ASSESSING DISTRIBUTION AND MOVEMENT OF BLUE CATFISH IN KANSAS RESERVOIRS

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OVERVIEW

This report is organized into three chapters that address six objectives. The first chapter addresses objectives 1-3. The second chapter addresses objectives 4-5. The third chapter addresses objective 6. The objectives for the project are listed below for reference.

OBJECTIVES

1. Develop and test tagging protocols for blue catfish.
2. Develop and test protocols for setting up and calibrating stationary receivers.
3. Summarize tagging and tracking protocols for use in other systems with other species.
4. Determine where tagged blue catfish spend their time within Milford reservoir.
5. Determine when, size distribution, and how many blue catfish exit Milford reservoir.
6. Quantify potential drivers of distribution

OBJECTIVES 1-3

DEVELOPMENT / EVALUATION OF METHODOLOGIES FOR EFFECTIVE ACOUSTIC TAGGING AND STATIONARY RECEIVER ARRAY SET-UP

INTRODUCTION

Benefits of Tagging Fish for Research and Management. Knowing fish location is useful for many questions related to research and management (Hubert 1999; Millspaugh and Marzluff 2001). The variable distribution patterns that result from movement are the foundation for effective fisheries, ecology, and conservation (Alldredge at al. 2011). In recent years, the number of tagging studies has increased dramatically (*Chapter 1 Figure 1*). 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 has become one of the most popular methods to study fish in their natural environment (Bridger and Booth 2003).

Lack of Detections. Changes in timing and location of detections are the essential pieces of information that radio or acoustically tagged fish provide. Thus, lack of detections is a problem for telemetry studies. Lack of detections can occur when a tagged fish: (a) naturally leaves the detection system temporarily or permanently; (b) dies from natural causes; (c) dies from tagging or handling associated with tagging; or (d) loses its tag via egestion (mouth, anus) or ejection (incision site). Lack of detections from each of these sources has different implications for data interpretation. Identifying why tagged fish are undetected in the field is difficult. However, a good tagging methodology and sound research design for detection of

tagged fish can reduce some of the uncertainty related to tagging mortality and tag loss (c-d above).

Methodological Challenges for Tagging. 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; Thiem 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). To ensure that the data generated from tagged fish are relevant to untagged conspecifics, fish tracking research can benefit from methodological synthesis and refinement (Cooke et al. 201). Thus, sound tagging methodology is important for all tracking studies. Here we evaluate a tagging methodology for Blue Catfish (*Ictalurus furcatus*) and Channel Catfish (*Ictalurus punctatus*).

Tag Loss. Tag loss (c-d above) is a problem for all fish and especially for catfish. An increasing number of studies have tracked Blue Catfish (e.g., Fischer et al. 1999; Grist 2002; Lee 2009; Garrett 2010; Garrett and Rabeni 2011) in the field. However, only a limited number of studies have developed or evaluated tagging methodologies for Blue Catfish (e.g., Holbrook et al. 2012; Bodine et al. 2014) and Channel Catfish (e.g., Summerfelt and Mosier 1984, Marty and Summerfelt 1986, 1990).

In this literature, tag retention (% tags retained) in evaluations of recreationally-important catfish species (Blue Catfish and Channel Catfish) is variable but usually low [Blue Catfish: ***33, 60****%* (Holbrook et al 2012); ***100, 42%*** (Bodine et al. 2014); Channel Catfish ***29%*** (Summerfelt and Mosier 1984); ***44, 2%*** (Marty and Summerfelt 1986, 1990)]. Through controlled hatchery and laboratory studies in which tags were found outside of previously-tagged catfish, we know

some catfish tag loss occurs via ejection (i.e. loss through incision site; Summerfelt and Mosier 1984; Marty and Summerfelt 1986). Even though new methods are being developed and evaluated (Bodine et al. 2013), a high-survival, high-retention methodology for tagging catfish has still not been identified.

Goals. Here, we (a) refine a methodology that minimizes stress and maximizes retention of acoustic tags for catfish, (b) evaluate this methodology four times for two catfish species over three years in two settings (hatchery and field), (c) and describe the receiver array and range test we used for field evaluation of Blue Catfish tags.

METHODS

Study System. Milford Reservoir (39°08'42"N, 96°56'54"W) is an impoundment of the Republican River (Dickinson, Clay, and Geary counties, KS) and is part of the Lower Republican watershed, KS. Milford reservoir has a surface area of 6,555 ha, 262 km of shoreline dominated by limestone cobble and boulders, an average depth of 6.7 m, and a maximum depth of 19.8 m (Reinke 2001).

Tagging Overview and Summary. We tagged Blue Catfish (BC) and Channel Catfish (CC) four times over three years (2012-2014) in two settings (Milford Hatchery and Milford Reservoir) *(Chapter 1 Table 1).* These trials served three purposes: to practice tagging techniques (2012, BC, Milford Hatchery); to evaluate field distribution (2012, 2013, BC, Milford Reservoir); and to test three variables in the hatchery that might affect tag retention (2014, CC, Milford Hatchery). We used the same tagging methodology 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, we tested our tagging protocol on live catfish (estimated range: 150-250 mm TL) at Milford hatchery (*Chapter 1 Table 1*). Each individual tagger sequentially tagged five fish, following the procedures in our written protocol. Tagged fish were held in a hatchery tank for seven days. Then tag placement was evaluated through euthanasia and dissection. This qualitative evaluation was an opportunity to standardize and improve our tagging technique.

2012, 2013 - Blue Catfish, Milford Reservoir, Field Evaluation of Distribution. In both 2012 and 2013, for our test of distributional patterns of Blue Catfish in Milford Reservoir, we targeted the size range of fish that was common in the reservoir (400-600 mm TL; *additional details are provided in Chapter 2*). In 2013, we added a limited number of smaller and larger fish to the study (*Chapter 1 Table 2*). In 2012, the average fish size tagged was 487 mm TL (range 383-1020, SE 14.5, *n*=48). In 2013, the average size of Blue Catfish tagged was 517 mm TL (range 343-1090, SE 17.8, *n*=75). In 2012, for field tagging, we used V9 tags (length: 29-47 mm, weight in air: 4.7-6.4 g, weight in water: 2.9-3.5 g). In 2013, we also tagged fish with V13 tags (length: 36-48 mm, weight in air: 11-13 g, weight in water: 6-6.5 g). We evaluated survival of tagged Blue Catfish and retention of tags in two ways (*Chapter 1 Table 1)*. First, we plotted detections for the first 10 days when post-tagging mortality and loss to acute stress was most likely to occur. For this plot, we first checked that fish moved across multiple receivers to make sure they were not dead. Second, we plotted the number of fish detected per month (%) across the first five months of the study for both years. We predicted that fish that were repeatedly detected at different locations survived the tagging process and retained their tags. No statistics were used for this evaluation.

2014 - Channel Catfish, Milford Hatchery, Evaluation. In 2014, we tested how three factors (incision location, antibiotics, and surgery time) affected tag loss for 70, age-0, hatchery-

reared channel catfish (*Chapter 1 Table 1*). The tagging protocol was the same as for other tagging evaluations except that we used smaller dummy tags to keep tag weight < 2% fish body weight (Bridger and Booth 2003).

In a review of tagging methodologies, Cooke (2011) noted that the importance of incision location and antibiotics are rarely tested. First, we chose to test the incision location because we used a lateral incision whereas most other tagging studies have used a ventral incision. We also chose to test if antibiotics have an effect on tag loss and survival because many catfish tagging studies do not use antibiotics. We chose to test surgery time because we suspect surgery time varies across surgeons and studies, and longer surgery time may increase post tagging stress. Our five treatments contained 14 fish each that were given different combinations of incision, antibiotics, and surgery time. Treatment 1 was the treatment we describe below for our 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 tagging, all dummy VEMCO tags were engraved with the tag number. Post-tagging, all fish were Floy tagged. We recorded treatment, VEMCO dummy tag number, and Floy tag number so we could link tag loss to a treatment. We held all 70 fish in a single (4 m X 4 m) compartment of a hatchery raceway for 12 weeks. We recorded general individual fish condition weekly, in addition to incision condition (suture present, redness at incision, redness at suture insertions, and general condition and healing of the incision), Floy tag number, and Floy tag insertion condition. We also took pictures of all fish. Each week we searched the bottom of

the hatchery compartment visually and manually four times (two times each by two people) to recapture ejected tags. At the end of 12 weeks, we euthanized all fish, measured and weighed fish, recovered tags, and photographed tag position within the body cavity. To summarize data, we plotted tag loss data by treatment. We used a Chi square test with 2,000 Monte Carlo simulations to evaluate if tag loss was distributed equally across all treatments. Two thousand simulations is a default value for a simulated P-value (chisq.test function; R Core Team 2013).

Tagging Methodology. We used an 8-step tagging procedure that included: 1-preparation before field work; 2-preparation in the field to allow quick and minimal stress tagging; 3-minimal stress fish collection and holding; 4-pre-surgery considerations; 5-quick, minimal stress surgery; 6-prophylaxis after surgery; 7-recovery and release; and 8-evaluation (*Chapter 1 Figure 2).* The same procedures were used for field and hatchery tagging

1. Pre-field preparations. To minimize stress, preparation before field work was essential. Existing literature on tagging studies, tagging techniques in general, fish morphology and fish physiology were reviewed and summarized. We also contacted authors who had published on catfish tagging via email for additional insights. As with most research facilities, we were required to submit an Institutional Animal Care and Use Committee (IACUC) protocol. Insights from a university veterinarian were very useful relative to anesthetic and surgical techniques.

In addition to the literature and technical expert consultations, practicing incisions and suturing was essential. Many useful print and online tutorials exist on surgical techniques. However, practice was perhaps the most important component of our protocol. Incision and suturing can be practiced on inanimate objects (oranges and bananas) any time. Dead fish added a new dimension to incision and suturing practice. A very important component of our technique,

however, was tagging live fish prior to field tagging. This tagging of hatchery fish was followed by an evaluation of survival, healing, and tag placement in the hatchery for seven days. In summary, a good literature review, thoughtful protocols, and extensive practice before field tagging were important parts of our protocol.

2. *Preparation in the Field.* For field preparation of the surgical area, pre-sampling organization was critical (*Chapter 1 Figure 2*). For our field sampling, we used jon boats as mobile surgical stations that were beached adjacent to the collection area. This allowed us to minimize the time fish were confined during transport before surgery. This setup also allowed us to release fish near the location where they were captured. For tagging in the field, workspace will be limited, so we pre-planned all steps for fish processing to make sure that a two-person surgical team could easily transfer fish from the capture boat to anesthesia tank to the operating arena to recovery tanks then to the lake for release. Often, this required thought about placement of tanks and work stations. We chose to use two operating teams in two separate jon boats with a shared salt bath recovery tank to process our fish quota more rapidly. We also ensured that all holding and recovery tanks were of adequate size (60 cm diameter circular bucket; 64 liter capacity). We monitored temperature in each bucket and compared it to ambient lake temperatures. When bucket temperature exceeded reservoir temperature we changed the water. When sun was intense, patio umbrellas over the holding and recovery tanks provided shade for the fish. This preparation and organization allowed us to process fish quickly with minimal stress.

3. *Minimal Stress Fish Capture and Pre-surgery Holding.* We collaborated with state colleagues on tagging. State biologists captured fish using boat electrofishing (1 stationary boat, 2 capture boats) with low pulse DC current (15 pulses/s, 3-5 amps) (Bodine and Shoup 2010).

All fish were collected in pre-identified areas. Fish were held on state electrofishing boats post-sampling in large aerated live wells. We only tagged 5-10 fish at a time so that fish were held on board our boat < 60 minutes post-capture. This step in our protocol allowed us 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. Pre-surgery, 5. Surgery, 6. Prophylaxis, 7. Recovery and Release. 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). Doses of anesthetic were tested in hatchery trials before field tagging. Two people processed each fish. One acted as the surgeon and never moved from the operating station. The other acted as the anesthesiologist and moved the fish from pre-tagging tank to the anesthesia tank to operating station 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.

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 – 300-700 mm TL Blue Catfish; 20-30 mm– >700 mm TL Blue Catfish). We 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, we were careful to make the incision into fish body wall in increments so that only skin and muscle, not intestines, were cut. A sterile tag was carefully inserted into the body cavity. The incision was closed with 2-4 sutures (Ethicon braided, coated Vicryl, 3-0, FS-1, 24 mm 3/8 c reverse cutting – fish > 700 mm TL; Ethicon, braided, coated Vicryl, 3-0, FS-2, 19 mm 3/8 c, reverse cutting –

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).

As a prophylaxis, after surgery we gave all fish an intramuscular injection of antibiotic (Liquamycin - 0.1 mg/kg fish), then allowed the tagged fish to recover in an individual tank 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). Next, tagged fish were transferred to a larger community recovery tank with a 0.05% salt solution to aid in slime coat recovery. 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 swim away (*Chapter 1 Figure 2).* All times were recorded.

Receiver Placement. In 2012 and 2013, we tracked tagged Blue Catfish with a 20-stationary receiver array (*discussed in Chapter 2*) and a 57-site monthly manual receiver survey (*discussed in Chapter 3*). For the stationary array, data were collected using VEMCO (VR2W-69kHz) receivers which received coded pings from tags each time a tagged fish came within range of the receiver. In 2012, we deployed receivers in June (*Chapter 1 Table 3*); receivers were located at 18 locations within the reservoir and two locations adjacent to the reservoir exits (*Chapter 1 Figure 3*). 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 receivers in the reservoir (receiver 19) and the river receiver below the dam (receiver 20) formed another two tier gate to detect downriver egress (*Chapter 1 Figure 3*). We also had two 3-stationary receiver gate arrays (receivers 6-8, 11-13) across the mid-reservoir constriction (i.e., the limited width allowed complete coverage of the entire reservoir as confirmed by range tests) to detect any fish that moved through the middle region of the

reservoir. In 2012, for data analysis, we removed data from 2 of the 3 receivers in these gates (7, 8, 11, 13) to obtain a more even distribution of detections *(Chapter 1 Figure 3A- dashed squares indicate receivers that were removed)*. Thus, in 2012, of the 18 within reservoir receivers, 14 were used for data analysis. In 2013, we deployed receivers similarly (May-November 2013; *Chapter 1 Table 3).* 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. As in 2012, in 2013, we also removed data from 2 of the 3 gate receivers (7,8, 11, 12) *(Chapter 1 Figure 3B- dashed squares indicate receivers that were removed)*. Thus, in 2013, of the 18 within reservoir receivers, 12 were used for data analysis. Receivers were grouped into five regions based on general size and location (upper, upper middle, Madison, lower middle, and lower; *Chapter 1 Figure 4)*.

We also collected data on acoustically tagged Blue Catfish at 57 (0.8 km^2) manual tracking sites (*Chapter 1 Figure 5).* Tracking sites were positioned to cover the maximum amount of surface area while preventing overlap among adjacent sites (i.e., < maximum range) (e.g., limited spatial arrangements were possible to cover the entire reservoir with sampling units of this size). We chose this design to quantify spatial heterogeneity. The choice of 57 spatially-explicit sampling locations that covered the entire reservoir provided good resolution for quantifying Blue Catfish distribution, allowed us to construct detailed spatial maps of Blue Catfish, and resulted in substantial statistical power. The manual tracking survey was conducted in June through November in 2013 (*described in detail in Chapter 3*).

Stationary Receiver Range Test. We conducted range tests using two methods. Both tests provided information on the distance at which a tag can be detected under field conditions. First, we conducted a range test using the methods provided by the receiver manufacturer, VEMCO.

For this, we deployed an array of receivers in an 800-m straight line, separated by 100-m intervals. A test tag was located near the first receiver. Receivers at 100-800 m were constantly exposed to the repetitive pinging of this tag. 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.

We also conducted a second set of range tests at three receiver locations within Milford Reservoir. We chose these three receivers because they were at sites with similar bathymetry (e.g., water depth), so we could get an estimate of range variation associated with individual sites. For this range test, we 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, we submerged test tags in the water for a count of five detection pings, determined using the manual tracker. From this design, we could determine distances that a tag was detected in four different directions. Data for the second range test was processed using Excel.

RESULTS

2012 – Blue Catfish, Milford Hatchery, Technique Practice and Evaluation. In our initial tagging during which we tested our protocols and evaluated our tagging techniques, all tagged fish survived seven days, all tags remained within the body cavity, incisions healed well, and we observed no differences among taggers. Based on this result, few changes were made to our field protocol.

2012, 2013 – Blue Catfish, Milford Hatchery, Technique Practice and Evaluation. For our field tagging of Blue Catfish, tagged fish suffered little short-term tag loss. In 2012, all 48 tagged fish were detected at least once in the first ten days (black squares per row=detection per

fish; *Chapter 1 Figure 6*). A fish was not scored as detected for this tag evaluation unless it moved between at least two receivers. This ensured that we did not score dead fish as live fish that had retained their tags. Seventy three percent of tagged fish were detected for five or more days during the first ten days (*Chapter 1 Figure 6*). Apart from methodological considerations, tagged fish had different patterns of distribution as some fish were detected more often than others (variation in black squares per row = variation in detections per fish; *Chapter 1 Figure 6*). For example, fish 12 was detected across five days (days 1, 5, 6, 9, 10) whereas fish 47-48 were detected daily (*Chapter 1 Figure 6)*. In 2013, all 75 tagged fish were detected at least once in the first ten days (*Chapter 1 Figure 7*). Ninety six percent of all fish tagged in 2013 were detected for five or more days within the first ten days post-tagging (*Chapter 1 Figure 7*).

In 2012, 95% of the fish were detected in early July and August (*Chapter 1 Figure 8)*. About 90% were detected in September and October. In November, 85% of the tagged Blue Catfish continued to be detected (*Chapter 1 Figure 8)*. In 2013, about 90% of the fish we tagged were detected in July (*Chapter 1 Figure 9)*. We continued to detect over 85% of the tagged fish from August through October, 2013 (*Chapter 1 Figure 8)*.

2014 - Channel Catfish, Milford Hatchery Tagging Experiment. Age-0 channel catfish from Milford Hatchery suffered little tag loss or mortality in any treatment during our 12-week study. No mortality occurred in treatment 1 (our methodology), treatment 3 (no antibiotics), and the control (Treatment 5) (data not shown). Fish in treatment 2 (ventral incision) had an overall mortality of 21% while those in treatment 4 had an overall mortality of 7%. Differences in mortality were not statistically significant, possibly because mortality was low for all fish in all treatments.

All tag loss occurred within the first week (*Chapter 1 Figure 9)* with the exception of one fish in treatment 3. Treatment 1, the treatment we used for field tagging, had no tag loss (*Chapter 1 Figure 10)*. Treatments 2 and 3 had an overall tag loss of 21% (3 individuals in each treatment lost tags). Treatment 4 had an overall tag loss of 29% (4 individuals lost their tags; *Chapter 1 Figure 10*). Our tagging methodology (treatment 1) had a significantly lower tag loss than treatment 4, based on a chi square test (*Chapter 1 Figure 10*). Other differences described above were not statistically significant, (P> 0.05), possibly because tag loss was low for all fish in all treatments.

Range Test Results. Both V9 and V13 tags were detected over 80% of the time at distances from 0-300 m (*Chapter 1 Figure 11*). Percent detections decreased to about 75% between 300-500 m. Detections declined to 70% at 600 m from the tag (*Chapter 1 Figure 11*). VEMCO recommends selecting a receiver range that corresponds to at least 70% of the detections. In our range test, the 70% detection range corresponded to a radius of 600 m (*Chapter 1 Figure 11*).

For our second range test, individual detection radii varied from 300-650 m (average 462 m) for receiver 4. Individual detection radii varied from 500-1,000 m (average 775 m) for receiver 7 (*Chapter 1 Figure 12A*). Individual detection radii varied from 700-900 m (average 825 m) for receiver 12 (*Chapter 1 Figure 12B*). Overall, the average range radius in the second range test (average 687 m) was similar to the range found in the VEMCO recommended range test (average 600 m) (*Chapter 1 Figure 12C*(*Chapter 1 Figure 12A*).). Based on these combined tests, we used a receiver range of 600 m.

DISCUSSION

High Tag Retention. A primary goal of this research was to develop a high-survival, high-retention tagging methodology for catfish. High retention of tags increases the quality and cost effectiveness of a tagging dataset. Conversely, a large proportion of undetected fish raises questions about fish stress during tagging and whether tagged fish behave like untagged fish (an assumption of tagging). For these reasons, we made high tag retention and a high detection rate priorities. In our hatchery trial of Channel Catfish tagging, our methodology (Treatment 1) resulted in no mortality and no tag loss. In one of the early studies that internally implanted tags into Channel Catfish, Marty and Summerfelt (1986) found that 22 of 39 (44% retention) and 45 of 46 (2% retention) fish expelled their tags in 19 and 20 days respectively after being tagged with traditional (non-anchored) implantation methods. In response to this tag ejection, complex internal anchoring procedures were developed (e.g., Siegwarth and Pitlo 1999) that had better, but still low, tag retention rates. 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, OK, Lee (2009) used both traditional and anchored attachment methods (*n*= 5 fish per attachment method). After 120 days in the hatchery pond, all fish retained their tags but 90% died from both methods. Seven of 10 fish died within 48 h of surgeries (Lee 2009). Recently, transmitter retention for adult Blue Catfish (> 600 mm TL) was again evaluated for traditional and anchored implantation methods (*n*=15 per attachment methods). Ten and six fish respectively expelled their tags 23-243 days post-surgery, resulting in retention rates of 33 and 60%, respectively, for traditional and anchored tag attachment methods (Holbrook et al. 2012). In a recent test of a new technique that externally attaches tags to skeletal structure, Bodine et al. (2014) had mixed retention rates. In two hatchery trials, tagged Blue

Catfish had 100% (*n*=20; TL range = 435-638mm) then 41.7% retention (*n*=24, TL range = 600-995) after two months. Thus, our tag retention rate exceeds that of most existing Blue Catfish tag evaluations.

High Detection. Our tagging methodology was also very successful in detecting fish in the reservoir, in that we repeatedly detected 85% of our tagged Blue Catfish in Milford Reservoir through five months across two years (*n*= 48, 75). Other Blue Catfish tagging studies have not detected such a high proportion of tagged fish. In Lake Norman, NC, only 15 of 29 (52%) Blue Catfish (500-900 mm TL) with externally attached radio tags were alive and retained their tags throughout the study (Grist 2002). In Lake Texoma, only 22 of 50 (44%) tagged Blue Catfish (639-1305 mm TL) were successfully tracked. Eight tagged fish were confirmed dead and 20 were not detected (Lee 2009). In the lower Missouri River, Garrett (2010) implanted radio tags into 40 Blue Catfish in each of two years (mean=872, range =569-1260 mm TL). Annual movement cycle data was based on only 12 fish in each year (30% detection of tagged fish throughout the study) because of the large number of tagged fish that were missing. Finally, for a field evaluation of 50 Blue Catfish (TL range = 600-995mm) in Lake Buchanan, Texas, Bodine et al. (2014) redetected only 40% of all tagged fish at 6 months and 19% at 12 months. Consequently, our methodology provides a more detailed dataset than has been previously collected and suggests that our tagged fish were not stressed post tagging. Both of these results increase confidence that our dataset will provide generalizable insights about Blue Catfish distribution.

Critical Attributes of Our Methodology. We attribute our success in tag retention to several factors. Our protocol emphasized preparation, practice, and organization before the tagging event, which allowed us to process fish quickly with minimal stress. A lateral incision

reduced our tag loss in the hatchery and was probably an important factor in successful field tagging. Cooke et al. (2011) reviewed trends in intracoelomic tagging effects studies and found that six of 108 studies compared elements of the incision, but only one study tested a ventral vs. lateral incision. Although a ventral incision may be less likely to puncture the ovaries and may be easier for the surgeon (Schramm and Black 1984), gravity may encourage tag loss in the initial weeks before a ventral incision heals. Although the effect of antibiotics was unclear in our hatchery evaluation, we suspect that antibiotics aided the survival and healing of our field caught fish. In a review of tagging studies, only one study of 108 evaluated the effectiveness of antibiotics. Specifically, Isely et al. (2002) found that the use of antibiotics was effective in preventing initial post-surgery infection.

Receiver Array Effectiveness. Our 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 (Welsh et al. 2012; Klimley et al. 1998). 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. Data from the manual receiver reinforced the results of the stationary receivers. Both regimes (stationary and manual) were designed to detect lake-wide patterns. Our detection regimes covered the whole extent of Milford Reservoir from the causeway in the upper reservoir to the dam. Neither of these regimes, however, detected small-scale movements because of the large detection diameter of receivers (1,200 m diameter) and the wide spacing between receivers.

The impetus for our 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 our 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 our knowledge when we initiated this study, we 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 we describe here (broad spatial scale, low resolution) was well suited for our question and likely would be useful for initial studies in other systems. Information goal, system morphometry, scientific question, and target species behavior also need to be considered in tracking study designs.

Management Implications. We have provided information on how we tagged fish and set up receiver arrays. Our intention was to provide guidance for future studies in other systems. First, our tagging was quite successful because of the organization, preparation, and training we invested. Because of the monetary and labor investment in a tagging program, we strongly recommend this level of preparation. The tagging protocol we describe should be directly applicable to other fish species including but not limited to catfish. Second, because of across-fish variability, future studies should seek to tag a large sample size with the high retention rate we have demonstrated here. A large sample size is essential for generalizable statistical analysis. Although the anecdotal observations about the behavior of a few individuals are interesting, the scientific generality of such isolated observations is low. Third, the choice of fish sizes should be made carefully. Elsewhere (*Chapter 2*), we illustrated that distribution of same size fish varied

widely. Hence a lack of replication of similar--sized fish may result in the erroneous conclusion that differences in distribution are related to size when in fact individual variation is responsible.

Fourth, to utilize the insights that we provide here in other systems, researchers and managers must identify the question for which tagging is being used. As we note above, for a reservoir-wide survey, the array setup we used (broad spatial coverage with relatively low resolution at any specific location) worked well. We argue that this design is the best for the initial study in any system when little knowledge exists about where fish are located. Likewise, if egress is the goal, then gating all exists from the reservoir with multiple stationary receivers would be advisable. Stationary receivers, especially in confined areas, are susceptible to human (vandalism) and natural (high flow, high sedimentation) damage. Multiple receivers in sequence can guard against study failure when receivers are lost and can also detect direction of movement. If stationary receivers are used, downloading data regularly is essential. Receiver loss is common in array studies. Once the receiver is gone, any unloaded data are also lost. Fifth, a thoughtful evaluation of fish behavior relative to system bathymetry is needed to apply the insights provided here to other species and systems. Many fish travel along a channel (Pautzke et al 2010; Kennedy et al 2014) so setting up receivers along this travel lane might be useful in other initial tracking efforts. Confluences are also good locations for initial receiver placement. If there is a central narrow constriction, setting up a series of gates that detect changes through the entire system is useful. Our across-reservoir gates were essential for bounding patterns of distribution for Blue Catfish in Milford Reservoir. Finally, the information gained from tracking studies will accelerate as more fish are tracked within a specific system. In any initial study, little is known about where the fish are located or the study would not be needed. Recognizing that

every question cannot be answered in a single study will facilitate realistic expectations about the steps needed for effective research or management planning relative to this issue.

Chapter 1 Table 1. Summary of evaluation procedures used to develop and evaluate tagging protocols for catfish including year, species, size (range, average, SE), location at Milford, KS, type of tag, number of fish used, surgery time, and evaluation methods.

Year	Species	Size (mm TL) •Range •Average •SE	Location	Tag Type	No. Fish	Average Surgery Time (s)	Evaluation
2012	CC	150-250*	Hatchery	V9 & V9TP	20	NA	<u>Euthanize / Dissect</u>
2012	BC	400-600 487 14.5	Reservoir	V9 & V9TP	48	158	<u>Detections</u> •10 days •5 months
2013	BC	300-1000+ 517 17.8	Reservoir	V9, V13, & V13TP	75	174	<u>Detections</u> •10 days •5 months
2014	CC	184-260 225 2.3	Hatchery	V6	70	114	<u>Response</u> •Tag Loss •Mortality •Growth <u>Tested</u> •Incision •Antibiotics •Surgery Time

Chapter 1 Table 2. Number, length (mm TL), weight (kg wet weight) and release location for Blue Catfish tagged in 2012, 2013 in Milford Reservoir, KS.

Fish	Length (mm)	Weight (kg)	Release Location
	2012		
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
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

Chapter 1 Table 2. Continued.

Fish	Length (mm)	Weight (kg)	Tagging Location
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
	2013		
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
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

Chapter 1 Table 2. Continued.

Fish	Length (mm)	Weight (kg)	Tagging Location
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
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

Chapter 1 Table 3. Dates of stationary acoustic receiver deployment and removal in Milford Reservoir, Kansas in 2012 and 2013 by receiver number.

Receiver	2012 Deployment	2012 Removal	2013 Deployment
1	6-20-12	Dec. 2012	5-16-13
2	6-20-12	NA	5-16-13
3	6-20-12	Mar. 2013	5-16-13
4	6-20-12	July 2013	5-16-13
5	6-20-12	Mar. 2013	5-16-13
6	6-20-12	Mar. 2013	5-16-13
7	6-20-12	Mar. 2013	5-16-13
8	6-20-12	Mar. 2013	5-16-13
9	6-20-12	Mar. 2013	5-16-13
10	6-20-12	Mar. 2013	5-16-13
11	6-20-12	Jan. 2013	5-16-13
12	6-20-12	Mar. 2013	5-16-13
13	6-20-12	NA	5-16-13
14	6-20-12	Jan. 2013	5-16-13
15	6-20-12	Jan. 2013	5-16-13
16	6-20-12	Jan. 2013	5-16-13
17	6-20-12	Jan. 2013	5-16-13
18	6-20-12	Jan. 2013	5-16-13
19	6-20-12	Jan. 2013	5-16-13
20	6-20-12	Dec. 2012	5-16-13

DEVELOPMENT / EVALUATION OF METHODOLOGIES FOR EFFECTIVE ACOUSTIC TAGGING AND STATIONARY RECEIVER ARRAY SET-UP

FIGURE CAPTIONS

Chapter 1 Figure 1. Results of a Web of Science literature search on the key words "acoustic tag" or "radio tag" and "fish" is shown. The results are sorted by calendar year.

Chapter 3 Figure 2. Shown is a flowchart that described the eight steps in our tagging protocol. Each step is described in greater detail in the text.

Chapter 1 Figure 3. Distribution of 20 stationary acoustic receivers within Milford Reservoir is shown for (A) 2012 and (A) 2013. Receiver 1 was deployed in the Republican River above the inflow to the reservoir in order to detect egress out of the reservoir. Receiver 20 was deployed in the Republican River below the dam in order to detect egress out of the reservoir. Receivers 2 and 19 were located within the reservoir and act as a second tier of egress gates. Receivers 6-8 and 11-13 formed two complete gates across the middle reservoir constriction to detect distribution changes. (A) Receivers 7, 8, 11, 13 were removed for data analysis in 2012 to provide a more even array distribution (red dashed boxes indicate the location of the receivers that were removed). (B) Receivers 7, 8, 11, 12 were removed for data analysis in 2013 for the same reason (red dashed boxes indicate the location of the receivers that were removed). Vandalism and boater conflicts resulted in the loss of receivers 1, 16, and 17 in 2013. As a result, in 2012 and 2013, we used 14 and 12 receivers for data analysis respectively.

Chapter 1 Figure 4. In order to more clearly explain reservoir wide distribution patterns, Milford Reservoir was divided into five regions. The main reservoir regions (upper, upper middle, lower middle, lower) are approximately the same size. Madison Creek is a distinct region.

Chapter 1 Figure 5. Sample sites for manual tracking survey at 57 sites to quantify Blue Catfish distribution in Milford Reservoir, KS. Sites were sampled once a month July through November, 2013. Details of the survey methodology are provided in the text.

Chapter 1 Figure 6. For 2012, shown are daily detections used to evaluate Blue Catfish response to tagging. On the X axis are first ten days. On the Y axis are fish number. A filled square indicates that a fish was detected by at least one stationary receiver in Milford Reservoir.

Chapter 1 Figure 7. For 2013, shown are daily detections used to evaluate Blue Catfish response to tagging. On the X axis are first ten days. On the Y axis are fish number. A filled square indicates that a fish was detected by at least one stationary receiver in Milford Reservoir. KS.

Chapter 1 Figure 8. For 2012 and 2013, shown are monthly detections of Blue Catfish in Milford Reservoir, KS. The X axis is month and the Y axis is percent of tagged fish. Numbers of fish tagged are also indicated.

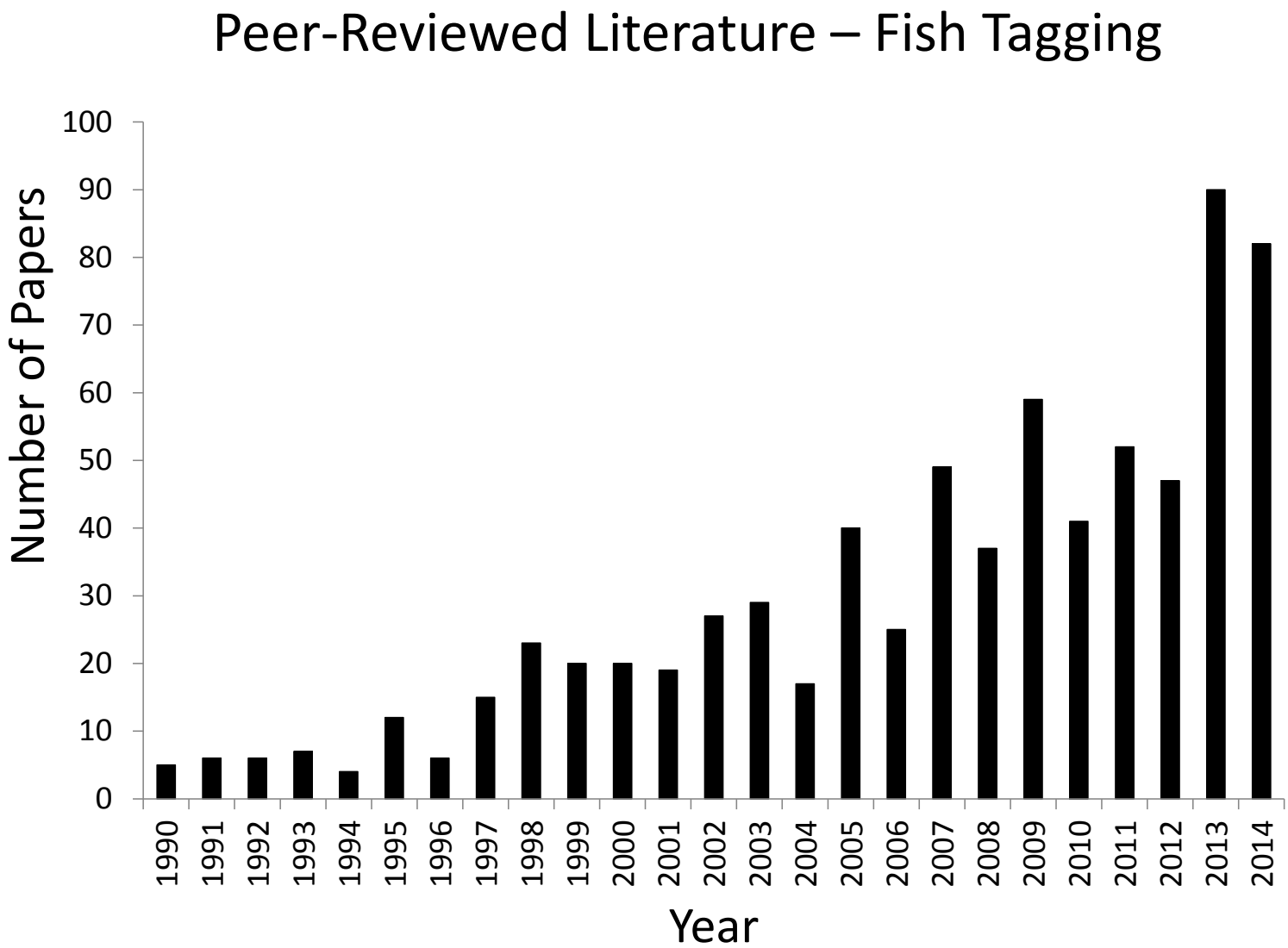
Chapter 1 Figure 9. Tag retention by hatchery Channel Catfish through time is shown for five treatments. (A) The X axis is week and the Y axis is number of fish that retained their tags (i.e.,

no tag loss). (B) The details of the treatments 1-5 are also shown related to incision location, antibiotic use, and surgery time.

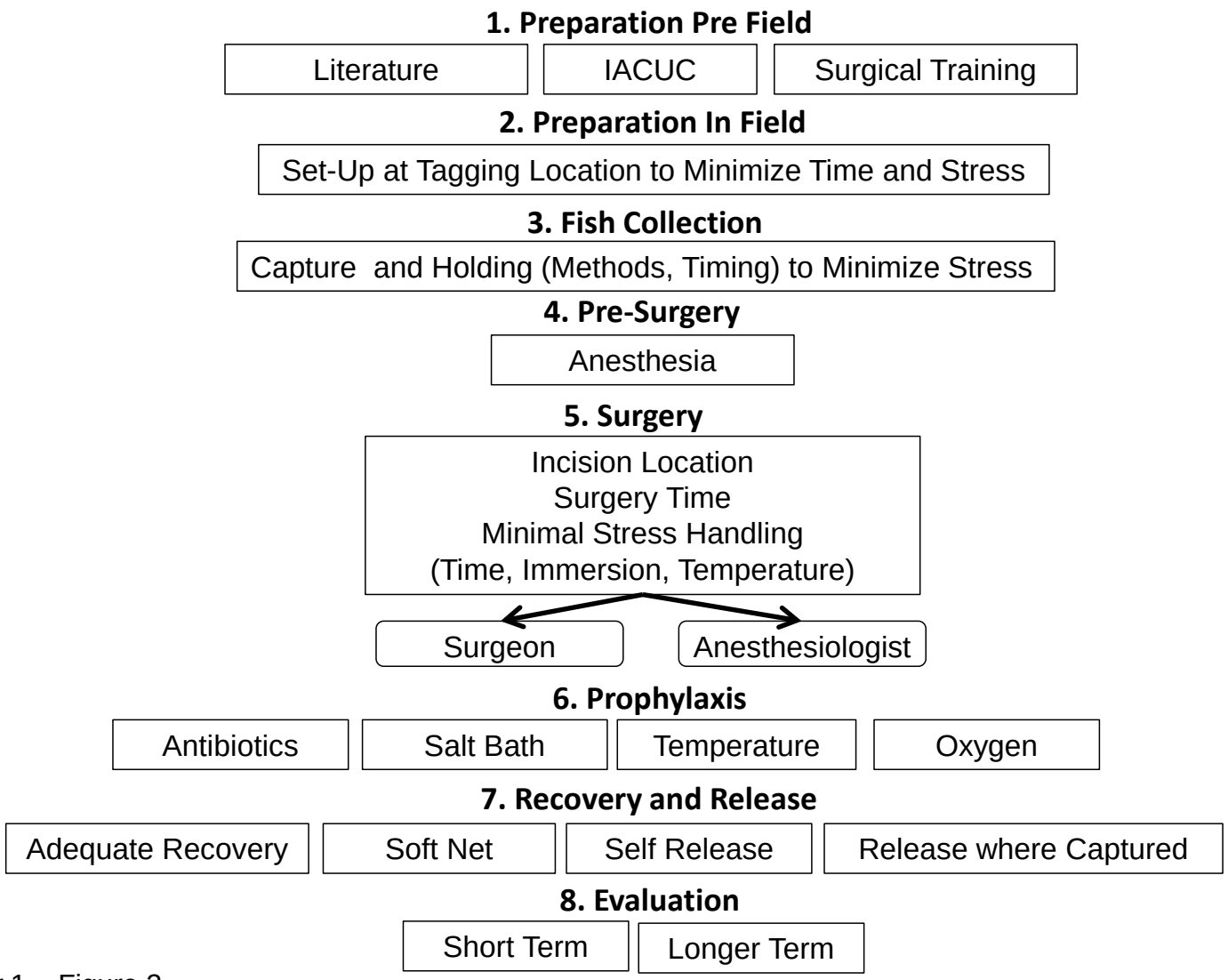
Chapter 1 Figure 10. Tag retention by hatchery Channel Catfish is shown. The X axis is treatment and the Y axis is number of fish that retained their tags (i.e., no tag loss). Our five treatments contained 14 fish each that were given different combinations of incision, antibiotics, and surgery time. Treatment 1 was the treatment we describe below for our 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, and 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.

Chapter 1 Figure 11. Distance at which VEMCO V9 and V13 tags were detected is shown. Distance (m) is shown on the X axis and percent detections is shown on the Y axis. The arrow indicates 70% detection, the range recommended by the tag manufacturer, VEMCO. The VEMCO recommended range test is described in more detail in the text.

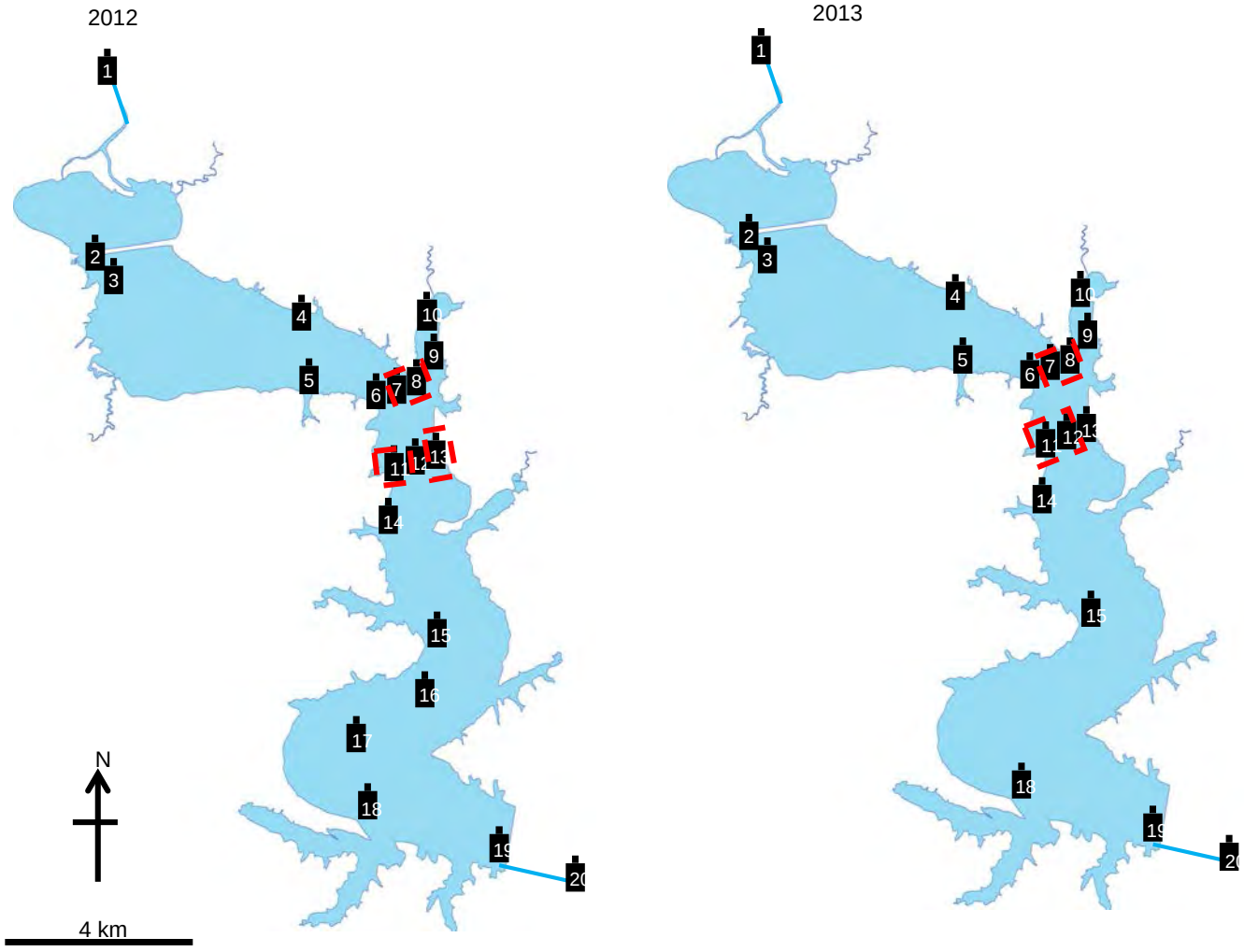
Chapter 1 Figure 12. Distances at which VEMCO tags were heard at three receivers (A) receiver 4, (B) receiver 7, and (C) receiver 2. The specific spatial pattern and mean, minimum, and maximum distances are shown for each receiver. This second range test is described in more detail in the text.



