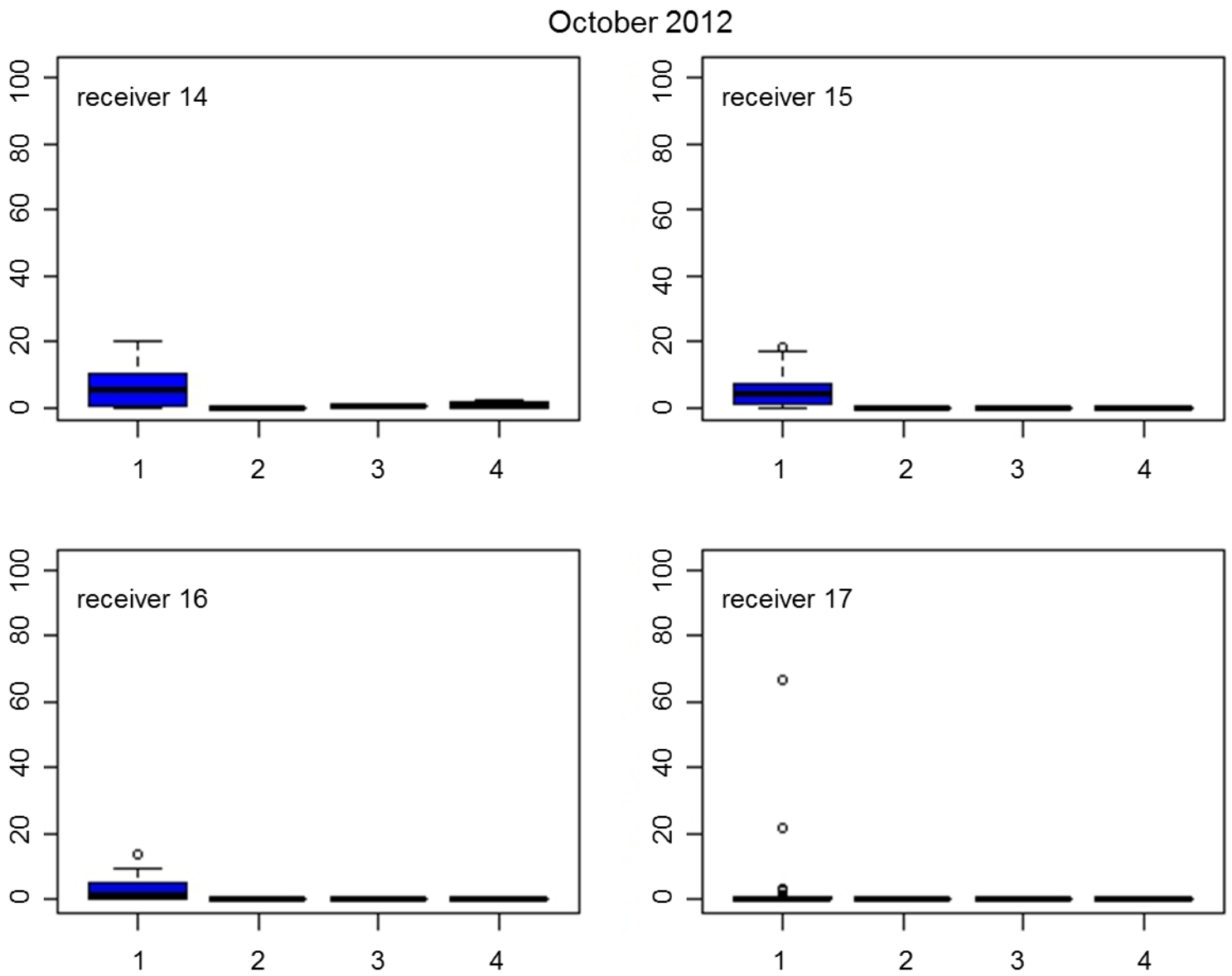


Figure J.15. Boxplots of residence times for receivers 14-17 in Milford Reservoir, KS in October, 2012. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

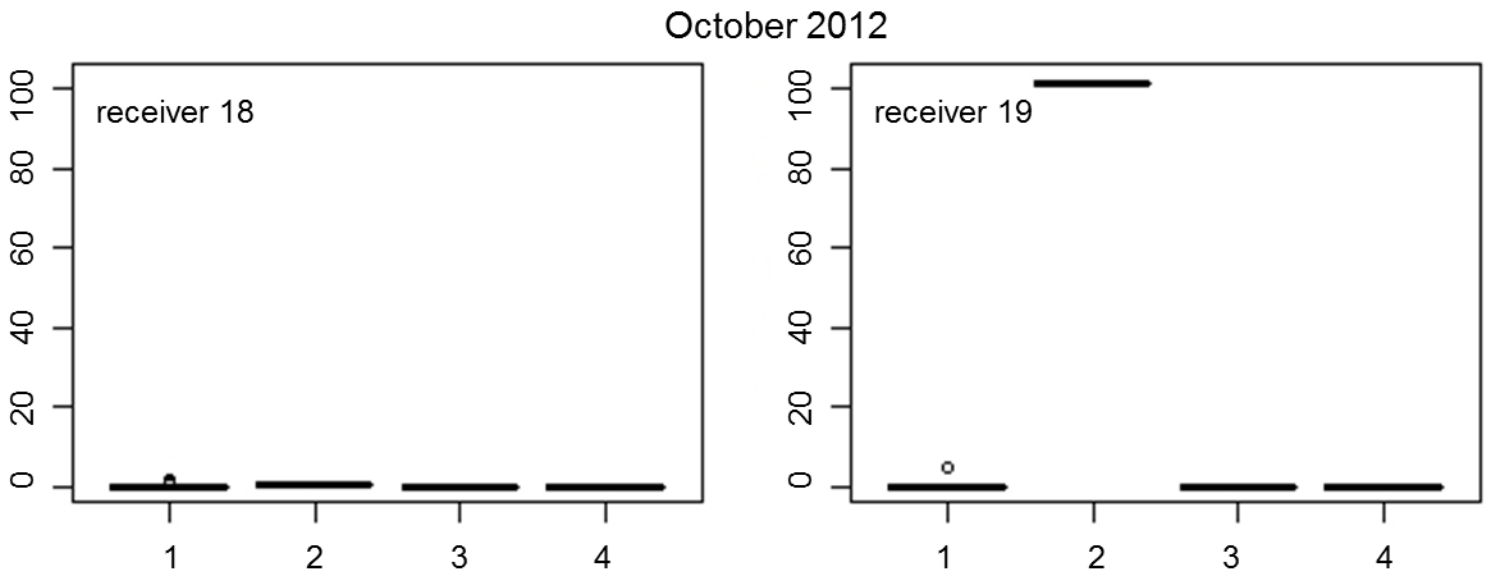


Figure J.16. Boxplots of residence times for receivers 18 & 19 in Milford Reservoir, KS in October, 2012. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

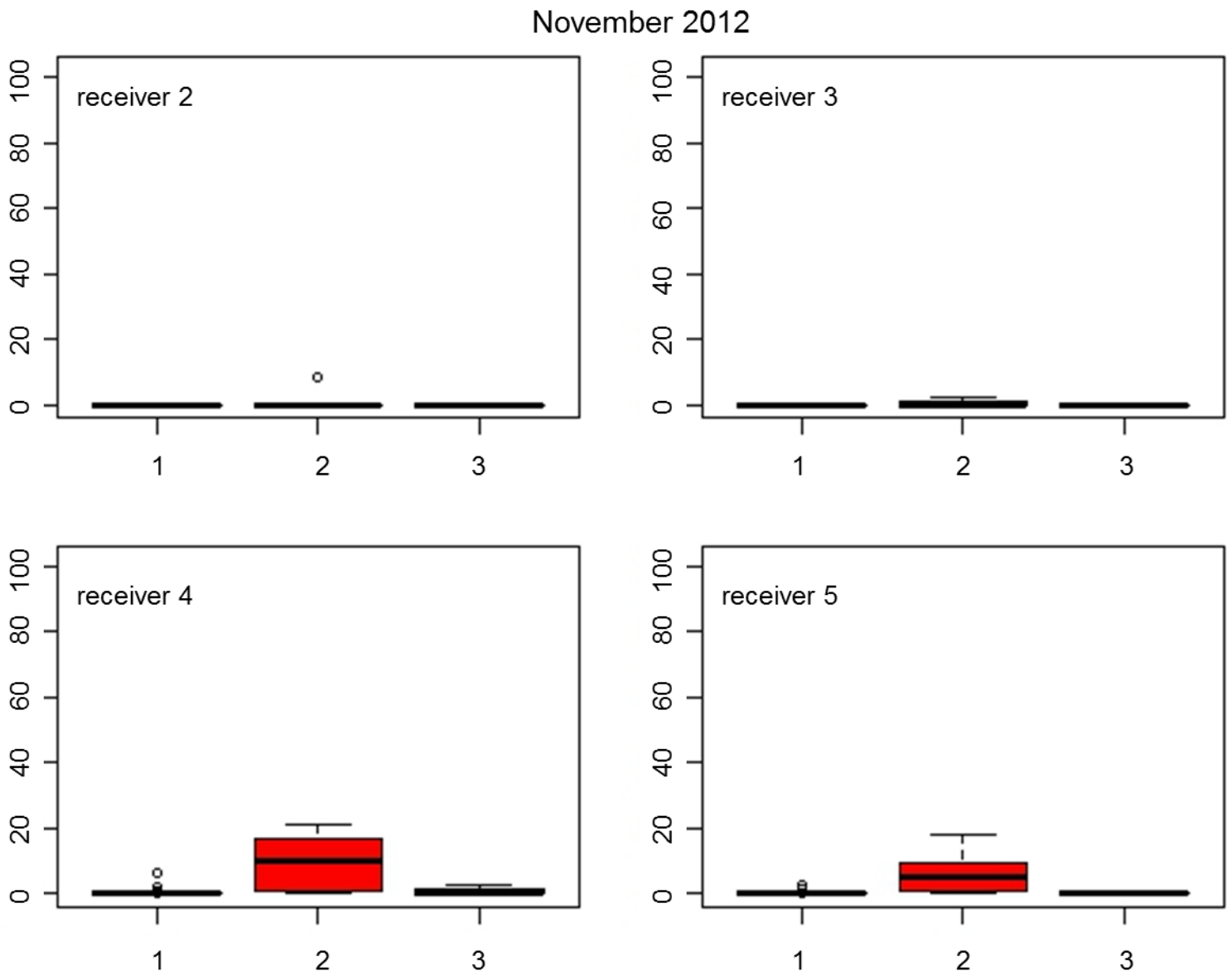


Figure J.17. Boxplots of residence times for receivers 2-5 in Milford Reservoir, KS in November, 2012. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

