

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

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

25 *Methodological Challenges for Tagging.* Surgically implanting acoustic tags within the
26 coelomic cavity of a fish is generally regarded as the most appropriate method for long-term
27 biotelemetry applications (Jepsen et al. 2002; Bridger and Booth 2003; Brown et al. 2011; Cooke
28 et al. 2011; Thiem et al. 2011). However, the surgical implantation of acoustic tags has the
29 potential to cause infection, alter behavior, and ultimately lead to mortality (Bridger and Booth
30 2003). To ensure that the data generated from tagged fish are relevant to untagged conspecifics,
31 fish tracking research can benefit from methodological synthesis and refinement (Cooke et al.
32 2011). Thus, sound tagging methodology is important for all tracking studies. Here we evaluate a
33 tagging methodology for Blue Catfish (*Ictalurus furcatus*) and Channel Catfish (*Ictalurus*
34 *punctatus*).

35 *Tag Loss.* Tag loss (c-d above) is a problem for all fish and especially for catfish. Several
36 studies have tracked Blue Catfish (e.g., Fischer et al. 1999; Grist 2002; Lee 2009; Garrett 2010;
37 Garrett and Rabeni 2011) in the field. However, only a limited number of studies have developed
38 or evaluated tagging methodologies for Blue Catfish (e.g., Holbrook et al. 2012; Bodine et al.
39 2014) and Channel Catfish (e.g., Summerfelt and Mosier 1984, Marty and Summerfelt 1986,
40 1990).

41 In this literature, tag retention (% tags retained) in evaluations of recreationally-important
42 catfish species (Blue Catfish and Channel Catfish) is variable but usually low [Blue Catfish: **33**,
43 **60%** (Holbrook et al 2012); **100, 42%** (Bodine et al. 2014); Channel Catfish **29%** (Summerfelt
44 and Mosier 1984); **44, 2%** (Marty and Summerfelt 1986, 1990)]. Through controlled hatchery
45 and laboratory studies in which tags were found outside of previously-tagged catfish, we know

46 some catfish tag loss occurs via ejection (i.e. loss through incision site; Summerfelt and Mosier
47 1984; Marty and Summerfelt 1986). Even though new methods are being developed and
48 evaluated (Bodine et al. 2013), a high-survival, high-retention methodology for tagging catfish
49 has still not been identified.

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

54

55

METHODS

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

61 *Tagging Overview and Summary.* We tagged Blue Catfish (BC) and Channel Catfish
62 (CC) four times over three years (2012-2014) in two settings (Milford Hatchery and Milford
63 Reservoir) (*Chapter 1 Table 1*). These trials served three purposes: to practice tagging techniques
64 (2012, BC, Milford Hatchery); to evaluate field distribution (2012, 2013, BC, Milford
65 Reservoir); and to test three variables in the hatchery that might affect tag retention (2014, CC,
66 Milford Hatchery). We used the same tagging methodology for all evaluations.

67 *2012 – Blue Catfish, Milford Hatchery, Technique Practice and Evaluation.* After
68 reviewing the literature, developing a surgical protocol, and practicing incision and suturing

69 techniques in the laboratory, we tested our tagging protocol on live catfish [estimated range: 150-
70 250 mm Total length (TL)] at Milford hatchery (*Chapter 1 Table 1*). Each individual tagger
71 sequentially tagged five fish, following the procedures in our written protocol. Tagged fish were
72 held in a hatchery tank for seven days. Then tag placement was evaluated through euthanasia and
73 dissection. This qualitative evaluation was an opportunity to standardize and improve our
74 tagging technique.

75 *2012, 2013 - Blue Catfish, Milford Reservoir, Field Evaluation of Distribution.* In both
76 2012 and 2013, for our test of distributional patterns of Blue Catfish in Milford Reservoir, we
77 targeted the size range of fish that was common in the reservoir (400-600 mm TL; *additional*
78 *details are provided in Chapter 2*). In 2013, we added a limited number of smaller and larger fish
79 to the study (*Chapter 1 Table 2*). In 2012, the average fish size tagged was 487 mm TL [range
80 383-1020, Standard Error (SE) 14.5, $n=48$]. In 2013, the average size of Blue Catfish tagged was
81 517 mm TL (range 343-1090, SE 17.8, $n=75$). In 2012, for field tagging, we used V9 tags
82 (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
83 fish with V13 tags (length: 36-48 mm, weight in air: 11-13 g, weight in water: 6-6.5 g). We
84 evaluated survival of tagged Blue Catfish and retention of tags in two ways (*Chapter 1 Table 1*).
85 First, we plotted detections for the first 10 days when post-tagging mortality and loss to acute
86 stress was most likely to occur. For this plot, we first checked that fish moved across multiple
87 receivers to make sure they were not dead. Second, we plotted the number of fish detected per
88 month (%) across the first five months of the study for both years. We predicted that fish that
89 were repeatedly detected at different locations survived the tagging process and retained their
90 tags. No statistics were used for this evaluation.

91 2014 - Channel Catfish, Milford Hatchery, Evaluation. In 2014, we tested how three
92 factors (incision location, antibiotics, and surgery time) affected tag loss for 70, age-0, hatchery-
93 reared channel catfish (*Chapter 1 Table 1*). The tagging protocol was the same as for other
94 tagging evaluations except that we used smaller dummy tags to keep tag weight < 2% fish body
95 weight (Bridger and Booth 2003).

96 In a review of tagging methodologies, Cooke (2011) noted that the importance of incision
97 location and antibiotics are rarely tested. First, we chose to test the incision location because we
98 used a lateral incision whereas most other tagging studies have used a ventral incision. We also
99 chose to test if antibiotics have an effect on tag loss and survival because many catfish tagging
100 studies do not use antibiotics. We chose to test surgery time because we suspect surgery time
101 varies across surgeons and studies, and longer surgery time may increase post tagging stress. Our
102 five treatments contained 14 fish each that were given different combinations of incision,
103 antibiotics, and surgery time. Treatment 1 was the treatment we describe below for our field
104 tagging [lateral incision, antibiotics, quick surgery time (2-3 min)]. Treatment 2 was similar to
105 treatment 1 but used a ventral incision (ventral incision, antibiotics, quick surgery time).
106 Treatment 3 used a lateral incision, no antibiotics, and a quick surgery time. Treatment 4 used
107 alternative options to treatment 1 [ventral incision, no antibiotics, longer surgery time (about 8
108 min)]. Treatment 5 was a control in which tagging was simulated but no fish were tagged.

109 Before tagging, all dummy VEMCO tags were engraved with the tag number. Post-
110 tagging, all fish were Floy tagged. We recorded treatment, VEMCO dummy tag number, and
111 Floy tag number so we could link tag loss to a treatment. We held all 70 fish in a single (4 m X 4
112 m) compartment of a hatchery raceway for 12 weeks. We recorded general individual fish
113 condition weekly, in addition to incision condition (suture present, redness at incision, redness at

114 suture insertions, and general condition and healing of the incision), Floy tag number, and Floy
115 tag insertion condition. We also took pictures of all fish. Each week we searched the bottom of
116 the hatchery compartment visually and manually four times (two times each by two people) to
117 recapture ejected tags. At the end of 12 weeks, we euthanized all fish, measured and weighed
118 fish, recovered tags, and photographed tag position within the body cavity. To summarize data,
119 we plotted tag loss data by treatment. We used a Chi square test with 2,000 Monte Carlo
120 simulations to evaluate if tag loss was distributed equally across all treatments. Two thousand
121 simulations is a default value for a simulated P-value (chisq.test function; R Core Team 2013).

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

127 *1. Pre-field preparations.* To minimize stress, preparation before field work was
128 essential. Existing literature on tagging studies, tagging techniques in general, fish morphology
129 and fish physiology were reviewed and summarized. We also contacted authors who had
130 published on catfish tagging via email for additional insights. As with most research facilities,
131 we were required to submit an Institutional Animal Care and Use Committee (IACUC) protocol
132 (#3151 and #3151.1). Insights from a university veterinarian were very useful relative to
133 anesthetic and surgical techniques.

134 In addition to the literature and technical expert consultations, practicing incisions and
135 suturing was essential. Many useful print and online tutorials exist on surgical techniques.
136 However, practice was perhaps the most important component of our protocol. Incision and

137 suturing can be practiced on inanimate objects (oranges and bananas) any time. Dead fish added
138 a new dimension to incision and suturing practice. A very important component of our technique,
139 however, was tagging live fish prior to field tagging. This tagging of hatchery fish was followed
140 by an evaluation of survival, healing, and tag placement in the hatchery for seven days. In
141 summary, a good literature review, thoughtful protocols, and extensive practice before field
142 tagging were important parts of our protocol.

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

159 3. *Minimal Stress Fish Capture and Pre-surgery Holding.* We collaborated with State
160 colleagues on tagging. State biologists captured fish using boat electrofishing (1 stationary boat,
161 2 capture boats) with low pulse DC current (15 pulses/s, 3-5 amps) (Bodine and Shoup 2010).
162 All fish were collected in pre-identified areas. Fish were held on State electrofishing boats post-
163 sampling in large aerated live wells. We only tagged 5-10 fish at a time so that fish were held on
164 board our boat < 60 minutes post-capture. This step in our protocol allowed us to tag fish of
165 predetermined size from known locations that were captured with minimal stress and held in low
166 stress conditions for a relatively short time per surgery.

167 4. *Pre-surgery, 5. Surgery, 6. Prophylaxis, 7. Recovery and Release.* Individual fish were
168 anesthetized one at a time with Aqui-S 30 mg-L in a single fish tank until they lost orientation
169 (2012: Average: 2 min. 16 sec. SE = 12 sec; 2013: Average = 2 min. 30 sec. SE = 7 sec). Doses
170 of anesthetic were tested in hatchery trials before field tagging. Two people processed each fish.
171 One acted as the surgeon and never moved from the operating station. The other acted as the
172 anesthesiologist and moved the fish from pre-tagging tank to the anesthesia tank to operating
173 station to the recovery tank. The anesthesiologist also constantly applied ambient water (with
174 Aqui-S if needed) to the fish skin and gills during surgery and made sure the fish remained in the
175 optimal position for a quick and stress-free surgery.

176 After anesthesia, fish were weighed (hanging scale with a cradle of soft mesh) and
177 measured on a wet measuring board. A 15-30 mm lateral incision was made below the pectoral
178 fin about $\frac{3}{4}$ of the way to the tip of the fin (15-20 mm – 300-700 mm TL Blue Catfish; 20-30
179 mm– >700 mm TL Blue Catfish). We used surgical scalpels of size 12 for fish < 700 mm TL and
180 22 for fish > 700 mm TL). As catfish intestines are very close to a thin body wall, we were
181 careful to make the incision into fish body wall in increments so that only skin and muscle, not

182 intestines, were cut. A sterile tag was carefully inserted into the body cavity. The incision was
183 closed with 2-4 sutures (Ethicon braided, coated Vicryl, 3-0, FS-1, 24 mm 3/8 c reverse cutting –
184 fish > 700 mm TL; Ethicon, braided, coated Vicryl, 3-0, FS-2, 19 mm 3/8 c, reverse cutting –
185 fish < 700 mm TL). Surgery time was relatively short (2012 Average = 2 min. 38 sec, SE = 7
186 sec; 2013 Average = 2 min. 54 sec, SE = 5 sec).

187 As a prophylaxis, after surgery we gave all fish an intramuscular injection of antibiotic
188 (Liquamycin - 0.1 mg/kg fish; Pautzke et al. 2010), then allowed the tagged fish to recover in an
189 individual tank with oxygenated, ambient water until the fish was upright and swimming
190 (Recovery times 2012: Average = 5 min. 7 sec, SE = 24 sec; 2013 Average = 7 min. 14 sec, SE =
191 13 sec). Next, tagged fish were transferred to a larger community recovery tank with a 0.05%
192 salt solution to aid in slime coat recovery. After at least 15 minutes in a salt bath (Long et al.
193 1977), fish were individually captured with a soft mesh trout net, placed in the lake close to
194 where they were captured, and allowed to swim away (*Chapter 1 Figure 2*). All times were
195 recorded.

196 *Receiver Placement.* In 2012 and 2013, we tracked tagged Blue Catfish with a benthic
197 20-stationary receiver array (*discussed in Chapter 2*) and a 57-site monthly manual receiver
198 survey (*discussed in Chapter 3*). For the stationary array, data were collected using VEMCO
199 (VR2W-69kHz) receivers which received coded pings from tags each time a tagged fish came
200 within range of the receiver. In 2012, we deployed receivers in June (*Chapter 1 Table 3*);
201 receivers were placed at 18 locations within the reservoir and two locations adjacent to the
202 reservoir exits (*Chapter 1 Figure 3*). The upper river receiver (receiver 1) and the upper within-
203 reservoir receiver (receiver 2) formed a two-tier gate to detect upriver egress from the reservoir.
204 The southernmost receivers in the reservoir (receiver 19) and the river receiver below the dam

205 (receiver 20) formed another two tier gate to detect downriver egress (*Chapter 1 Figure 3*). We
206 also had two 3-stationary receiver gate arrays (receivers 6-8, 11-13) across the mid-reservoir
207 constriction (i.e., the limited width allowed complete coverage of the entire reservoir as
208 confirmed by range tests) to detect any fish that moved through the middle region of the
209 reservoir. In 2012, for data analysis, we removed data from 2 of the 3 receivers in these gates (7,
210 8, 11, 13) to obtain a more even distribution of detections (*Chapter 1 Figure 3A- dashed squares*
211 *indicate receivers that were removed*). Thus, in 2012, of the 18 within reservoir receivers, 14
212 were used for data analysis. In 2013, we deployed receivers similarly (May-November 2013;
213 *Chapter 1 Table 3*). However, receiver 1 was vandalized in August, 2013. Receivers 16-17 were
214 lost due to vandalism or boating collisions. Gate receiver 13 replaced gate receiver 12 because
215 receiver 12 was lost. As in 2012, in 2013, we also removed data from 2 of the 3 gate receivers
216 (7,8, 11, 12) (*Chapter 1 Figure 3B- dashed squares indicate receivers that were removed*). Thus,
217 in 2013, of the 18 within reservoir receivers, 12 were used for data analysis. Receivers were
218 grouped into five regions based on general size and location (upper, upper middle, Madison,
219 lower middle, and lower; *Chapter 1 Figure 4*).

220 We also collected data on acoustically tagged Blue Catfish at 57 (0.8 km²) manual
221 tracking sites (*Chapter 1 Figure 5*). Tracking sites were positioned to cover the maximum
222 amount of surface area while preventing overlap among adjacent sites (i.e., < maximum range)
223 (e.g., limited spatial arrangements were possible to cover the entire reservoir with sampling units
224 of this size). We chose this design to quantify spatial heterogeneity. The choice of 57 spatially-
225 explicit sampling locations that covered the entire reservoir provided good resolution for
226 quantifying Blue Catfish distribution, allowed us to construct detailed spatial maps of Blue

227 Catfish, and resulted in substantial statistical power. The manual tracking survey was conducted
228 in June through November in 2013 (*described in detail in Chapter 3*).

229 *Stationary Receiver Range Test.* We conducted range tests using two methods. Both tests
230 provided information on the distance at which a tag can be detected under field conditions. First,
231 we conducted a range test using the methods provided by the receiver manufacturer, VEMCO.
232 For this, we deployed an array of receivers in an 800-m straight line, separated by 100-m
233 intervals. A test tag, vertically oriented, was located near the first receiver. Receivers at 100-800
234 m were constantly exposed to the repetitive pinging of this tag. Over a week, adequate data were
235 collected at each receiver to get a probability of detection at 100 m intervals. These range test
236 data were processed using VEMCO software.

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

245

246

RESULTS

247 *2012 – Blue Catfish, Milford Hatchery, Technique Practice and Evaluation.* In our initial
248 tagging during which we tested our protocols and evaluated our tagging techniques, all tagged
249 fish survived seven days, all tags remained within the body cavity, incisions healed well, and we

250 observed no differences among taggers. Based on this result, few changes were made to our field
251 protocol.

252 *2012, 2013 – Blue Catfish, Milford Hatchery, Technique Practice and Evaluation.* For
253 our field tagging of Blue Catfish, tagged fish suffered little short-term tag loss. In 2012, all 48
254 tagged fish were detected at least once in the first ten days (black squares per row=detection per
255 fish; *Chapter 1 Figure 6*). A fish was not scored as detected for this tag evaluation unless it
256 moved between at least two receivers. This ensured that we did not score dead fish as live fish
257 that had retained their tags. Seventy three percent of tagged fish were detected for five or more
258 days during the first ten days (*Chapter 1 Figure 6*). Apart from methodological considerations,
259 tagged fish had different patterns of distribution as some fish were detected more often than
260 others (variation in black squares per row = variation in detections per fish; *Chapter 1 Figure 6*).
261 For example, fish 12 was detected across five days (days 1, 5, 6, 9, 10) whereas fish 47-48 were
262 detected daily (*Chapter 1 Figure 6*). In 2013, all 75 tagged fish were detected at least once in the
263 first ten days (*Chapter 1 Figure 7*). Ninety six percent of all fish tagged in 2013 were detected
264 for five or more days within the first ten days post-tagging (*Chapter 1 Figure 7*).

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

270 *2014 - Channel Catfish, Milford Hatchery Tagging Experiment.* Age-0 channel catfish
271 from Milford Hatchery suffered little tag loss or mortality in any treatment during our 12-week
272 study. No mortality occurred in treatment 1 (our methodology), treatment 3 (no antibiotics), and

273 the control (Treatment 5) (data not shown). Fish in treatment 2 (ventral incision) had an overall
274 mortality of 21% while those in treatment 4 [[ventral incision, no antibiotics, longer surgery time
275 (about 8 min)]. had an overall mortality of 7%. Differences in mortality were not statistically
276 significant, possibly because mortality was low for all fish in all treatments.

277 All tag loss occurred within the first week (*Chapter 1 Figure 9*) with the exception of one
278 fish in treatment 3. Treatment 1, the treatment we used for field tagging, had no tag loss (*Chapter*
279 *1 Figure 10*). Treatments 2 and 3 had an overall tag loss of 21% (3 individuals in each treatment
280 lost tags). Treatment 4 had an overall tag loss of 29% (4 individuals lost their tags; *Chapter 1*
281 *Figure 10*). Our tagging methodology (treatment 1) had a significantly lower tag loss than
282 treatment 4, based on a chi square test (*Chapter 1 Figure 10*). Other differences described above
283 were not statistically significant, ($P > 0.05$), possibly because tag loss was low for all fish in all
284 treatments.

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

291 For our second range test, individual detection radii varied from 300-650 m (average 462
292 m) for receiver 4. Individual detection radii varied from 500-1,000 m (average 775 m) for
293 receiver 7 (*Chapter 1 Figure 12A*). Individual detection radii varied from 700-900 m (average
294 825 m) for receiver 12 (*Chapter 1 Figure 12B*). Overall, the average range radius in the second
295 range test (average 687 m) was similar to the range found in the VEMCO recommended range

296 test (average 600 m) (Chapter 1 Figure 12C(Chapter 1 Figure 12A).). Based on these combined
297 tests, we used a receiver range of 600 m.

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299

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DISCUSSION

301 *High Tag Retention.* A primary goal of this research was to develop a high-survival, high-

302 retention tagging methodology for catfish. High retention of tags increases the quality and cost

303 effectiveness of a tagging dataset. Conversely, a large proportion of undetected fish raises

304 questions about fish stress during tagging and whether tagged fish behave like untagged fish (an

305 assumption of tagging). For these reasons, we made high tag retention and a high detection rate

306 priorities. In our hatchery trial of Channel Catfish tagging, our methodology (Treatment 1)

307 resulted in no mortality and no tag loss. In one of the early studies that internally implanted tags

308 into Channel Catfish, Marty and Summerfelt (1986) found that 22 of 39 (44% retention) and 45

309 of 46 (2% retention) fish expelled their tags in 19 and 20 days respectively after being tagged

310 with traditional (non-anchored) implantation methods. In response to this tag ejection, complex

311 internal anchoring procedures were developed (e.g., Siegwarth and Pitlo 1999) that had better,

312 but still low, tag retention rates. However, this anchored implantation technique can be

313 physiologically stressful to tagged fish. For example, in preparation for using ultrasonic

314 telemetry on Blue Catfish in Lake Texoma, OK, Lee (2009) used both traditional and anchored

315 attachment methods ($n= 5$ fish per attachment method). After 120 days in the hatchery pond, all

316 fish retained their tags but 90% died from both methods. Seven of 10 fish died within 48 h of

317 surgeries (Lee 2009). Recently, transmitter retention for adult Blue Catfish (> 600 mm TL) was

318 again evaluated for traditional and anchored implantation methods ($n=15$ per attachment

319 methods). Ten and six fish respectively expelled their tags 23-243 days post-surgery, resulting in
320 retention rates of 33 and 60%, respectively, for traditional and anchored tag attachment methods
321 (Holbrook et al. 2012). In a recent test of a new technique that externally attaches tags to skeletal
322 structure, Bodine et al. (2014) had mixed retention rates. In two hatchery trials, tagged Blue
323 Catfish had 100% ($n=20$; TL range = 435-638mm) then 41.7% retention ($n=24$, TL range = 600-
324 995) after two months. Thus, our tag retention rate exceeds that of most existing Blue Catfish tag
325 evaluations.

326 *High Detection.* Our tagging methodology was also very successful in detecting fish in
327 the reservoir, in that we repeatedly detected 85% of our tagged Blue Catfish in Milford Reservoir
328 through five months across two years ($n= 48, 75$). Other Blue Catfish tagging studies have not
329 detected such a high proportion of tagged fish. In Lake Norman, NC, only 15 of 29 (52%) Blue
330 Catfish (500-900 mm TL) with externally attached radio tags were alive and retained their tags
331 throughout the study (Grist 2002). In Lake Texoma, only 22 of 50 (44%) tagged Blue Catfish
332 (639-1305 mm TL) were successfully tracked. Eight tagged fish were confirmed dead and 20
333 were not detected (Lee 2009). In the lower Missouri River, Garrett (2010) implanted radio tags
334 into 40 Blue Catfish in each of two years (mean=872, range =569-1260 mm TL). Annual
335 movement cycle data were based on only 12 fish in each year (30% detection of tagged fish
336 throughout the study) because of the large number of tagged fish that were missing. Finally, for a
337 field evaluation of 50 Blue Catfish (TL range = 600-995mm) in Lake Buchanan, Texas, Bodine
338 et al. (2014) redetected only 40% of all tagged fish at 6 months and 19% at 12 months.
339 Consequently, our methodology provides a more detailed dataset than has been previously
340 collected and suggests that our tagged fish were not stressed post tagging. Both of these results

341 increase confidence that our dataset will provide generalizable insights about Blue Catfish
342 distribution.

343 *Critical Attributes of Our Methodology.* We attribute our success in tag retention to
344 several factors. Our protocol emphasized preparation, practice, and organization before the
345 tagging event, which allowed us to process fish quickly with minimal stress. A lateral incision
346 reduced our tag loss in the hatchery and was probably an important factor in successful field
347 tagging. Cooke et al. (2011) reviewed trends in intracoelomic tagging effects studies and found
348 that six of 108 studies compared elements of the incision, but only one study tested a ventral vs.
349 lateral incision. Although a ventral incision may be less likely to puncture the ovaries and may
350 be easier for the surgeon (Schramm and Black 1984), gravity may encourage tag loss in the
351 initial weeks before a ventral incision heals. Although the effect of antibiotics was unclear in our
352 hatchery evaluation, we suspect that antibiotics aided the survival and healing of our field caught
353 fish. In a review of tagging studies, only one study of 108 evaluated the effectiveness of
354 antibiotics. Specifically, Isely et al. (2002) found that the use of antibiotics was effective in
355 preventing initial post-surgery infection.

356 *Receiver Array Effectiveness.* Our receiver array detected fish throughout the lake.
357 Detection ranges of receiver arrays are important for understanding whether the data collected
358 represent an accurate estimate of a fish's space use (Welsh et al. 2012; Klimley et al. 1998).
359 Detection ranges are often just assumed based on manufacturer specifications (Welsh et al. 2012;
360 Kessel et al. 2014); when tested by researchers they can deviate within different aquatic habitats
361 (Heupel et al. 2006) and across temporal, and spatial scales (Simpfendorfer et al. 2008; Payne et
362 al. 2010). Our two range evaluation methods provided similar range estimates which enhanced
363 our confidence in the range at which our tags could be detected. Data from the manual receiver

364 reinforced the results of the stationary receivers. Both regimes (stationary and manual) were
365 designed to detect lake-wide patterns. Our detection regimes covered the whole extent of Milford
366 Reservoir from the causeway in the upper reservoir to the dam. Neither of these regimes,
367 however, detected small-scale movements because of the large detection diameter of receivers
368 (1,200 m diameter) and the wide spacing between receivers.

369 The impetus for our field study was to understand broad-scale distributional patterns
370 throughout an entire reservoir. Receiver sites were designed to identify lake-wide aggregations,
371 not heterogeneity or frequent distribution changes within localized areas. When our field study
372 was initiated, little information existed about Blue Catfish distribution in Milford Reservoir.
373 Hence, an extensive sampling design with many samples across the reservoir was required.
374 Given the state of our knowledge when we initiated this study, we simply would not have known
375 where to place receivers to detect Blue Catfish. Conducting an extensive and intensive design
376 simultaneously is logistically unfeasible. Thus, the design we describe here (broad spatial scale,
377 low resolution) was well suited for our question and likely would be useful for initial studies in
378 other systems. Information goal, system morphometry, scientific question, and target species
379 behavior also need to be considered in tracking study designs.

380 *Management Implications.* We have provided information on how we tagged fish and set
381 up receiver arrays. Our intention was to provide guidance for future studies in other systems.
382 First, our tagging was quite successful because of the organization, preparation, and training we
383 invested. Because of the monetary and labor investment in a tagging program, we suggest this
384 level of preparation. The tagging protocol we describe should be directly applicable to other fish
385 species including but not limited to catfish. Second, because of across-fish variability, future
386 studies should seek to tag a large sample size with the high retention rate we have demonstrated

387 here. A large sample size is essential for generalizable statistical analysis. Although the
388 anecdotal observations about the behavior of a few individuals are interesting, the scientific
389 generality of such isolated observations is low. Third, the choice of fish sizes should be made
390 carefully. Elsewhere (*Chapter 2*), we illustrated that distribution of same size fish varied widely.
391 Hence a lack of replication of similar--sized fish may result in the erroneous conclusion that
392 differences in distribution are related to size when in fact individual variation is responsible.

393 Fourth, to utilize the insights that we provide here in other systems, researchers and
394 managers should identify the question for which tagging is being used. As we note above, for a
395 reservoir-wide survey, the array setup we used (broad spatial coverage with relatively low
396 resolution at any specific location) worked well. We argue that this design is the best for the
397 initial study in any system when little knowledge exists about where fish are located. Likewise, if
398 egress is the goal, then gating all exits from the reservoir with multiple stationary receivers
399 would be advisable. Stationary receivers, especially in confined areas, are susceptible to human
400 (vandalism) and natural (high flow, high sedimentation) damage. Multiple receivers in sequence
401 can guard against study failure when receivers are lost and can also detect direction of
402 movement. If stationary receivers are used, downloading data regularly is essential. Receiver loss
403 is common in array studies. Once the receiver is gone, any unloaded data are also lost. Fifth, a
404 thoughtful evaluation of fish behavior relative to system bathymetry is suggested to apply the
405 insights provided here to other species and systems. Many fish travel along a channel (Pautzke et
406 al 2010; Kennedy et al 2014) so setting up receivers along this travel lane might be useful in
407 other initial tracking efforts. Confluences are also good locations for initial receiver placement. If
408 there is a central narrow constriction, setting up a series of gates that detect changes through the
409 entire system is useful. Our across-reservoir gates were essential for bounding patterns of

Chapter 1 - Methodology – Objectives 1-3

410 distribution for Blue Catfish in Milford Reservoir. Finally, the information gained from tracking
411 studies will accelerate as more fish are tracked within a specific system. In any initial study, little
412 is known about where the fish are located or the study would not be needed. Recognizing that
413 every question cannot be answered in a single study will facilitate realistic expectations about the
414 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

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

3
4 **FIGURE CAPTIONS**

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

7
8 *Chapter 1 Figure 2.* Shown is a flowchart that described the eight steps in our tagging protocol.
9 Each step is described in greater detail in the text.

10
11 *Chapter 1 Figure 3.* Distribution of 20 stationary acoustic receivers within Milford Reservoir is
12 shown for (A) 2012 and (A) 2013. Receiver 1 was deployed in the Republican River above the
13 inflow to the reservoir in order to detect egress out of the reservoir. Receiver 20 was deployed in
14 the Republican River below the dam in order to detect egress out of the reservoir. Receivers 2
15 and 19 were located within the reservoir and act as a second tier of egress gates. Receivers 6-8
16 and 11-13 formed two complete gates across the middle reservoir constriction to detect
17 distribution changes. (A) Receivers 7, 8, 11, 13 were removed for data analysis in 2012 to
18 provide a more even array distribution (red dashed boxes indicate the location of the receivers
19 that were removed). (B) Receivers 7, 8, 11, 12 were removed for data analysis in 2013 for the
20 same reason (red dashed boxes indicate the location of the receivers that were removed).

21 Vandalism and boater conflicts resulted in the loss of receivers 1, 16, and 17 in 2013. As a result,
22 in 2012 and 2013, we used 14 and 12 receivers for data analysis respectively.

Chapter 1 – Methodology - Figure Captions

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

27

28 *Chapter 1 Figure 5.* Sample sites for manual tracking survey at 57 sites to quantify Blue Catfish
29 distribution in Milford Reservoir, KS. Sites were sampled once a month July through November,
30 2013. Details of the survey methodology are provided in the text.

31

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

35

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

39

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

43

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

Chapter 1 – Methodology - Figure Captions

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

48

49 *Chapter 1 Figure 10.* Tag retention by hatchery Channel Catfish is shown. The X axis is
50 treatment and the Y axis is number of fish that retained their tags (i.e., no tag loss). Our five
51 treatments contained 14 fish each that were given different combinations of incision, antibiotics,
52 and surgery time. Treatment 1 was the treatment we describe below for our field tagging [lateral
53 incision, antibiotics, quick surgery time (2-3 min)]. Treatment 2 was similar to treatment 1 but
54 used a ventral incision (ventral incision, antibiotics, quick surgery time). Treatment 3 used a
55 lateral incision but no antibiotics (lateral incision, no antibiotics, and quick surgery time).
56 Treatment 4 used alternative options to treatment 1 [ventral incision, no antibiotics, longer
57 surgery time (about 8 min)]. Treatment 5 was a control in which tagging was simulated but no
58 fish were tagged.

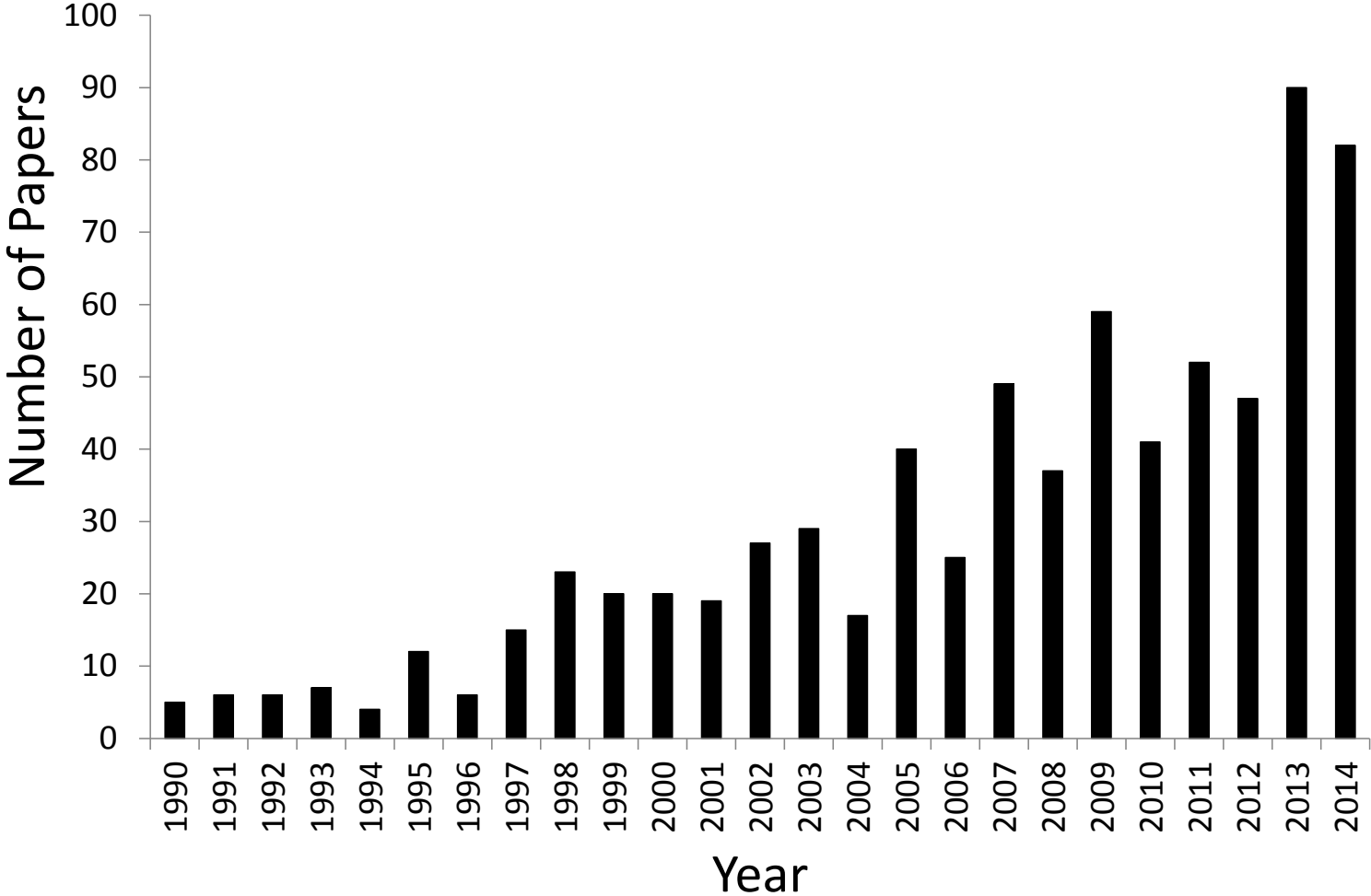
59

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

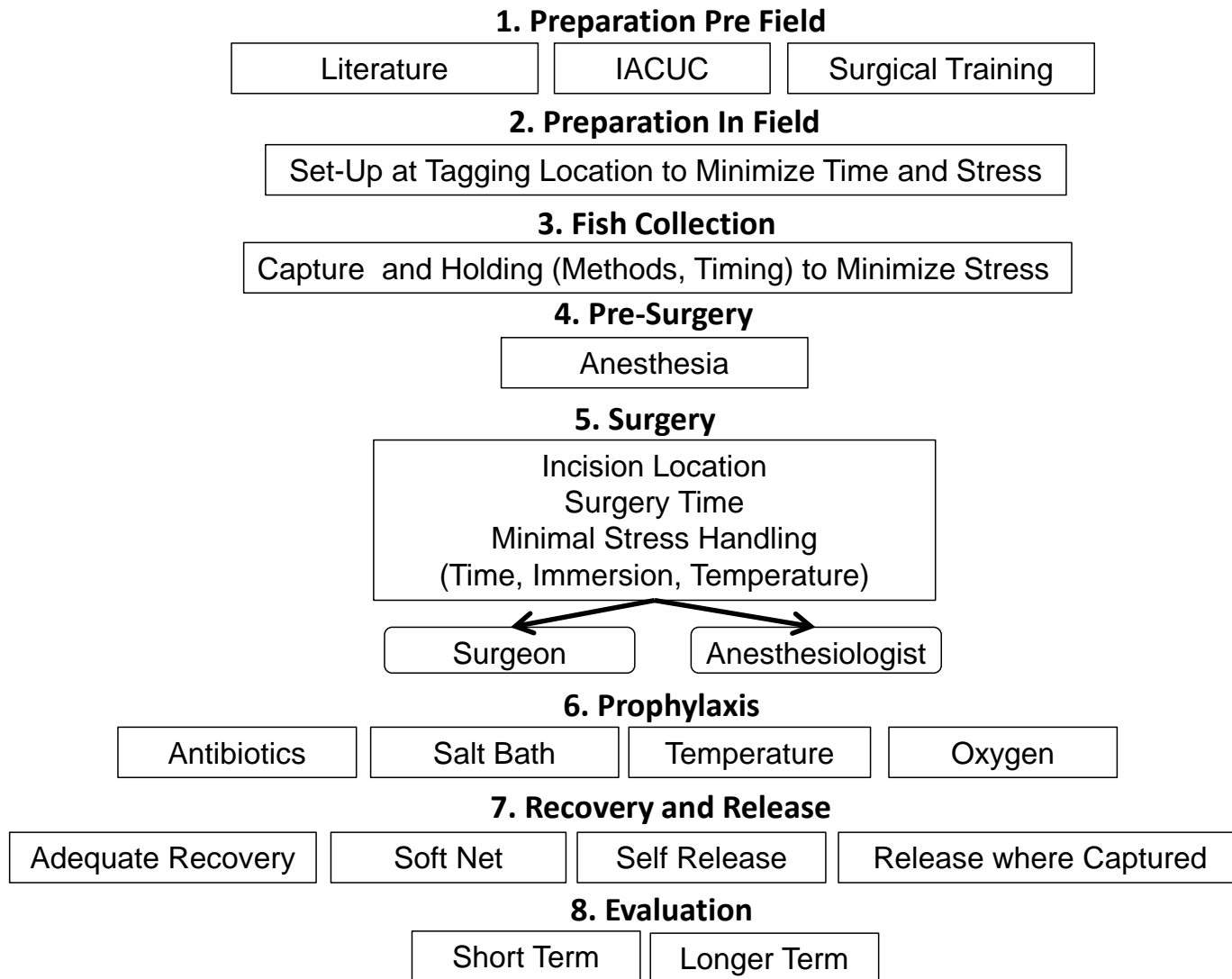
64

65 *Chapter 1 Figure 12.* Distances at which VEMCO tags were heard at three receivers (A) receiver
66 4, (B) receiver 7, and (C) receiver 2. The specific spatial pattern and mean, minimum, and
67 maximum distances are shown for each receiver. This second range test is described in more
68 detail in the text.