Chapter 1 – Figure 1

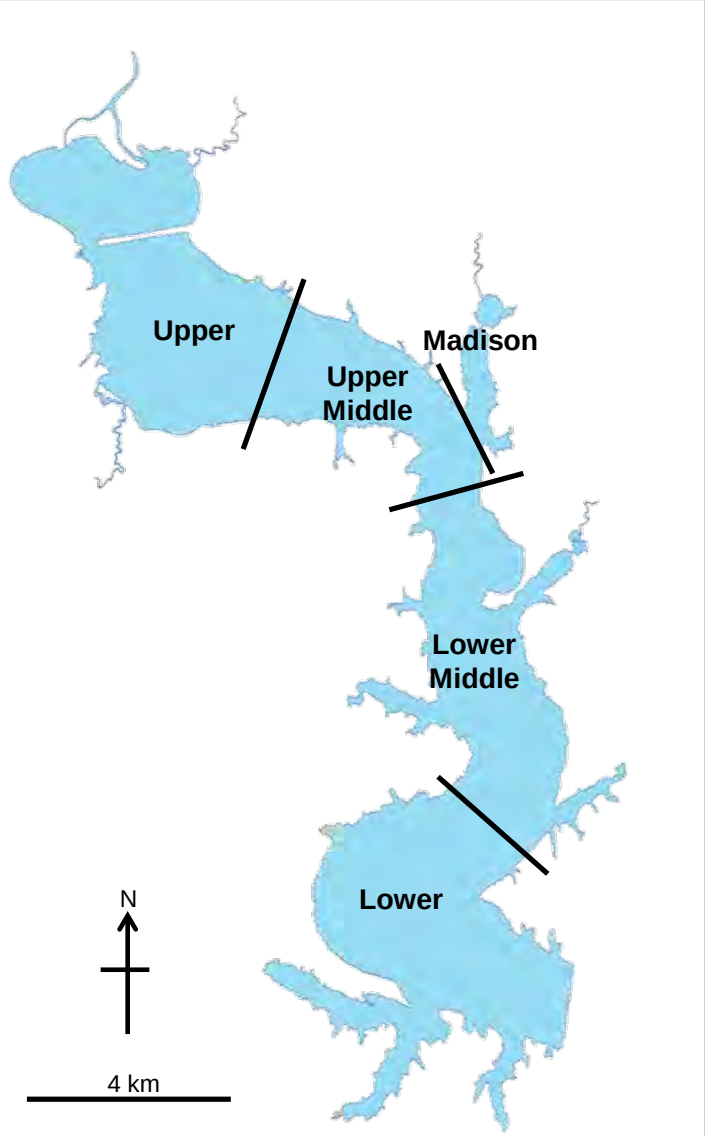


Chapter 1 – Figure 2



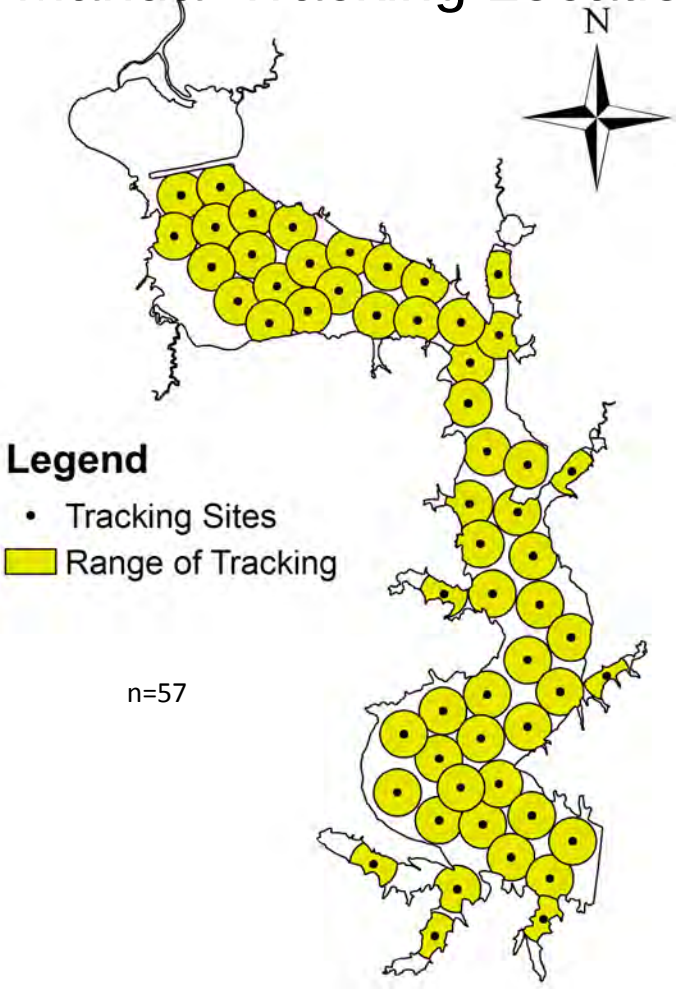
Chapter 1 – Figure 3

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



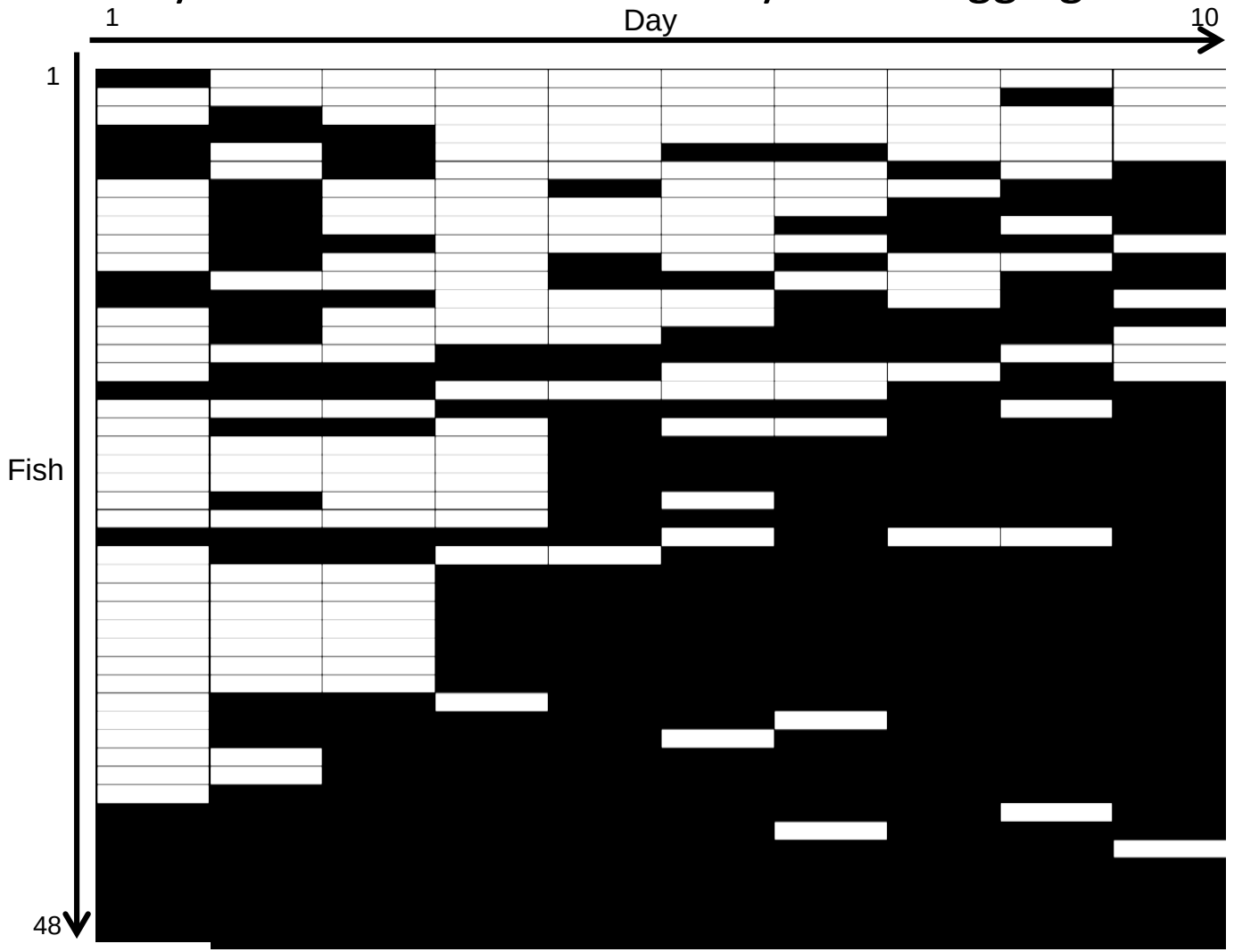
Chapter 1 – Figure 4

Manual Tracking Locations



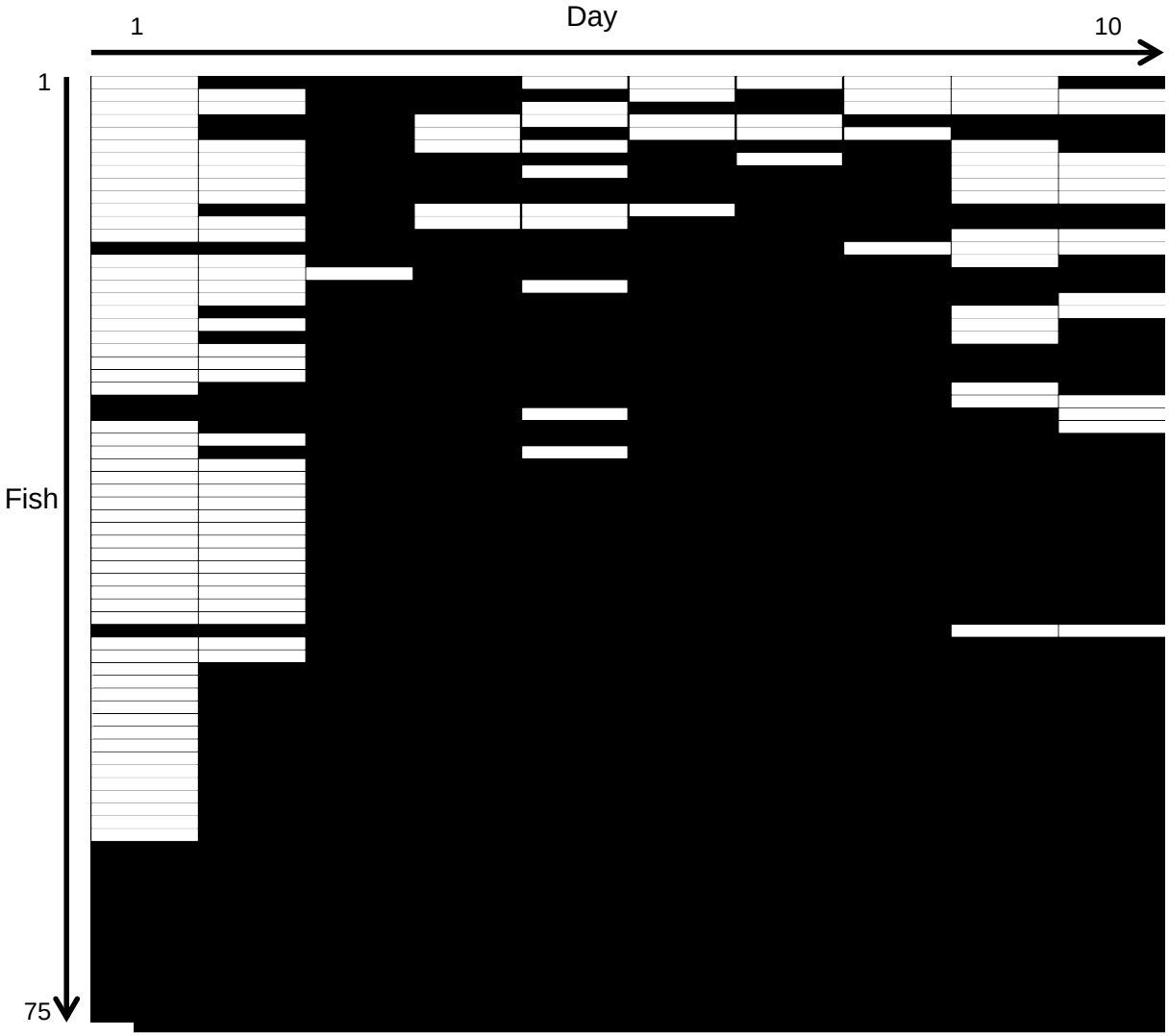
Chapter 1 – Figure 5

Daily Detections for First 10 Days Post Tagging - 2012

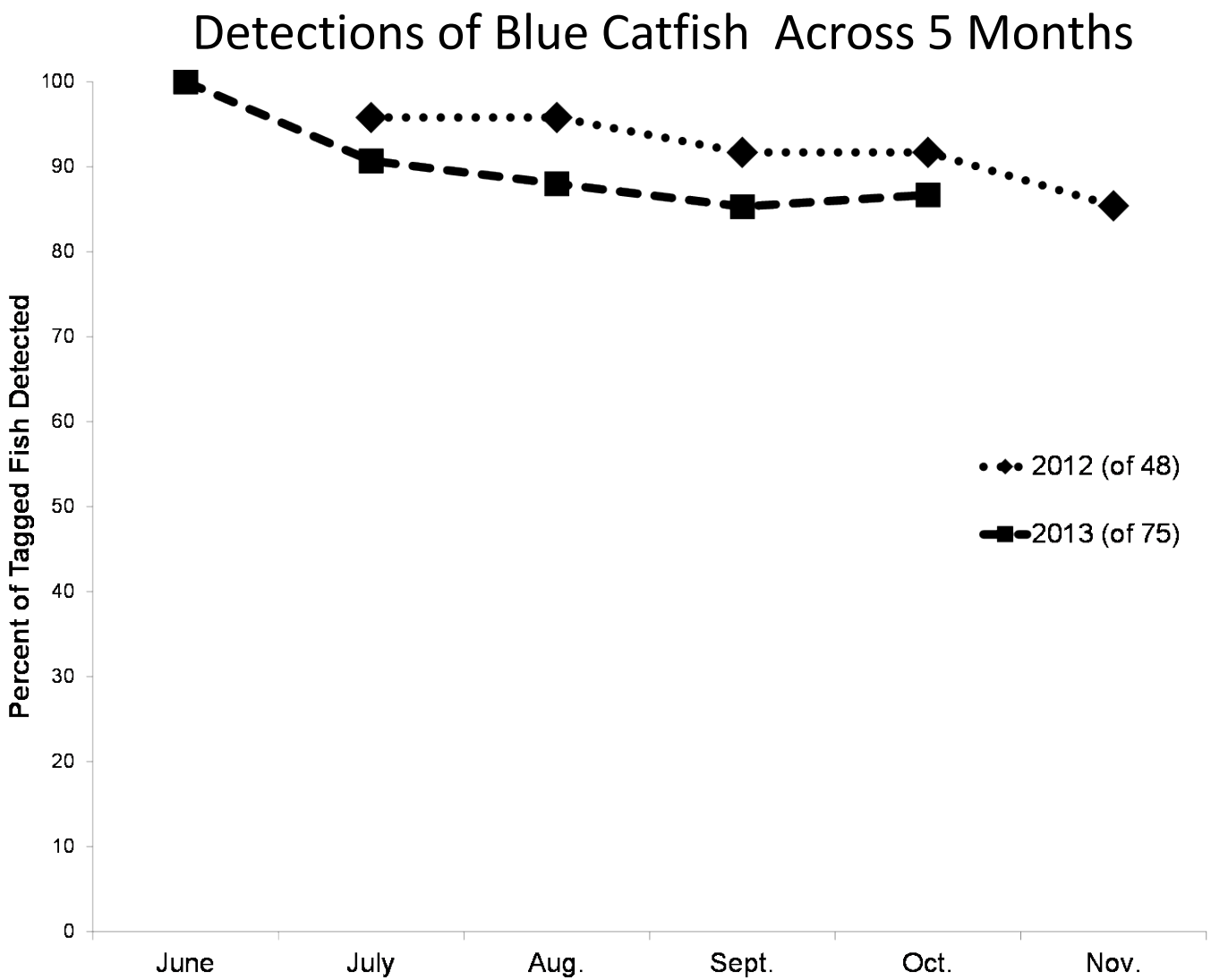


Chapter 1 – Figure 6

Daily Detections for First 10 Days Post Tagging – 2013

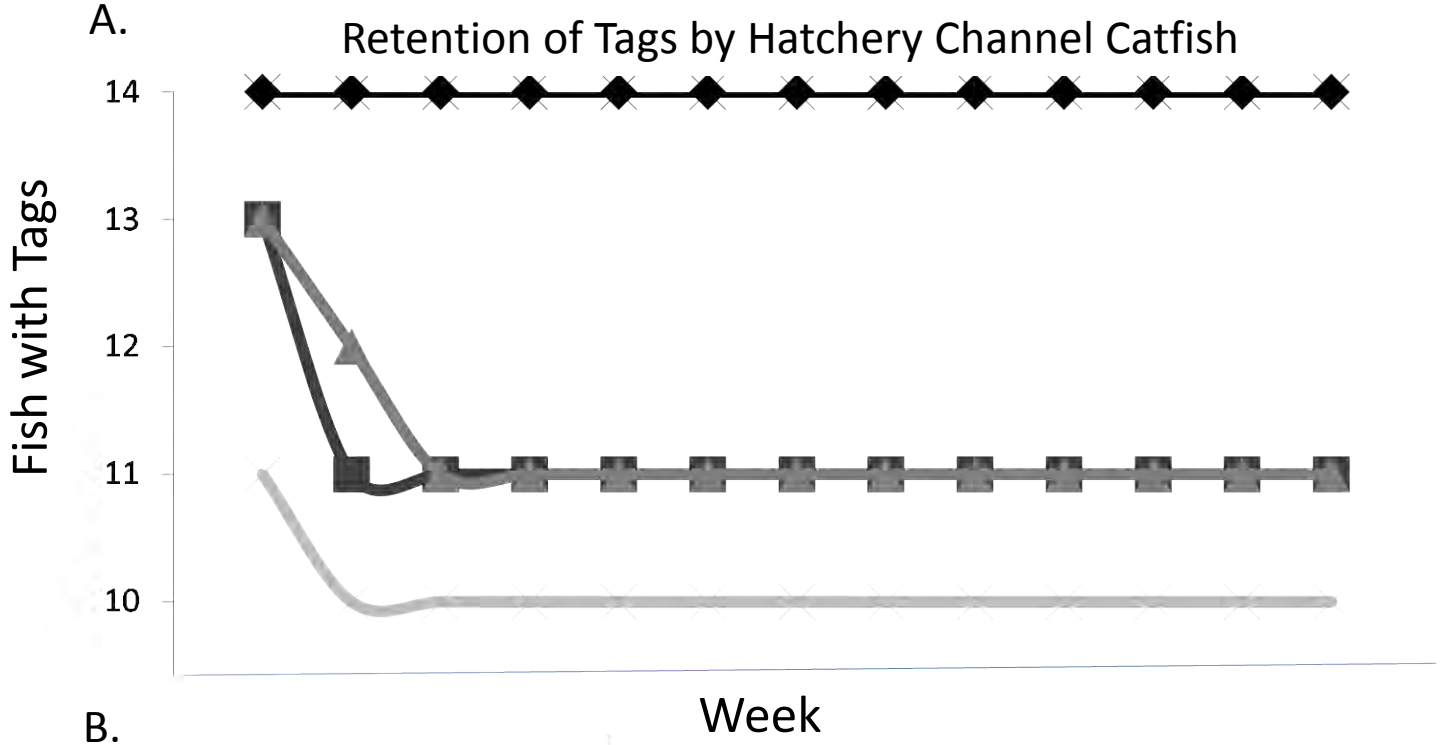


Chapter 1 – Figure 7



Chapter 1 – Figure 8

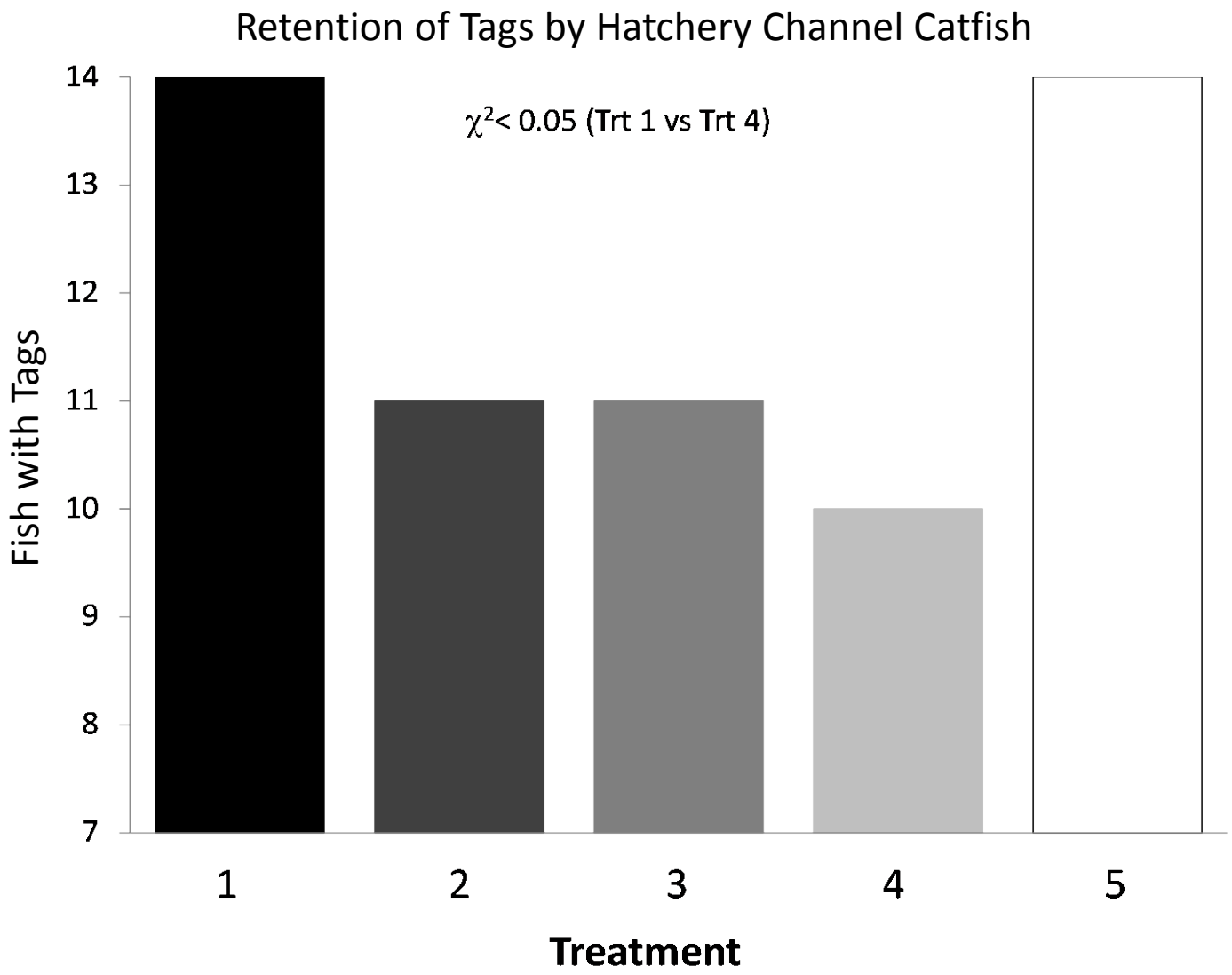
A.



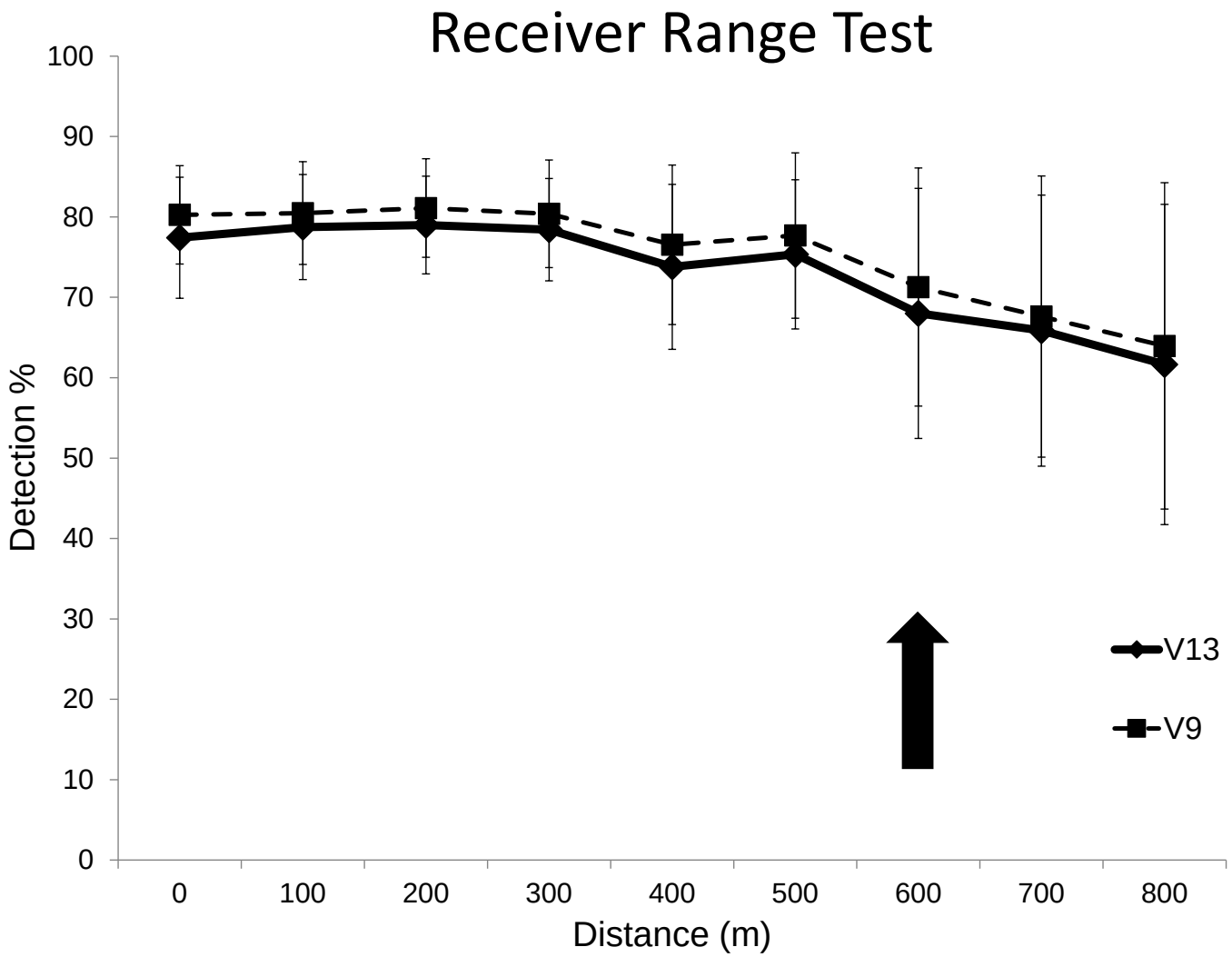
B.

	T1	T2	T3	T4	T5
Treatment	1	2	3	4	5
Incision	L	V	L	V	NA
Antibiotic	Y	Y	N	N	NA
Surgery Time	S	S	S	L	NA

Chapter 1 – Figure 9



Chapter 1 – Figure 10



Chapter 1 – Figure 11

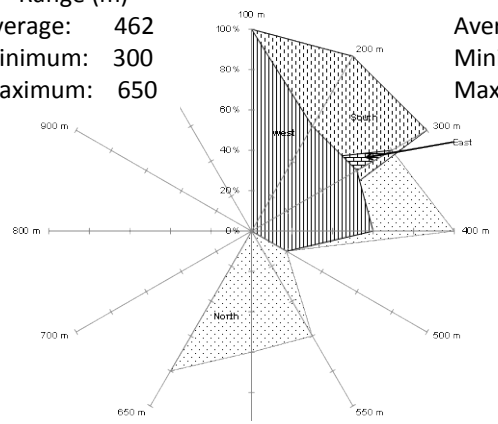
A. Receiver 4

Range (m)

Average: 462

Minimum: 300

Maximum: 650



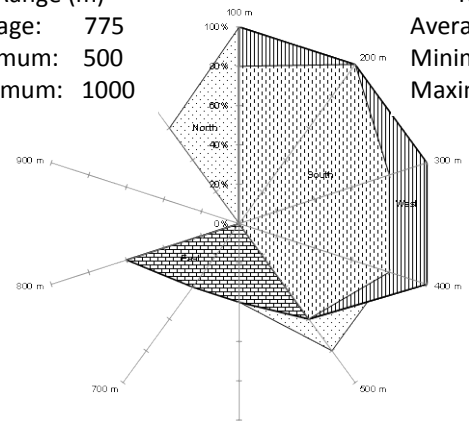
B. Receiver 7

Range (m)

Average: 775

Minimum: 500

Maximum: 1000



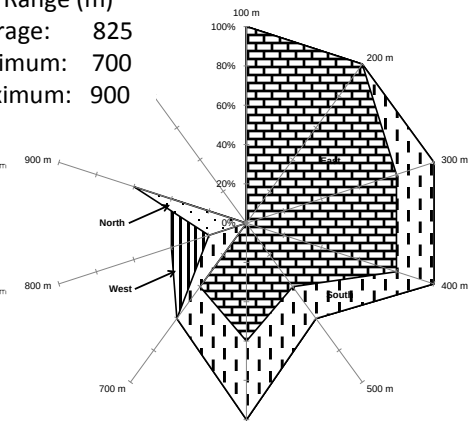
C. Receiver 2

Range (m)

Average: 825

Minimum: 700

Maximum: 900



Chapter 1 – Figure 12

CHAPTER 2 – DISTRIBUTION OF BLUE CATFISH WITHIN AND EGRESS OF BLUE CATFISH FROM MILFORD RESERVOIR (OBJECTIVES 4-5)

INTRODUCTION

Overview. 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, little is known about geographically-localized distribution patterns 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. This lack of information on how mobile fish are distributed and if they move into and out of a study system has been an obstacle for both research and management. Blue Catfish, *Ictalurus furcatus*, is a model organism for addressing the tradeoffs between residency and mobility that influence distribution patterns because of an array of life history features. Here, we use a newer technology (acoustic telemetry and stationary receivers) to identify distributional patterns of Blue Catfish, if tagged fish leave the reservoir in which they were tagged, and factors that may affect distributional patterns (e.g., season, time of day, fish size, and individual variation).

*Importance of Knowing Distribution***.** 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). Understanding variation in distribution (Kennedy and Gray

1993; Jackson et al. 2001; Metcalfe 2006; Roberts and Angermeier 2007) is foundational for research and management. For example, knowing fish distribution is important for stock assessment and for the 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. Anything less than a complete census (i.e., sampling) gives a very limited view of where the fish are located. Consequently, most existing distributional data on fish give a limited view of where fish spend their time.

Mobility Adds a Special Challenge to Quantifying Distribution. Blue Catfish, native to large rivers throughout the United States, can move tens of kilometers in reservoirs and several hundreds of kilometers in rivers (Graham 1999). Blue Catfish may move upstream in the spring and summer (Lagler 1961, Graham 1999) in reservoirs (Timmons 1999; Grist 2002) and rivers (Garrett 2010). They also move 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). Seasonal patterns may vary (Lagler 1961, Pflieger 1997; Graham 1999; Timmons 1999; Fisher et al. 1999; Grist 2002, Garrett 2010). In addition, diel conditions can alter catfish distribution (Graham 1999; Pugh and Schramm 1999; Baras and Laleye 2003; Nunn et al. 2010). Variation in distribution and movement across systems reinforces the need to compare patterns across catfish populations (Kwak et al. 2011). Blue Catfish distribution in reservoirs is not well known, whether Blue Catfish exit reservoirs is not well known, and how season, diel period, size, and individual variation affect Blue Catfish distribution are not well known. Although little quantitative data exist on these issues, researchers and managers have assumed certain patterns of Blue Catfish distribution that have

not been adequately tested, especially in KS reservoirs. As such, this research seeks to fill this information gap on how Blue Catfish are distributed.

Smaller scale distribution patterns (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) and long distance migrations (Hobson 1999; Borcherding et al. 2002; Roberts and Angermeier 2007) alter organismal distribution. New technology (e.g., electronic tags) now allow for quantification of animal distributions (Hobson 1999; Metcalfe 2006). The objectives of this chapter are to,: (1) document locations of tagged Blue Catfish within Milford Reservoir, (2) assess if Blue Catfish migrate out of Milford Reservoir, (3) quantify changes in distribution across months and diel periods, (4) test if Blue Catfish size affects distribution, and (5) identify whether groups of same-sized individual Blue Catfish are distributed in the same way.

METHODS

Study System. Milford Reservoir (39°08'42"N, 96°56'54"W) is an impoundment of the Republican River (Dickinson, Clay, and Geary counties, KS) and is part of the Lower Republican watershed, KS (*Chapter 2 Figure 1*). Milford Reservoir has a surface area of 6,555 ha, 262 km of shoreline dominated by limestone cobble and boulders, an average depth of 6.7 m, and a maximum depth of 19.8 m (Reinke 2001).

*Fish Tagging (Number, Size, Timing)***.** In both 2012 and 2013, we targeted the most common size of Blue Catfish in Milford Reservoir (about 400-600 mm) as determined from previous field assessments (*Chapter 1 Appendix Figure 1*). In 2013, a limited number of smaller and larger Blue Catfish were added (*Chapter 1 Table 2).* On 26-28 June, 2012, we internally

implanted 48 Blue Catfish with VEMCO V9 acoustic tags (mean fish size = 487 mm TL, range 383-1020, SE 14.5, *n*=48). On 3-5 June, 2013, we internally implanted 75 Blue Catfish with VEMCO 9 and V13 tags (mean fish size = 517 mm TL, range 343-1090, SE 17.8, *n*=75). Tagging procedures are described in detail elsewhere (*Chapter 1*). Blue Catfish were collected at three locations within Milford Reservoir: Causeway, Madison Creek, and School Creek. Fish were released in the same location where they were caught and tagged. Equal numbers of fish were tagged at each location on sequential days using identical protocols. We test whether capture location affected distribution with a Kruskal-Wallis test and post-hoc multiple comparison (kruskalmc, pgirmess package R).

*Receiver Placement***.** In 2012 and 2013, we tracked tagged Blue Catfish with a 20-stationary receiver array and a 57-site monthly manual receiver survey (*discussed in Chapter 3*). For the stationary array, data were collected using VEMCO (VR2W-69kHz) receivers which received coded pings from tags each time a tagged fish came within range (i.e, 600 m of the receiver). In 2012, the receivers were located at 18 locations within the reservoir and two locations adjacent to the reservoir exits (*Chapter 1 Figure 3).* The upper river receiver (receiver 1) and the upper within-reservoir receiver (receiver 2) formed a two-tiered gate to detect upriver egress from the reservoir. The southernmost receivers in the reservoir (receiver 19) and the river receiver below the dam (receiver 20) formed a two-tiered gate to detect downriver egress (*Chapter 1 Figure 3*). We also had two 3-stationary receiver gate arrays (receivers 6-8, 11-13) across the mid-reservoir constriction (i.e., the limited width allowed complete coverage of the entire reservoir as confirmed by range tests) to detect any fish that moved through the middle region of the reservoir. In 2012, for data analysis, we removed data from 2 of the 3 receivers in these gates (7, 8, 11, 13) to obtain a more even distribution of receivers. Thus, in 2012, of the 18

within reservoir receivers, 14 were used for data analysis. In 2013, we deployed receivers similarly (May-November 2013; *Chapter 1 Table 5).* 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 12 was lost. As in 2012, in 2013, we also removed data from 2 of the 3 gate receivers (7, 8, 11, 12) for the same reasons. Thus, in 2013, of the 18 within reservoir receivers, 12 were used for data analysis. Details of array deployment and range testing are described in detail elsewhere (*Chapter 1*). Receivers were grouped into five regions (upper, upper middle, Madison, lower middle, and lower; *Chapter 1 Figure 4*). The manual tracking survey, undertaken in June through November, 2013 (*described in detail in Chapter 3*), was used to confirm stationary distribution data.

*Data Format***.** When each receiver was downloaded, each individual tag detection was recorded as a single data line including a date, time, and fish tag number. After field data downloads were complete, data from all receivers were combined using VEMCO's VUE software, Microsoft ACCESS, and Microsoft EXCEL.

Egress. To test egress through the river up reservoir or past the dam down reservoir, the four extreme receivers (1, 2, 19, 20) were downloaded regularly to check for detections. The downloaded data for these receivers were examined for fish number. Discharge was examined during the field season in both years (USGS 06857100 Republican River at Junction City, KS)**.**

*Overview of Experimental Design***.** Here, we first provide an overview of the research design. Then we give more details for each component in subsequent sections. Because an intact trajectory is too complex for quantitative analysis, to quantify distribution we focused on three component metrics: unique individuals, residence time, and numbers of movements (*Chapter 2 Figure 2*). These responses are defined in more detail below. For distribution at each receiver, we

examined two responses (numbers of unique individuals, mean residence time) using maps and Chi square analyses. Then we used one response (residence time at each receiver) to visually depict and statistically test three treatments that might affect distribution: season, diel period, and fish size. Numbers of movements were quantified for individual fish, receiver, and season. Individual fish variation was examined with cluster analyses and box plots.

Responses. We used three specific components of trajectories (unique individuals, residence time, and numbers of movements between receivers) to describe Blue Catfish distribution within Milford Reservoir. Unique individuals, residence time, and movements were summarized to provide a system-wide distribution pattern. Residence time was used to test all treatments (season, diel, and size) and to calculate clusters.

Numbers of unique individuals, residence time, and numbers of movements are all approaches to quantifying the distribution of tagged fish. To obtain this metric, the above described data base was manipulated by fish number and date for each receiver and the presence of individual fish at a specific location at a specific time was recorded. Residence time is a relatively new metric for fish tracking and is only possible with an extensive array of stationary receivers as we have deployed here. Residence time, likely our most useful response, quantifies how much time each animal spends at each location. For fixed receivers that record data 24 h day in the same location, residence time is the preferred metric and replaces home range, which typically require detections at random not fixed locations. To calculate residence time, raw detection data from the receivers was 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 records a fish as present (or resident) at a specific location after two detections and until it is not detected for a period of time specified by the researchers (here 1 h). Movements between

receivers were also calculated by the VTrack program. For this metric, detection between receivers is tallied as a single movement.

Distribution. To quantify distribution, unique individuals and residence time were calculated for the entire study period (June through November). These data were plotted on maps of Milford Reservoir. Unique individuals and residence time were compared across receivers using a Chi square analysis with 2000 Monte Carlo simulations in which the expected was an even distribution. For unique individuals, an even distribution is calculated as the same number of fish at each receiver. For residence time, an even distribution is calculated as an equal amount of time spent at each receiver. For unique individuals, the Chi square analysis evaluated if fish were evenly distributed. For residence time, Chi square analysis assessed if fish were spending more time, less time, or the same amount of time at all receivers.

Tests of Season, Diel Period, and Fish Size Effects. We also tested if residence time differed across season (months), diel period, and fish size. For season, residence time for June, July, August, September, October, and November were calculated for each fish. Then differences in residence time among months was tested with a Kruskal-Wallis test and post-hoc multiple comparisons Individual fish were treated as replicates. For diel periods, residence times were calculated for four daily time periods: (a) a 2 hour period centered around dawn, (b) day, (c) a 2 h period centered around dusk, and (d) night. Residence time was divided by hours in each diel period before these four diel periods were compared with a Kruskal Wallis test. To test the effect of fish size, we ran a univariate regression between fish total length (mm TL, treatment or X) and residence time (response or Y).

*Calculation of Clusters***.** To compare individual behavior, we used separate cluster analyses on residence time for each month and all seasons combined. For cluster analysis,

residence time data were log transformed and then a Euclidean distance matrix was created. The non-hierarchical method PAM (partitioning around medoids) was run on the data using the PAM function in R (source) ('cluster' package) to determine if there were similar groups of fish present throughout the reservoir. The optimal number of clusters was determined using silhouette plots and Jaccard bootstrap mean values obtained from the bootstrap method ('clusterboot' function; 'fpc' package). Jaccard bootstrap mean values >0.60 confirmed cluster patterns (Hennig 2010). The ecological meaning of the clusters was determined by receiver and season-specific boxplots for each cluster. For synthesis, we combined all monthly clusters into three general movement patterns. This synthesis combined the voluminous original cluster data (shown as monthly clusters in the appendix) into synthesis clusters.

RESULTS

Overall. In July - November, 2012, we recorded 1,139,515 detections. In June-October, 2013, we recorded 2,044,881 detections. These detections were made by 85% of the fish we tagged. In 2012, five fish either died or lost their tags. In 2013, 11 fish died or lost their tags with one fish a confirmed catch by an angler. These "missing" fish were not considered in the data analysis.

Distribution: Unique Individuals and Residence Time. For both unique individuals and mean residence time, tagged Blue Catfish did not spend equal amounts time in all areas of Milford Reservoir. In 2012, for unique individuals, fish were concentrated in the upper middle and lower middle regions of the reservoir with more fish than expected at receivers 4, 5, 6, 12, 14, 15 (*Chapter 2 Figure 3A, B*) and less fish than expected at receivers 2, 3, 9, 10, 17, 18, 19 (*Chapter 2 Figure 3A, C*). Chi square simulations statistically confirmed these patterns of

aggregation (P<0.001; *Chapter 2 Figure 3B, C*). In 2013, for unique individuals, fish were again concentrated in the upper middle and lower middle regions of the reservoir as well as in the upper reservoir region, with more fish than expected at receivers 2-6, 9, 13-14 (*Chapter 2 Figure 4A, B*) and less fish than expected at receivers 10, 15, 18-19 (*Chapter 2 Figure 4A, C*). Chi square simulations again statistically confirmed patterns of aggregation (*P<0.001; Chapter 2 Figure 4B, C*).

In 2012, for mean residence time, fish were concentrated in the upper middle and lower middle regions of the reservoir as well as Madison Creek with fish spending more time than expected at receivers 6, 9, 10, 12 (*Chapter 2 Figure 5A, B*) and less time than expected at receivers 2, 3, 4, 5, 14-19 (*Chapter 2 Figure 5A, C*). Chi square simulations statistically confirmed these patterns of aggregation (*P<0.001; Chapter 2 Figure 5B, C*). In 2013, for mean residence time, fish favored the upper middle region with fish spending more time than expected at receivers 4, 6 (*Chapter 2 Figure 6A, B*) and less time than expected at receivers 2, 3, 5, 10, 14-15, 18-19 (*Chapter 2 Figure 6A, C*). Chi square simulations statistically confirmed patterns of aggregation *(P<0.001; Chapter 2 Figure 6 B, C*). For both responses in both years, this clustering occurred in the funnel above the reservoir constriction (upper middle region) and within the upper constriction (upper part of lower middle region).

Egress. In 2012 and 2013, no fish left Milford Reservoir through the downstream egress via the dam (*receiver 20; Chapter 2 Figure 7*). In 2012, no fish left Milford Reservoir through the upstream egress (*receiver 1; Chapter 2 Figure 7; Chapter 2 Table* 1). However, because of the vandalized upstream receiver (receiver 1) in 2013, we had to rely on the inner gate (receiver 2) to detect potential upstream egress. In 2013, only five fish were last seen at the upstream receiver 2 (*receiver 20; Chapter 2 Figure 7*). All five of these fish repeatedly traversed the upper

and upper middle reservoir in spring as is shown by the repeated vertical lines of detections (*Chapter 2 Figure 8).* Two of these fish were not detected subsequently because receivers were removed at the end of the study (*Chapter 2 Figure 8A, B*). The remaining three fish traversed frequently between receiver 2 and other reservoir receivers. These repeated movements back and forth through the upper reservoir (i.e. repeating vertical bands of detections) are unlike the quick unidirectional movement (i.e., one single vertical line) that would be expected for long-distance, unidirectional upstream migrants (*Chapter 2 Figure 8C, E*). In summary, no fish left through the downstream egress in either year, no fish left through the upstream egress in 2012, and < 3 of 75 tagged fish could have left the reservoir through the upper egress in 2013. Because our 2012 and 2013 field seasons corresponded with a regional drought, discharge was relatively low in June through November in either year (*Chapter 2 Appendix Figure 2*).

Seasonal Differences. Seasonal distribution varied across select receivers in 2012 (*Chapter 2 Figure 9*) and 2013 (*Chapter 2 Figure 10*). When comparing boxplots for residence time across months, in 2012, fish spent more time at upper reservoir receiver 2 in October (*2; P<0.05; Chapter 2 Figure 9A*), but less time at upper reservoir receiver 3 in November (*3; P<0.05; Chapter 2 Figure 9B*). No statistically significant monthly differences existed across other receivers in the upper middle region (*4, 5, 6; P>0.05; Chapter 2 Figure 9C-E*), Madison Creek (*9, 10; P>0.05; Chapter 2 Figure 9F, G*) or in select lower middle reservoir receivers (*12; P>0.05; Chapter 2 Figure 9H*). However, other lower middle reservoir receivers (*14-15; P< 0.0; Chapter 2 Figure 9I, J*), and lower reservoir receivers (*16-19; P< 0.05; Chapter 2 Figure 9K-N*) were significantly different across months. For these southern receivers, residence times were higher in the fall. In general, these seasonal changes reflected decreases in residence time at upper reservoir receivers and increases in residence time at lower reservoir receivers in fall as

upper reservoir fish moved south to the middle reservoir and middle reservoir fish moved south to the lower reservoir.

Seasonal trends in 2013 were more variable. In 2013, upper reservoir receivers again had variable visitation across months (*2, 3; P< 0.05; Chapter 2 Figure 10A, B*). In 2013, fish again spent more time at lower reservoir receivers in the later fall (*18, 19; P< 0.05; Chapter 2 Figure 10K, L)* as fish moved from north to south. In 2013, upper middle receivers (*4, 5; P< 0.05; Chapter 2 Figure 10C, D)* and Madison Creek receivers (*9, 10; P< 0.05; Chapter 2 Figure 10F,* G) differed across months but a consistent overall trend was unclear. Other upper middle (6) and lower middle reservoir receivers (13, 14) were not significantly different across months (*P> 0.05; Chapter 2 Figure 10E, H, I*). As in 2012, for 2013, this pattern generally reflected higher use of the lower region of the reservoir in fall. In fact, more movements occurred at receivers in the lower middle and lower reservoir (receivers 12-18) in the fall (*Chapter 2 Figure 11*) even though movements were not greater for these lower reservoir receivers when all time periods were combined (*Chapter 2 Figure 12*).

Diel and Size Differences. We found no significant differences among residence times across diel periods at any of the receiver locations for 2012 *(P> 0.05; Chapter 2 Figure 13A-N)* or 2013 (*P>0.05; Chapter 2 Figure 14A-L*). Neither residence time (*P>0.05; Fig. 15A, C*) nor number of movements (*P>0.05; Fig. 15B-D*) differed by fish size. As a distribution of movements across individuals in 2012 shows, even individual fish of similar sizes vary substantially in the amount they move (*Chapter 2 Figure 16).*

Capture, Tag, and Release Location. In both 2012 and 2013, tagged Blue Catfish were detected more often near the receivers where they were originally captured, tagged, and released (*Chapter 2 Figure 17-18*). Tagged Blue Catfish that were captured, tagged and released at the

Causeway site (near receiver 5; *Chapter 2 Figure* 17 D, 18D) were detected more frequently at receiver 5 (*Chapter 2 Figure* 17 D, 18D) and at the adjacent receivers 4 and 6 (*Chapter 2 Figure* 17C,17E, 18C. 18E). Tagged Blue Catfish that were captured, tagged and released at the Madison site (near receiver 9; *Chapter 2 Figure* 17F, 18F) were detected more frequently at receiver 9 (*Chapter 2 Figure* 17F, 18F) and at the adjacent receivers 6 and 10 (*Chapter 2 Figure* 17E, 17G, 18E, 18G). Tagged Blue Catfish that were captured, tagged and released at the School Creek site (near receiver 15; *Chapter 2 Figure* 17J, 18J) were detected more frequently at receiver 15 (*Chapter 2 Figure* 17J, 18J) and at the adjacent receiver 14 (*Chapter 2 Figure* 17I, 18I). These trends were not surprising since the fish were aggregated at Causeway, Madison, and School Creek when there were captured and continued to stay in those aggregations after they were tagged and released. These results do not alter any of the interpretations of our data because we captured and released fish in the same location.

Cluster Synthesis. With cluster analysis, we identified that different groups of individual fish existed. Within groups, individuals were distributed similarly, but across groups differences in distribution existed. By combining clusters across seasons, we identified three types of distribution. The first type of distribution included fish that changed their seasonal distribution (*Chapter 2 Figure 19*). In July and August, these fish were most common at receiver 6 (*Chapter 2 Figure 19A, B*). In September, eight clusters emerged that were spread throughout the upper middle, lower middle, and lower reservoir (*Chapter 2 Figure 19C*). In October and November, these clusters merged into one mega cluster that frequented the lower middle and lower reservoir, especially receivers 12-19 (*Chapter 2 Figure 19D, E*).

The second type of distribution included the non-migrating reservoir fish which were regulars in the funnel just above and within the upper reservoir constriction (*Chapter 2 Figure*

20A-E). This distribution group was composed of a single cluster in July and August (*Chapter 2 Figure 20A, B).* This distributional group did not migrate south in fall, and across all seasons remained in the upper middle and lower middle reservoir near receivers 6 and 12 (*Chapter 2 Figure 20C-E*).

A third type of distribution group included the Madison Creek fish (*Chapter 2 Figure 21A-E*) that stayed near Madison Creek receivers (9, 10) in July (*Chapter 2 Figure 21A*), September (*Chapter 2 Figure 21C*), October (*Chapter 2 Figure 21D*), and November (*Chapter 2 Figure 21E).* These synthesis groups were derived from the original monthly clusters which are presented here as an appendix but are not interpreted separately (*Chapter 2, Appendix Figures 3-32*).

In summary, the uneven distribution, observed across the entire reservoir, is the result of clusters of fish using upper, upper middle, lower middle, and lower regions of the reservoir differently with southern movements by some fish in the fall.

DISCUSSION

Overview of Unique Contributions of Our Research. Our extensive Blue Catfish tracking data set provided novel insights into a long-standing, but largely untested, question in fisheries biology, fisheries management, and fish ecology (e.g., where are fish located?). Our unique data set is unprecedented relative to the numbers of tagged fish, numbers of detections, temporal extent of detections, and spatial distribution of detections. Specifically, our research design included 123 fish tagged across 2 years, 85% tag retention over 5 months per year, continuous 24-h tag detections during summer and fall; 2 tiers of gates at each reservoir egress point; 2 3-receiver, across-reservoir gates; and a 12-14-stationary receiver array distributed throughout the

reservoir. With this data set of substantial spatial and temporal scope, we tested focused questions about Blue Catfish distribution (e.g., nature of distributional patterns) and factors that may change Blue Catfish distribution (e.g., existence of seasonal egress, role of seasonal and diel time periods, influence of fish size, behavioral patterns of same-sized individuals). Although many aspects of Blue Catfish distributional patterns are widely accepted, assumptions about the distribution of this important sport fish have rarely been tested. This is because an effective and affordable methodology to track large numbers of individuals over an entire system at a detailed time scale was not available in the past.

Our quantification of Blue Catfish distribution was more detailed than any previous study (e.g., Fisher et al. 1999; Edds et al. 2002; Grist 2002; Garrett 2010) because we used this newly available fish tracking technology effectively (e.g., acoustic tags and a stationary receiver, a substantial receiver array, a high sample size of tagged fish, strong research design). As a result, our results on distributional patterns neither supports nor contradicts existing data on Blue Catfish distribution simply because the novel level of detail we provide through our fish tracking did not exist previously. However, our quantitative tests of treatments that might alter distributional patterns (e.g. Blue Catfish egress, seasonal patterns, diel periodicity, fish size, and variability in individual behavior) are comparable to questions asked previously (e.g., Fisher et al. 1999; Grist 2002; Garrett 2010). Relative to these variables, our results suggest that many assumptions about egress, season, diel periodicity, fish size, and individual variation may not be widely applicable. We hope our research stimulates future tests of across system synthesis. Together, these data (past descriptive research, this present study, and future studies) will provide synthesis and generalization about distribution patterns of this important, popular, and mobile sport fish predator.

Distribution Patterns. Blue Catfish in Milford Reservoir were consistently clustered in an upper middle reservoir aggregation. This pattern was similar for two different fish responses (e.g., numbers of unique tagged individuals, average residence time per individual). Specifically, for all months and both years, more fish were present and individual fish spent more time in the upper middle reservoir funnel that starts just above the upper reservoir constriction and ends just below the Madison Creek confluence. Interestingly, this concentration of fish and elevated fish residence is not in the geographic center of the reservoir and does not include the entire middle reservoir constriction, but instead focuses on the geographic area leading into the constriction funnel down through the upper constriction (through the first major tributary, Madison Creek). Although fish were consistently concentrated in this funnel, they were not sedentary and frequently moved to other locations before returning to the above described location.

The spatial resolution of our results far exceeds that provided by previous studies. Other peer-reviewed Blue Catfish distributional studies do not provide detailed maps of system-wide distributional patterns (e.g. Fisher et al. 1999; Edds 2002; Grist 2002; Garrett 2010). Although an uneven distribution is probably common in fisheries and ecology, the detailed and consistent view of an aggregated and clustered population, apparent from our data, is not frequently seen in the existing fish ecology or fisheries management literature. Much scientific research discusses and speculates about uncertainty in research results. Because of the design of our study and the quality of our data, we know where Blue Catfish were located in Milford Reservoir. As seen in the next chapter, manual tracking which covers more locations (n=57) for a shorter time confirms this consistent aggregation in the mid-reservoir funnel and adds some additional details on localized heterogeneity.

Egress. We did not detect any tagged Blue Catfish migrating out of Milford Reservoir from June through November, 2012-2013, based on our continuous (24 h a day) tracking of 123 tagged fish at double egress gates at both upstream and downstream exits. We know that 85% of the fish, tagged in both years, do not leave the reservoir because they were continually detected at specific locations within the reservoir. We know for certain that no tagged Blue Catfish left downstream past the dam in 2012 or 2013 because of our intact double gates at downstream egress points (receivers 19 upstream of the dam; receiver 20 downstream of the dam) in both years. We also know for certain that none of the 48 fish tagged in 2012 left the reservoir through the upstream exit because of the presence of an intact double gate at the upstream egress point (receiver 1; receiver 2). During the last part of the 2013 field season, receiver 1 was lost. Unfortunately, receiver loss is common in tracking studies with fixed gear. However, the second or inner tier of the upper gate (i.e., , receiver 2) remained in place throughout the 2013 field season and allowed us to evaluate if any tagged Blue Catfish might have exited the reservoir using this route. Only five of 75 Blue Catfish, tagged in 2013, were last seen at receiver 2. Of these, two were not redetected because the study ended and receivers were removed. Thus, the ultimate fate of < 3 of 75 Blue Catfish tagged in 2013 is uncertain. Because these three fish repeatedly moved back and forth between receiver 2 and other reservoir receivers, it is unlikely that these three fish left the reservoir in 2013. Despite the unknown final disposition of these three fish, our data clearly indicate that most Blue Catfish tagged in Milford Reservoir in 2012-2013 did not make long distance migrations out of the study system in our summer-fall field season.

In other studies, upriver or up-reservoir movements of Blue Catfish have been observed in spring and downriver or down-reservoir movement have been observed in fall (Fisher et al.

1999; Garrett 2010). In Milford, a few fish irregularly moved from the lower receiver to the upper receiver, but these rare movements for a few fish occurred over several weeks and were not a common response. Spring movements are often associated with spawning, typically in April-June at 21-24°C (Graham 1999). We did not track Blue Catfish in spring. If Blue Catfish individuals left Milford Reservoir during June on a spawning migration, we would not have captured them for tagging. In Milford Reservoir, during June 2014, water temperatures exceeded 21° C, the optimal for spawning. If Blue Catfish spawned within Milford Reservoir, likely our study missed that April-May period of spawning activity. Hence, if long distance movement is associated with spring spawning, we would not detect these trends because of the timing of our study. Discharge may be a variable influencing egress (Garrett 2010). In 2012 and 2013, stream flow and discharge from Milford Reservoir was low. If long distance migration out of the reservoir is linked to changes in discharge, lack of hydrological variability during our study may have prevented or reduced emigration.

When fish are tagged and not detected, stocked and never recovered, or just never captured in standardized sampling, disentangling mortality and emigration is difficult. Researchers and managers are often simply unable to answer whether fish die, leave, or evade capture. Long distance movement may be erroneously suspected when simpler explanations (e.g., mortality, sampling inefficiency) are in fact the underlying cause. If egress is variable across fish within and across systems, system specific characteristics (system size, up and down river configurations, availability of spawning and overwintering habitats within the reservoir, population characteristics, and possible sampling design) may be responsible. Movement out of reservoirs may be more common for stocked fish. Blue Catfish in Milford Reservoir are naturally

reproducing (Goeckler et al. 2003), thus adequate spawning habitat may be available within the reservoir itself.

For most existing studies, extreme movements are described for a brief period for a few fish. Unquestionably, Blue Catfish can move great distances (e.g., Lagler 1961; Garrett 2010). Although an intriguing life history anecdote, a few observations of a few individuals provides only a small piece of the distributional puzzle. Our depiction of how a large tagged population is distributed over a long time period and a large spatial framework provides a different view of Blue Catfish distribution that is perhaps more useful for research and management. Whether our results of no egress are unusual for Blue Catfish in reservoirs or the more common pattern is unclear. Tagging provides a way of testing these residency-migration patterns, but this methodology requires resources (tags and receivers) and constant vigilance (i.e. labor intensive) to maintain receivers.

Role of Season. Seasonal changes in distribution of Blue Catfish in Milford Reservoir were more complex than previously assumed and varied across individuals**.** In Milford Reservoir, some, but not all, tagged Blue Catfish moved south in fall. In addition, not all tagged individuals moved down reservoir to the same extent. Others (Fisher et al. 1999; Garrett 2010) have observed a southern shift in distribution in the fall and have speculated that this shift may be related to overwintering. Most previous data on fall distributional shifts are based on a few fish in a few locations (Fisher et al. 1999; Garrett 2010). Our data provide a much more detailed view of seasonal changes in distribution. In our research, some tagged Blue Catfish in Milford Reservoir moved south to the deepest part of the reservoir by the dam, as suggested by other studies (Fisher et al. 1999). However, some of our tagged fish also moved to the middle and lower middle region of the reservoir, south of their original location but not to the southernmost

part of the reservoir. In addition, some tagged Blue Catfish fish did not move down reservoir at all but remained either in the middle reservoir or in Madison Creek. Without tagging and tracking of individual fish of the same size, the complex and subtle details in this distributional shift would not have been detected.

Individual Variation. Only a subset of individually-tagged Blue Catfish made a down-reservoir shift in distribution. Individuals of the same size have been assumed to behave in the same general way. For the Blue Catfish that we tagged in Milford Reservoir, this was not true. We observed clusters of similar-sized fish that were distributed differently both within and across months. This pattern of clustering was complex. As a simplification of this individual variation pattern revealed by the cluster analysis integrated across months, three types of spatial distributions were observed. The first pattern was composed of Blue Catfish that used the upper middle reservoir funnel in summer, then visited a range of southern locations in fall. The second pattern was composed of Blue Catfish that used the upper middle reservoir funnel in summer and fall and did not move south. The third pattern was composed of Blue Catfish that used the Madison Creek region and also did not migrate seasonally. Our study is one of the first to document these individual distributional groups for freshwater fish of the same size. This may be a general pattern for predators as contingents of acoustically-tagged individuals have been documented in coastal systems (e.g., striped bass, Pautzke et al. 2010). As the incidence of these patterns increase, likely more sophisticated tools for analyzing and simplifying these data will emerge (e.g., network analyses).

Behavioral syndromes occur when individuals or a group of individuals display specialized traits or behaviors that vary from the population mean (Sih et al. 2004; Huntingford et al. 2010). Behaviors exhibited by groups of individuals can have important ecological and

evolutionary impacts, which can affect species distributions and responses to environmental change (Sih et al. 2004; Flaxman et al. 2011). Behavior of animals has been used in very few studies to try to understand its influence on the spatial structure of populations (Knaepkens et al. 2005; Giuggioli and Bartumeus 2010; Fullerton et al. 2010). Within the behavioral syndrome literature, few have used distribution patterns to distinguish groups of individuals. The patterns we observed may be an example of behavioral syndromes based on distribution,

Effect of Diel Period. The distribution of the tagged Blue Catfish in Milford Reservoir did not differ across diel period. Specifically, we observed no significant differences in residence time at any receiver among the dawn, day, dusk, and night time periods for either year. Differences in diel distribution of fish and other organisms has been a topic of interest in fisheries and ecology for decades. However, diel patterns are rarely tested so much of this speculation is based on limited quantitative data. In fisheries, many of our expectations are influenced by angler experiences. In addition, traditional sampling across seasons, diel periods, and locations, are unlikely to capture the full range of variability (i.e., diel differences or no diel differences). For this reason, our data on residence time collected at 12-14 locations 24 hours a day for 123 tagged fish over five months provides some of the most credible evidence available that differential distribution did not occur among dawn, day, dusk and night time periods. Physiological and diet generalists, like Blue Catfish, may take advantage of favorable conditions for feeding, resting, and other activities without regard for time of day.