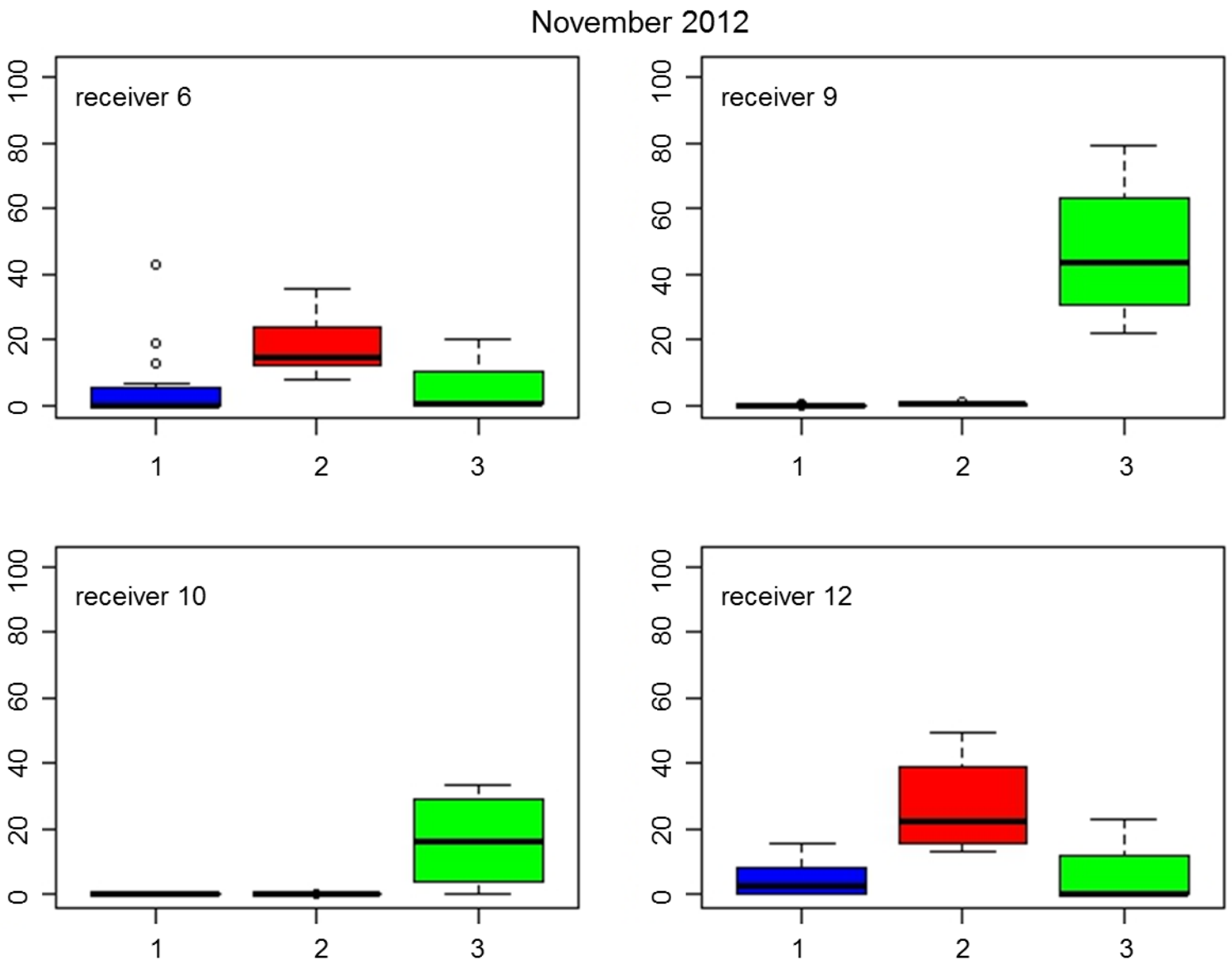


Figure J.18. Boxplots of residence times for receivers 6-12 in Milford Reservoir, KS in November, 2012. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

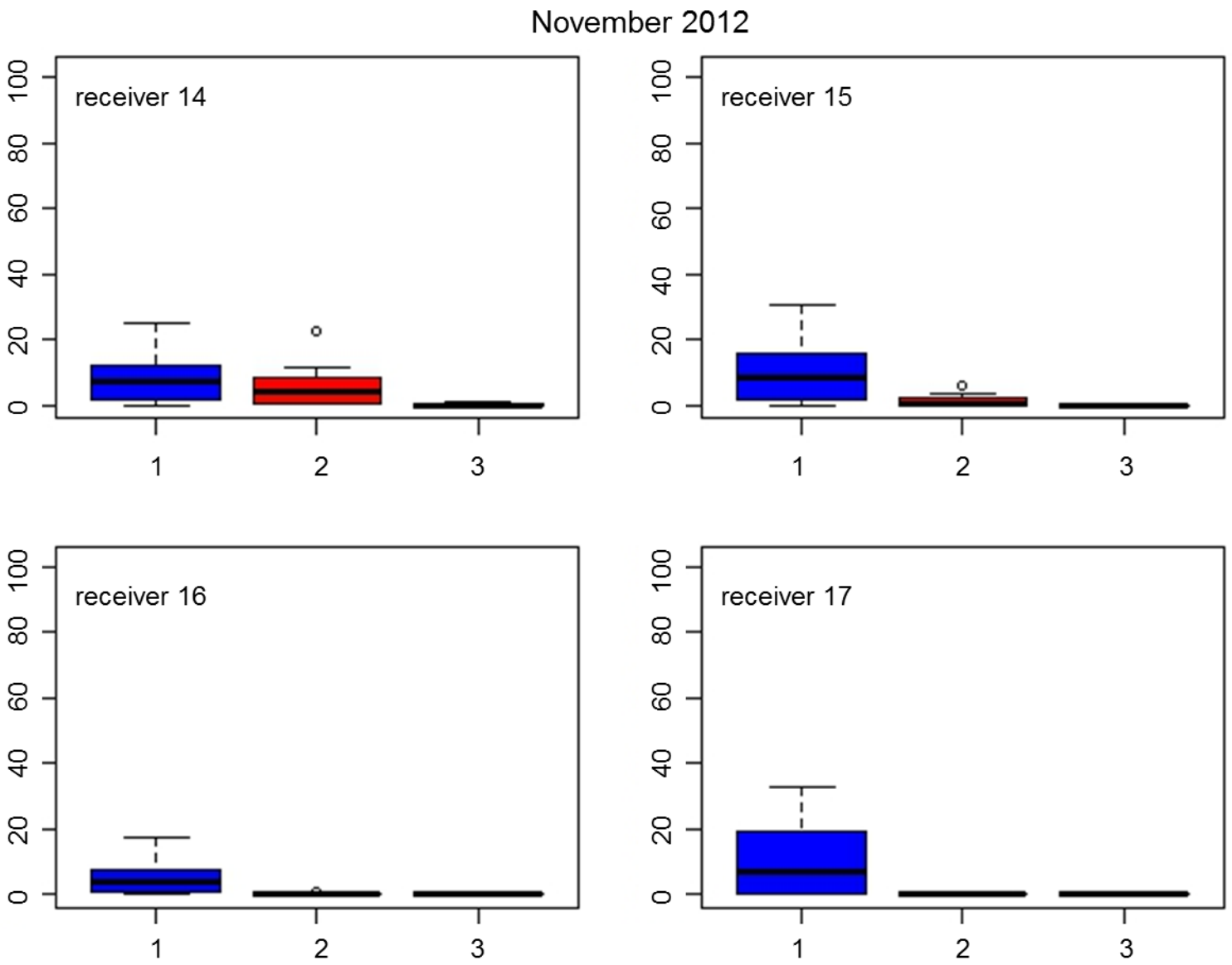


Figure J.19. Boxplots of residence times for receivers 14-17 in Milford Reservoir, KS in November, 2012. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

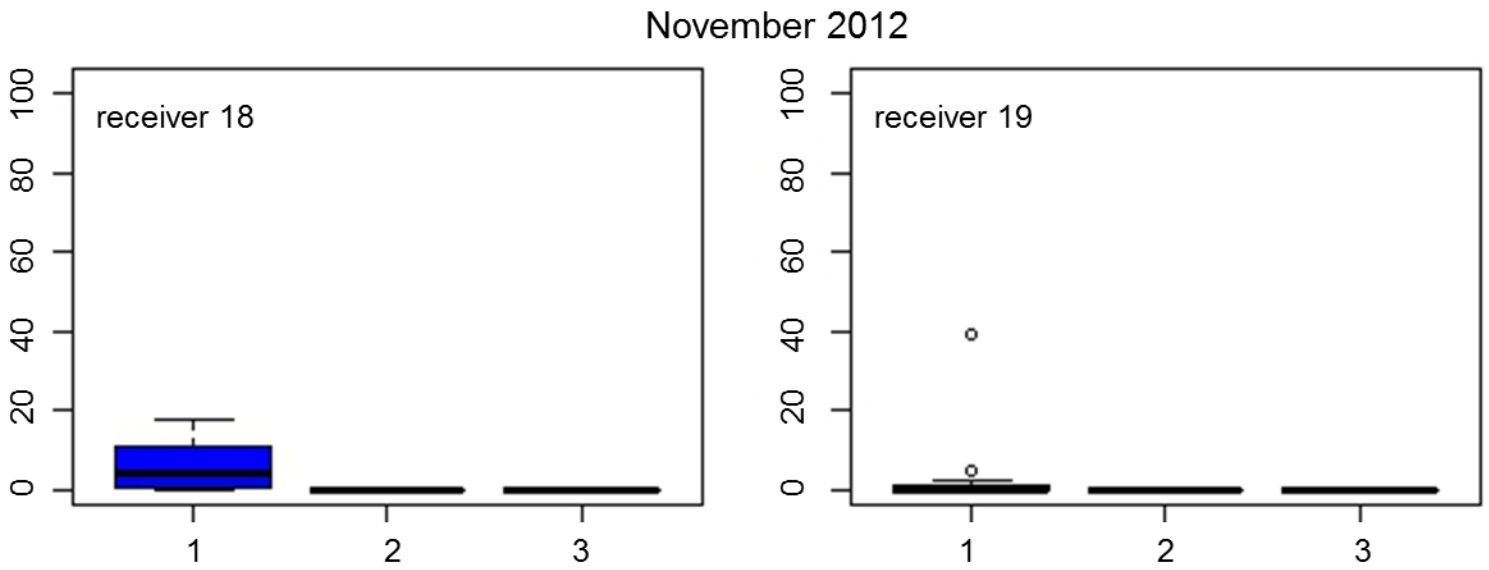


Figure J.20. Boxplots of residence times for receivers 18 & 19 in Milford Reservoir, KS in November, 2012. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

Appendix K - 2013 Cluster Analyses by Month

Do fish group together?

Clusters were created using residence time (h) for each individual month for 2013. In June, this resulted in two clusters (Fig. K.3-5). In July, this resulted in seven clusters (Fig. K.6-8). In August, this resulted in two clusters (Fig. K.9-11). In September, this resulted in eight clusters (Fig. K.12-14). In October, this resulted in twelve clusters (Fig. K.15-17).