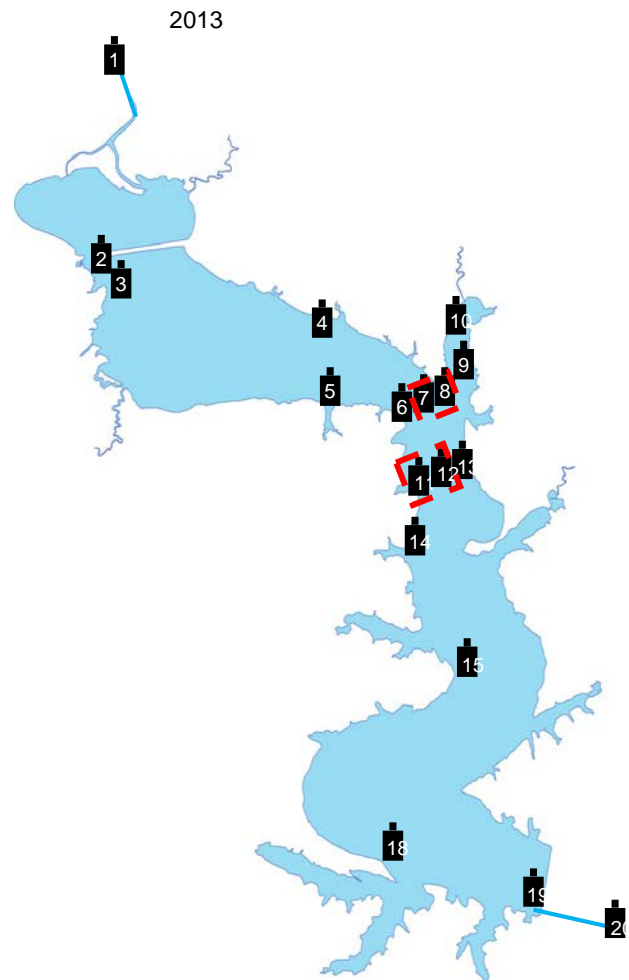
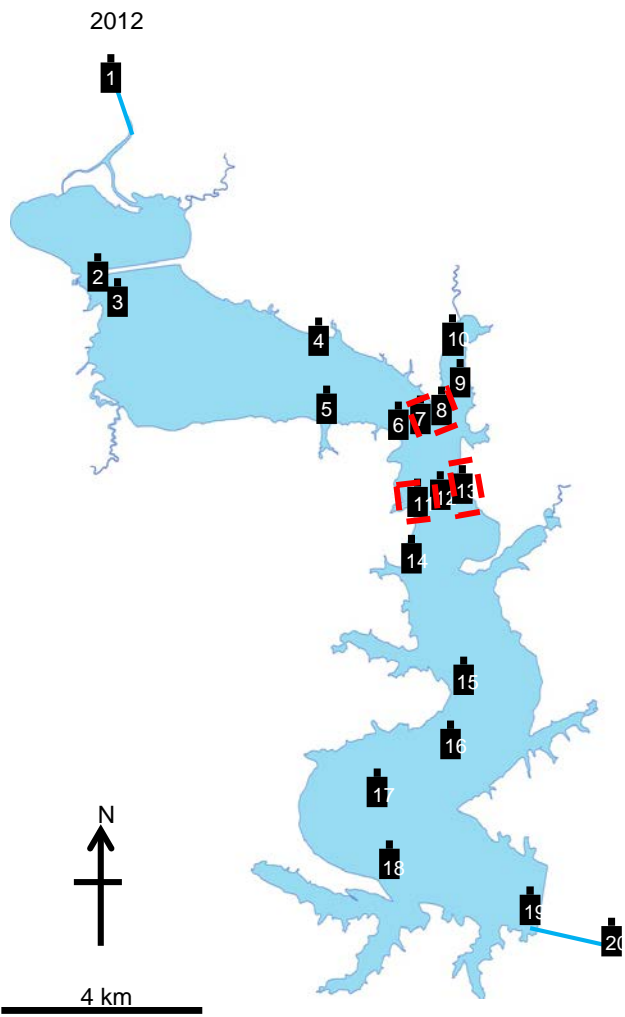
Peer-Reviewed Literature – Fish Tagging



Chapter 1 – Figure 1

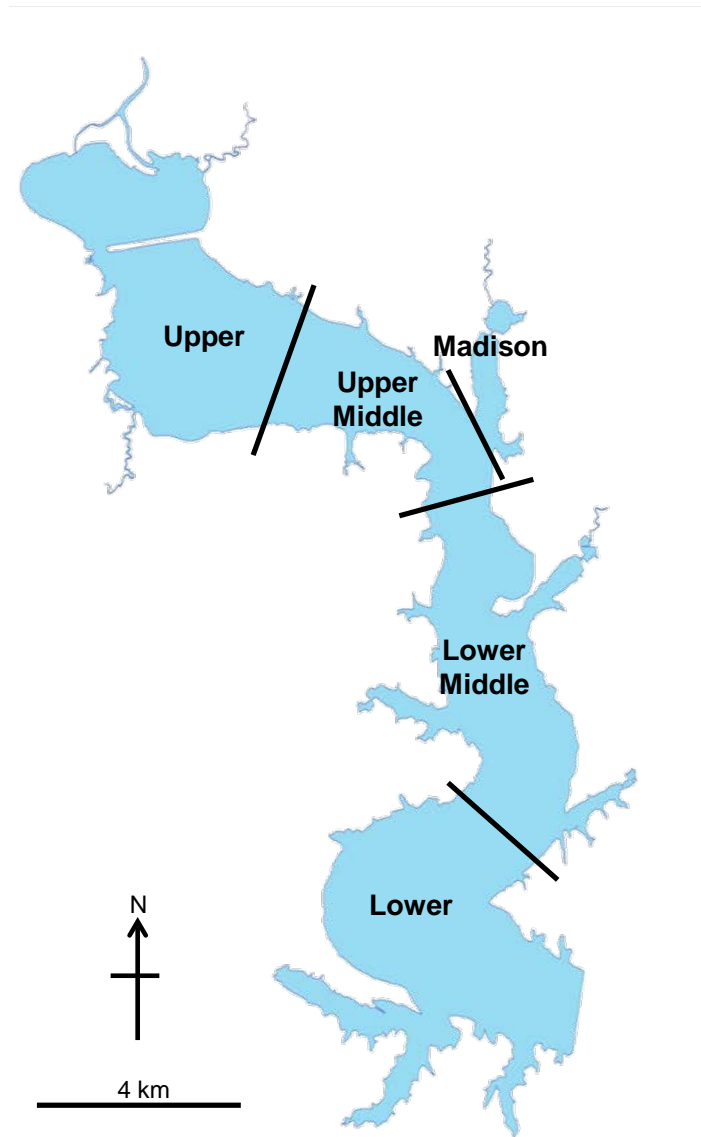


Chapter 1 – Figure 2



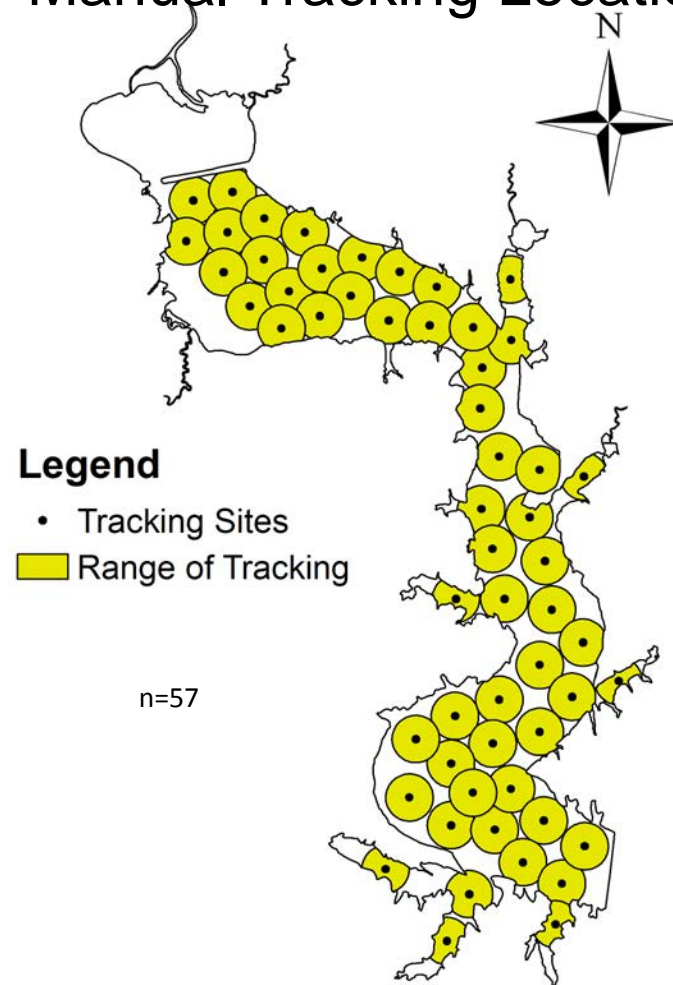
Chapter 1 – Figure 3

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

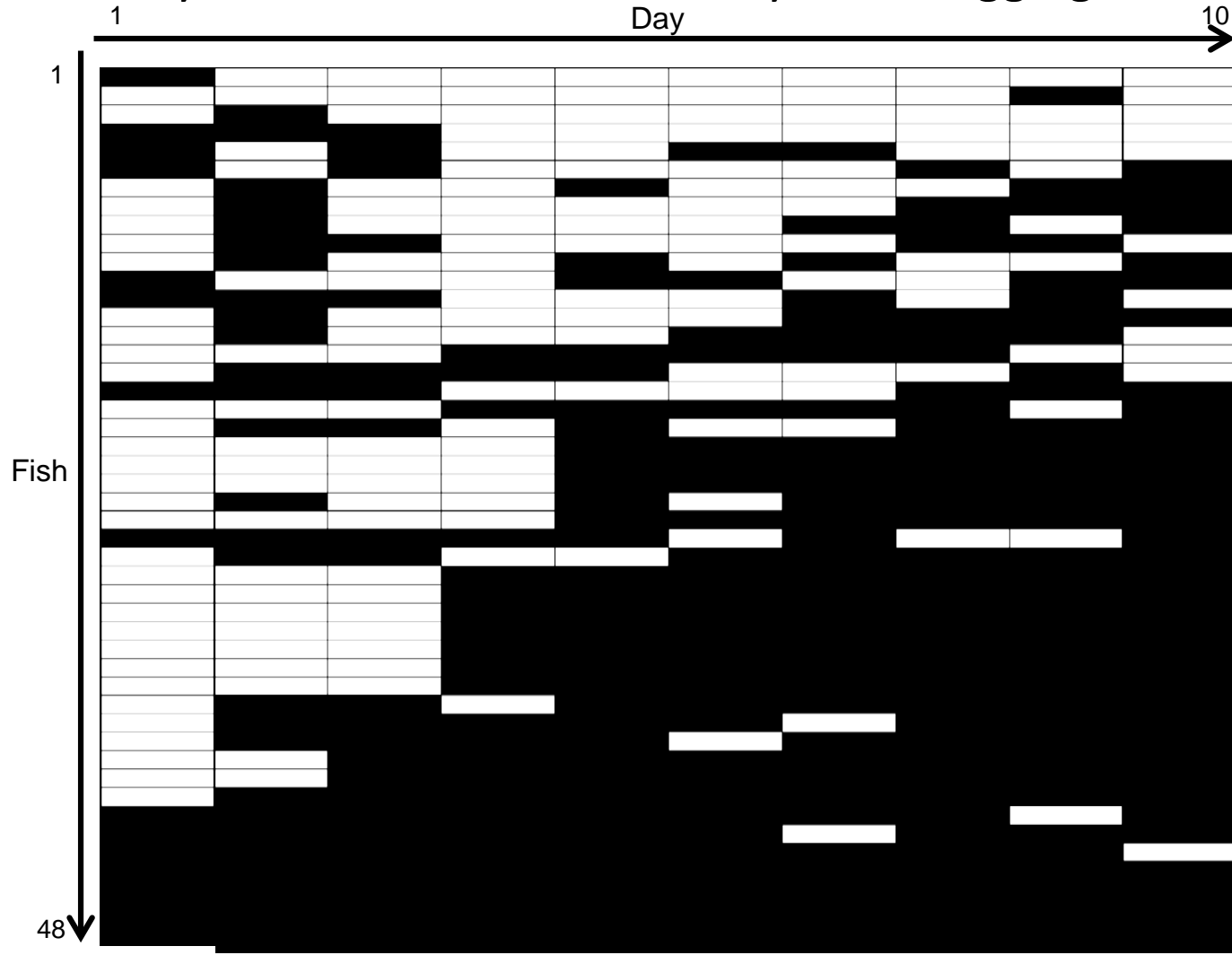


Chapter 1 – Figure 4

Manual Tracking Locations

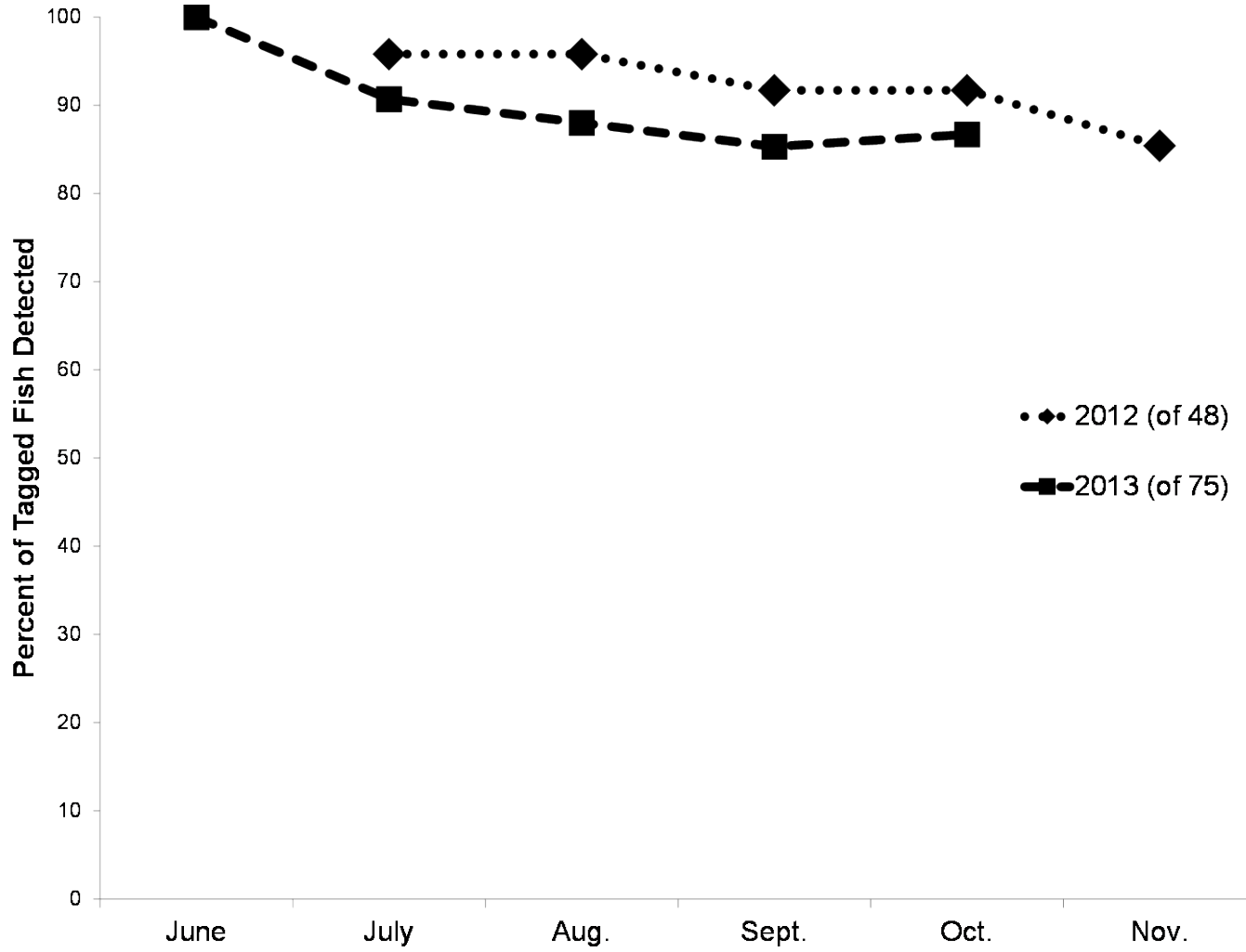


Daily Detections for First 10 Days Post Tagging - 2012

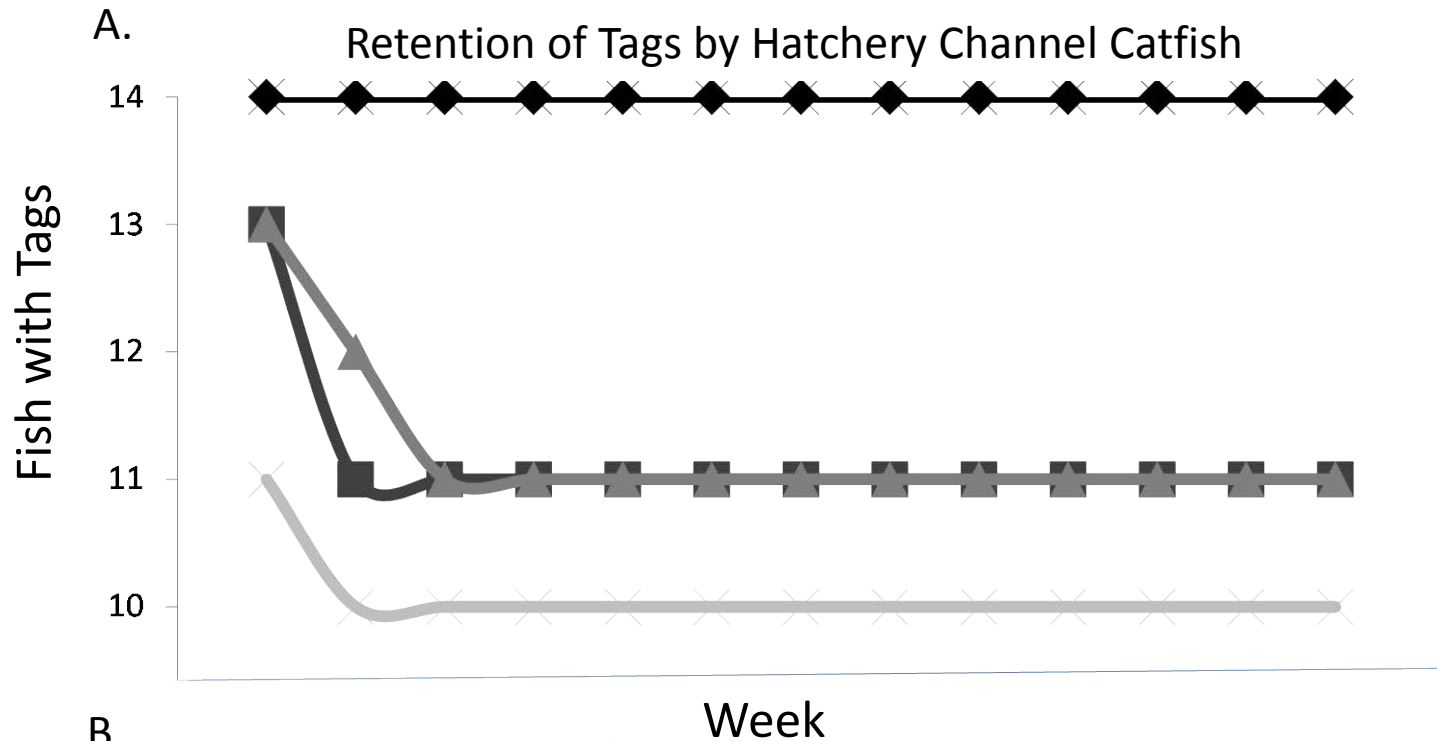


Chapter 1 – Figure 6

Detections of Blue Catfish Across 5 Months



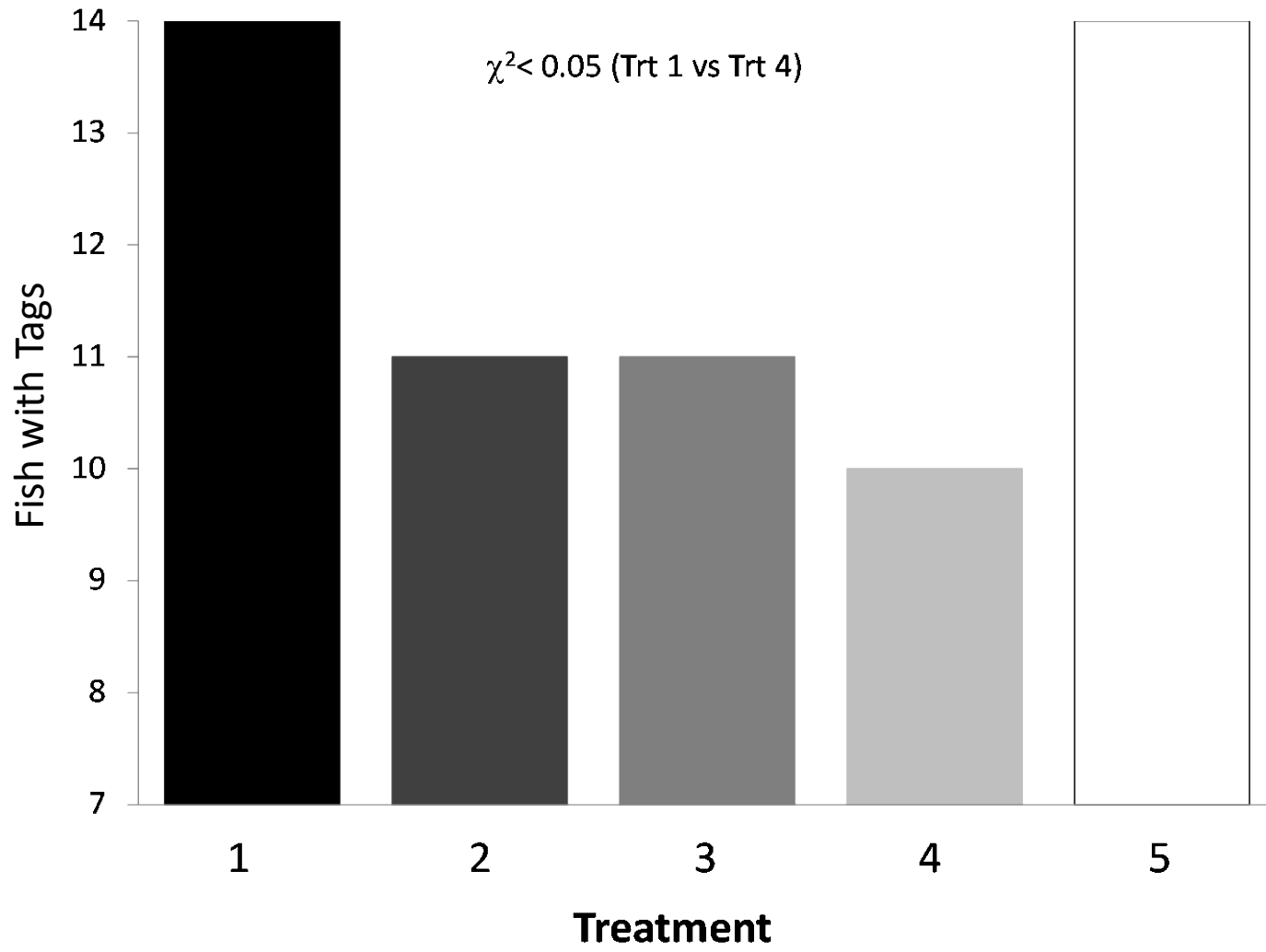
Chapter 1 – Figure 8



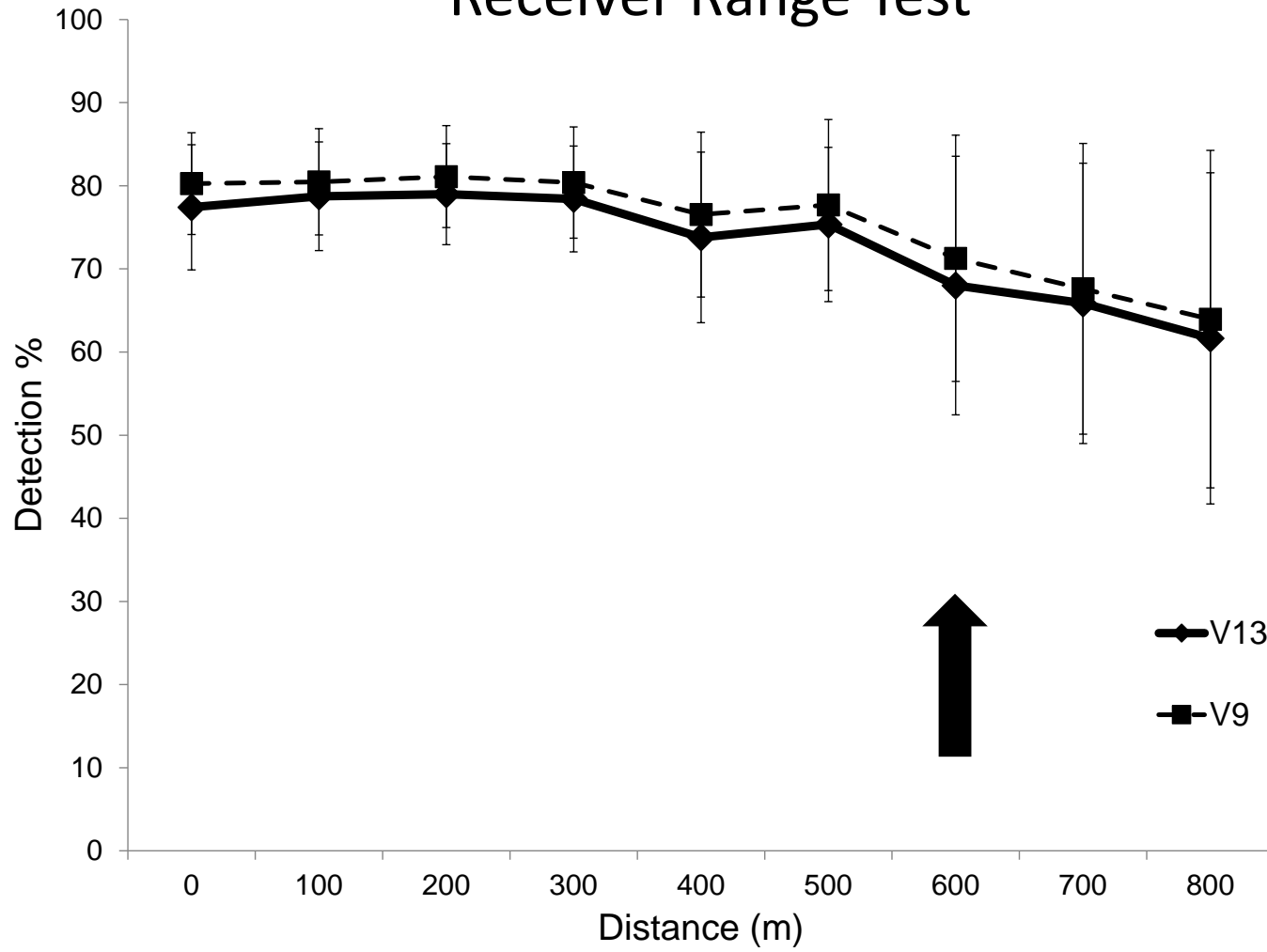
B.

	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

Retention of Tags by Hatchery Channel Catfish

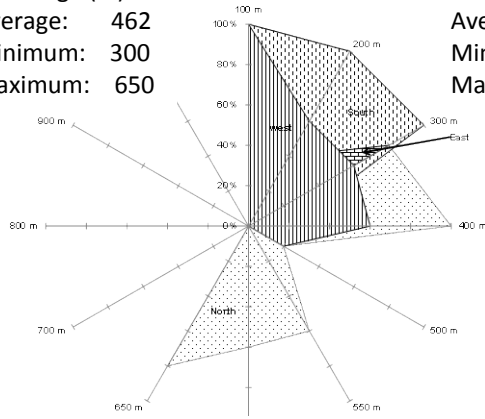


Receiver Range Test



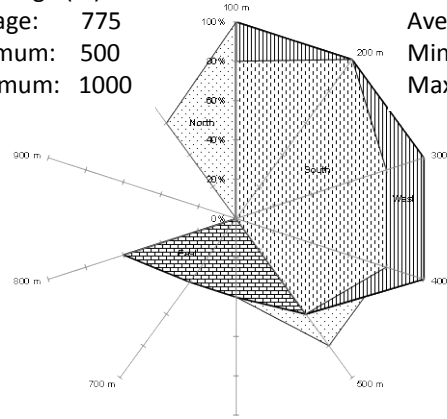
A. Receiver 4

Range (m)
Average: 462
Minimum: 300
Maximum: 650



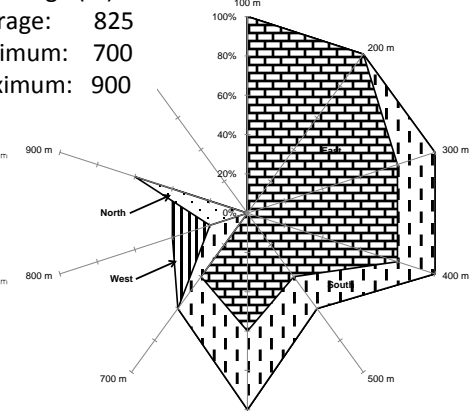
B. Receiver 7

Range (m)
Average: 775
Minimum: 500
Maximum: 1000



C. Receiver 2

Range (m)
Average: 825
Minimum: 700
Maximum: 900



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

3
4 **INTRODUCTION**

5 *Overview.* Flexibility in distribution is essential to the life history and ecological niche of
6 many taxa and is an adaptive response that allows animals to take advantage of spatial variation
7 in the fluctuation of resources (Baker 1978, Gross et al. 1988). However, mobility adds
8 complexity to quantifying distribution. Although many fish species change distributions for
9 spawning, foraging, and overwintering, little is known about geographically-localized
10 distribution patterns or the extent of individual or group variation within and across geographic
11 areas (Cadrin and Secor 2009). Until recently, researchers and managers had limited
12 methodological options for quantifying distributions of mobile organisms. This lack of
13 information on how mobile fish are distributed and if they move into and out of a study system
14 has been an obstacle for both research and management. Blue Catfish, *Ictalurus furcatus*, is a
15 model organism for addressing the tradeoffs between residency and mobility that influence
16 distribution patterns because of an array of life history features. Here, we use a newer technology
17 (acoustic telemetry and stationary receivers) to identify distributional patterns of Blue Catfish, if
18 tagged fish leave the reservoir in which they were tagged, and factors that may affect
19 distributional patterns (e.g., season, time of day, fish size, and individual variation).

20 *Importance of Knowing Distribution.* Knowing distribution is important for research and
21 management. Animals are not distributed evenly throughout their environments but instead
22 display spatially and temporally heterogeneous patterns (Albanese et al. 2004; Planque et al.
23 2011; Scheiner and Willig 2011). Understanding variation in distribution (Kennedy and Gray

24 1993; Jackson et al. 2001; Metcalfe 2006; Roberts and Angermeier 2007) is foundational for
25 research and management. For example, knowing fish distribution is important for stock
26 assessment and for the collection of biological samples (e. g. diets, scales, otoliths). Without
27 knowing where fish are located, effective sampling for survival, recruitment, growth, and other
28 research and management objectives will be ineffective. Anything less than a complete census
29 (i.e., sampling) gives a very limited view of where the fish are located. Consequently, most
30 existing distributional data on fish give a limited view of where fish spend their time.

31 *Mobility Adds a Special Challenge to Quantifying Distribution.* Blue Catfish, native to
32 large rivers throughout the United States, can move tens of kilometers in reservoirs and several
33 hundreds of kilometers in rivers (Graham 1999). Blue Catfish may move upstream in the spring
34 and summer (Lagler 1961, Graham 1999) in reservoirs (Timmons 1999; Grist 2002) and rivers
35 (Garrett 2010). They also move downstream in the fall and winter (Lagler 1961; Pflieger 1997;
36 Graham 1999) in reservoirs (Grist 2002) and rivers (Garrett 2010), including downstream
37 emigration out of reservoirs (Graham and DeiSanti 1999). Seasonal patterns may vary (Lagler
38 1961, Pflieger 1997; Graham 1999; Timmons 1999; Fisher et al. 1999; Grist 2002, Garrett 2010).
39 In addition, diel conditions can alter catfish distribution (Graham 1999; Pugh and Schramm
40 1999; Baras and Laleye 2003; Nunn et al. 2010). Variation in distribution and movement across
41 systems reinforces the need to compare patterns across catfish populations (Kwak et al. 2011).
42 Blue Catfish distribution in reservoirs is not well known, whether Blue Catfish exit reservoirs is
43 not well known, and how season, diel period, size, and individual variation affect Blue Catfish
44 distribution are not well known. Although little quantitative data exist on these issues,
45 researchers and managers have assumed certain patterns of Blue Catfish distribution that have

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

48 Smaller scale distribution patterns (e.g. daily, seasonal, non-breeding periods, ontogenetic
49 and habitat shifts; Werner and Gilliam 1984; Albanese et al. 2004; Roberts and Angermeier
50 2007; Albanese et al. 2009) and long distance migrations (Hobson 1999; Borcharding et al. 2002;
51 Roberts and Angermeier 2007) alter organismal distribution. New technology (e.g., electronic
52 tags) now allows for quantification of animal distributions (Hobson 1999; Metcalfe 2006). The
53 objectives of this chapter are to: (1) document locations of tagged Blue Catfish within Milford
54 Reservoir, (2) assess if Blue Catfish migrate out of Milford Reservoir, (3) quantify changes in
55 distribution across months and diel periods, (4) test if Blue Catfish size affects distribution, and
56 (5) identify whether groups of same-sized individual Blue Catfish are distributed in the same
57 way.

58

59

METHODS

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

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

69 implanted 48 Blue Catfish with VEMCO V9 acoustic tags (mean fish size = 487 mm TL, range
70 383-1020, SE 14.5, $n=48$). On 3-5 June, 2013, we internally implanted 75 Blue Catfish with
71 VEMCO 9 and V13 tags (mean fish size = 517 mm TL, range 343-1090, SE 17.8, $n=75$).
72 Tagging procedures are described in detail elsewhere (*Chapter 1*). Blue Catfish were collected at
73 three locations within Milford Reservoir: Causeway, Madison Creek, and School Creek. Fish
74 were released in the same location where they were caught and tagged. Equal numbers of fish
75 were tagged at each location on sequential days using identical protocols. We test whether
76 capture location affected distribution with a Kruskal-Wallis test and post-hoc multiple
77 comparison (kruskalmc, pgirmess package R).

78 *Receiver Placement.* In 2012 and 2013, we tracked tagged Blue Catfish with a 20-
79 stationary receiver array (deployed on the bottom) and a 57-site monthly manual receiver survey
80 (*discussed in Chapter 3*). For the stationary array, data were collected using VEMCO (VR2W-
81 69kHz) receivers which received coded pings from tags each time a tagged fish came within
82 range (i.e., 600 m of the receiver). In 2012, the receivers were placed at 18 locations within the
83 reservoir and two locations adjacent to the reservoir exits (*Chapter 1 Figure 3*). The upper river
84 receiver (receiver 1) and the upper within-reservoir receiver (receiver 2) formed a two-tiered gate
85 to detect upriver egress from the reservoir. The southernmost receivers in the reservoir (receiver
86 19) and the river receiver below the dam (receiver 20) formed a two-tiered gate to detect
87 downriver egress (*Chapter 1 Figure 3*). We also had two 3-stationary receiver gate arrays
88 (receivers 6-8, 11-13) across the mid-reservoir constriction (i.e., the limited width allowed
89 complete coverage of the entire reservoir as confirmed by range tests) to detect any fish that
90 moved through the middle region of the reservoir. In 2012, for data analysis, we removed data
91 from 2 of the 3 receivers in these gates (7, 8, 11, 13) to obtain a more even distribution of

92 receivers. Thus, in 2012, of the 18 within reservoir receivers, 14 were used for data analysis. In
93 2013, we deployed receivers similarly (May-November 2013; *Chapter 1 Table 5*). However,
94 receiver 1 was vandalized in August, 2013. Receivers 16-17 were lost due to vandalism or
95 boating collisions. Gate receiver 13 replaced gate receiver 12 because 12 was lost. As in 2012, in
96 2013, we also removed data from 2 of the 3 gate receivers (7, 8, 11, 12) for the same reasons.
97 Thus, in 2013, of the 18 within reservoir receivers, 12 were used for data analysis. Details of
98 array deployment and range testing are described in detail elsewhere (*Chapter 1*). Receivers were
99 grouped into five regions (upper, upper middle, Madison, lower middle, and lower; *Chapter 1*
100 *Figure 4*). The manual tracking survey, undertaken in June through November, 2013 (*described*
101 *in detail in Chapter 3*), was used to confirm stationary distribution data.

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

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

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

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

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

125 Numbers of unique individuals, residence time, and numbers of movements are all
126 approaches to quantifying the distribution of tagged fish. To obtain this metric, the above
127 described data base was manipulated by fish number and date for each receiver and the presence
128 of individual fish at a specific location at a specific time was recorded. Residence time is a
129 relatively new metric for fish tracking and is only possible with an extensive array of stationary
130 receivers as we have deployed here. Residence time, likely our most useful response, quantifies
131 how much time each animal spends at each location. For fixed receivers that record data 24 h day
132 in the same location, residence time is the preferred metric and replaces home range, which
133 typically requires detections at random not fixed locations. To calculate residence time, raw
134 detection data from the receivers were transformed into residence times for each fish at each
135 receiver location using VTrack (R 2.15.2 software; R Core Team) (Campbell et al. 2012). This
136 program records a fish as present (or resident) at a specific location after two detections and until
137 it is not detected for a period of time specified by the researchers (here 1 h). Movements between

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

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

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

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

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

171

172 RESULTS

173 *Overall.* In July - November, 2012, we recorded 1,139,515 detections. In June-October,
174 2013, we recorded 2,044,881 detections. These detections were made by 85% of the fish we
175 tagged. In 2012, five fish either died or lost their tags. In 2013, 11 fish died or lost their tags with
176 one fish a confirmed catch by an angler. These "missing" fish were not considered in the data
177 analysis.

178 *Distribution: Unique Individuals and Residence Time.* For both unique individuals and
179 mean residence time, tagged Blue Catfish did not spend equal amounts time in all areas of
180 Milford Reservoir. In 2012, for unique individuals, fish were concentrated in the upper middle
181 and lower middle regions of the reservoir with more fish than expected at receivers 4, 5, 6, 12,
182 14, 15 (*Chapter 2 Figure 3A, B*) and less fish than expected at receivers 2, 3, 9, 10, 17, 18, 19
183 (*Chapter 2 Figure 3A, C*). Chi square simulations statistically confirmed these patterns of

184 aggregation ($P < 0.001$; *Chapter 2 Figure 3B, C*). In 2013, for unique individuals, fish were again
185 concentrated in the upper middle and lower middle regions of the reservoir as well as in the
186 upper reservoir region, with more fish than expected at receivers 2-6, 9, 13-14 (*Chapter 2 Figure*
187 *4A, B*) and less fish than expected at receivers 10, 15, 18-19 (*Chapter 2 Figure 4A, C*). Chi
188 square simulations again statistically confirmed patterns of aggregation ($P < 0.001$; *Chapter 2*
189 *Figure 4B, C*).

190 In 2012, for mean residence time, fish were concentrated in the upper middle and lower
191 middle regions of the reservoir as well as Madison Creek with fish spending more time than
192 expected at receivers 6, 9, 10, 12 (*Chapter 2 Figure 5A, B*) and less time than expected at
193 receivers 2, 3, 4, 5, 14-19 (*Chapter 2 Figure 5A, C*). Chi square simulations statistically
194 confirmed these patterns of aggregation ($P < 0.001$; *Chapter 2 Figure 5B, C*). In 2013, for mean
195 residence time, fish favored the upper middle region with fish spending more time than expected
196 at receivers 4, 6 (*Chapter 2 Figure 6A, B*) and less time than expected at receivers 2, 3, 5, 10, 14-
197 15, 18-19 (*Chapter 2 Figure 6A, C*). Chi square simulations statistically confirmed patterns of
198 aggregation ($P < 0.001$; *Chapter 2 Figure 6 B, C*). For both responses in both years, this
199 clustering occurred in the funnel above the reservoir constriction (upper middle region) and
200 within the upper constriction (upper part of lower middle region).