Effect of Fish Size. We also did not observe any difference is distribution and movement related to Blue Catfish size. We included some smaller and some larger individuals, but most fish we tracked were within the most common 400-600 mm TL size range**. S**ubstantial literature exists to suggest that fish change their ecological role with size, but this ontogenetic niche shift is

most pronounced when fish life stage or ecological habitats change with size (e.g., Werner and Gilliam 1984). Blue Catfish are reputed to spawn at 420-480 mm (Graham and DeiSanti 1999), which suggests most adults we tagged were mature. For our data, although individual distribution varied, fish size did not cause this this pattern. As suggested above, physiological and diet generalists of a range of sizes may all take advantage of conditions for feeding, resting, and spawning, as they occur. As such, other variables may affect distribution of Blue Catfish more than size.

Management Implications. Our research on distribution has several management implications. First, we have provided substantial information on where Blue Catfish are located. Knowing distribution is critical for all management and research activities. Existing data on distribution are very limited. Using a newer technology, we have compiled the best understanding we have ever had of where Blue Catfish are located in Milford Reservoir. Our spatially explicit approach suggests that fish are highly aggregated often in consistent locations. Trends were surprisingly similar across years. If managers can identify the locations of these Blue Catfish clusters 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 clusters, managers might implement an extensive survey in which they systematically sample the entire reservoir to identify patterns of aggregation. For example, in the future, managers might shock 50 locations once rather than 10 locations five times.

Second, we did not observe Blue Catfish leaving Milford Reservoir. Blue Catfish are thought to be attracted by flow. Our study occurred during a regional drought so the absence of movement out of the reservoir might be related to the lack of hydrological cues. If river discharge or releases at the dam had been higher, our results might have been different. On the

other hand, this lack of Blue Catfish egress may be typical of Milford Reservoir and other reservoirs. Many documented longer distance movements of Blue Catfish may be irregular observations of relatively few individuals. Our results and those of others clearly document that movement varies dramatically among individuals. Of course, tools exist to track long distance movements. However, in Milford and other reservoirs, effort might be better used to map the distribution of the Blue Catfish reservoir population that does not migrate which may be comprised of as many or more individuals than the migrators.

Third, the number of empirical studies on Blue Catfish distribution, movement, and habitat is increasing. However, at present, each one represents an isolated data point because of system-specific differences 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. This synthetic working group effort could formulate a range of broader questions of interest then use existing data to objectively test hypotheses about distribution and movements.

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. As such, their present applications are unclear. However, knowledge of this pattern could be useful in the future. For example, awareness that a subset of Blue Catfish in Milford Reservoir remain within Madison Creek could influence habitat management, restoration, and planning.

Finally, in its conception, this study was designed to look at the distribution of mobile organisms in the most transparent way possible. Specifically, a decision was made to look at a

system with a naturally reproducing population where there was no stocking to confound patterns. Likely systems with other morphometric characters and fish that are stocked will show different patterns. Our data provides a very strong baseline for across system comparison.

In summary, our data have addressed the research objectives of the original study. Of course, as in any complex research and management area, a host of important questions about distribution and movement remain. Nevertheless, our study has provided a wealth of information on distribution and egress that was previously unknown.

Chapter 2 Table 1. Fish, date, and receiver at which tagged Blue Catfish were last seen for 2012 and 2013 in Milford Reservoir, Kansas. Fish last seen at receiver 2 in 2013 are boxed.

2012 Overall Last Seen			2013 Overall Last Seen		
Fish	Date	Receiver	Fish	Date	Receiver
1	Jan. 15 2013	19	1	July 21 2013	6
2	Jan. 15 2013	12	2	Dec. 21 2013	4
3	Jan. 6 2013	18	3	Dec. 4 2013	8
4	Jan. 17 2013	17	4	Nov.25 2013	8
5	Jan. 9 2013	18	5	June 21 2013	6
6	Jan. 9 2013	18	6	Nov. 17 2013	8
7	Jan. 15 2013	12	7	June 17 2013	4
8	Jan. 8 2013	18	8	Nov. 9 2013	18
9	Jan. 9 2013	18	9	Nov. 7 2013	13
10	Jan. 9 2013	18	10	Nov. 9 2013	15
11	Jan. 9 2013	18	11	Dec. 11 2013	4
12	Jan. 15 2013	12	12	June 9 2014	$\boxed{2}$
13	Jan. 15 2013	12	13	June 18 2014	8
14	Jan. 15 2013	12	14	June 18 2014	10
15	Dec. 28 2012	18	15	June 18 2014	8
16	Jan. 9 2013	18	16	June 18 2014	7
17	Jan. 9 2013	18	17	June 18 2014	8
18	Jan. 9 2013	18	18	June 1 2014	5
19	Jan. 9 2013	18	19	June 6 2014	5
20	Jan. 8 2013	18	20	May 20 2014	8
21	Jan. 10 2013	11	21	April 13 2014	8
22	Aug. 8 2012	5	22	June 16 2014	10
23	Jan. 16 2013	5	23	June 16 2014	10
24	Jan. 16 2013	12	24	June 18 2014	10
25	Jan. 16 2013	12	25	June 17 2014	10
26	Jan. 9 2013	18	26	June 18 2014	10
27	June 27 2012	5	27	April 28 2014	10
28	Jan. 9 2013	18	28	June 15 2014	7
29	Jan. 8 2013	16	29	June 11 2013	10
30	Oct. 5 2012	8	30	April 11 2014	8
31	Jan. 9 2013	17	31	June 18 2014	8
32	Aug. 6 2012	4	32	Feb. 26 2014	8
33	Aug. 20 2012	10	33	May 30 2014	5
34	Jan. 16 2013	12	34	June 19 2014	4
35	Jan. 9 2013	18	35	June 8 2014	5
36	Jan. 6 2013	7	36	May 8 2014	8

Chapter 2 Table 1. Continued.

2012 Overall Last Seen			2013 Overall Last Seen		
Fish	Date	Receiver	Fish	Date	Receiver
37	Jan. 10 2013	19	37	June 15 2014	5
38	Jan. 17 2013	8	38	June 15 2014	8
39	Dec. 5 2012	6	39	April 9 2014	5
40	Dec. 5 2012	16	40	June 22 2013	15
41	Dec. 5 2012	17	41	July 20 2013	14
42	Dec. 4 2012	18	42	June 7 2014	5
43	Dec. 5 2012	13	43	Aug. 30 2013	4
44	Dec. 5 2012	17	44	June 20 2014	4
45	Dec. 4 2012	16	45	June 19 2014	7
46	Dec. 6 2012	18	46	June 17 2014	8
47	Dec. 6 2012	8	47	June 21 2014	4
48	Dec. 23 2012	17	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 2013	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
			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

CHAPTER 2 – DISTRIBUTION BLUE CATFISH WITHIN AND EGRESS OF BLUE CATFISH FROM MILFORD RESERVOIR (OBJECTIVES 4-5)

CHAPTER 2 FIGURE CAPTIONS

Chapter 2 Figure 1. (A) Our study site, Milford Reservoir, is an impoundment of (B) the Lower Republican River watershed in (C) northeastern Kansas.

Chapter 2 Figure 2. Examples of a trajectory made by a single tagged Blue Catfish that illustrates select components of a complex trajectory pattern. Residence time quantifies how long a tagged fish is at a single receiver location when detections for the entire time period of interest are summed. Numbers of movements quantifies how many times a fish moves from receiver to receiver for the entire period of interest. Numbers of unique individuals (i.e., the presence of a single individual fish) and mean residence time are metrics that quantify the distribution of all individuals together (i.e., the tagged population).

Chapter 2 Figure 3. (A) The spatial distribution of *unique individuals* (number) is shown for 48 tagged Blue Catfish at 14 receivers (18 receivers with four gate receivers removed) in 2012. Each dot represents a receiver location. The size of the dot is proportional to numbers of unique individuals. Also shown are the results of a Chi square analysis that identifies at which receivers (B) more unique individuals occurred than were expected and (C) fewer unique individuals occurred than were expected based on an even distribution (i.e., the same number of fish at all receivers). In B-C, receiver numbers are shown. On the map in A, dark gray dots indicate more

unique individuals than expected and light gray dots indicate fewer unique individual than expected based on an even distribution.

Chapter 2 Figure 4. (A) The spatial distribution of *unique individuals* (number) is shown for 75 tagged Blue Catfish at 12 receivers (18 receivers with four gate and two missing receivers removed) in 2013. Each dot represents a receiver location. The size of the dot is proportional to numbers of unique individuals. Also shown are the results of a Chi square analysis that identifies at which receivers (B) more unique individuals occurred than were expected and (C) fewer unique individuals occurred than were expected, based on an even distribution (i.e., the same number of fish at all receivers). In B-C, receiver numbers are indicated. On the map in A, dark gray dots indicate more unique individuals than expected and light gray dots indicate fewer unique individual than expected based on an even distribution.

Chapter 2 Figure 5. (A) The spatial distribution of *mean residence time* (h) is shown for 48 tagged Blue Catfish at 14 receivers (18 receivers with four gate receivers removed) in 2012. Each dot represents a receiver location. The size of the dot is proportional to mean residence time. Also shown are the results of a Chi square analysis that identifies at which receivers mean residence time was (B) higher than that expected or (C) less than expected based on an even distribution (i.e., fish spent the same amount of time at all receivers). In B-C, receiver numbers are indicated. On the map in A, dark gray dots indicate a higher residence time than expected, white dots indicate residence times equal to what was expected, and light gray dots indicate a lower residence time than was expected based on an even distribution.

Chapter 2 Figure 6. (A) The spatial distribution of *mean residence time* (h) is shown for 75 tagged Blue Catfish at 12 receivers (18 receivers with four gate and two missing receivers removed) in 2013. Each dot represents a receiver location. The size of the dot is proportional to mean residence time. Also shown are the results of a Chi square analysis that identifies at which receivers mean residence time was (B) higher than that expected or (C) less than expected based on an even distribution (i.e., fish spent the same amount of time at all receivers). In B-C, receiver numbers are indicated. On the map in A, dark gray dots indicate a higher residence time than expected, white dots indicate residence times equal to what was expected, and light gray dots indicate a lower residence time than was expected based on an even distribution.

Chapter 2 Figure 7. For 2012 and 2013, numbers of tagged Blue Catfish detected at the upper and lower reservoir egresses are shown. To assess egress, we examined the outer gates first (receivers 1, 20). If data were missing from receivers 1, 20, we next examined the inner gates, receivers 2 and 19. In 2012, no fish were detected at receiver 1. In 2013, receiver 1 was vandalized and five fish were last seen at receiver 2. The numbers on the right side of the plot indicate numbers of fish last detected at receivers 1, 2, 19, 20 in 2012 and 2013. A dashed line indicates that the receiver was not examined because the outer gate was in place. More details on these five fish are provided in Figure 8. In both 2012, 2013, no fish were detected at receiver 20, which remained intact throughout the study for both years.

Chapter 2 Figure 8. The detections of the five fish last seen at receiver 2 in 2013 are shown. The X axis depicts the time period and the Y axis shows receiver number. Diamonds are detections of individual fish. Receiver 2, at the top of each plot, is indicated with an arrow. Shown in A-E

are five individuals. These plots should be interpreted as fish movements through time (left to right) and from the lower to the upper reservoir (bottom to top). For example, fish 12 (panel A) in July repeatedly traversed the upper and upper middle reservoir. (A) Fish 12 and (B) fish 56 were not detected because the study ended and receivers were removed. (C) Fish 62, (D) 67, and (E) 75 exhibited extensive movements between receiver 2 and other receivers which is more typical of resident rather than migratory movements.

Chapter 2 Figure 9. For 2012, box plots depicting *monthly* changes in mean residence time (h) are shown for (A) receiver 2, (B) receiver 3, (C) receiver 4, (D) receiver 5, (E) receiver 6, (F) receiver 9, (G) receiver 10, (H) receiver 12, (I) receiver 14, (J) receiver 15, (K) receiver 16, (L) receiver 17, (M) receiver 18, and (N) receiver 19. Gate receivers 7, 8, 11, 13 were removed for analysis to ensure a more evenly distributed tracking array. The X axis is month. The Y axis is average residence time at a receiver for all fish detected at that receiver. Y axes are standardized in order to compare trends across receiver locations. Also shown are the results of a Kruskal Wallis nonparametric ANOVA that tested the effect of season. $P<0.05$ was considered significant.

Chapter 2 Figure 10. For 2013, box plots depicting *monthly* changes in mean residence time (h) are shown for (A) receiver 2, (B) receiver 3, (C) receiver 4, (D) receiver 5, (E) receiver 6, (F) receiver 9, (G) receiver 10, (H) receiver 13, (I) receiver 14, (J) receiver 15, (K) receiver 18, and (L) receiver 19. Gate (7, 8, 11, and 12) and missing (16, 17) receivers were removed for analysis to ensure a more evenly distributed tracking array. The X axis is month. The Y axis is average residence time at a receiver for all fish detected at that receiver. Y axes are standardized in order

to compare trends across receiver locations. Also shown are the results of a Kruskal Wallis nonparametric ANOVA that tested the effect of season. $P<0.05$ was considered significant.

Chapter 2 Figure 11. Movements (number, Y axis) by receiver (X axis) averaged across individual fish shown by month. Data are means.

Chapter 2 Figure 12. Movements (number, Y axis) by receiver (X axis) averaged across individual fish. Data are mean and standard deviation.

Chapter 2 Figure 13. For 2012, box plots depicting *diel* changes in mean residence time (h) are shown for (A) receiver 2, (B) receiver 3, (C) receiver 4, (D) receiver 5, (E) receiver 6, (F) receiver 9, (G) receiver 10, (H) receiver 12, (I) receiver 14, (J) receiver 15, (K) receiver 16, (L) receiver 17, (M) receiver 18, and (N) receiver 19. Gate receivers 7, 8, 11, 13 were removed for analysis to ensure a more evenly distributed tracking array. The X axis is dawn, day, dusk, and night diel periods. The Y axis is average residence time per hour per receiver. Y axes are standardized in order to compare trends across receiver locations. Also shown are the results of a Kruskal Wallis nonparametric ANOVA that tested the effect of diel period. $P<0.05$ was considered significant.

Chapter 2 Figure 14. For 2013, box plots depicting *diel* changes in mean residence time (h) are shown for (A) receiver 2, (B) receiver 3, (C) receiver 4, (D) receiver 5, (E) receiver 6, (F) receiver 9, (G) receiver 10, (H) receiver 13, (I) receiver 14, (J) receiver 15, (K) receiver 18, and (L) receiver 19. Gate (7, 8, 11, and 12) and missing (16, 17) receivers were removed for analysis

to ensure a more evenly distributed tracking array. The X axis is dawn, day, dusk, and night diel periods. The Y axis is average residence time per hour per receiver. Y axes are standardized in order to compare trends across receiver locations. Also shown are the results of a Kruskal Wallis nonparametric ANOVA that tested the effect of season. $P<0.05$ was considered significant.

Chapter 2 Figure 15. Residence time (h) (A, C) and movements (number) (B, D) are shown by *fish size* (TL mm) for 2012 (A, B) and 2013 (C, D). Data points are individual fish. For each plot panel also shown are the results of a univariate regression including the regression line equation, R^2, and *P* values. $P<0.05$ was considered significant.

Chapter 2 Figure 16. Movements (number, Y axis) made by individual fish (X axis) averaged across receiver numbers. Data are mean and standard deviation.

Chapter 2 Figure 17. For 2012, shown are the relationships between capture-release location and residence time (h) for (A) receiver 2, (B) receiver 3, (C) receiver 4, (D) receiver 5, (E) receiver 6, (F) receiver 9, (G) receiver 10, (H) receiver 12, (I) receiver 14, (J) receiver 15, (K) receiver 16, (L) receiver 17, (M) receiver 18, and (N) receiver 19. The X axis is location: C=Causeway, M= Madison, S=School. The Y axis is average residence time at a receiver for all fish detected at that receiver. Y axes are standardized in order to compare trends across receiver locations. Also shown are the results of a Kruskal Wallis nonparametric ANOVA that tested the effect of location. $P<0.05$ was considered significant. The Causeway release site was near receiver 5, the Madison release site was near receiver 9, and the School release site was near receiver 15 Data are means +/1 1 SE.

Chapter 2 Figure 18. For 2013, shown are the relationships between capture-release location and residence time (h) for (A) receiver 2, (B) receiver 3, (C) receiver 4, (D) receiver 5, (E) receiver 6, (F) receiver 9, (G) receiver 10, (H) receiver 13, (I) receiver 14, (J) receiver 15, (K) receiver 18, and (L) receiver 19. The X axis is location: C=Causeway, M= Madison, S=School. The Y axis is average residence time at a receiver for all fish detected at that receiver. Y axes are standardized in order to compare trends across receiver locations. Also shown are the results of a Kruskal Wallis nonparametric ANOVA that tested the effect of location. $P<0.05$ was considered significant. The Causeway release site was near receiver 5, the Madison release site was near receiver 9, and the School release site was near receiver 15 Data are means +/1 1 SE.

Chapter 2 Figure 19. This is the first of three syntheses of individual by-month cluster analyses created to show general distribution patterns. Individual panels show the months of (A) July, (B) August, (C) September, (D) October, and (E) November. On the right side of each panel is a map of the reservoir with individual clusters (circles) indicating where fish from each cluster were detected. Bars on the left side of each plot are residence times (h, X axis) at each receiver (Y axis) for each cluster. Cluster circles and bars are indicated by different colors. Cluster numbers within the circles are listed at the bottom of each panel as C1-C8 and correspond to individual cluster numbers in the monthly cluster analysis figures that follow. Also shown for each cluster are Jaccard bootstrap values (JB), and numbers of fish (N*). (We know this is challenging to look at but it is the only way to integrate the numerous cluster figures. We present this first because we know the individual clusters are difficult to process).* This panel of clusters depicts fish that are seasonal movers.

Chapter 2 Figure 20. This is the second of three syntheses of individual by-month cluster analyses that show general distribution patterns. Individual panels show the months of (A) July, (B) August, (C) September, (D) October, and (E) November. On the right side of each panel is a map of the reservoir with individual clusters (circles) indicating where fish from each cluster were detected. Bars on the left side of each plot are residence times (h, X axis) at each receiver (Y axis) for each cluster. Cluster circles and bars are indicated by different colors. Cluster numbers within the circles are listed at the bottom of each panel as C1-C8 and correspond to individual cluster numbers in the monthly cluster analysis figures that follow. Also shown for each cluster are Jaccard bootstrap values (JB), and numbers of fish (N). This panel of clusters depicts fish that are not seasonal movers but remain in the upper middle funnel constriction.

Chapter 2 Figure 21. This is the last of three syntheses of individual by-month cluster analyses that show general distribution patterns. Individual panels show the months of (A) July, (B) August, (C) September, (D) October, and (E) November. On the right side of each panel is a map of the reservoir with individual clusters (circles) indicating where fish from each cluster were detected. Bars on the left side of each plot are residence times (h, X axis) at each receiver (Y axis) for each cluster. Cluster circles and bars are indicated by different colors. Cluster numbers within the circles are listed at the bottom of each panel as C1-C8 and correspond to individual cluster numbers in the monthly cluster analyses that follow. Also shown for each cluster are Jaccard bootstrap values (JB), and numbers of fish (N). This panel of clusters depicts fish that are not seasonal movers but remain in the Madison Creek Area.

CHAPTER 2 APPENDIX

Chapter 2 Appendix Figure 1. Frequency of Blue Catfish in Milford Reservoir in 2012 for the size range 100-1000 mm TL. Survey sizes are compared to the sizes of Blue Catfish tagged in this study in 2012 and 2013.

Chapter 2 Appendix Figure 2. Hydrograph from USGS gage 06857100 downstream of Milford Reservoir for March-November (A) 2012 and (B) 2013. Discharge and median for 47 years are shown. July-November corresponds to our field season in both years. http://nwis.waterdata.usgs.gov/ks/nwis/uv?cb_00065=on&cb_00060=on&format=gif_stats&site_no=06857100&period=&begin_date=2012-03-01&end_date=2012-11-03

Chapter 2 Appendix Figure 3. Shown is a silhouette plot identifying clusters based on residence time (h) for the combined July-November time period. Identity and Jaccard bootstrap values for all clusters are indicated. Appendix Figures 2-6 depict a single cluster analysis.

Chapter 2 Appendix Figure 4. For the clusters in the combined July-November time period, shown are boxplots of residence times for receivers 2-5. The Y axis is residence time (h); the X axis is cluster number. These data are means for all individual fish in each cluster.

Chapter 2 Appendix Figure 5. For the clusters in the combined July-November time period, shown are boxplots of residence times for receivers 6, 9, 10, 12. The Y axis is residence time (h); the X axis is cluster number. These data are means for all individual fish within a cluster.

Chapter 2 Appendix Figure 6. For the clusters in the combined July-November time period, shown are boxplots of residence times for receivers 14- 17. The Y axis is residence time (h); the X axis is cluster number. These data are means for all individual fish within a cluster.

Chapter 2 Appendix Figure 7. For the clusters in the combined July-November, shown are boxplots of residence times for receivers 18 and 19. The Y axis is residence time (h); the X axis is cluster number. These data are means for all individual fish in a cluster.

Chapter 2 Appendix Figure 8. Shown is a silhouette plot identifying clusters based on residence time (h) for July. Identity and Jaccard bootstrap values for all clusters are indicated. Appendix Figures 7-11 depict a single cluster analysis.

Chapter 2 Appendix Figure 9. For the clusters in July, shown are boxplots of residence times for receivers 2- 5. The Y axis is residence time (h); the X axis is cluster number. These data are means for all individual fish in each cluster.

Chapter 2 Appendix Figure 10. For the clusters in July, shown are boxplots of residence times for receivers 6, 9, 10, 12. The Y axis is residence time (h); the X axis is cluster number. These data are means for all individual fish within a cluster.

Chapter 2 Appendix Figure 11. For the clusters in July, shown are boxplots of residence times for receivers 14- 17. The Y axis is residence time (h); the X axis is cluster number. These data are means for all individual fish within a cluster.

Chapter 2 Appendix Figure 12. For the clusters in July, shown are boxplots of residence times for receivers 18 and 19. The Y axis is residence time (h); the X axis is cluster number. These data are means for all individual fish in a cluster.

Chapter 2 Appendix Figure 13. Shown is a silhouette plot identifying clusters based on residence time for August. Identity and Jaccard bootstrap values for all clusters are indicated. Appendix Figures 12-16 depict a single cluster analysis.

Chapter 2 Appendix Figure 14. For the clusters in August, shown are boxplots of residence times for receivers 2- 5. The Y axis is residence time (h); the X axis is cluster number. These data are means for all individual fish in each cluster.

Chapter 2 Appendix Figure 15. For the clusters in August, shown are boxplots of residence times for receivers 6, 9, 10, 12. The Y axis is residence time (h); the X axis is cluster number. These data are means for all individual fish within a cluster.

Chapter 2 Appendix Figure 16. For the clusters in August, shown are boxplots of residence times for receivers 14- 17. The Y axis is residence time (h); the X axis is cluster number. These data are means for all individual fish within a cluster.

Chapter 2 Appendix Figure 17. For the clusters in August, shown are boxplots of residence times for receivers 18 and 19. The Y axis is residence time (h); the X axis is cluster number. These data are means for all individual fish in a cluster.

Chapter 2 Appendix Figure 18. Shown is a silhouette plot identifying clusters based on residence time for September. Identity and Jaccard bootstrap values for all clusters are indicated. Appendix Figures 17-21 depict a single cluster analysis.

Chapter 2 Appendix Figure 19. For the clusters in September, shown are boxplots of residence times for receivers 2- 5. The Y axis is residence time (h); the X axis is cluster number. These data are means for all individual fish in each cluster.

Chapter 2 Appendix Figure 20. For the clusters in September, shown are boxplots of residence times for receivers 6, 9, 10, 12. The Y axis is residence time (h); the X axis is cluster number. These data are means for all individual fish within a cluster.

Chapter 2 Appendix Figure 21. For the clusters in September, shown are boxplots of residence times for receivers 14-17. The Y axis is residence time (h); the X axis is cluster number. These data are means for all individual fish within a cluster.

Chapter 2 Appendix Figure 22. For the clusters in September, shown are boxplots of residence times for receivers 18 and 19. The Y axis is residence time (h); the X axis is cluster number. These data are means for all individual fish in a cluster.

Chapter 2 Appendix Figure 23. Shown is a silhouette plot identifying clusters based on residence time (h) for October. Identity and Jaccard bootstrap values for all clusters are indicated. Appendix Figures 22-26 depict a single cluster analysis.

Chapter 2 Appendix Figure 24. For the clusters in October, shown are boxplots of residence times for receivers 2- 5. The Y axis is residence time (h); the X axis is cluster number. These data are means for all individual fish in each cluster.

Chapter 2 Appendix Figure 25. For the clusters in October, shown are boxplots of residence times for receivers 6, 9, 10, 12. The Y axis is residence time (h); the X axis is cluster number. These data are means for all individual fish within a cluster.

Chapter 2 Appendix Figure 26. For the clusters in October, shown are boxplots of residence times for receivers 14-17. The Y axis is residence time (h); the X axis is cluster number. These data are means for all individual fish within a cluster.

Chapter 2 Appendix Figure 27. For the clusters in October, shown are boxplots of residence times for receivers 18 and 19. The Y axis is residence time (h); the X axis is cluster number. These data are means for all individual fish in a cluster.

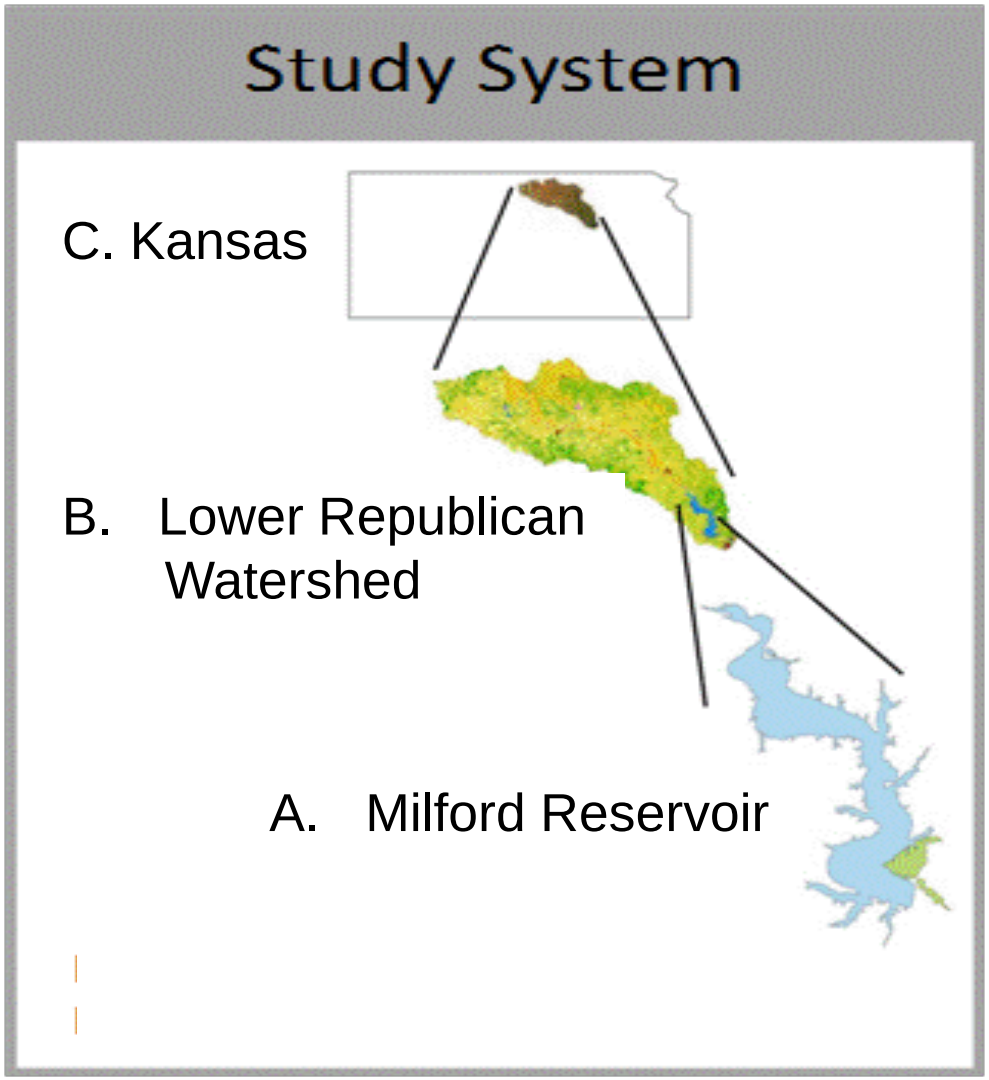
Chapter 2 Appendix Figure 28. Shown is a silhouette plot identifying clusters based on residence time (h) for November. Identity and Jaccard bootstrap values for all clusters are indicated. Appendix Figures 27-31 depict a single cluster analysis.

Chapter 2 Appendix Figure 29. For the clusters in November, shown are boxplots of residence times for receivers 2- 5. The Y axis is residence time (h); the X axis is cluster number. These data are means for all individual fish in each cluster.

Chapter 2 Appendix Figure 30. For the clusters in November, shown are boxplots of residence times for receivers 6, 9, 10, 12. The Y axis is residence time (h); the X axis is cluster number. These data are means for all individual fish within a cluster.

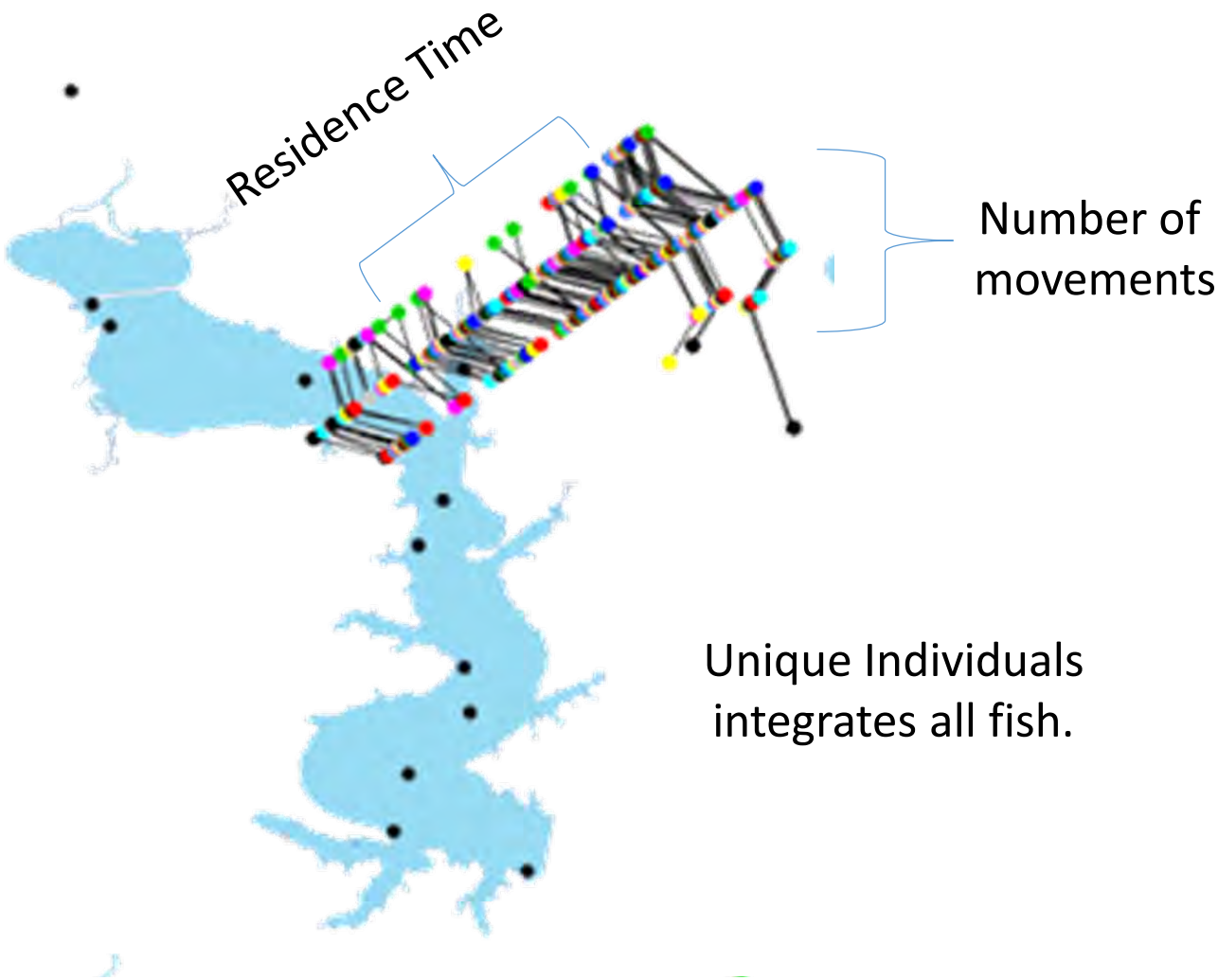
Chapter 2 Appendix Figure 31. For the clusters in November, shown are boxplots of residence times for receivers 14- 17. The Y axis is residence time (h); the X axis is cluster number. These data are means for all individual fish within a cluster.

Chapter 2 Appendix Figure 32. For the clusters in November, shown are boxplots of residence times for receivers 18 and 19. The Y axis is residence time (h); the X axis is cluster number. These data are means for all individual fish in a cluster.

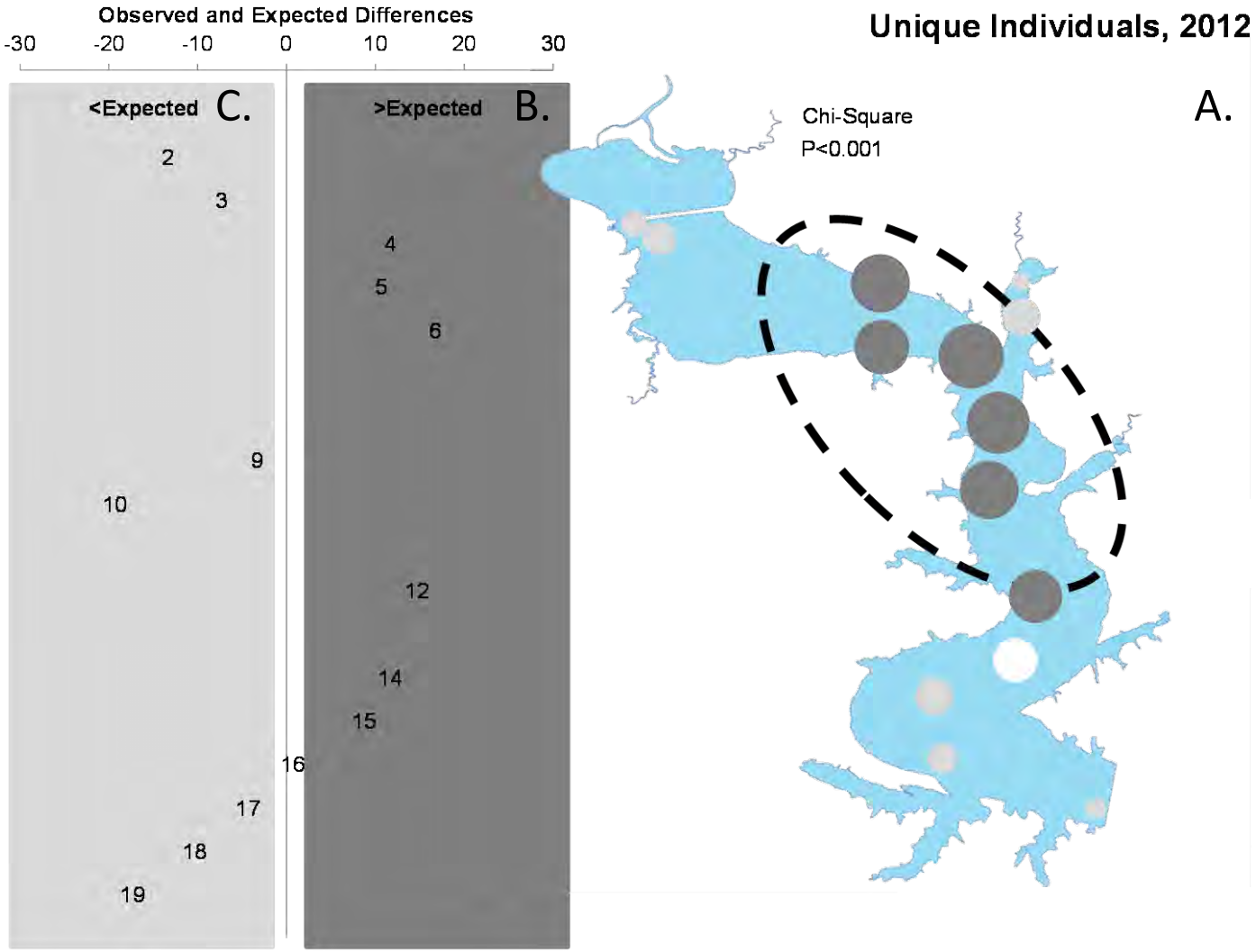


Chapter 2 Figure 1

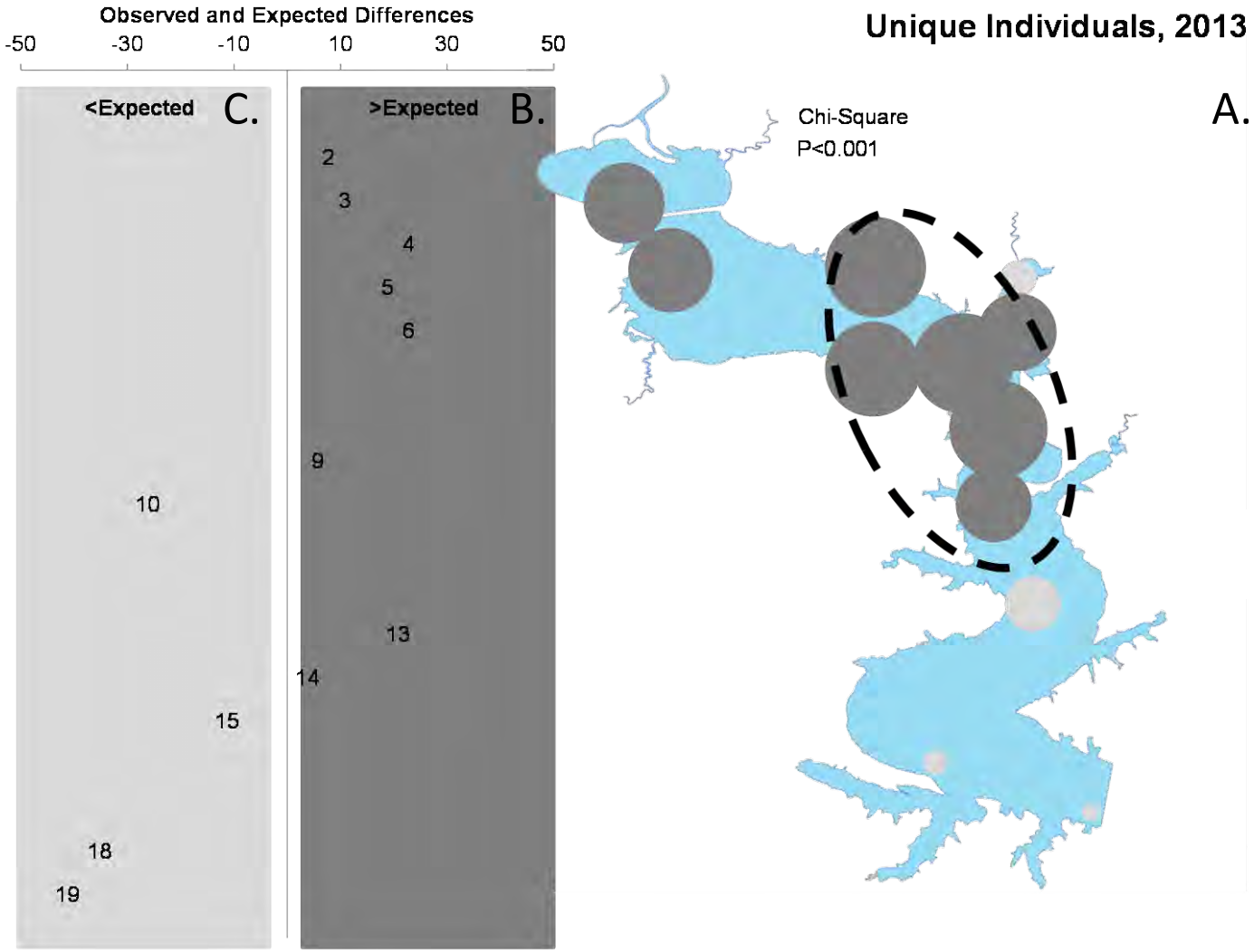
Components of a Blue Catfish Trajectory



Chapter 2 Figure 2

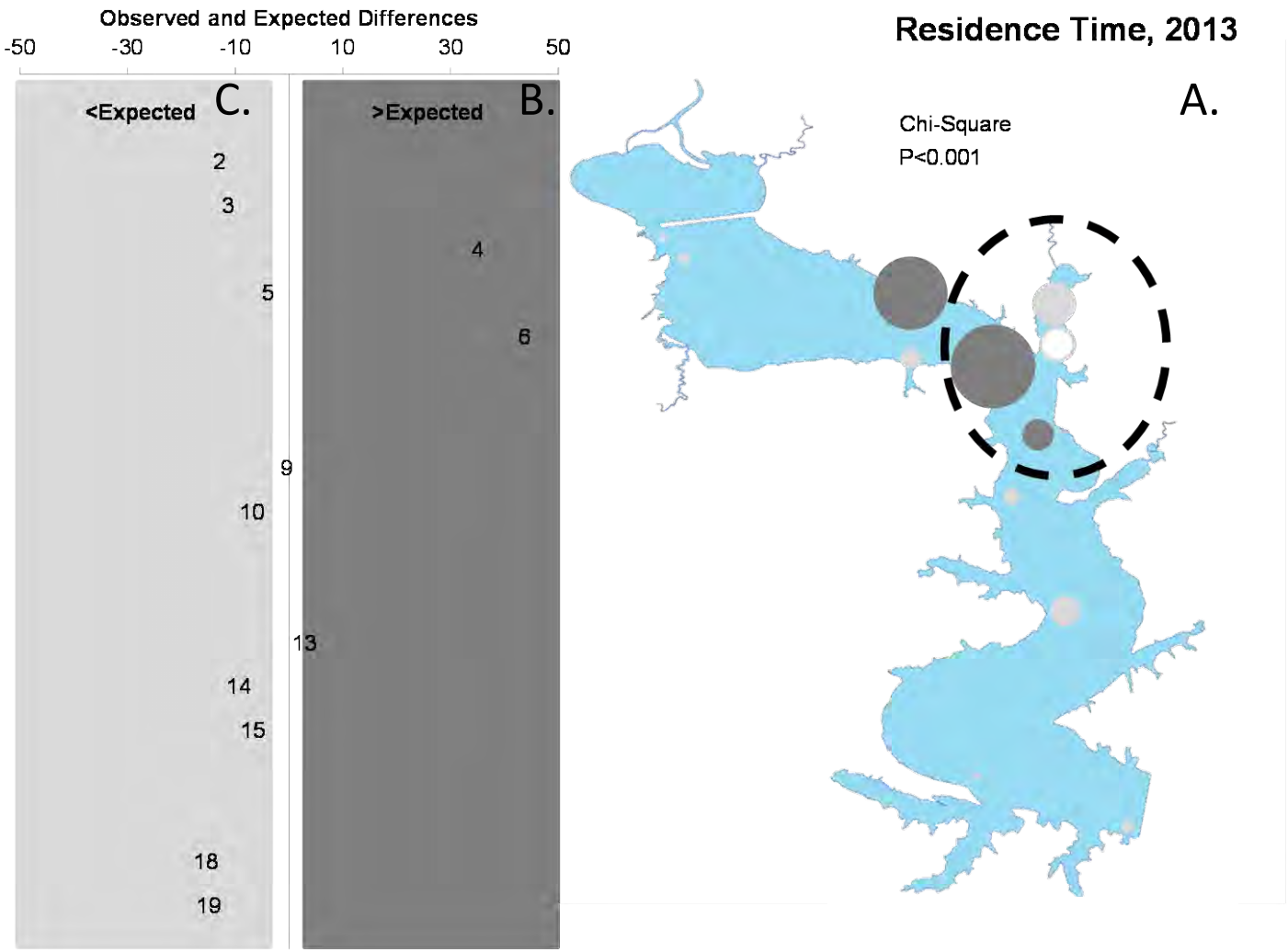


Chapter 2 Figure 3



Chapter 2 Figure 4

Chapter 2 Figure 5



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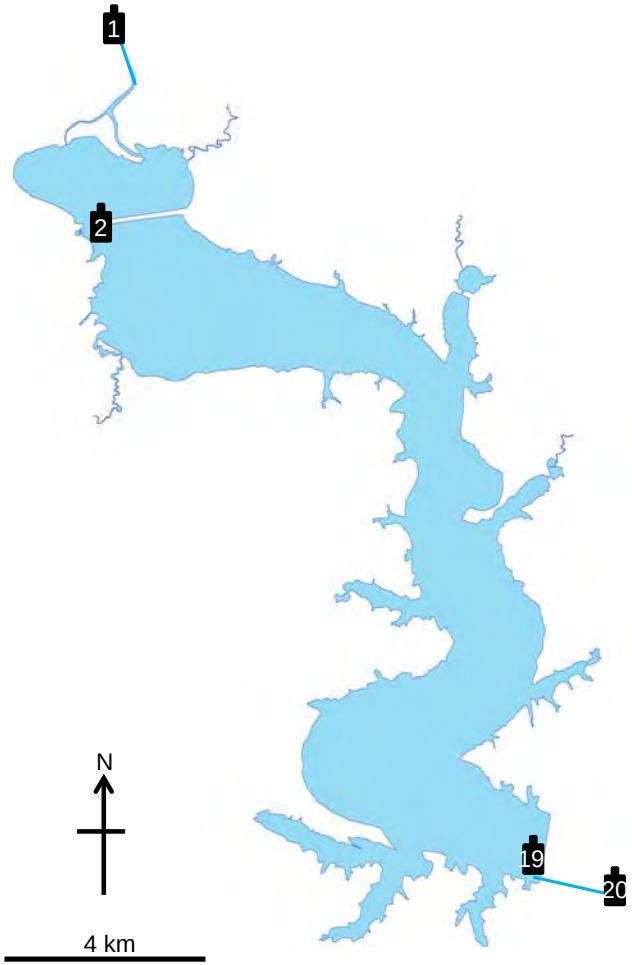
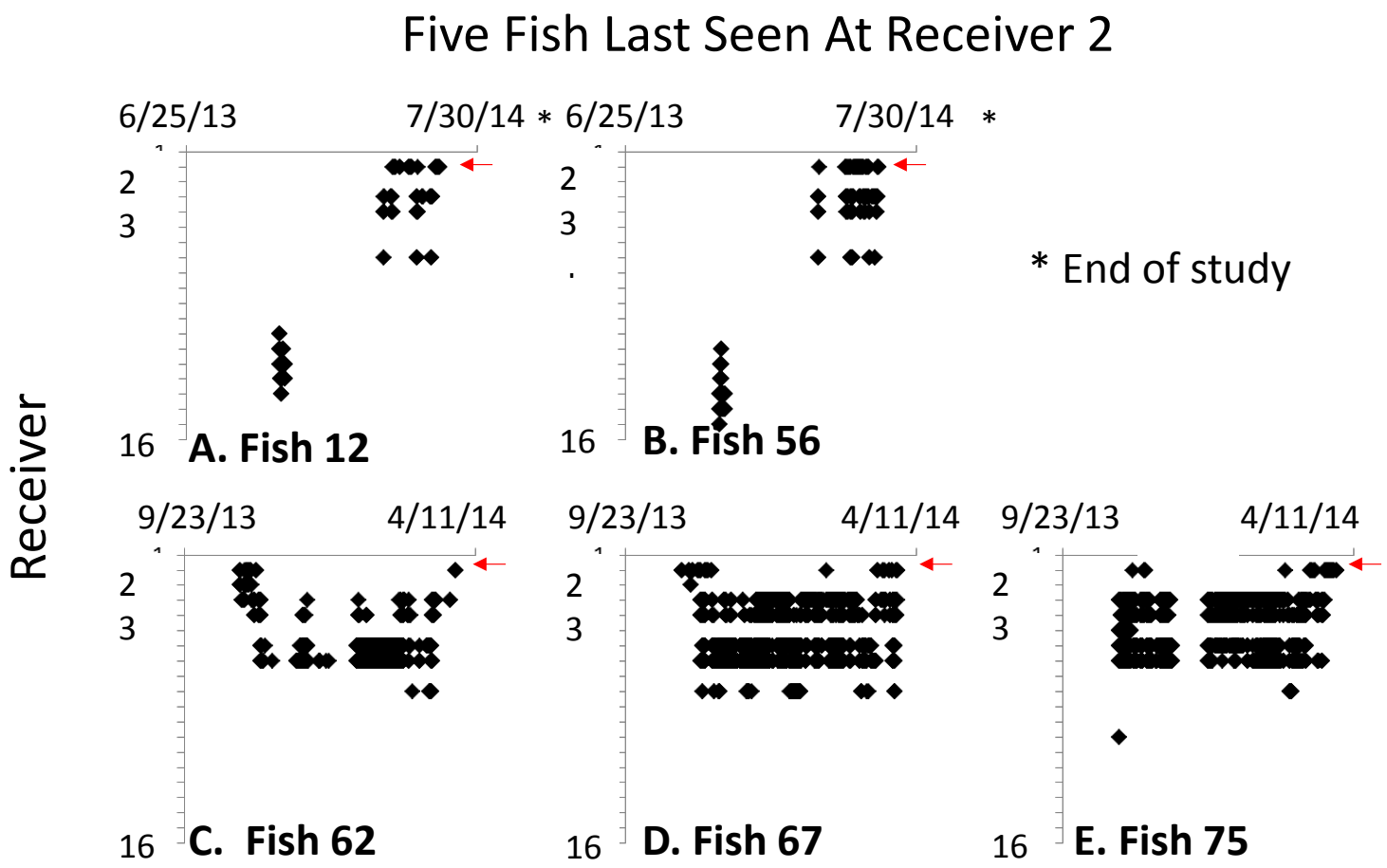