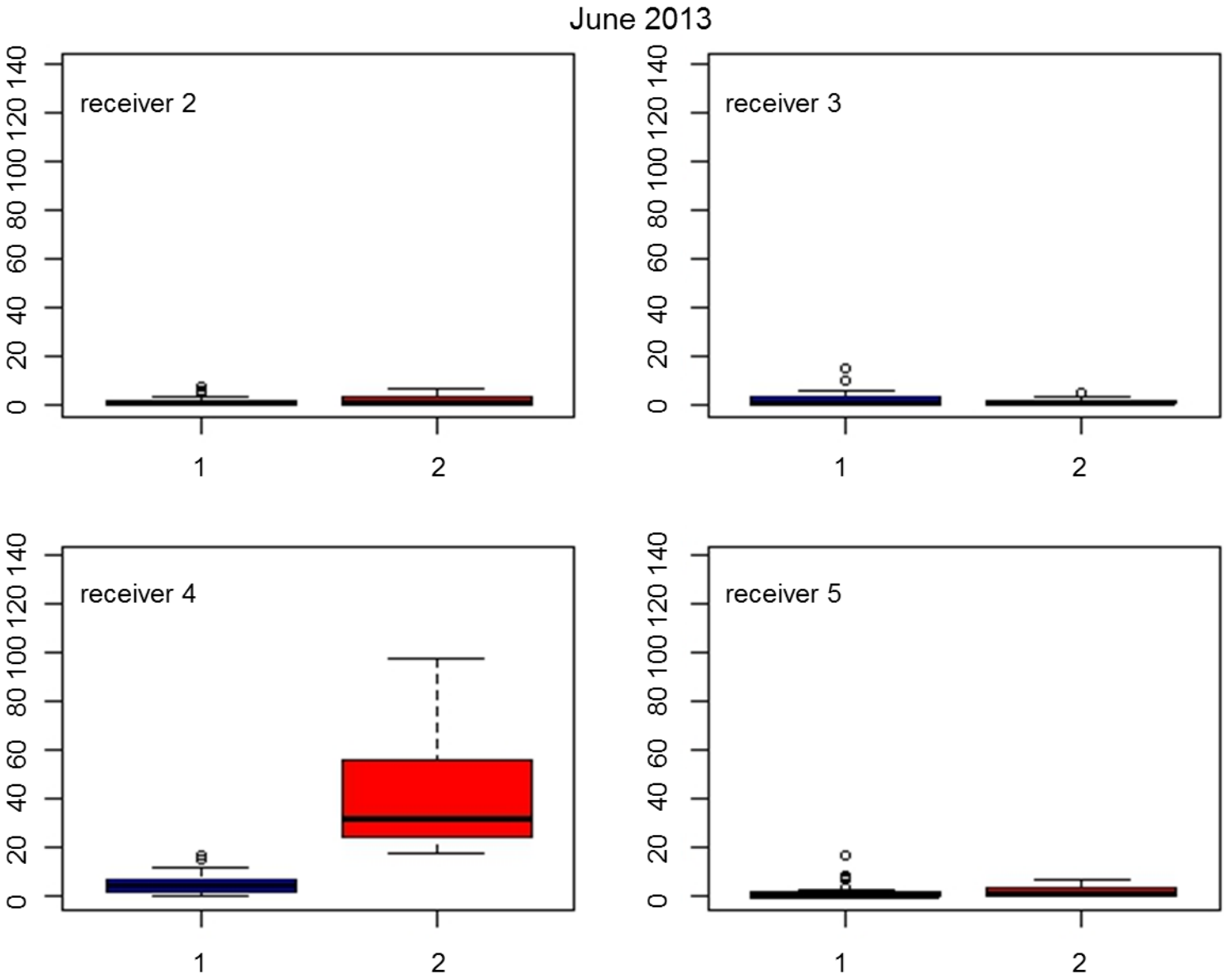


Figure K.1. Boxplots of residence times for receivers 2-5 in Milford Reservoir, KS in June, 2013. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

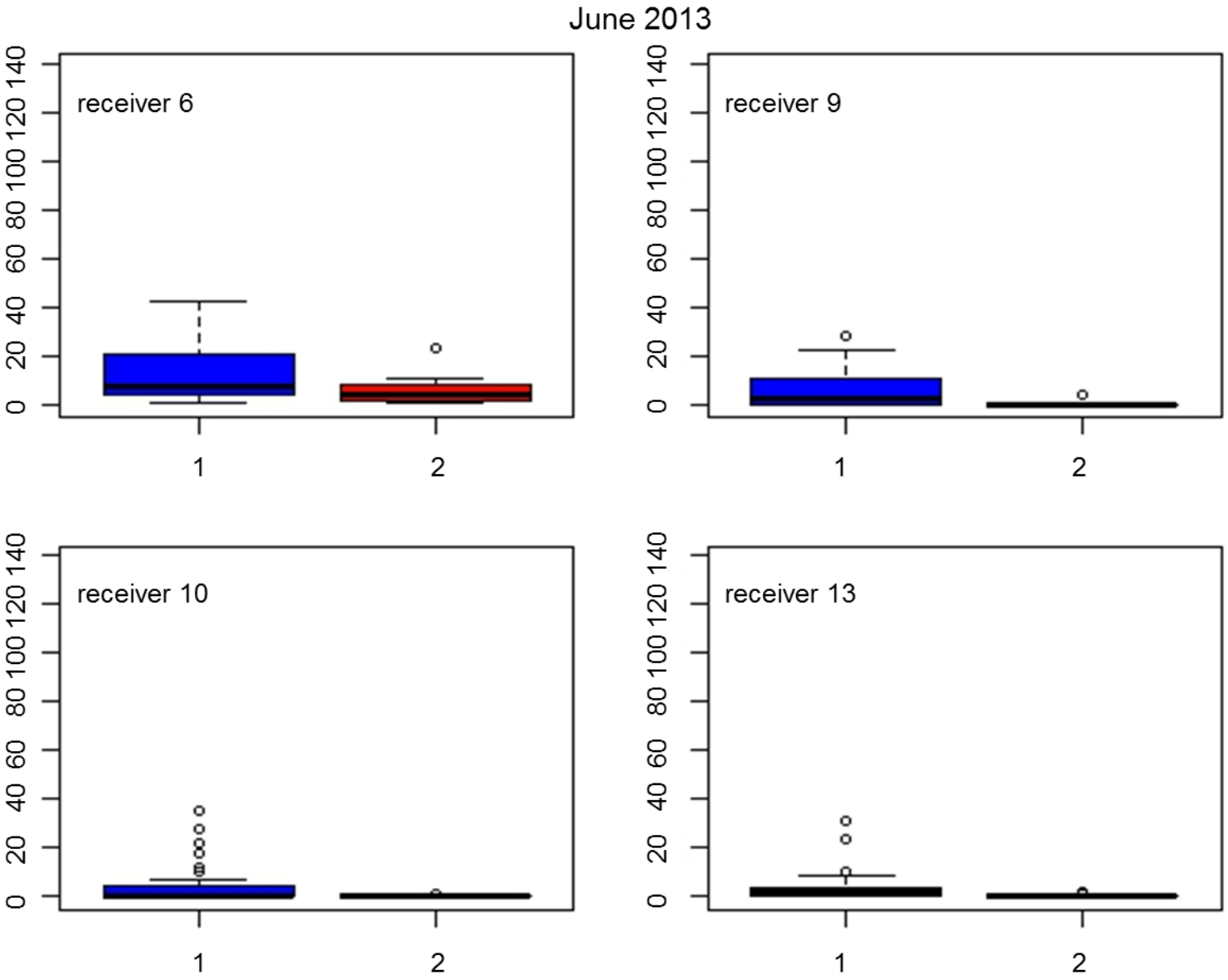


Figure K.2. Boxplots of residence times for receivers 6-13 in Milford Reservoir, KS in June, 2013. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

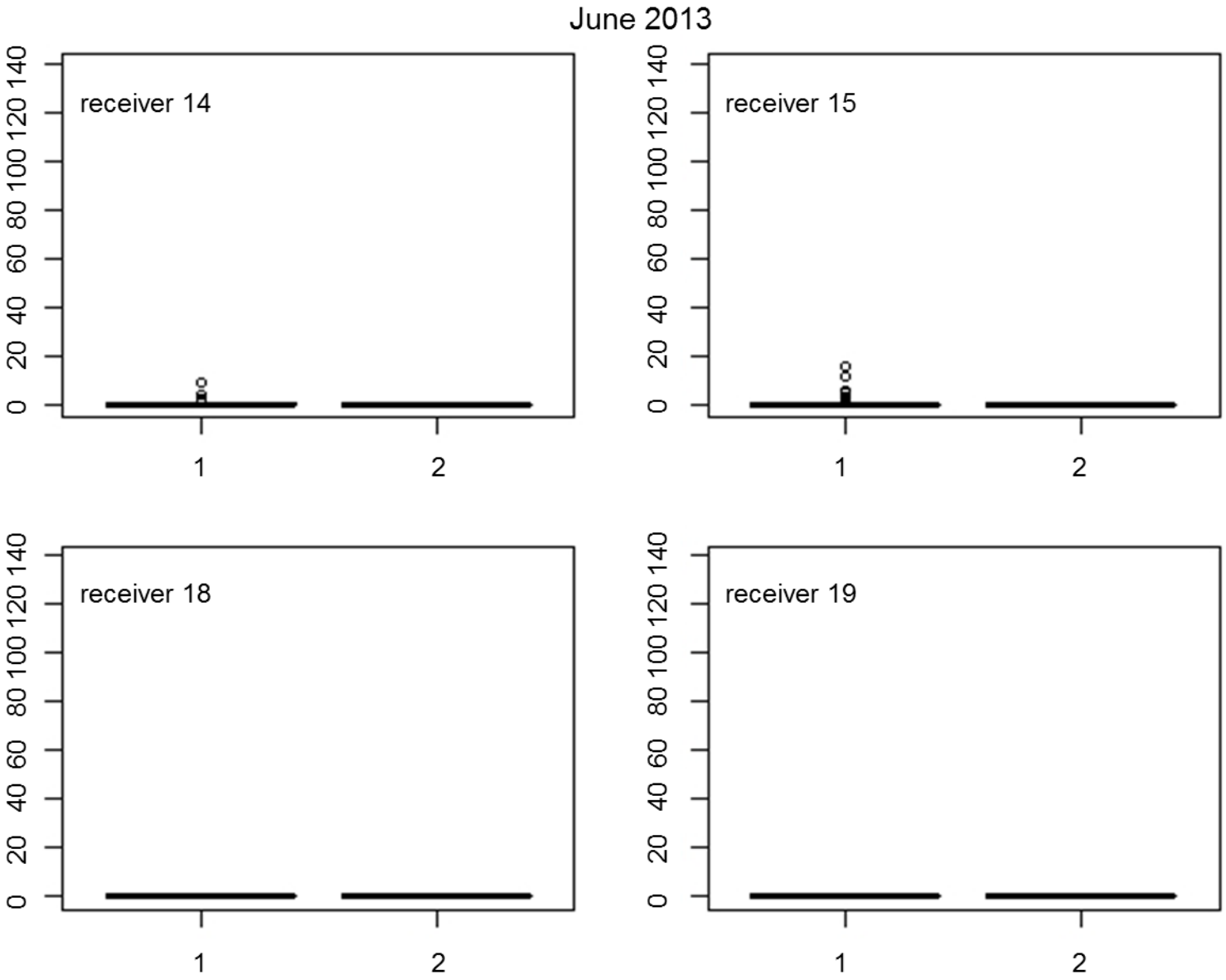


Figure K.3. Boxplots of residence times for receivers 14-19 in Milford Reservoir, KS in June, 2013. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