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

207 and upper middle reservoir in spring as is shown by the repeated vertical lines of detections
208 (*Chapter 2 Figure 8*). Two of these fish were not detected subsequently because receivers were
209 removed at the end of the study (*Chapter 2 Figure 8A, B*). The remaining three fish traversed
210 frequently between receiver 2 and other reservoir receivers. These repeated movements back and
211 forth through the upper reservoir (i.e. repeating vertical bands of detections) are unlike the quick
212 unidirectional movement (i.e., one single vertical line) that would be expected for long-distance,
213 unidirectional upstream migrants (*Chapter 2 Figure 8C, E*). In summary, no fish left through the
214 downstream egress in either year, no fish left through the upstream egress in 2012, and < 3 of 75
215 tagged fish could have left the reservoir through the upper egress in 2013. Because our 2012 and
216 2013 field seasons corresponded with a regional drought, discharge was relatively low in June
217 through November in either year (*Chapter 2 Appendix Figure 2*).

218 *Seasonal Differences.* Seasonal distribution varied across select receivers in 2012
219 (*Chapter 2 Figure 9*) and 2013 (*Chapter 2 Figure 10*). When comparing boxplots for residence
220 time across months, in 2012, fish spent more time at upper reservoir receiver 2 in October (2;
221 $P < 0.05$; *Chapter 2 Figure 9A*), but less time at upper reservoir receiver 3 in November (3;
222 $P < 0.05$; *Chapter 2 Figure 9B*). No statistically significant monthly differences existed across
223 other receivers in the upper middle region (4, 5, 6; $P > 0.05$; *Chapter 2 Figure 9C-E*), Madison
224 Creek (9, 10; $P > 0.05$; *Chapter 2 Figure 9F, G*) or in select lower middle reservoir receivers (12;
225 $P > 0.05$; *Chapter 2 Figure 9H*). However, other lower middle reservoir receivers (14-15; $P < 0.05$;
226 *Chapter 2 Figure 9I, J*), and lower reservoir receivers (16-19; $P < 0.05$; *Chapter 2 Figure 9K-N*)
227 were significantly different across months. For these southern receivers, residence times were
228 higher in the fall. In general, these seasonal changes reflected decreases in residence time at
229 upper reservoir receivers and increases in residence time at lower reservoir receivers in fall as

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

232 Seasonal trends in 2013 were more variable. In 2013, upper reservoir receivers again had
233 variable visitation across months (2, 3; $P < 0.05$; Chapter 2 Figure 10A, B). In 2013, fish again
234 spent more time at lower reservoir receivers in the later fall (18, 19; $P < 0.05$; Chapter 2 Figure
235 10K, L) as fish moved from north to south. In 2013, upper middle receivers (4, 5; $P < 0.05$;
236 Chapter 2 Figure 10C, D) and Madison Creek receivers (9, 10; $P < 0.05$; Chapter 2 Figure 10F,
237 G) differed across months but a consistent overall trend was unclear. Other upper middle (6) and
238 lower middle reservoir receivers (13, 14) were not significantly different across months ($P >$
239 0.05 ; Chapter 2 Figure 10E, H, I). As in 2012, for 2013, this pattern generally reflected higher
240 use of the lower region of the reservoir in fall. In fact, more movements occurred at receivers in
241 the lower middle and lower reservoir (receivers 12-18) in the fall (Chapter 2 Figure 11) even
242 though movements were not greater for these lower reservoir receivers when all time periods
243 were combined (Chapter 2 Figure 12).

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

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

253 Causeway site (near receiver 5; *Chapter 2 Figure 17 D, 18D*) were detected more frequently at
254 receiver 5 (*Chapter 2 Figure 17 D, 18D*) and at the adjacent receivers 4 and 6 (*Chapter 2 Figure*
255 *17C,17E, 18C. 18E*). Tagged Blue Catfish that were captured, tagged and released at the
256 Madison site (near receiver 9; *Chapter 2 Figure 17F, 18F*) were detected more frequently at
257 receiver 9 (*Chapter 2 Figure 17F, 18F*) and at the adjacent receivers 6 and 10 (*Chapter 2 Figure*
258 *17E, 17G, 18E, 18G*). Tagged Blue Catfish that were captured, tagged and released at the School
259 Creek site (near receiver 15; *Chapter 2 Figure 17J, 18J*) were detected more frequently at
260 receiver 15 (*Chapter 2 Figure 17J, 18J*) and at the adjacent receiver 14 (*Chapter 2 Figure 17I,*
261 *18I*). These trends were not surprising since the fish were aggregated at Causeway, Madison, and
262 School Creek when there were captured and continued to stay in those aggregations after they
263 were tagged and released. These results do not alter any of the interpretations of our data because
264 we captured and released fish in the same location.

265 *Cluster Synthesis.* With cluster analysis, we identified that different groups of individual
266 fish existed. Within groups, individuals were distributed similarly, but across groups differences
267 in distribution existed. By combining clusters across seasons, we identified three types of
268 distribution. The first type of distribution included fish that changed their seasonal distribution
269 (*Chapter 2 Figure 19*). In July and August, these fish were most common at receiver 6 (*Chapter*
270 *2 Figure 19A, B*). In September, eight clusters emerged that were spread throughout the upper
271 middle, lower middle, and lower reservoir (*Chapter 2 Figure 19C*). In October and November,
272 these clusters merged into one mega cluster that frequented the lower middle and lower
273 reservoir, especially receivers 12-19 (*Chapter 2 Figure 19D, E*).

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

276 20A-E). This distribution group was composed of a single cluster in July and August (*Chapter 2*
277 *Figure 20A, B*). This distributional group did not migrate south in fall, and across all seasons
278 remained in the upper middle and lower middle reservoir near receivers 6 and 12 (*Chapter 2*
279 *Figure 20C-E*).

280 A third type of distribution group included the Madison Creek fish (*Chapter 2 Figure*
281 *21A-E*) that stayed near Madison Creek receivers (9, 10) in July (*Chapter 2 Figure 21A*),
282 September (*Chapter 2 Figure 21C*), October (*Chapter 2 Figure 21D*), and November (*Chapter 2*
283 *Figure 21E*). These synthesis groups were derived from the original monthly clusters which are
284 presented here as an appendix but are not interpreted separately (*Chapter 2, Appendix Figures 3-*
285 *32*).

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

289

290

DISCUSSION

291 *Overview of Unique Contributions of Our Research.* Our extensive Blue Catfish tracking
292 data set provided novel insights into a long-standing, but largely untested, question in fisheries
293 biology, fisheries management, and fish ecology (e.g., where are fish located?). Our unique data
294 set is unprecedented relative to the numbers of tagged fish, numbers of detections, temporal
295 extent of detections, and spatial distribution of detections. Specifically, our research design
296 included 123 fish tagged across 2 years, 85% tag retention over 5 months per year, continuous
297 24-h tag detections during summer and fall; 2 tiers of gates at each reservoir egress point; 2 3-
298 receiver, across-reservoir gates; and a 12-14-stationary receiver array distributed throughout the

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

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

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

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

344 *Egress.* We did not detect any tagged Blue Catfish migrating out of Milford Reservoir
345 from June through November, 2012-2013, based on our continuous (24 h a day) tracking of 123
346 tagged fish at double egress gates at both upstream and downstream exits. We know that 85% of
347 the fish, tagged in both years, do not leave the reservoir because they were continually detected
348 at specific locations within the reservoir. We know for certain that no tagged Blue Catfish left
349 downstream past the dam in 2012 or 2013 because of our intact double gates at downstream
350 egress points (receivers 19 upstream of the dam; receiver 20 downstream of the dam) in both
351 years. We also know for certain that none of the 48 fish tagged in 2012 left the reservoir through
352 the upstream exit because of the presence of an intact double gate at the upstream egress point
353 (receiver 1; receiver 2). During the last part of the 2013 field season, receiver 1 was lost.
354 Unfortunately, receiver loss is common in tracking studies with fixed gear. However, the second
355 or inner tier of the upper gate (i.e., receiver 2) remained in place throughout the 2013 field
356 season and allowed us to evaluate if any tagged Blue Catfish might have exited the reservoir
357 using this route. Only five of 75 Blue Catfish, tagged in 2013, were last seen at receiver 2. Of
358 these, two were not redetected because the study ended and receivers were removed. Thus, the
359 ultimate fate of < 3 of 75 Blue Catfish tagged in 2013 is uncertain. Because these three fish
360 repeatedly moved back and forth between receiver 2 and other reservoir receivers, it is unlikely
361 that these three fish left the reservoir in 2013. Despite the unknown final disposition of these
362 three fish, our data clearly indicate that most Blue Catfish tagged in Milford Reservoir in 2012-
363 2013 did not make long distance migrations out of the study system in our summer-fall field
364 season.

365 In other studies, upriver or up-reservoir movements of Blue Catfish have been observed
366 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

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

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

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

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

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

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

435 evolutionary impacts, which can affect species distributions and responses to environmental
436 change (Sih et al. 2004; Flaxman et al. 2011). Behavior of animals has been used in very few
437 studies to try to understand its influence on the spatial structure of populations (Knaepkens et al.
438 2005; Giuggioli and Bartumeus 2010; Fullerton et al. 2010). Within the behavioral syndrome
439 literature, few have used distribution patterns to distinguish groups of individuals. The patterns
440 we observed may be an example of behavioral syndromes based on distribution,

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

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

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

465 *Management Implications.* Our research on distribution has several management
466 implications. First, we have provided substantial information on where Blue Catfish are located.
467 Knowing distribution is critical for all management and research activities. Existing data on
468 distribution are very limited. Using a newer technology, we have compiled the best
469 understanding we have ever had of where Blue Catfish are located in Milford Reservoir. Our
470 spatially explicit approach suggests that fish are highly aggregated often in consistent locations.
471 Trends were surprisingly similar across years. If managers can identify the locations of these
472 Blue Catfish clusters in other reservoirs, they should be able to better assess the stock and more
473 effectively collect biological samples (e.g., diet, aging structures). To find these clusters,
474 managers might implement an extensive survey in which they systematically sample the entire
475 reservoir to identify patterns of aggregation. For example, in the future, managers might shock
476 50 locations once rather than 10 locations five times.

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

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

488 Third, the number of empirical studies on Blue Catfish distribution, movement, and
489 habitat is increasing. However, at present, each one represents an isolated data point because of
490 system-specific differences in morphometry, bathymetry, habitat, and researcher-specific
491 methodological differences across studies. Researchers and managers would benefit from a
492 standardized synthesis of what is actually known about Blue Catfish distribution and movements
493 across a wide range of states and ecological systems. This synthetic working group effort could
494 formulate a range of broader questions of interest then use existing data to objectively test
495 hypotheses about distribution and movements.

496 Some management utility may arise from the awareness that discrete groups of same-
497 sized fish can differ in their distribution. These results are novel in the field of freshwater fish
498 biology and management. As such, their present applications are unclear. However, knowledge
499 of this pattern could be useful in the future. For example, awareness that a subset of Blue Catfish
500 in Milford Reservoir remain within Madison Creek could influence habitat management,
501 restoration, and planning.

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

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

507 In summary, our data have addressed the research objectives of the original study. Of
508 course, as in any complex research and management area, a host of important questions about
509 distribution and movement remain. Nevertheless, our study has provided a wealth of information
510 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	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

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

3
4 **CHAPTER 2 FIGURE CAPTIONS**

5
6 *Chapter 2 Figure 1.* (A) Our study site, Milford Reservoir, is an impoundment of (B) the Lower
7 Republican River watershed in (C) northeastern Kansas.

8
9 *Chapter 2 Figure 2.* Examples of a trajectory made by a single tagged Blue Catfish that
10 illustrates select components of a complex trajectory pattern. Residence time quantifies how long
11 a tagged fish is at a single receiver location when detections for the entire time period of interest
12 are summed. Numbers of movements quantifies how many times a fish moves from receiver to
13 receiver for the entire period of interest. Numbers of unique individuals (i.e., the presence of a
14 single individual fish) and mean residence time are metrics that quantify the distribution of all
15 individuals together (i.e., the tagged population).

16
17 *Chapter 2 Figure 3.* (A) The spatial distribution of *unique individuals* (number) is shown for 48
18 tagged Blue Catfish at 14 receivers (18 receivers with four gate receivers removed) in 2012.
19 Each dot represents a receiver location. The size of the dot is proportional to numbers of unique
20 individuals. Also shown are the results of a Chi square analysis that identifies at which receivers
21 (B) more unique individuals occurred than were expected and (C) fewer unique individuals
22 occurred than were expected based on an even distribution (i.e., the same number of fish at all
23 receivers). In B-C, receiver numbers are shown. On the map in A, dark gray dots indicate more

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

26

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

36

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

46

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

56

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

66

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

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

76

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

86

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

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

95

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

98

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

101

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

111

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

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

120

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

125

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

128

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

139

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

149

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

162

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

173

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

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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.

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

209

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

213

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

217

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

221

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

225

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

229

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

233

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

237

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

241

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

245

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

249

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

253

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

257

258 *Chapter 2 Appendix Figure 18.* Shown is a silhouette plot identifying clusters based on residence
259 time for September. Identity and Jaccard bootstrap values for all clusters are indicated.

260 Appendix Figures 17-21 depict a single cluster analysis.

261

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

265

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

269

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

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273

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

277

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

281

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

285

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

289

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

293

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

297
298 *Chapter 2 Appendix Figure 28.* Shown is a silhouette plot identifying clusters based on residence
299 time (h) for November. Identity and Jaccard bootstrap values for all clusters are indicated.

300 Appendix Figures 27-31 depict a single cluster analysis.

301

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

305

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

309

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

313

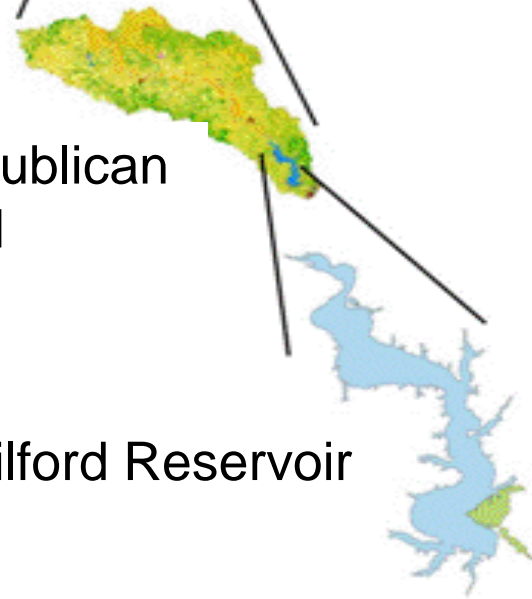
314 *Chapter 2 Appendix Figure 32.* For the clusters in November, shown are boxplots of residence
315 times for receivers 18 and 19. The Y axis is residence time (h); the X axis is cluster number.
316 These data are means for all individual fish in a cluster.