Receiver	Numbers of Fish 2012	2013
1	0	
2	--	< 5
19	--	--
20	0	0

Chapter 2 Figure 7



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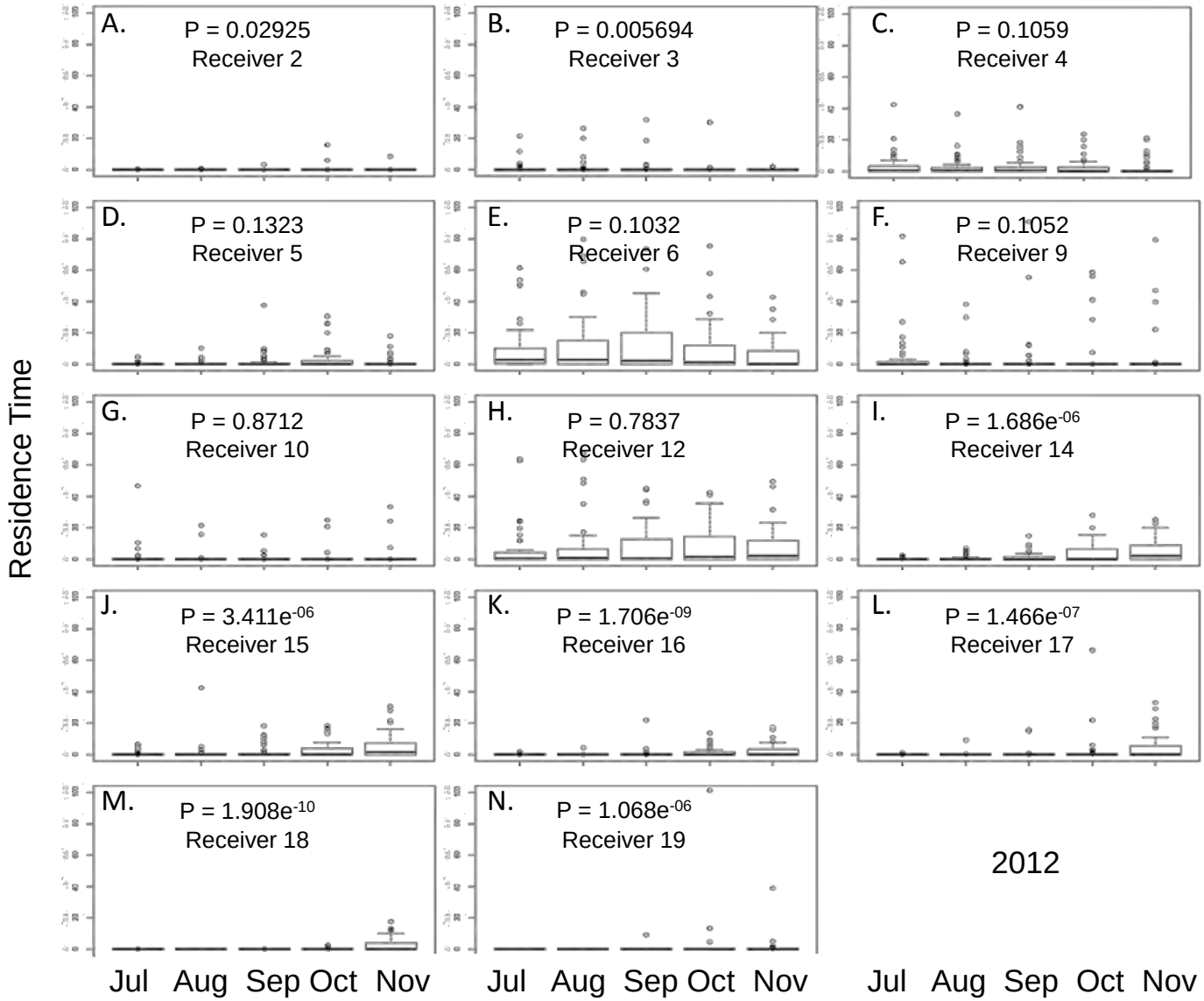
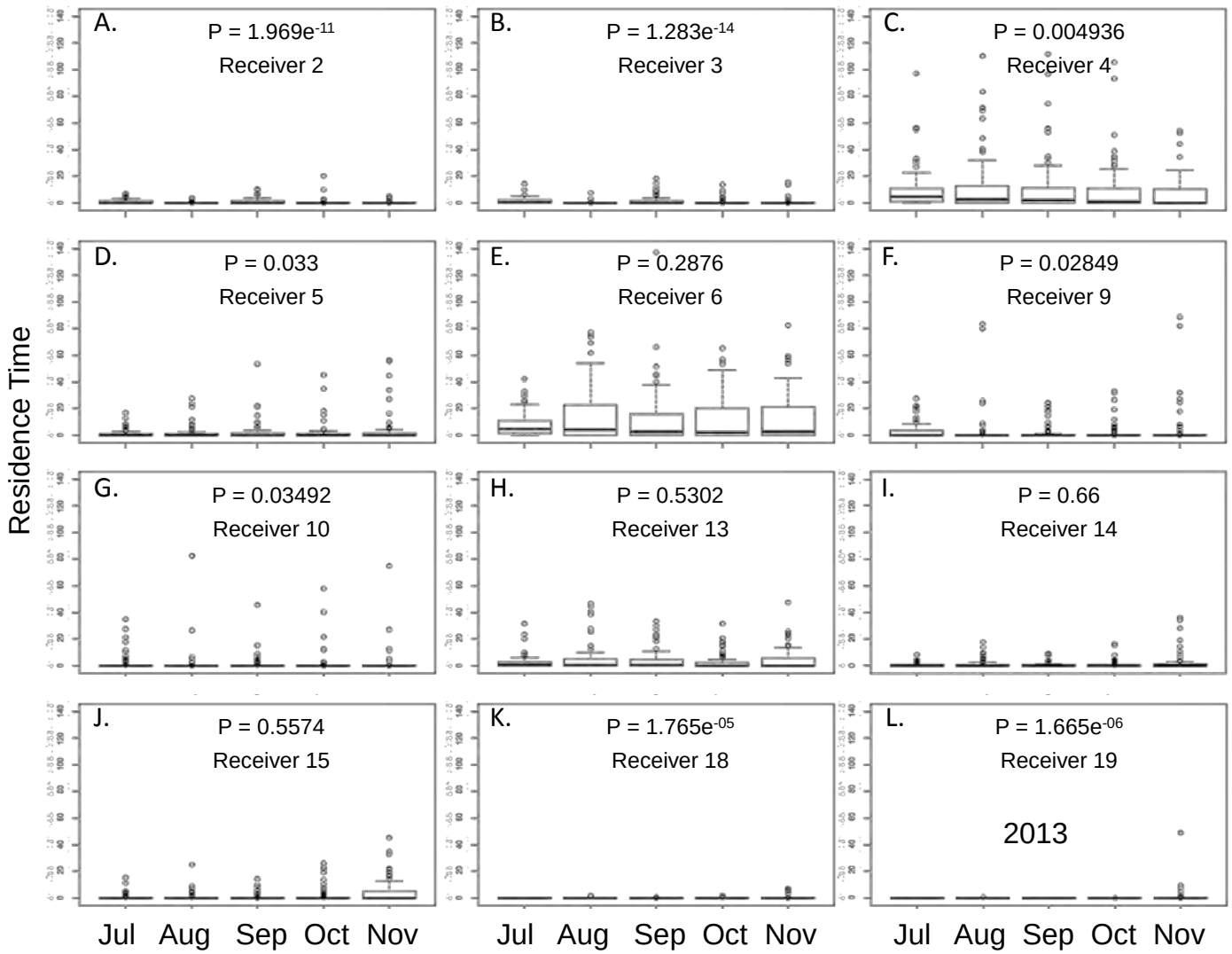
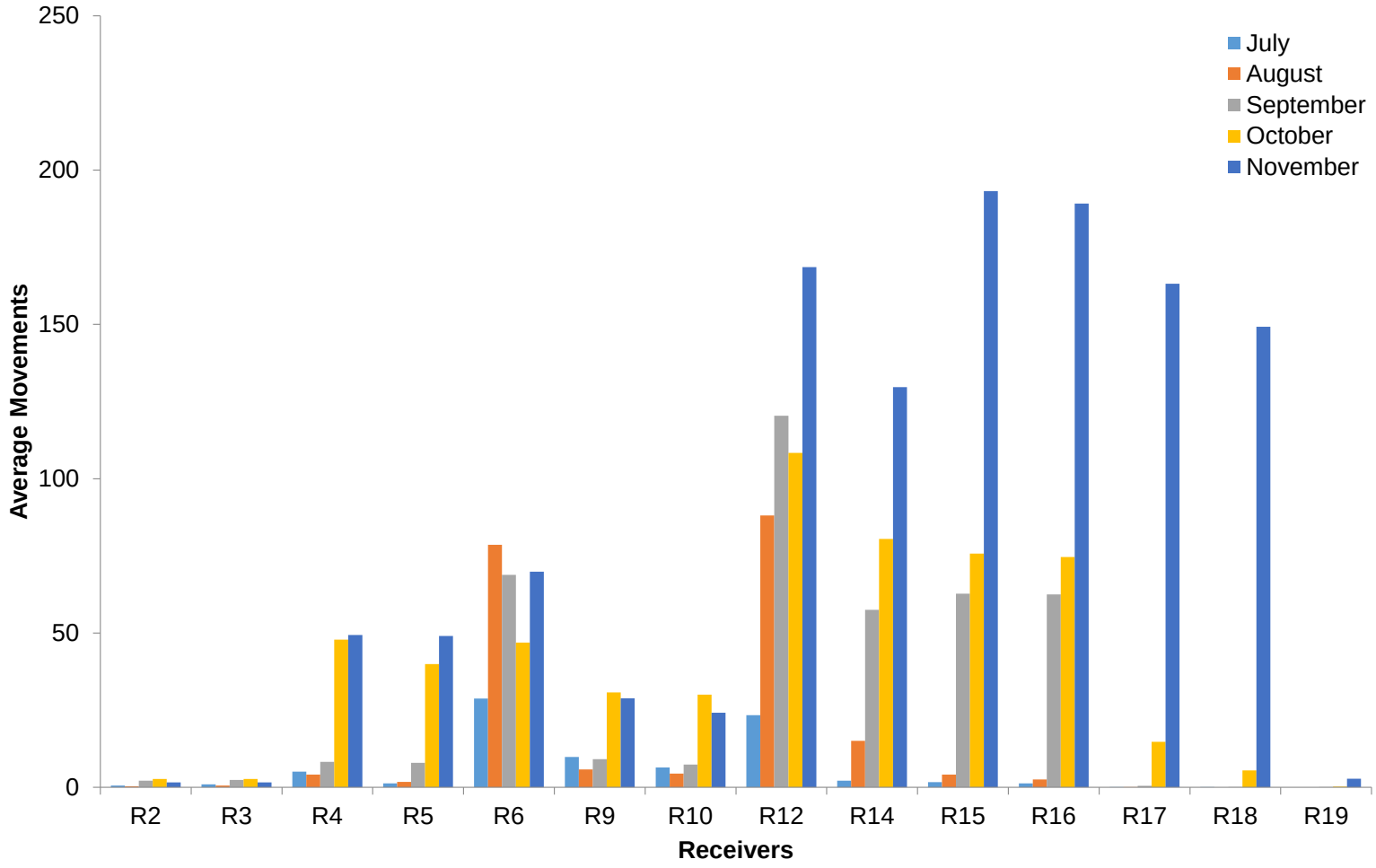


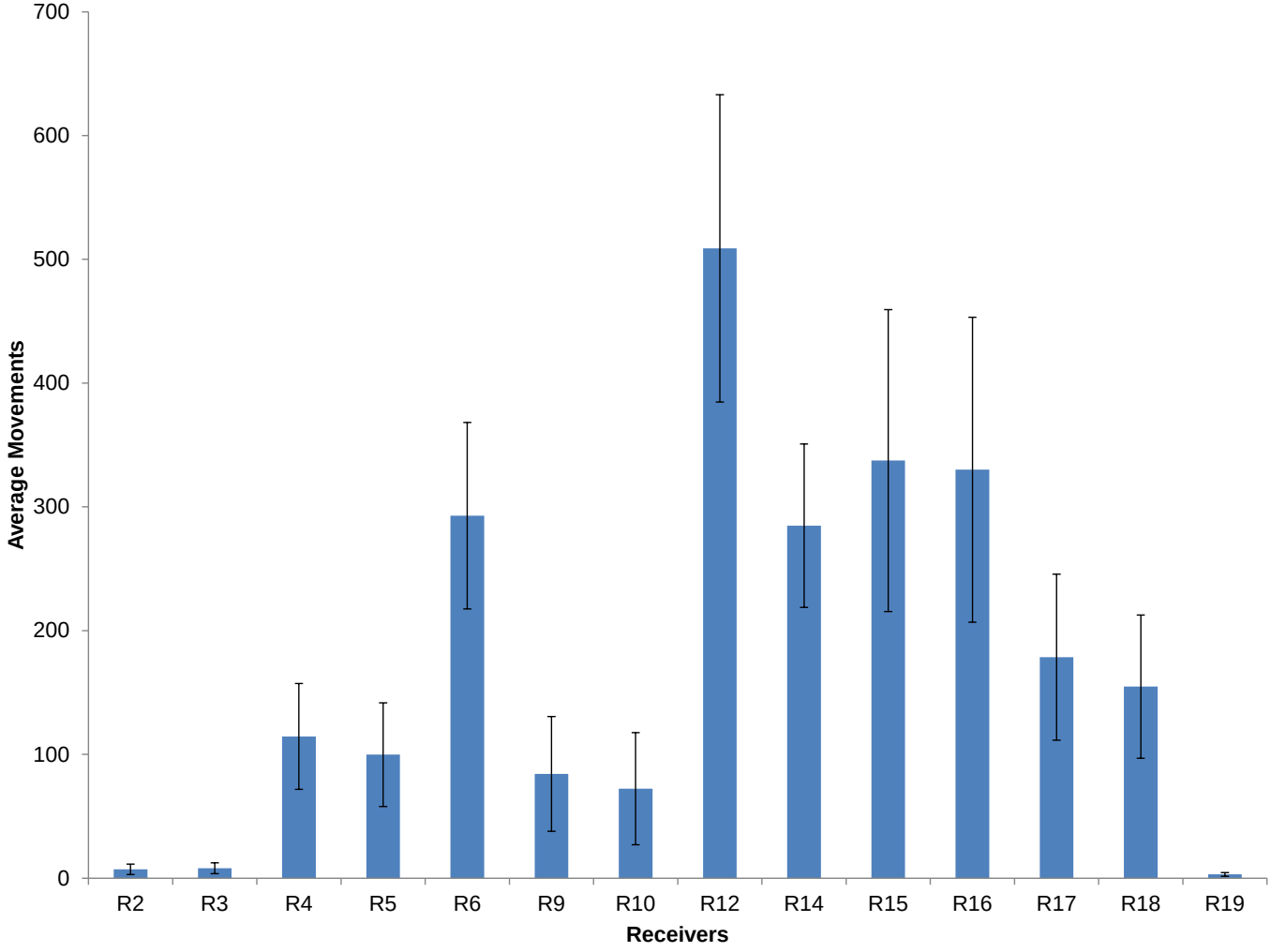
Chapter 2 Figure 9



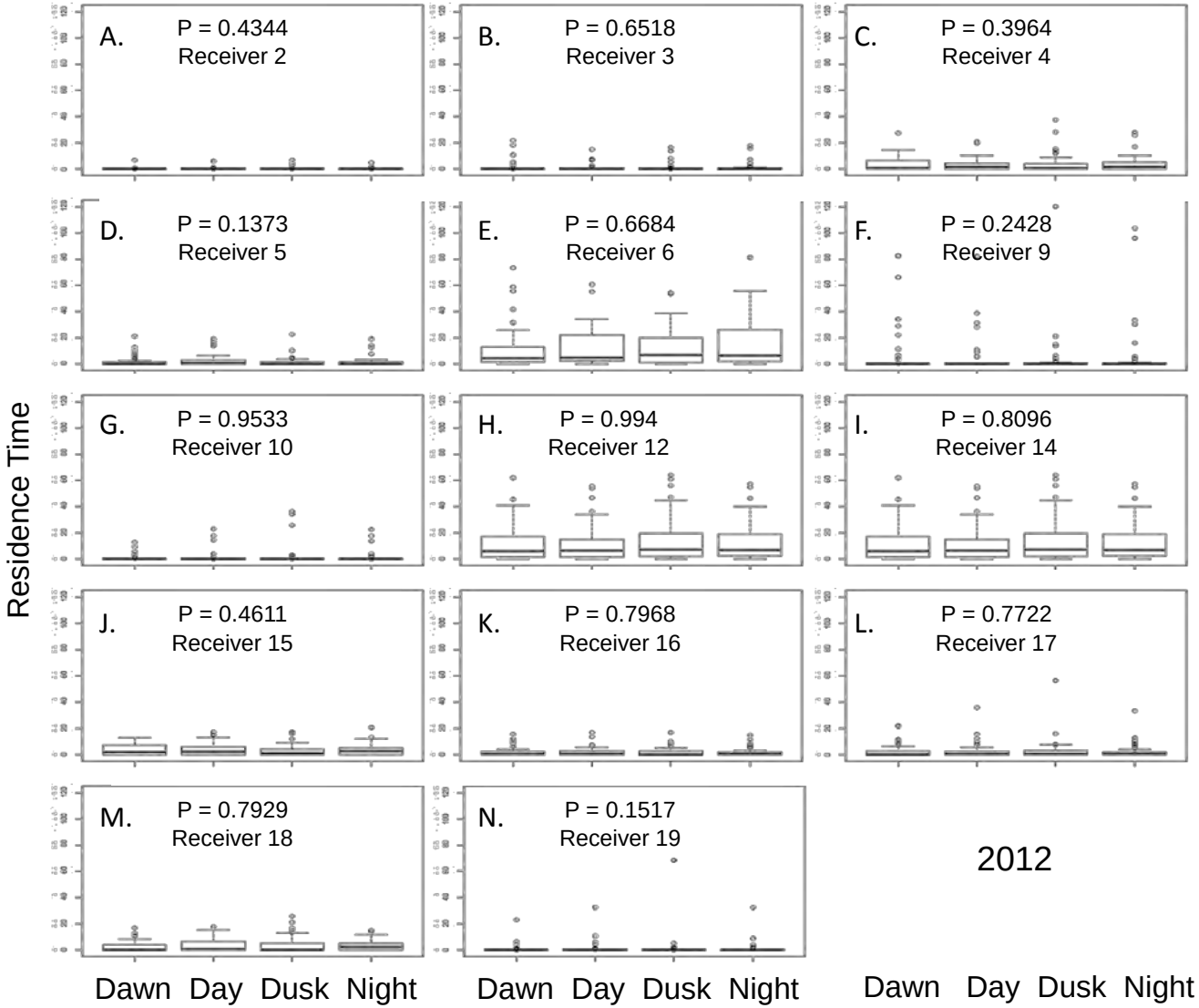
Chapter 2 Figure 10



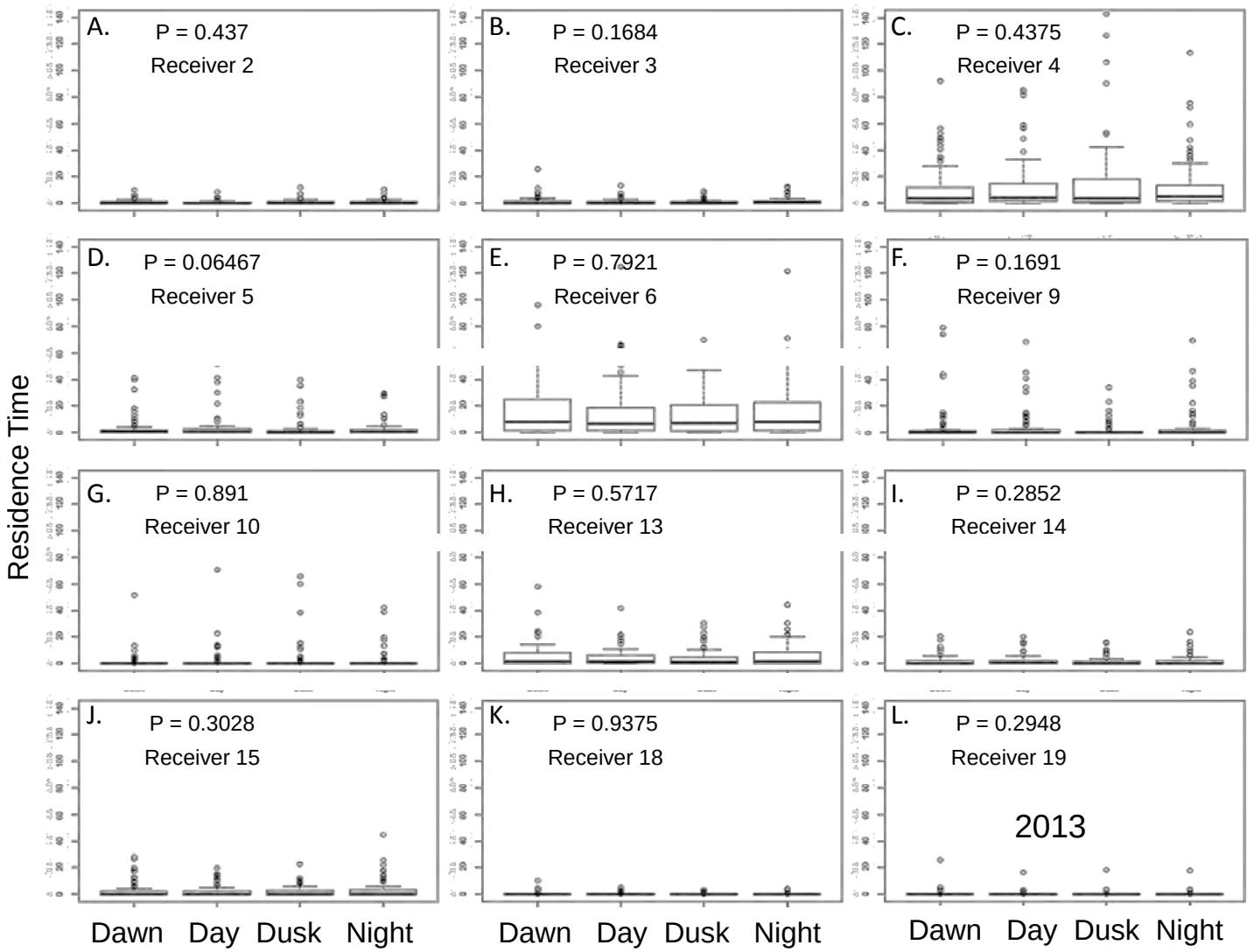
Chapter 2 Figure 11



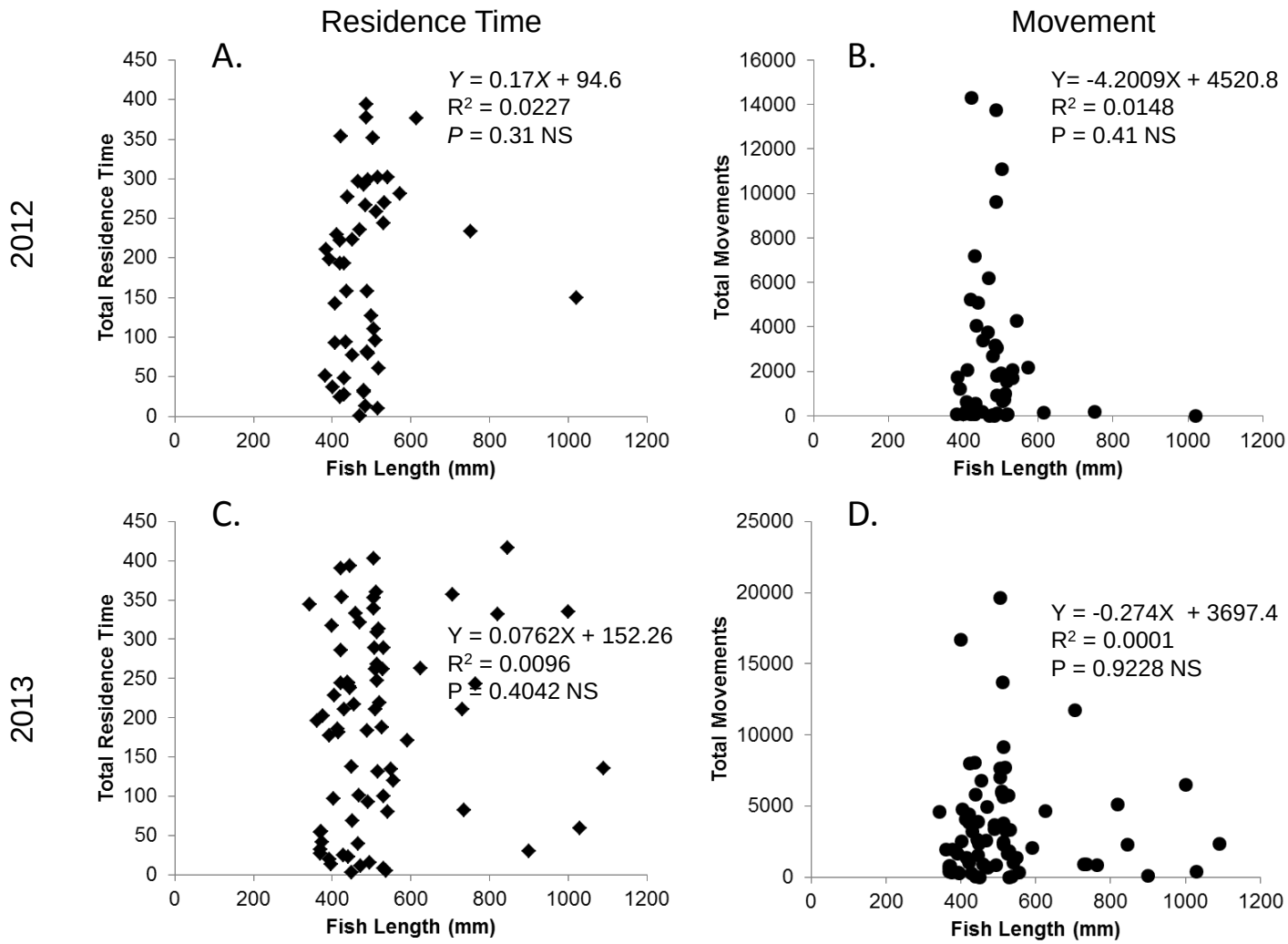
Chapter 2 Figure 12



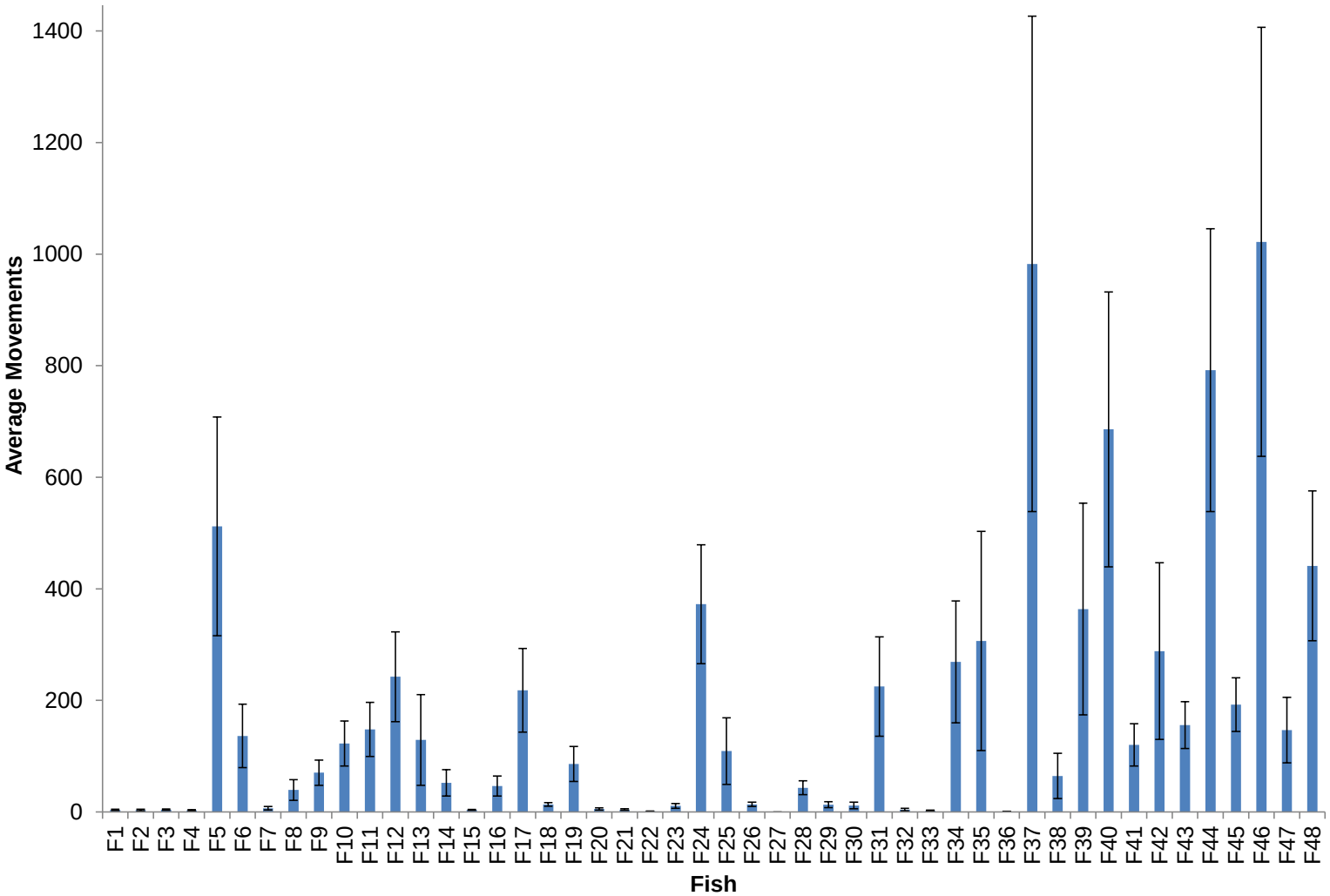
Chapter 2 Figure 13



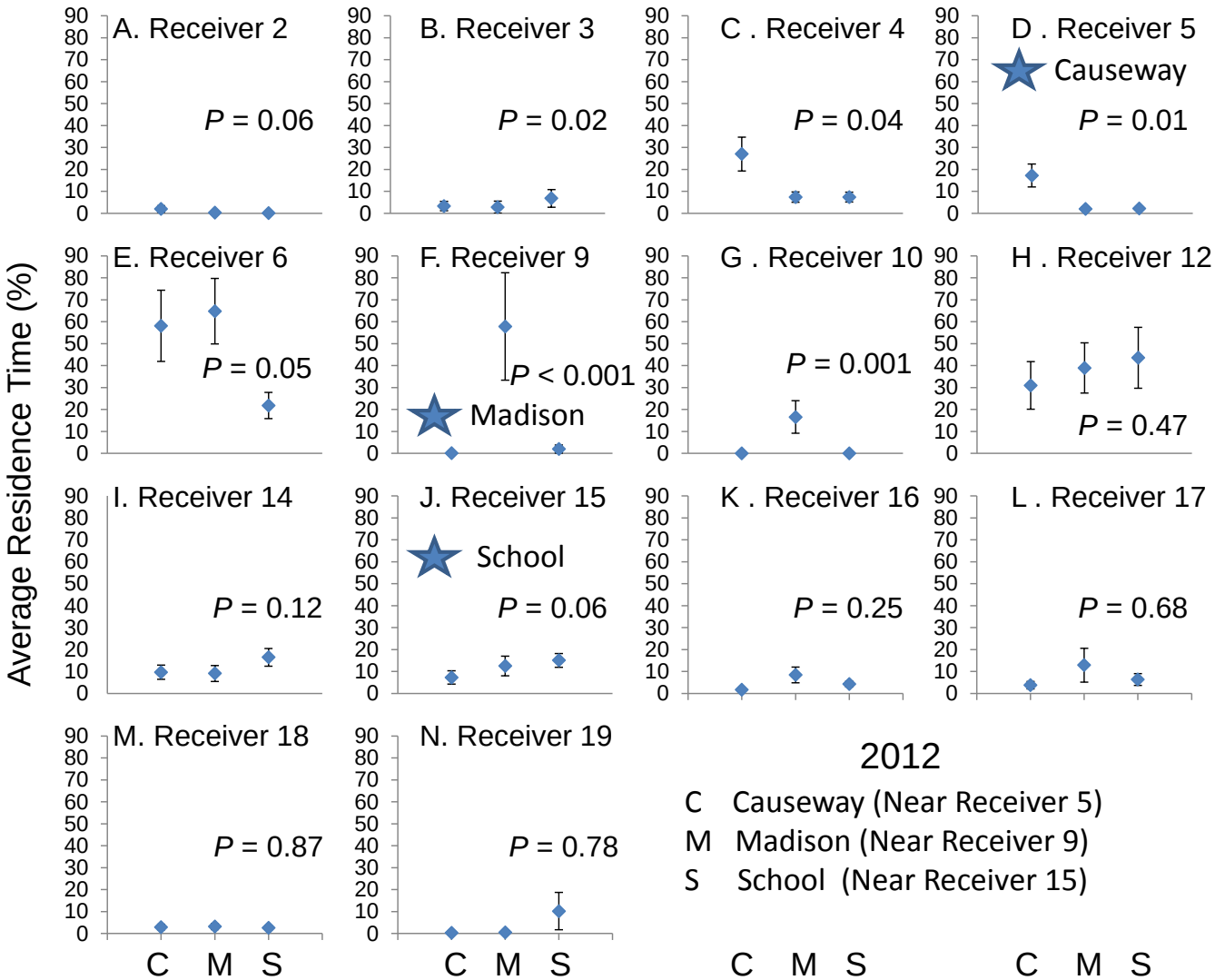
Chapter 2 Figure 14



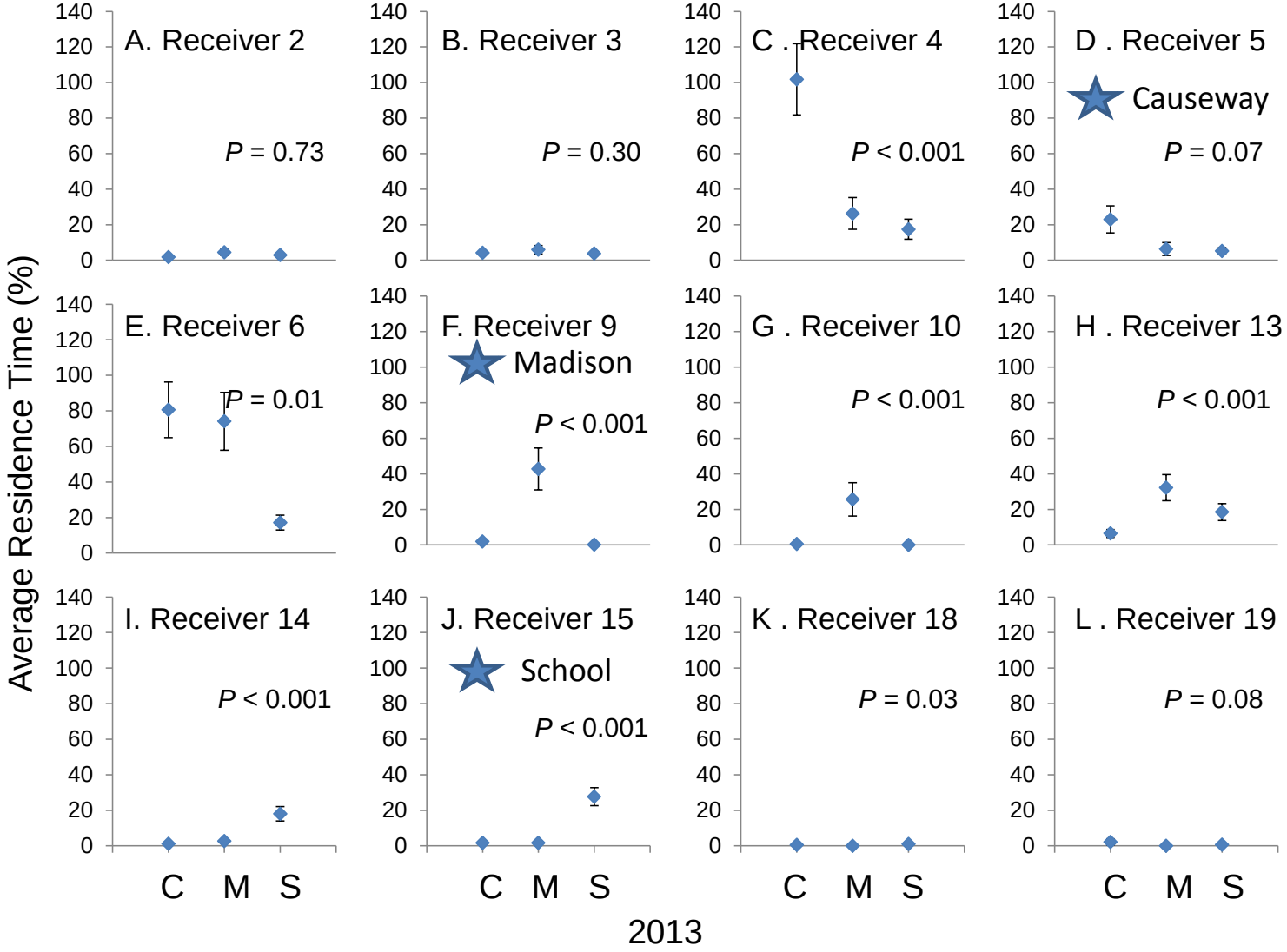
Chapter 2 Figure 15



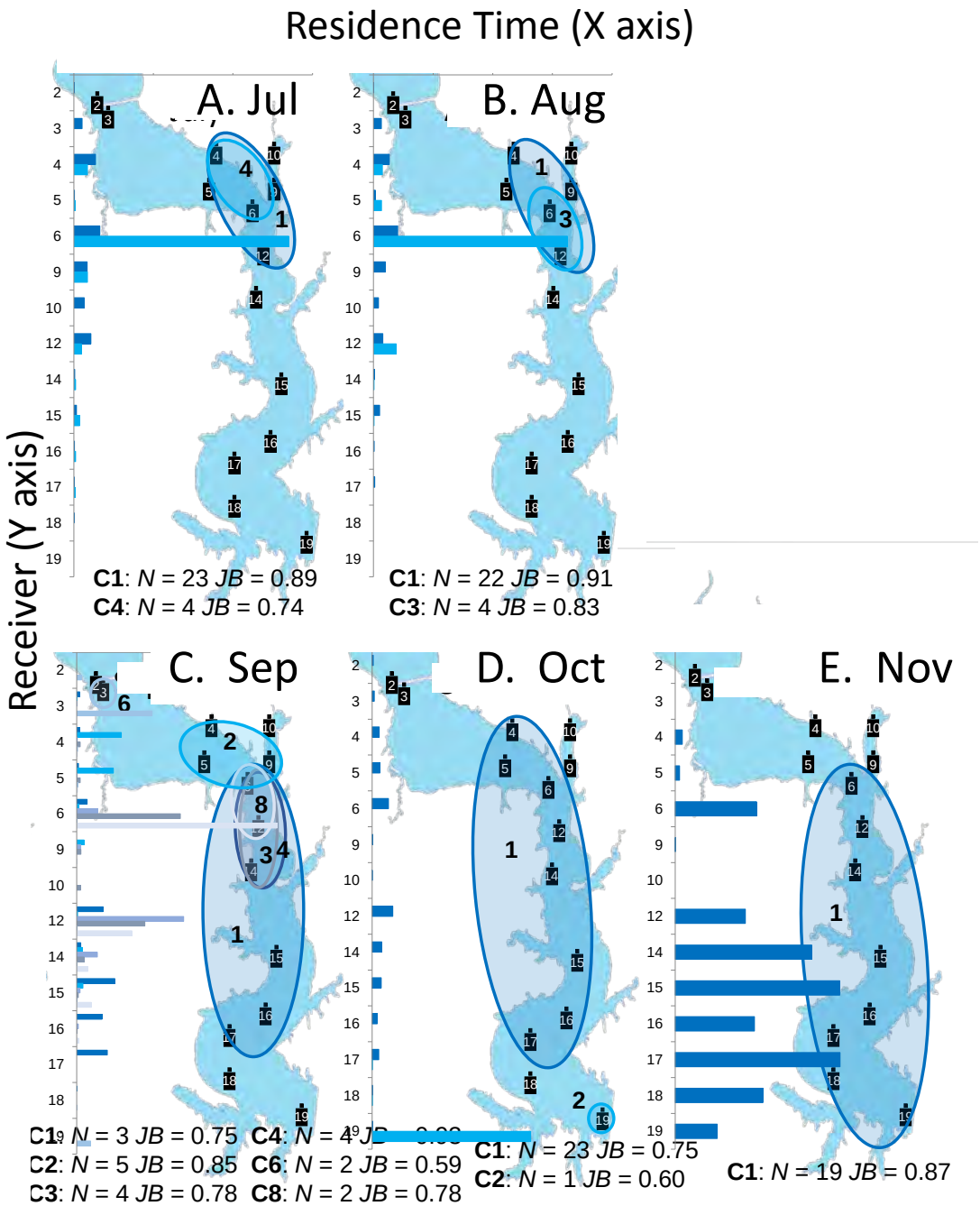
Chapter 2 Figure 16



Chapter 2 Figure 17

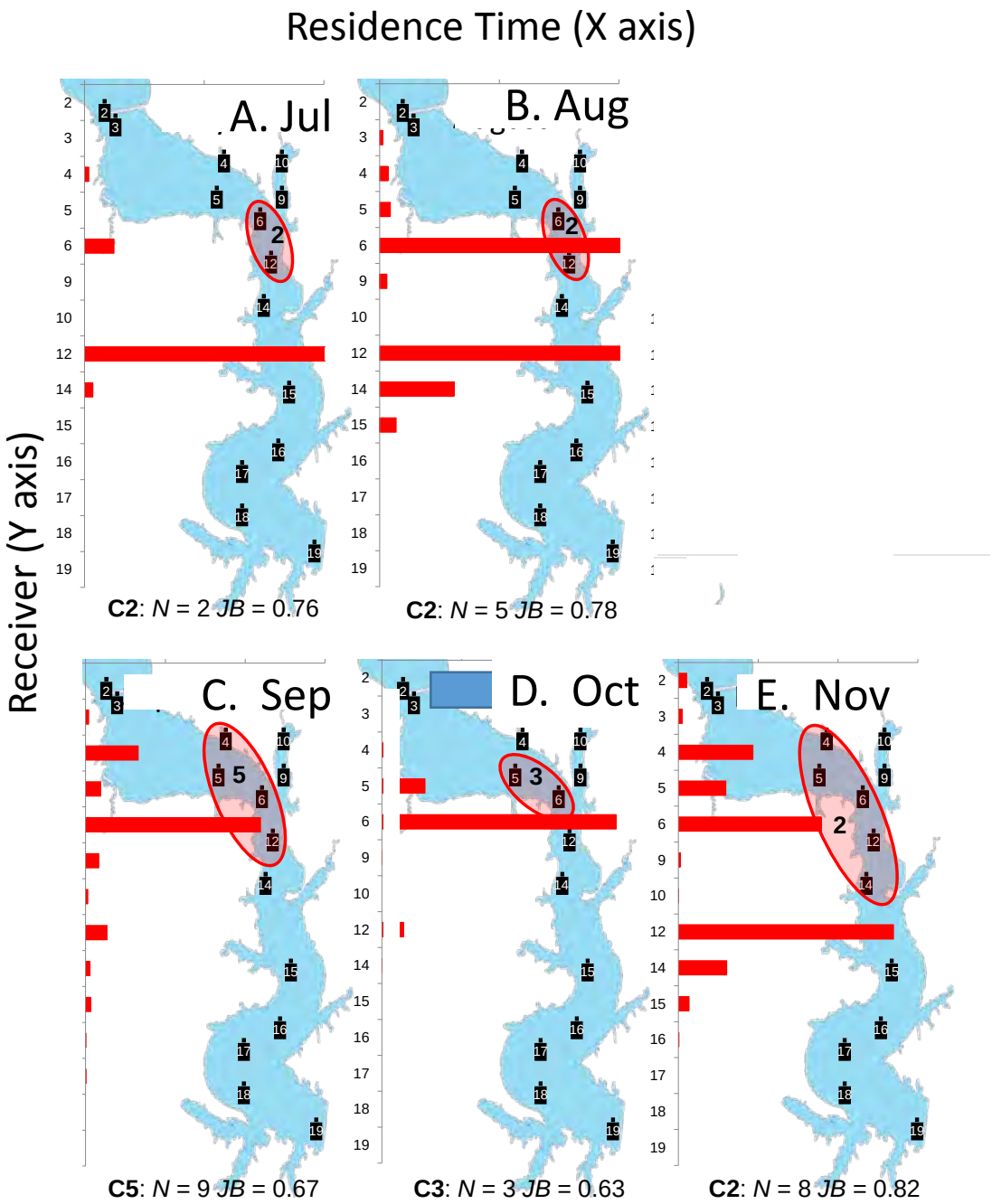


Chapter 2 Figure 18



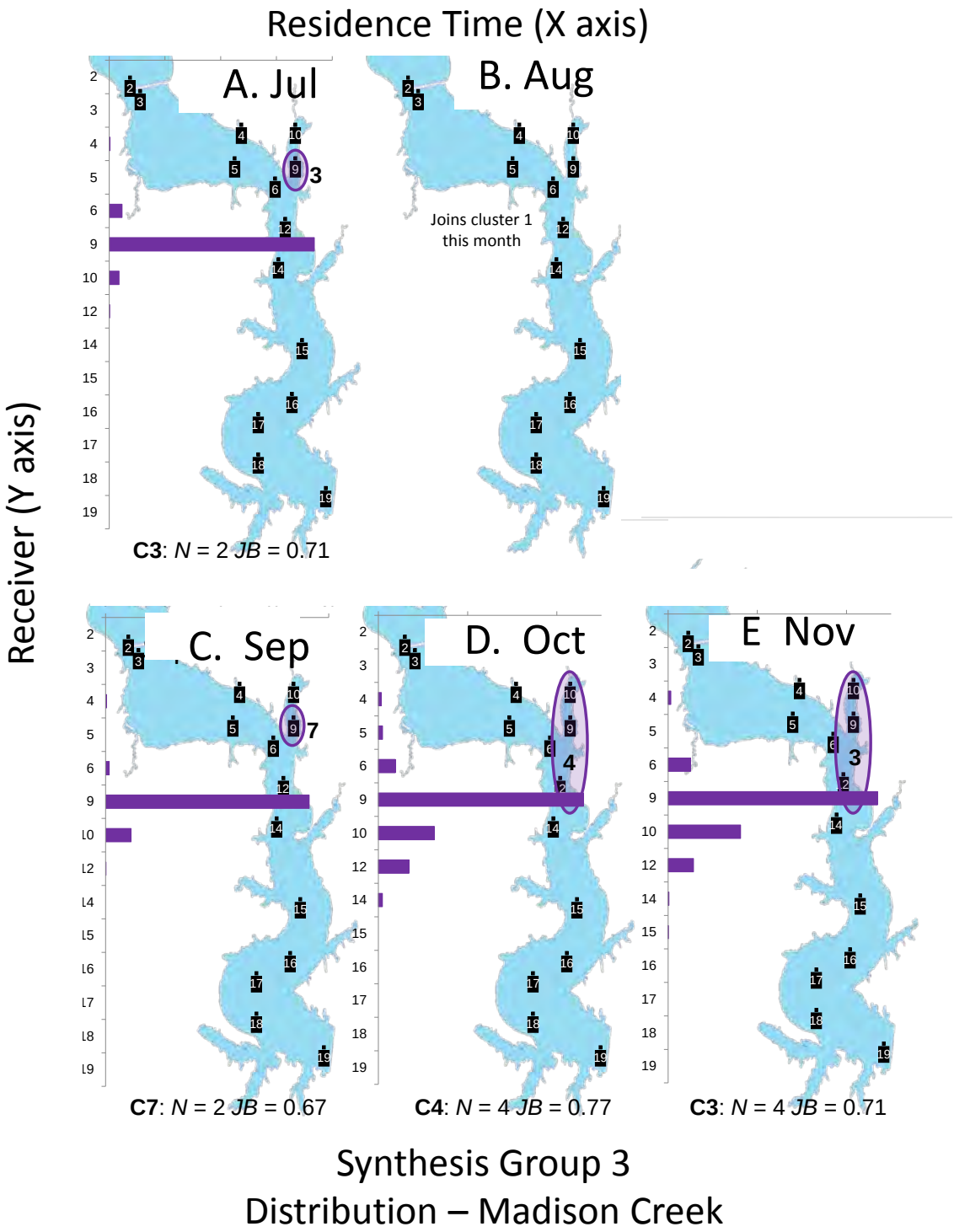
Synthesis Group 1
Distribution – The Seasonals

Chapter 2 Figure 19



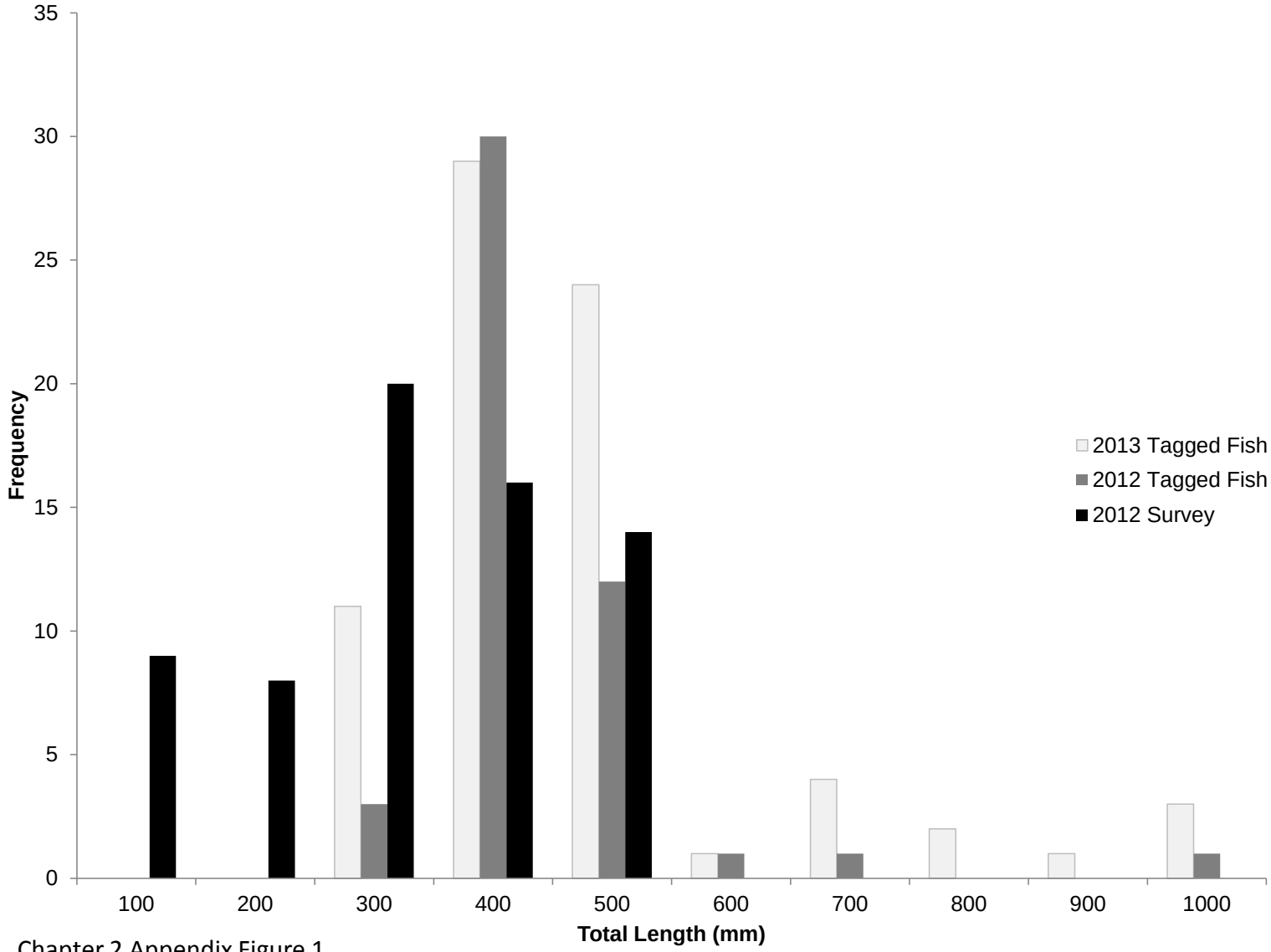
Synthesis Group 2
Distribution – The 6-12 Funnel Regulars

Chapter 2 Figure 20



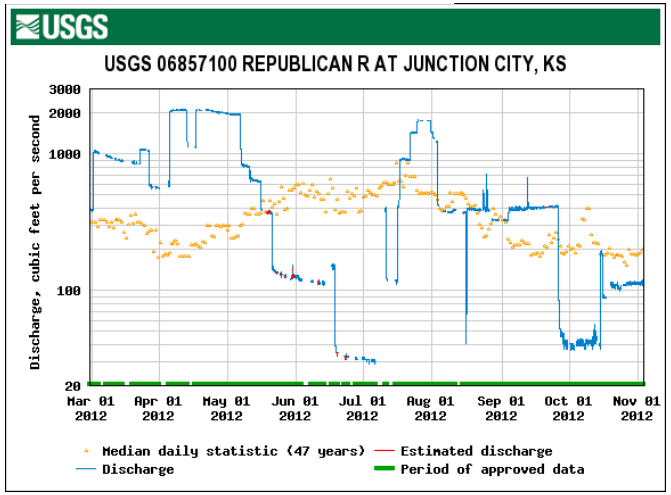
Synthesis Group 3
Distribution – Madison Creek