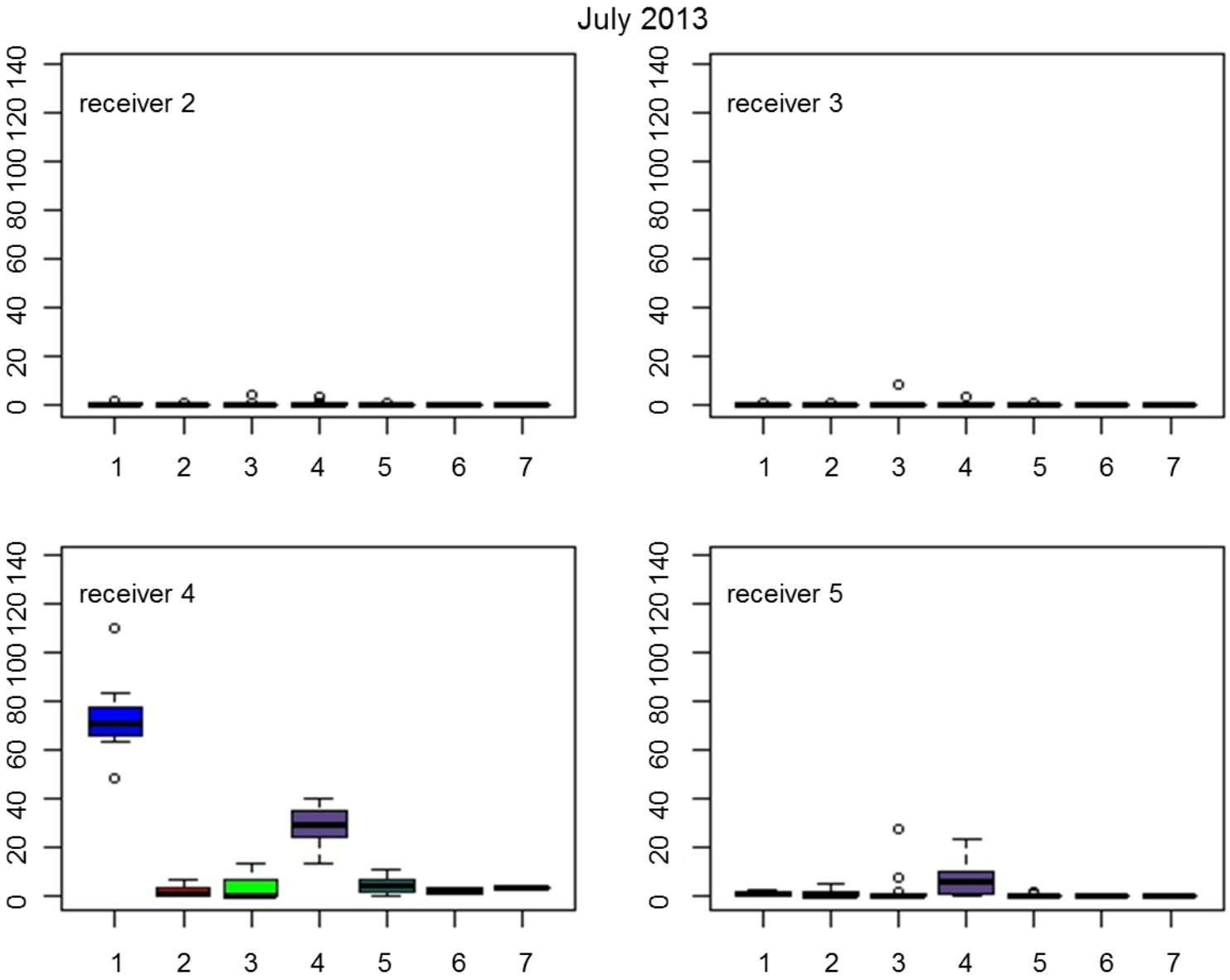


Figure K.4. Boxplots of residence times for receivers 2-5 in Milford Reservoir, KS in July, 2013. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

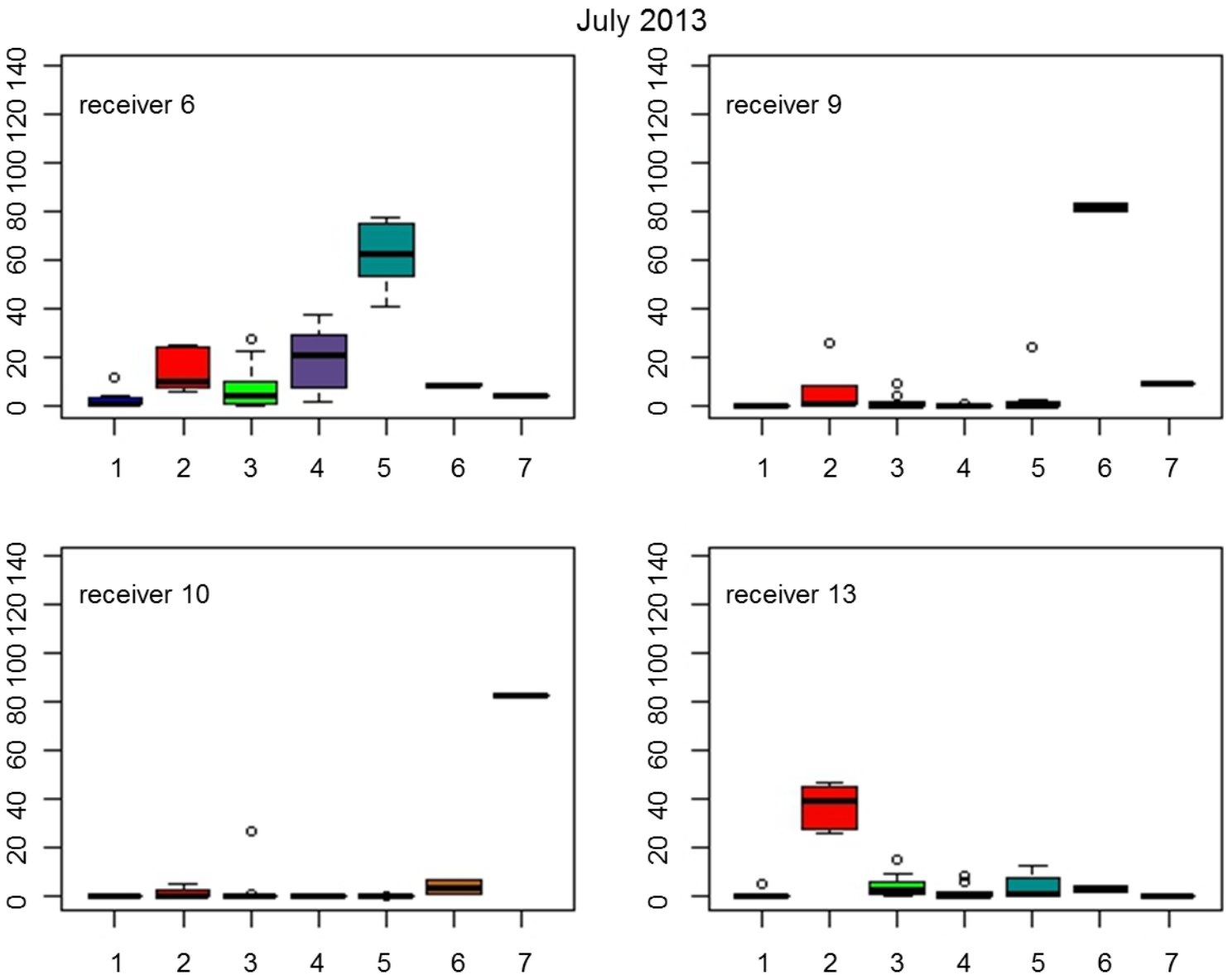


Figure K.5. Boxplots of residence times for receivers 6-13 in Milford Reservoir, KS in July, 2013. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

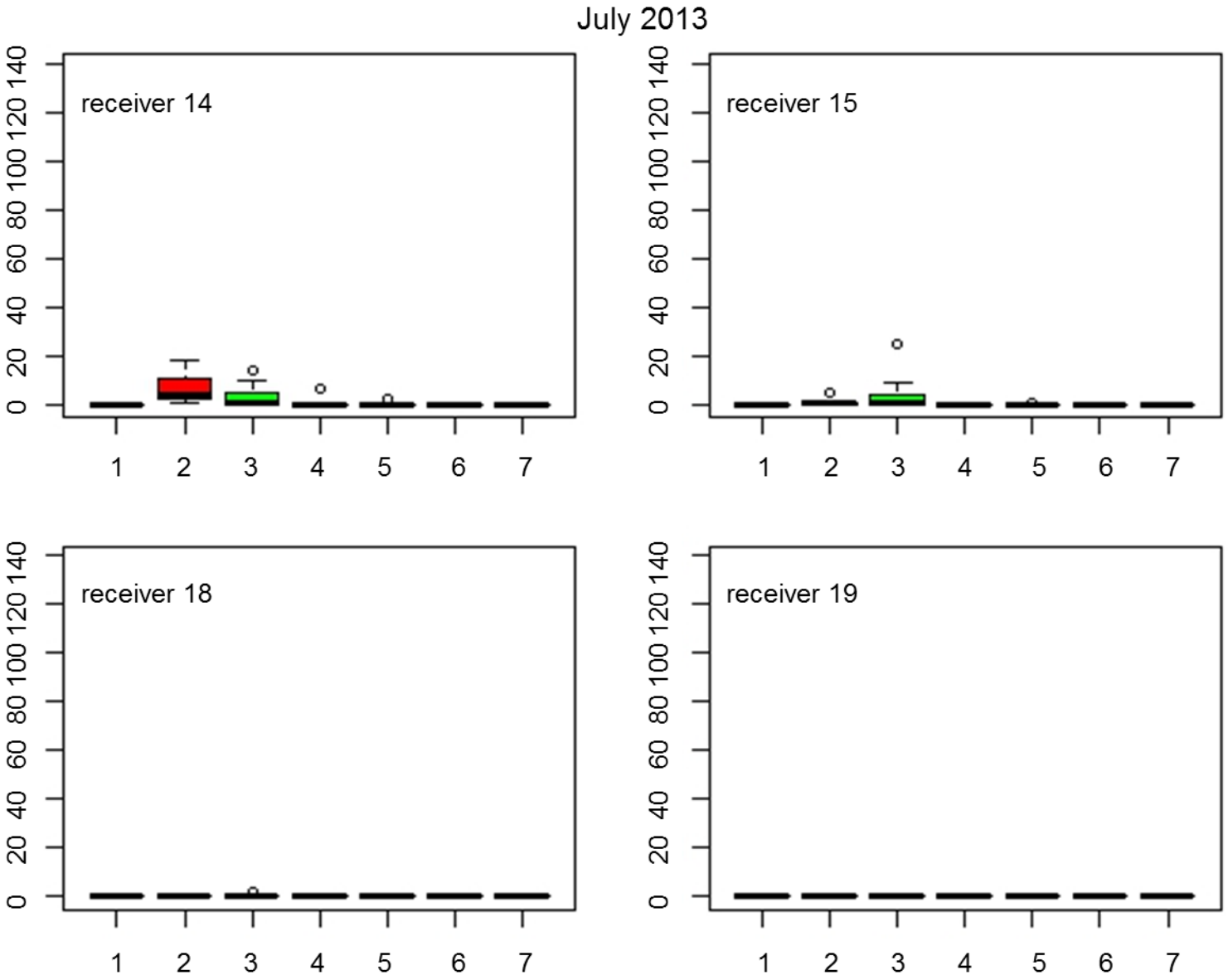


Figure K.6. Boxplots of residence times for receivers 14-19 in Milford Reservoir, KS in July, 2013. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