Study System

C. Kansas



B. Lower Republican Watershed

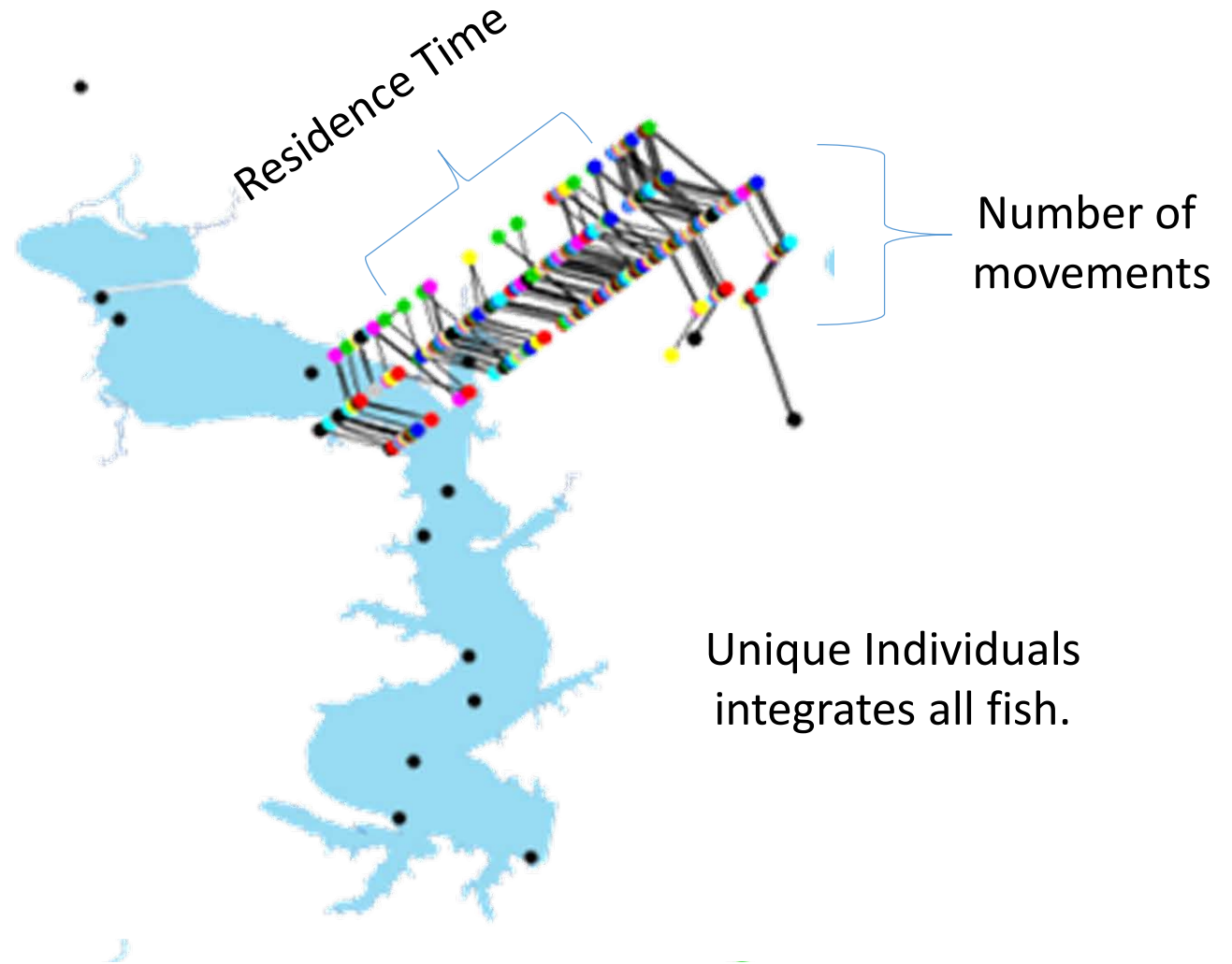


A. Milford Reservoir

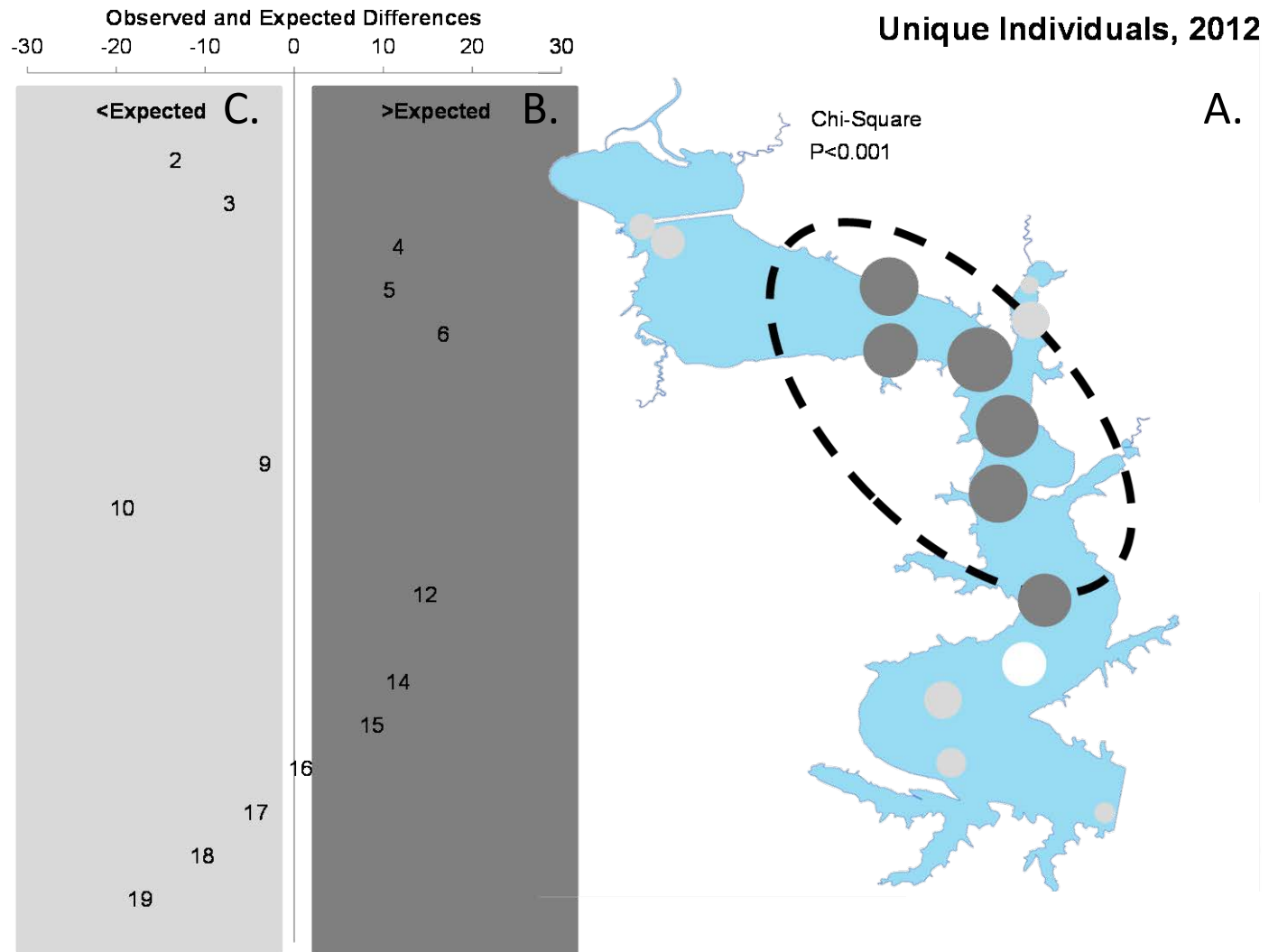


Chapter 2 Figure 1

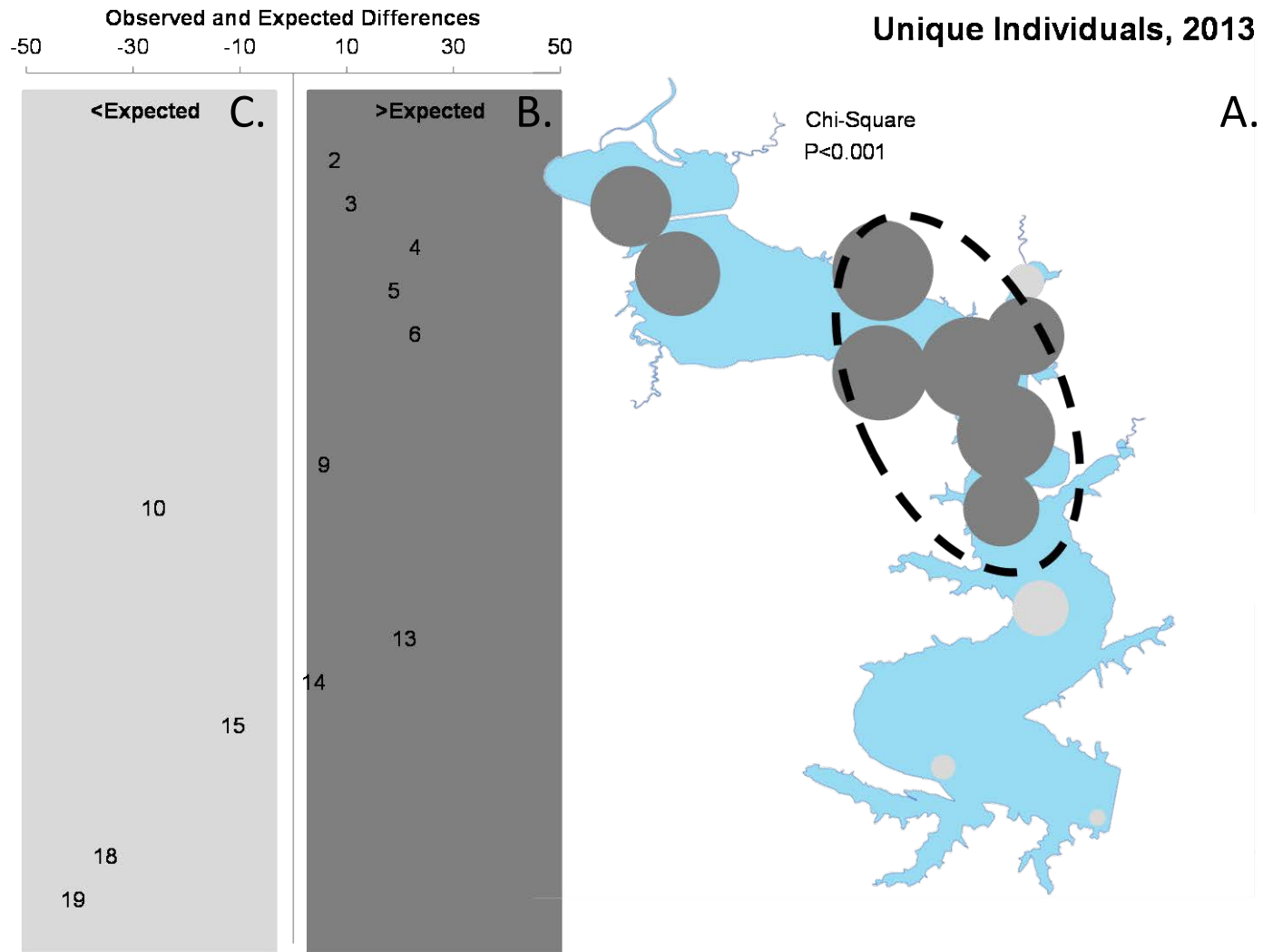
Components of a Blue Catfish Trajectory



Chapter 2 Figure 2



Chapter 2 Figure 3



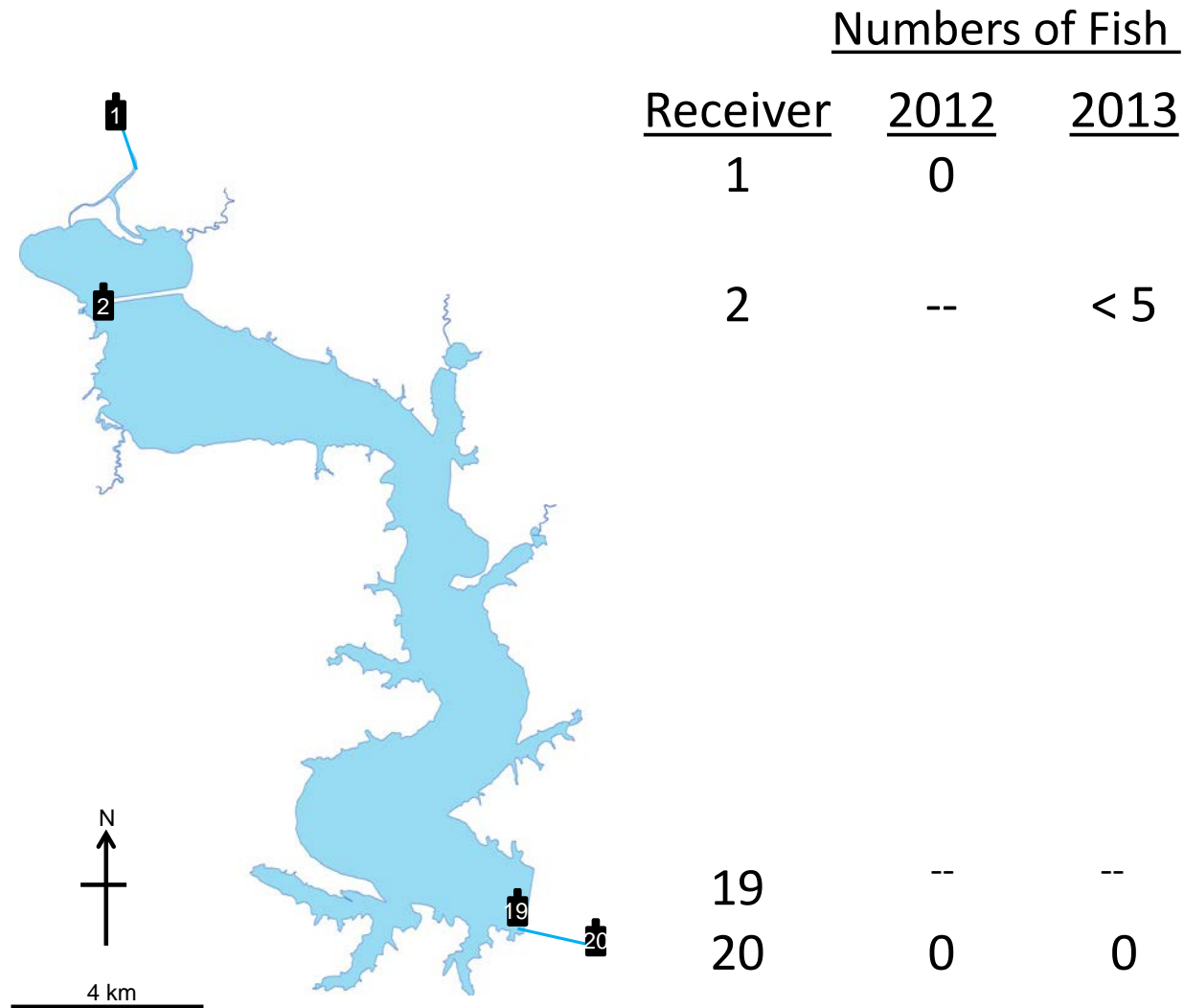
Chapter 2 Figure 4



Chapter 2 Figure 5

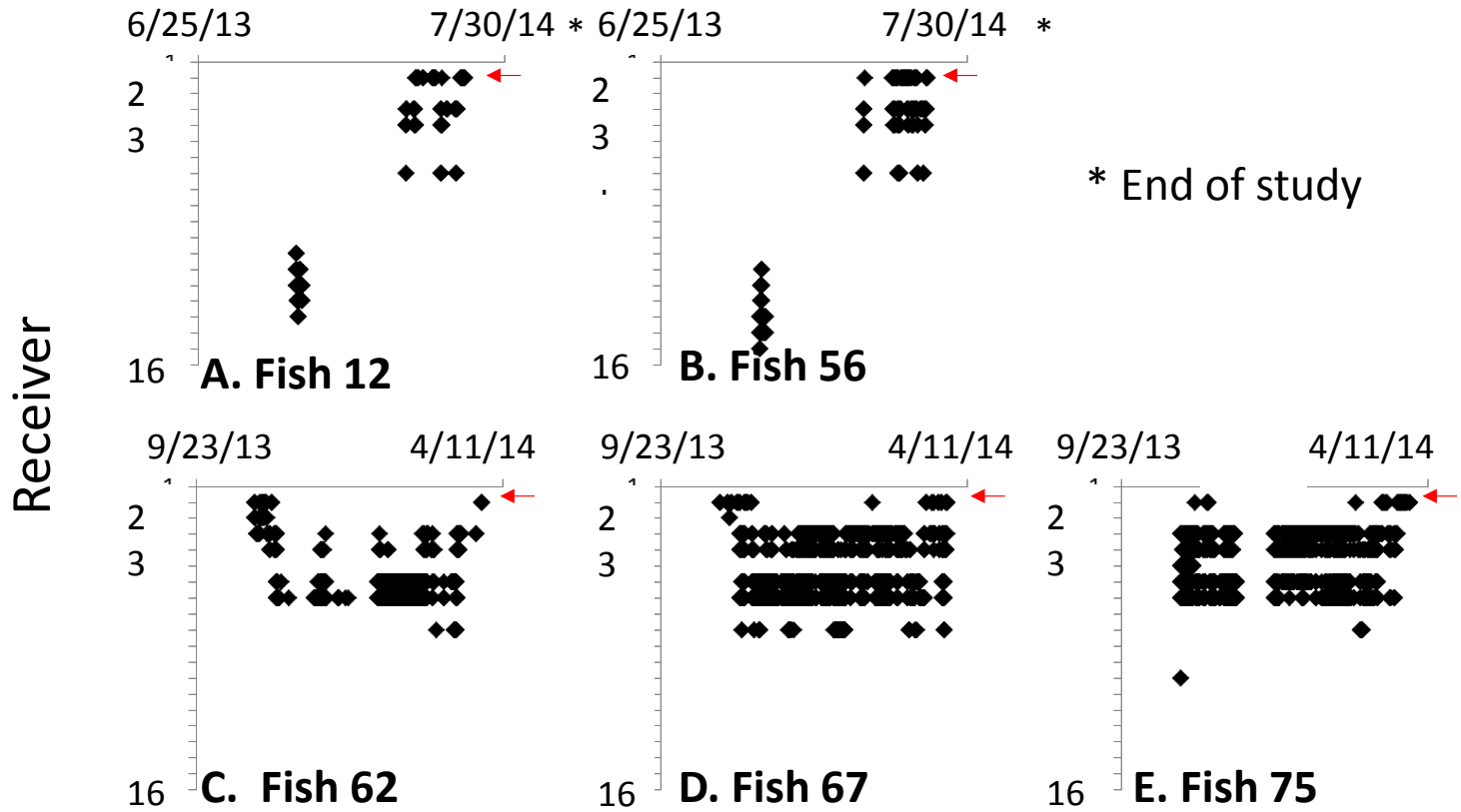


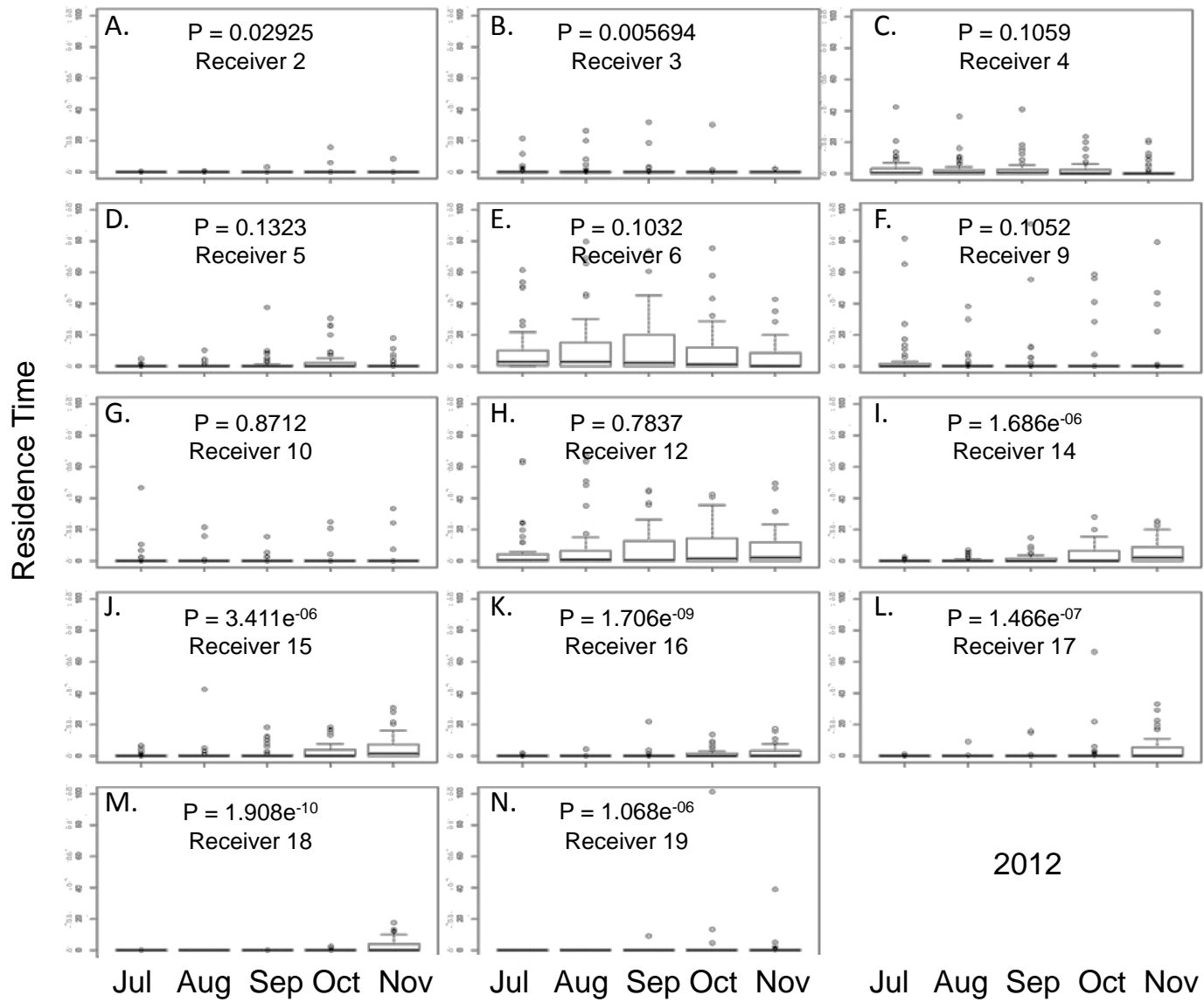
Chapter 2 Figure 6



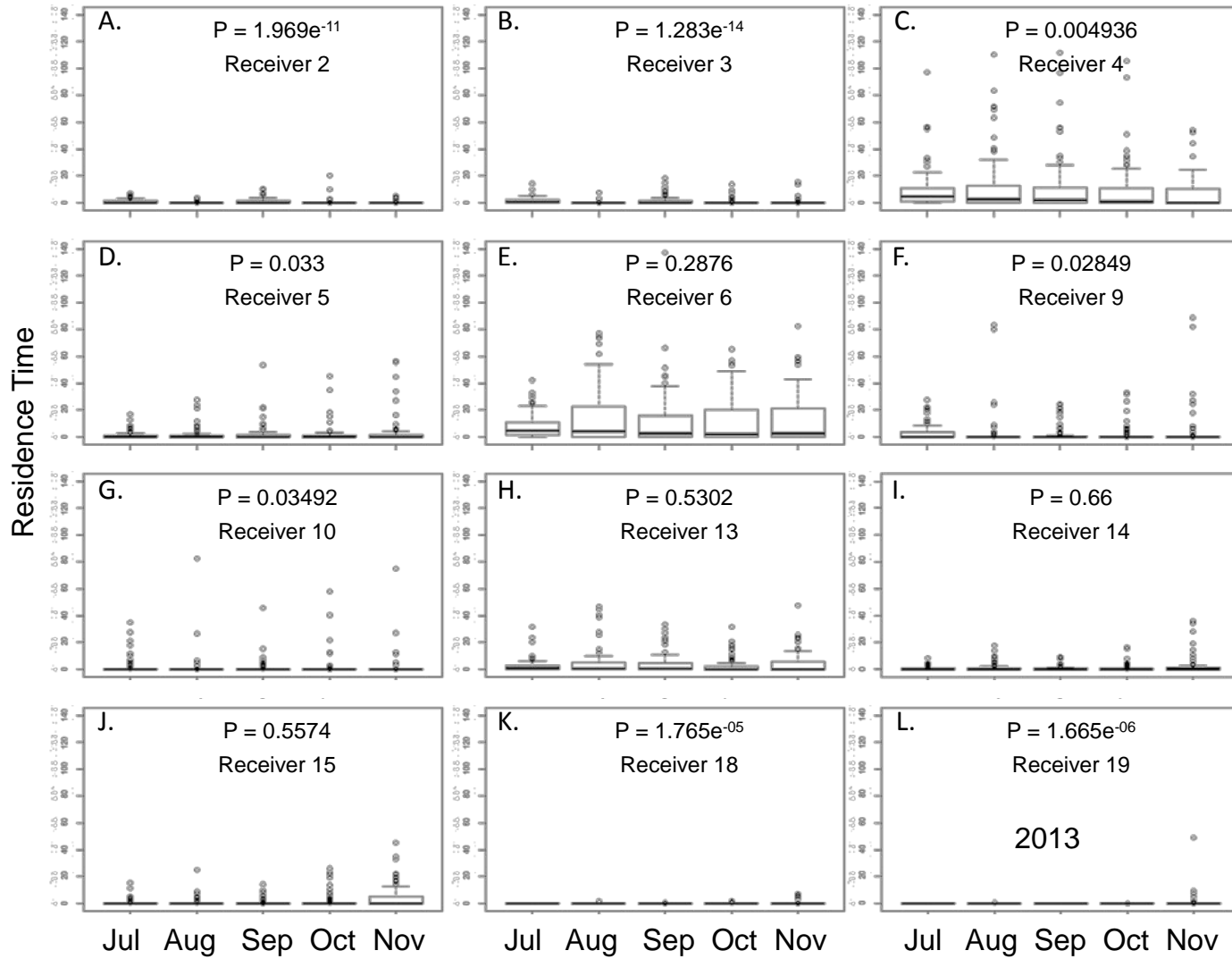
Chapter 2 Figure 7

Five Fish Last Seen At Receiver 2

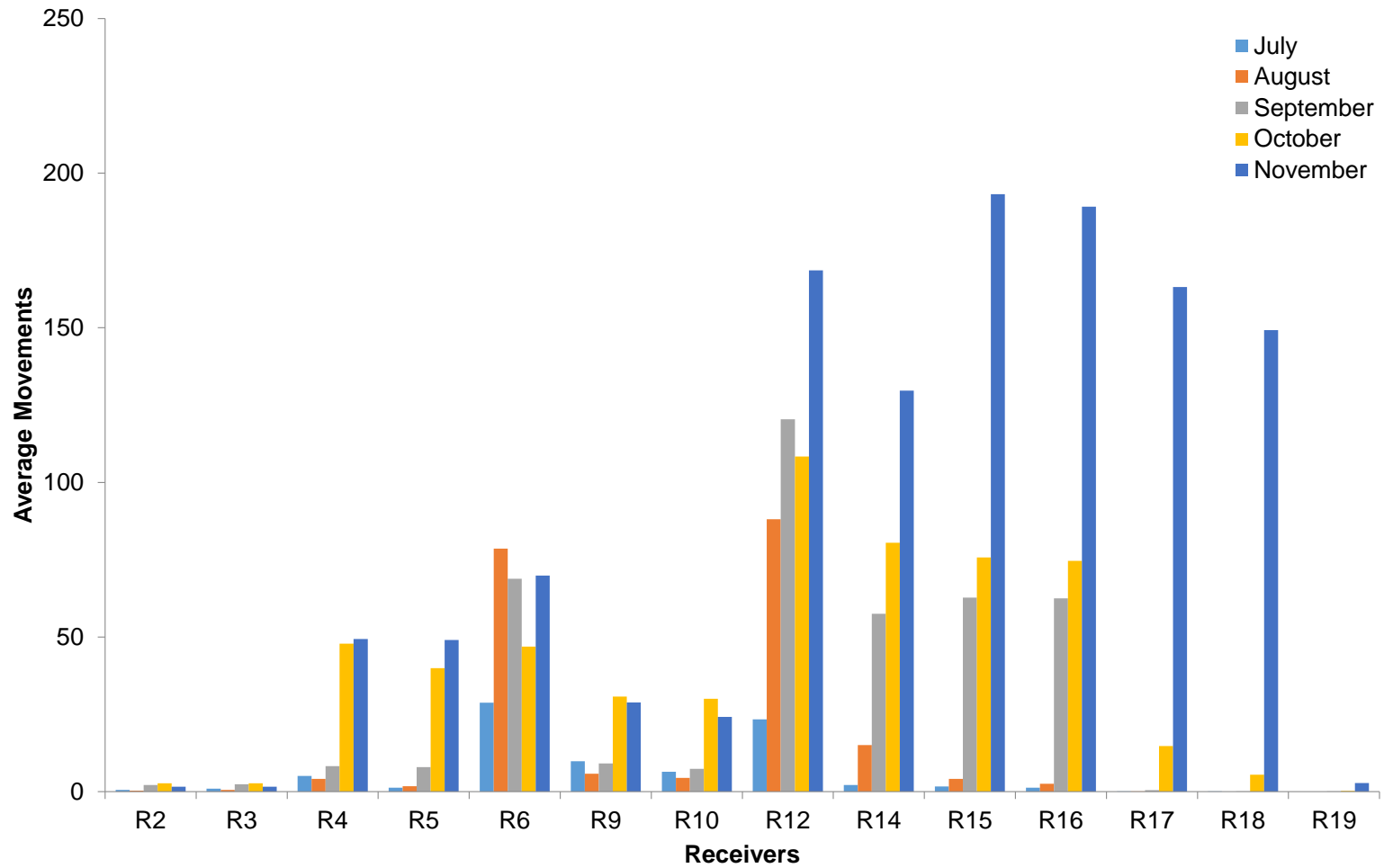




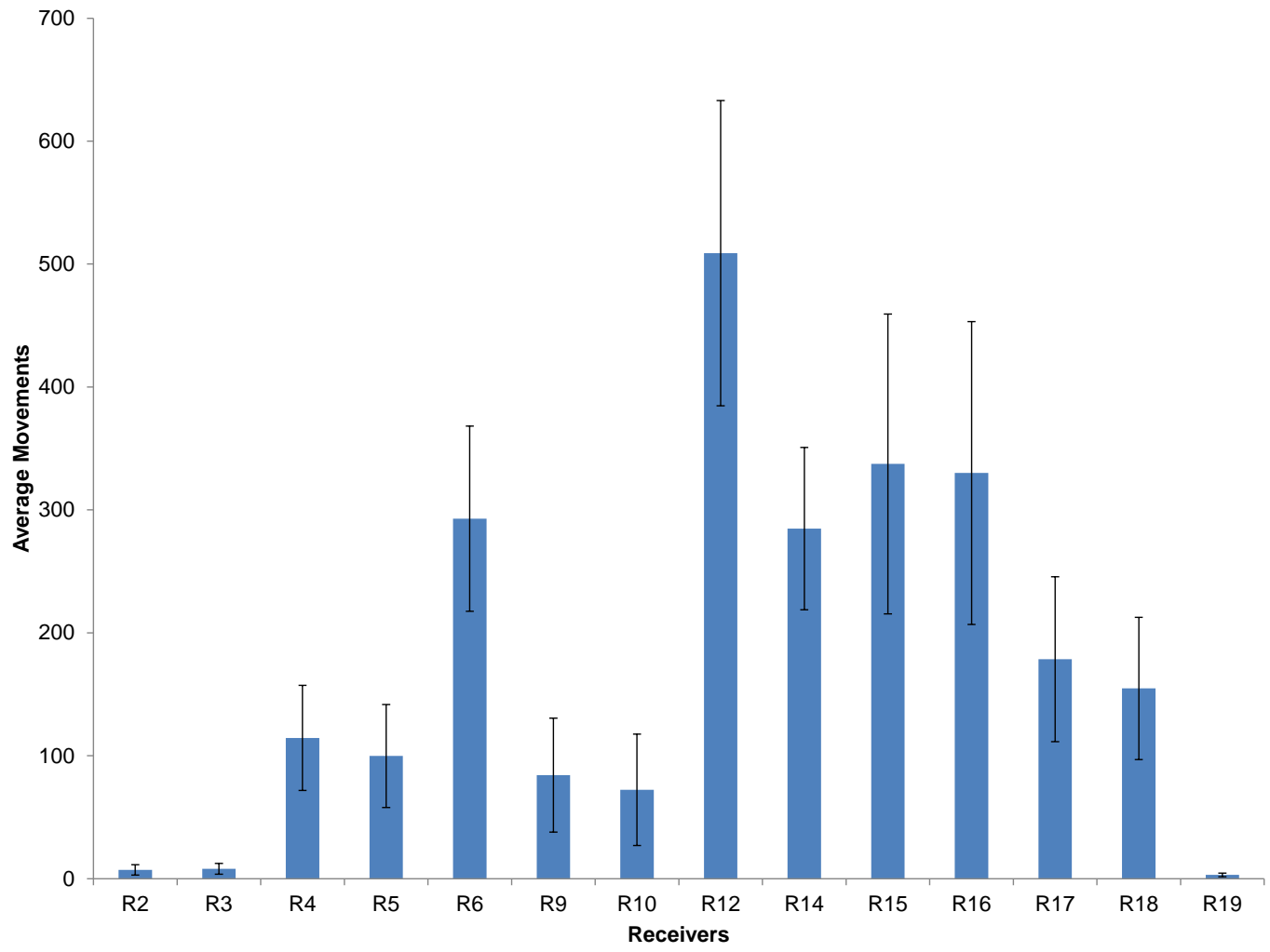
Chapter 2 Figure 9



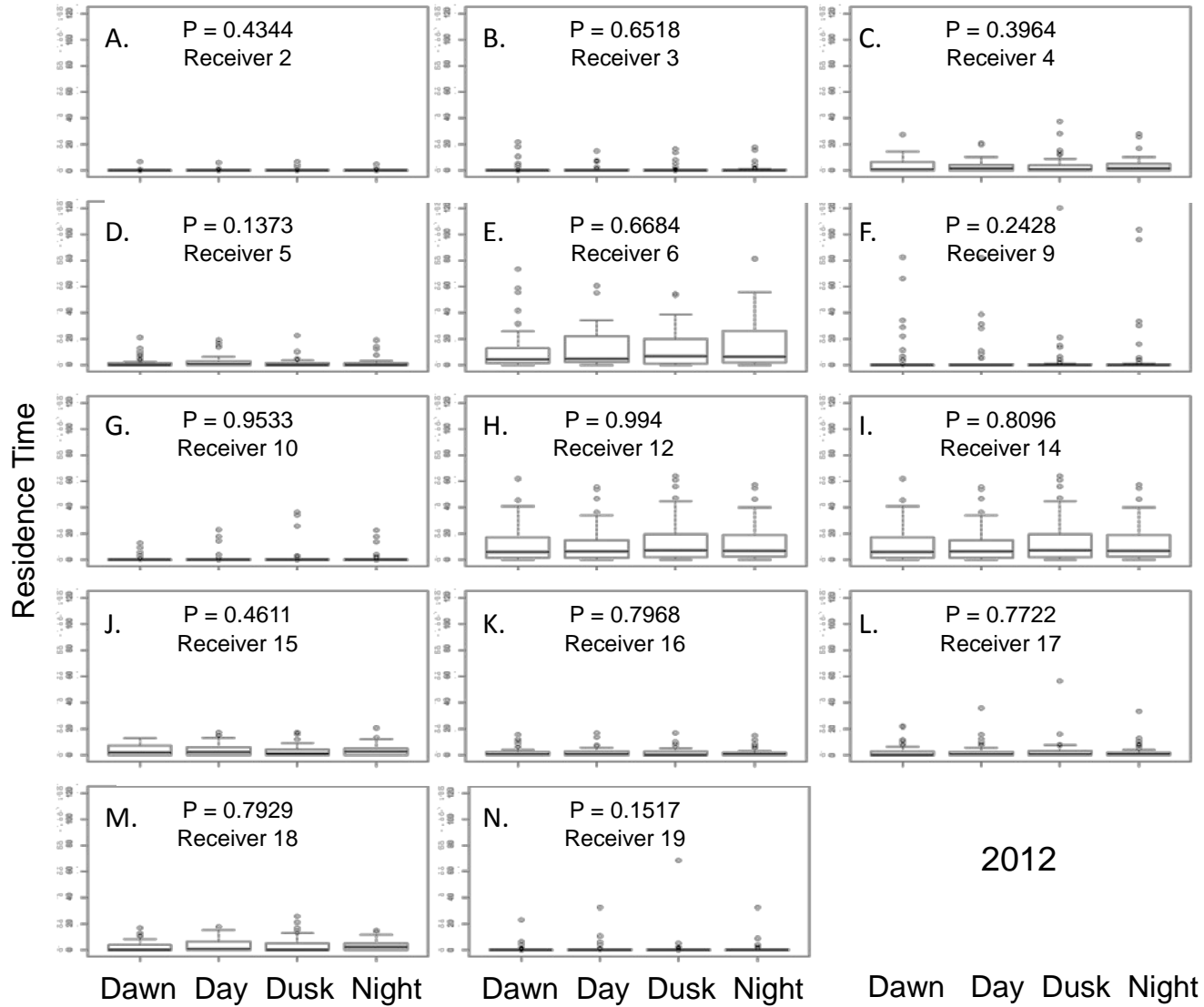
Chapter 2 Figure 10



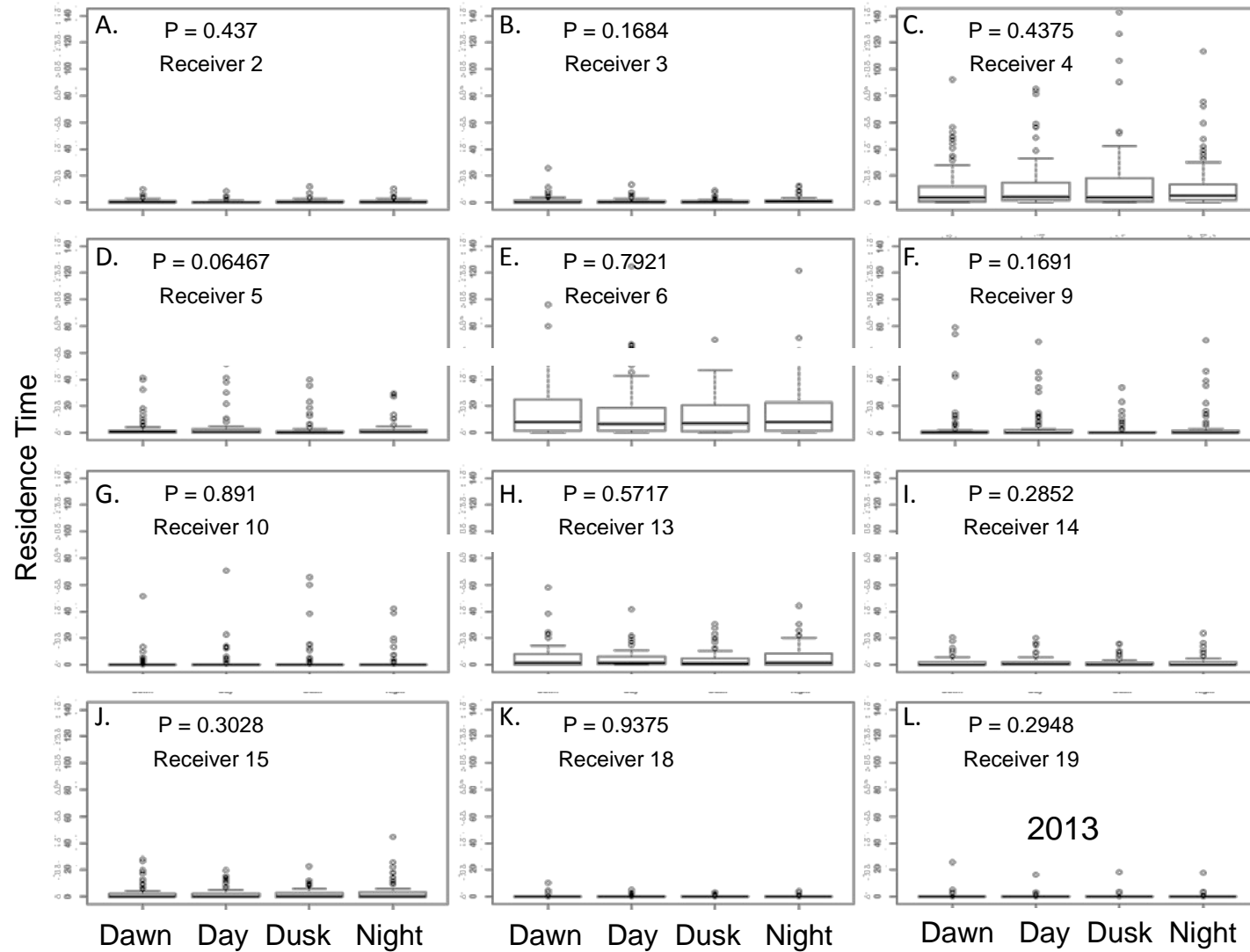
Chapter 2 Figure 11



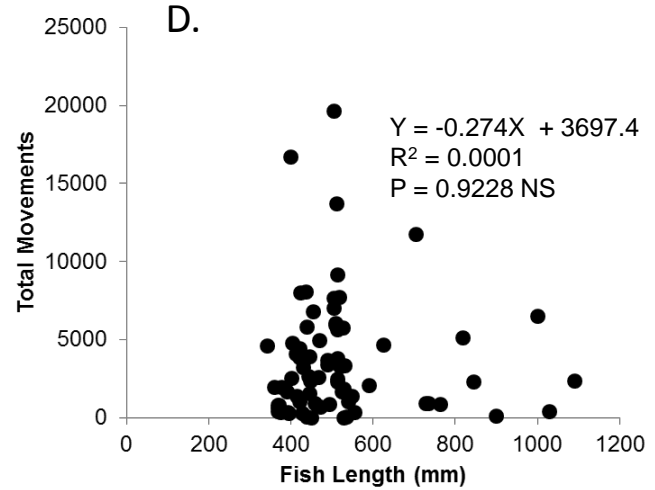
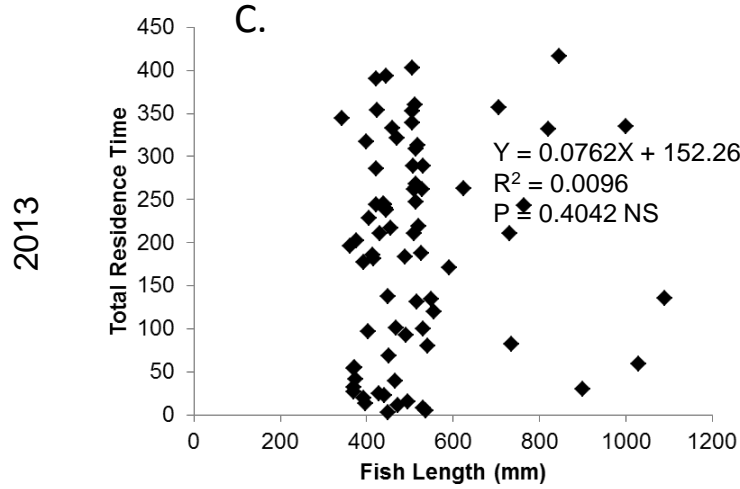
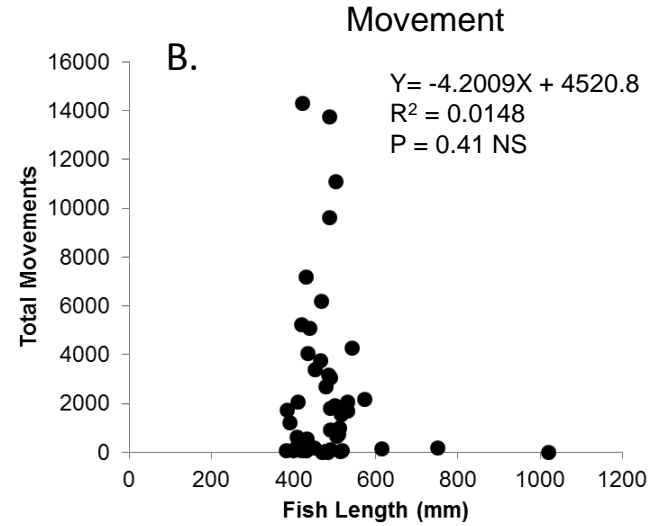
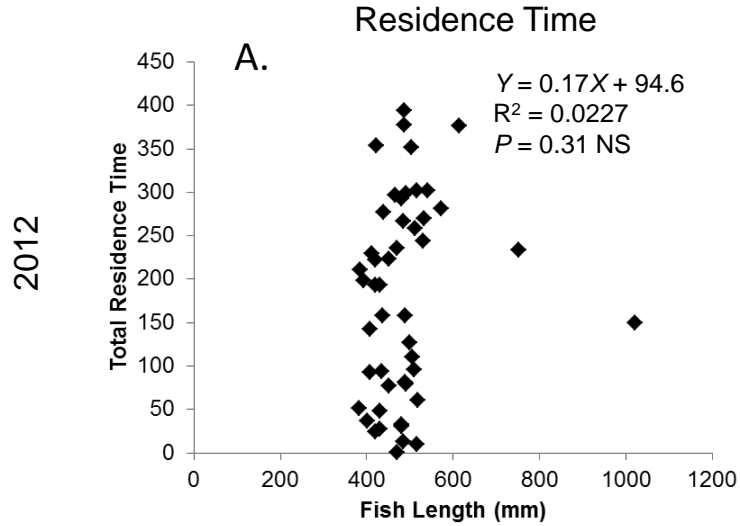
Chapter 2 Figure 12



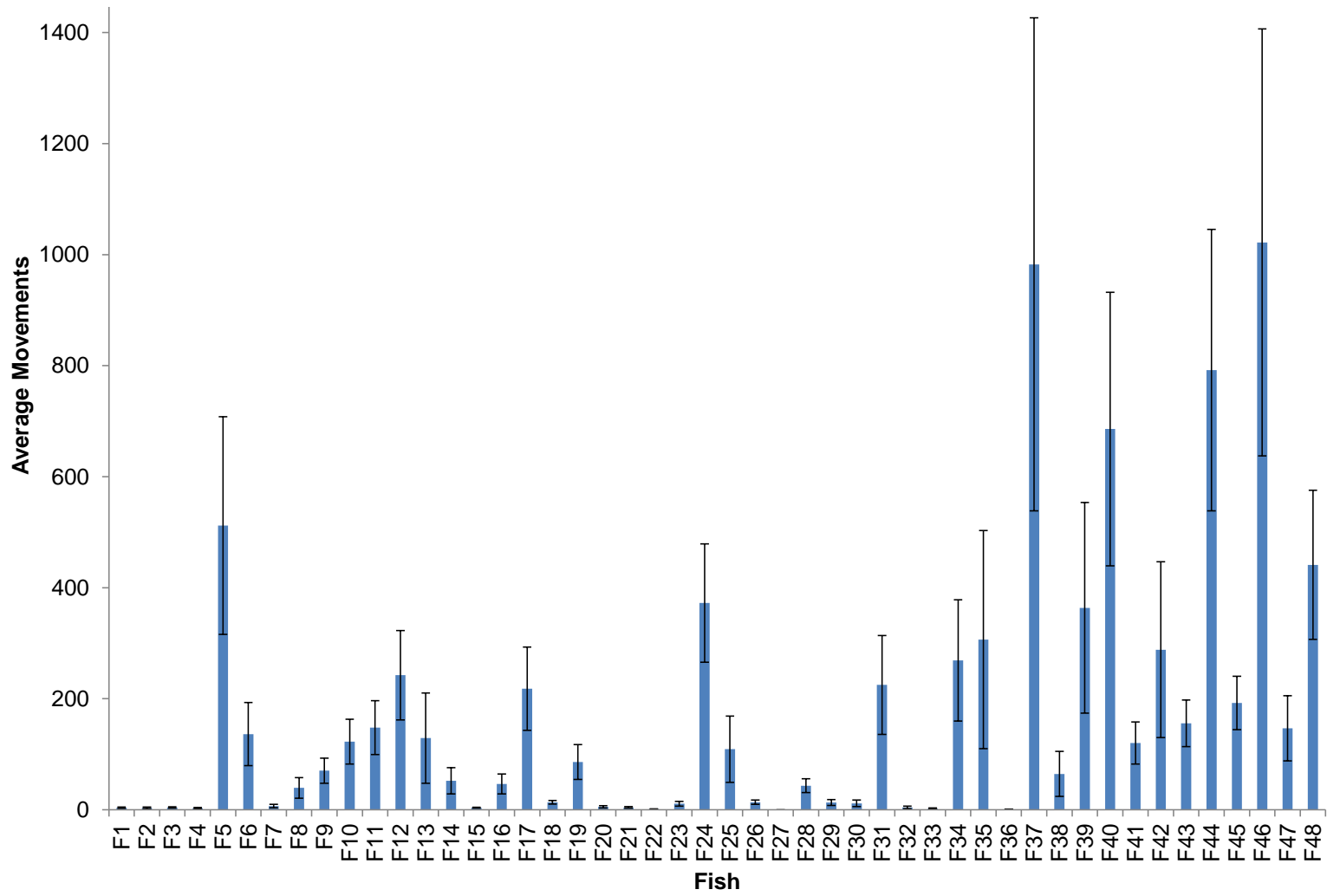
Chapter 2 Figure 13



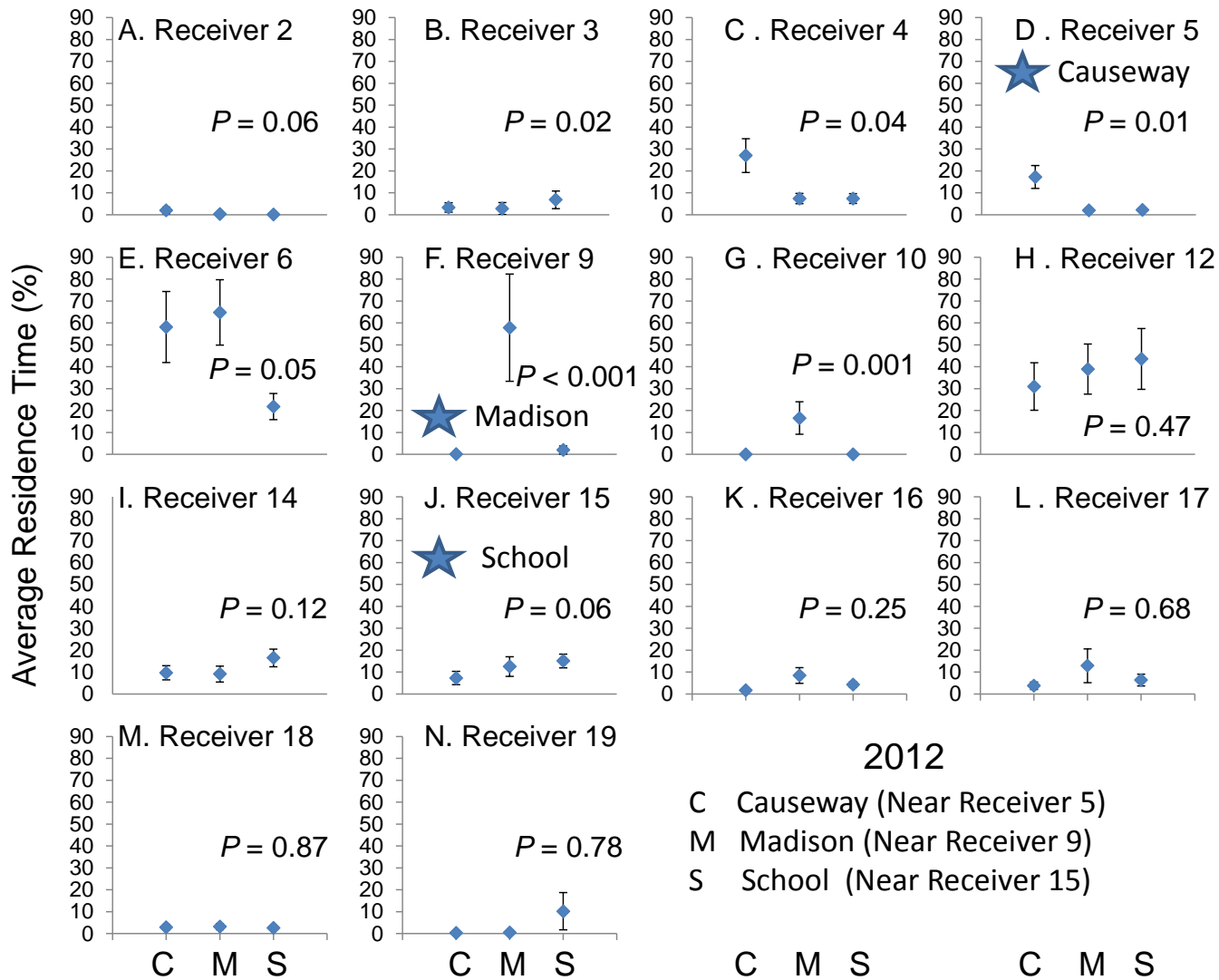
Chapter 2 Figure 14



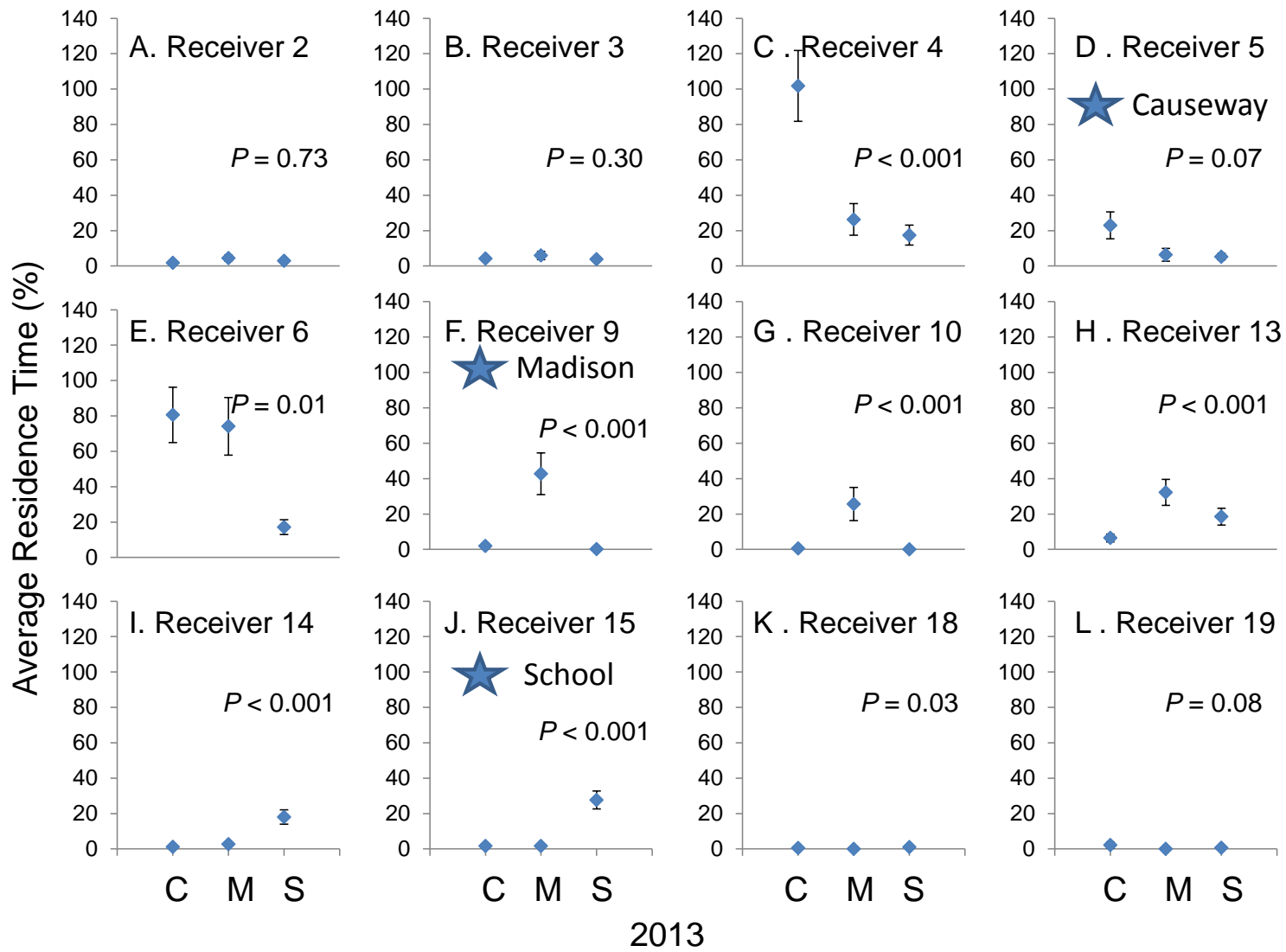
Chapter 2 Figure 15



Chapter 2 Figure 16

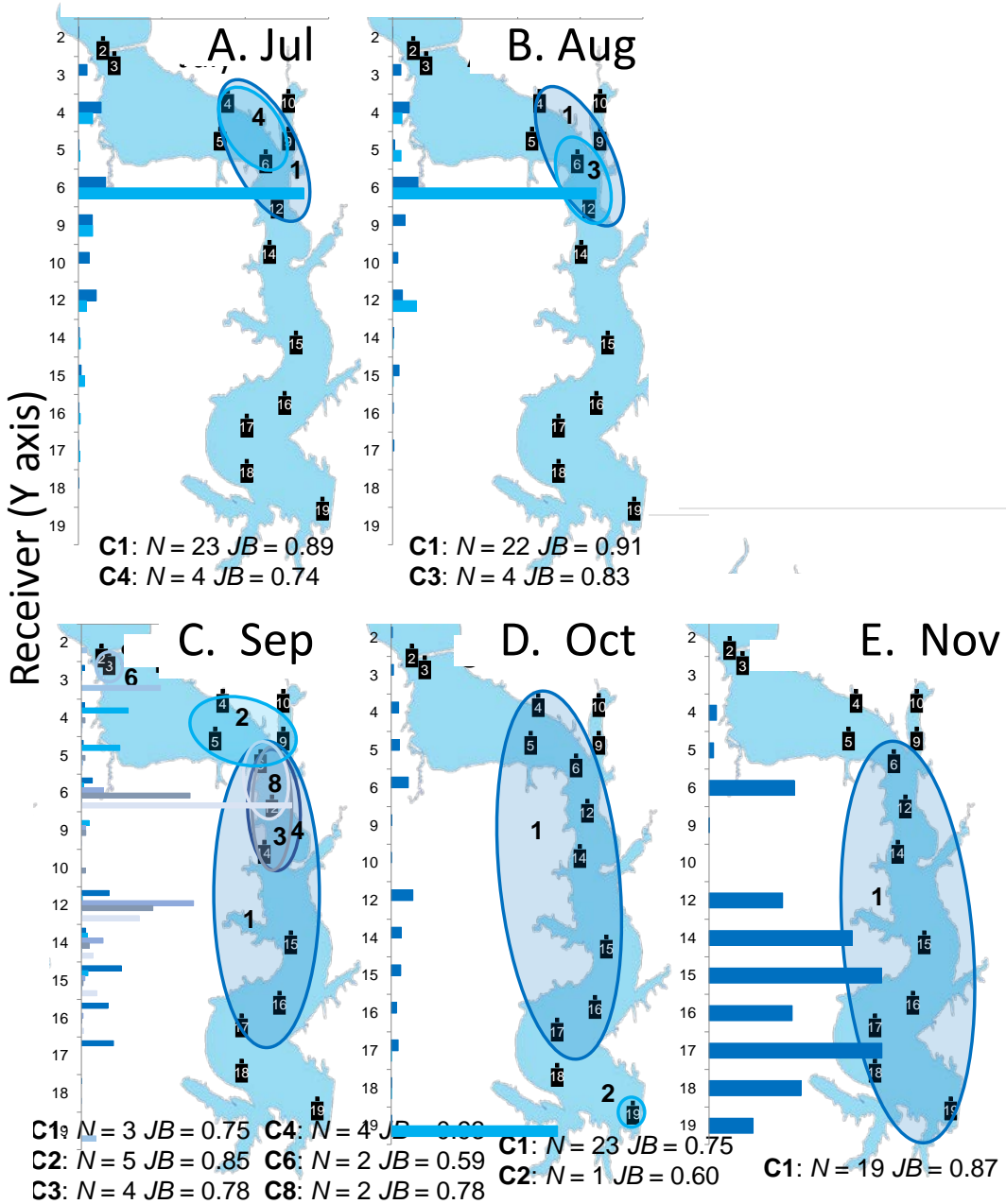


Chapter 2 Figure 17



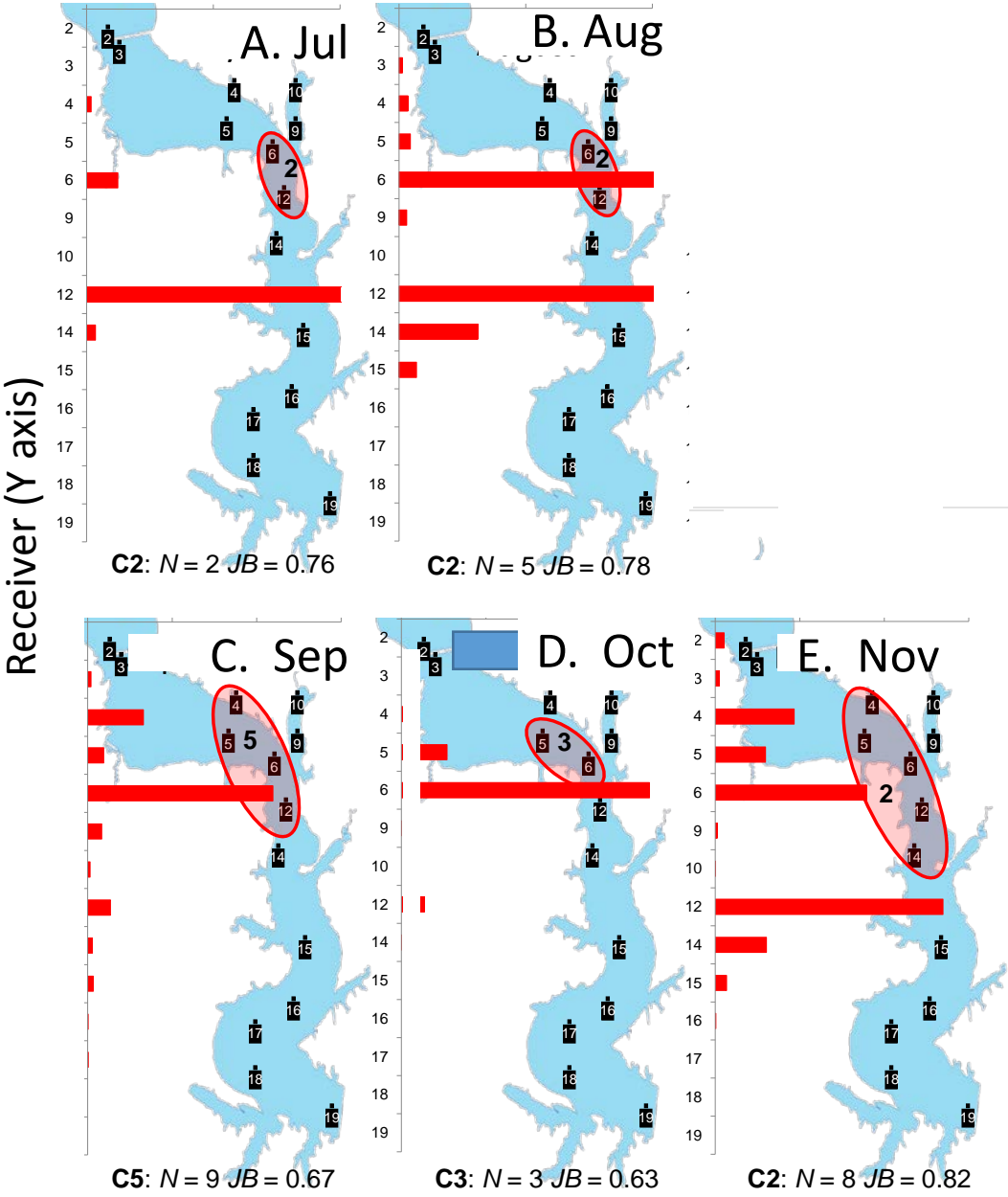
Chapter 2 Figure 18

Residence Time (X axis)