Chapter 2 Figure 21



Chapter 2 Appendix Figure 1

A. Mar – Nov, 2012



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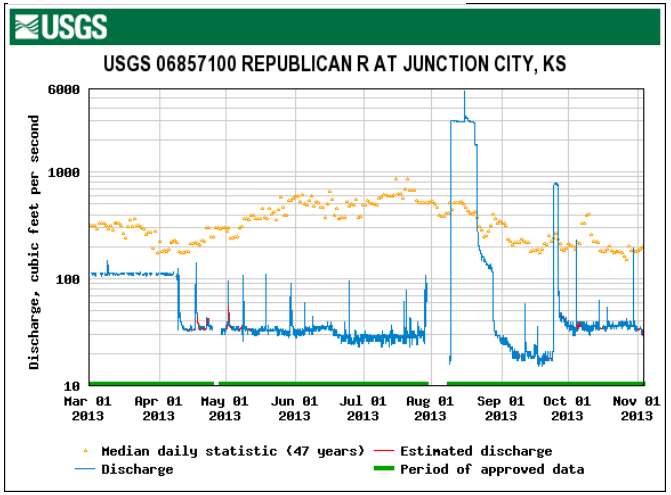
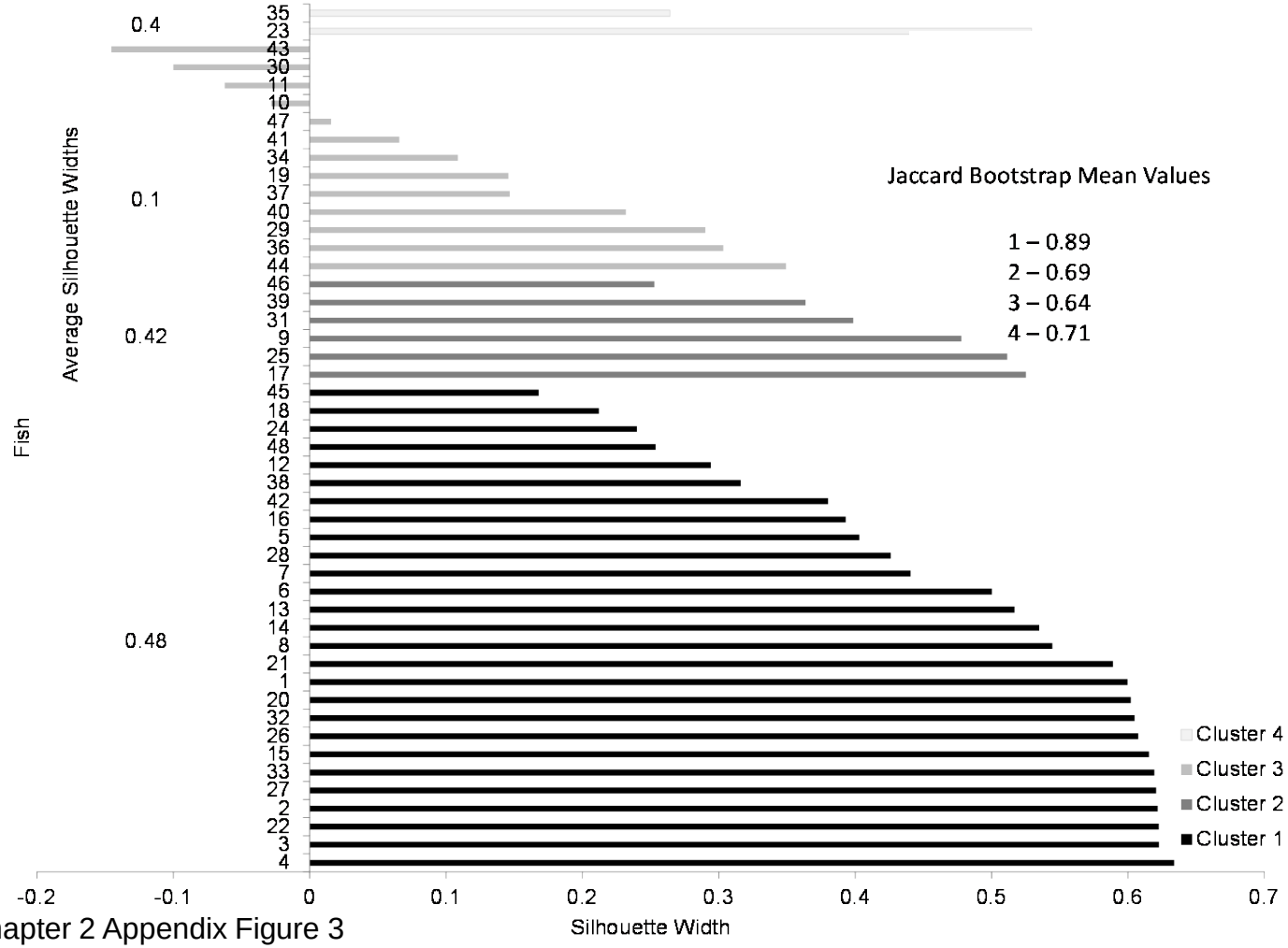


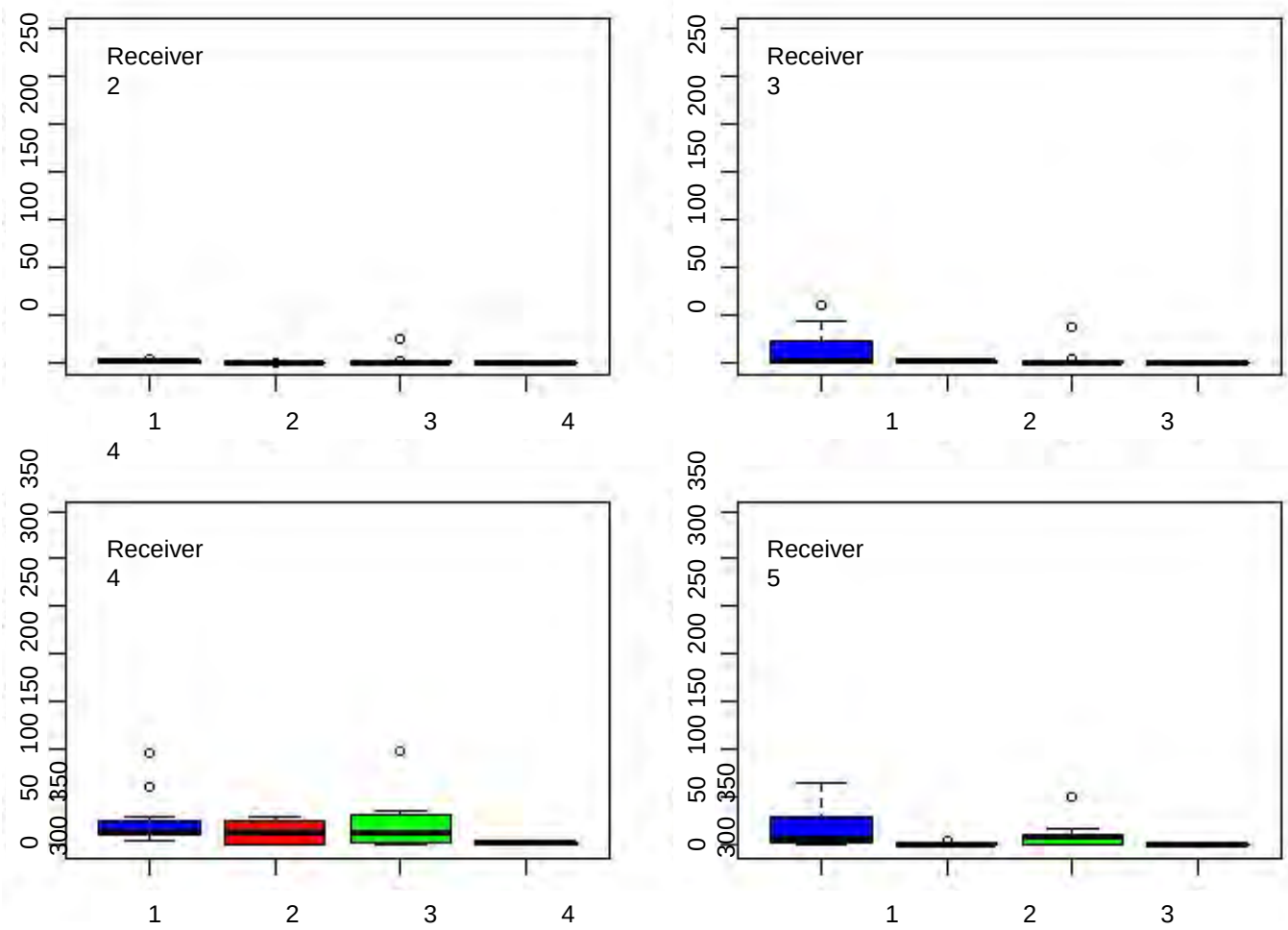
Chapter 2 Appendix Figure 2

Residence Time (July – November)



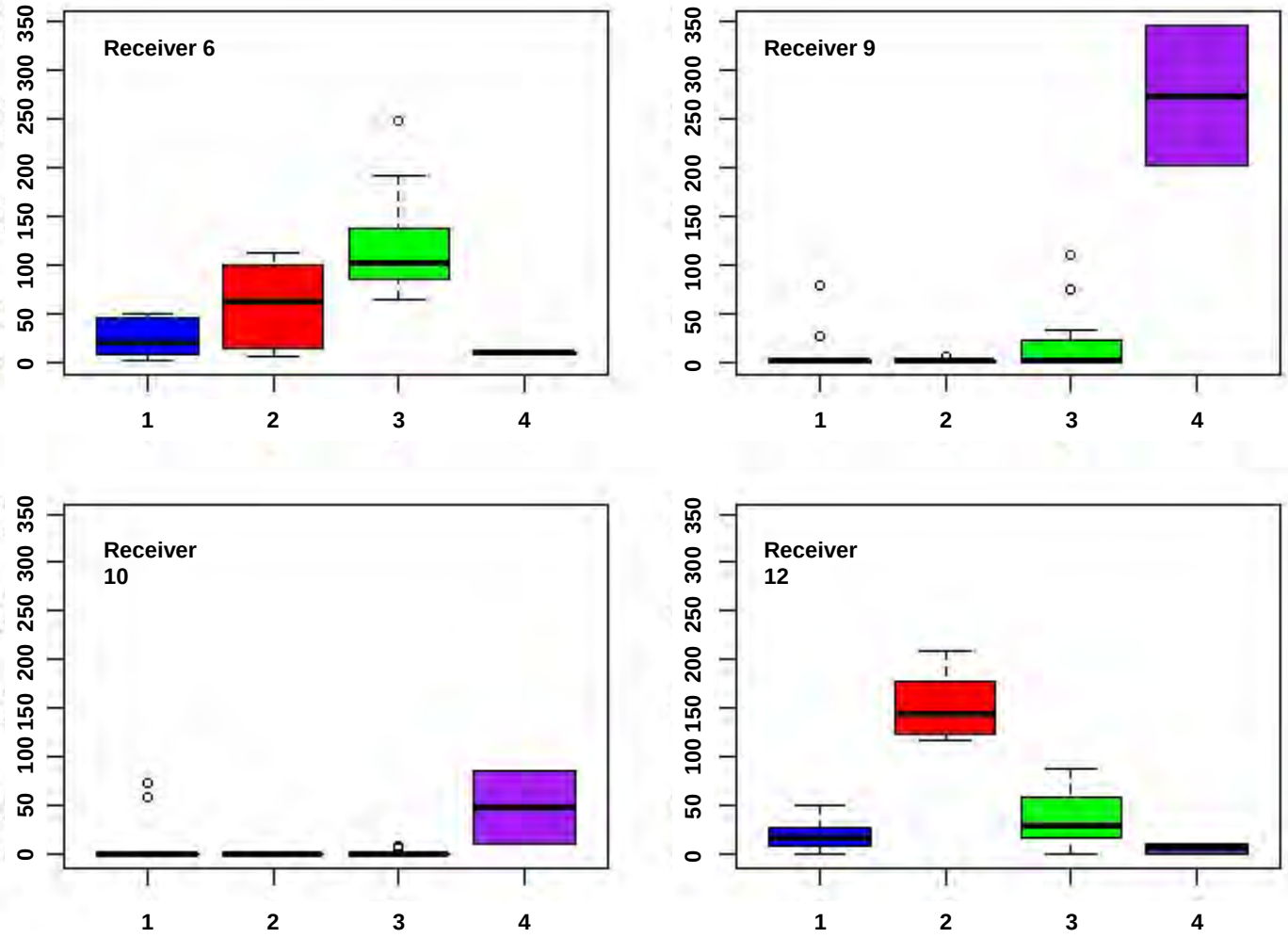
Chapter 2 Appendix Figure 3

Residence Time (July – November)



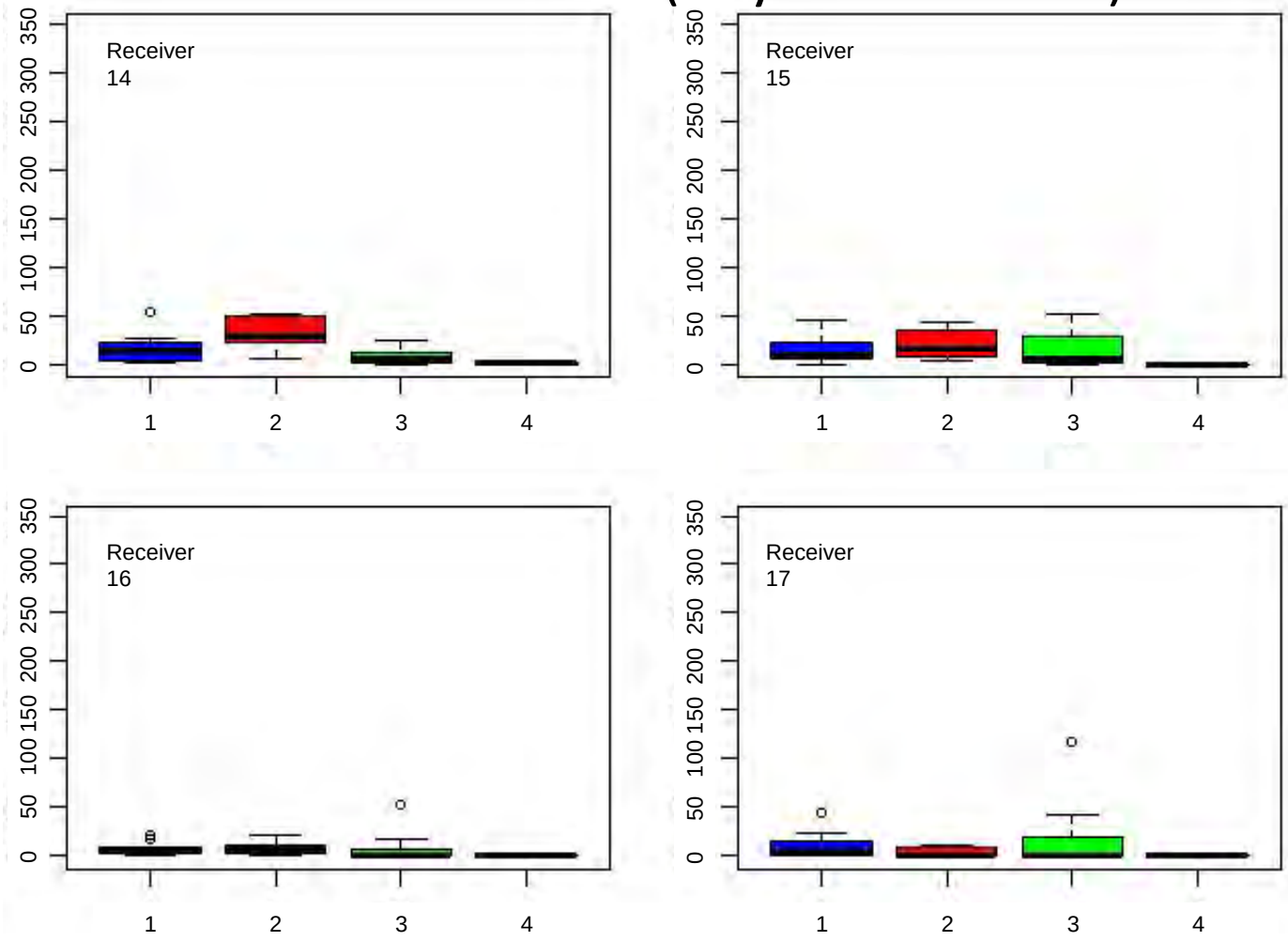
Chapter 2 Appendix Figure 4

Residence Time (July – November)



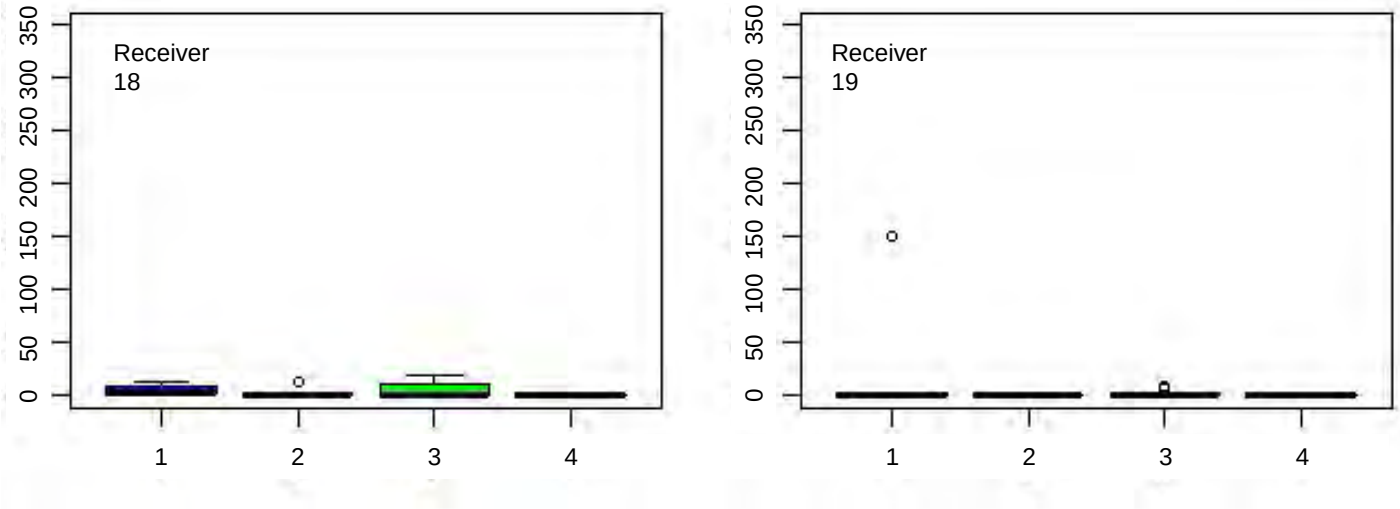
Chapter 2 Appendix Figure 5

Residence Time (July – November)

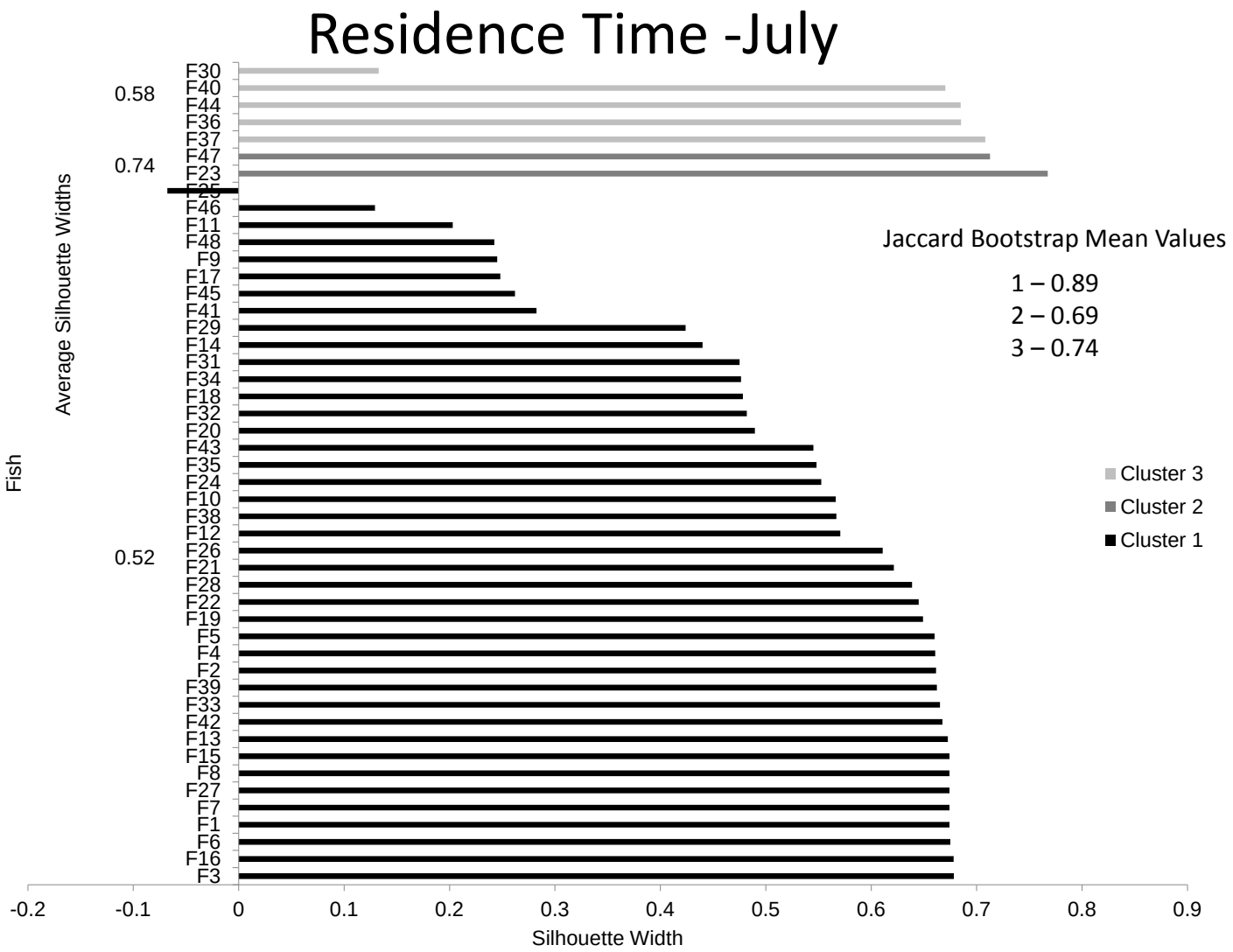


Chapter 2 Appendix Figure 6

Residence Time (July – November)

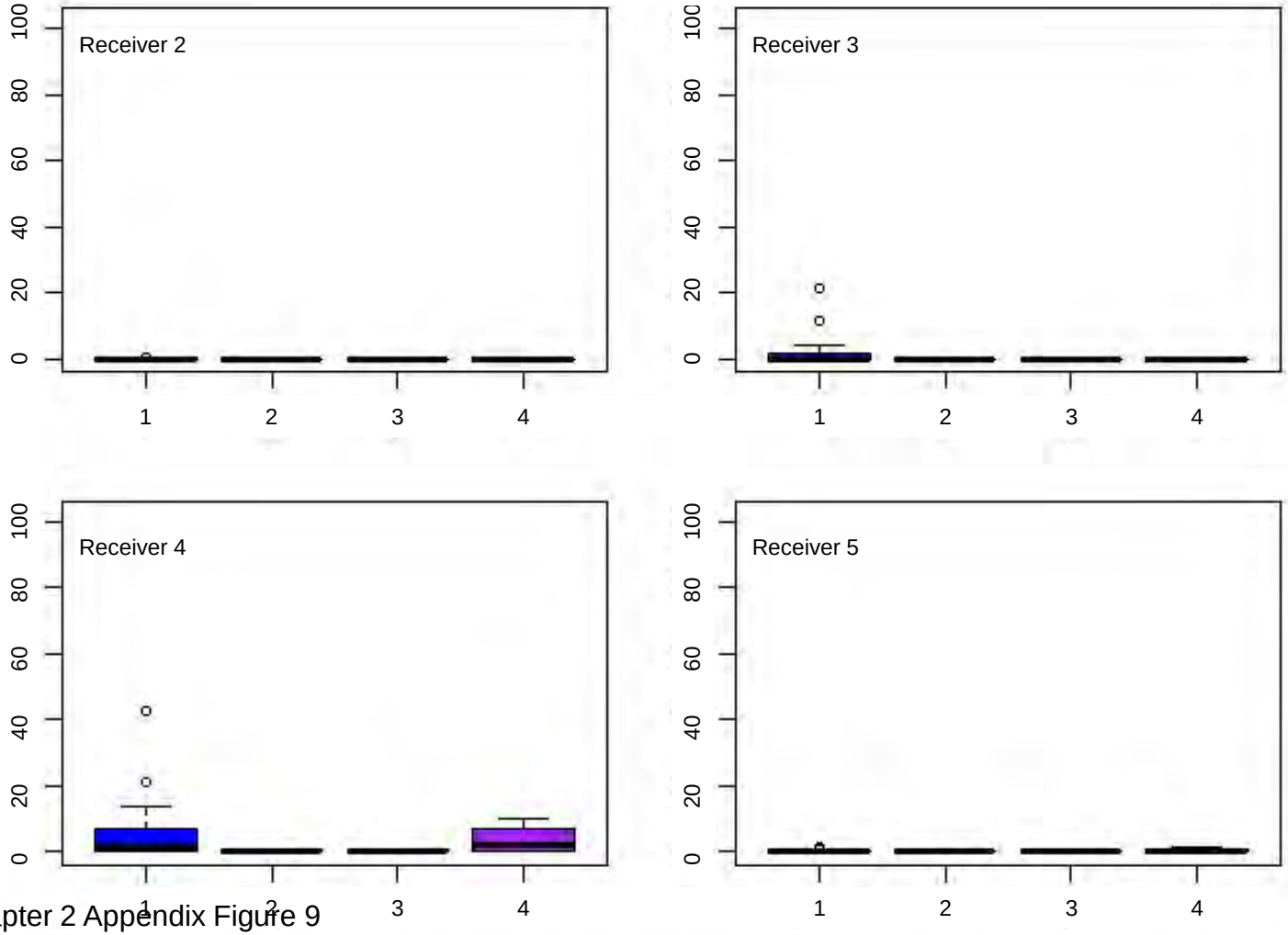


Chapter 2 Appendix Figure 7



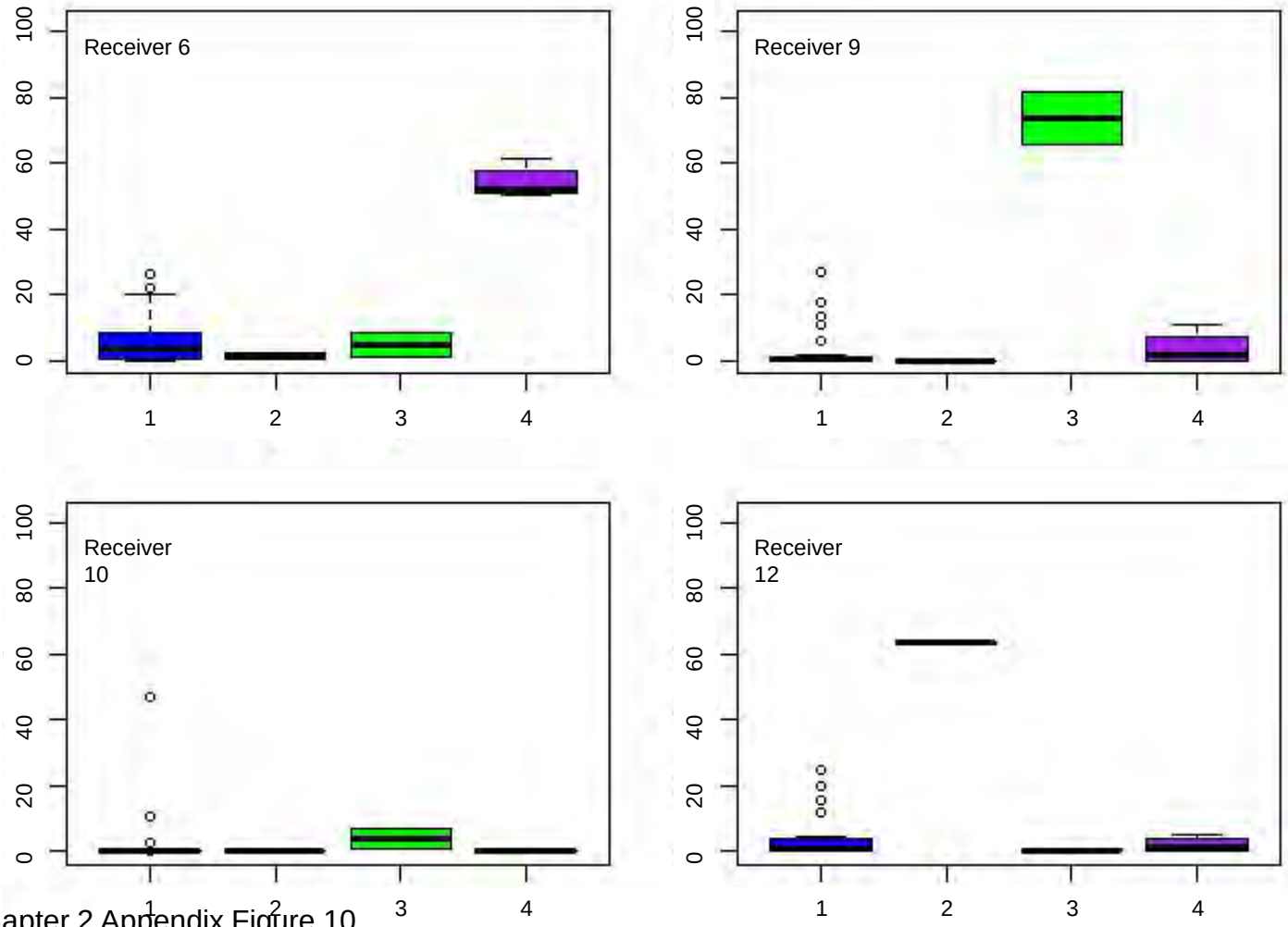
Chapter 2 Appendix Figure 8

Residence Time (July)



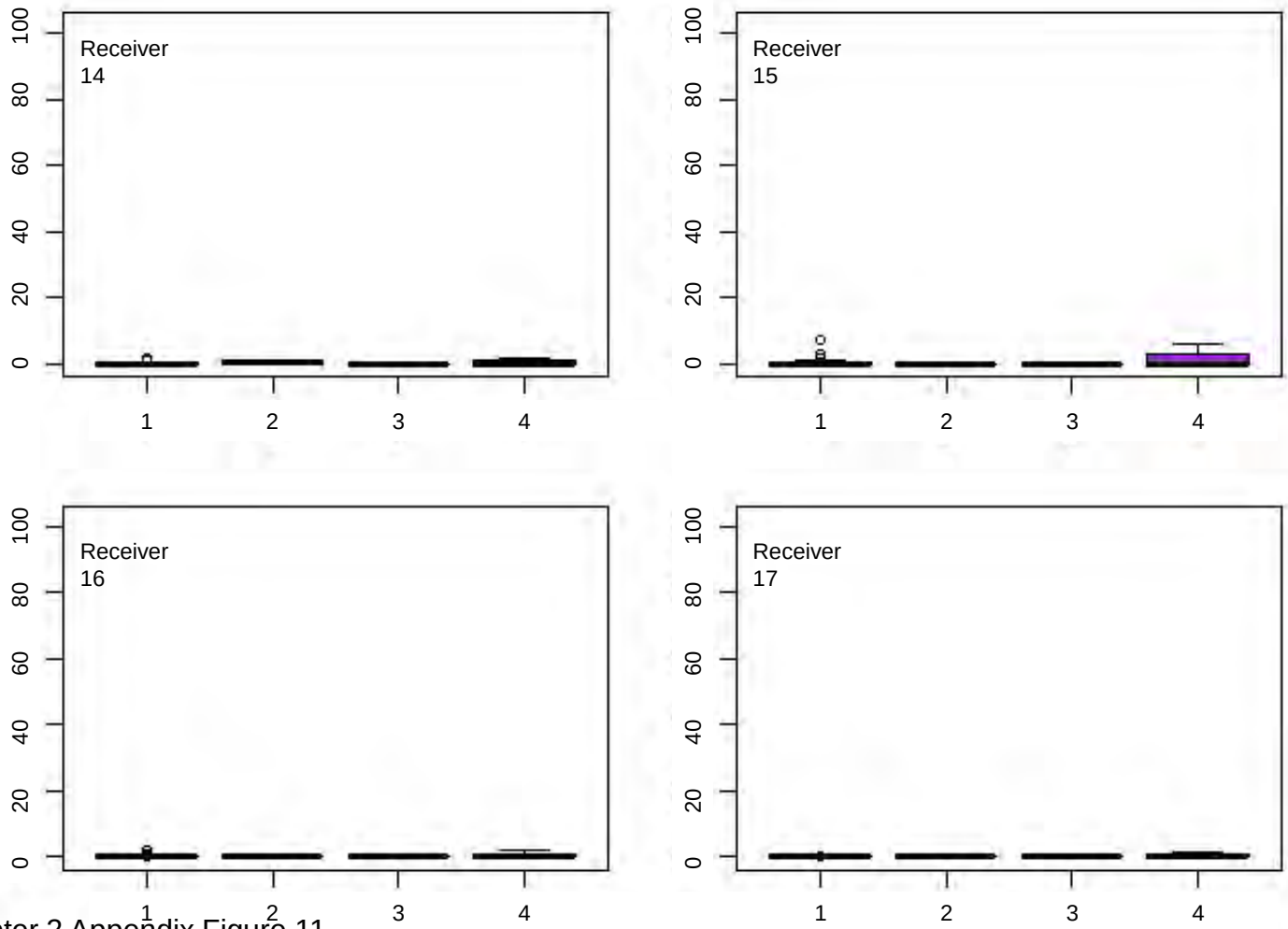
Chapter 2 Appendix Figure 9

Residence Time (July)



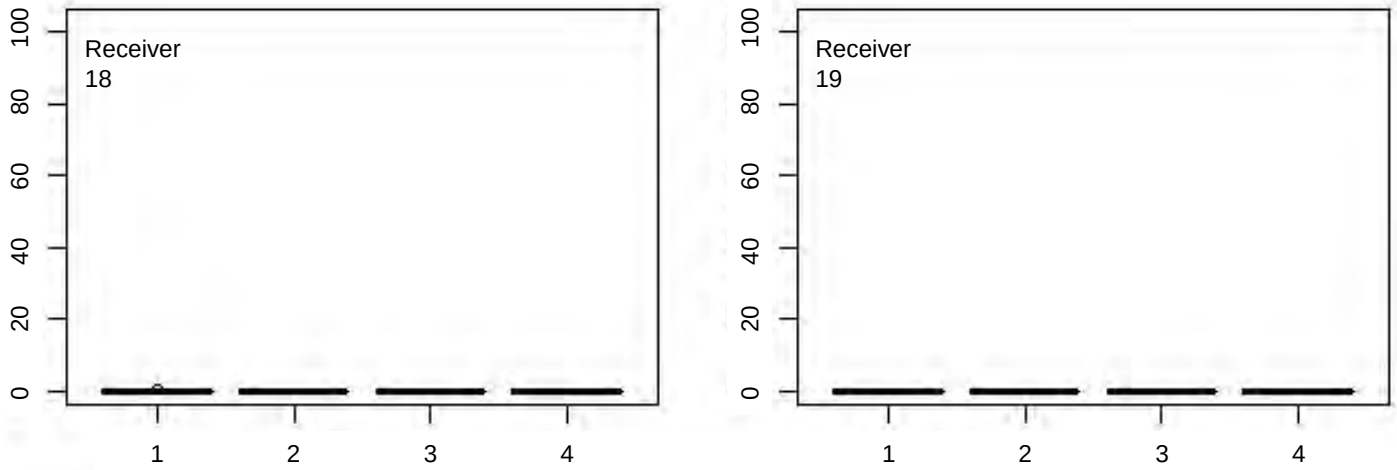
Chapter 2 Appendix Figure 10

Residence Time (July)



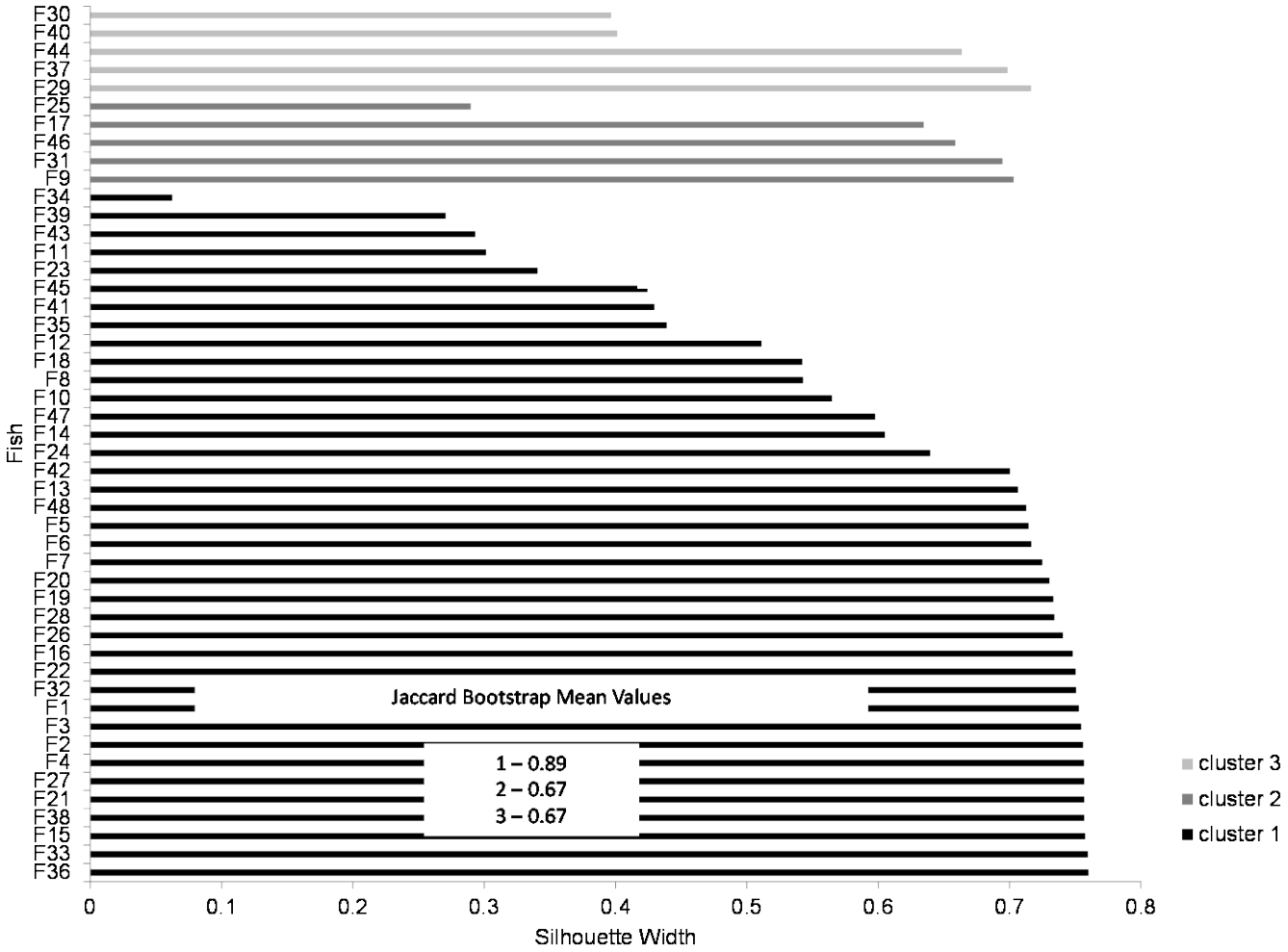
Chapter 2 Appendix Figure 11

Residence Time (July)



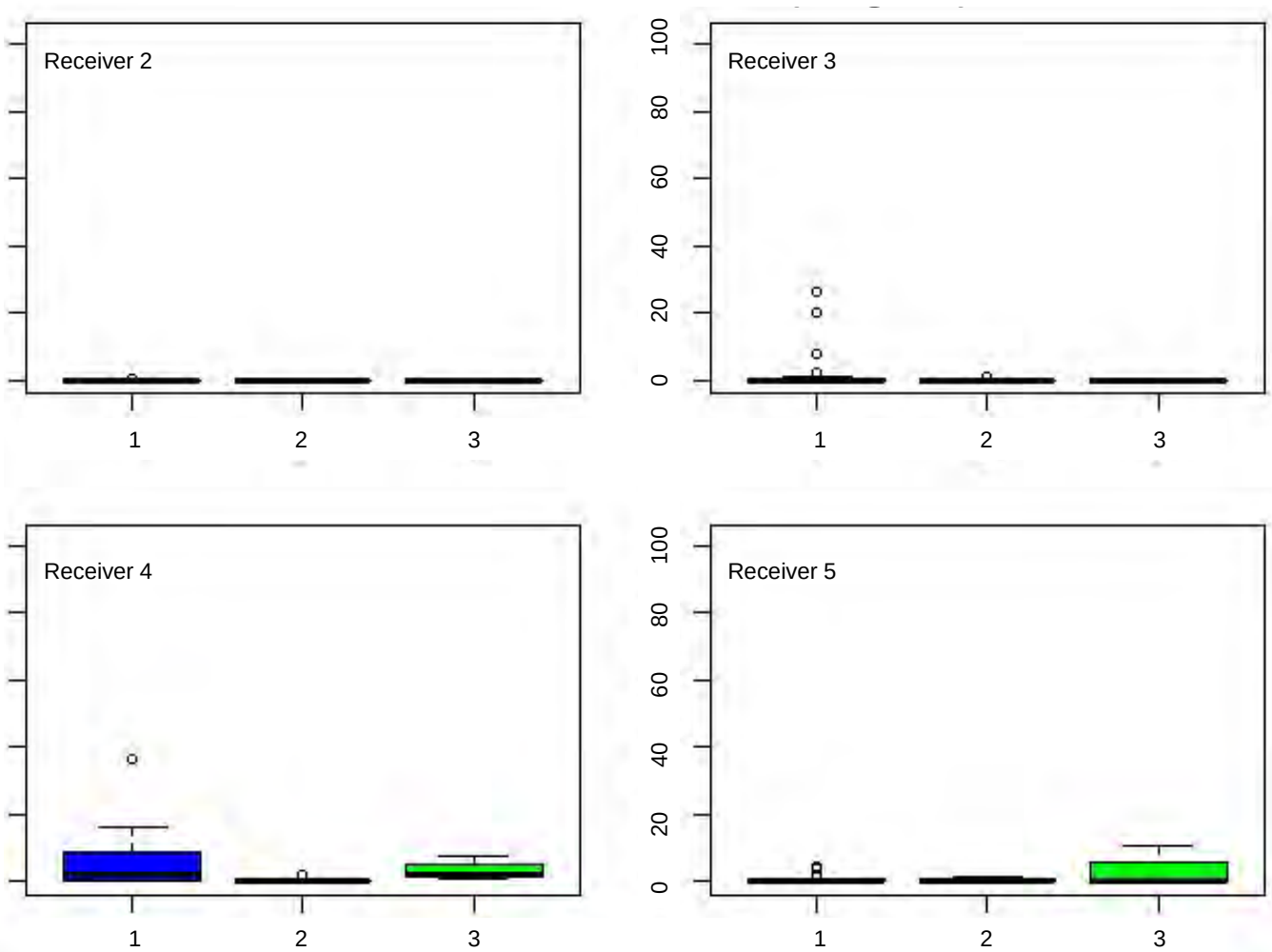
Chapter 2 Appendix Figure 12

Residence Time - August



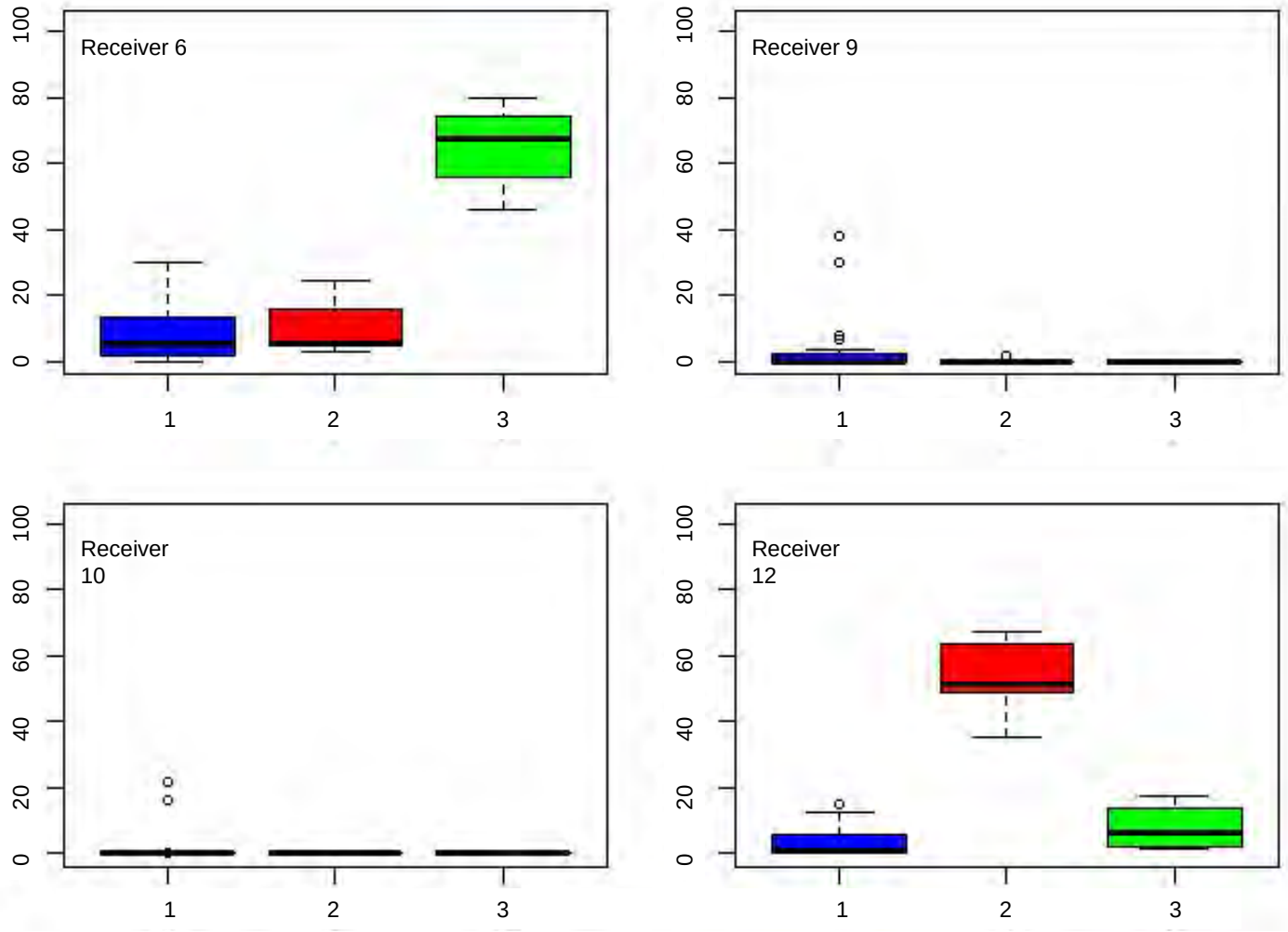
Chapter 2 Appendix Figure 13

Residence Time (August)



Chapter 2 Appendix Figure 14

Residence Time (August)



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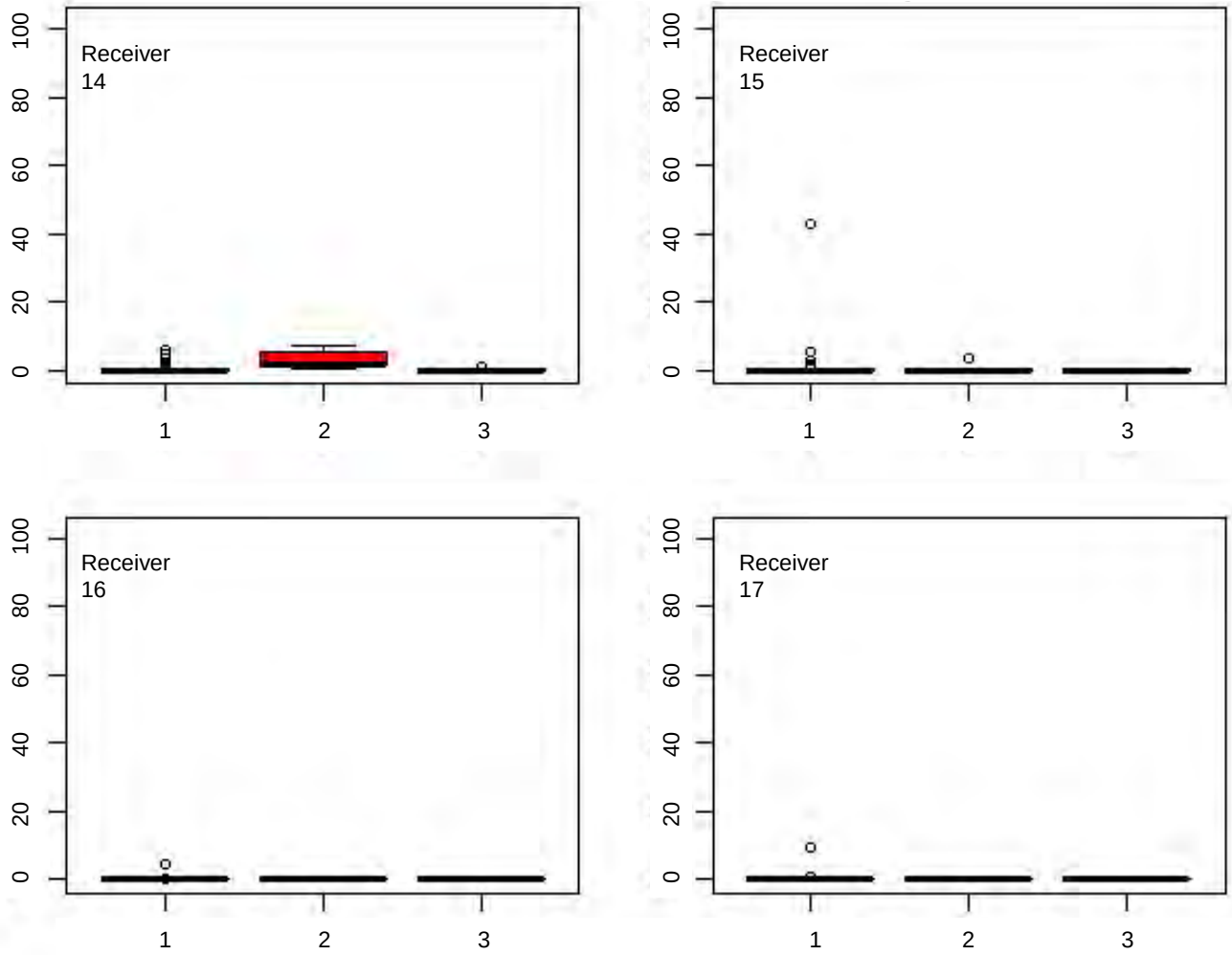
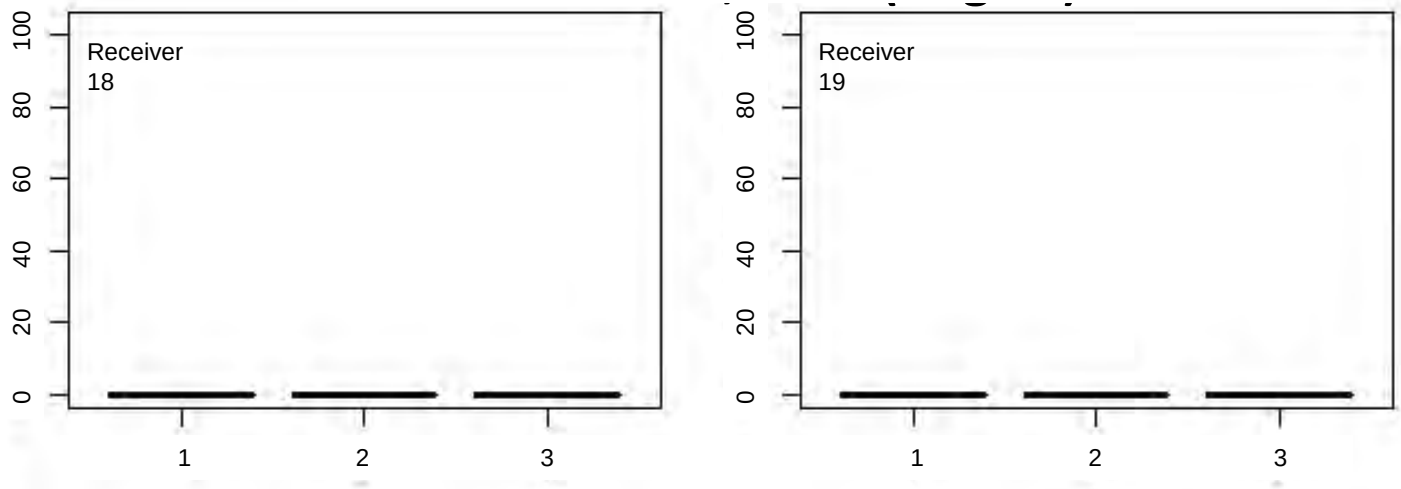
Residence Time (August)