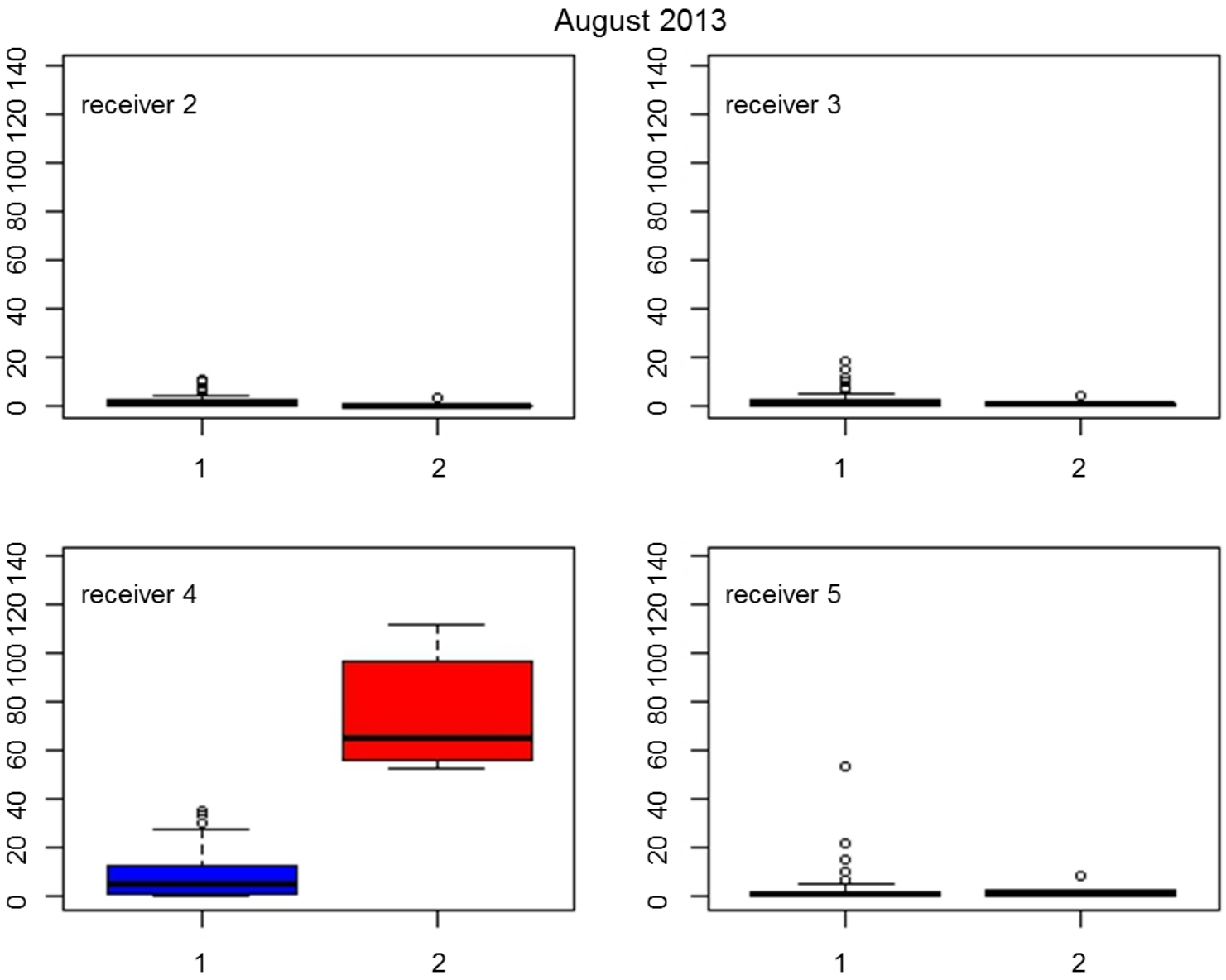


Figure K.7. Boxplots of residence times for receivers 2-5 in Milford Reservoir, KS in August, 2013. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

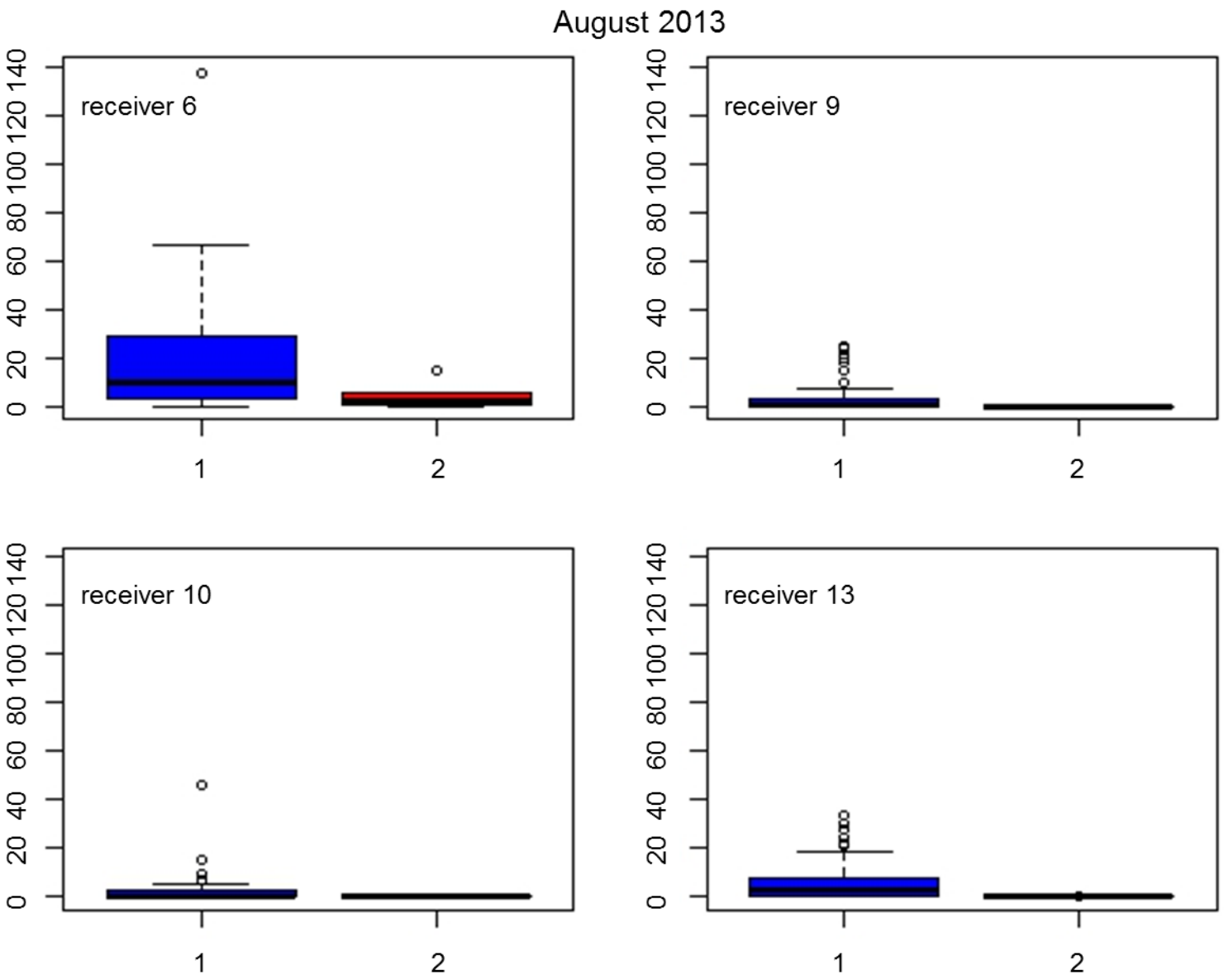


Figure K.8. Boxplots of residence times for receivers 6-13 in Milford Reservoir, KS in August, 2013. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

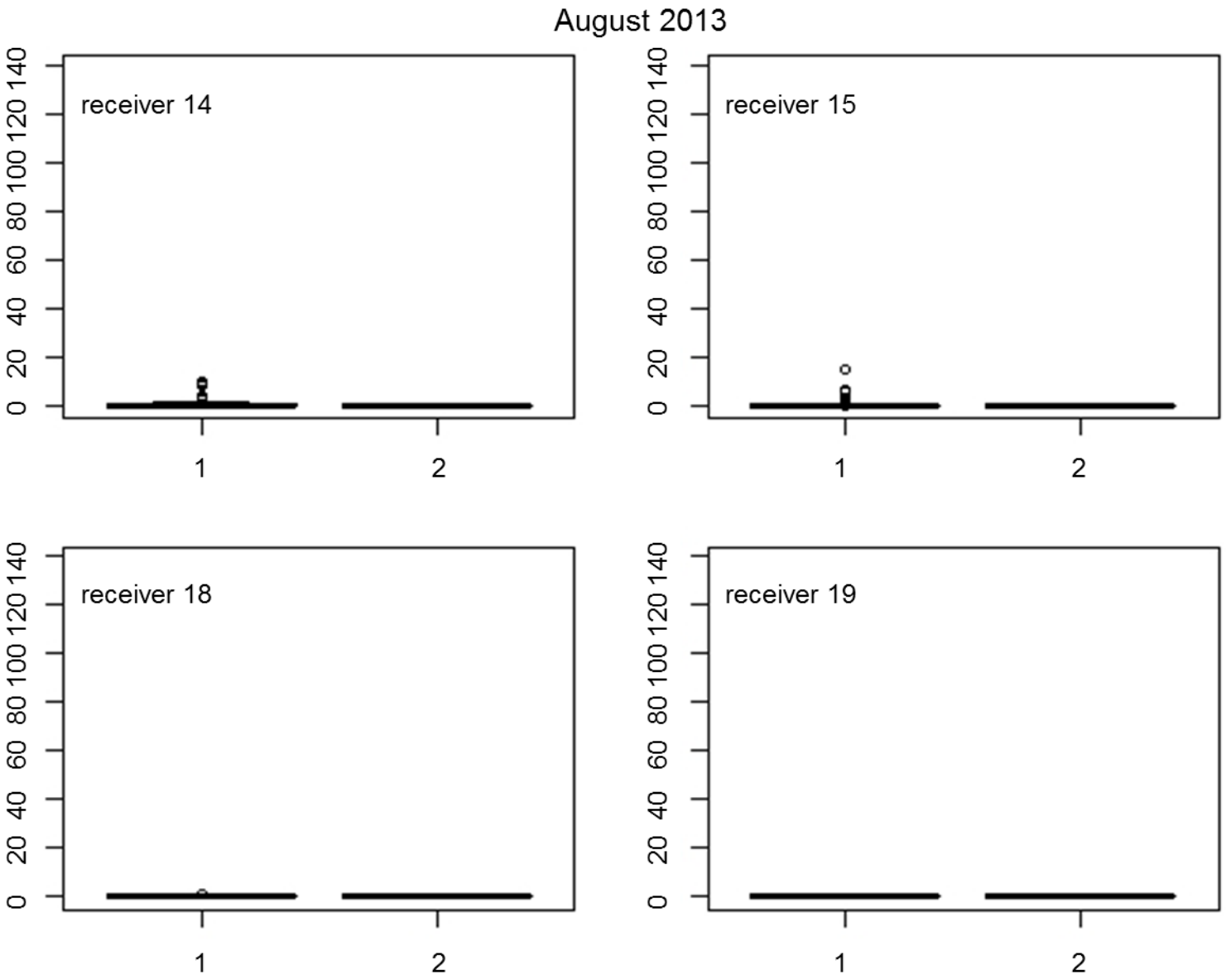


Figure K.9. Boxplots of residence times for receivers 14-19 in Milford Reservoir, KS in August, 2013. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