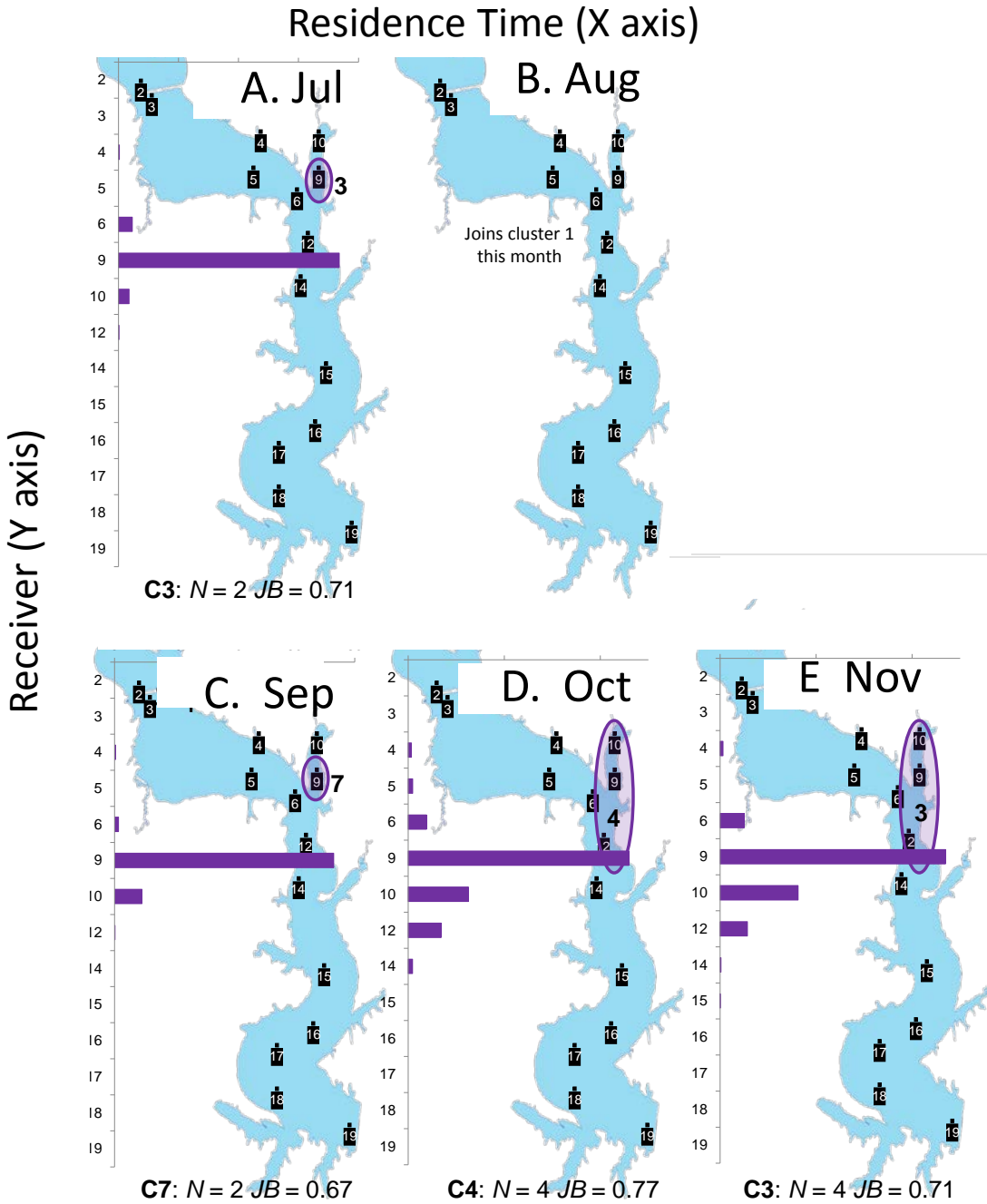


Synthesis Group 1 Distribution – The Seasonals

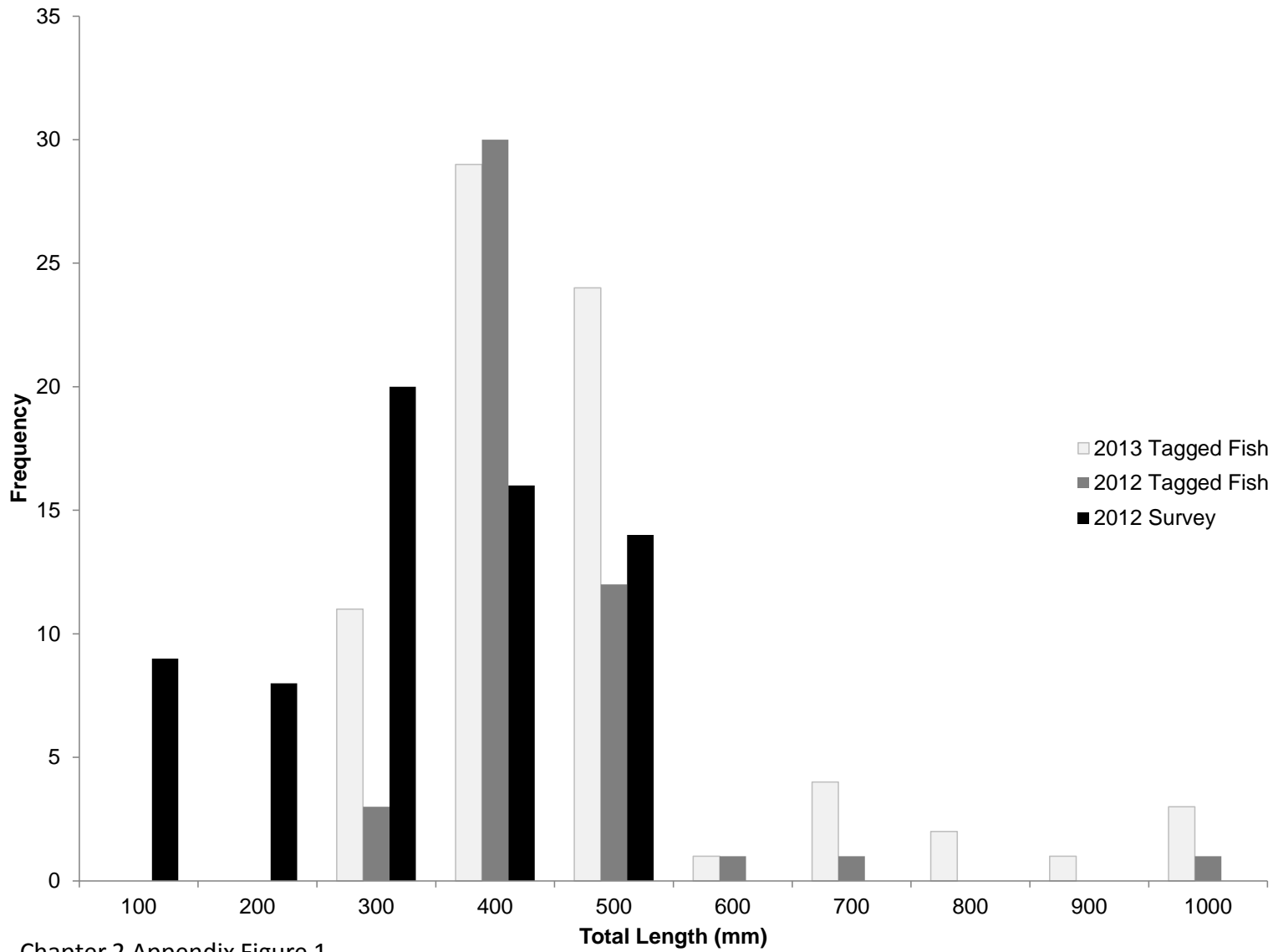
Residence Time (X axis)



Synthesis Group 2
Distribution – The 6-12 Funnel Regulars

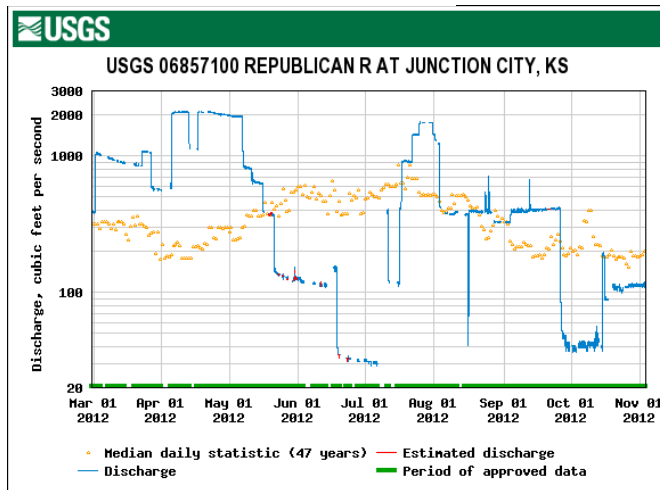


Synthesis Group 3
Distribution – Madison Creek

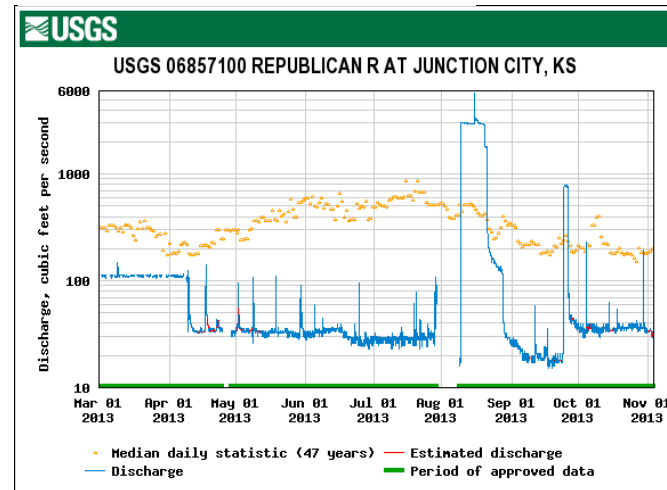


Chapter 2 Appendix Figure 1

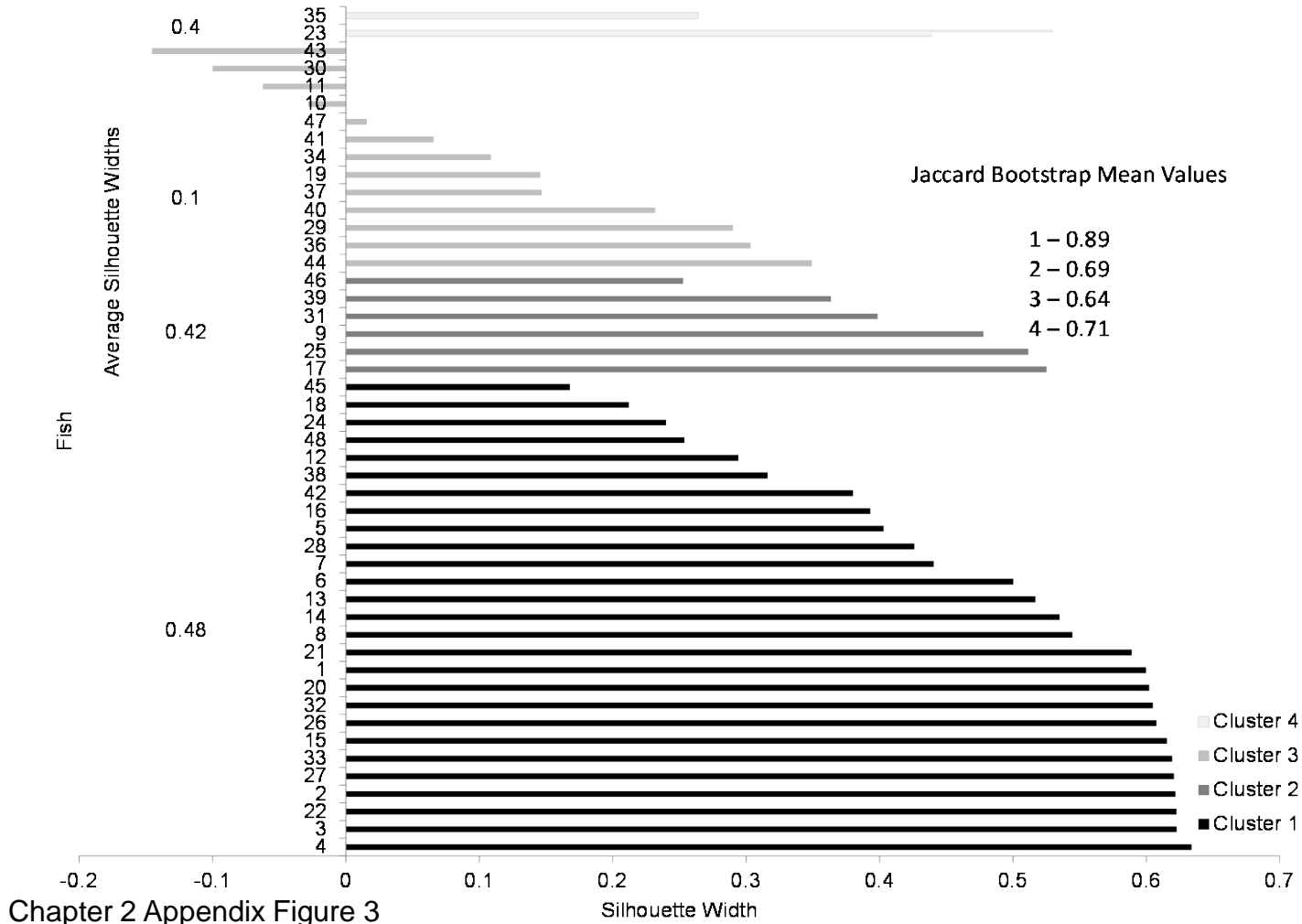
A. Mar – Nov, 2012



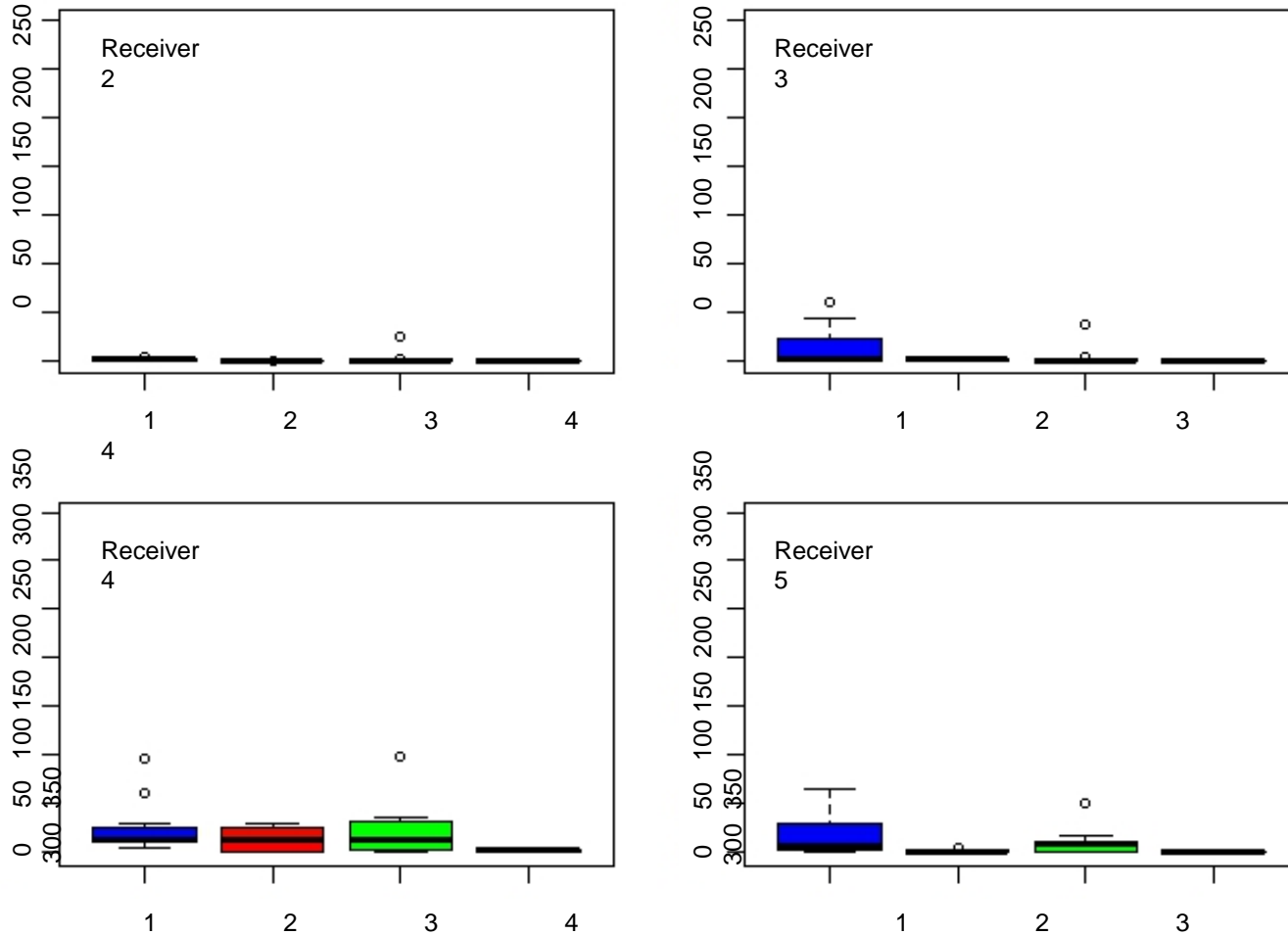
B. Mar – Nov, 2013



Residence Time (July – November)

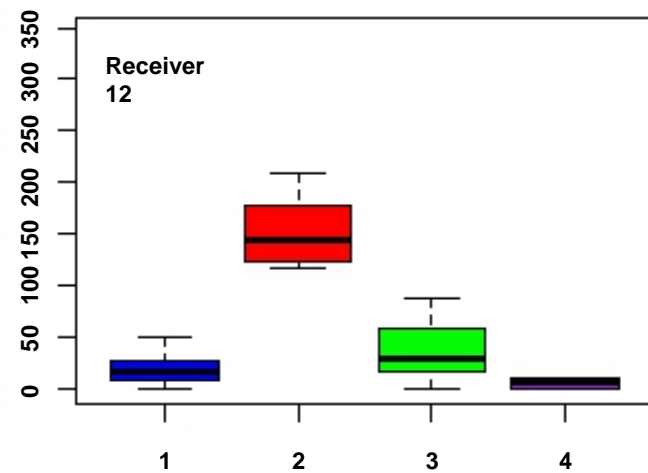
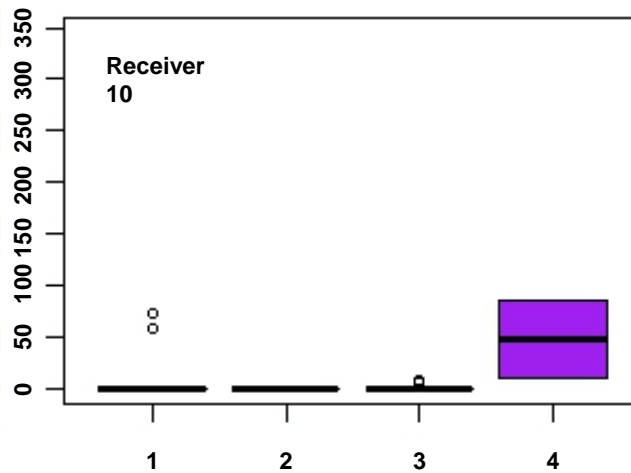
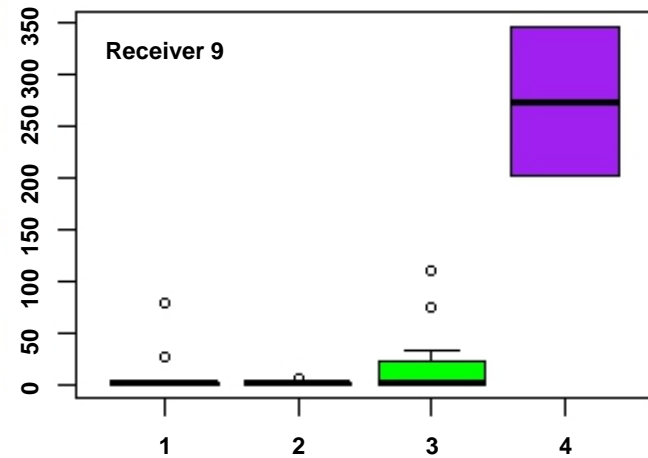
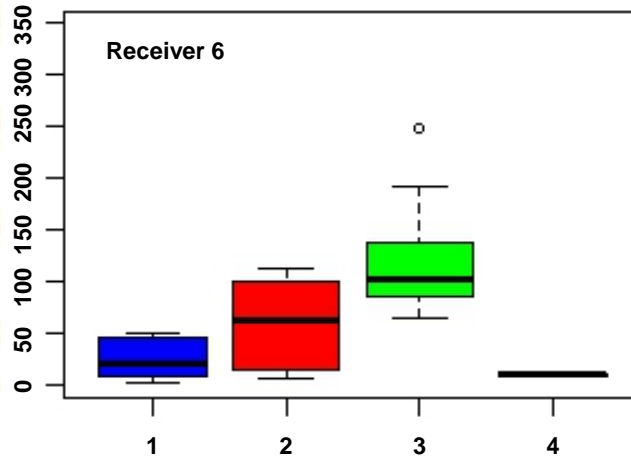


Residence Time (July – November)



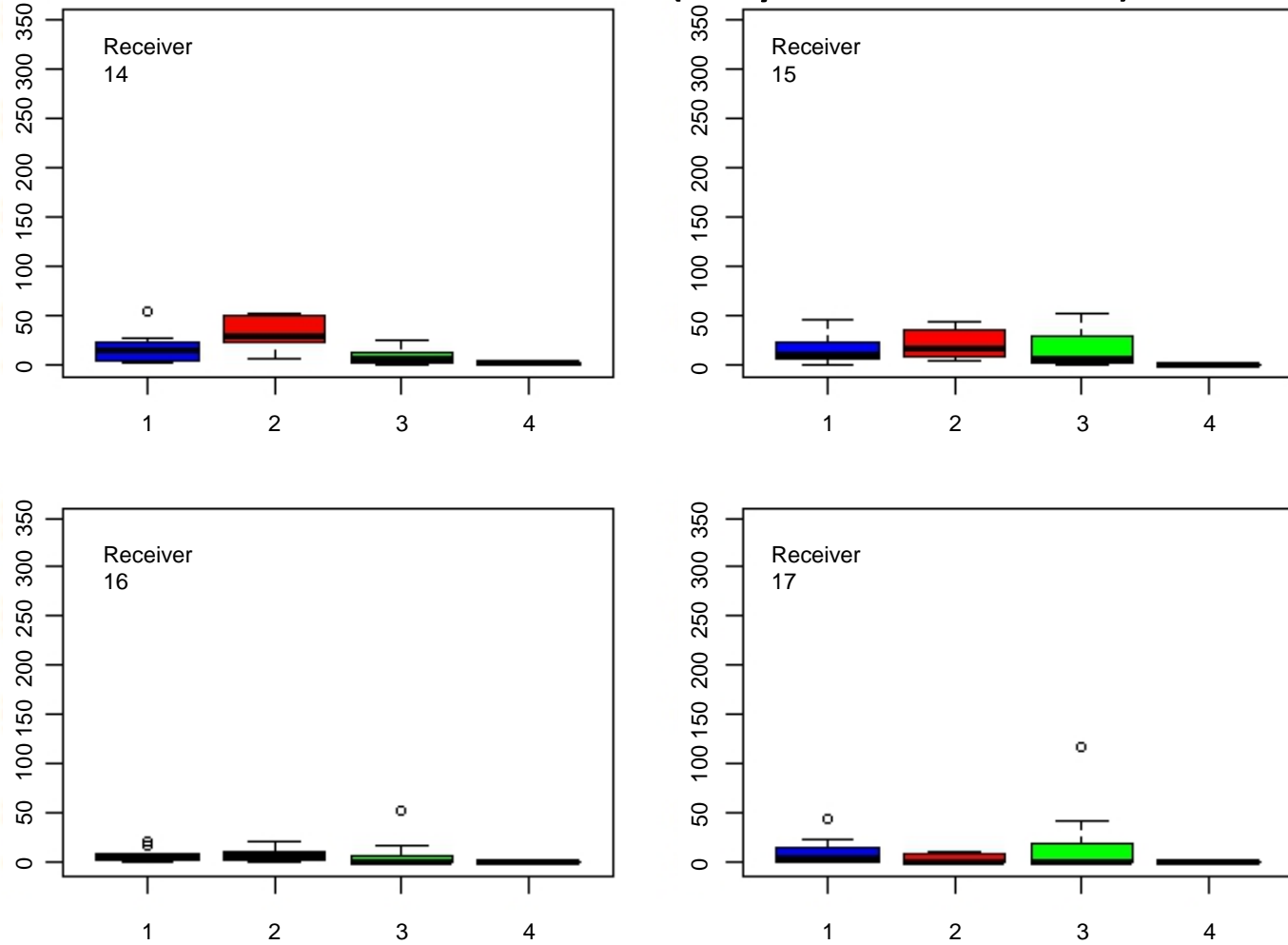
Chapter 2 Appendix Figure 4

Residence Time (July – November)



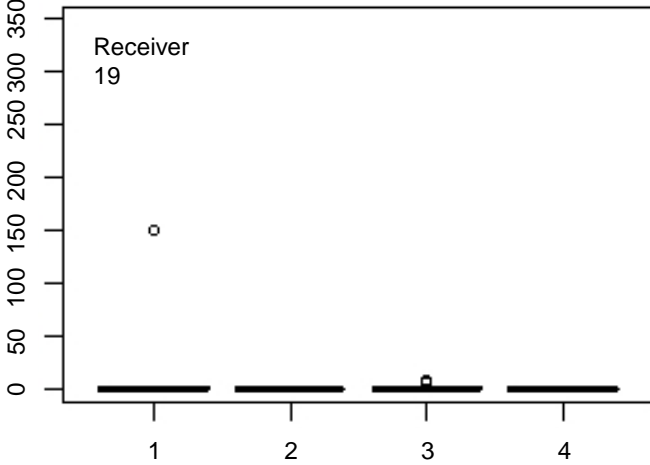
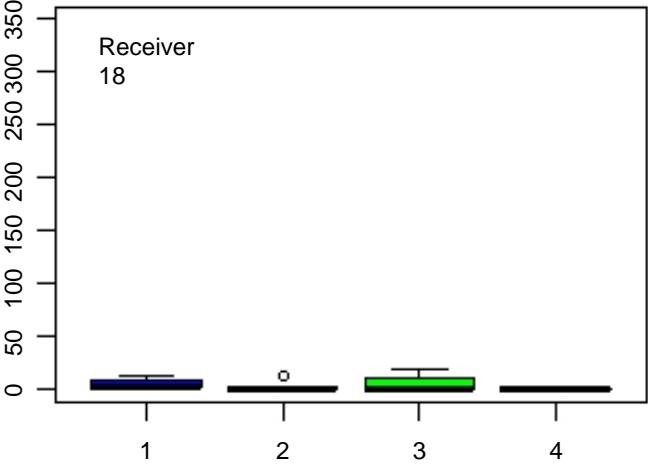
Chapter 2 Appendix Figure 5

Residence Time (July – November)

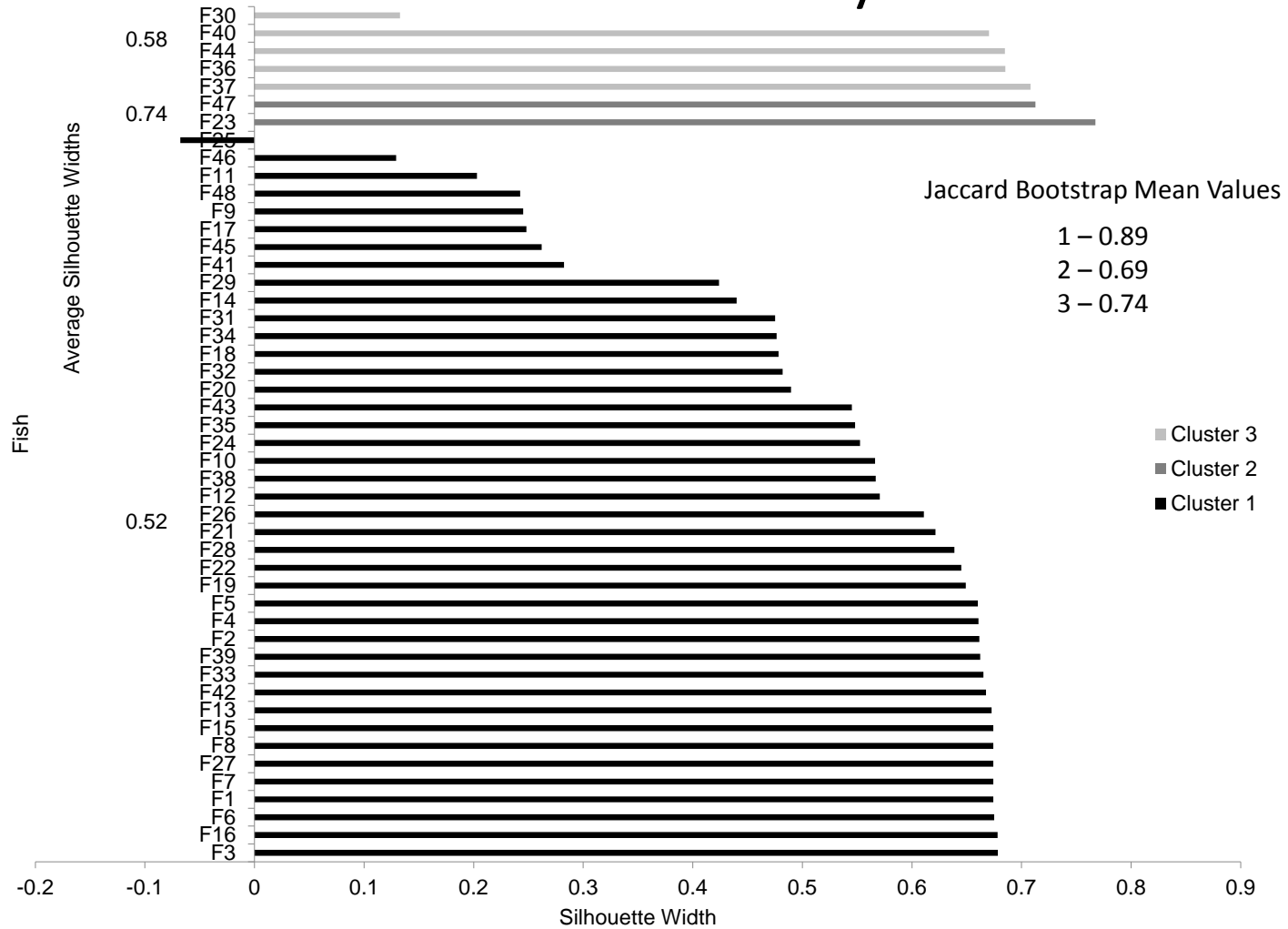


Chapter 2 Appendix Figure 6

Residence Time (July – November)

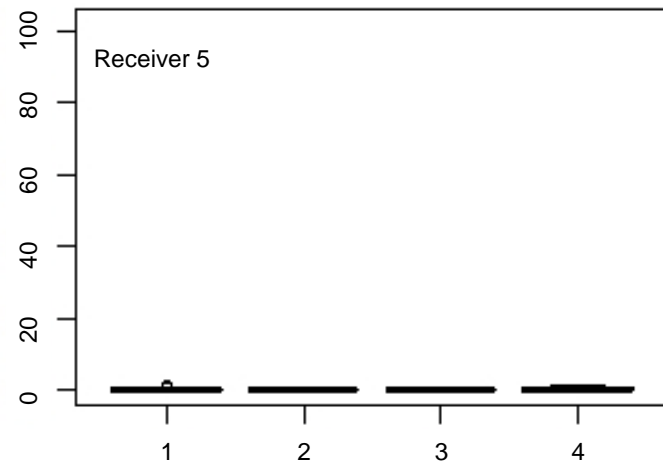
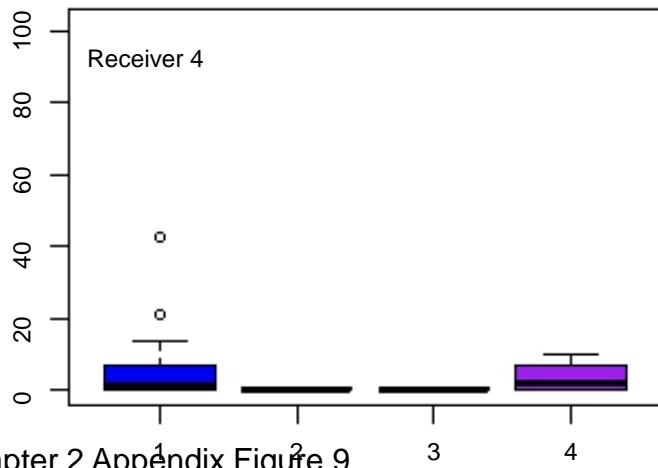
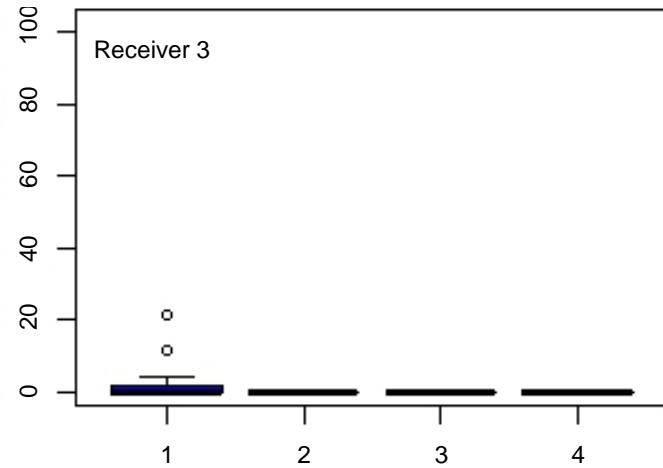
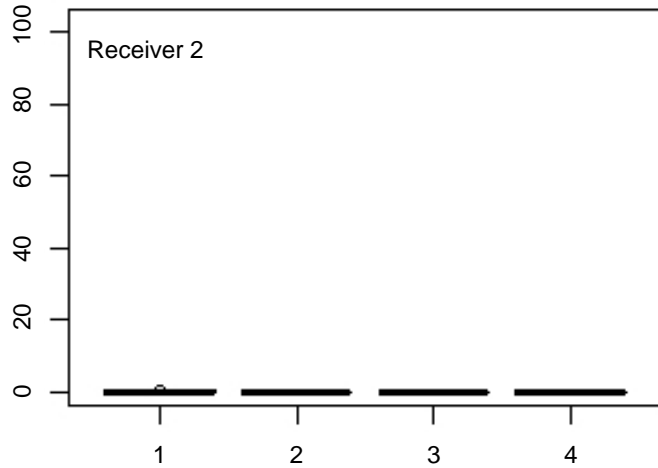


Residence Time -July



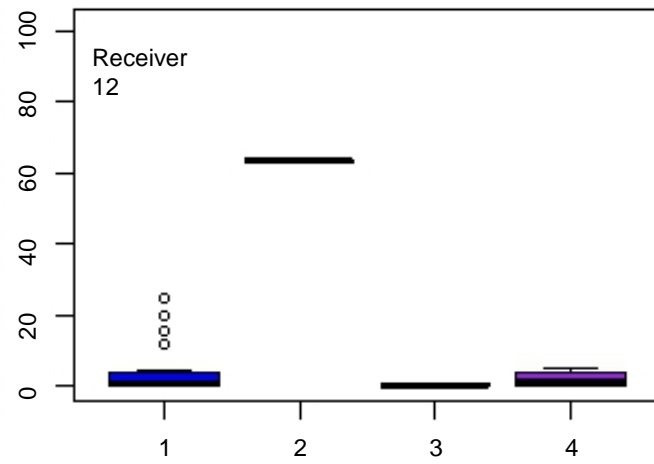
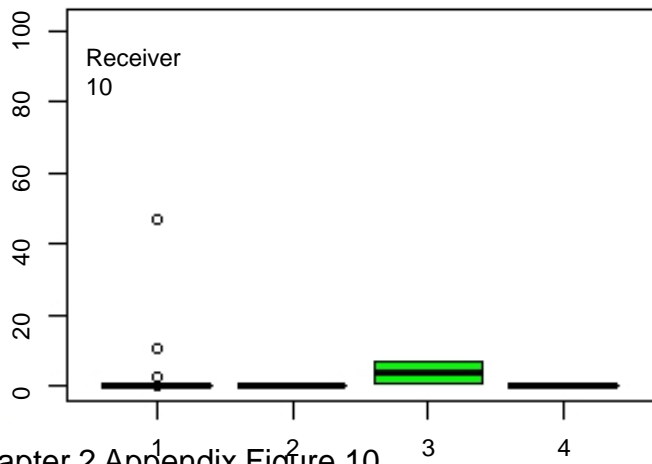
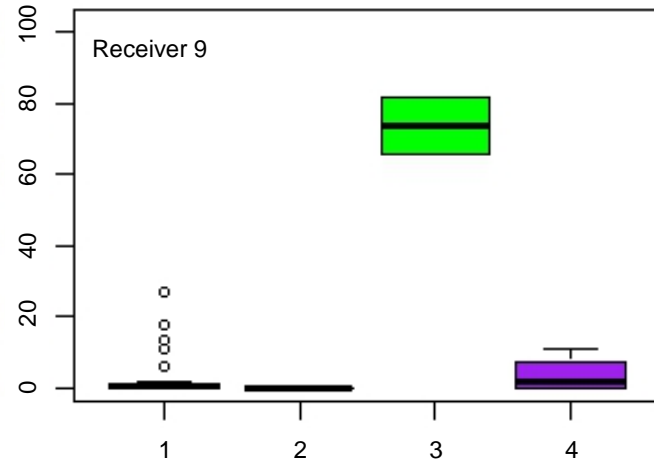
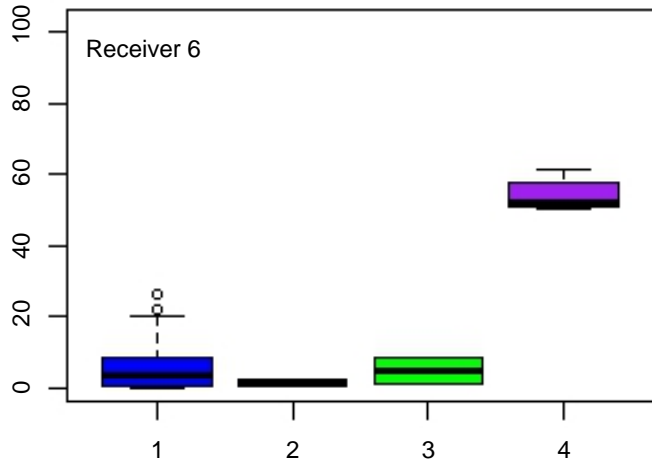
Chapter 2 Appendix Figure 8