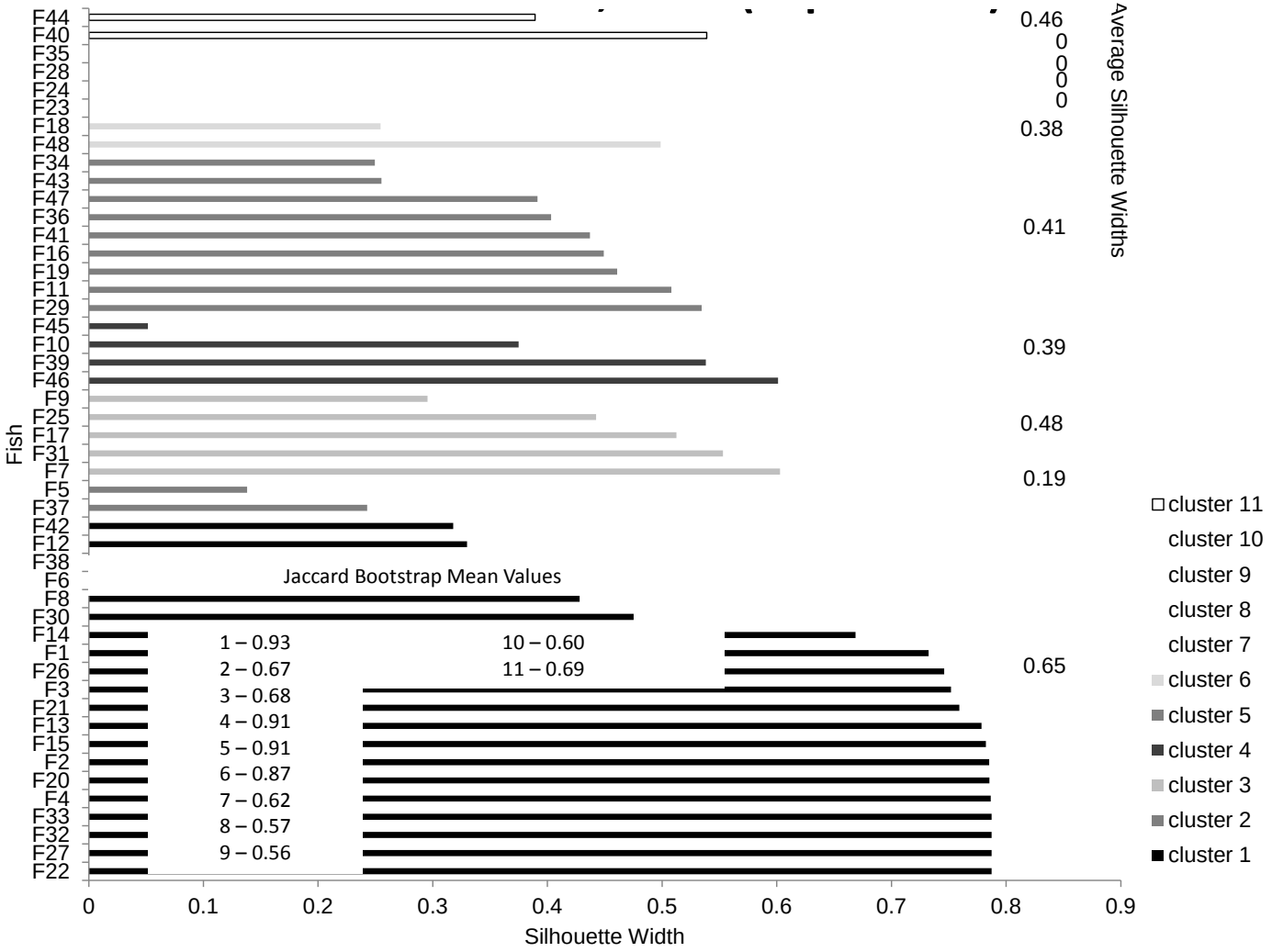
Chapter 2 Appendix Figure 16

Residence Time (August)



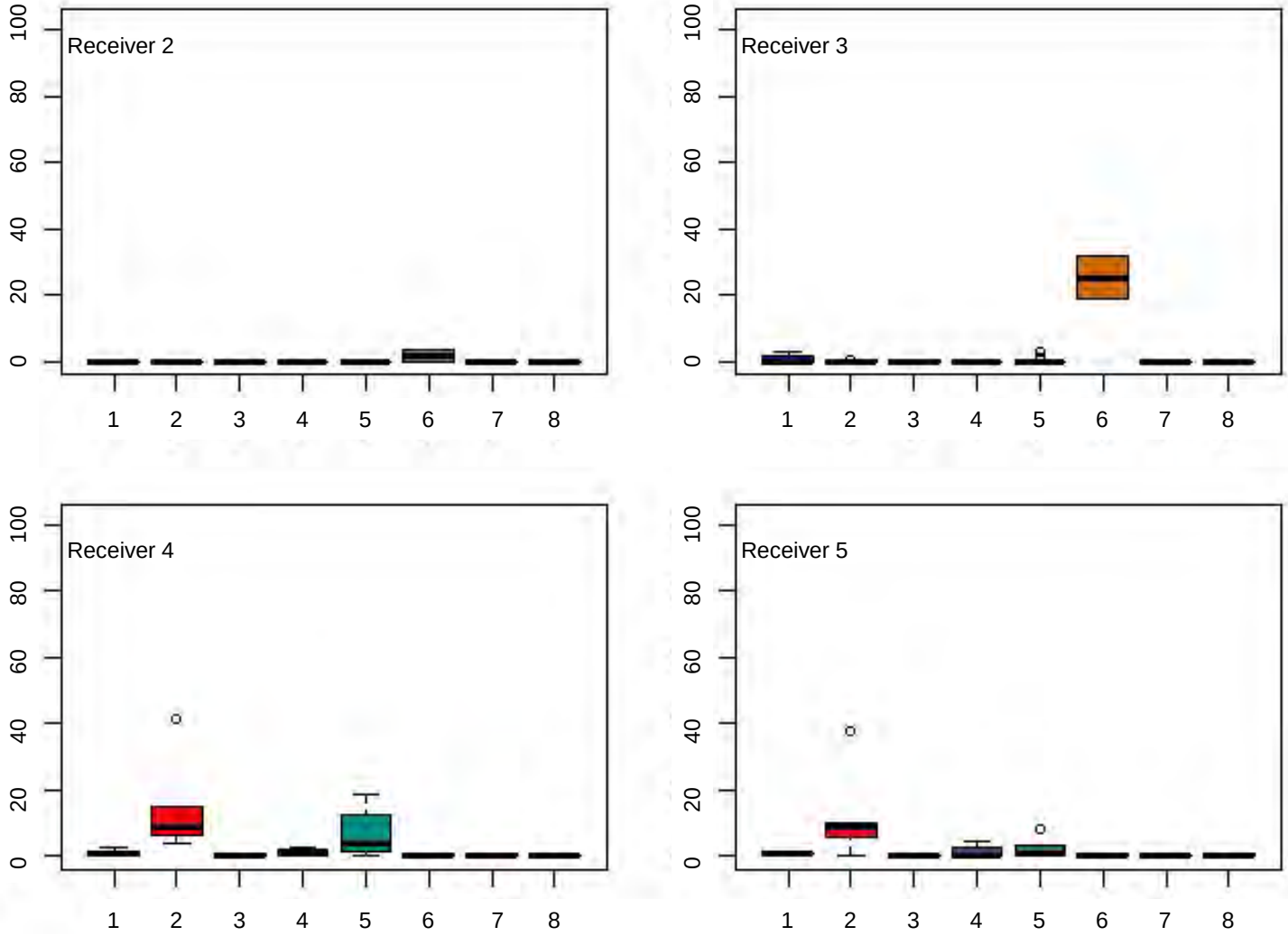
Chapter 2 Appendix Figure 17

Residence Time - September



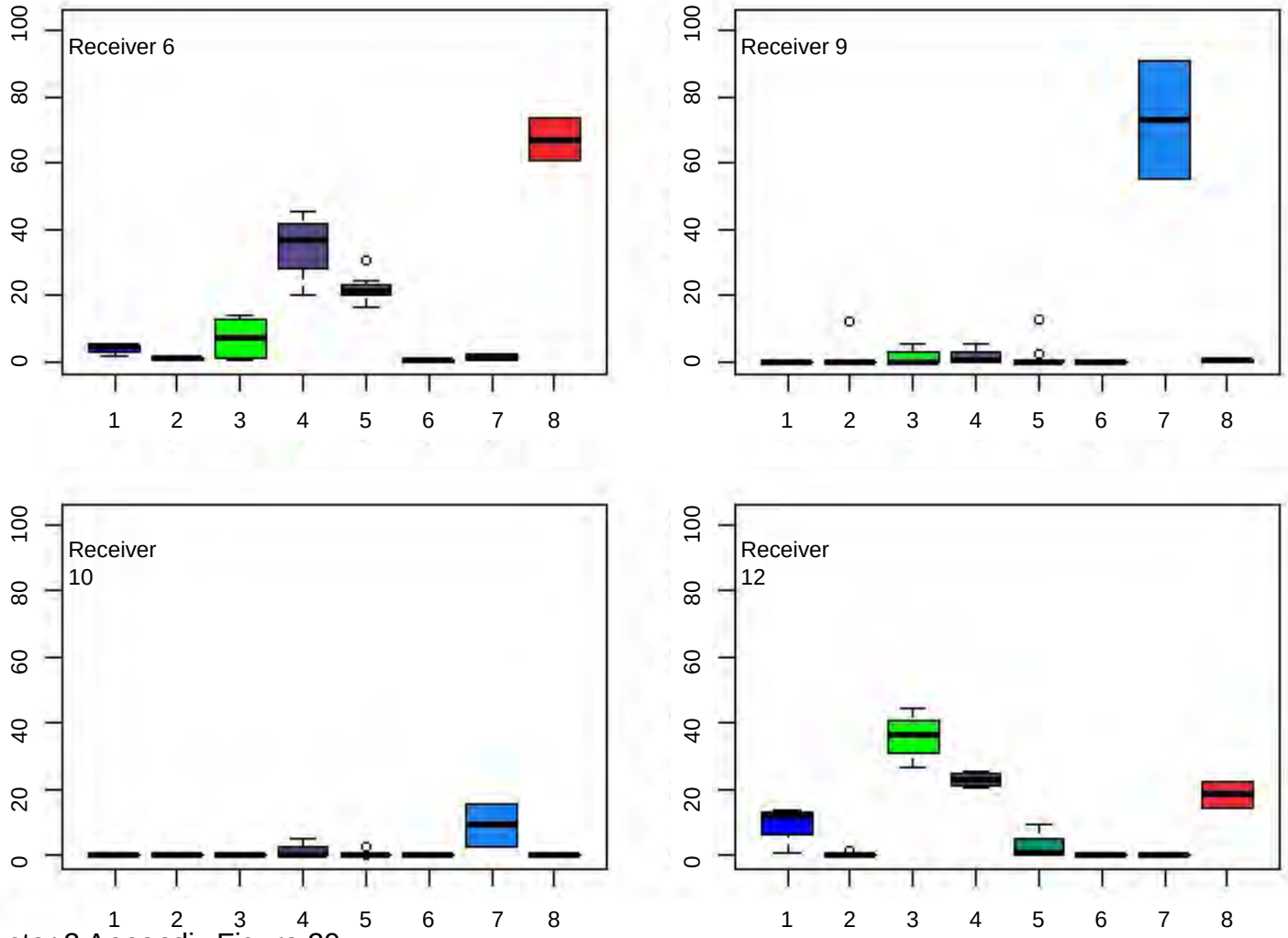
Chapter 2 Appendix Figure 18

Residence Time (September)



Chapter 2 Appendix Figure 19

Residence Time (September)



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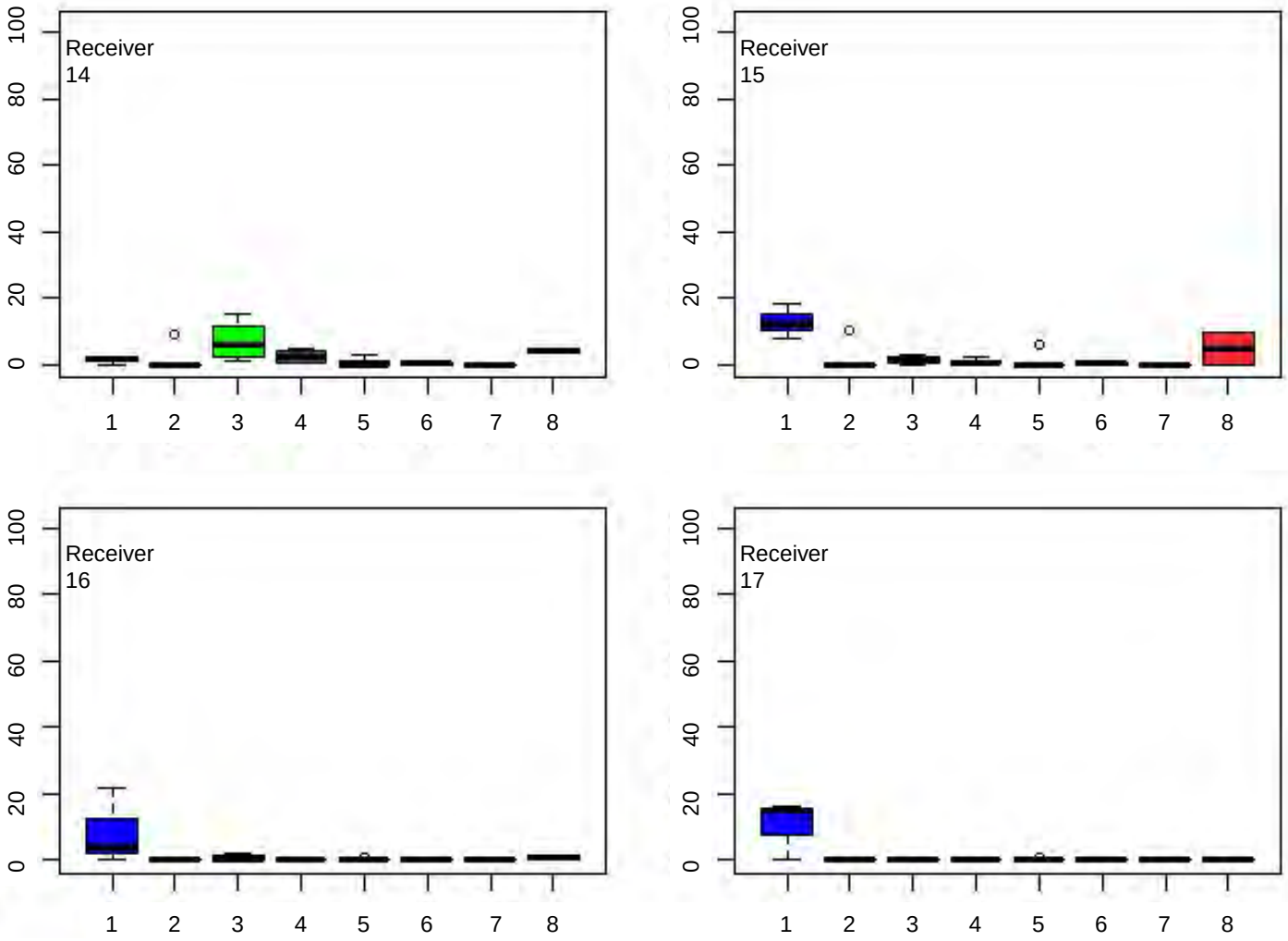
Residence Time (September)



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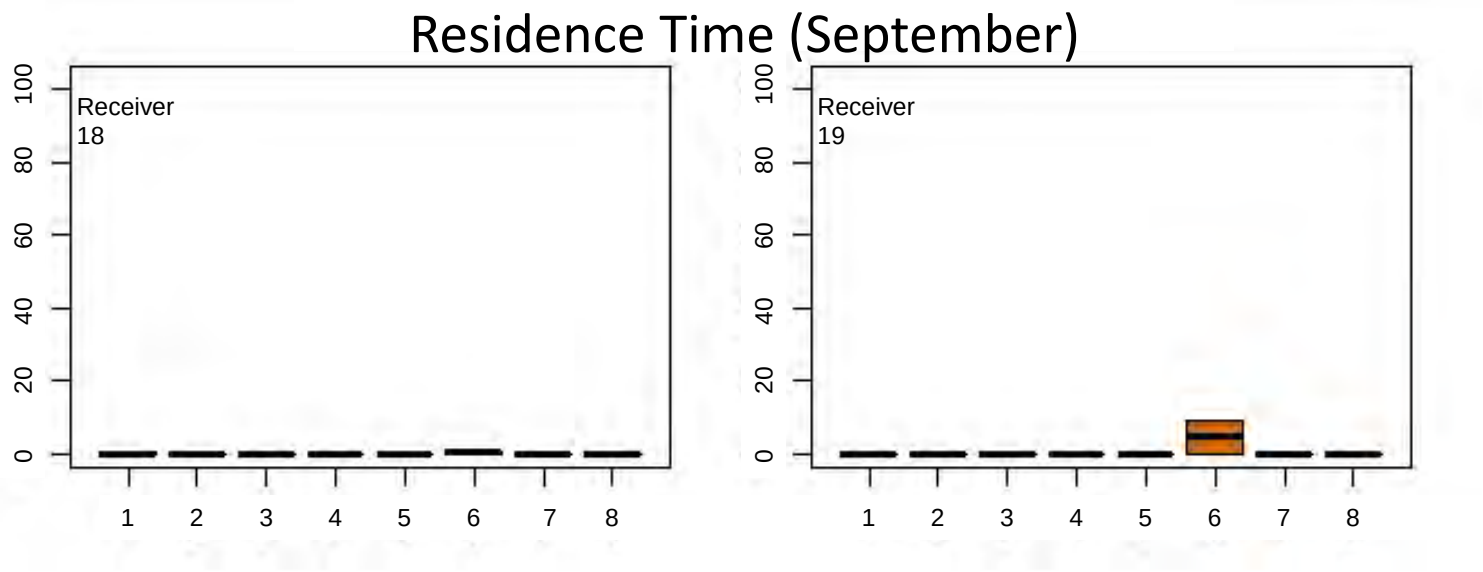
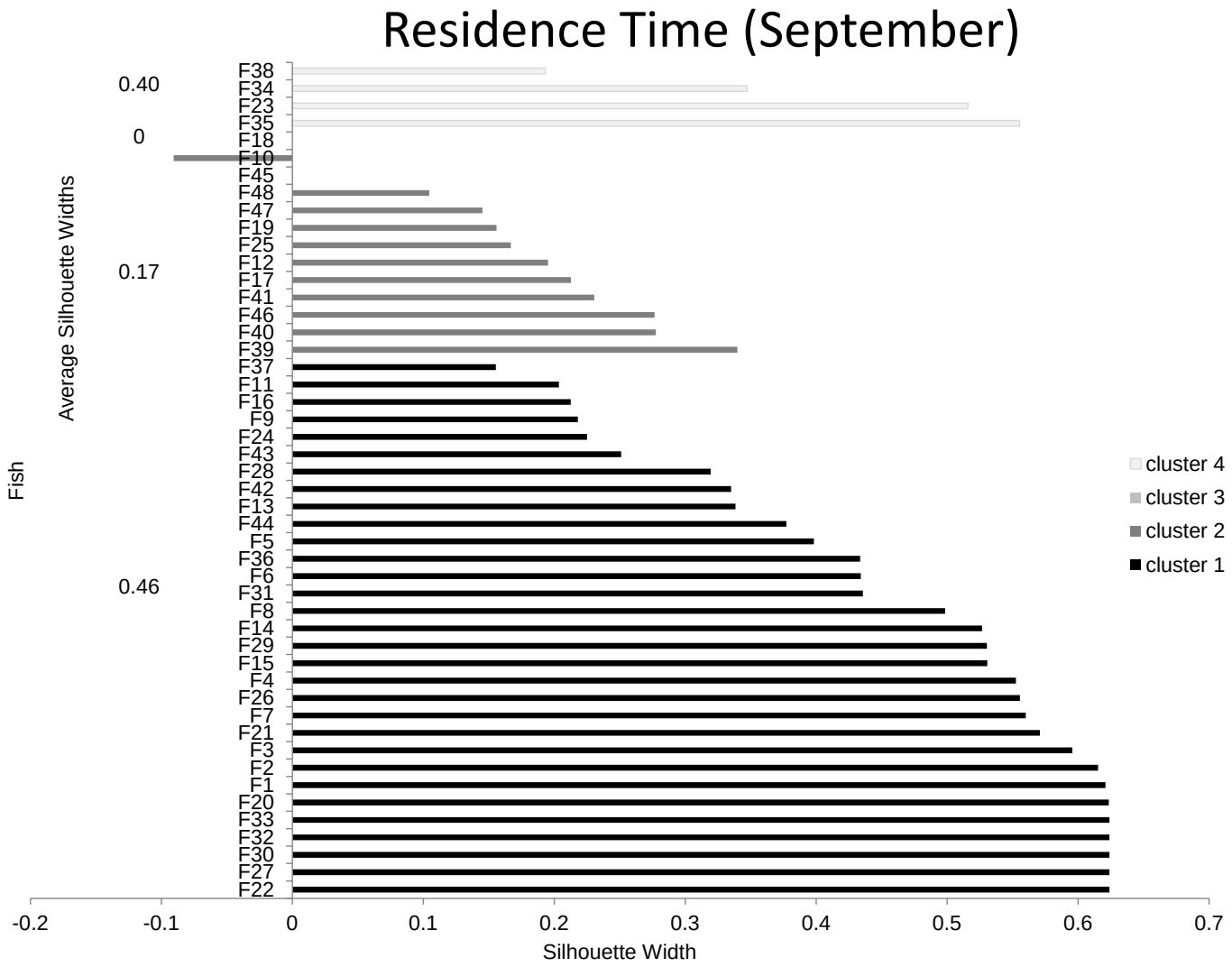
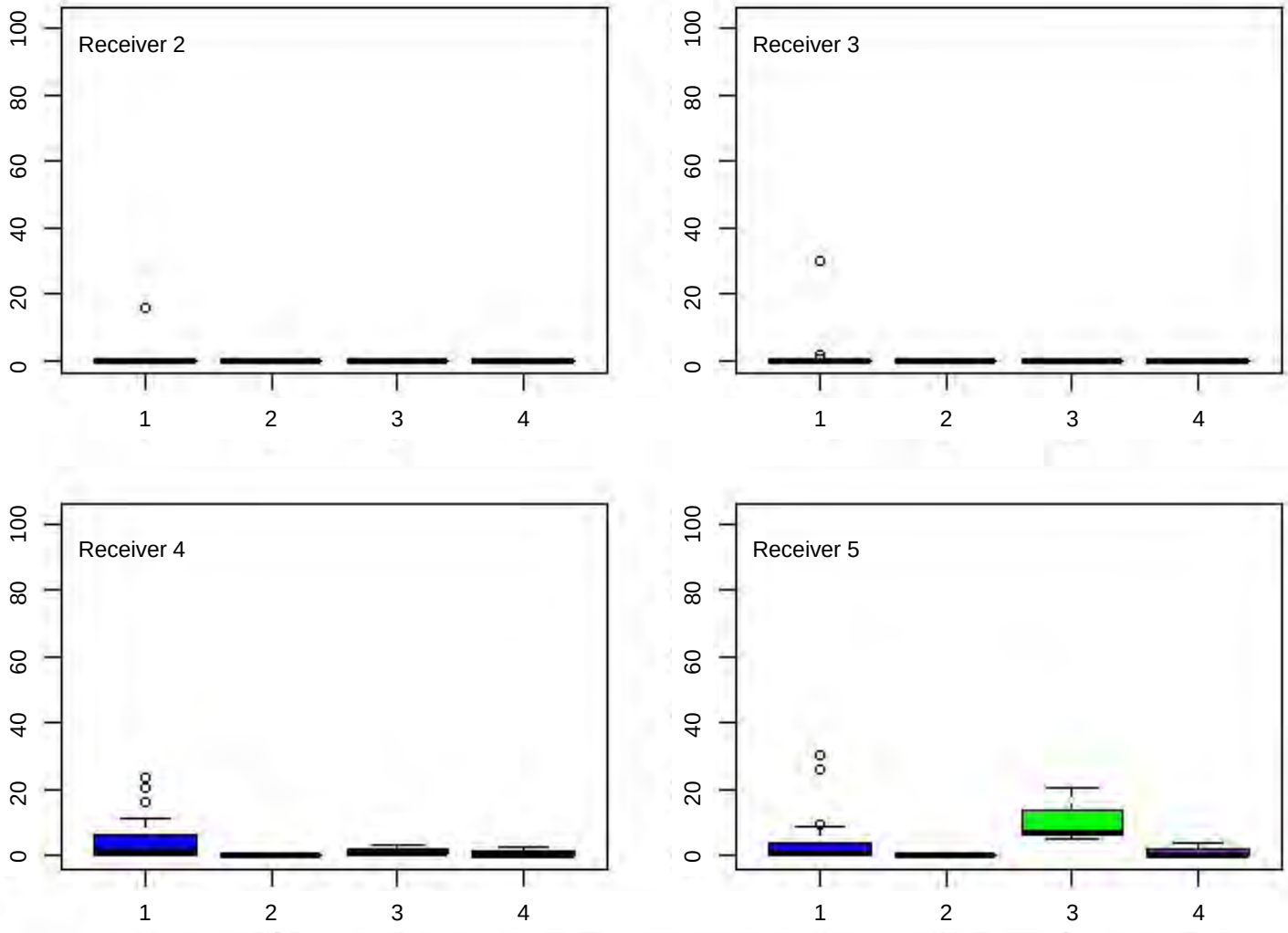


Chapter 2 Appendix Figure 22



Chapter 2 Appendix Figure 23

Residence Time (October)



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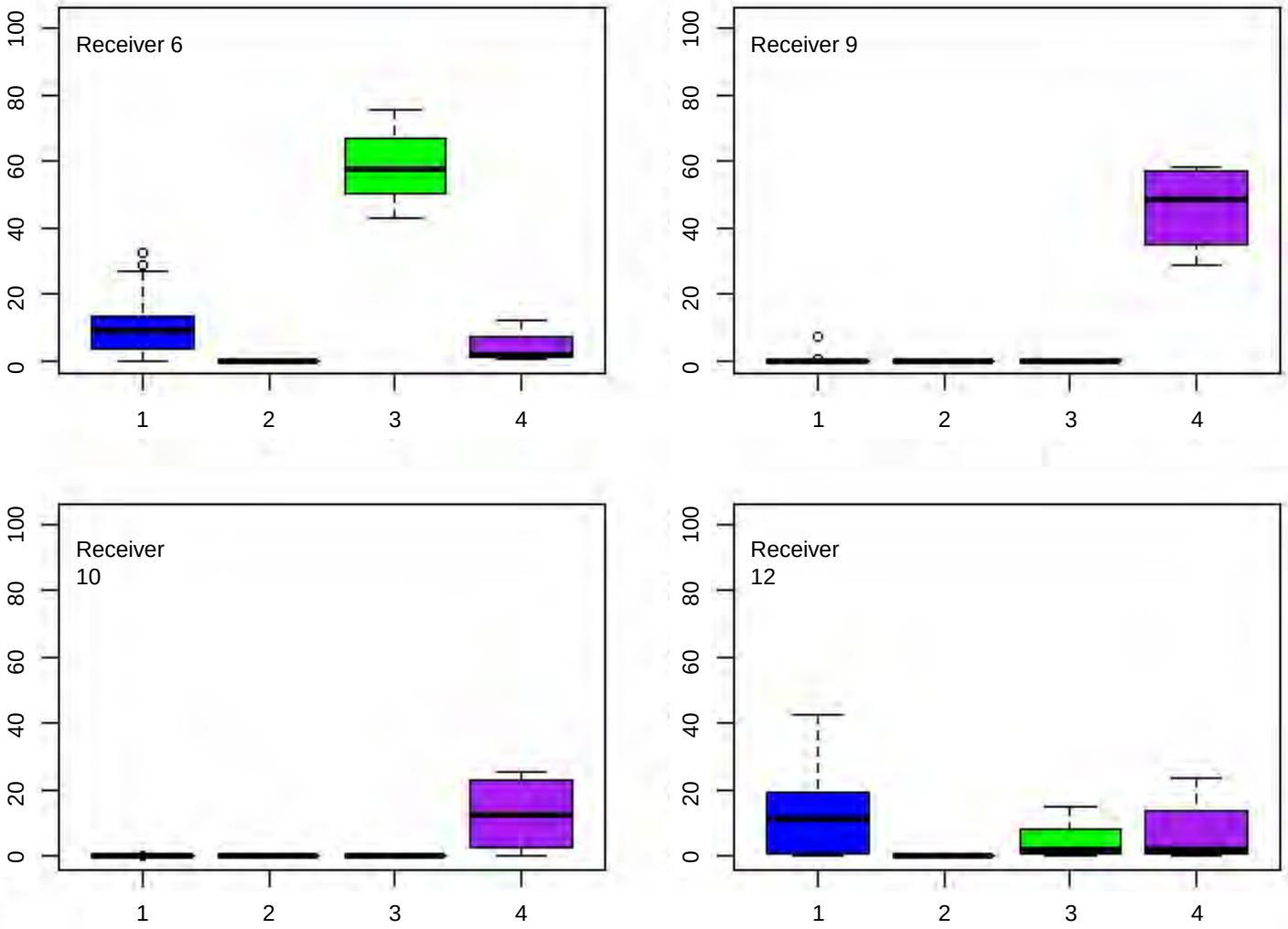

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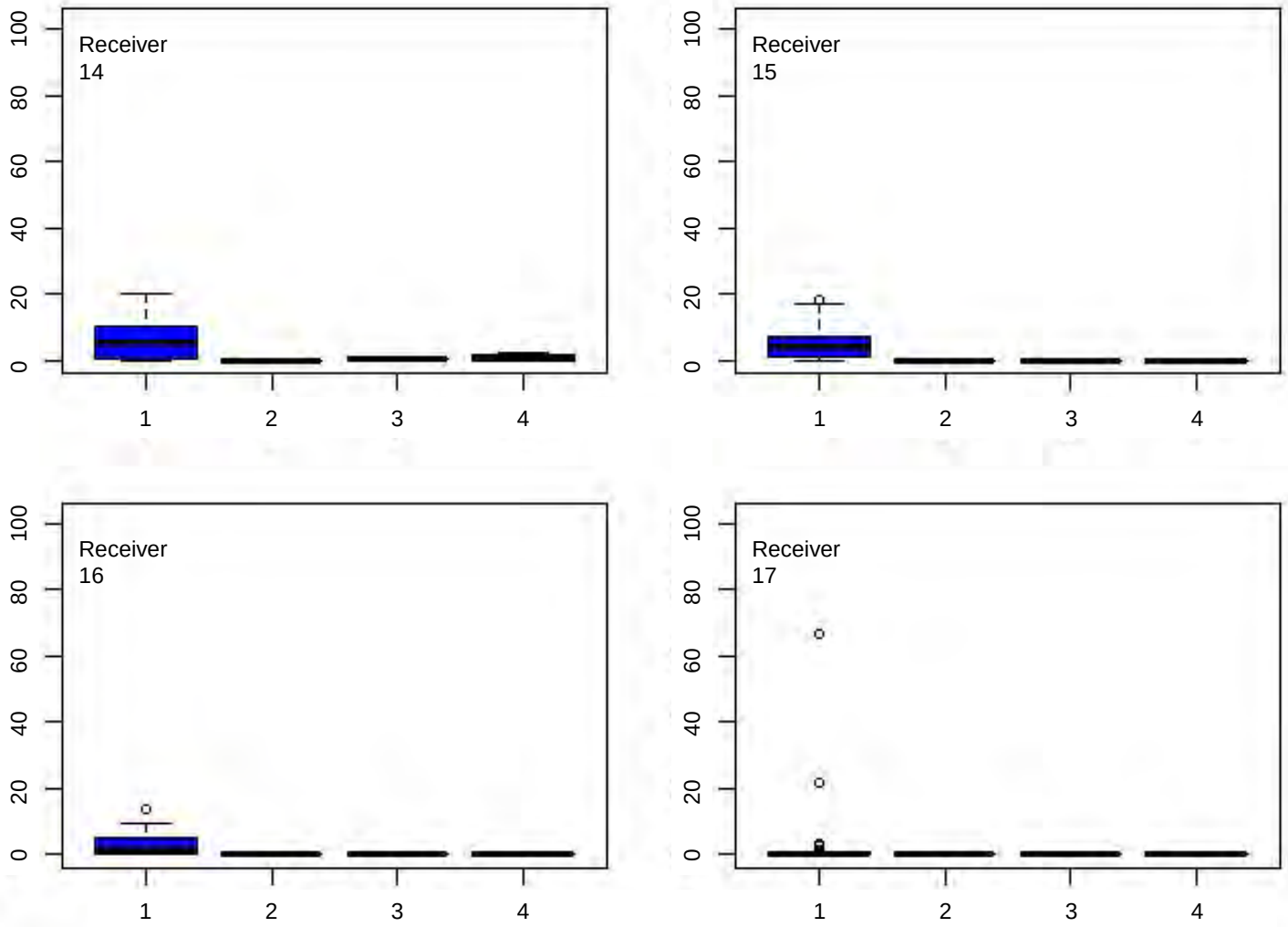

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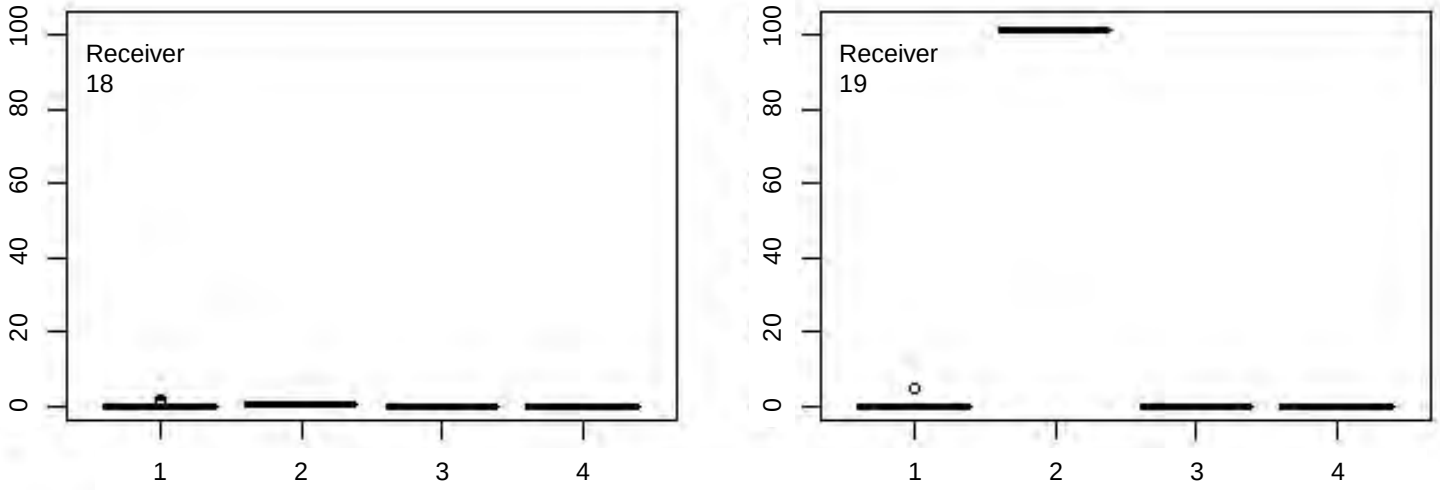
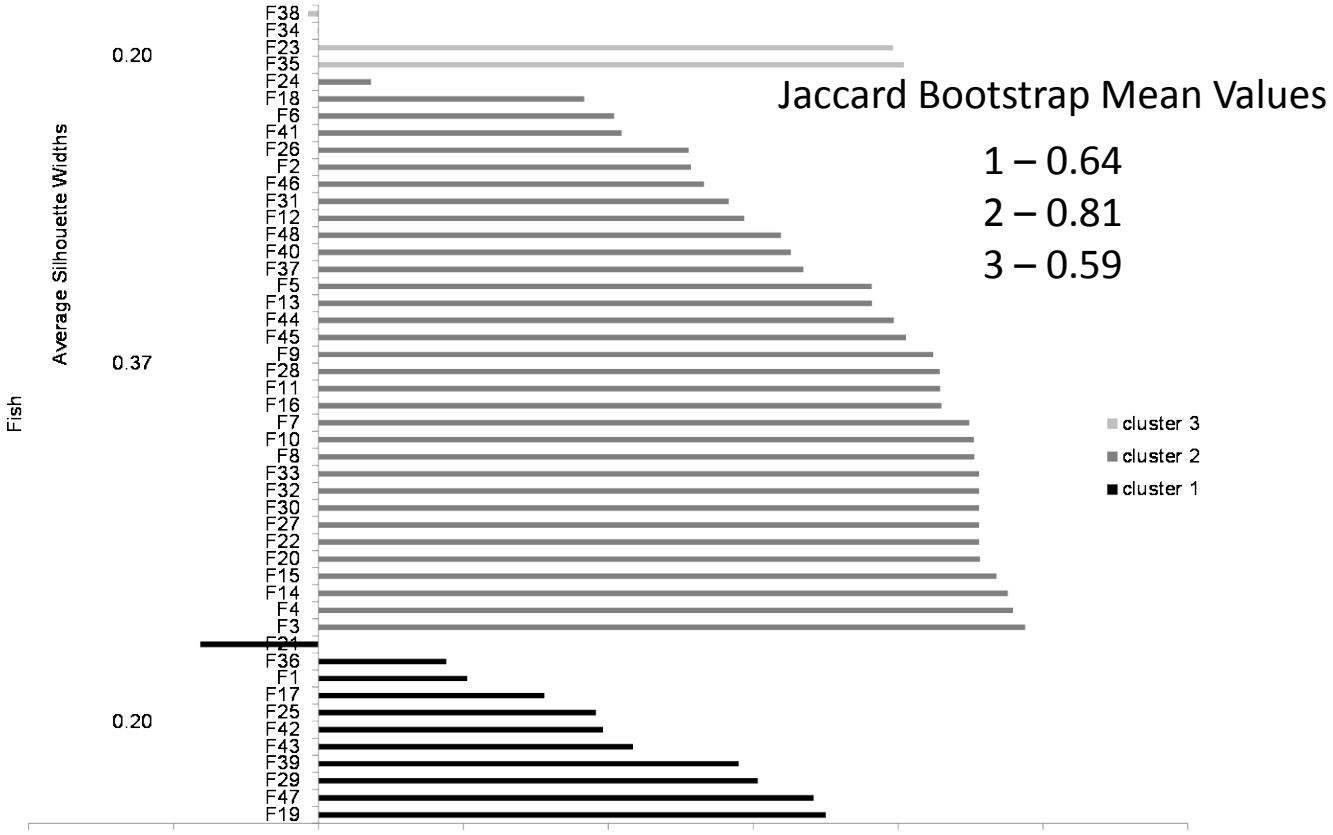


Chapter 2 Appendix Figure 27

Residence Time (November)



Chapter 2 Appendix Figure 28

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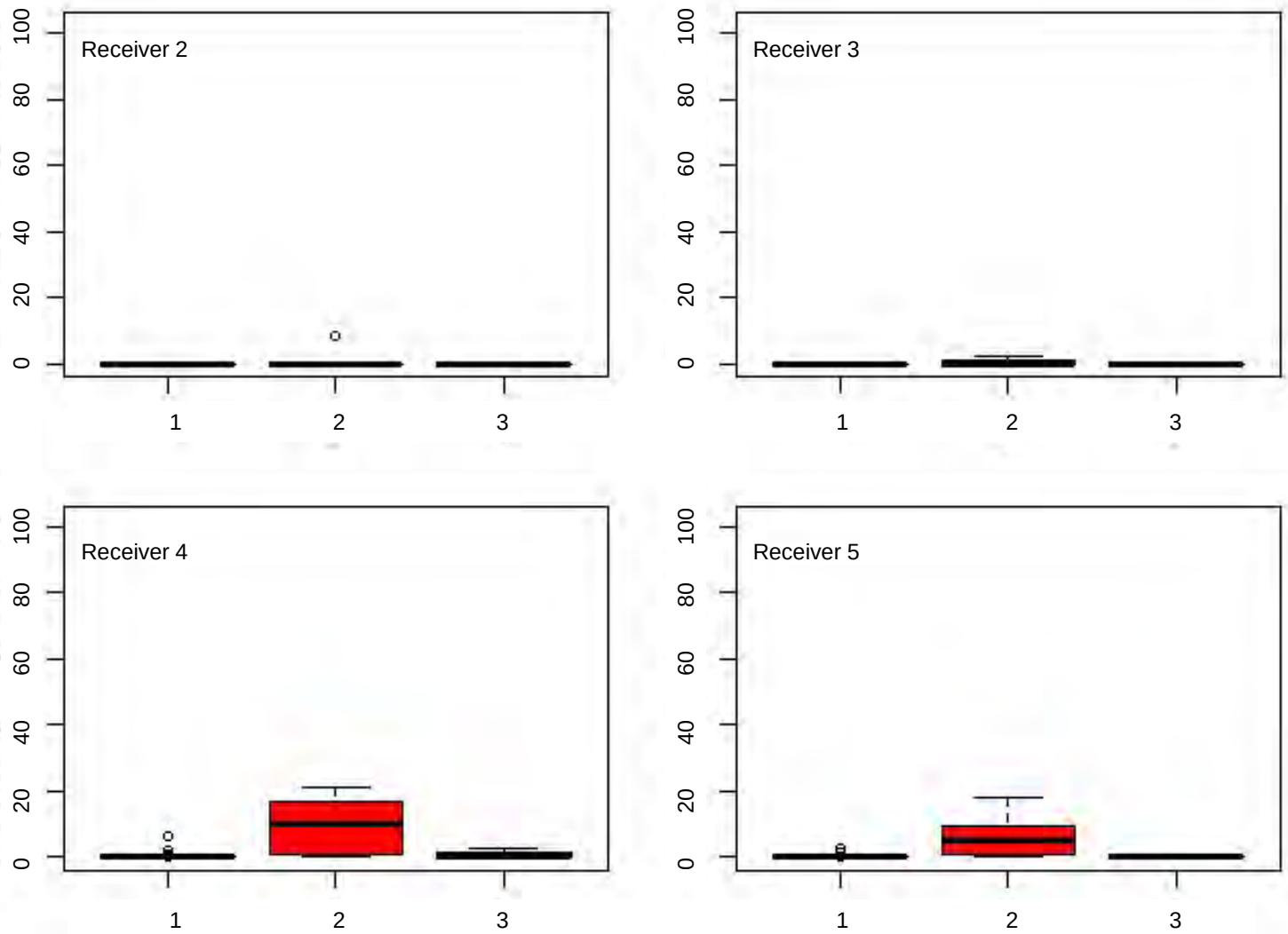

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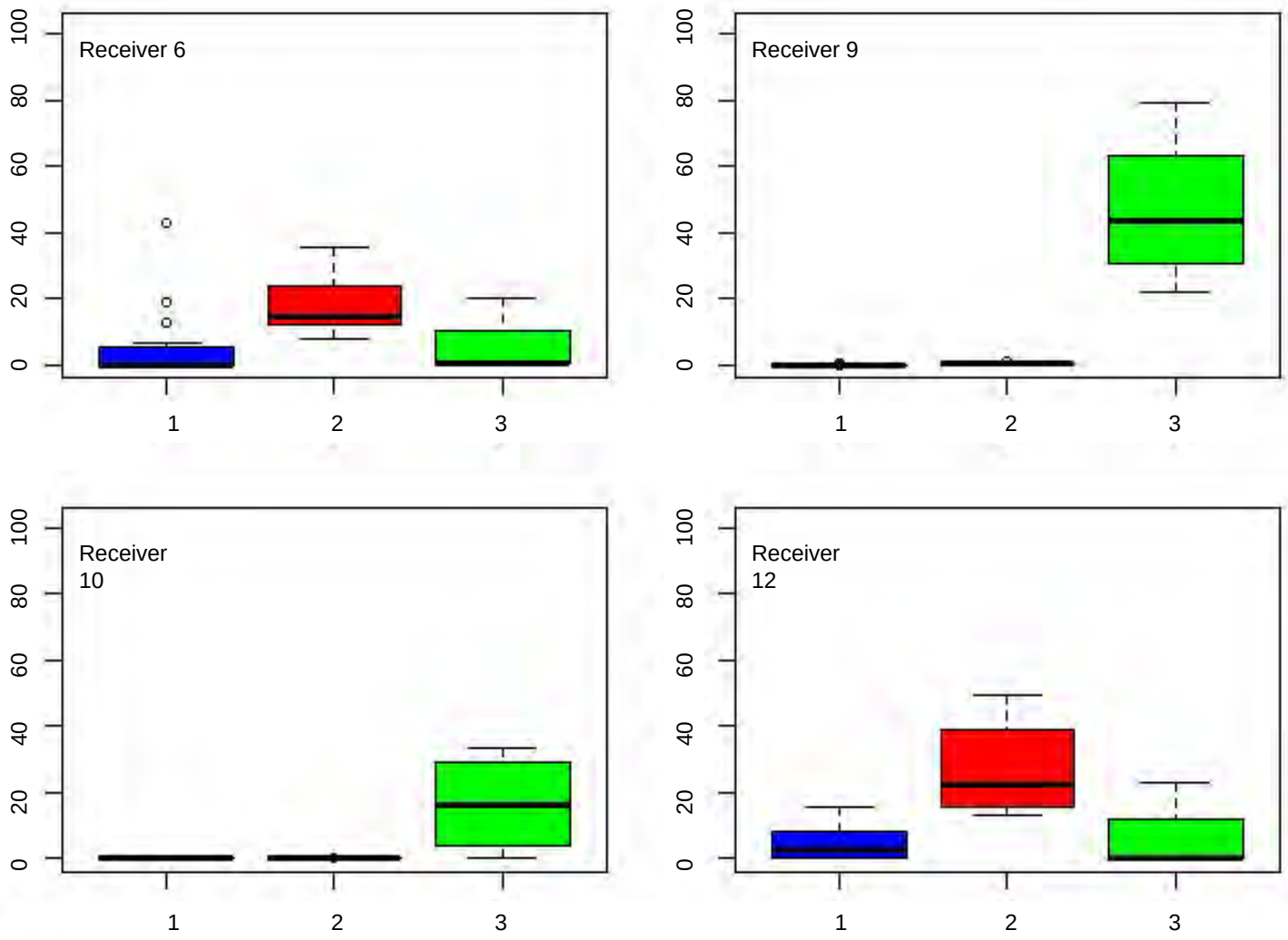
Residence Time (November)



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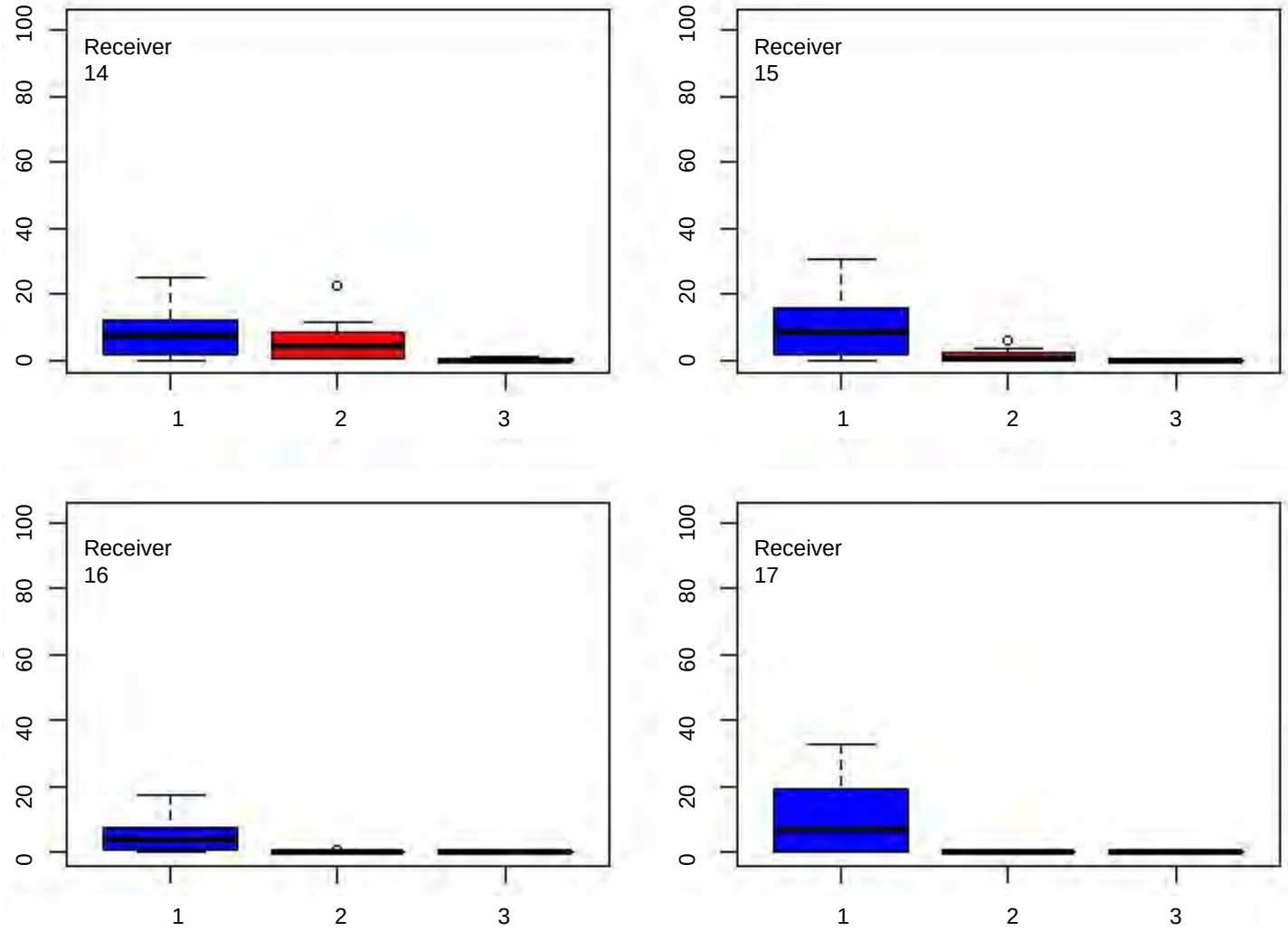
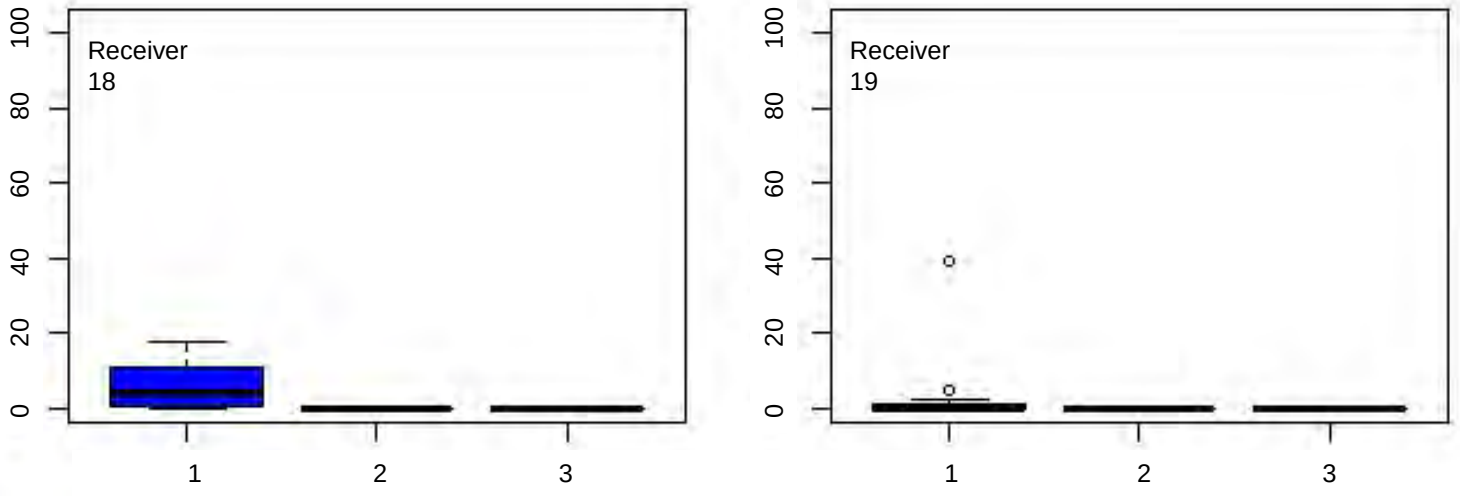
Residence Time (November)



Chapter 2 Appendix Figure 31

Residence Time (November)



Chapter 2 Appendix Figure 32

ENVIRONMENTAL CORRELATES OF BLUE CATFISH DISTRIBUTION IN MILFORD RESERVOIR (OBJECTIVE 6)

INTRODUCTION

Overview. Knowledge of where fish are located influences the effectiveness of fish ecology and fisheries management efforts. Specifically, analyses that are needed to develop and maintain productive sport fisheries (e.g., mortality, recruitment, age, growth, and diet) require some knowledge of fish distribution (Hubert 1999; Millspaugh and Marzluff 2001). Mobility of fish complicates distributional patterns. Because fisheries gear is inefficient, traditional sampling methods provide few comprehensive distributional datasets. Thus, more data on fish distribution will assist research and management. Previously, environmental professionals who collected field data had few options for identifying where fish were located. With the advent of sophisticated fish tracking tools, improved approaches to this problem are now available. Here we use acoustic tags and a manual tracking survey to provide detailed distributional data about Blue Catfish *Ictalurus furcatus* and associated environmental correlates of their distribution.