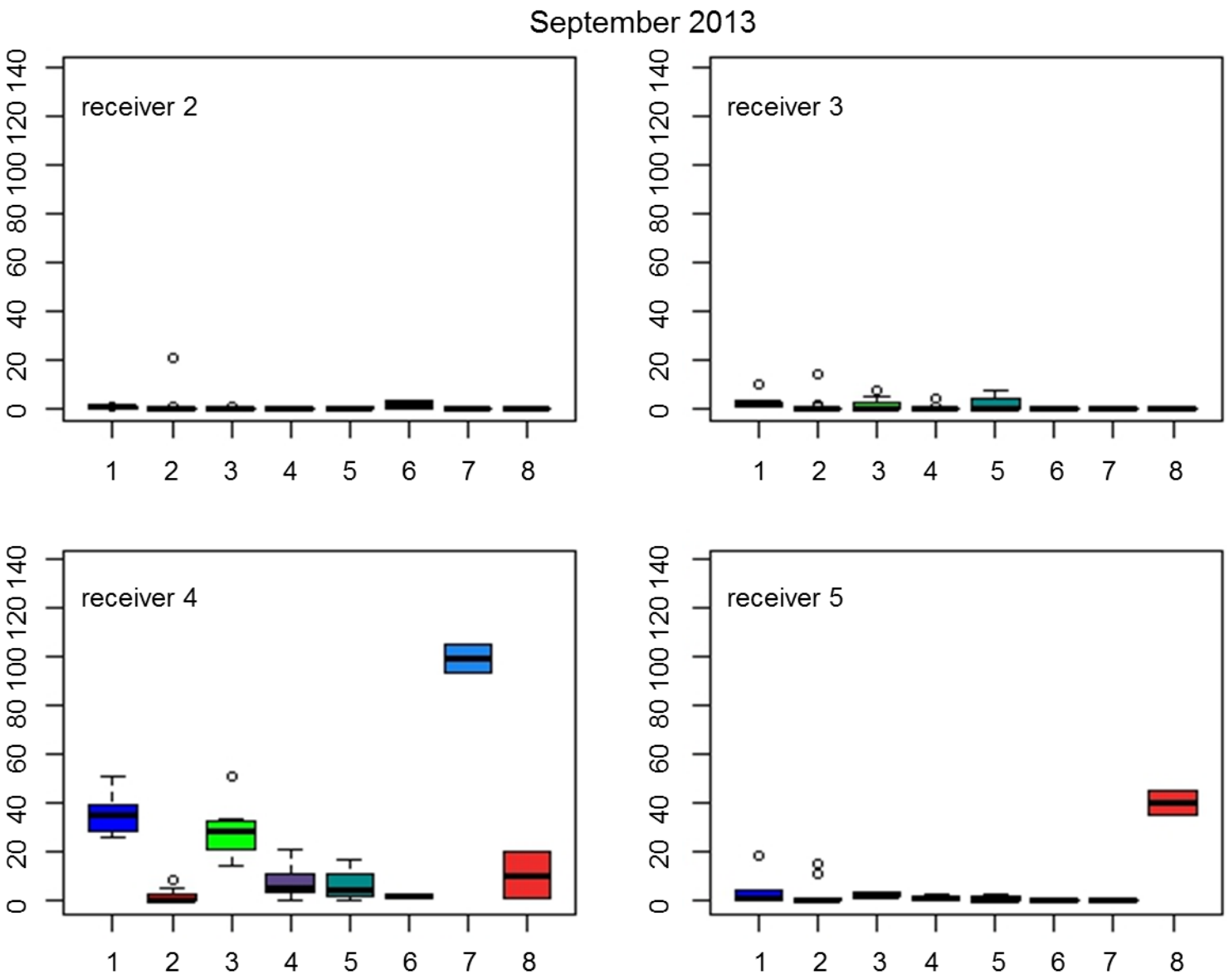


Figure K.10. Boxplots of residence times for receivers 2-5 in Milford Reservoir, KS in September, 2013. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

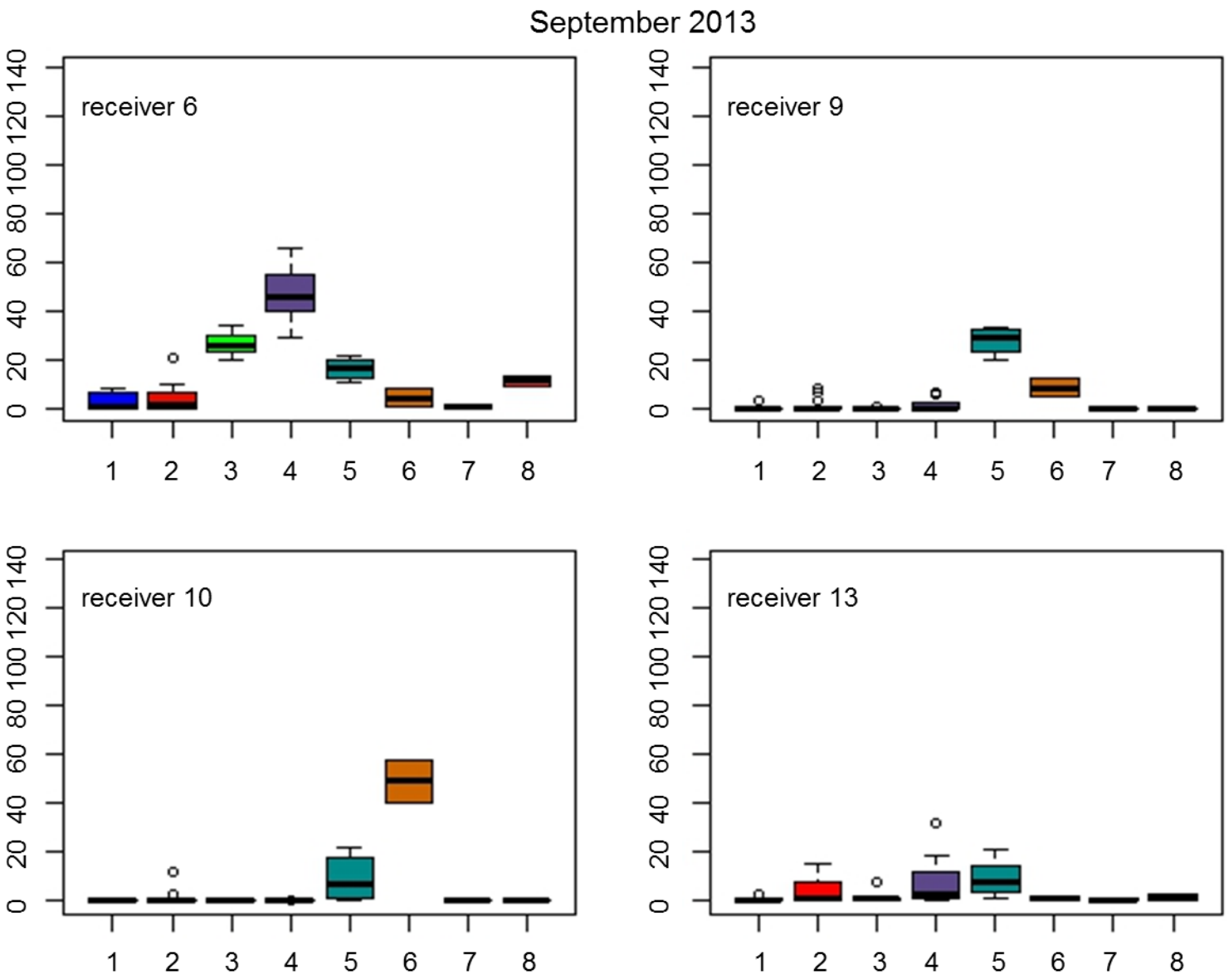


Figure K.11. Boxplots of residence times for receivers 6-13 in Milford Reservoir, KS in September, 2013. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