Residence Time (July)

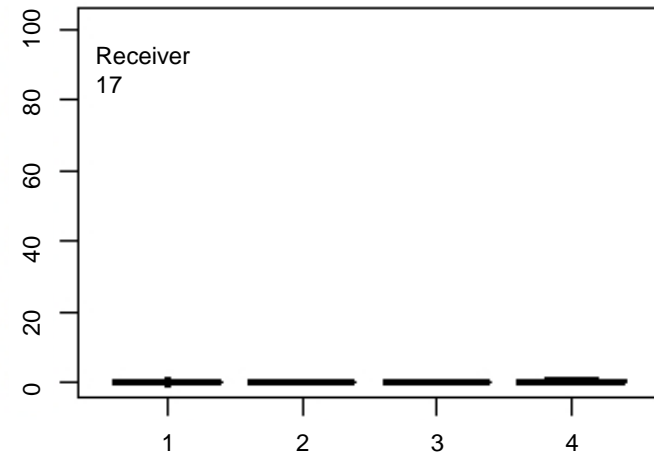
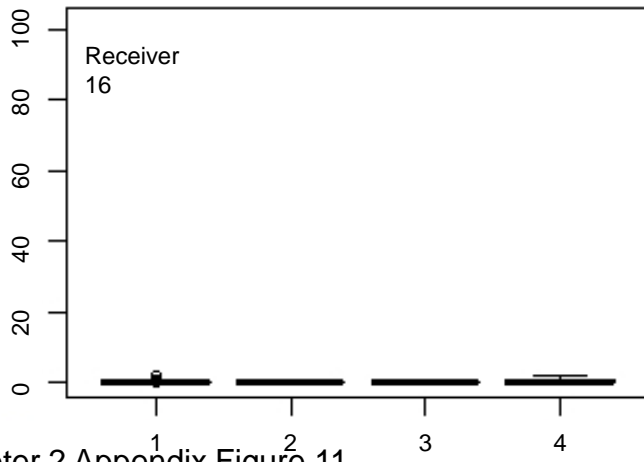
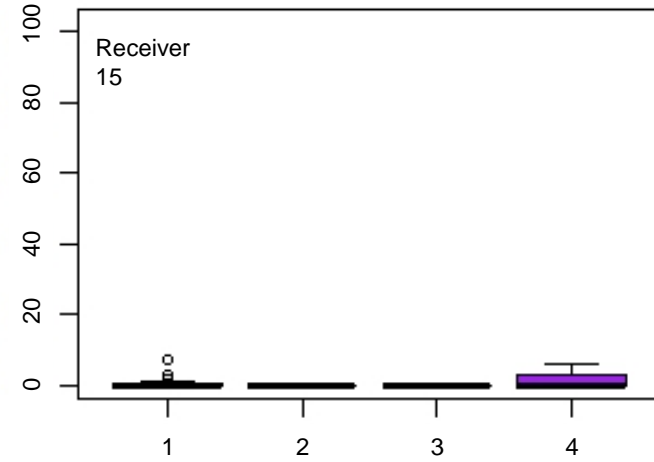
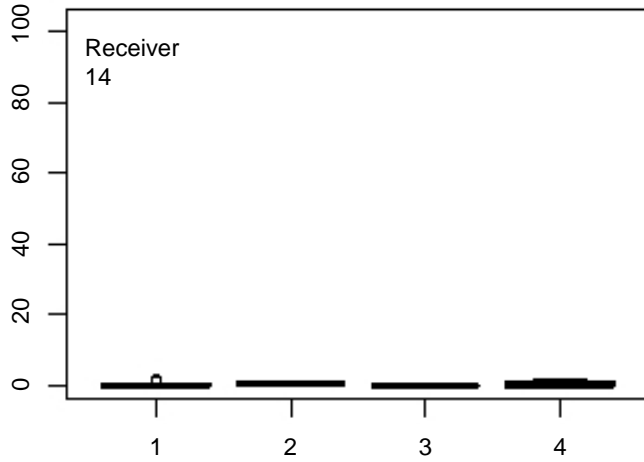


Chapter 2 Appendix Figure 9

Residence Time (July)

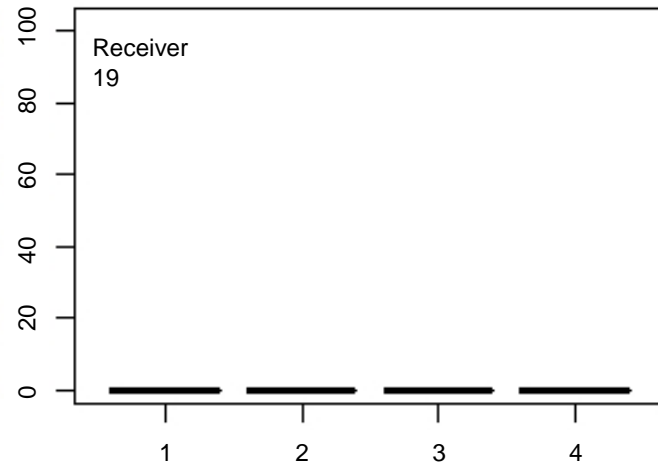
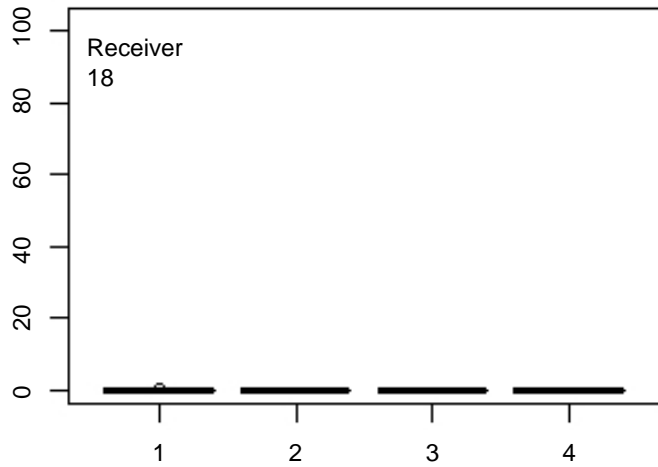


Residence Time (July)

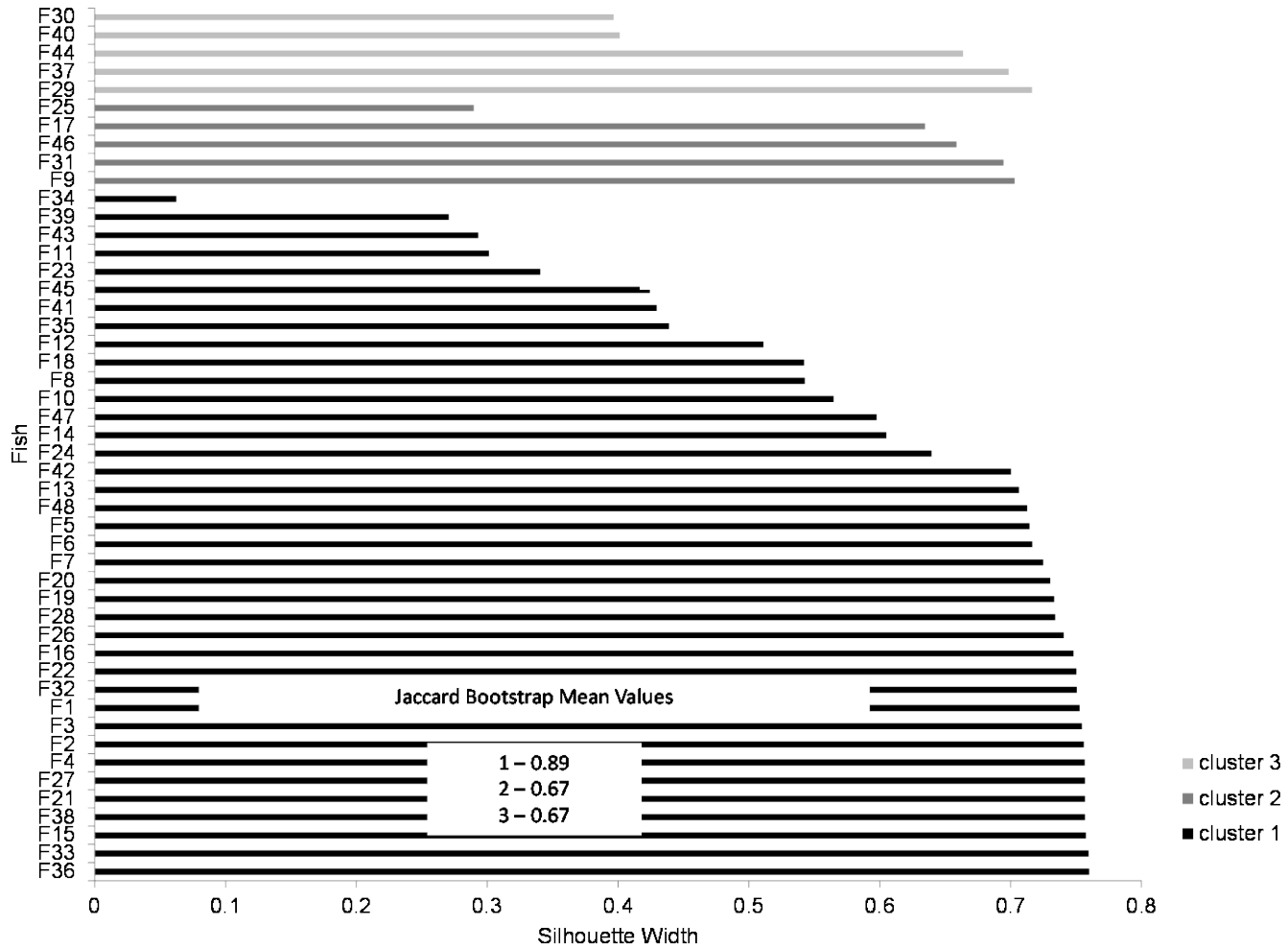


Chapter 2 Appendix Figure 11

Residence Time (July)

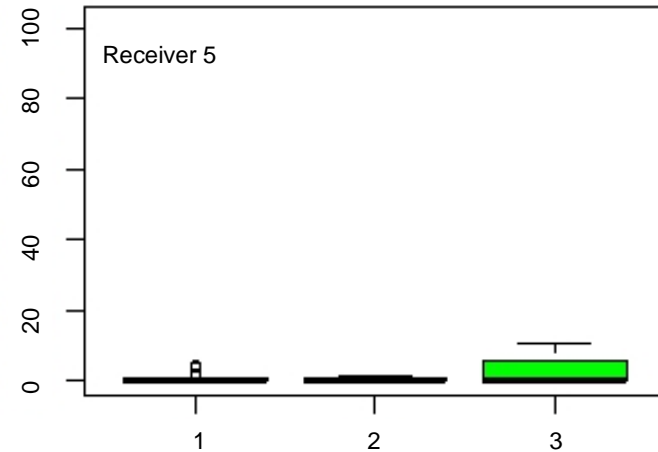
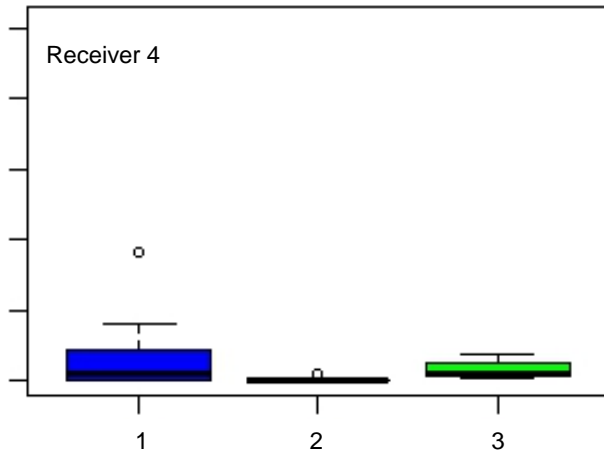
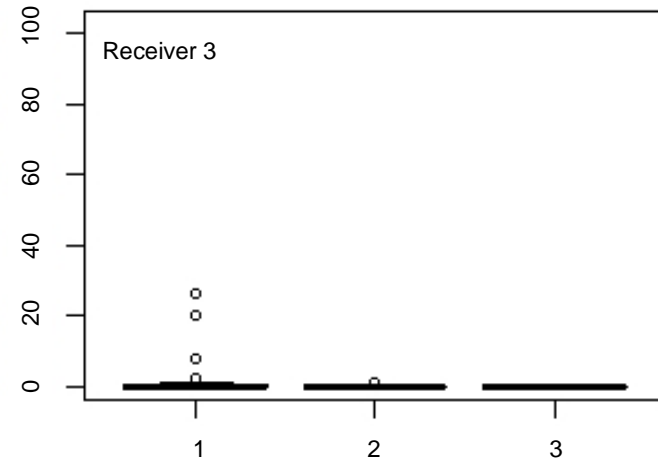
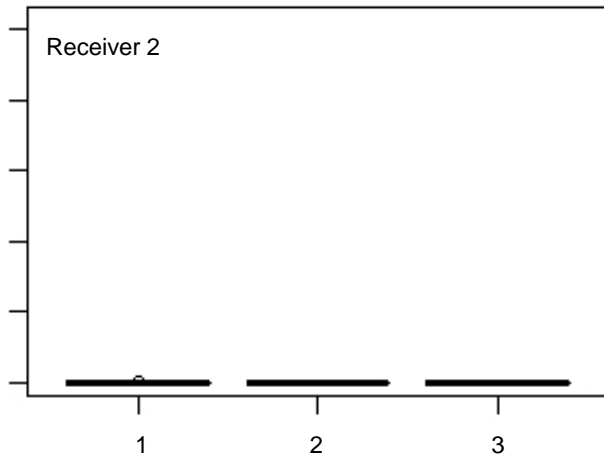


Residence Time - August



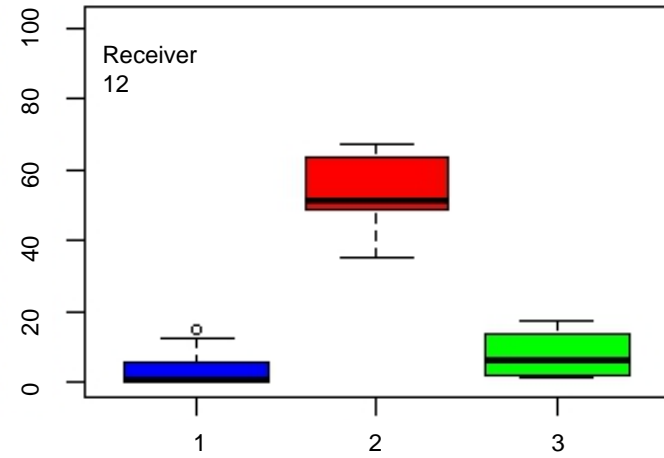
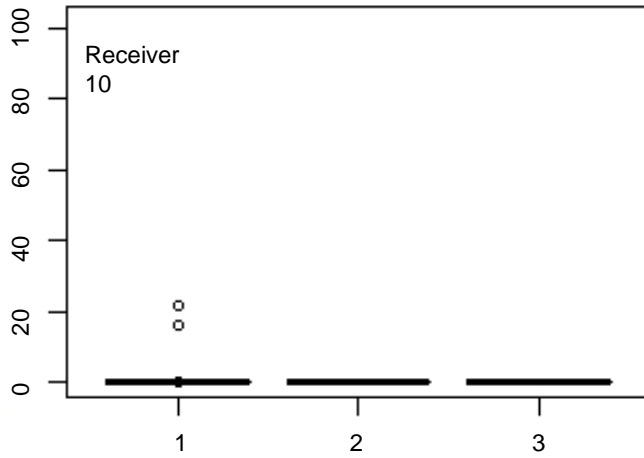
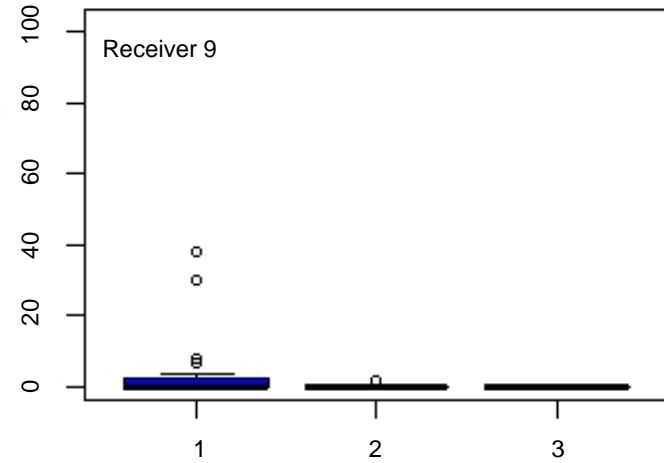
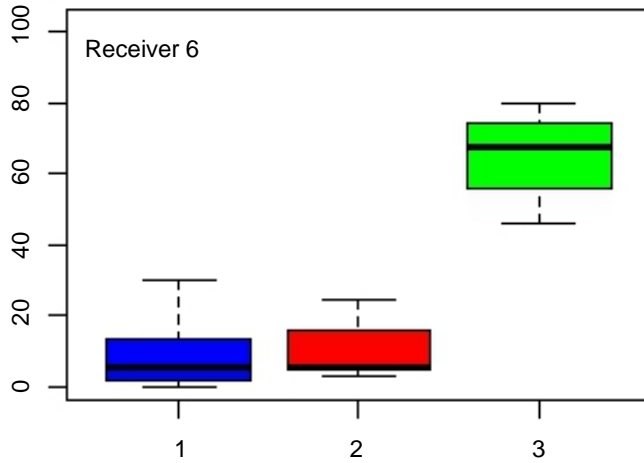
Chapter 2 Appendix Figure 13

Residence Time (August)



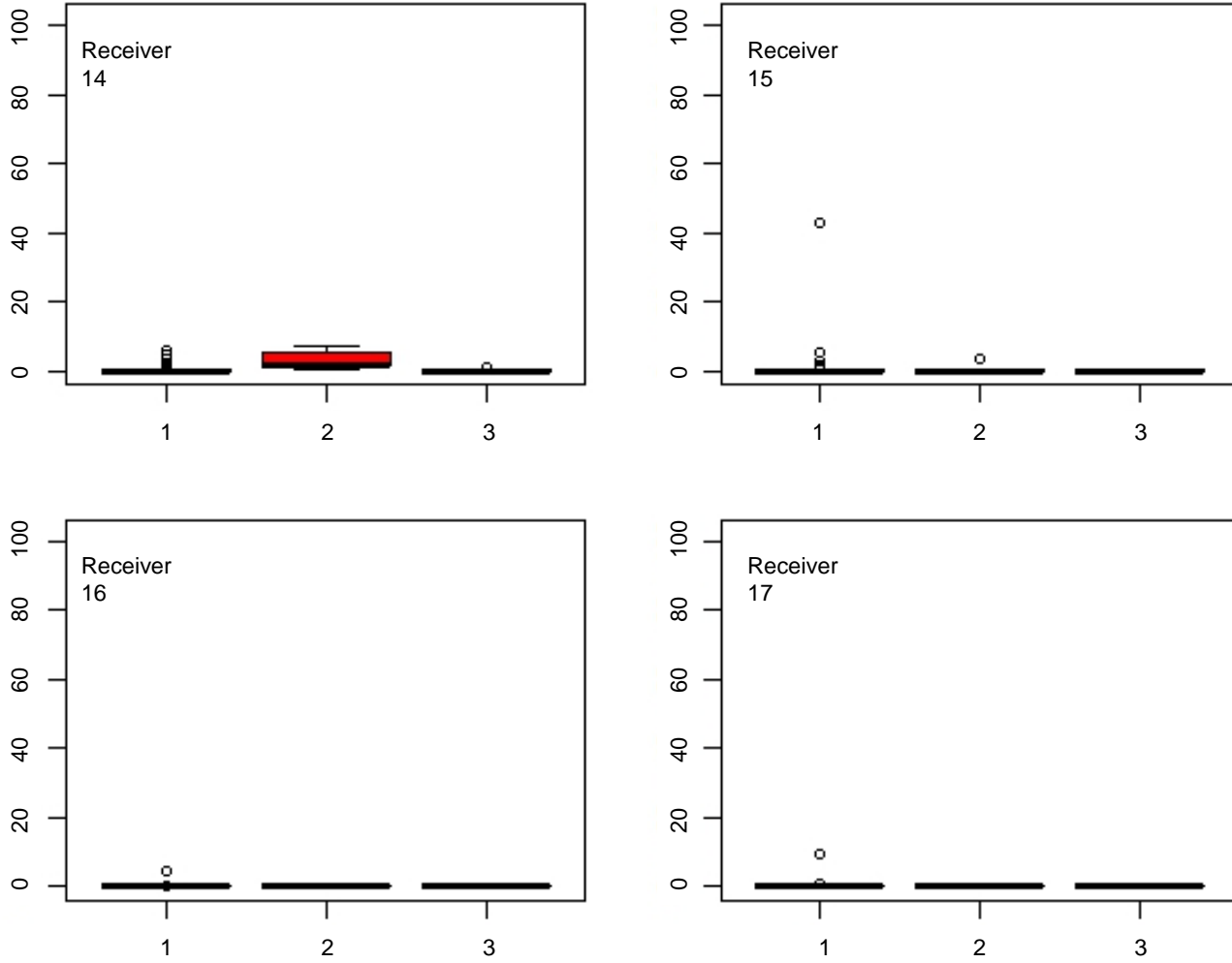
Chapter 2 Appendix Figure 14

Residence Time (August)



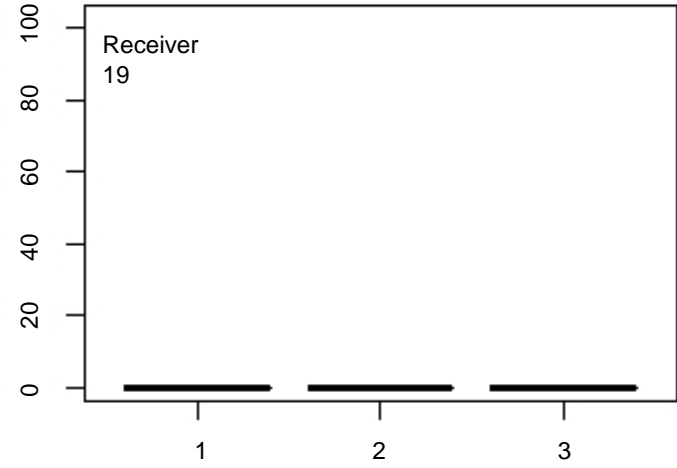
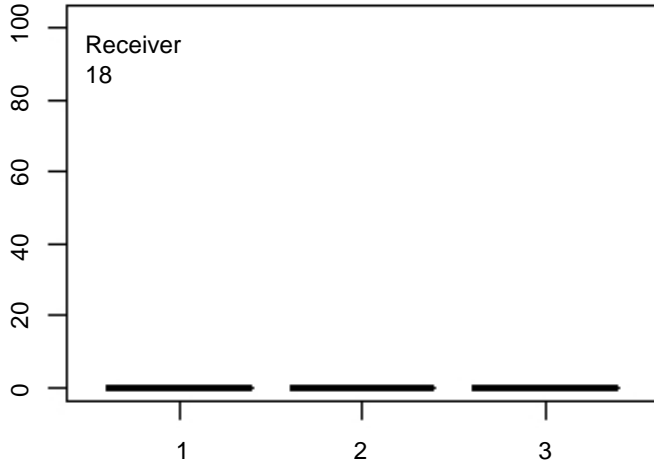
Chapter 2 Appendix Figure 15

Residence Time (August)

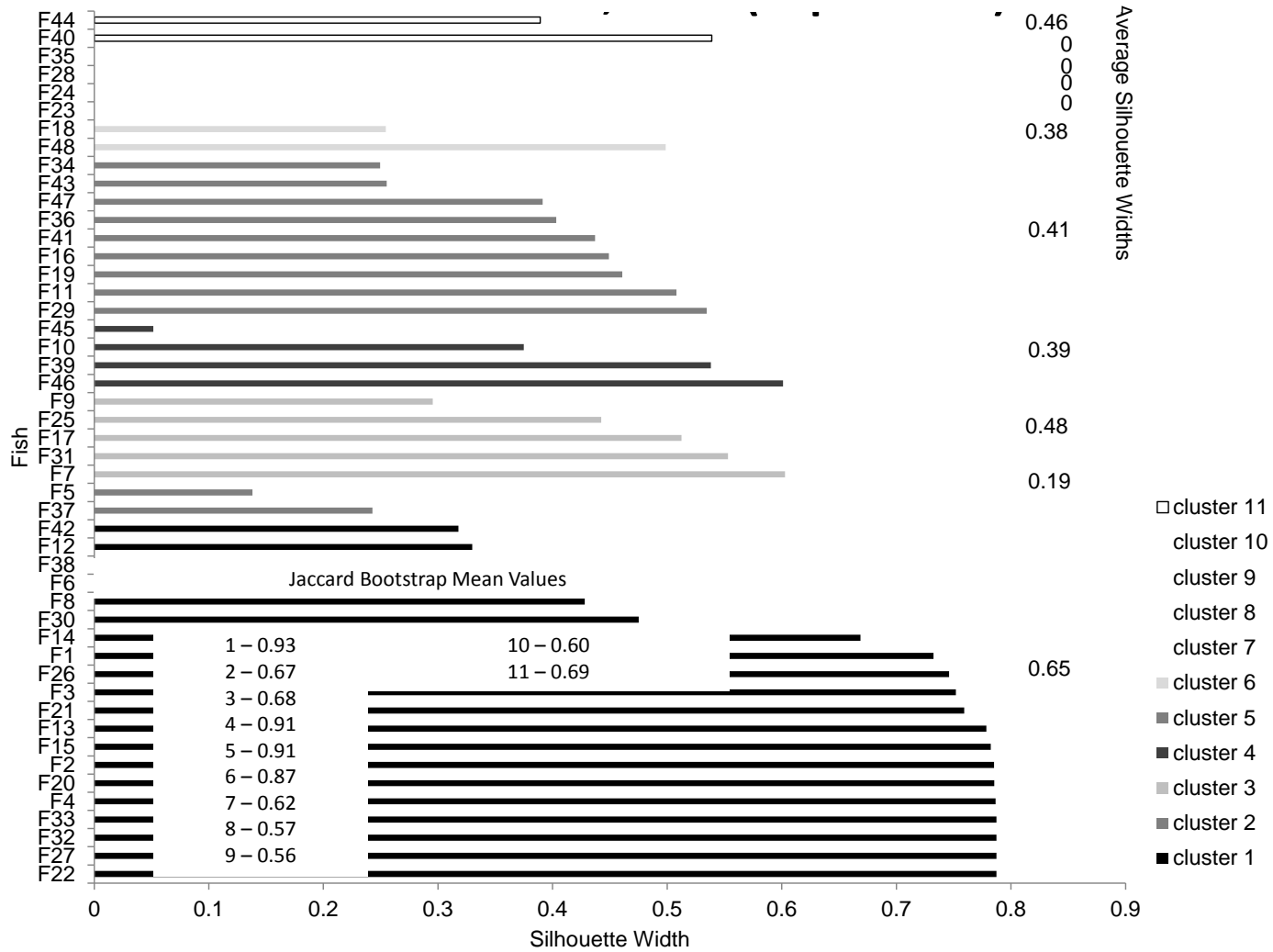


Chapter 2 Appendix Figure 16

Residence Time (August)

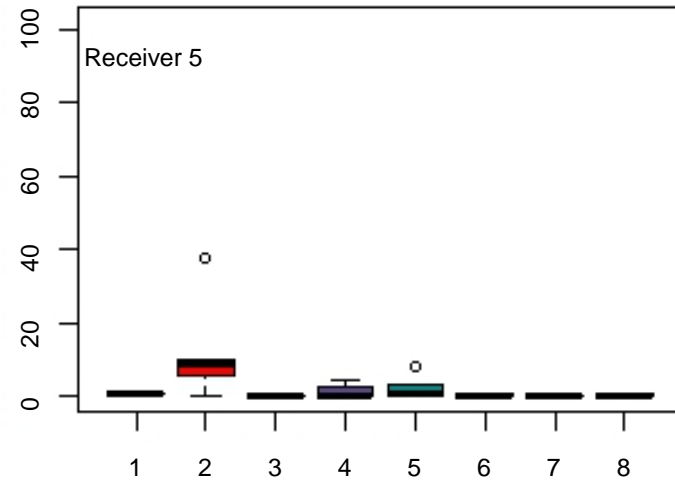
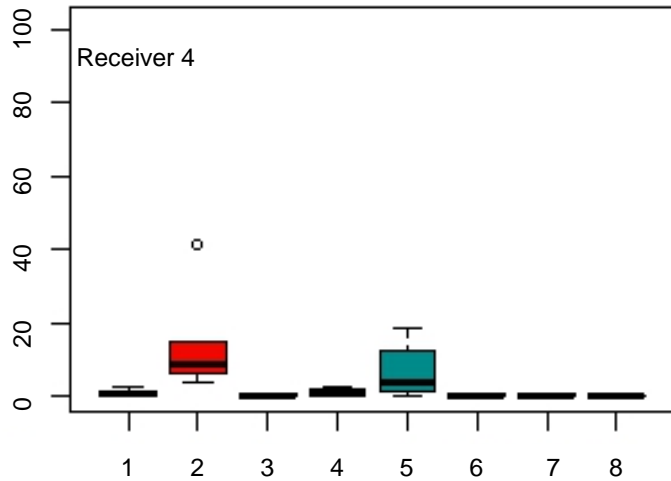
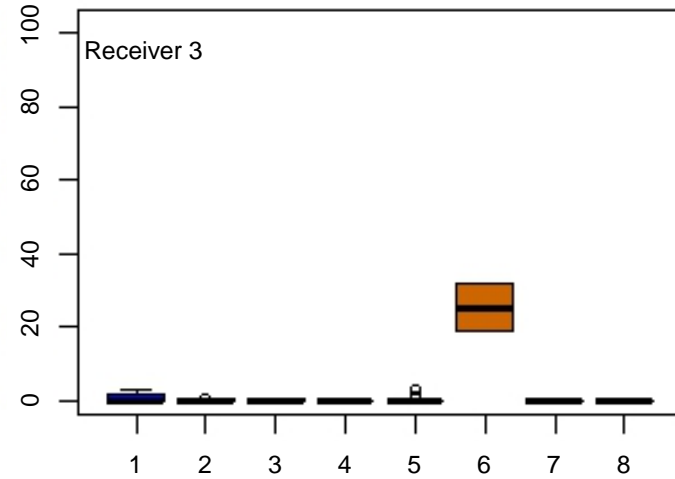
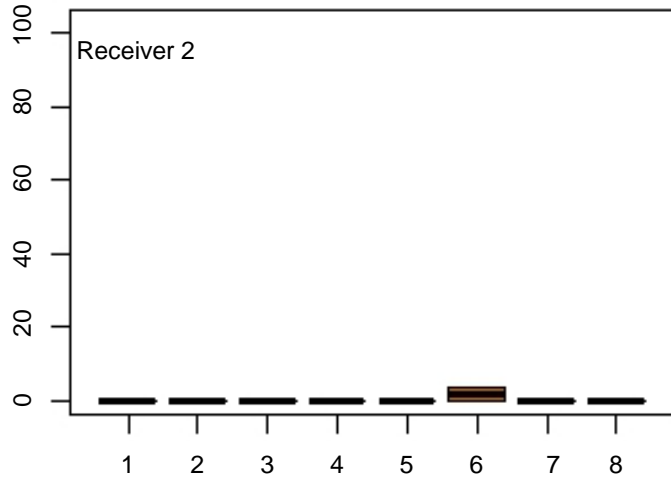


Residence Time - September



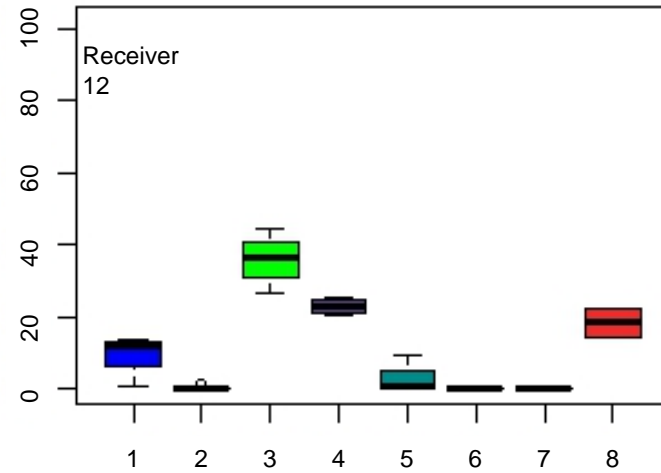
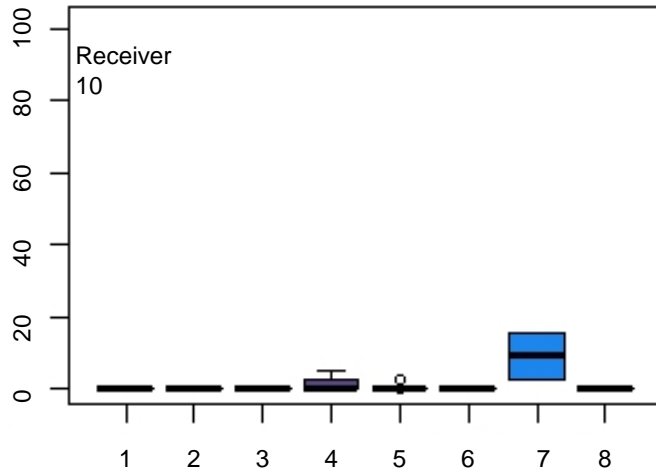
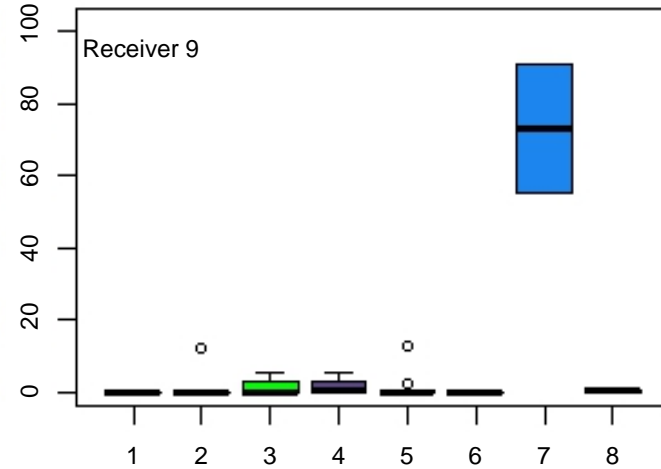
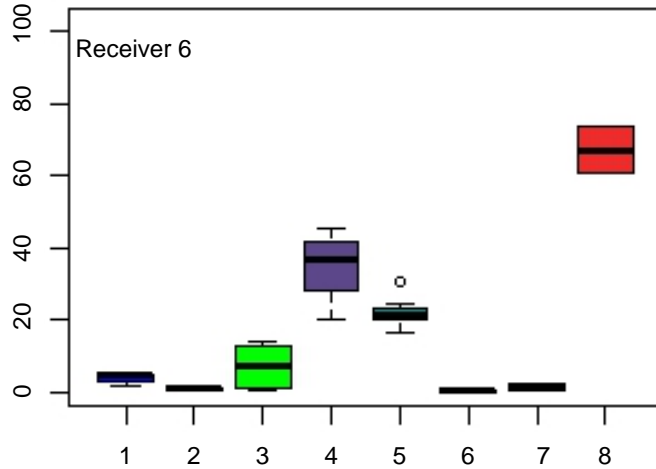
Chapter 2 Appendix Figure 18

Residence Time (September)



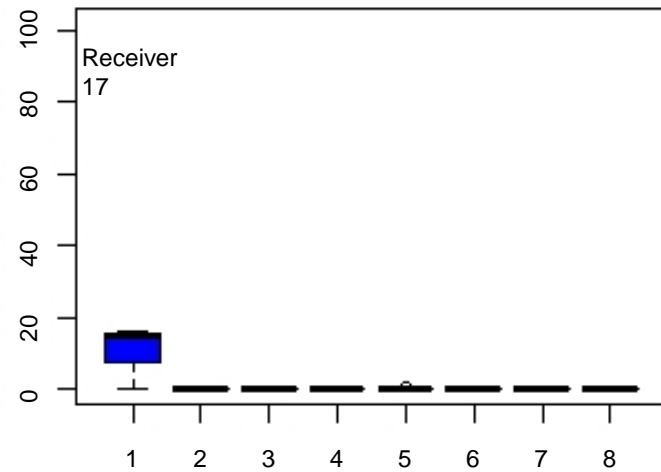
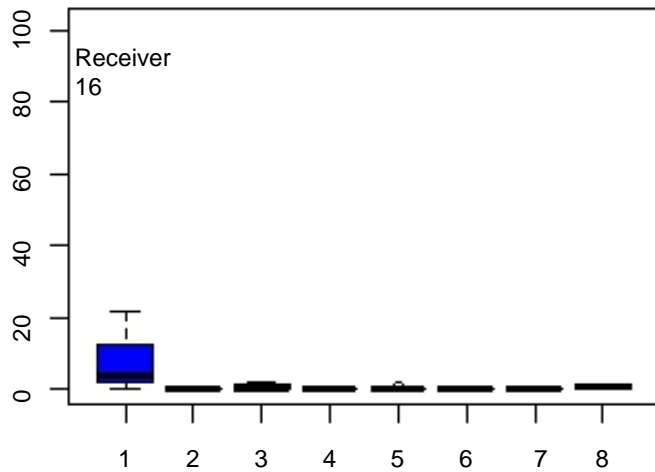
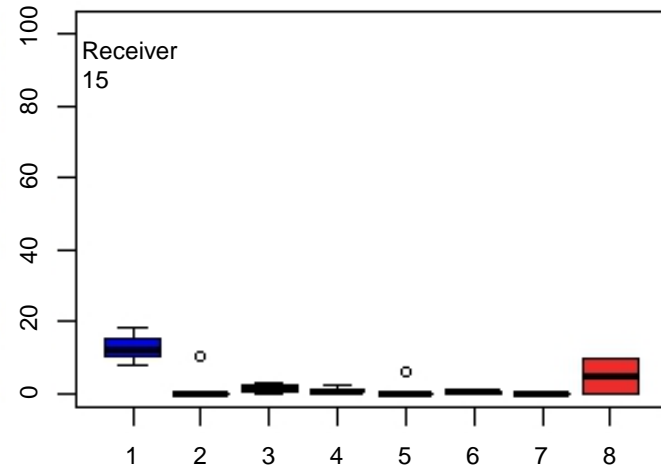
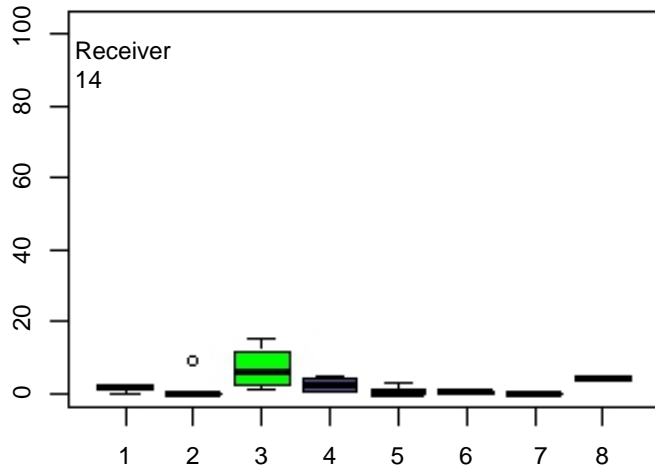
Chapter 2 Appendix Figure 19