Blue Catfish. Blue Catfish are native to large rivers (Cross 1967). As a popular sport fish, Blue Catfish have been successfully introduced to reservoir systems and are an important species for many agencies (Schmitt and Shoup 2013). However, they remain the least studied of the ictalurid catfishes (Boxrucker 2007). While angler interest in trophy catfishing is high (Arterburn et al. 2002), lack of information about Blue Catfish continues to hinder the development of trophy catfishing opportunities by state agencies (Schmitt and Shoup 2013).

Relatively little peer-reviewed literature exists on Blue Catfish distribution, movements, habitat use, and ecology. A review of three environmental science literature data bases (i.e., Web

of Science, Wildlife and Ecology Studies Worldwide, Environmental Sciences and Pollution Management), technical committee websites for the Ictalurid Technical Committees (North Central Division-American Fisheries Society, Southern Division-American Fisheries Society), and published specialty symposia on catfish (Catfish 2000, Catfish 2010) revealed only 437 peer reviewed publications on Blue Catfish. Of these, 59% (*n*=257) addressed sub-organismal or non-field topics such as aquaculture, genetics, physiology, disease, or parasites (*Chapter 3 Figure 1*). Another 28% (*n*=122) addressed management issues, sampling techniques, and monitoring. Only 13% (*n*=57) addressed ecological topics such as feeding or habitat. Of these, only a subset report original data on habitat (*n*=9).

The literature on Blue Catfish distribution includes taxonomic keys (e.g., Lagler 1961; Cross 1967; Jenkins and Burkhead 1994; Cross and Collins 1995) and review articles (Graham 1999). Original peer-reviewed habitat research also exists on Blue Catfish in rivers (e.g., Graham and DeiSanti 1999; Jackson 1999; Garrett 2010; Garrett and Rabeni 2011; Miranda and Kilgore 2011) and reservoirs (e.g., Fischer et al. 1999; Edds et al. 2002; Grist 2002; Bartram et al. 2011).

Below, we briefly review some of this literature as a background for our study and to justify our choice of abiotic and biotic variables. Factors that may influence Blue Catfish distribution includes temperature, dissolved oxygen, channel characteristics, depth, flow velocity, and food resources. Temperature influences fish distribution in general and Blue Catfish in particular. Because fish are ectotherms, consumption and growth are related to temperature (Watz and Piccolo 2011). Blue Catfish increase growth rates in summer when temperatures are 20-28 ^{o}C (Grant and Robinette 1992). Although optimal temperature for Blue Catfish, when food is unlimited, has been reported as 26-29 ^{o}C (Wyatt et al. 2009), Blue Catfish use the lower end of this range in summer (26 ^{o}C, Grist 2002). For example, Blue catfish in Lake

Norman selected mean temperatures of 22.7 ºC (range 22-26 ºC) in summer and fall (Grist 2002). In general, fish will not consume food or grow well at extremely high or low temperatures, but will have optimal growth at some intermediate values (Rushworth et al. 2011).

Dissolved oxygen levels can also impact catfish distribution (Fischer et al. 1999; Graham 1999; Baras and Laleye 2003). Dissolved oxygen below 4 ppm can stress Blue Catfish (Wyatt et al. 2006). Blue Catfish rarely occur in locations with low dissolved oxygen and are often found at high dissolved oxygen concentrations (Grist 2002). Specifically, Blue Catfish in Lake Norman selected mean dissolved oxygen concentrations of 7.1 ppm (range 5.1 – 8.9 ppm, Grist 2002).

Blue Catfish use channels (e.g., Fischer et al. 1999; Jackson 1999; Edds et al. 2002; Grist et al. 2002; Garrett and Rabeni 2011), are affected by depth (e.g., Graham and DeiSanti 1999; Edds et al. 2002; Fischer et al. 2002; Grist et al. 2002; Miranda and Kilgore 2011), and may select specific flow velocities (e.g., Graham and DeiSanti 1999; Tripp et al. 2011). Specifically, Blue Catfish often occur near channels in rivers (Garrett and Rabeni 2011), near shorelines in rivers (Miranda and Kilgore 2011), and in open waters, channels, or tributary arms of reservoirs (Burr and Warren 1986, Edds et al. 2002).

Blue Catfish eat fish and invertebrates (e.g., zooplankton, terrestrial insects, aquatic insects, freshwater mussels, zebra mussels crayfish, clams; Brown and Dendy 1961; Minckley 1962; Perry 1969; Graham and DeiSanti 1999; Graham 1999; Edds et al. 2002; Grist 2002; Magoulick and Lewis 2002). Small Blue Catfish (100 mm) eat invertebrates and some fish but larger Blue Catfish (300+mm) eat mostly fish and larger invertebrates (Edds et al. 2002).

Abiotic and biotic conditions can interact to determine habitat use. For example, physical conditions can change the success rate of predation for fish in general. Flow conditions can disorient prey (Koehl 1984) and variation in bathymetry can concentrate prey (Flebbe and Dollof

1995), allowing for more efficient predation. However, increased flow velocity can also increase the energetic requirements of fish. Thus, benefits and consequences of current velocity for feeding needs to be considered both within and across habitats.

Summary of Variables that May Affect Distribution. In the literature reviewed above, three groups of variables have been consistently suggested to influence Blue Catfish distribution. The first group of variables measured are physicochemical conditions that occur at specific point locations, and are often collectively referred to as microhabitat variables (e.g., temperature, dissolved oxygen, slope, depth, flow velocity). A second group of macrohabitat variables characterize physical conditions at a larger spatial scale (e.g., distance to channel, distance to shore, geographic region, drop-offs), A third group of variables are biotic factors such as food resources (e.g., fish prey, invertebrate prey, productivity).

*Goals***.** For this chapter, we had three goals. First, we quantified the spatial distribution of acoustically tagged Blue Catfish with a monthly, 57-site acoustic tracking survey. Second, we summarized spatial distribution of microhabitat variables (e.g., temperature, dissolved oxygen, depth, slope, flow velocity), macrohabitat variables (e.g., distance to channel, distance to shore, region of reservoir as defined by river mile, drop-offs), and biotic variables (fish prey, invertebrate prey, Secchi depth as an indicator of productivity). Third, we graphically and statistically examined univariate and multivariate relationships between Blue Catfish distribution and these abiotic and biotic variables using multiple regression and Akaike Information Criteria (AIC) model selection.

METHODS

Study System. Milford Reservoir (39°08'42"N, 96°56'54"W) is an impoundment of the Republican River (Dickinson, Clay, and Geary counties, KS) and is part of the Lower Republican watershed, KS. Milford reservoir has a surface area of 6,555 ha, 262 km of shoreline dominated by limestone cobble and boulders, an average depth of 6.7 m and a maximum depth of 19.8 m (Reinke 2001) (*Chapter 2 Figure 1).* For this study, Milford Reservoir was divided into five, similar-sized regions, based on stationary receiver locations described earlier (*Chapter 1, 2*). These regions include upper, upper middle, Madison Creek, lower middle, and lower reservoir areas (*Chapter 1 Figure 4*).

Overall Research Design. To identify where Blue Catfish were located and what environmental correlates influenced their distribution, we collected data on acoustically-tagged Blue Catfish detections and select abiotic and biotic conditions at 57 0.8 km^2 tracking sites (*Chapter 1 Figure 5).* Tracking sites were positioned to cover the maximum amount of surface area while preventing overlap among adjacent sites. We chose this design to quantify spatial heterogeneity, an important consideration in fish ecology (Scheiner and Willig 2008). The choice of 57 spatially-explicit sampling locations that covered the entire reservoir provided good resolution for quantifying Blue Catfish distribution, allowed us to construct detailed spatial maps of Blue Catfish and potential environmental correlates, and resulted in substantial statistical power for model selection using multiple regression.

Choice of Variables and Hypotheses. Based on the literature review above, we selected 12 variables to measure at each of the 57 sampling locations. These environmental correlates included microhabitat variables (temperature, dissolved oxygen, slope, depth, flow velocity); macrohabitat variables (distance to channel, distance to shore, river mile), and biotic variables (e.g., fish prey, invertebrate prey, productivity as measured by Secchi depth).

Hypotheses. We tested four sets of ecological and statistical hypotheses which combined the 12 variables identified above in different ways to allow a parsimonious examination of the relationship between these abiotic and biotic variables and Blue Catfish distribution per location In any use of multiple regression, the statistical goals are to (a) thoughtfully select variables of interest, (b) limit the number of regressors in any single multiple regression model to maintain statistical power, and (c) through *a priori* planning, limit the number of statistical models to reduce across comparison error rates. Our use of four sets of hypotheses accomplished these statistical goals. Hypothesis 1 tested the relative importance of local microhabitat variables (temperature, dissolved oxygen, depth, slope, flow velocity). Hypothesis 2 tested the relative importance of macrohabitat (distance to channel, distance to shore, river mile, and drop-offs). Hypothesis 3 tested significant general habitat variables outlined in hypotheses 1, 2. Hypothesis 4 tested the relative importance of biotic factors (numbers of gizzard shad, numbers of chironomids, and productivity as measured by Secchi depth.

Fish Tagging (Number, Size, Timing). In 2013, we targeted a common size of Blue Catfish in Milford Reservoir (about 400-600 mm) as determined from previous field assessments *(Chapter 2 Appendix 1*). To these common-sized fish, we added a limited number of smaller and larger Blue Catfish (*Chapter 1 Table 4*). On 3-5 June, 2013, we internally implanted 75 Blue Catfish with VEMCO 9 and V13 tags (mean fish size = 517 mm TL, range 343-1090, SE 17.8). Details of tagging are described in detail earlier in this report (*Chapter 1*).

Tracking Survey of Tagged Blue Catfish. In June through November 2013, tagged Blue Catfish were tracked with a VEMCO VR-100 manual receiver fitted with a VH-165 omni-directional hydrophone. At each tracking location centroid, the hydrophone was deployed from the side of a boat for 15 minutes to determine the number of individual Blue Catfish at that

location (*Chapter 1 Figure 5*. In the monthly survey, all tracking sites were visited within six consecutive sampling days. This design has been effective elsewhere (Kennedy et al. In review). In these previous studies, all unique tagged individuals at a location were detected within a 15 minute period. The focus for the manual survey was the habitat used by tagged Blue Catfish (*n*=57), not the behavior of individual fish. At select locations, stationary receiver and manual tracking data were compared.

After each survey, data from the manual receiver unit were downloaded. The number of unique individual tagged Blue Catfish at each location on each date was recorded. Because we used a standard method to survey an identical area across all locations, number of unique individuals at each of the 57 survey sites was used as the response variable for maps of fish distribution, scatterplots of fish distribution, and univariate and multivariate regressions. For mapping, visualizations, and statistical analysis, number of fish at each location was log-transformed to satisfy the assumptions of multiple regression analysis.

Timing of Environmental Correlate Data Collection. To relate Blue Catfish distribution (numbers of acoustically tagged fish detected within 15 min at each sample location) to potential environmental correlates, abiotic and biotic data were collected at all 57 tracking sites. Some variables were measured on a monthly basis [i.e., temperature, dissolved oxygen, number of gizzard shad (*Dorosoma cepedianum*), number of chironomid larvae, Secchi depth]. Other variables were measured once during the field season (i.e., depth, slope, water velocity, number of drop-offs, distance to the channel, distance to the shoreline, river mile).

Temperature and Dissolved Oxygen. Temperature and dissolved oxygen were measured at each manual tracking site at the same time as tagged fish were tracked. For these environmental variables, data were collected at the centroid of each tracking site. Temperature

and dissolved oxygen were recorded along each meter of the water column using a YSI Pro2030. For scatterplots, univariate, and multivariate regressions, temperatures and dissolved oxygen values, were measured at 2 m off the bottom.

Depth and Slope. At each manual tracking site, depth was quantified by taking a total of 200 depth measurements across two 1 km perpendicular transects, one transect oriented north-south and the other oriented east-west. Along these transects, depth measurements were taken every 10 m with a Hummingbird 1198c SI Combo unit. Slope was quantified by calculating the change in depth across every 10-m transect section. For scatterplots, univariate, and multivariate regressions, depth and slope were summarized as the mean of all measurements at a site. For statistical analysis, slope was log transformed to satisfy assumptions of regression analysis.

Flow Velocity. Current velocity was measured using an acoustic doppler current profiler system (SonTek/YSI RiverSurveyor M9 system). A custom transect line was determined for each site to ensure transects would best capture the latitudinal flow velocity through Milford Reservoir. For each tracking site, ArcMap 10.2.2 was used to draw a line that intersected the centroid of the tracking site, extended to both latitudinal banks of the reservoir, and intersected both banks closest to perpendicular. The line passing through each tracking site was 1km in length and was used as the transect line for the acoustic doppler current profiler. We measured flow velocity with the acoustic doppler current profiler twice along each transect to ensure accurate measurements. Velocity data were recorded at one second intervals. Water velocity data were collected at each manual tracking site one time throughout the field season from August to October, 2013. For scatterplots, univariate, and multivariate regressions, flow velocity was summarized as the mean of all measurements at a site.

Distance to Channel, Distance to Shoreline, River Mile. Spatial variables such as distance to channel, distance to shoreline, and river mile were calculated using ArcMap 10.2.2. To calculate distance from the channel, a channel line was drawn to represent the best known location of the channel from a Navionics bathymetric map. The distance of each site from the channel was calculated by measuring the shortest distance, by water, from the centroid of each tracking site to the channel line. The distance of each site from the shoreline was calculated by measuring the shortest distance, by water, from the centroid of each tracking site to the shoreline, including the dam. The river mile of each manual tracking site represented the distance of the site from the dam, measured along a line extending longitudinally through the center of Milford Reservoir. To measure river miles, 30 points were positioned along a line extending longitudinally through the center of Milford Reservoir. The distance of each point from the dam was measured along the center line (i.e., dam= 0 km). Then, each manual tracking site was assigned the river mile distance of the closest point along the centerline, measured from the centroid of each tracking site. All distance measures were made in kilometers. A single value was calculated for these three distance metrics at each site.

Drop-offs. The number of drop-offs at each site was quantified by calculating the number of slope values greater than 10cm/m. For scatterplots, univariate, and multivariate regressions, number of drop-offs at a site were summed. For statistical analysis, drop-offs were log transformed to satisfy the assumptions of regression analysis.

Secchi Depth. Secchi depth was measured using a 20-cm Secchi disk the center of each sample site each month. To identify how trends in Secchi depth were related to productivity, in August, 2014 we measured Secchi depth and simultaneously collected water samples at twenty locations positioned along a latitudinal gradient in Milford Reservoir, from the causeway to the

dam. Samples, collected in dark bottles, were immediately packed on ice in the field, and then kept in the refrigerator until samples were processed (< three days). In the lab, spectrophometric analysis was used to quantify corrected chlorophyll a concentration in water samples following methods outlined in Environmental Sciences Section (Environmental Protection Agency 1991). Relationships between Secchi depth and water quality parameters were calculated by regressing Secchi depth against total suspended solids, total inorganic solids, total organic solids, and cholorphyll a.

Numbers of Gizzard Shad. We estimated the abundance of gizzard shad at each tracking site by subsampling locations from each region (upper, middle, lower) and habitat type (tributary, channel without shoreline, channel and shoreline, shoreline without channel, midway between channel and shore) (n=1-3 per region-habitat). We subsampled because all sites could not have been sampled in a reasonable amount of time each month. We sampled gizzard shad using pulsed DC boat electrofishing (Miranda 2009) during a three-day period each month from July to October, 2013. The order in which sites were sampled was changed between months to prevent temporal bias in the sampling design. Electrofishing was started at the centroid of the tracking location and the boat was driven in a continuously expanding spiraling pattern for 10 minutes to capture fish in the most efficient way possible while covering the largest amount of area. Two netters collected, then counted, and measured gizzard shad. Numbers of gizzard shad were estimated for all manual tracking sites as follows. The average number of fish from sampled sites within each region and habitat type group was used to generate a Poisson distribution (a distribution that is defined by a single parameter in which the variance equals the mean). For each region-habitat distribution, 10 samples were drawn from this Poisson

distribution for each of our 57 tracking sites. The average of these 10 estimates of gizzard shad numbers was used to calculate a single gizzard shad estimate per site - time period.

Number of Chironomid Larvae. Chironomid larvae were quantified by filtering a sediment grab (i.e., 7 kg Ponar grab) collected at the center of each sampling site through a sediment sieve (Field Master 500 micron). Samples were collected monthly in June – October, 2013, at the same time as manual tracking.

Gastric Lavage. On July 11, August 22, and October 7, 2013, we collected Blue Catfish from Milford Reservoir to examine diets. Our goals were to connect specific prey taxa to Blue Catfish through diet, provide a link between spatial patterns of select prey and Blue Catfish distribution, and examine variation in diets across sites. Blue Catfish were collected using electrofishing. On each of the three sample dates (July 11, 2013, August 22, 2013, October 7, 2013), Blue Catfish diets were examined using gastric lavage. Gastric lavage is a nonlethal diet sampling method in which pressurized water is flushed into fish stomachs to force out contents (Ferry and Mather 2012). After stomach pumping, all Blue Catfish were allowed to recover then released back into the estuary. For each Blue Catfish, flushed prey items were bagged, stored on ice, and then frozen. In the laboratory, we identified prey (Ferry and Mather 2012). Three major prey categories dominated the diets: fish (mostly gizzard shad), zebra mussels, chironomid larvae. Most of the fish identified in Blue Catfish diets were gizzard shad. However, we leave this as a general “fish” category because many samples were well digested or only represented by a backbone. We also note a fourth, less common prey category, miscellaneous insects. We present the data as frequency of occurrence (number of individuals in a sample that have a given prey item). Frequency of occurrence is the preferred diet analysis method for a broad perspective on diet differences across space and time. Diet was only used to link Blue Catfish to specific

prey items. These data were not included in the multiple regression analysis (described below) because we did not have diet data for all sample sites and dates.

Statistical Analyses. Multiple linear regression (MLR) and an information-theoretic model selection approach were used to test relationships between Blue Catfish and the 12 explanatory variables described above (temperature, dissolved oxygen, slope, depth, flow velocity, distance to channel, distance to shore, river mile, fish prey, invertebrate prey, Secchi depth.

The resulting models were calculated using AIC_c, a model selection tool for small sample sizes (Burnham and Anderson 2011). Models that varied in the number of regressors (K) were ranked in ascending order by ΔAIC_c. Because both two and four AIC_c units have been used to identify top models, (source) models within 4 ΔAIC_c units were retained to ensure that all relevant models were included. For each model, the statistical significance of regressor coefficients (β) was tested with *F* tests ($P<0.05$). The model weight (ω) was calculated to measure importance for each model (Burnham and Anderson 2011). Traditional model-specific *P* values and adjusted R^2 were also reported. Homogeneity of variance and independence met MLR assumptions. Cook's D (< 1) and condition number (CN) (< 25) did not identify influential observations or multicollinearity (Quinn & Keough 2002; Graham 2003). Regression analysis and other statistics can only accommodate a single measure of each explanatory variable for each response variable, so the mean of five monthly samples (July-November) was used in regressions for all variables except dissolved oxygen. For dissolved oxygen, deviation from median was used to test if fish were aggregated at intermediate values. Deviation from median was only used when exploratory analysis identified a concave trend in the data.

How Data Are Presented. Below, we first show a spatial map of the distribution of Blue Catfish across all 57 locations. Then we review environmental correlates by hypothesis. For each hypothesis, we show the AIC table to identify which explanatory variables were statistically influential in explaining variation in Blue Catfish numbers across locations. We follow with scatter plots of the relationships between each variable and numbers of Blue Catfish to visualize the slope coefficient from the AIC table. Then we show spatial maps of explanatory variables across the 57 sample sites. Finally, we compare maps of the observed data to predictions from the best AIC multiple regression model to see if the best model correctly predicted Blue Catfish aggregations or incorrectly estimated Blue Catfish numbers.

RESULTS

Blue Catfish Distribution. Detections of Blue Catfish were not evenly distributed throughout the reservoir. Overall, Blue Catfish were not common in the six northern sample sites in the upper reservoir (*Chapter 3 Figure 2, green circles*), the lower reservoir sample sites especially near the dam (*Chapter 3 Figure 2, green circles*), and many of the samples sites within the central constriction (*Chapter 3 Figure 2, green circles*). Two zones of higher fish counts were seen. One aggregation occurred at the funnel in the upper middle region of the reservoir starting where the width starts to narrow and extended to just below the Madison creek confluence (*Chapter 3 Figure 2, yellow, orange, red circles*). The other smaller aggregation occurred on the western edge of the lower constriction (*Chapter 3 Figure 2, orange, red circles*). Within both aggregations, some sites had especially high numbers of fish (*Chapter 3 Figure 2, red circles*).

Hypothesis 1: Microhabitat. In hypothesis 1, we tested the relative importance of local microhabitat variables (temperature, dissolved oxygen, slope, depth, flow velocity). For all combinations of the five variables in hypothesis 1, six models had a ΔAIC < 4 (*Chapter 3 Table 1*). These models had *P* values < 0.001 and R^2=0.30-0.34. Consistently present and significant regressors (shown in bold) in these top models included temperature, dissolved oxygen, and slope (*Chapter 3 Table 1*). Temperature, deviation from median dissolved oxygen, and bathymetric slope had negative statistical slopes in the multiple regression (*Chapter 3 Table 1; P< 0.001*). At high values of temperature, few tagged Blue Catfish were detected (*Chapter 3 Table 1*; *P< 0.001; Chapter 3 Figure 3A).* Where high variation in dissolved oxygen occurred, few tagged Blue Catfish were detected (*Chapter 3 Table 1*; *P< 0.001; Chapter 3 Figure 3B).* At sites with a high bathymetric slope, few tagged Blue Catfish were detected (*Chapter 3 Table 1*; *P< 0.001; Chapter 3 Figure 3C).* Depth and flow were included in select top models but these regressors were not consistently significant (β was not different than 0) (*Chapter 3 Table 1; Chapter 3 Figure 3D-E).*

All five microhabitat variables tested in hypothesis 1 were heterogeneous across Milford Reservoir (*Chapter 3 Figure 4*). Temperatures were higher in the upper reservoir (*Chapter 3 Figure 4A, orange, red circles*). Some extreme temperatures also occurred in the lower reservoir (*Chapter 3 Figure 4A, orange, red circles*). However, moderate intermediate temperatures generally were present throughout much of the upper middle, and lower middle regions (*Chapter 3 Figure 4A, green, yellow circles*).

Low deviation from median indicates non-extreme conditions. Low values of this calculation for dissolved oxygen illustrated moderate or intermediate values of dissolved oxygen throughout the upper middle and lower middle reservoir regions (*Chapter 3 Figure 4B, green*

circles). In particular, the funnel and constriction above Madison Creek had intermediate values of dissolved oxygen (*Chapter 3 Figure 4B, green circles*). Extreme values of dissolved were most common at a few sites in the upper reservoir and throughout the lower reservoir (*Chapter 3 Figure 4B, orange, red circles*).

Slope or bottom unevenness was highly variable but tended to be lower in the upper reservoir (*Chapter 3 Figure 4C, green circles*) and greater in the constriction and lower reservoir (*Chapter 3 Figure 4C, orange, red circles).* The funnel above Madison Creek had both low and intermediate slopes (*Chapter 3 Figure 4C, green, yellow circles*). Extreme changes in bathymetry occurred near the dam (*Chapter 3 Figure 4C, orange, red circles).*

Not surprisingly, depth increased from the upper to the lower reservoir and was < 10 m in the upper and upper middle regions of the reservoir (*Chapter 3 Figure 4D, green, yellow circles*). Flow velocity was highly variable but was consistently high in the upper region and upper middle funnel as the reservoir narrowed above Madison Creek (*Chapter 3 Figure 4E, red, yellow circles*). Irregular high velocities occurred throughout the rest of the reservoir.

In summary, relative to microhabitat or local, site-specific variables, Blue Catfish aggregations occurred at the funnel that was formed as the reservoir constricted just above Madison Creek and to a lesser extent on the west bank of the lower constriction. Sites associated with this aggregation were characterized by intermediate temperatures, consistent and moderate dissolved oxygen levels, low slopes, intermediate depths, and intermediate to high flow velocities. In support of these patterns, scatterplots showed that the high numbers of Blue Catfish did not occur at extremely high temperatures (*Chapter 3 Table 1, β for temperature $P < 0.001$; Chapter 3 Figure 3A*), extreme variation in oxygen (*Chapter 3 Table 1, β for dissolved oxygen $P < 0.001$; Chapter 3 Figure 3B*), or extremely high bathymetric slopes (*Chapter 3 Table 1, β for*

slope, P< 0.001; Chapter 3 Figure 3C). In select models, numbers of Blue Catfish were associated with significant increases in flow (*Chapter 3 Table 1, β for flow, model 1, P< 0.001*; *Chapter 3 Figure 3E)*. The best model for hypothesis 1 predicted the observed high density Blue Catfish sites well (funnel and upper constriction) (*Chapter 3 Figure 5A, red, orange circles*), but also erroneously predicted high densities of Blue Catfish at low density sites in the lower constriction (*Chapter 3 Figure 5B).*

Hypothesis 2, Macrohabitat. Our hypothesis 2 tested the relative importance of four larger-scale macrohabitat features (distance to channel, distance to shore, river mile, and number of drop-offs). When all combinations of these four variables were considered, four models had a ΔAIC< 4 (*Chapter 3 Table 2; P < 0.001;* R^2*=0.39-0.41*). In these top models, distance to channel and river mile were consistently, statistically significant (*Chapter 3 Table 2; P < 0.001*). More tagged Blue Catfish were detected close to the channel (*Chapter 3 Table 2; P < 0.001; Distance to channel β < 0; Chapter 3 Figure 6A*). As distance from the dam increased, more tagged Blue Catfish were detected (*Chapter 3 Table 2; P < 0.001; β for River Mile > 0; Chapter 3 Figure 6C*). Distance to shore and numbers of drop-offs were present in a few top models but the slopes of these variables were not significantly different from zero (no statistical effect; *Chapter 3 Table 2; Chapter 3 Figure 6D*).

The characteristics that defined distance to channel and river mile showed obvious geographic patterns when mapped (*Chapter 3 Figure 7A-B*). Sites with a large number of drop-offs were restricted to the lower reservoir (*Chapter 3 Figure 7C, red, orange circles*), but sites with an intermediate number of drop-offs occurred throughout the middle regions of the reservoir (*Chapter 3 Figure 7C, yellow circles*). In summary, relative to macrohabitat, Blue Catfish were found close to the channel (*Chapter 3 Table 2; β for Distance to Channel <0; P<*

0.001; Chapter 3 Figure 6A) and away from the dam (*Chapter 3 Table 2; β for River Mile > 0; P< 0.001; Chapter 3 Figure 6C*). As with hypothesis 1, the our best multiple regression model correctly predicted Blue Catfish aggregations (*Chapter 3 Figure 8A, red, orange circles)* but also over predicted Blue Catfish numbers at some low density sites (*Chapter 3 Figure 8B*).

Hypothesis 3 – General Habitat. In our hypothesis 3, we combined significant regressors from the microhabitat and macrohabitat hypotheses (temperature, dissolved oxygen, slope, depth, flow, distance to channel, and river mile). Twenty seven models fit the data similarly, had ΔAIC < 4, P < 0.001, and R^2 =0.40-0.43 (*Chapter 3 Table 3*). The slopes of the regressors and the relationship between regressors and Blue Catfish numbers were the same as reported above (*Chapter 3 Table 3*) so we do not describe them again here in detail. Briefly, river mile continued to be significant in all models. Temperature, depth and distance to channel were significant in some models. Dissolved oxygen, slope, and flow velocity were not significant in any models (*Chapter 3 Table 3*). Although hypothesis 3 explained a little more variation in the data (R^2=0.43 vs R^2=0.34 or R^2=0.41; *Chapter 3 Tables1-3*), few new ecological insights were provided.

Hypothesis 4 – Biotic Variables. In hypothesis 4, we tested the relative importance of three biotic variables [numbers of gizzard shad, numbers of invertebrates measured as chironomids, and Secchi depth as a proxy for productivity (*Chapter 3 Table 4*)]. In this hypothesis, when all combinations of these three variables were considered, four models emerged that had < 4 ΔAIC, P< 0.001, and R^2=0.32-0.33 (*Chapter 3 Table 4*). For hypothesis 4, Secchi depth (a proxy for both productivity and turbidity) was a strong and consistent predictor of high catfish abundance (*Chapter 3 Table* 4). At sites with low Secchi (high chlorophyll a), many tagged Blue Catfish were detected (*Chapter 2 Table 4; β for Secchi <0; P< 0.001; Chapter 2 Figure 9C*). Numbers of fish and invertebrate prey were present in these top models,

but were not significantly related to Blue Catfish numbers (*Chapter 3 Table 4; Chapter 3 Figure 9A-B, P>0.05).*

Geographically, the distribution of Gizzard Shad and chironomids were highly variable across sites (*Chapter 3 Figure 10A*, B). Gizzard shad catch tended to be moderately high in the upper reservoir (*Chapter 3 Figure 10A; yellow, orange circles*), irregularly high on the east side of the constriction (*Chapter 3 Figure 10A; red circles*), and low in the lower reservoir (*Chapter 3 Figure 10A; green circles*). Chironomids were variable throughout the upper and middle regions of the reservoir with isolated locations of high abundance in the upper, upper middle and lower middle regions (*Chapter 3 Figure 10B, yellow, red, orange circles*). The lower reservoir had consistently low levels of these invertebrate prey (*Chapter 3 Figure 9B; green circles*).

Secchi/ Productivity Relationship A negative relationship was found between Secchi depth and total suspended solids (*Chapter 3 Figure 11A;* β*=-0.36,* R^2*=0.53, P=0.001*), inorganic solids (*Chapter 3 Figure 11B* β *=-0.25,*R^2*=0.48, P=0.001*), organic solids (*Chapter 3 Figure 11C;* β *=-0.11,*R^2*=0.64, P=0.001*), and corrected chlorophyll a concentration *(Chapter 3 Figure 11D;* β *=-0.0004,*R^2*=0.32,P=0.001).* These data suggest that reductions in Secchi depth were related to both suspension of inorganic material, organic solids, and primary productivity.

Secchi depth was the only variable with a biotic association that was quantitatively related to Blue Catfish density (*Chapter 3 Table 4; P< 0.001).* Secchi depth was consistently low in the upper and upper middle reservoir corresponding to high productivity (*Chapter 3 Figure 10C, green circles*). Secchi depth decreased throughout the lower middle and lower reservoir (*Chapter 3 Figure 10C, green circles*).

We also observed a significant (albeit highly variable) relationship between Secchi depth and numbers of gizzard shad (*Chapter 3 Figure 12*; y = -0.6853x + 1.7739; R^2=0.405; P <

0.001). Elsewhere gizzard shad have been found in waters with high phytoplankton production (Sullivan 2009).The best model for hypothesis 4 predicted where high numbers of catfish might occur (*Chapter 3 Figure 13A*), but, like other models, erroneously identified some low density sites as aggregations (*Chapter 3 Figure 13B*).

Lavage Results. On each of three sample dates, we collected 63, 115, and 91 Blue Catfish from 4, 10, and 11 locations in Milford Reservoir (*Chapter 3 Table 5*). Blue Catfish were an average of 315 mm TL (range 212-703 mm TL, n=63), 316 mm TL (range 235-571 mm TL, n=115), and 390 mm TL (range 253-813, TL, n=91) on each date respectively. In July, 29 of 63 (46%) Blue Catfish had empty stomachs (*Chapter 3 Table 5*). In August, 71 of 115 (62%) Blue Catfish had empty stomachs (*Chapter 3 Table 5*). In October, 19 of 91 (21%) Blue Catfish had empty stomachs (*Chapter 3 Table 5*). Across sites, the number of empty stomachs was quite variable. For example, in July, Site 18 in the upper middle region had a lower incidence of empty stomachs (6%) than all other sites (sites 1, 23, 27 had 50, 58, 64% empty stomachs respectively) (*Chapter 3 Table 5*). In August, all but three sites had a high incidence of empty stomachs (> 50% empty) but across site variability was still evident (*Chapter 3 Table 5*). In October, Blue Catfish at most sites were feeding, but again across site variation in the incidence of empty stomachs existed (*Chapter 3 Table 5*).

In July, Blue Catfish fed on a mix of fish prey (mostly gizzard shad), zebra mussels, and chironomids (*Chapter 3 Figure 14A*). In September, fish prey virtually disappeared from Blue Catfish diets, some zebra mussels continued to be eaten, but chironomids dominated the diets (*Chapter 3 Figure 14B*). In October, chironomids continued to be an important prey item, but Blue Catfish again included fish prey in their diets (*Chapter 3 Figure 14*C). Relative to spatial variation, fish prey were most common in sites in the upper and upper middle regions (*Chapter 3*

Figure 14 A, C; U, UM). Chironomids dominated the diets in August and October (*Chapter 3 Figure 14B-C*), especially in the upper middle region (UM).

DISCUSSION

In Milford Reservoir, tagged Blue Catfish were highly aggregated. Across most of the reservoir, few or no tagged catfish were detected. Intermediate to high numbers of Blue Catfish were concentrated in two general locations. The primary aggregation was in the upper middle region funnel where the reservoir started to narrow and extended through to Madison Creek. In this location, 16 sample locations had intermediate or high numbers of tagged Blue Catfish (*Chapter 3 Figure 2, yellow, orange, or red circles*). A second, smaller aggregation occurred on the west bank of the lower constriction where three sample locations had intermediate or high numbers of tagged Blue Catfish (*Chapter 3 Figure 2, yellow, orange, or red circles*). Within these two general aggregations, additional across-site heterogeneity occurred at two sites (*red circles*) in the upper zone and one site (*red circle*) in the lower zone. A spatially-explicit sampling regime was key to identifying these patterns. The reservoir-wide array of 12-16 stationary receivers (*Chapter 2*) detected the upper funnel and confirmed that aggregations of fish persisted through time. However, the stationary receiver detections did not provide the same spatial resolution as the manual tracking survey. Although clustering of Blue Catfish is rarely examined with the resolution used in our study, aggregations of Blue Catfish have been documented in other studies (Grist 2002). Thus, locating these aggregations is essential for understanding patterns of Blue Catfish distribution and related environmental correlates.

This clustered distribution of tagged Blue Catfish was not driven by a single variable but instead was the result of a combination of variables. Below, we propose that abiotic and biotic

variables interact with Blue Catfish distribution through three hierarchical filters. Via filter one, tagged Blue Catfish avoided sites with extremely high temperatures, extremely low temperatures, and very low dissolved oxygen. Relative to the spatial distribution of temperatures, three general trends emerged across seasons that were supported by monthly trends. First, the lower region of the reservoir had both extremely warm (western bank) and extremely cool (eastern bank) temperatures that were typically the warmest and coolest temperatures found in the reservoir at any given time. Monthly extremes (< 22 ^{o}C, > 27 ^{o}C) persisted in the lower reservoir in June through July. Second, the northernmost end of the reservoir had sites with extremely warm temperatures in the summer and extremely cold temperatures in the fall (June and July: 26-29 ^{o}C; October 11-13 ^{o}C). Third, the funnel shaped area that occurred upstream of the reservoir constriction was warm but not too warm from June-August (about 26 ^{o}C) and had the warmest temperatures in the reservoir in September (23-24 ^{o}C). +Although optimal temperatures for Blue Catfish, when food is unlimited, is 26-29 ^{o}C (Wyatt et al. 2009), Blue Catfish use the lower end of this range in summer (26 ^{o}C, Grist 2002). Blue Catfish in Milford Reservoir were present at sites when monthly temperatures were around 26 ^{o}C and not present at sites where the monthly temperatures were extreme relative to Milford, i.e., cool < 21 ^{o}C or warm > 28 ^{o}C. This corresponds to an across month average of about 22-23 ^{o}C.

Others have quantified how Blue Catfish respond to temperatures in lab studies and the field (Grant and Robinette 1992; Fisher et al. 1999; Grist 2002). The focus of these temperature studies was an evaluation of average fish-temperature relationships, not an examination of response to extremes. Other studies have shown that Blue Catfish avoid low dissolved oxygen (Grist 2002). Although other studies quantify multiple environmental variables, most studies

interpret temperature and dissolved oxygen as if fish were assessing these variables independently. Our data suggest this is not the case.

When water quality (e.g., temperature and dissolved oxygen) values were not extreme, via filter 2, Blue Catfish were clustered near a combination of permanent physical features that caused heterogeneity in bathymetry. These physical features combined microhabitat variables (depth, slope) and macrohabitat variables (distant to channel, river mile). A complexity index that includes spatial discontinuities has been linked to fish aggregations elsewhere (Kennedy 2014, Kennedy et al. In Review). Previous studies have shown associations among Blue Catfish and depth (e.g., Driscoll et al. 1999; Graham and DeiSanti 1999; Edds et al. 2002; Fischer et al. 2002; Grist et al. 2002; Miranda and Kilgore 2011). Although Blue Catfish are associated with specific depths in individual studies, a clear and consistent association with depth conditions across studies (e.g., shallow depths, great depths, or any consistent depth) has not emerged. Blue Catfish often associate with macrohabitat features such as channels (e.g., Fischer et al. 1999; Jackson 1999; Edds et al. 2002; Grist et al. 2002; Garrett and Rabeni 2011), as we did. Although we did not find flow to be a consistently significant correlate of distribution, Blue Catfish distribution can be associated with higher flow velocity, especially in river systems (e.g., Graham and DeiSanti 1999; Tripp et al. 2011). Bathymetry at the microhabitat and macrohabitat scales may interact with flow velocity to provide adjacent feeding and resting sites. Individual physical variables are often cited as determinants of Blue Catfish distribution, but Garrett (2010) suggested that a complex interaction among flow velocity, local habitat structure, and depth existed for Blue Catfish in rivers. We concur that a combination of physical variables likely acts together. A cumulative index of bottom irregularities, as we proposed here, is novel way of thinking about habitat relationships for this species.

As a third filter, Blue Catfish may aggregate in areas with high productivity. Others have found an association between low Secchi values and Blue Catfish as we did here. For example, Blue Catfish are most abundant in reservoirs with Secchi depth <65cm (Bartram 2011). In Milford Reservoir, Secchi depth (related to primary productivity) was correlated to Blue Catfish distribution. Secchi was highest in the upper middle reservoir funnel through spring and summer. Blue Catfish may be indirectly tracking prey via chlorophyll a. Alternately, if they are not able to locate concentrations of highly mobile fish prey, Blue Catfish may be tracking the prey of the prey.

Adult Blue Catfish eat a combination of fish and invertebrate prey (e.g., Graham 1999; Edds et al. 2002; Grist 2002; Magoulick and Lewis 2002). In Milford Reservoir, the three most common prey groups were fish prey (predominately gizzard shad), zebra mussels, and chironomid larvae. We have quantitatively examined the relationship between diets and distribution. In Milford Reservoir, we observed substantial variation in Blue Catfish diets within a location, within a time period, across times, and across sample locations. Fish prey is highly variable. Blue Catfish may or may not be able to track this variation. Sampling predator and prey overlap on a finer time scale could address whether Blue Catfish are able to consistently locate concentrations of fish and invertebrate prey. However, linking diets to prey on the spatial and temporal scale that is required to assess this issue will be logistically difficult and will require the allocation of substantial sampling effort that may not be feasible for most research and management efforts.

Because our sampling design was extensive, i.e., a standard effort across a wide number of locations, for both prey and diet, high variability existed. Likely intensive sampling at a few locations is required to understand variability in diets. When this project started, we simply did

not know at which sites to concentrate sampling effort. However, now we know where and when to look for prey and diet differences. For better resolution, more diet samples would be required more frequently at fewer locations. These sample sizes should be chosen based on high or low Blue Catfish concentrations.

Our use of a combination of spatial maps, scatterplots, and multiple regression at 57 sample sites was a useful method for identifying potentially important variables. Multiple regression allowed us to identify consistently influential variables. Maps and scatterplots allowed us to confirm that these statistical relationships were ecologically meaningful. In summary, Blue Catfish in Milford Reservoir avoided physiological extremes to concentrate in select locations that have intermediate temperature and dissolved oxygen, heterogeneous bathymetry (that may result from a combination of physical features), and high productivity. Examining any one of these abiotic and biotic variables alone will not reveal the complex and interactive patterns that influenced Blue Catfish distribution.

Management Implications. Below, we provide several management implications. Most of these themes have been developed throughout this chapter. They are recapped here as a synthesis. Some applications are shared with the research reported in Chapter 2, others are unique to this chapter.

First, knowing how fish are distributed is a critical information need that underlies the effectiveness of all research and management activities. Without knowing fish distribution, many research and management activities are compromised including collection of data for the efficient management of populations (size, growth, survival, recruitment) and biological data collection (scales, otolith, diet, genetic, isotope samples). Existing data, collected using traditional sampling techniques, provides an inadequate view of fish distribution in general and

of Blue Catfish in particular. For effective research and management in Milford Reservoir and other systems, identifying detailed patterns of heterogeneity in Blue Catfish distribution is a priority. *Our sampling has identified the locations of Blue Catfish aggregations in Milford Reservoir. For Milford Reservoir, we have provided a spatially detailed map of distribution and abundance of tagged Blue Catfish*. Data from the stationary receiver array (Chapter 2) confirmed these patterns and extended the generality of this heterogeneity through time. However, the stationary receiver dataset did not provide the resolution provided by the manual survey. In the future, management surveys would benefit from sampling sites with high and low concentrations that we have identified here.

Second, this distribution of Blue Catfish was not consistent with the simplistic habitat predictions in the Blue Catfish literature. Specifically, at Milford Reservoir, Blue Catfish were not detected in deeper water, at greater slopes, at large drop-offs, or at faster current. At Milford Reservoir, Blue Catfish did not avoid the shallower upper reservoir. Nor were Blue Catfish always in the channel, near shore, or near a tributary. *Blue Catfish responded to a combination of macrohabitat and microhabitat variables (see management recommendation 3 below).* Identifying misconceptions and providing accurate information were important contributions of this study to research and management.

Third, trends were explained by a combination of variables rather than any single variable alone. We have proposed a sequence of filters to explain patterns. *We not only know where Blue Catfish are in Milford reservoir, we know why they are there. Blue Catfish are (1) avoiding locations that have physiological extremes (low temperatures, high temperatures, low dissolved oxygen), (2) where macrohabitat variables create intermediate scale bathymetric heterogeneity,*

and (3) with higher productivity. These correlates of distribution need to viewed as complex interactions rather than individual variables that act independently.

Fourth, the entire reservoir needs to be considered as an integrated, multi-scale unit. Regions and channels function were important, but so were local conditions. Most research and management efforts focus on microhabitat *or* macrohabitat. Our results show that both were important and interact to create patterns of distribution. Integrating these scales is essential.

Fifth, our data may be useful for habitat conservation planning. Environmental professionals face the challenge of prioritizing scarce funding and resources when planning conservation efforts for threatened ecosystems and populations (Wilson et al. 2009). The effect of conservation efforts can be maximized by defining target areas where the use of limited resources will have the greatest effect (Fehevari et al. 2012). Management effectiveness might be enhanced by targeting within reservoir areas where Blue Catfish aggregated, for example the upper middle reservoir funnel and Madison Creek.

Finally, consideration should be given to research design, especially what design is appropriate for a specific research or management question. The original motivations for this project were to (a) understand broad-scale distributional patterns of Blue Catfish throughout the largest reservoir in Kansas, (b) quantify egress out of the reservoir, and (c) broadly investigate general environmental correlates of reservoir wide distribution. The existence of two research approaches, extensive and intensive, is well established in the scientific literature. Most researchers acknowledge that eventually both extensive and intensive approaches are needed to address ecological and fisheries questions. However, logistically both approaches cannot be addressed at once. Based on the original motivations for the project (see above), an extensive sampling design (broad geographic and temporal scale relative to a wide variety of

environmental variables) was adopted. When our field study was initiated, little information existed on Blue Catfish distribution in Milford Reservoir. Even if we had wished to pursue the alternative intensive design (localized spatial coverage, high resolution, detailed time frame, detailed assessment of individual environmental variables), we simply would not have known where, when, and how to allocate effort. *Consequently, our data collection and analysis has focused on a broad spatial and temporal scale in which many environmental variables were examined in limited detail and has worked well for this scientific design*. If additional questions are asked about Blue Catfish distribution, a different data collection design might be warranted, but future data collection designs would need to be tailored to the specific research or management question. In summary, we have provided an excellent and substantial product for the investment.

Chapter 3 Table 1. Results are shown for a multiple regression for hypothesis 1, microhabitat. The response variable was Blue Catfish abundance (No). Explanatory variables included mean average temperature (°C), deviation from median dissolved oxygen (mg/L), mean slope (cm/m), mean depth (m), and mean flow velocity (m/s). Data were from a 57 site field survey conducted once a year for physical variables and monthly for all other variables. Multiple data points per sample site were averaged. Blue Catfish and slope were log transformed. Coefficients with significant F tests are bolded. Standard errors are in parentheses. Evaluation criteria include number of parameters (K), ΔAIC_c, Akaike weights (ω_i), model P, adjusted R^2, variance inflation factor (VIF) and condition number (CN).

No.	Temperature	DO	Slope	Depth	Flow	K	ΔAIC	ω	*P*	Adj R^2	VIF	CN
1	**-0.19** (0.06)	**-0.11** (0.03)	**-0.73** (0.20)		**3.27** (1.60)	6	0.00	0.27	0.00	0.34	1.09	1.09
2	**-0.27** (0.08)	-0.08 (0.04)	**-0.59** (0.21)	-0.02 (0.01)		6	0.31	0.23	0.00	0.34	1.99	1.99
3	**-0.25** (0.08)	**-0.09** (0.04)	**-0.65** (0.21)	-0.01 (0.01)	2.32 (1.78)	7	1.04	0.16	0.00	0.35	2.48	2.48
4	**-0.17** (0.06)	**-0.11** (0.04)	**-0.71** (0.20)			5	1.91	0.10	0.00	0.30	1.09	1.34
5	**-0.31** (0.08)		**-0.64** (0.21)	**-0.03** (0.01)		5	2.04	0.10	0.00	0.30	1.81	2.27
6	**-0.29** (0.08)		**-0.68** (0.21)	-0.02 (0.01)	1.69 (1.82)	6	3.61	0.04	0.00	0.30	2.21	2.21

Chapter 3 Table 2. Results of a multiple regression for hypothesis 2, macrohabitat, are shown. The response variable was Blue Catfish abundance (No). Explanatory variables included distance to channel (km), distance to shoreline (km), river mile (km), and number of drop-offs. Catfish count and numbers of drop offs were log transformed. Data were from a 57 site field survey conducted once a year for physical variables and monthly for all other variables. Multiple data points per sample site were averaged. Coefficients with significant F tests are bolded. Standard errors are in parentheses. Evaluation criteria include number of parameters (K), ΔAIC_c, Akaike weights (ω_i), model P, adjusted R^2, variance inflation factor (VIF) and condition number (CN).

No.	Distance to Channel		Distance to Shore		River Mile		Drop Offs		K	ΔAIC	ω	*P*	Adj R^2	VIF	CN
1	**-0.16**	(0.04)	-0.15	(0.09)	**0.02**	(0.00)			5	0.00	0.33	0.00	0.41	1.16	1.49
2	**-0.14**	(0.04)			**0.02**	(0.00)			4	0.42	0.26	0.00	0.39	1.03	1.19
3	**-0.12**	(0.04)			**0.02**	(0.00)	0.12	(0.08)	5	0.69	0.23	0.00	0.40	1.36	1.77
4	**-0.15**	(0.05)	-0.11	(0.10)	**0.02**	(0.00)	0.07	(0.09)	6	1.87	0.13	0.00	0.40	1.68	2.33

Chapter 3 Table 3. Results of a multiple regression for hypothesis 3, microhabitat and macrohabitat, are shown. The response variable was Blue Catfish abundance (No). Explanatory variables included mean average temperature (°C), deviation from median dissolved oxygen (mg/L), mean slope (cm/m), mean depth (m), mean flow velocity (m/s), distance to channel (km), and river mile. Catfish count, slope, and numbers of drop offs were log transformed. Data were from a 57 site field survey conducted once a year for physical variables and monthly for all other variables. Multiple data points per sample site were averaged. Coefficients with significant F tests are bolded. Standard errors are in parentheses. Evaluation criteria include number of parameters (K), ΔAIC_c, Akaike weights (ω_i), model P, adjusted R^2, variance inflation factor (VIF) and condition number (CN).

No.	Temp	DO	Slope	Depth	Flow	Channel	Mile	K	ΔAIC	ω	*P*	Adj R^2	VIF	CN
1		-0.07 (0.03)		**0.03** (0.01)			**0.03** (0.01)	5	0.00	0.08	0.00	0.43	2.45	2.85
2				**0.03** (0.01)			**0.04** (0.01)	4	0.76	0.05	0.00	0.40	2.28	2.64
3	**-0.19** (0.06)	-0.06 (0.03)					**0.02** (0.00)	5	0.81	0.05	0.00	0.42	1.22	1.57
4	**-0.20** (0.06)						**0.02** (0.00)	4	0.99	0.05	0.00	0.40	1.04	1.22
5	-0.13 (0.07)	-0.06 (0.03)				-0.08 (0.05)	**0.02** (0.00)	6	1.05	0.04	0.00	0.43	1.56	2.06
6	-0.10 (0.08)	-0.06 (0.03)		0.02 (0.01)			**0.03** (0.01)	6	1.15	0.04	0.00	0.43	4.85	4.32
7	-0.13 (0.07)					-0.08 (0.05)	**0.02** (0.00)	5	1.26	0.04	0.00	0.41	1.55	2.03
8		-0.07 (0.03)		0.02 (0.01)		-0.06 (0.06)	**0.03** (0.01)	6	1.43	0.04	0.00	0.43	4.48	4.27
9		-0.07 (0.03)		**0.03** (0.01)	1.51 (1.61)		**0.03** (0.01)	6	1.56	0.03	0.00	0.42	2.48	2.96
10	-0.11 (0.09)			0.02 (0.01)			**0.03** (0.01)	5	1.58	0.03	0.00	0.41	4.83	4.17
11		-0.06 (0.03)				**-0.13** (0.04)	**0.02** (0.00)	5	1.72	0.03	0.00	0.41	1.20	1.55
12				0.02 (0.01)		-0.07 (0.06)	**0.03** (0.01)	5	2.03	0.03	0.00	0.41	4.47	4.02
13						**-0.14** (0.04)	**0.02** (0.00)	4	2.15	0.03	0.00	0.39	1.03	1.19
14		-0.07 (0.03)	0.06 (0.24)	**0.03** (0.01)			**0.03** (0.01)	6	2.44	0.02	0.00	0.42	3.94	3.84
15	**-0.19** (0.06)	-0.06 (0.03)	-0.20 (0.24)				**0.02** (0.01)	6	2.58	0.02	0.00	0.41	2.00	2.46
16				**0.03** (0.01)	1.01 (1.63)		**0.04** (0.01)	5	2.76	0.02	0.00	0.40	2.37	2.82
17	**-0.20** (0.06)		-0.18 (0.24)				**0.02** (0.01)	5	2.83	0.02	0.00	0.40	1.78	2.26
18		-0.07 (0.03)		0.02 (0.01)	1.58 (1.61)	-0.07 (0.06)	**0.03** (0.01)	7	2.98	0.02	0.00	0.43	4.54	4.44
19			0.08 (0.25)	**0.03** (0.01)			**0.04** (0.01)	5	3.05	0.02	0.00	0.39	3.70	3.62
20	-0.13 (0.07)	-0.06 (0.03)	-0.17 (0.24)			-0.08 (0.05)	**0.02** (0.01)	7	3.12	0.02	0.00	0.42	2.08	2.51
21	**-0.19** (0.06)	-0.06 (0.03)			0.56 (1.60)		**0.02** (0.00)	6	3.18	0.02	0.00	0.41	1.38	1.79
22	-0.12 (0.07)	-0.07 (0.03)			1.02 (1.61)	-0.09 (0.05)	**0.02** (0.00)	7	3.21	0.02	0.00	0.42	1.60	2.24
23	-0.14 (0.07)		-0.15 (0.24)			-0.08 (0.05)	**0.02** (0.01)	6	3.37	0.01	0.00	0.41	1.86	2.29
24	**-0.20** (0.06)				0.15 (1.60)		**0.02** (0.00)	5	3.39	0.01	0.00	0.39	1.14	1.45
25		-0.07 (0.04)			1.26 (1.63)	**-0.14** (0.04)	**0.02** (0.00)	6	3.58	0.01	0.00	0.40	1.39	1.80
26	-0.13 (0.07)				0.58 (1.61)	-0.08 (0.05)	**0.02** (0.00)	6	3.63	0.01	0.00	0.40	1.60	2.15
27		-0.07 (0.03)	-0.12 (0.24)			**-0.13** (0.04)	**0.02** (0.01)	6	3.99	0.01	0.00	0.40	2.00	2.46

Chapter 3 Table 4. Results of a multiple regression for hypothesis 4, biotic, are shown. The response variable was Blue Catfish abundance (No). Explanatory variables included mean number of gizzard shad, mean number of chironomids, and mean Secchi depth (m). Data were from a 57 site field survey conducted once a year for physical variables and monthly for all other variables. Multiple data points per sample site were averaged. Coefficients with significant F tests are bolded. Standard errors are in parentheses. Evaluation criteria include number of parameters (K), ΔAIC_c, Akaike weights (ω_i), model P, adjusted R^2, variance inflation factor (VIF) and condition number (CN).