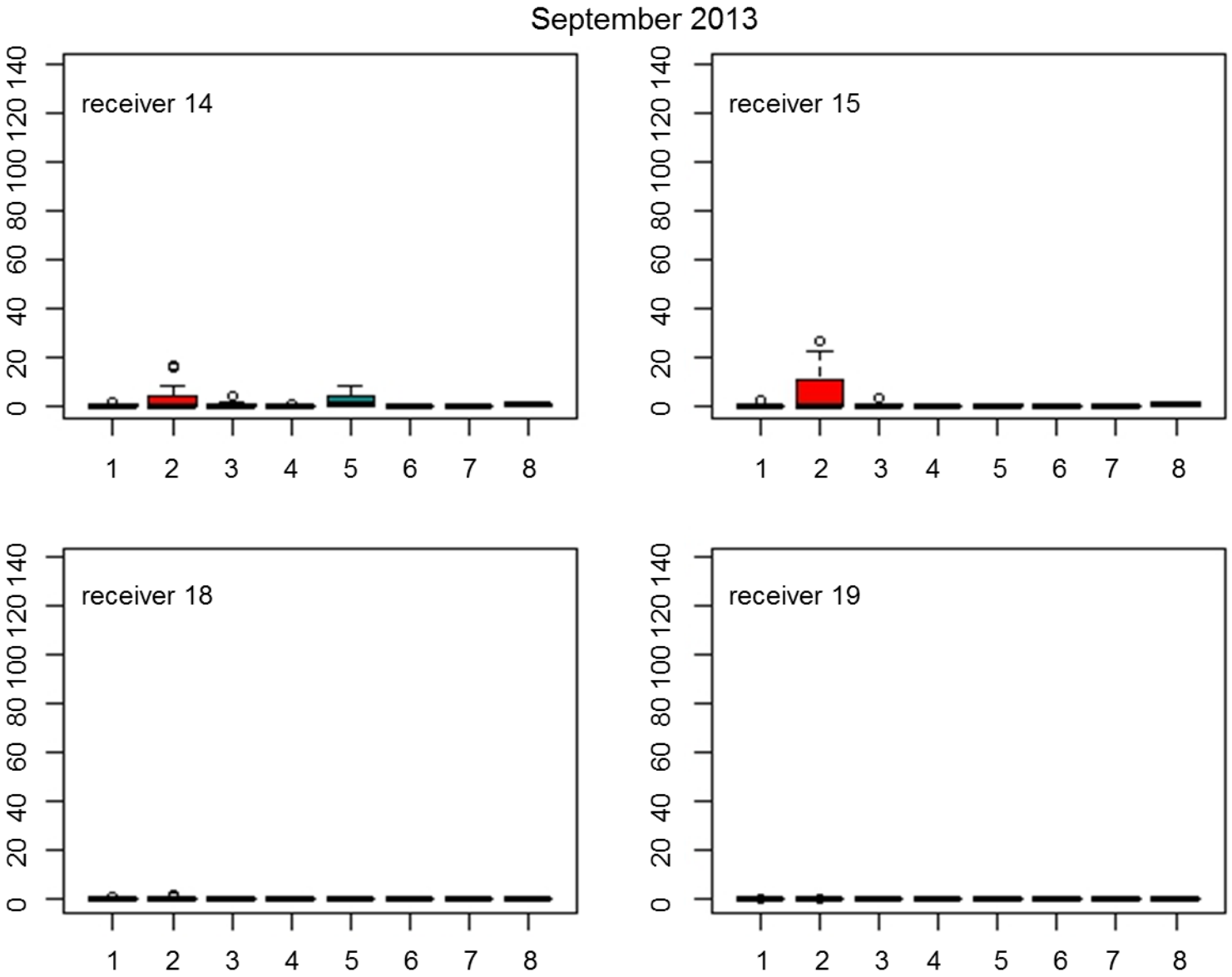


Figure K.12. Boxplots of residence times for receivers 14-19 in Milford Reservoir, KS in September, 2013. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

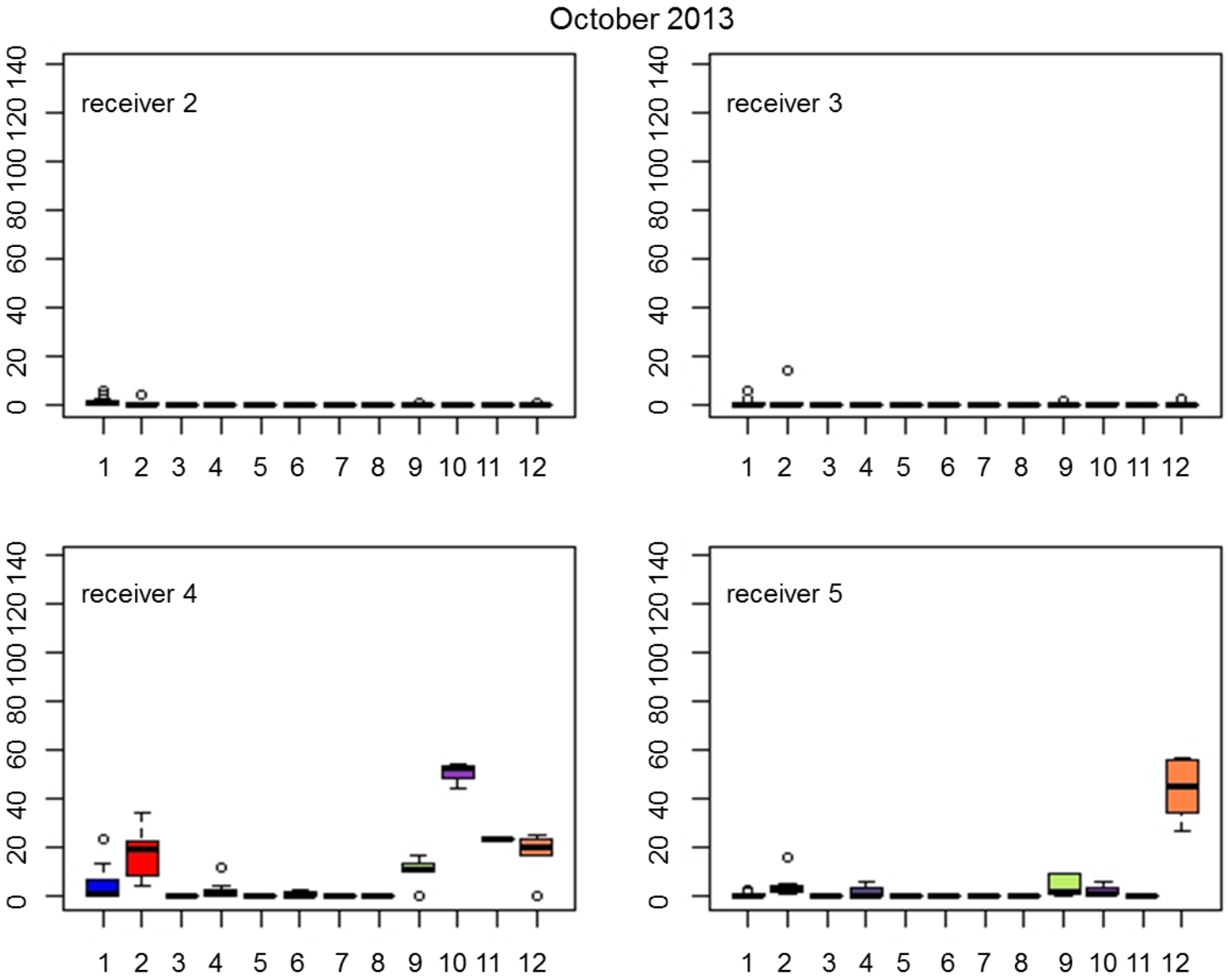


Figure K.13. Boxplots of residence times for receivers 2-5 in Milford Reservoir, KS in October, 2013. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

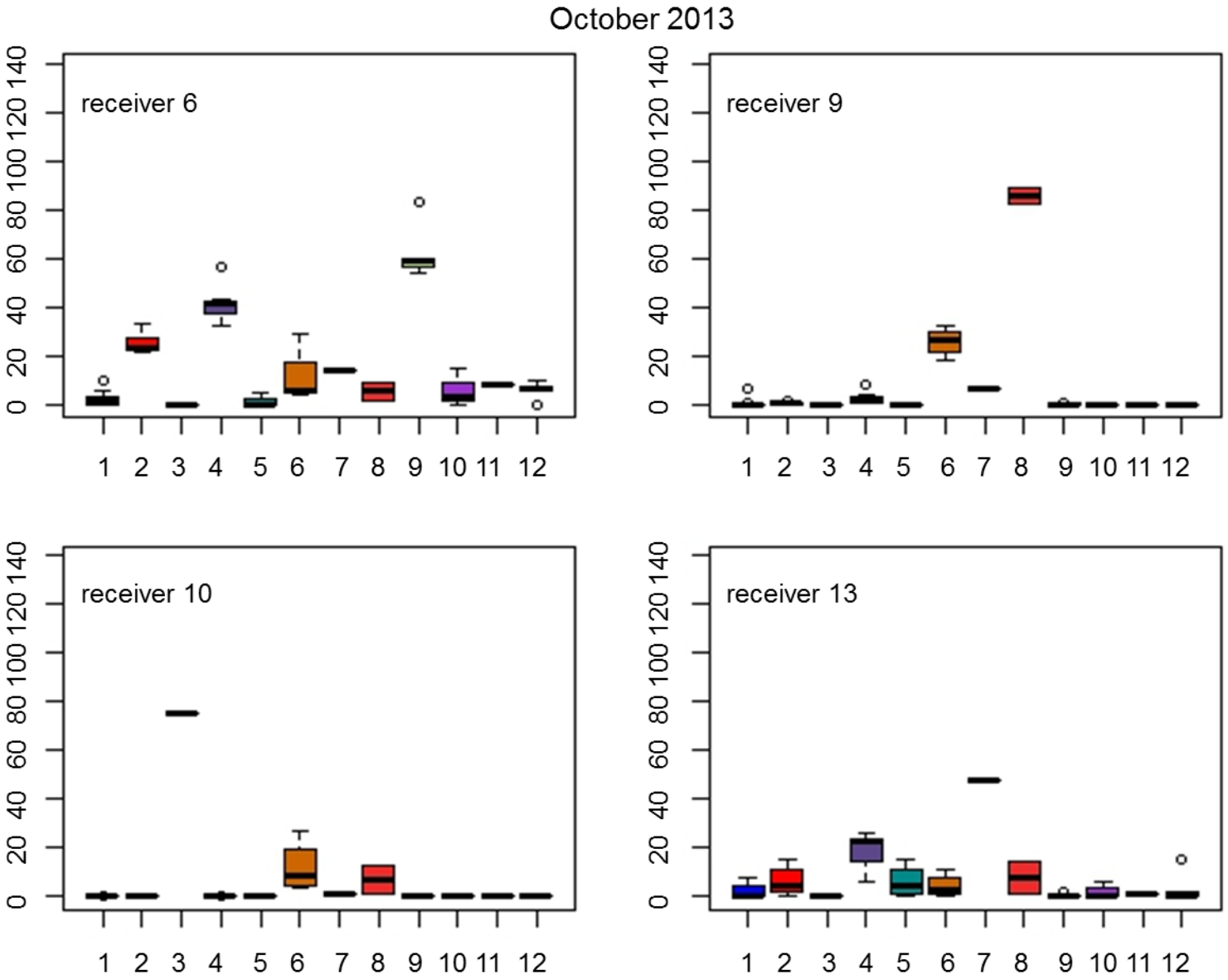


Figure K.14. Boxplots of residence times for receivers 6-13 in Milford Reservoir, KS in October, 2013. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