Residence Time (September)



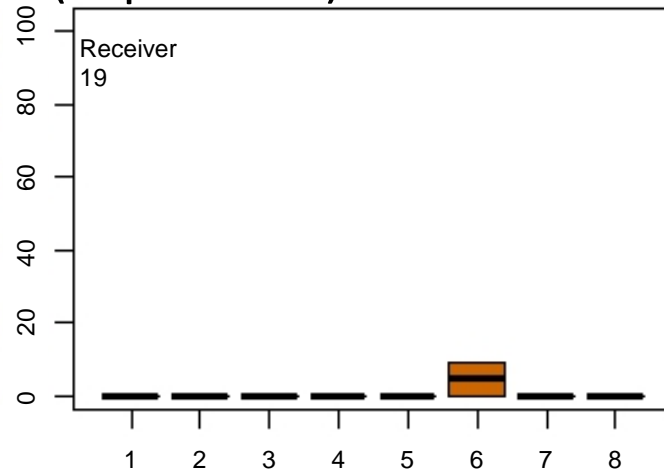
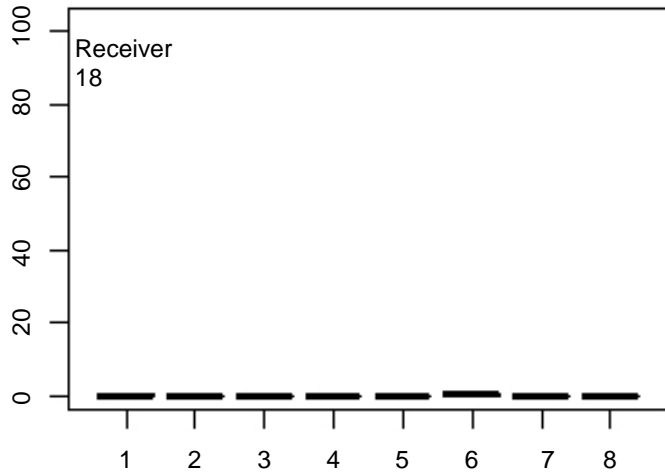
Chapter 2 Appendix Figure 20

Residence Time (September)

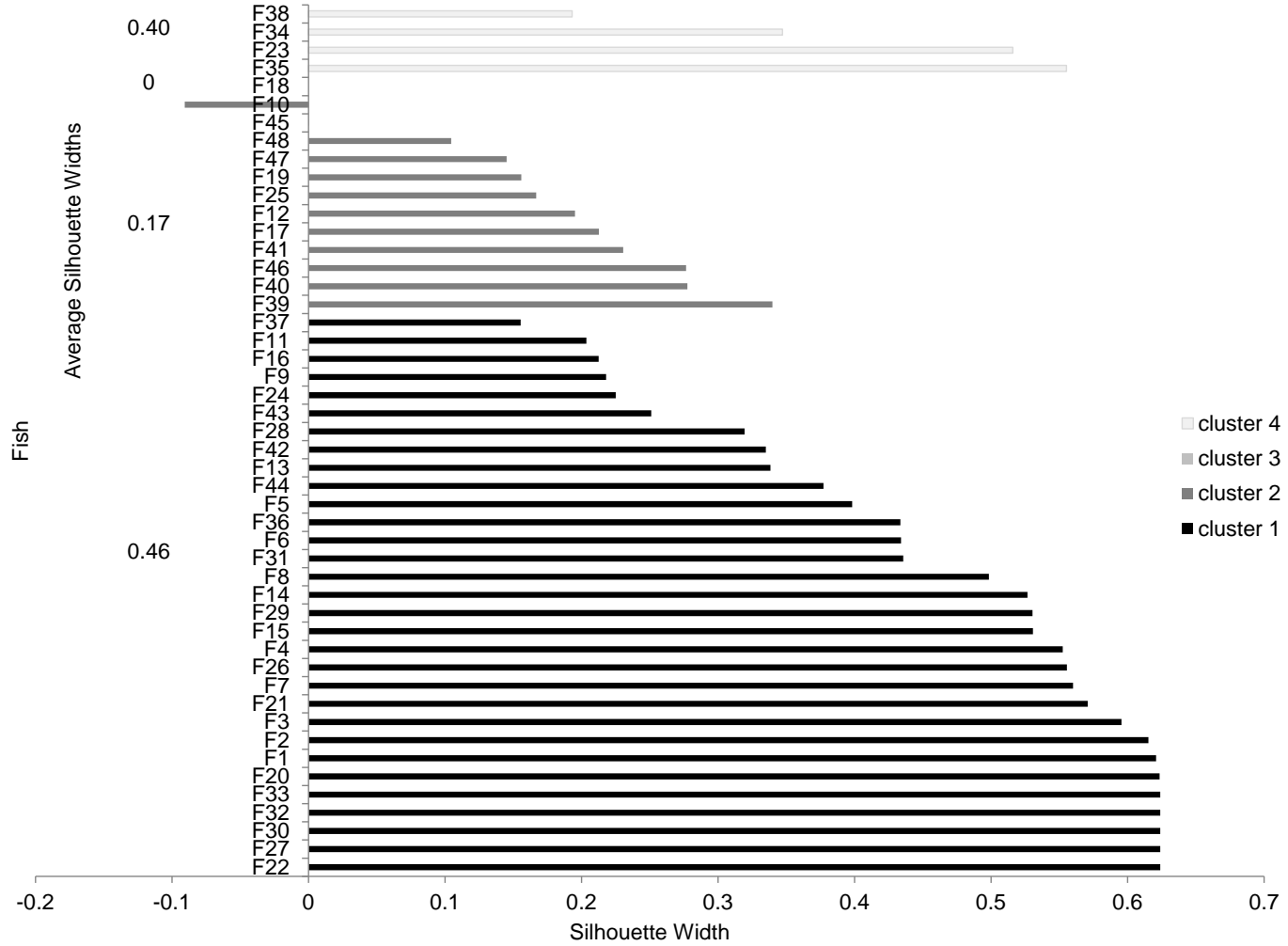


Chapter 2 Appendix Figure 21

Residence Time (September)

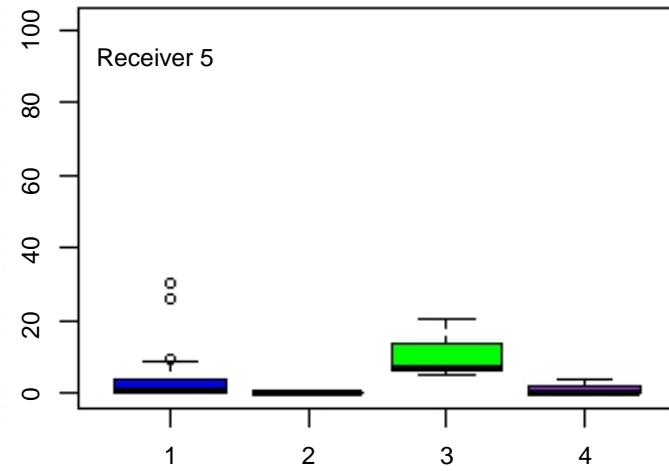
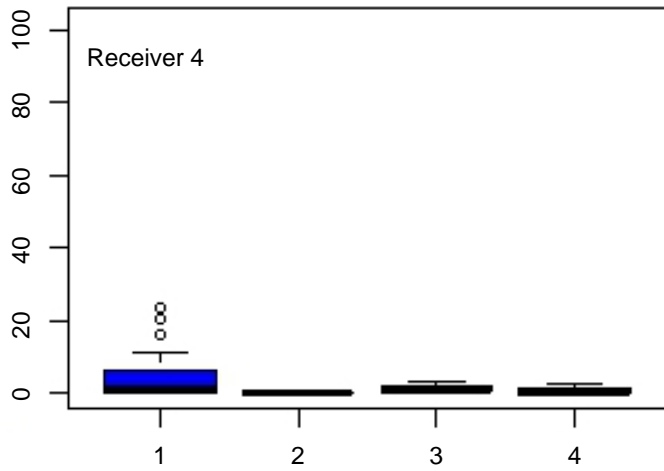
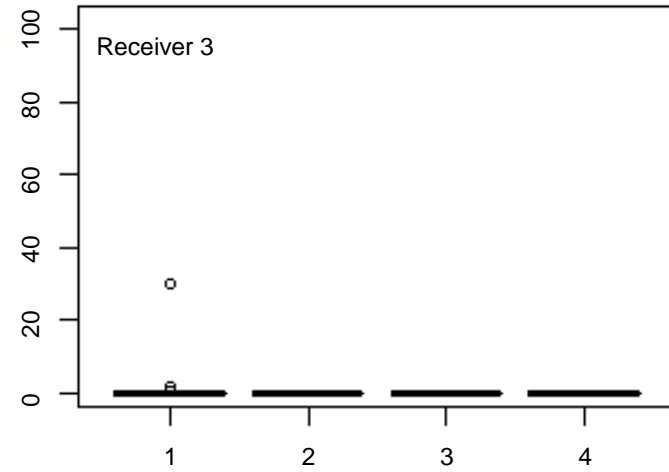
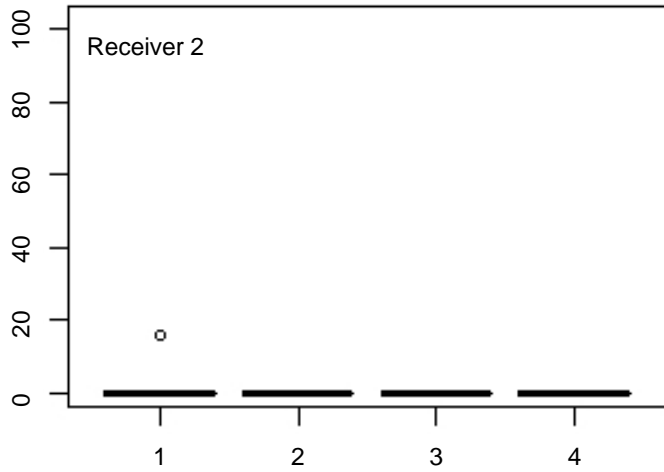


Residence Time (September)



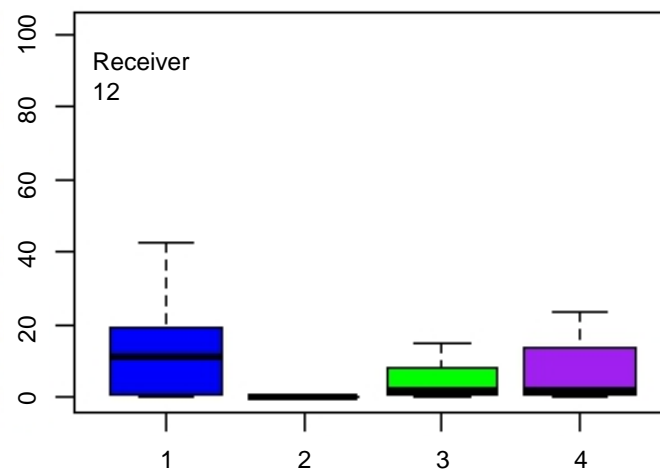
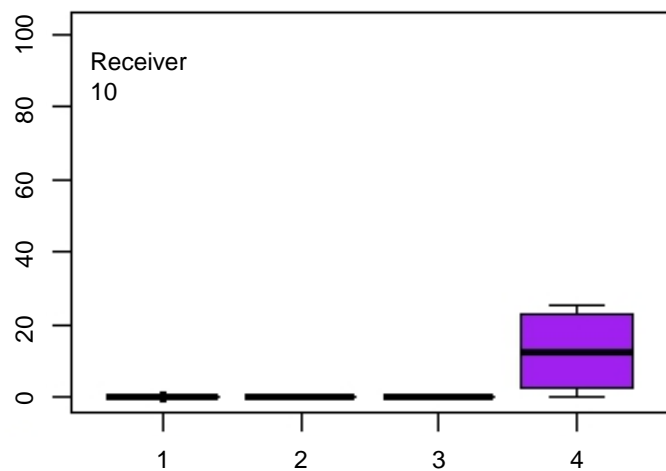
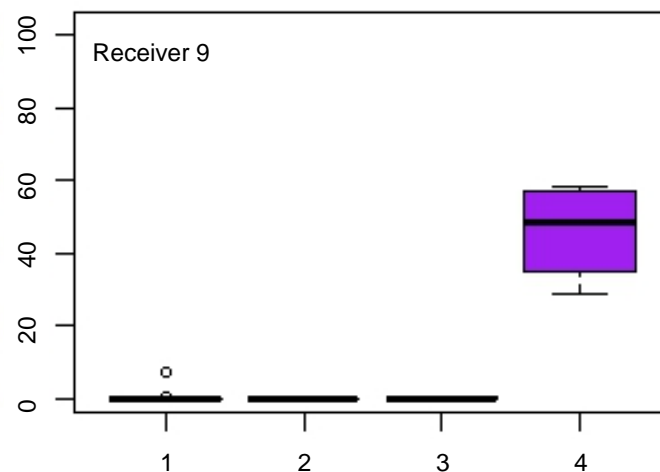
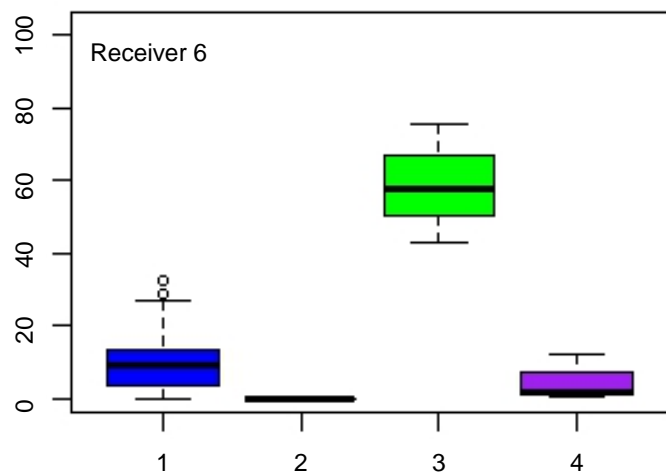
Chapter 2 Appendix Figure 23

Residence Time (October)



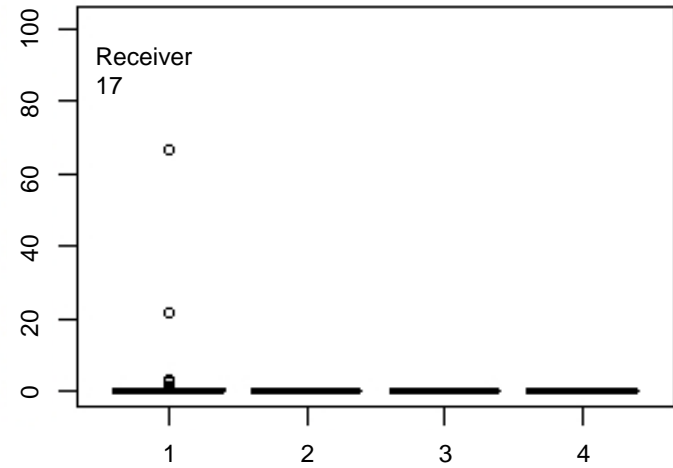
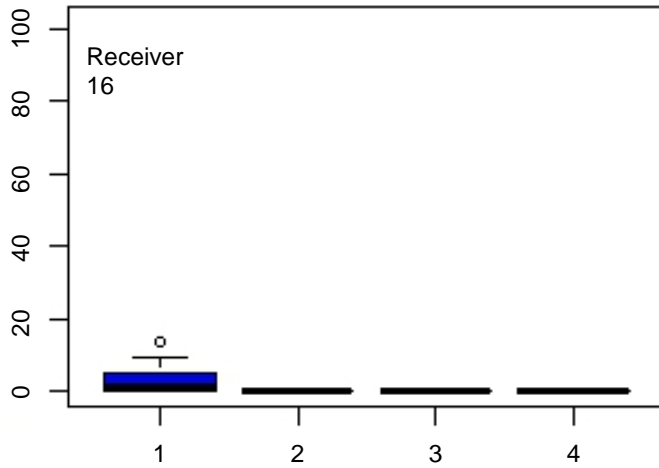
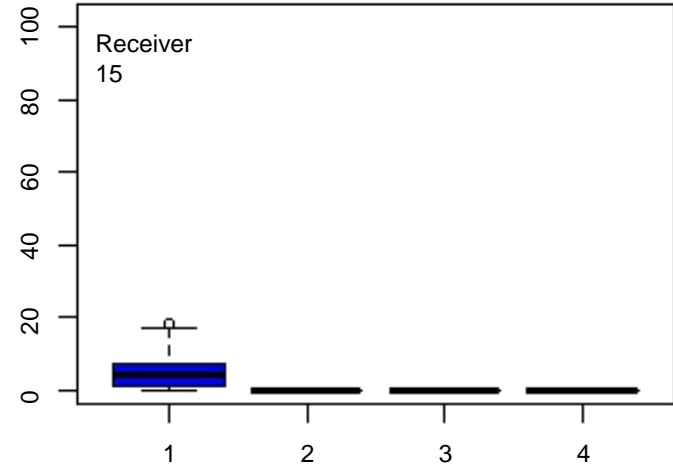
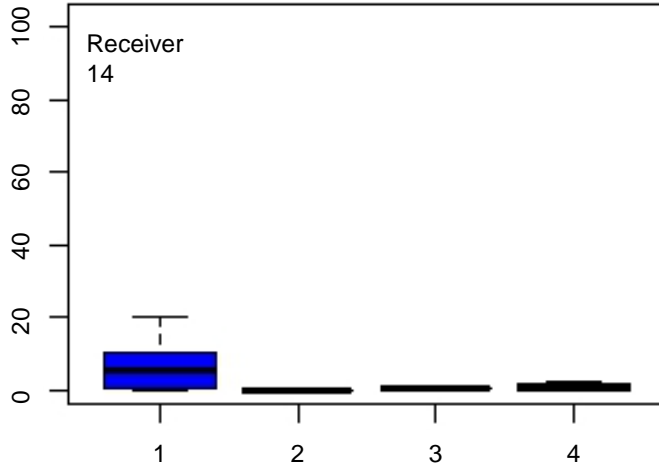
Chapter 2 Appendix Figure 24

Residence Time (October)



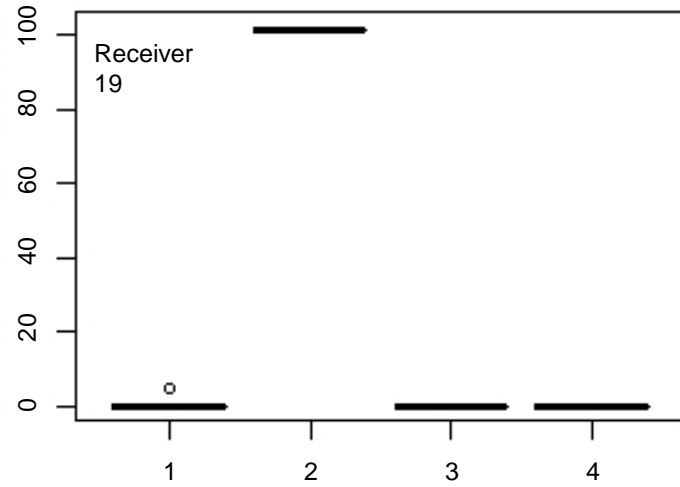
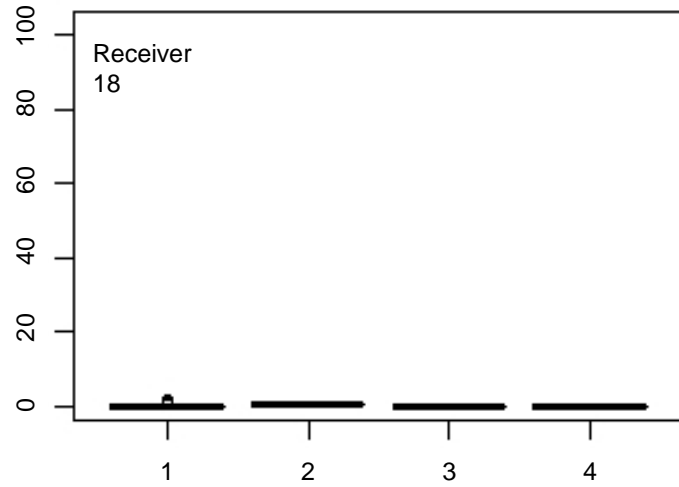
Chapter 2 Appendix Figure 25

Residence Time (October)

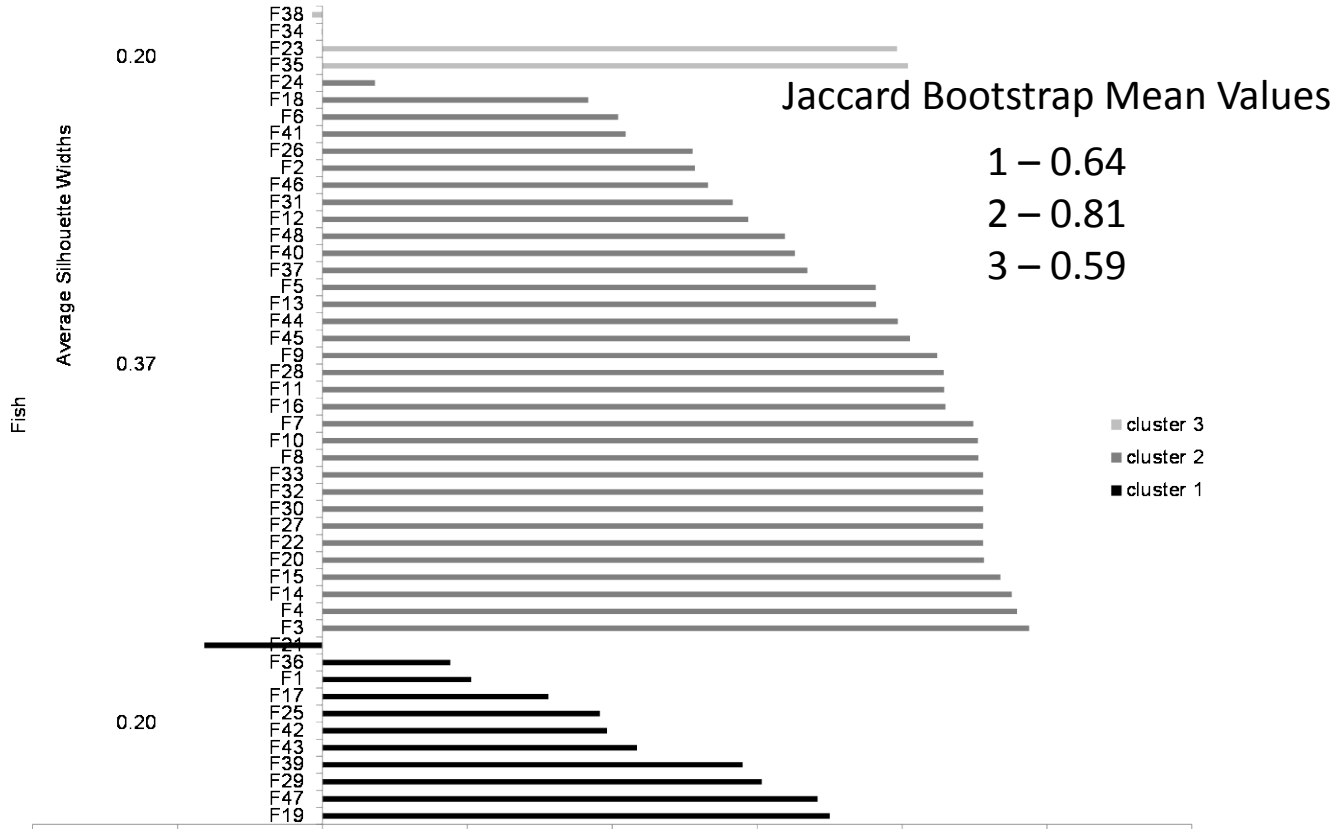


Chapter 2 Appendix Figure 26

Residence Time (October)

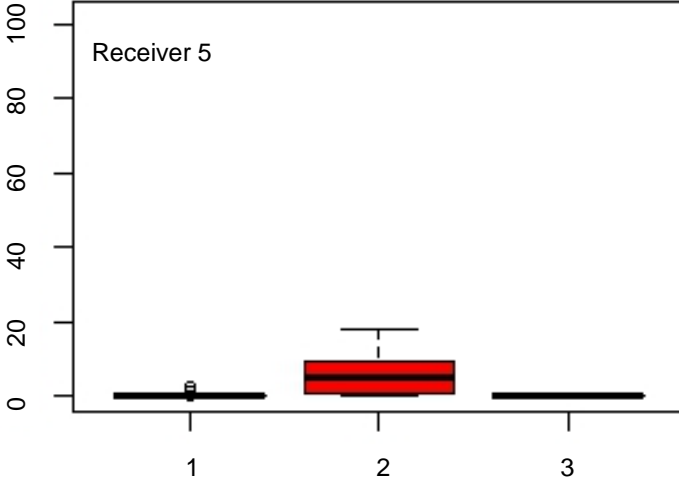
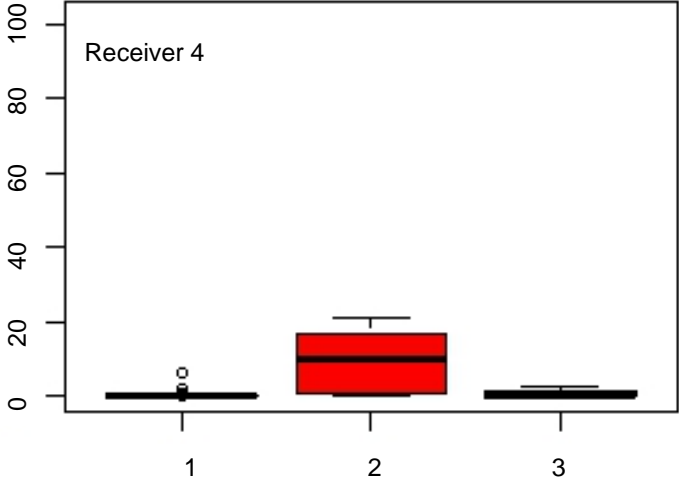
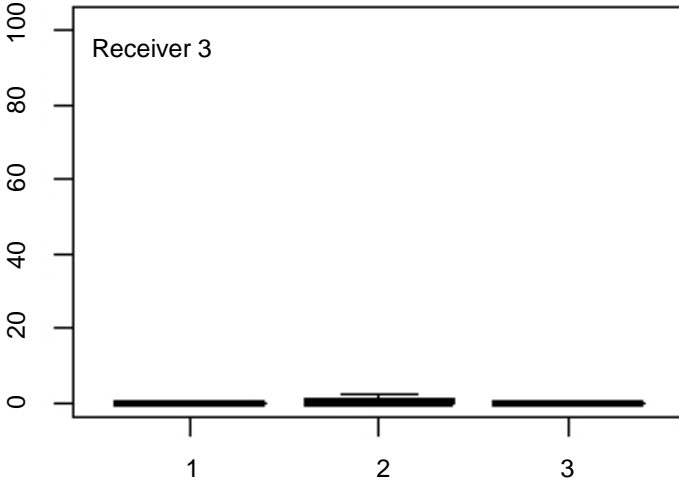
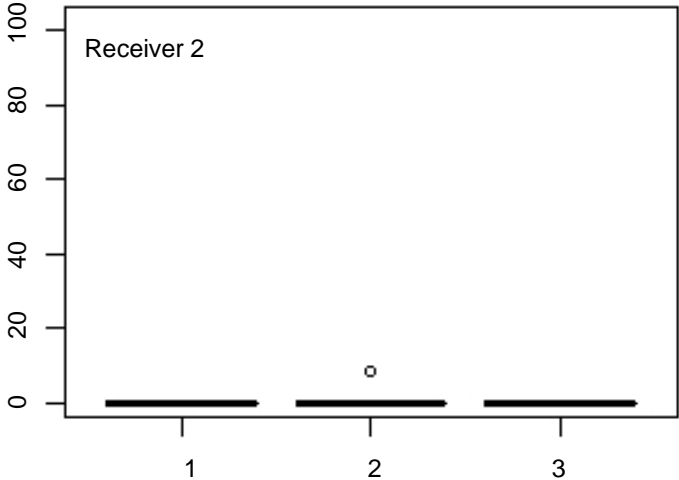


Residence Time (November)



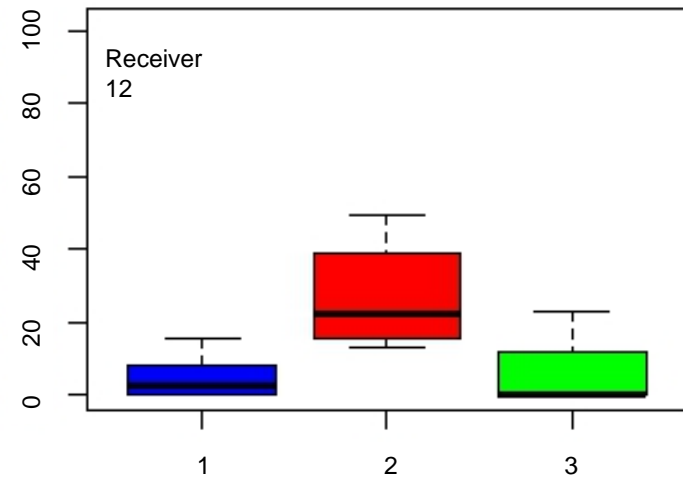
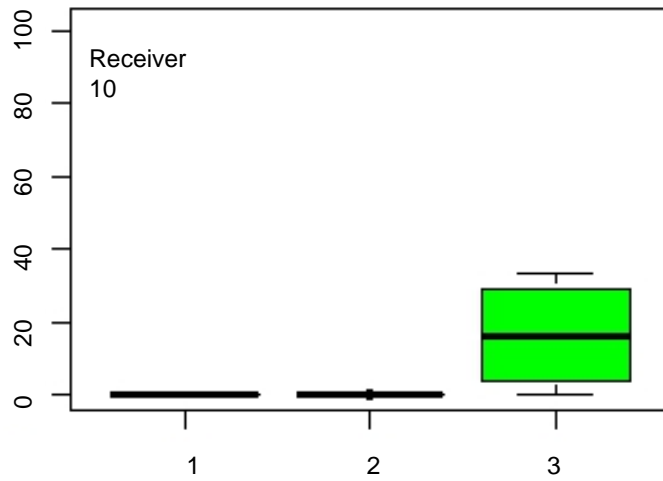
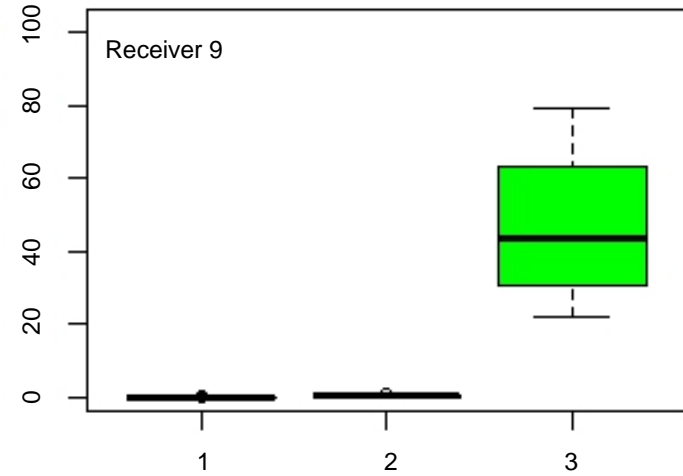
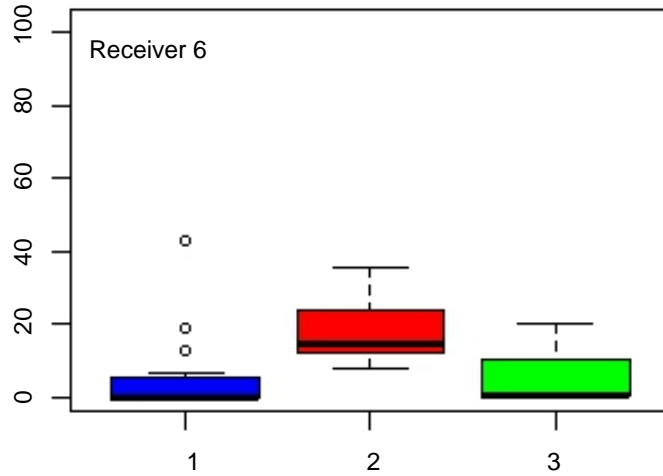
Chapter 2 Appendix Figure 28

Residence Time (November)



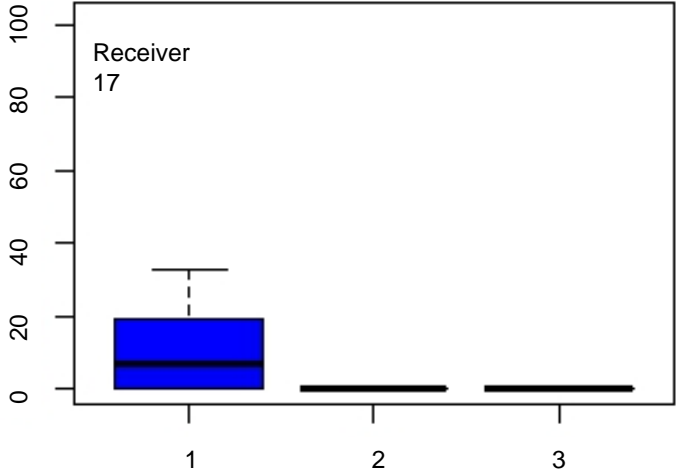
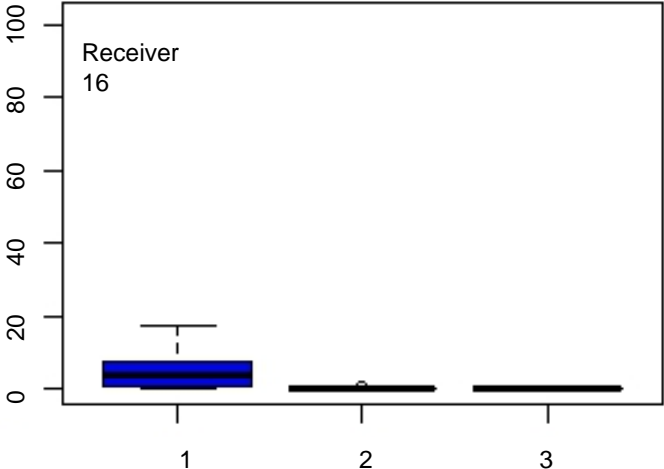
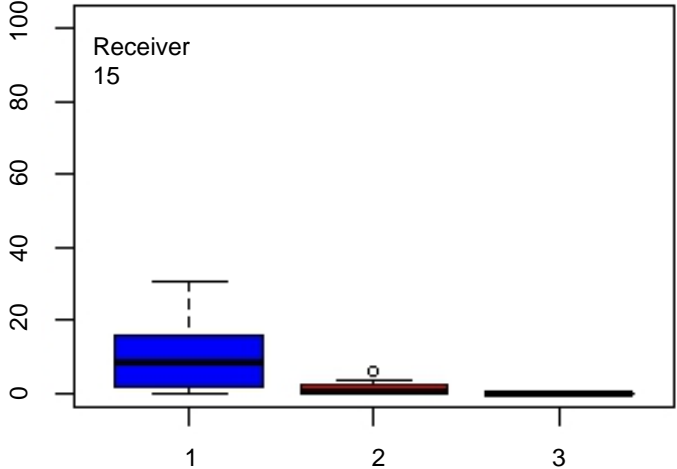
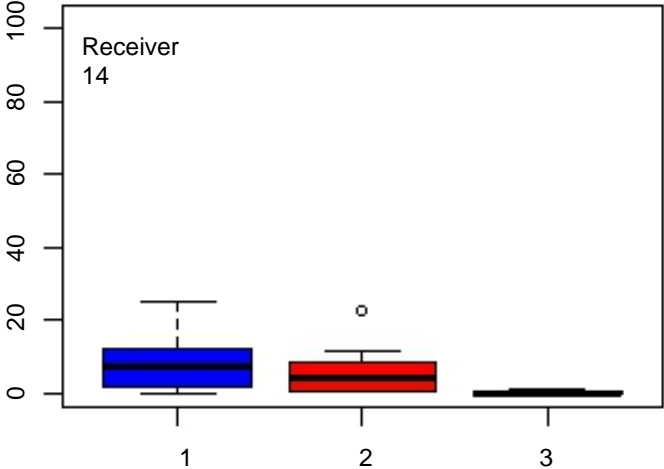
Chapter 2 Appendix Figure 29

Residence Time (November)



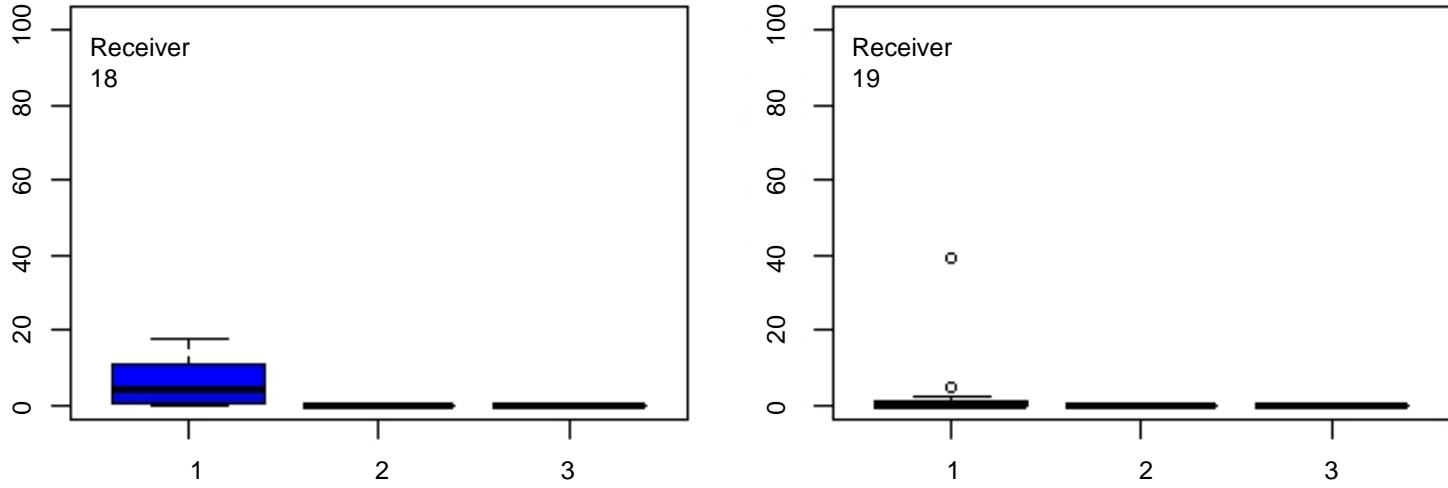
Chapter 2 Appendix Figure 30

Residence Time (November)



Chapter 2 Appendix Figure 31

Residence Time (November)



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

3
4 **INTRODUCTION**

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

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

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

24 of Science, Wildlife and Ecology Studies Worldwide, Environmental Sciences and Pollution
25 Management), technical committee websites for the Ictalurid Technical Committees (North
26 Central Division-American Fisheries Society, Southern Division-American Fisheries Society),
27 and published specialty symposia on catfish (Catfish 2000, Catfish 2010) revealed only 437 peer
28 reviewed publications on Blue Catfish. Of these, 59% ($n=257$) addressed sub-organismal or non-
29 field topics such as aquaculture, genetics, physiology, disease, or parasites (*Chapter 3 Figure 1*).
30 Another 28% ($n=122$) addressed management issues, sampling techniques, and monitoring. Only
31 13% ($n=57$) addressed ecological topics such as feeding or habitat. Of these, only a subset report
32 original data on habitat ($n=9$).