No.	Gizzard Shad	Chironomids		Secchi		K	ΔAIC	ω	*P*	Adj R^2	VIF	CN
1				**-0.40**	(0.08)	3	0.00	0.47	0.00	0.33	-	-
2	0.00 (0.00)			**-0.45**	(0.09)	4	1.15	0.27	0.00	0.33	1.37	1.78
3		-0.02	(0.03)	**-0.43**	(0.09)	4	2.01	0.17	0.00	0.32	1.31	1.69
4	0.00 (0.00)	-0.01	(0.03)	**-0.47**	(0.09)	5	3.32	0.09	0.00	0.32	1.63	2.10

Chapter 3 Table 5. For 15 sites in five regions of Milford Reservoir, for three sampling dates, shown are number of Blue Catfish lavaged, percent empty stomachs, and the frequency of occurrence of four prey types: fish, zebra mussels (ZM), chironomid larvae, and miscellaneous aquatic insects.

		July 11, 2013						August 22, 2013						October 7, 2013					
				FO						FO						FO			
Sites	Region	N	Empty (%)	Fish	ZM	Chironomids	Insecta	N	Empty (%)	Fish	ZM	Chironomids	Insecta	N	Empty (%)	Fish	ZM	Chironomids	Insecta
1	Upper	6	50	0.17	0.00	0.17	0.17	8	88	0.00	0.00	0.13	0.00	11	18	0.50	0.00	0.50	0.10
13	Upper Middle													19	21	0.40	0.00	0.40	0.10
16								4	50	0.00	0.00	0.50	0.00	4	25	0.00	0.00	0.80	0.00
18		16	6	0.81	0.06	0.06	0.06	15	93	0.00	0.00	0.07	0.00	6	17	0.17	0.00	0.67	0.17
19														12	25	0.30	0.00	0.40	0.20
20								15	60	0.07	0.07	0.33	0.00	12	0	0.10	0.00	1.00	0.00
58								15	93	0.00	0.00	0.07	0.00	10	30	0.10	0.00	0.50	0.10
23	Tribs	19	58	0.00	0.32	0.46	0.00	15	33	0.07	0.20	0.47	0.00	5	20	0.20	0.00	0.60	0.00
52								9	11	0.11	0.00	0.56	0.22						
25	Lower Middle							15	73	0.00	0.13	0.13	0.00						
27		22	64	0.00	0.00	0.32	0.09												
28								15	53	0.00	0.27	0.13	0.07	9	22	0.30	0.10	0.40	0.00
29								4	0	0.00	0.00	1.00	0.00						
38	Lower													2	100	0.00	0.00	0.00	0.00
44														2	0	0.00	0.00	0.50	0.50
Totals																			
Blue Catfish		63						115						91					
Empty (No)		29						71						19					
Empty (%)		46						62						21					

ENVIRONMENTAL CORRELATES OF DISTRIBUTION OF BLUE CATFISH IN MILFORD RESERVOIR (OBJECTIVE 6)

FIGURE CAPTIONS.

Chapter 3 Figure 1. Breakdown by topic of peer reviewed literature on Blue Catfish from three environmental science literature data bases (Web of Science, Wildlife and Ecology Studies Worldwide, Environmental Sciences and Pollution Management); technical committee websites for the Ictalurid Technical Committees (NCD-AFS, SD-AFS); and published specialty symposia on catfish (Catfish 2000, Catfish 2010). Numbers are percentages of 437 papers.

Chapter 3 Figure 2. Map of blue catfish relative abundances (No.) based on a manual 57 site acoustic tracking survey conducted monthly from July through November, 2013 in Milford Reservoir, KS. Data were the average of 15 min detection periods for each month. Data were log transformed.

Chapter 3 Figure 3. For the first hypothesis that tests the importance of five microhabitat variables, shown are scatterplots of Blue Catfish counts (No.) (Y) versus (A) average temperature (^{o}C) (X), (B) deviation from median dissolved oxygen (mg/L) (X), (C) mean slope (cm/m) (X), (D) mean depth (m) (X), and (E) mean flow velocity (m/s) (X). Catfish count and slope were log transformed. Each point represents a sample site (n=57). Blue Catfish numbers, temperature, dissolved oxygen, and flow velocity were averaged across July-November 2013.

Depth and slope were averaged for a site. The significance of these regression slope coefficients are shown in *Chapter 3 Table 1* (AIC Model selection on multiple regression models) where a bolded coefficient indicates a statistically significant slope.

Chapter 3 Figure 4. Maps of Milford Reservoir, KS showing (A) average temperature (^{o}C), (B) deviation from median dissolved oxygen (mg/L), (C) mean slope (cm/m), (D) mean depth (m), and (E) mean flow velocity (m/s). Data were from a 57 site manual survey conducted monthly July through November, 2013 (temperature, dissolved oxygen, flow) or once a field season (slope and depth). Slope was log transformed.

Chapter 3 Figure 5. Maps of (A) observed Blue Catfish abundance (No.) vs (B) Blue Catfish abundance (No.) predicted from the top multiple regression model for hypothesis 1, microhabitat in Milford Reservoir, KS July – November 2013*(Chapter 3 Table 1).* Data were from a 57 site survey.

Chapter 3 Figure 6. For the second hypothesis that tests the importance of four macrohabitat variables, shown are scatterplots of Blue Catfish counts (Y) versus (A) distance to channel (km) (X), (B) distance to shoreline (km) (X), (C) river mile (km) (X), and (D) number of drop-offs (X). Blue Catfish count and numbers of drop offs were log transformed. Each point represents a sample site (*n*=57). Blue Catfish were averaged across five months. The significance of these regression slopes are shown in *Chapter 3Table 2 (*AIC Model selection on multiple regression models) where a bolded coefficient indicates a statistically significant slope.

Chapter 3 Figure 7. Maps of Milford Reservoir, KS showing the importance of macrohabitat variables (A) distance to channel (km), (B) river mile (km) (X), and (C) number of drop-offs. Data were from a 57 site survey conducted once a field season July – November 2103. Number of drop-offs was log transformed.

Chapter 3 Figure 8. Maps of (A) observed Blue Catfish abundance (No.) vs (B) Blue Catfish abundance (No) predicted from the top multiple regression model for macrohabitat in Milford Reservoir, KS July - November 2013 *(Chapter 3 Table 2).* Data were from a 57 site survey.

Chapter 3 Figure 9. For the fourth hypothesis that tests the importance of three biotic variables, shown are scatterplots of Blue Catfish counts (No.) (Y) versus (A) mean number of gizzard shad (X), (B) mean number of invertebrates measured as chironomids (X), and (C) mean Secchi depth (m) (X). Blue Catfish count was log transformed. Each point represents a sample site (*n*=57). All data were averaged across months. The significance of these regression slopes are shown in *Chapter 3Table 4* (AIC Model selection on multiple regression models) where a bolded coefficient indicates a statistically significant slope.

Chapter 3 Figure 10. Maps of Milford Reservoir, KS showing the importance of biotic variables (A) mean number of gizzard shad (X), (B) mean number of chironomids (X), and (C) mean

Chapter 3 Figure 11. Relationship among Secchi depth and (A) Total Suspended Solids (mg/L), (B) Inorganic Solids (mg/L), (C) Organic Solids (mg/L), and (D) Corrected Chlorophyll a (mg/ml) for a longitudinal transects of water samples in Milford Reservoir. Sampling was

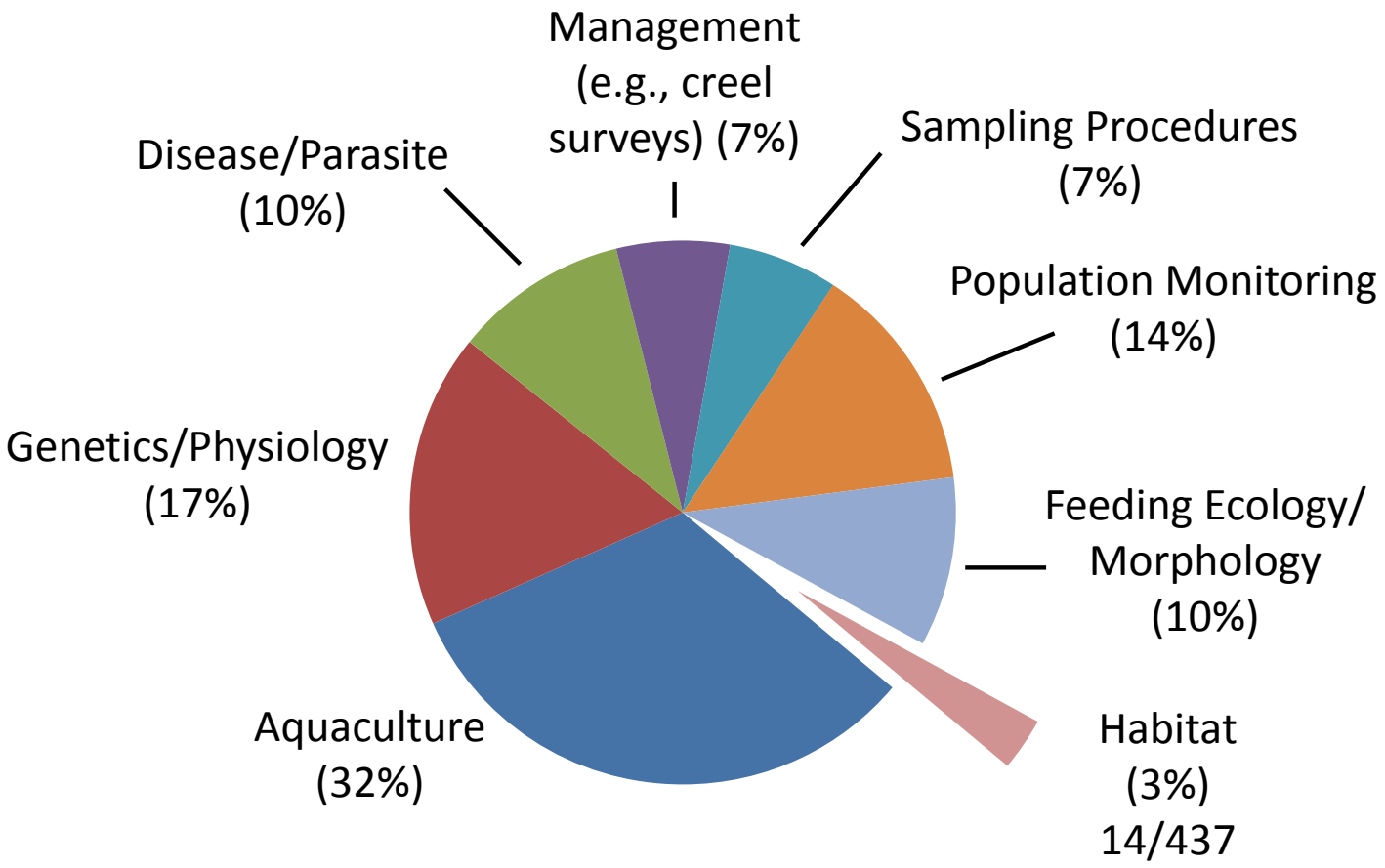
undertaken in August, 2014. Results of a linear regression are shown.

Chapter 3 Figure 12. Relationship among Secchi depth and gizzard shad numbers are shown. Gizzard shad numbers are logged. Results of a linear regression are shown

Chapter 3 Figure 13. Maps of (A) observed Blue Catfish abundance (No.) vs (B) Blue Catfish abundance (No.) predicted from the top multiple regression model for hypothesis 4, biotic in Milford Reservoir, KS July – November 2013*(Chapter 3 Table 1).* Data were from a 57 site survey.

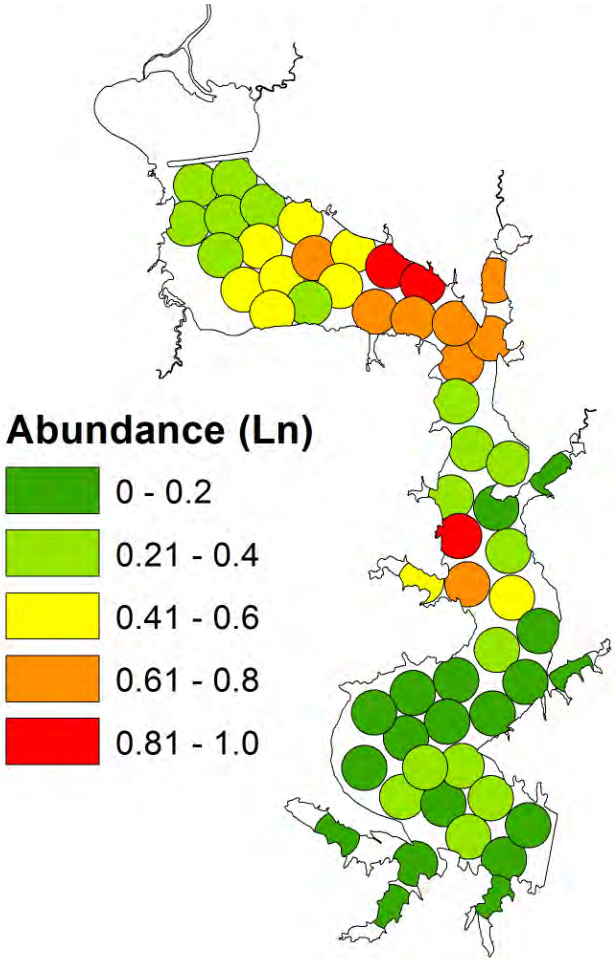
Chapter 3 Figure 14. Frequency of occurrence of fish prey, zebra mussels, and chironomids across 14 sites for (A) July 11, 2013, (B) August 22, 2013, and (C) October 7, 2013. The sites are divided into 5 regions: U= upper, UM = upper middle, T=tributaries, LM =lower middle, and L- lower.

Peer-Reviewed Literature – Blue Catfish



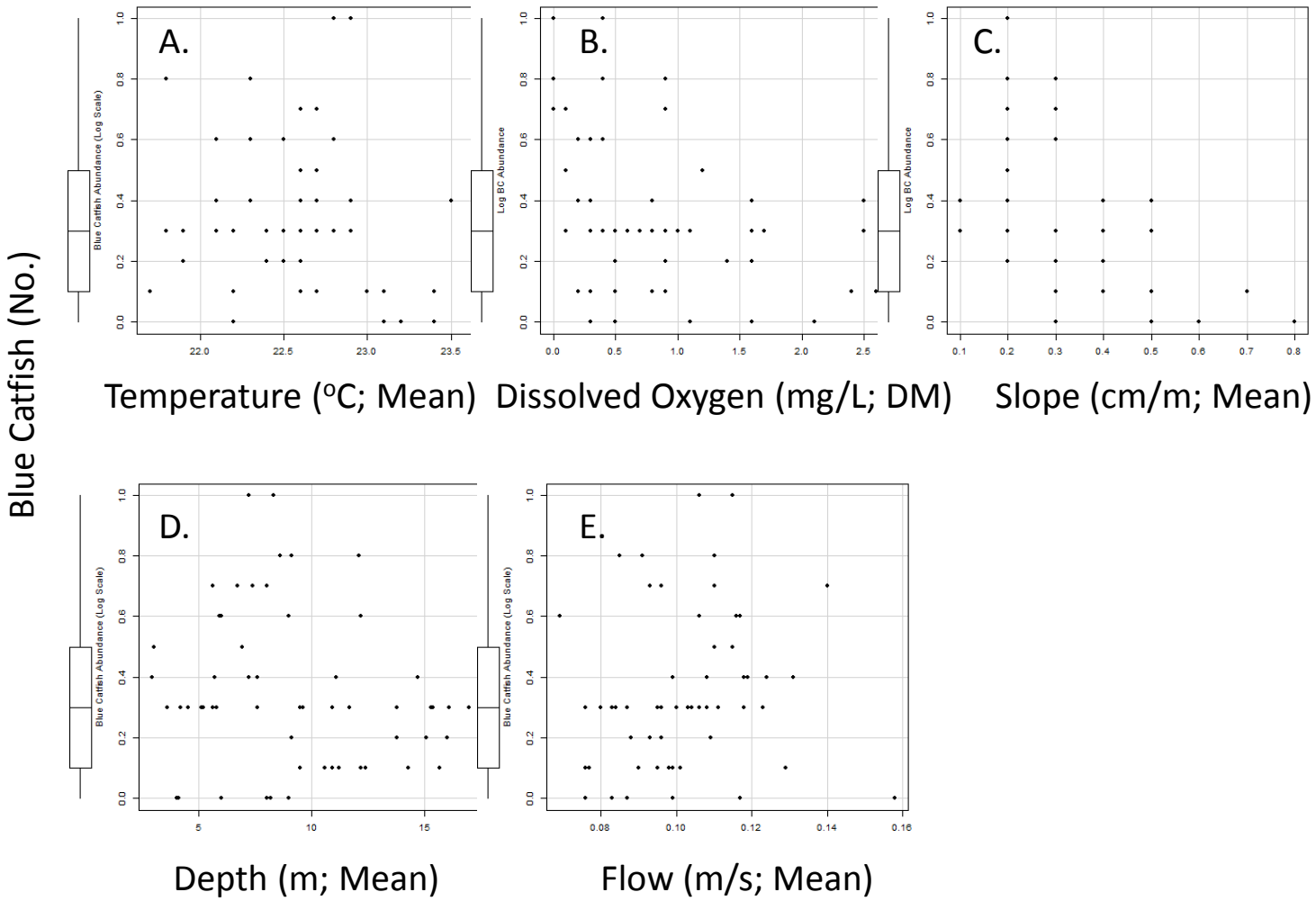
Chapter 3 Figure 1

Blue Catfish Abundance (No.)



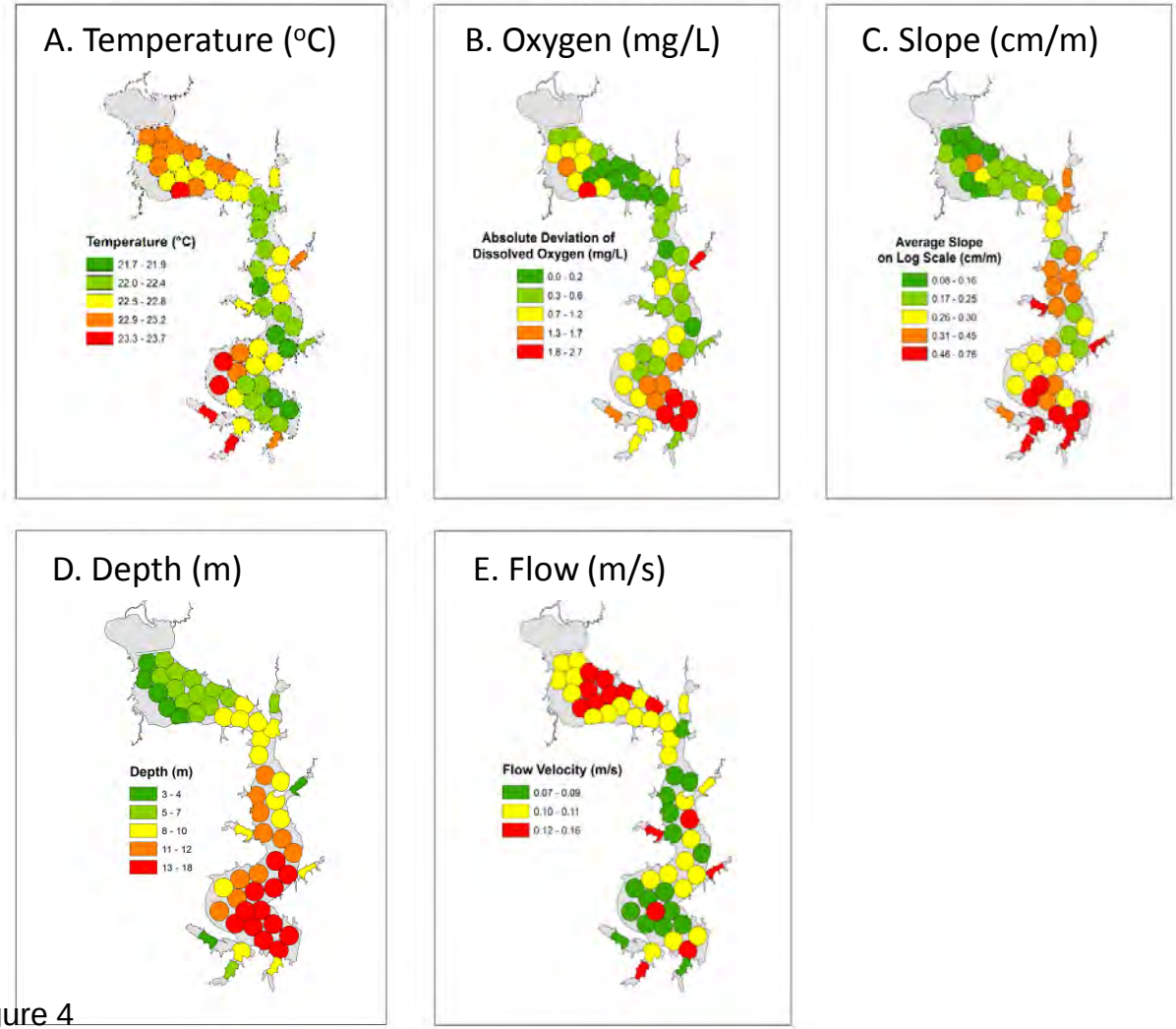
Chapter 3 Figure 2

HYPOTHESIS 1 – MICROHABITAT



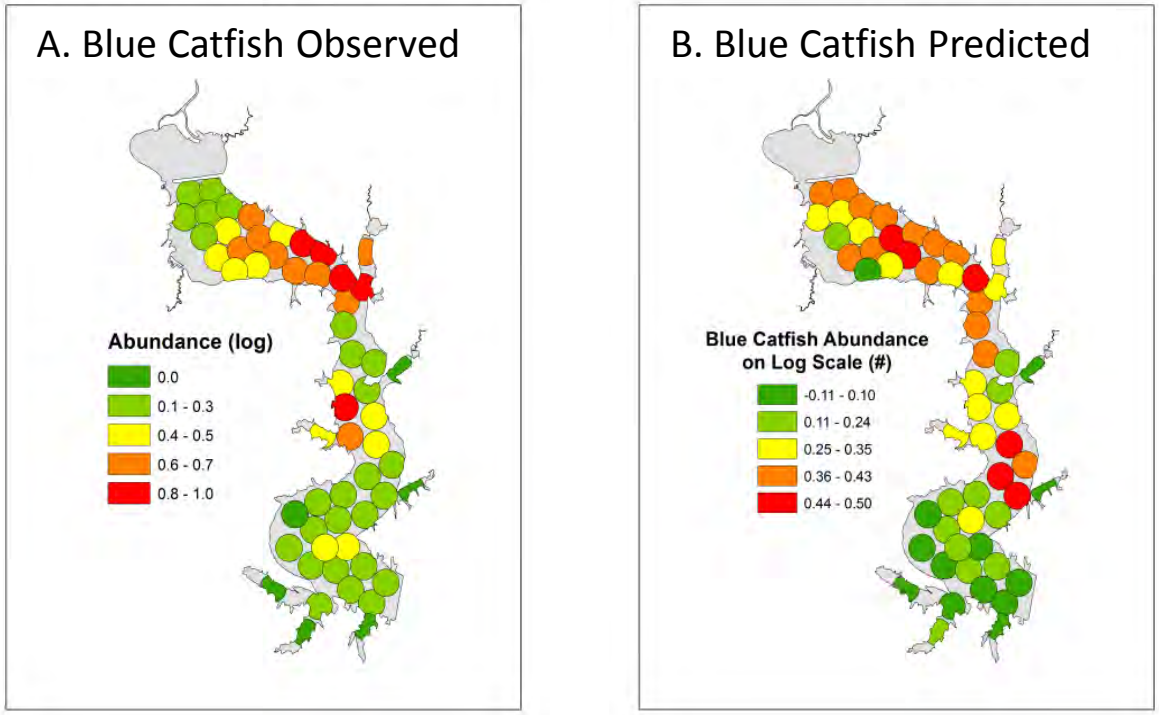
Chapter 3 Figure 3

HYPOTHESIS 1 – MICROHABITAT



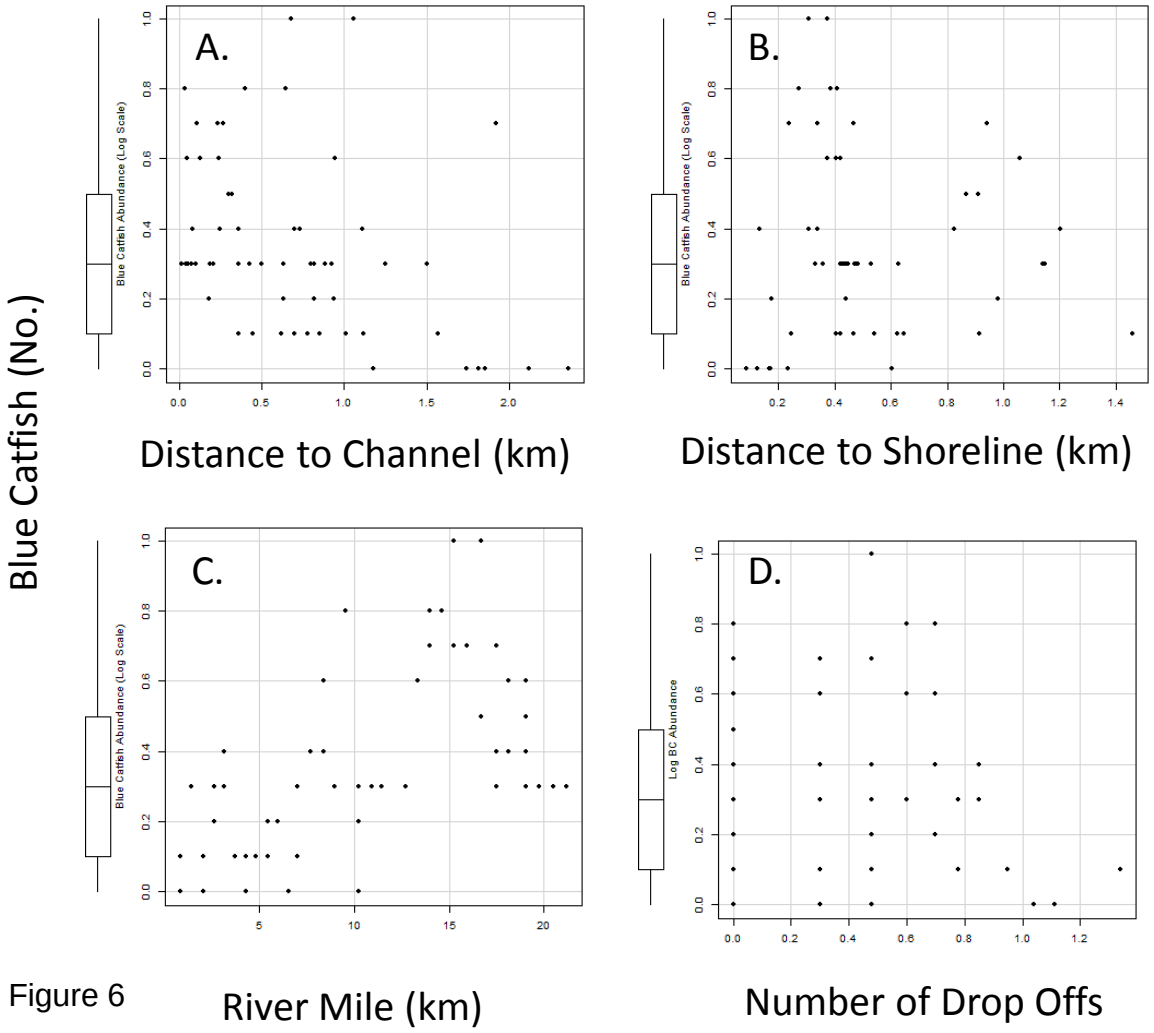
Chapter 3 Figure 4

HYPOTHESIS 1 – MICROHABITAT



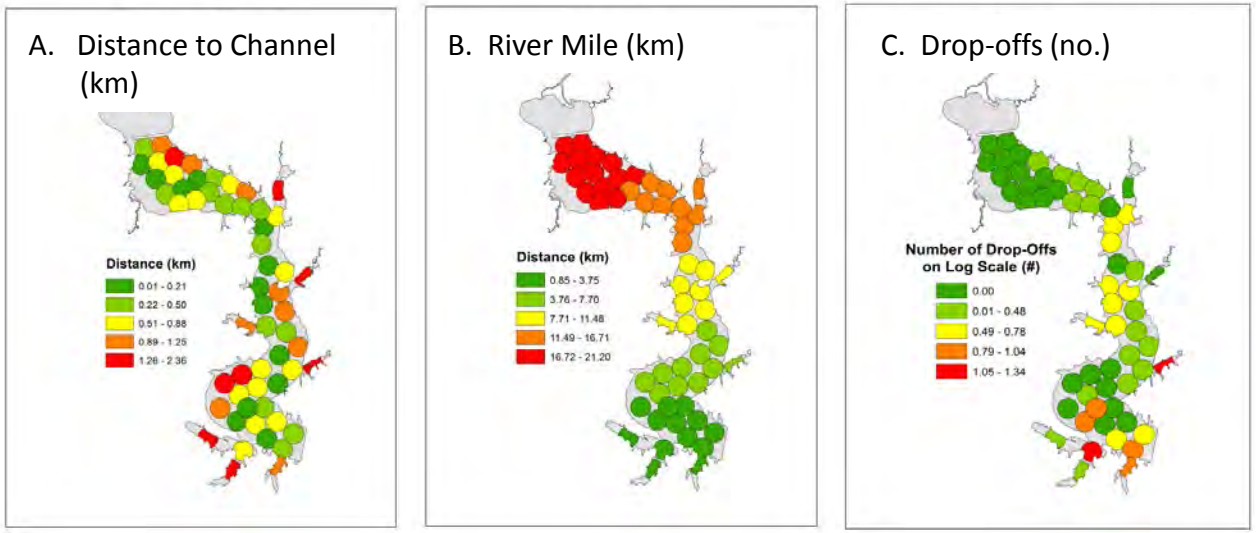
Chapter 3 Figure 5

HYPOTHESIS 2 – MACROHABITAT



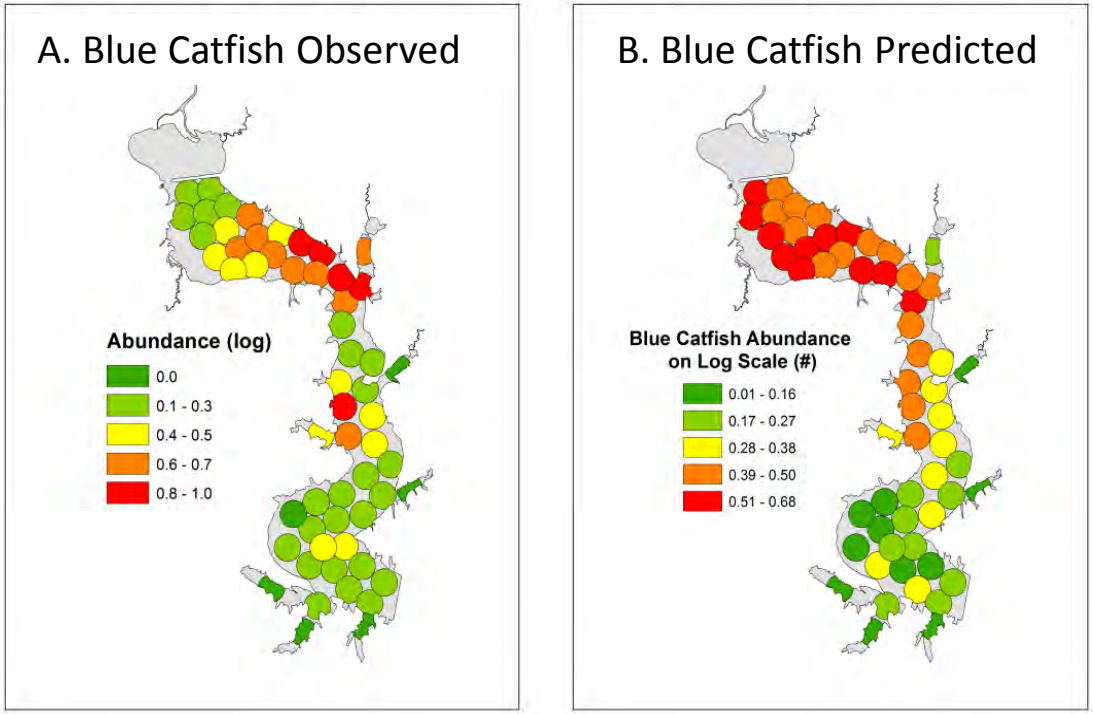
Chapter 3 Figure 6

HYPOTHESIS 2 - MACROHABITAT



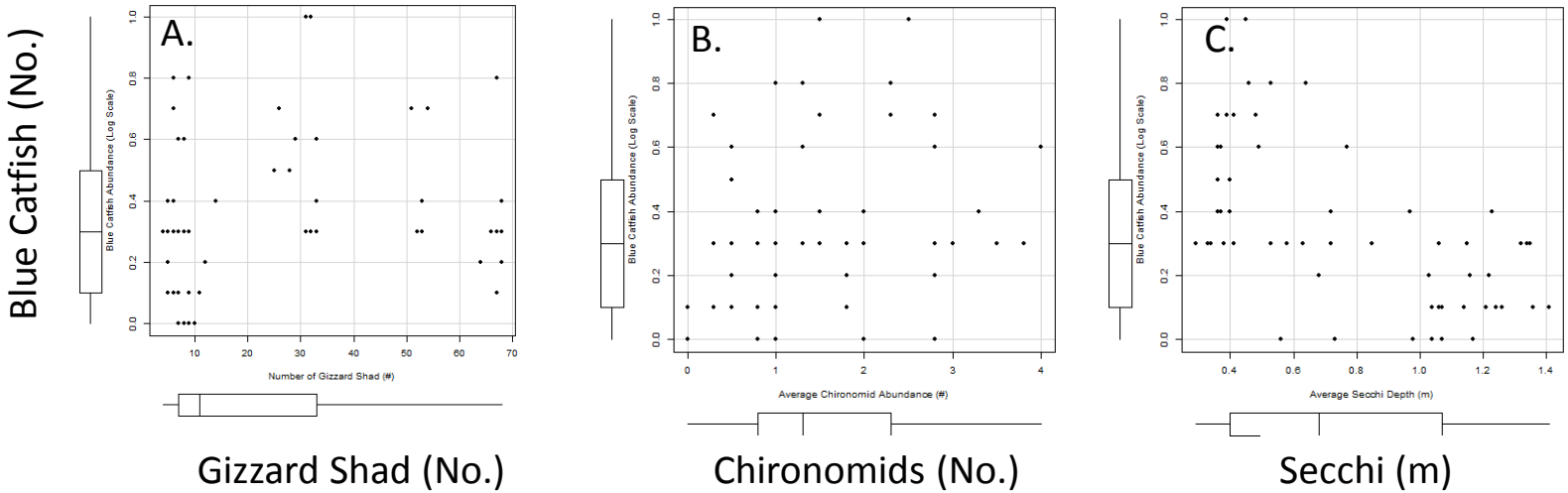
Chapter 3 Figure 7

HYPOTHESIS 2 – MACROHABITAT



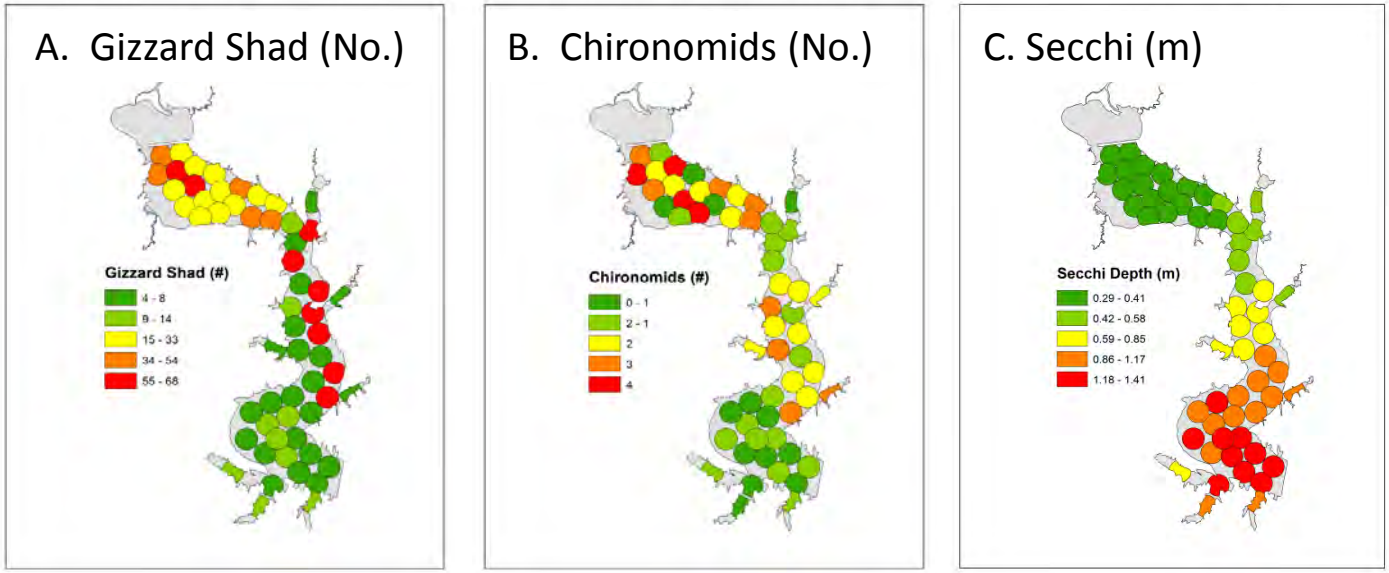
Chapter 3 Figure 8

HYPOTHESIS 4 – BIOTIC

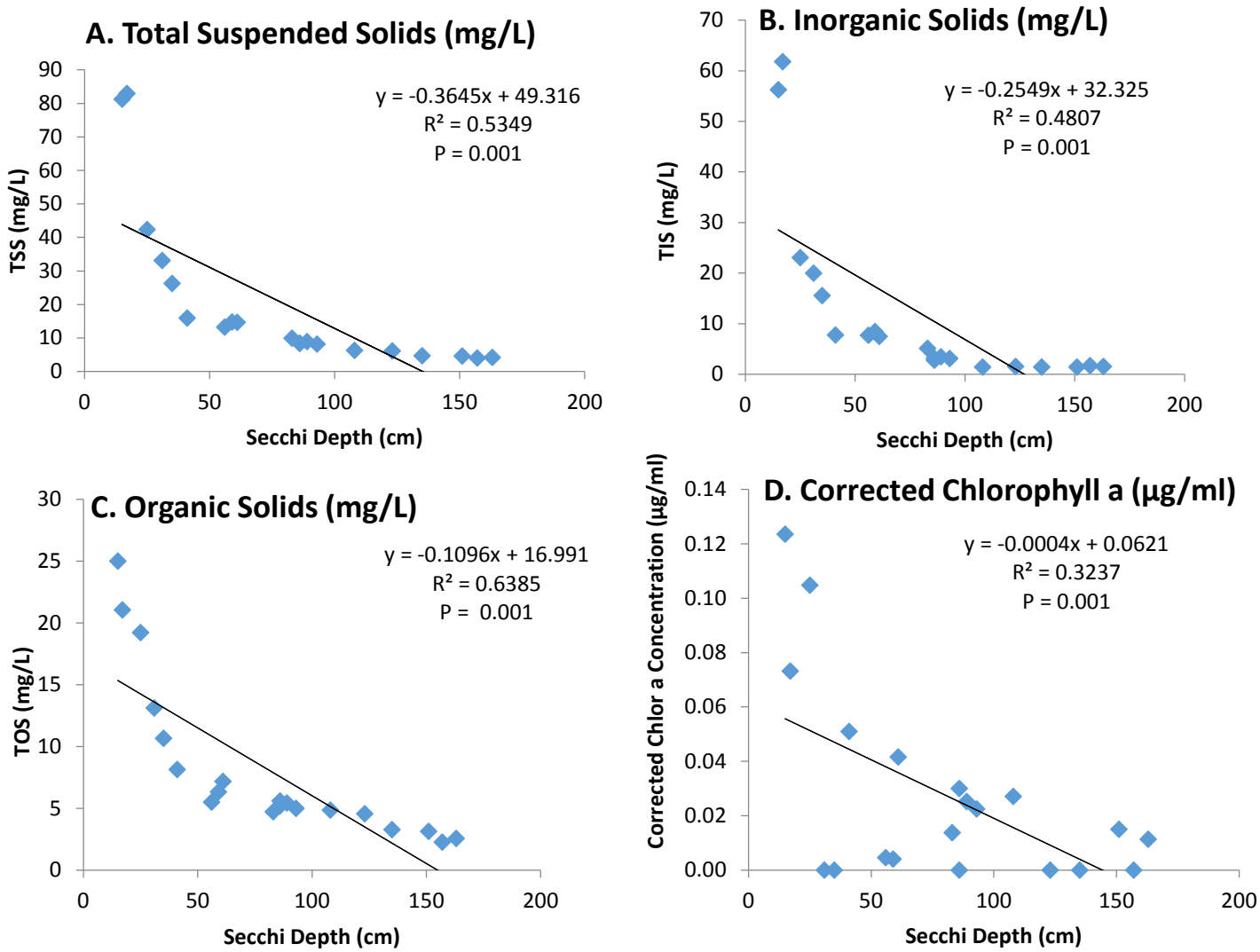


Chapter 3 Figure 9

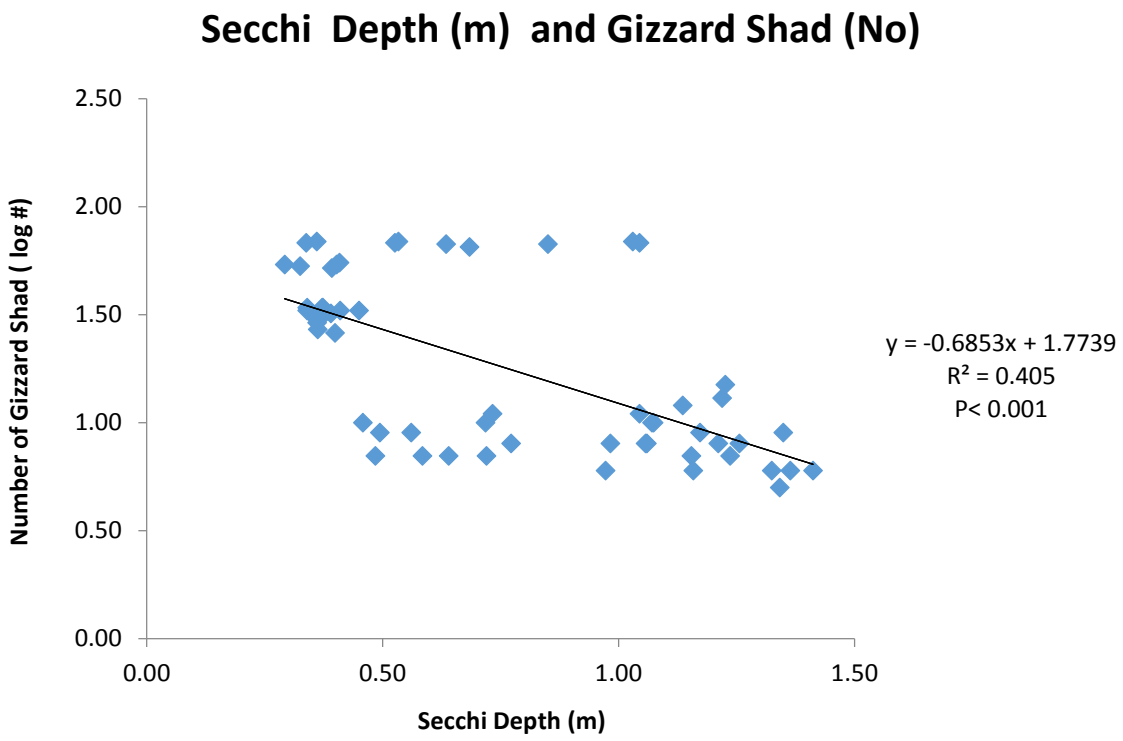
HYPOTHESIS 4 – BIOTIC



Chapter 3 Figure 10

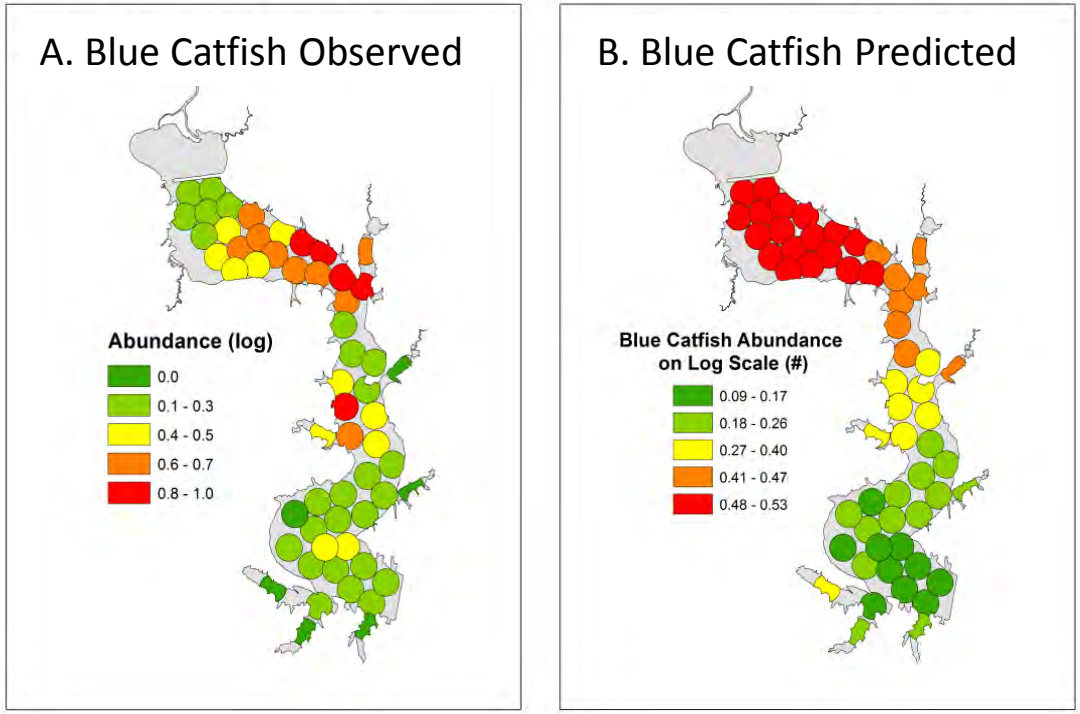


Chapter 3 Figure 11

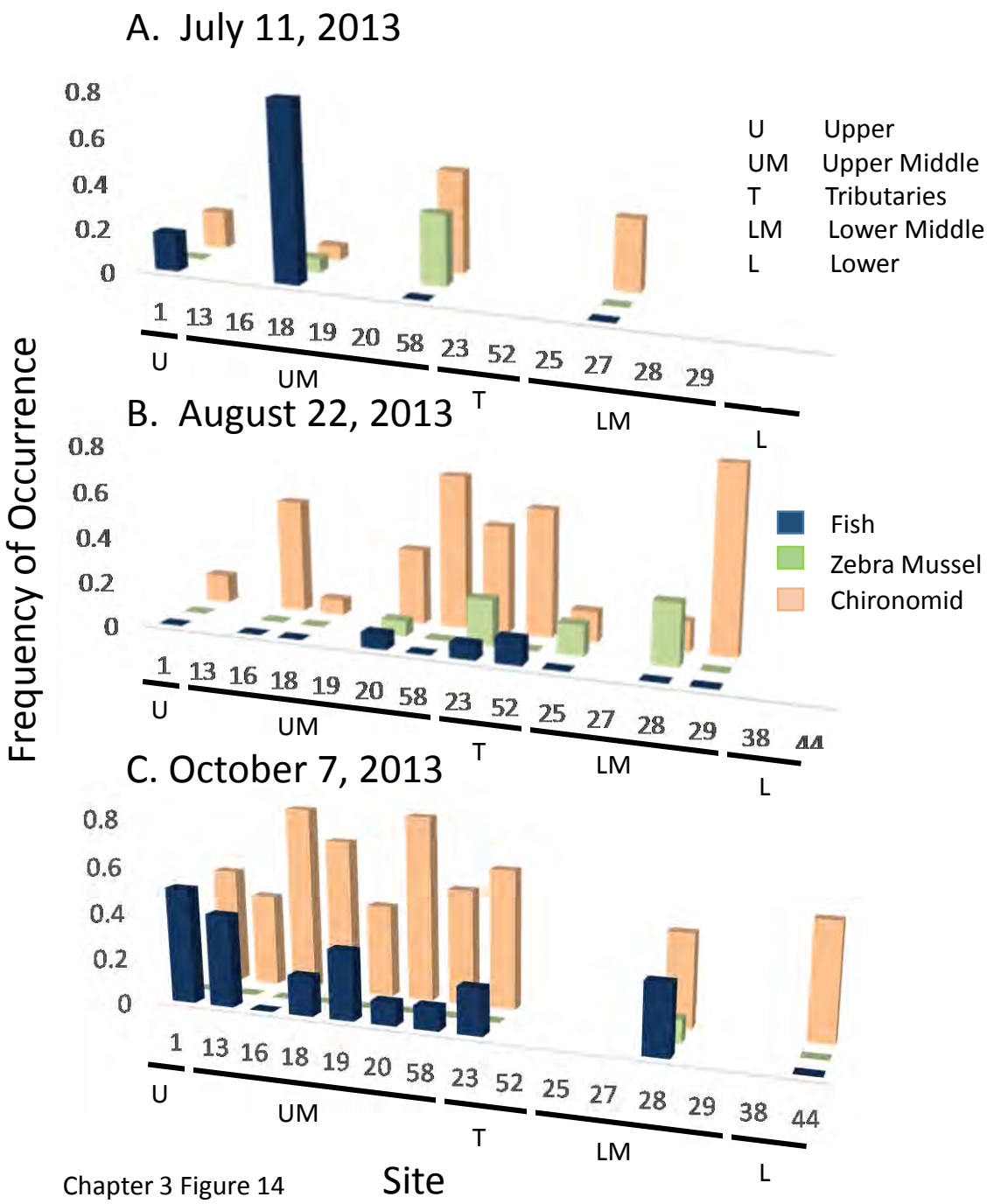


March 10 Figure 12

HYPOTHESIS 4 - BIOTIC



Chapter 3 Figure 13



Chapter 3 Figure 14

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