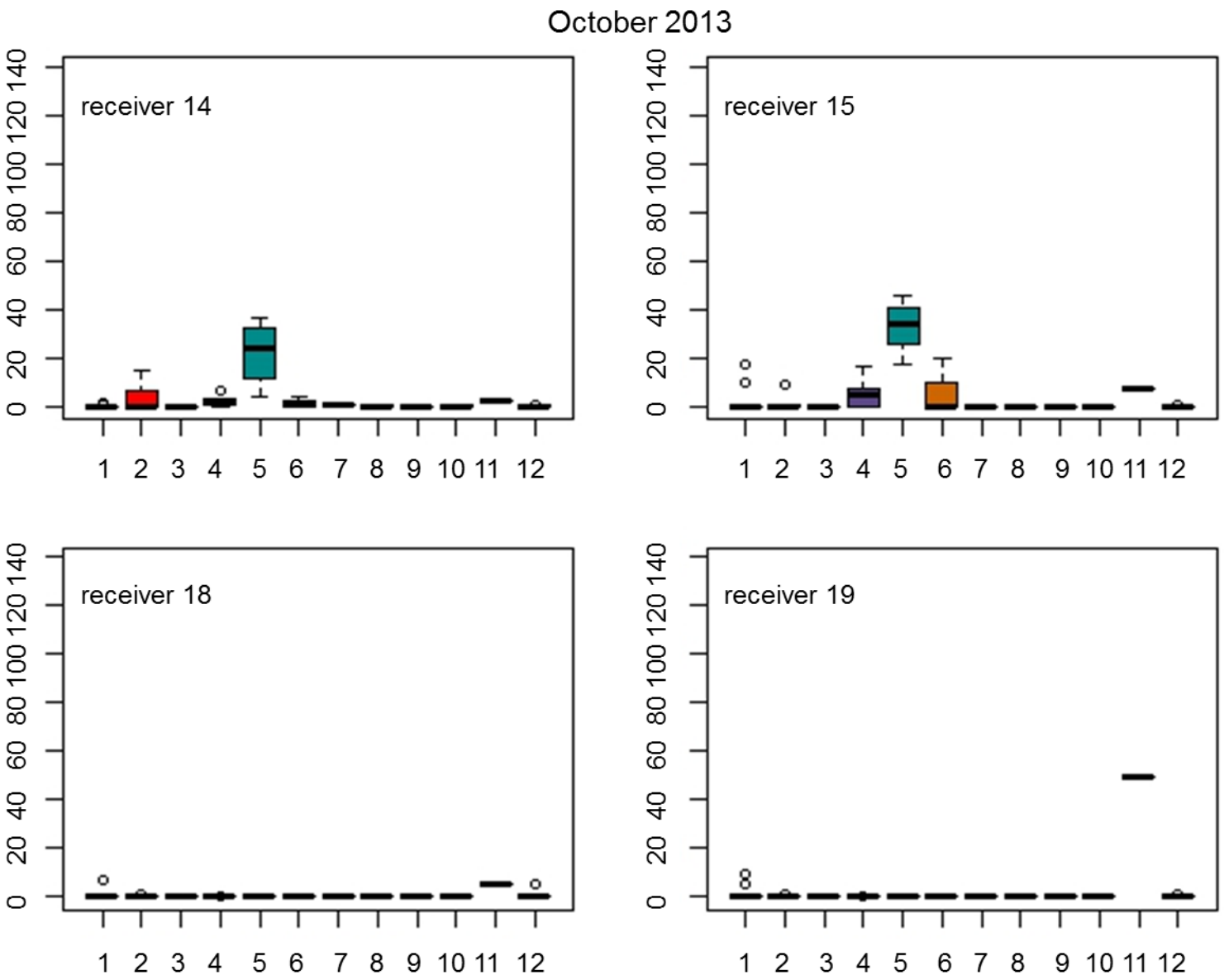


Figure K.15. Boxplots of residence times for receivers 14-19 in Milford Reservoir, KS in October, 2013. The Y axis is residence time (h); the X axis is cluster number. These data are means for individual fish in each cluster.

Appendix L - Individual-level Responses

What information can individual-level responses provide?

Tagged Blue Catfish were detected at multiple receivers in Milford Reservoir with individual fish, on average, visiting 9 and 8 receivers over the 5 month studies for 2012 and 2013, respectively (range: 1-14 and 3-12, SE: 2.9 and 0.2). As such, the first individual response, presence/absence, provided useful but not definitive information about distribution. Total residence time per individual for all receivers over five months varied among tagged fish, ranging from 9.2 to 393.4 hours in 2012 and 2.5 to 415.9 hours in 2013 (2012 – Fig. L.1A and 2013 – Fig. L.1B). Similarly, tagged individual Blue Catfish varied in the total number of movements they made to and from all receivers, which ranged from 1 to 943 in 2012 and 1 to 1,307 in 2013 (2012 – Fig. L.1C and 2013 – Fig. L.1D).

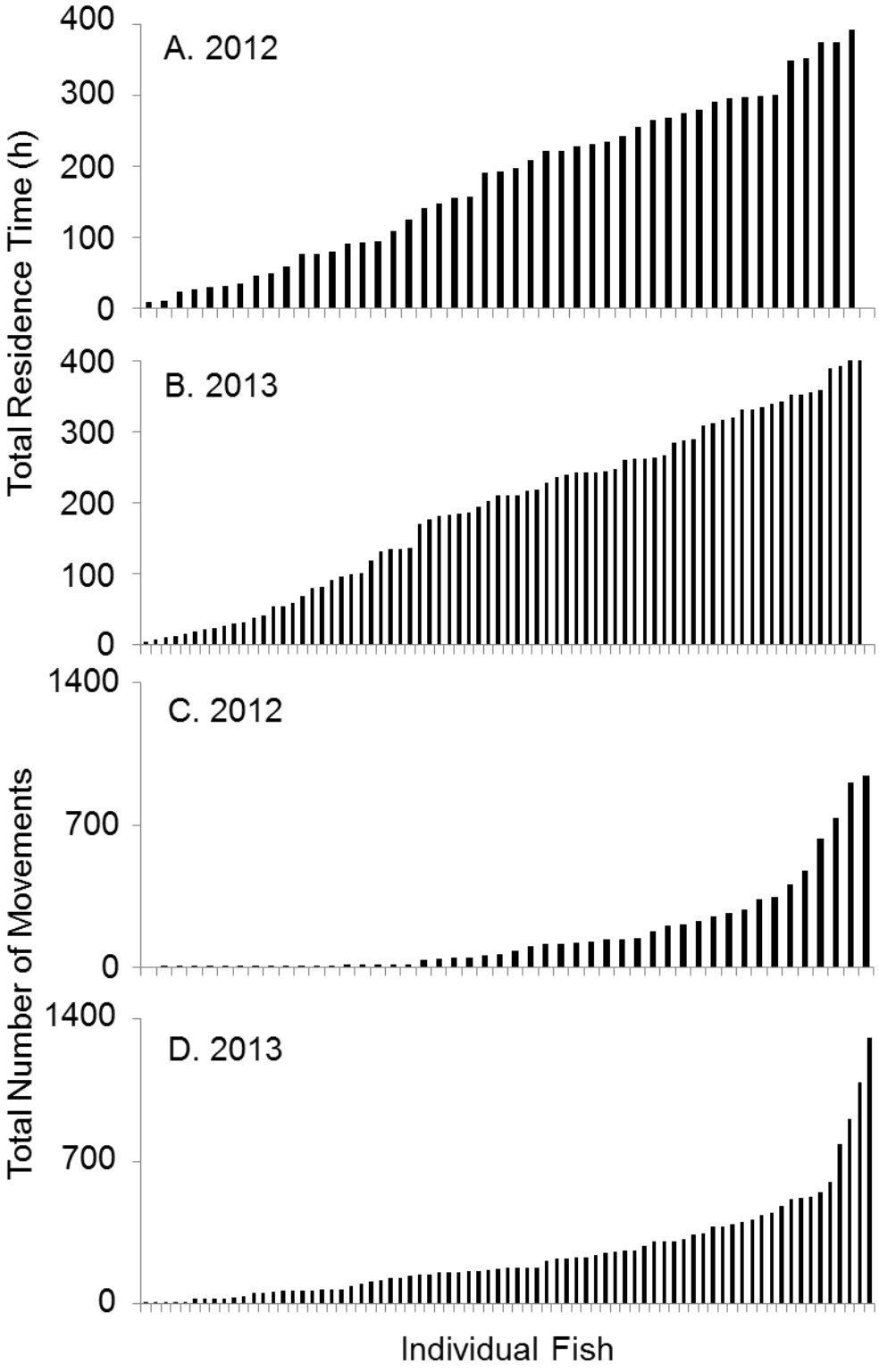


Figure L.1. Individual responses total residence time (h) and total number of movements in Milford Reservoir, KS for both 2012 (A, C) and 2013 (B, D). On the X-axis is individual fish and on the Y-axis is total residence time (h) (A, B) and total number of movements (C, D).

Appendix M - Temperature and Depth

What is the temperature and depth for individual fish?

Ten Blue Catfish were tagged with VEMCO V9TP (length: 47 mm, weight in air: 6.4g, weight in water: 3.5g) that transmitted the temperature (°C) and depth (m; every 60-180 seconds) at which the fish was located in addition to the individual tag number. With this information I was able to calculate the average temperature and depth for all ten fish during the entire study period (June-November 2012) and each individual month.

In general, Blue Catfish temperature decreases across months with a maximum of 31.7 °C in July and a minimum of -5 °C in November. The overall average temperature for the tagged fish ranges from 12.6 °C to 18.9 °C (Table M.1). The Blue Catfish average depth increases across month with a maximum of 16.3 m in November. The overall average depth for the tagged fish ranges from 4.39 m to 7.88 m (Table M.2). The maximum depth coordinates with receiver 17 in the lower region (Table M.3). The overall average depth coordinates with receivers 3-10 which are in the upper, middle, and Madison regions.

Table M.1. Average temperature (°C) for individual fish in Milford Reservoir, KS in June-November, 2012. Temperature is listed out overall (June-November) and by each individual month.

	Average Temperature (°C)						
Fish	Overall	June	July	August	September	October	November
39	15.3	27.9	27.6	24.3	21.5	14.7	10.4
40	18.8	27.4	28.4	25	21.7	14.5	11.2
41	16.5	27.8	28.3	24.6	20.9	14.5	11.1
42	12.6	27.5	28.3	24.8	20.7	13.6	10
43	17.4	27.4	27.9	25.6	21.1	14.2	10.3
44	18.2	28.6	28.4	25.1	20.8	15.6	11.2
45	18.7	28.4	28.1	25.3	22.4	14.6	11.1
46	18.9	27.7	27.7	25.6	21.8	15.2	10.6
47	15	28.1	28.4	25.9	21.2	14	10.2
48	16.9	27.5	27.8	26.4	22.4	14.5	11.4

Table M.2. Average depth (m) for individual fish in Milford Reservoir, KS in June-November, 2012. Depth is listed out overall (June-November) and by each individual month.

	Average Depth (m)						
Fish	Overall	June	July	August	September	October	November
39	5.92	4.12	3.72	4.79	5.76	6.24	6.2
40	5.17	2.96	4.56	4.09	4.73	4.46	8.39
41	5.34	3.37	5.12	4.18	4.94	5.04	6.28
42	4.48	3.3	2.71	2.46	3.4	3.43	5.22
43	6.02	1.82	6.44	8.27	6.44	2.8	6.07
44	7.88	2.4	3.58	4.8	6.38	9.48	11.08
45	4.39	0.27	0.51	2.43	3.63	4.9	8.2
46	5.93	5.81	5.44	5.62	5.11	5.51	7.46
47	6.47	4.81	3.27	4.68	6.53	7.24	7.14
48	6.11	7.03	6.31	1.17	1.22	5.62	7.95

Table M.3. Depth (m) at each of the receiver locations throughout Milford Reservoir, KS in 2012.

Receiver	Depth (m)
2	2.6
3	3
4	7.6
5	7.3
6	7.8
7	8.8
8	9
9	7.1
10	3.3
11	10.3
12	10.1
13	10.3
14	12.5
15	15.3
16	11.8
17	16.8
18	8.3
19	14