33 The literature on Blue Catfish distribution includes taxonomic keys (e.g., Lagler 1961;
34 Cross 1967; Jenkins and Burkhead 1994; Cross and Collins 1995) and review articles (Graham
35 1999). Original peer-reviewed habitat research also exists on Blue Catfish in rivers (e.g., Graham
36 and DeiSanti 1999; Jackson 1999; Garrett 2010; Garrett and Rabeni 2011; Miranda and Kilgore
37 2011) and reservoirs (e.g., Fischer et al. 1999; Edds et al. 2002; Grist 2002; Bartram et al. 2011).

38 Below, we briefly review some of this literature as a background for our study and to
39 justify our choice of abiotic and biotic variables. Factors that may influence Blue Catfish
40 distribution include temperature, dissolved oxygen, channel characteristics, depth, flow velocity,
41 and food resources. Temperature influences fish distribution in general and Blue Catfish in
42 particular. Because fish are ectotherms, consumption and growth are related to temperature
43 (Watz and Piccolo 2011). Blue Catfish increase growth rates in summer when temperatures are
44 20-28 °C (Grant and Robinette 1992). Although optimal temperature for Blue Catfish, when food
45 is unlimited, has been reported as 26-29 °C (Wyatt et al. 2009), Blue Catfish use the lower end of
46 this range in summer (26 °C, Grist 2002). For example, Blue catfish in Lake Norman selected

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

50 Dissolved oxygen levels can also impact catfish distribution (Fischer et al. 1999; Graham
51 1999; Baras and Laleye 2003). Dissolved oxygen below 4 ppm can stress Blue Catfish (Wyatt et
52 al. 2006). Blue Catfish rarely occur in locations with low dissolved oxygen and are often found
53 at high dissolved oxygen concentrations (Grist 2002). Specifically, Blue Catfish in Lake Norman
54 selected mean dissolved oxygen concentrations of 7.1 ppm (range 5.1 – 8.9 ppm, Grist 2002).

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

62 Blue Catfish eat fish and invertebrates (e.g., zooplankton, terrestrial insects, aquatic
63 insects, freshwater mussels, zebra mussels crayfish, clams; Brown and Dendy 1961; Minckley
64 1962; Perry 1969; Graham and DeiSanti 1999; Graham 1999; Edds et al. 2002; Grist 2002;
65 Magoulick and Lewis 2002). Small Blue Catfish (100 mm) eat invertebrates and some fish but
66 larger Blue Catfish (300+mm) eat mostly fish and larger invertebrates (Edds et al. 2002).

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

70 1995), allowing for more efficient predation. However, increased flow velocity can also increase
71 the energetic requirements of fish. Thus, benefits and consequences of current velocity for
72 feeding needs to be considered both within and across habitats.

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

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

90

91

METHODS

92 *Study System.* Milford Reservoir (39°08'42"N, 96°56'54"W) is an impoundment of the
93 Republican River (Dickinson, Clay, and Geary counties, KS) and is part of the Lower
94 Republican watershed, KS. Milford reservoir has a surface area of 6,555 ha, 262 km of shoreline
95 dominated by limestone cobble and boulders, an average depth of 6.7 m and a maximum depth
96 of 19.8 m (Reinke 2001) (*Chapter 2 Figure 1*). For this study, Milford Reservoir was divided
97 into five, similar-sized regions, based on stationary receiver locations described earlier (*Chapter*
98 *1, 2*). These regions include upper, upper middle, Madison Creek, lower middle, and lower
99 reservoir areas (*Chapter 1 Figure 4*).

100 *Overall Research Design.* To identify where Blue Catfish were located and what
101 environmental correlates influenced their distribution, we collected data on acoustically-tagged
102 Blue Catfish detections and select abiotic and biotic conditions at 57 0.8 km² tracking sites
103 (*Chapter 1 Figure 5*). Tracking sites were positioned to cover the maximum amount of surface
104 area while preventing overlap among adjacent sites. We chose this design to quantify spatial
105 heterogeneity, an important consideration in fish ecology (Scheiner and Willig 2008). The choice
106 of 57 spatially-explicit sampling locations that covered the entire reservoir provided good
107 resolution for quantifying Blue Catfish distribution, allowed us to construct detailed spatial maps
108 of Blue Catfish and potential environmental correlates, and resulted in substantial statistical
109 power for model selection using multiple regression.

110 *Choice of Variables and Hypotheses.* Based on the literature review above, we selected
111 12 variables to measure at each of the 57 sampling locations. These environmental correlates
112 included microhabitat variables (temperature, dissolved oxygen, slope, depth, flow velocity);
113 macrohabitat variables (distance to channel, distance to shore, river mile), and biotic variables
114 (e.g., fish prey, invertebrate prey, productivity as measured by Secchi depth).

115 *Hypotheses.* We tested four sets of ecological and statistical hypotheses which combined
116 the 12 variables identified above in different ways to allow a parsimonious examination of the
117 relationship between these abiotic and biotic variables and Blue Catfish distribution per location
118 In any use of multiple regression, the statistical goals are to (a) thoughtfully select variables of
119 interest, (b) limit the number of regressors in any single multiple regression model to maintain
120 statistical power, and (c) through *a priori* planning, limit the number of statistical models to
121 reduce across comparison error rates. Our use of four sets of hypotheses accomplished these
122 statistical goals. Hypothesis 1 tested the relative importance of local microhabitat variables
123 (temperature, dissolved oxygen, depth, slope, flow velocity). Hypothesis 2 tested the relative
124 importance of macrohabitat (distance to channel, distance to shore, river mile, and drop-offs).
125 Hypothesis 3 tested significant general habitat variables outlined in hypotheses 1, 2. Hypothesis
126 4 tested the relative importance of biotic factors (numbers of gizzard shad, numbers of
127 chironomids, and productivity as measured by Secchi depth).

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

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

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

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

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

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

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

164 *Depth and Slope.* At each manual tracking site, depth was quantified by taking a total of
165 200 depth measurements across two 1 km perpendicular transects, one transect oriented north-
166 south and the other oriented east-west. Along these transects, depth measurements were taken
167 every 10 m with a Hummingbird 1198c SI Combo unit. Slope was quantified by calculating the
168 change in depth across every 10-m transect section. For scatterplots, univariate, and multivariate
169 regressions, depth and slope were summarized as the mean of all measurements at a site. For
170 statistical analysis, slope was log transformed to satisfy assumptions of regression analysis.

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

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

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

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

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

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

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

230 *Number of Chironomid Larvae.* Chironomid larvae were quantified by filtering a
231 sediment grab (i.e., 7 kg Ponar grab) collected at the center of each sampling site through a
232 sediment sieve (Field Master 500 micron). Samples were collected monthly in June – October,
233 2013, at the same time as manual tracking.

234 *Gastric Lavage.* On July 11, August 22, and October 7, 2013, we collected Blue Catfish
235 from Milford Reservoir to examine diets. Our goals were to connect specific prey taxa to Blue
236 Catfish through diet, provide a link between spatial patterns of select prey and Blue Catfish
237 distribution, and examine variation in diets across sites. Blue Catfish were collected using
238 electrofishing. On each of the three sample dates (July 11, 2013, August 22, 2013, October 7,
239 2013), Blue Catfish diets were examined using gastric lavage. Gastric lavage is a nonlethal diet
240 sampling method in which pressurized water is flushed into fish stomachs to force out contents
241 (Ferry and Mather 2012). After stomach pumping, all Blue Catfish were allowed to recover then
242 released back into the estuary. For each Blue Catfish, flushed prey items were bagged, stored on
243 ice, and then frozen. In the laboratory, we identified prey (Ferry and Mather 2012). Three major
244 prey categories dominated the diets: fish (mostly gizzard shad), zebra mussels, chironomid
245 larvae. Most of the fish identified in Blue Catfish diets were gizzard shad. However, we leave
246 this as a general “fish” category because many samples were well digested or only represented
247 by a backbone. We also note a fourth, less common prey category, miscellaneous insects. We
248 present the data as frequency of occurrence (number of individuals in a sample that have a given
249 prey item). Frequency of occurrence is the preferred diet analysis method for a broad perspective
250 on diet differences across space and time. Diet was only used to link Blue Catfish to specific

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

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

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

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

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RESULTS

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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*).

295 *Hypothesis 1: Microhabitat.* In hypothesis 1, we tested the relative importance of local
296 microhabitat variables (temperature, dissolved oxygen, slope, depth, flow velocity). For all
297 combinations of the five variables in hypothesis 1, six models had a $\Delta AIC < 4$ (*Chapter 3 Table*
298 *1*). These models had P values < 0.001 and $R^2=0.30-0.34$. Consistently present and significant
299 regressors (shown in bold) in these top models included temperature, dissolved oxygen, and
300 slope (*Chapter 3 Table 1*). Temperature, deviation from median dissolved oxygen, and
301 bathymetric slope had negative statistical slopes in the multiple regression (*Chapter 3 Table 1*;
302 $P < 0.001$). At high values of temperature, few tagged Blue Catfish were detected (*Chapter 3*
303 *Table 1*; $P < 0.001$; *Chapter 3 Figure 3A*). Where high variation in dissolved oxygen occurred,
304 few tagged Blue Catfish were detected (*Chapter 3 Table 1*; $P < 0.001$; *Chapter 3 Figure 3B*). At
305 sites with a high bathymetric slope, few tagged Blue Catfish were detected (*Chapter 3 Table 1*;
306 $P < 0.001$; *Chapter 3 Figure 3C*). Depth and flow were included in select top models but these
307 regressors were not consistently significant (β was not different than 0) (*Chapter 3 Table 1*;
308 *Chapter 3 Figure 3D-E*).

309 All five microhabitat variables tested in hypothesis 1 were heterogeneous across Milford
310 Reservoir (*Chapter 3 Figure 4*). Temperatures were higher in the upper reservoir (*Chapter 3*
311 *Figure 4A, orange, red circles*). Some extreme temperatures also occurred in the lower reservoir
312 (*Chapter 3 Figure 4A, orange, red circles*). However, moderate intermediate temperatures
313 generally were present throughout much of the upper middle, and lower middle regions (*Chapter*
314 *3 Figure 4A, green, yellow circles*).

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

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

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

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

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

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

347 *Hypothesis 2, Macrohabitat.* Our hypothesis 2 tested the relative importance of four
348 larger-scale macrohabitat features (distance to channel, distance to shore, river mile, and number
349 of drop-offs). When all combinations of these four variables were considered, four models had a
350 $\Delta AIC < 4$ (Chapter 3 Table 2; $P < 0.001$; $R^2 = 0.39-0.41$). In these top models, distance to channel
351 and river mile were consistently, statistically significant (Chapter 3 Table 2; $P < 0.001$). More
352 tagged Blue Catfish were detected close to the channel (Chapter 3 Table 2; $P < 0.001$; Distance
353 to channel $\beta < 0$; Chapter 3 Figure 6A). As distance from the dam increased, more tagged Blue
354 Catfish were detected (Chapter 3 Table 2; $P < 0.001$; β for River Mile > 0 ; Chapter 3 Figure
355 6C). Distance to shore and numbers of drop-offs were present in a few top models but the slopes
356 of these variables were not significantly different from zero (no statistical effect; Chapter 3
357 Table 2; Chapter 3 Figure 6D).

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

364 0.001; Chapter 3 Figure 6A) and away from the dam (Chapter 3 Table 2; β for River Mile > 0 ;
365 $P < 0.001$; Chapter 3 Figure 6C). As with hypothesis 1, our best multiple regression model
366 correctly predicted Blue Catfish aggregations (Chapter 3 Figure 8A, red, orange circles) but also
367 over predicted Blue Catfish numbers at some low density sites (Chapter 3 Figure 8B).

368 *Hypothesis 3 – General Habitat.* In our hypothesis 3, we combined significant regressors
369 from the microhabitat and macrohabitat hypotheses (temperature, dissolved oxygen, slope, depth,
370 flow, distance to channel, and river mile). Twenty seven models fit the data similarly, had ΔAIC
371 < 4 , $P < 0.001$, and $R^2 = 0.40-0.43$ (Chapter 3 Table 3). The slopes of the regressors and the
372 relationship between regressors and Blue Catfish numbers were the same as reported above
373 (Chapter 3 Table 3) so we do not describe them again here in detail. Briefly, river mile continued
374 to be significant in all models. Temperature, depth and distance to channel were significant in
375 some models. Dissolved oxygen, slope, and flow velocity were not significant in any models
376 (Chapter 3 Table 3). Although hypothesis 3 explained a little more variation in the data ($R^2 = 0.43$
377 vs $R^2 = 0.34$ or $R^2 = 0.41$; Chapter 3 Tables 1-3), few new ecological insights were provided.

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

387 but were not significantly related to Blue Catfish numbers (*Chapter 3 Table 4; Chapter 3 Figure*
388 *9A-B, $P > 0.05$*).

389 Geographically, the distribution of Gizzard Shad and chironomids were highly variable
390 across sites (*Chapter 3 Figure 10A, B*). Gizzard shad catch tended to be moderately high in the
391 upper reservoir (*Chapter 3 Figure 10A; yellow, orange circles*), irregularly high on the east side
392 of the constriction (*Chapter 3 Figure 10A; red circles*), and low in the lower reservoir (*Chapter*
393 *3 Figure 10A; green circles*). Chironomids were variable throughout the upper and middle
394 regions of the reservoir with isolated locations of high abundance in the upper, upper middle and
395 lower middle regions (*Chapter 3 Figure 10B, yellow, red, orange circles*). The lower reservoir
396 had consistently low levels of these invertebrate prey (*Chapter 3 Figure 9B; green circles*).

397 *Secchi/ Productivity Relationship* A negative relationship was found between Secchi
398 depth and total suspended solids (*Chapter 3 Figure 11A; $\beta = -0.36, R^2 = 0.53, P = 0.001$*), inorganic
399 solids (*Chapter 3 Figure 11B $\beta = -0.25, R^2 = 0.48, P = 0.001$*), organic solids (*Chapter 3 Figure*
400 *11C; $\beta = -0.11, R^2 = 0.64, P = 0.001$*), and corrected chlorophyll a concentration (*Chapter 3 Figure*
401 *11D; $\beta = -0.0004, R^2 = 0.32, P = 0.001$*). These data suggest that reductions in Secchi depth were
402 related to both suspension of inorganic material, organic solids, and primary productivity.

403 Secchi depth was the only variable with a biotic association that was quantitatively
404 related to Blue Catfish density (*Chapter 3 Table 4; $P < 0.001$*). Secchi depth was consistently low
405 in the upper and upper middle reservoir corresponding to high productivity (*Chapter 3 Figure*
406 *10C, green circles*). Secchi depth decreased throughout the lower middle and lower reservoir
407 (*Chapter 3 Figure 10C, green circles*).

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

410 0.001). Elsewhere gizzard shad have been found in waters with high phytoplankton production
411 (Sullivan 2009). The best model for hypothesis 4 predicted where high numbers of catfish might
412 occur (*Chapter 3 Figure 13A*), but, like other models, erroneously identified some low density
413 sites as aggregations (*Chapter 3 Figure 13B*).

414 *Lavage Results.* On each of three sample dates, we collected 63, 115, and 91 Blue Catfish
415 from 4, 10, and 11 locations in Milford Reservoir (*Chapter 3 Table 5*). Blue Catfish were an
416 average of 315 mm TL (range 212-703 mm TL, n=63), 316 mm TL (range 235-571 mm TL,
417 n=115), and 390 mm TL (range 253-813, TL, n=91) on each date respectively. In July, 29 of 63
418 (46%) Blue Catfish had empty stomachs (*Chapter 3 Table 5*). In August, 71 of 115 (62%) Blue
419 Catfish had empty stomachs (*Chapter 3 Table 5*). In October, 19 of 91 (21%) Blue Catfish had
420 empty stomachs (*Chapter 3 Table 5*). Across sites, the number of empty stomachs was quite
421 variable. For example, in July, Site 18 in the upper middle region had a lower incidence of empty
422 stomachs (6%) than all other sites (sites 1, 23, 27 had 50, 58, 64% empty stomachs respectively)
423 (*Chapter 3 Table 5*). In August, all but three sites had a high incidence of empty stomachs (>
424 50% empty) but across site variability was still evident (*Chapter 3 Table 5*). In October, Blue
425 Catfish at most sites were feeding, but again across site variation in the incidence of empty
426 stomachs existed (*Chapter 3 Table 5*).

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

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

435

436

DISCUSSION

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

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

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

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

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

480 When water quality (e.g., temperature and dissolved oxygen) values were not extreme,
481 via filter 2, Blue Catfish were clustered near a combination of permanent physical features that
482 caused heterogeneity in bathymetry. These physical features combined microhabitat variables
483 (depth, slope) and macrohabitat variables (distant to channel, river mile). A complexity index
484 that includes spatial discontinuities has been linked to fish aggregations elsewhere (Kennedy
485 2014, Kennedy et al. In Review). Previous studies have shown associations among Blue Catfish
486 and depth (e.g., Driscoll et al. 1999; Graham and DeiSanti 1999; Edds et al. 2002; Fischer et al.
487 2002; Grist et al. 2002; Miranda and Kilgore 2011). Although Blue Catfish are associated with
488 specific depths in individual studies, a clear and consistent association with depth conditions
489 across studies (e.g., shallow depths, great depths, or any consistent depth) has not emerged. Blue
490 Catfish often associate with macrohabitat features such as channels (e.g., Fischer et al. 1999;
491 Jackson 1999; Edds et al. 2002; Grist et al. 2002; Garrett and Rabeni 2011), as we did. Although
492 we did not find flow to be a consistently significant correlate of distribution, Blue Catfish
493 distribution can be associated with higher flow velocity, especially in river systems (e.g.,
494 Graham and DeiSanti 1999; Tripp et al. 2011). Bathymetry at the microhabitat and macrohabitat
495 scales may interact with flow velocity to provide adjacent feeding and resting sites. Individual
496 physical variables are often cited as determinants of Blue Catfish distribution, but Garrett (2010)
497 suggested that a complex interaction among flow velocity, local habitat structure, and depth
498 existed for Blue Catfish in rivers. We concur that a combination of physical variables likely acts
499 together. A cumulative index of bottom irregularities, as we proposed here, is novel way of
500 thinking about habitat relationships for this species.

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

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

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

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

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

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

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

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

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

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

569 *and (3) with higher productivity.* These correlates of distribution could be viewed as complex
570 interactions rather than individual variables that act independently.

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

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

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

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

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_c	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_c	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 R², variance inflation factor (VIF) and condition number (CN).

No.	Temp	DO	Slope	Depth	Flow	Channel	Mile	K	ΔAIC_c	ω_i	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_c	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.

Sites	Region	July 11, 2013						August 22, 2013						October 7, 2013					
		FO						FO						FO					
		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														19	21	0.40	0.00	0.40	0.10
16	Middle							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	Upper													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								15	73	0.00	0.13	0.13	0.00						
27	Lower Middle	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					

1 **ENVIRONMENTAL CORRELATES OF DISTRIBUTION**
2 **OF BLUE CATFISH IN MILFORD RESERVOIR**

3 **(OBJECTIVE 6)**

4
5 **FIGURE CAPTIONS.**

6
7 *Chapter 3 Figure 1.* Breakdown by topic of peer reviewed literature on Blue Catfish from three
8 environmental science literature data bases (Web of Science, Wildlife and Ecology Studies
9 Worldwide, Environmental Sciences and Pollution Management); technical committee websites
10 for the Ictalurid Technical Committees (NCD-AFS, SD-AFS); and published specialty symposia
11 on catfish (Catfish 2000, Catfish 2010). Numbers are percentages of 437 papers.

12
13 *Chapter 3 Figure 2.* Map of blue catfish relative abundances (No.) based on a manual 57 site
14 acoustic tracking survey conducted monthly from July through November, 2013 in Milford
15 Reservoir, KS. Data were the average of 15 min detection periods for each month. Data were log
16 transformed.

17
18 *Chapter 3 Figure 3.* For the first hypothesis that tests the importance of five microhabitat
19 variables, shown are scatterplots of Blue Catfish counts (No.) (Y) versus (A) average
20 temperature (°C) (X), (B) deviation from median dissolved oxygen (mg/L) (X), (C) mean slope
21 (cm/m) (X), (D) mean depth (m) (X), and (E) mean flow velocity (m/s) (X). Catfish count and
22 slope were log transformed. Each point represents a sample site ($n=57$). Blue Catfish numbers,
23 temperature, dissolved oxygen, and flow velocity were averaged across July-November 2013.

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

27

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

33

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

38

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

46

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

51

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

55

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

63

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

66

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

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

71

72 *Chapter 3 Figure 12.* Relationship among Secchi depth and gizzard shad numbers are shown.

73 Gizzard shad numbers are logged. Results of a linear regression are shown

74

75 *Chapter 3 Figure 13.* Maps of (A) observed Blue Catfish abundance (No.) vs (B) Blue Catfish

76 abundance (No.) predicted from the top multiple regression model for hypothesis 4, biotic in

77 Milford Reservoir, KS July – November 2013(*Chapter 3 Table 1*). Data were from a 57 site

78 survey.

79

80 *Chapter 3 Figure 14.* Frequency of occurrence of fish prey, zebra mussels, and chironomids

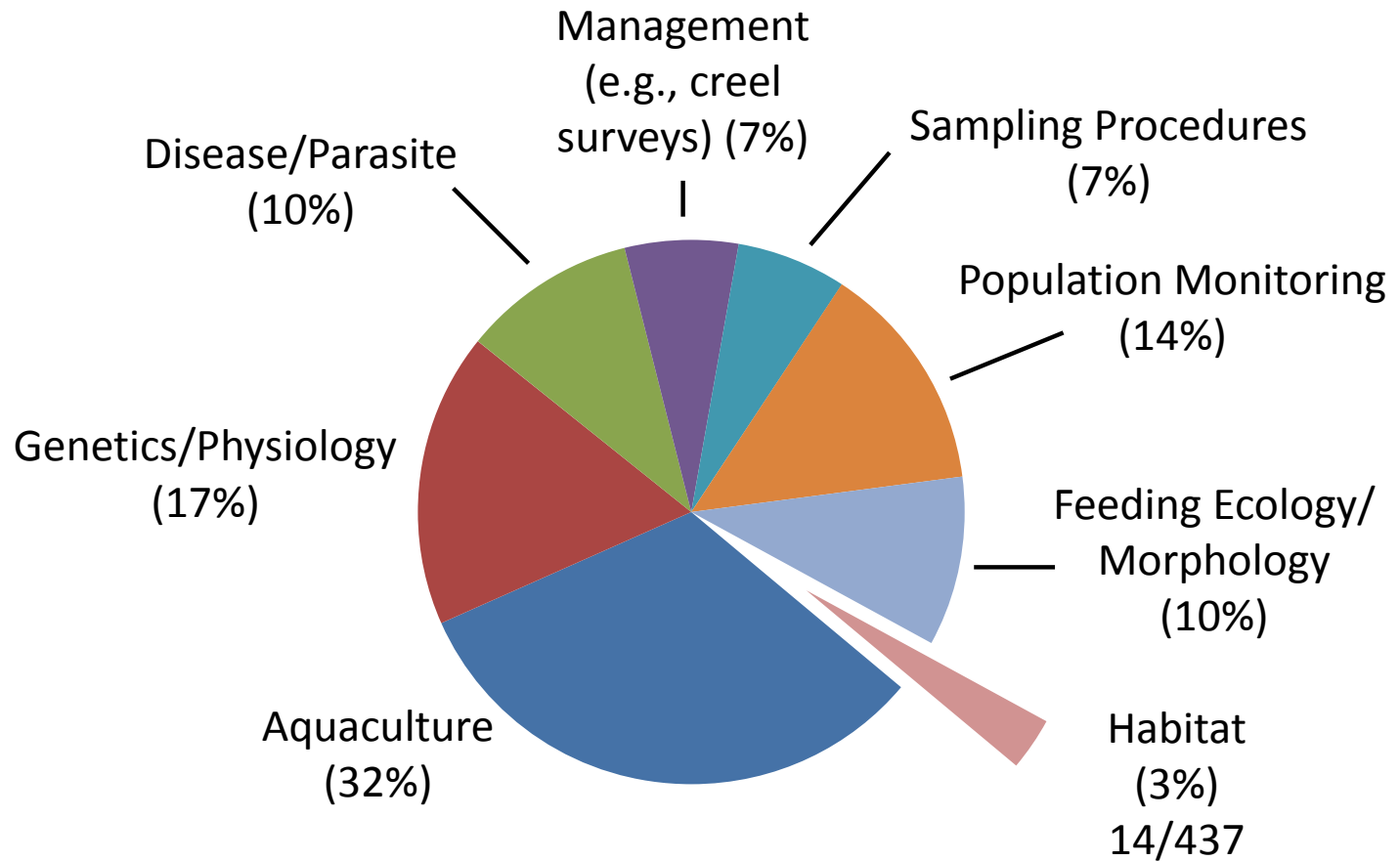
81 across 14 sites for (A) July 11, 2013, (B) August 22, 2013, and (C) October 7, 2013. The sites

82 are divided into 5 regions: U= upper, UM = upper middle, T=tributaries, LM =lower middle,

83 and L- lower.

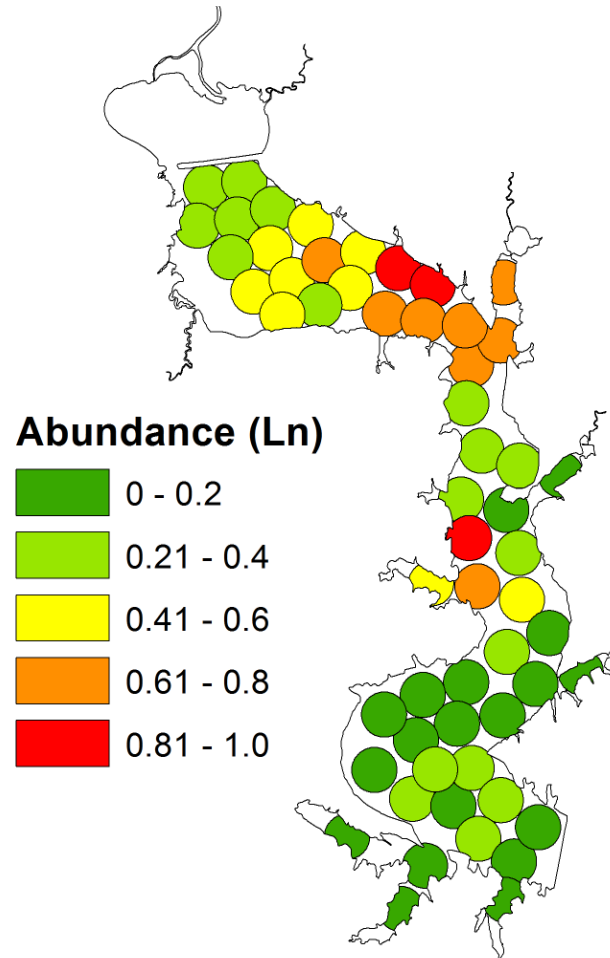
84

Peer-Reviewed Literature – Blue Catfish



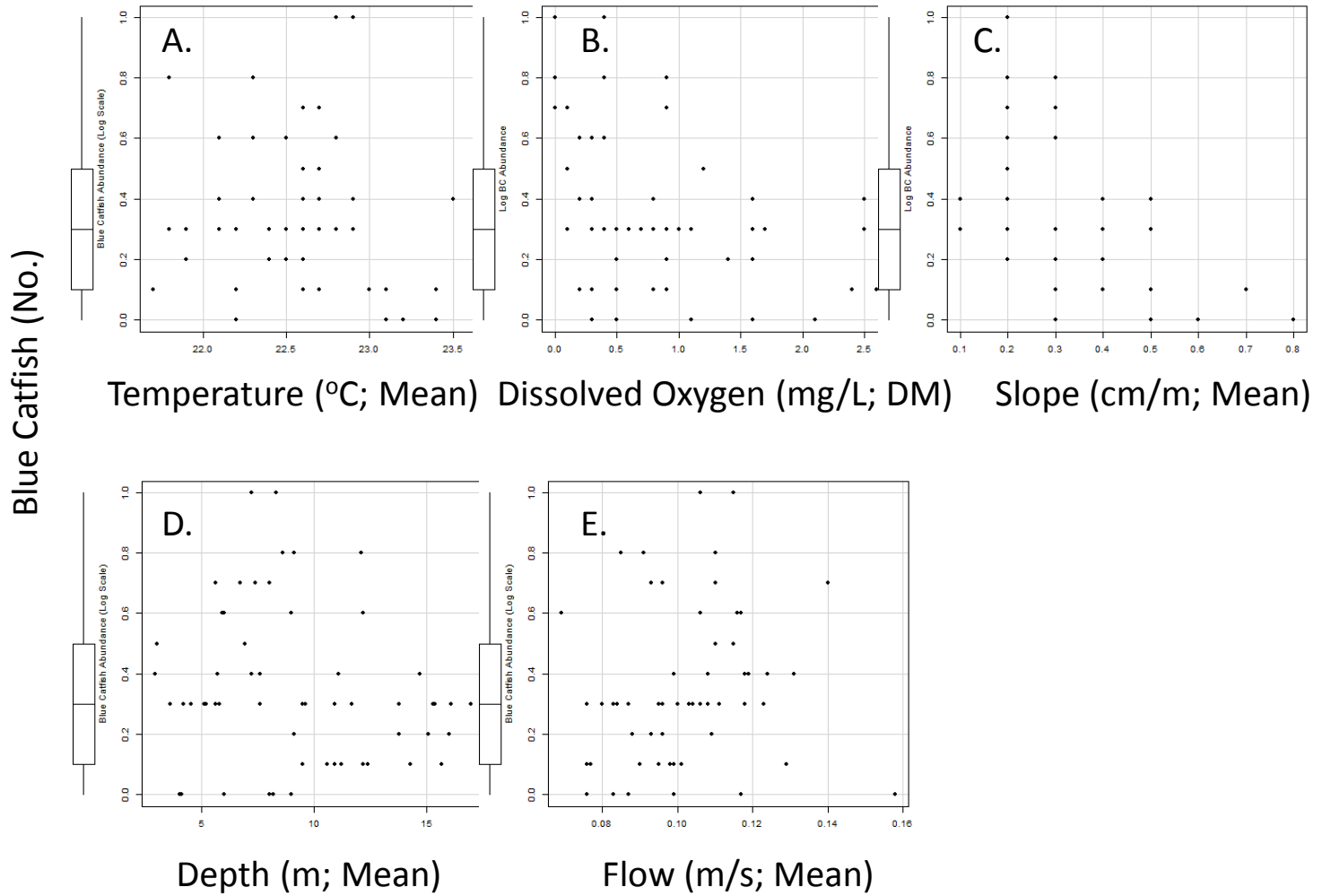
Chapter 3 Figure 1

Blue Catfish Abundance (No.)



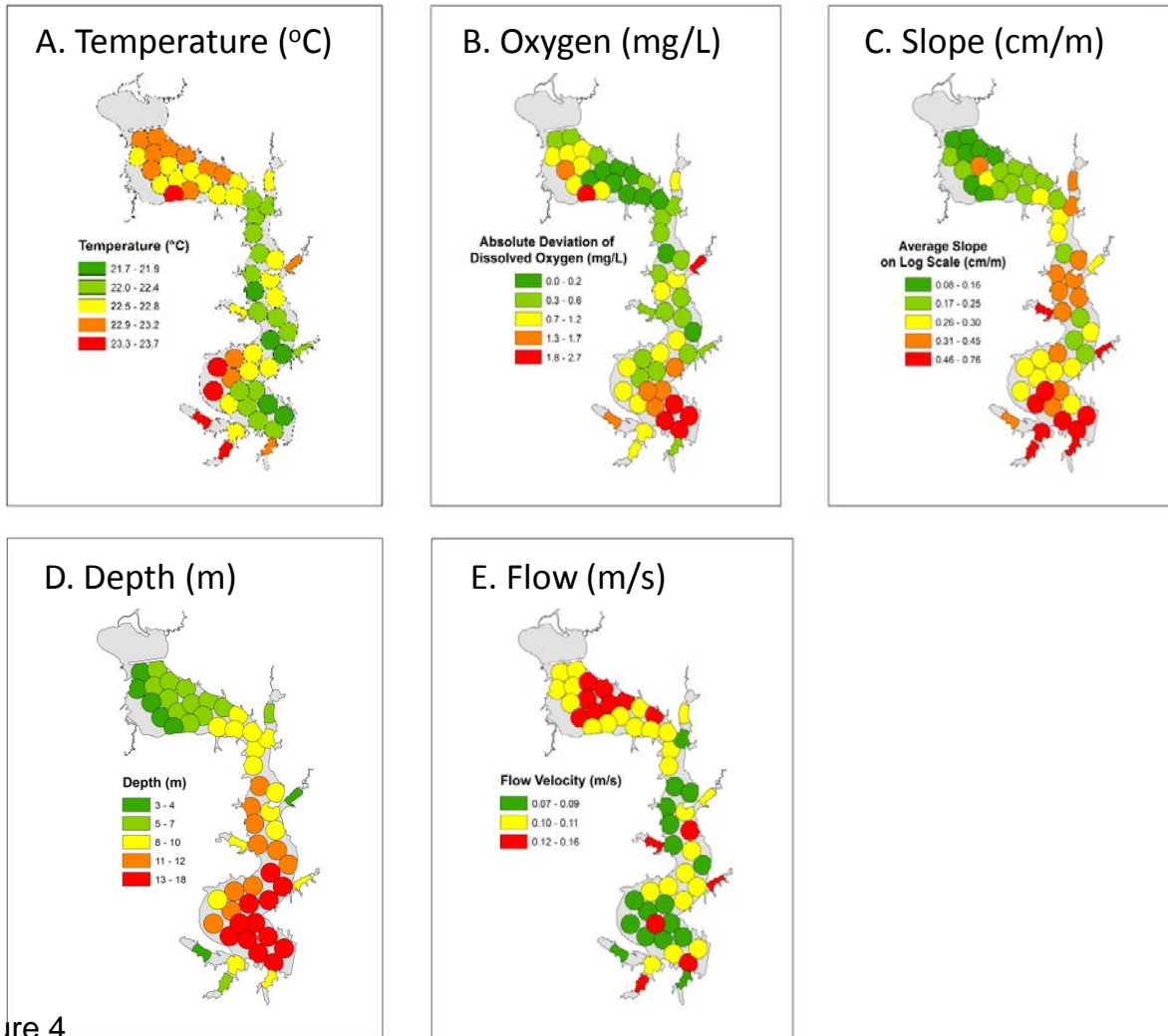
Chapter 3 Figure 2

HYPOTHESIS 1 – MICROHABITAT



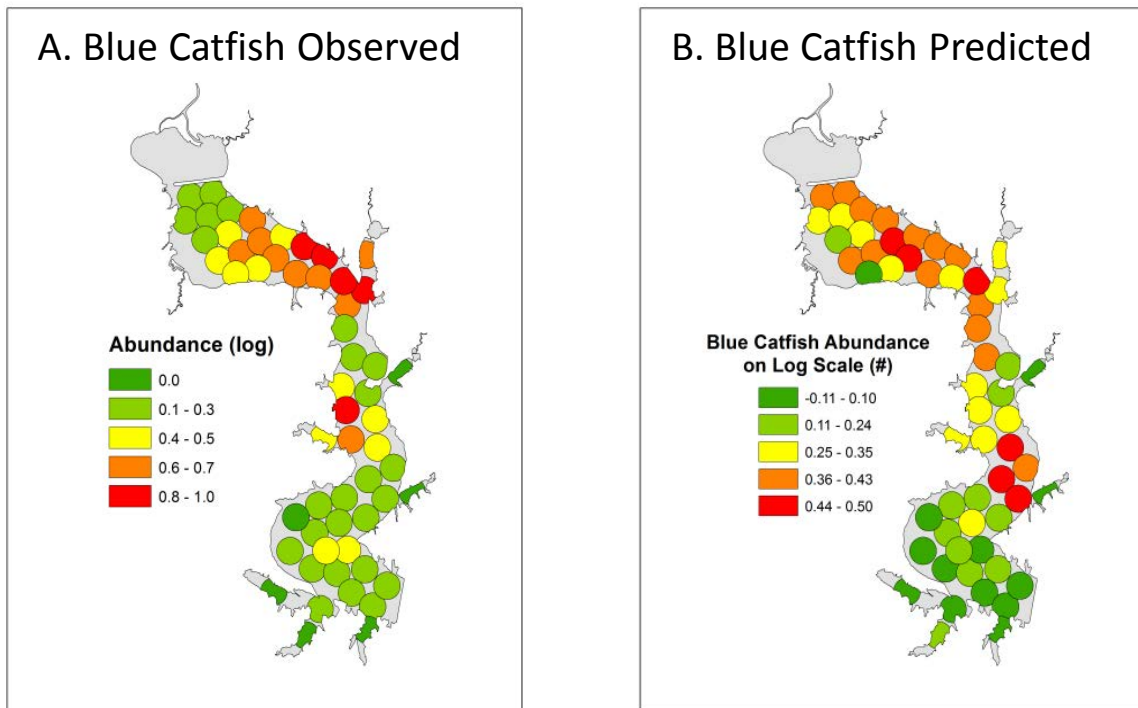
Chapter 3 Figure 3

HYPOTHESIS 1 – MICROHABITAT



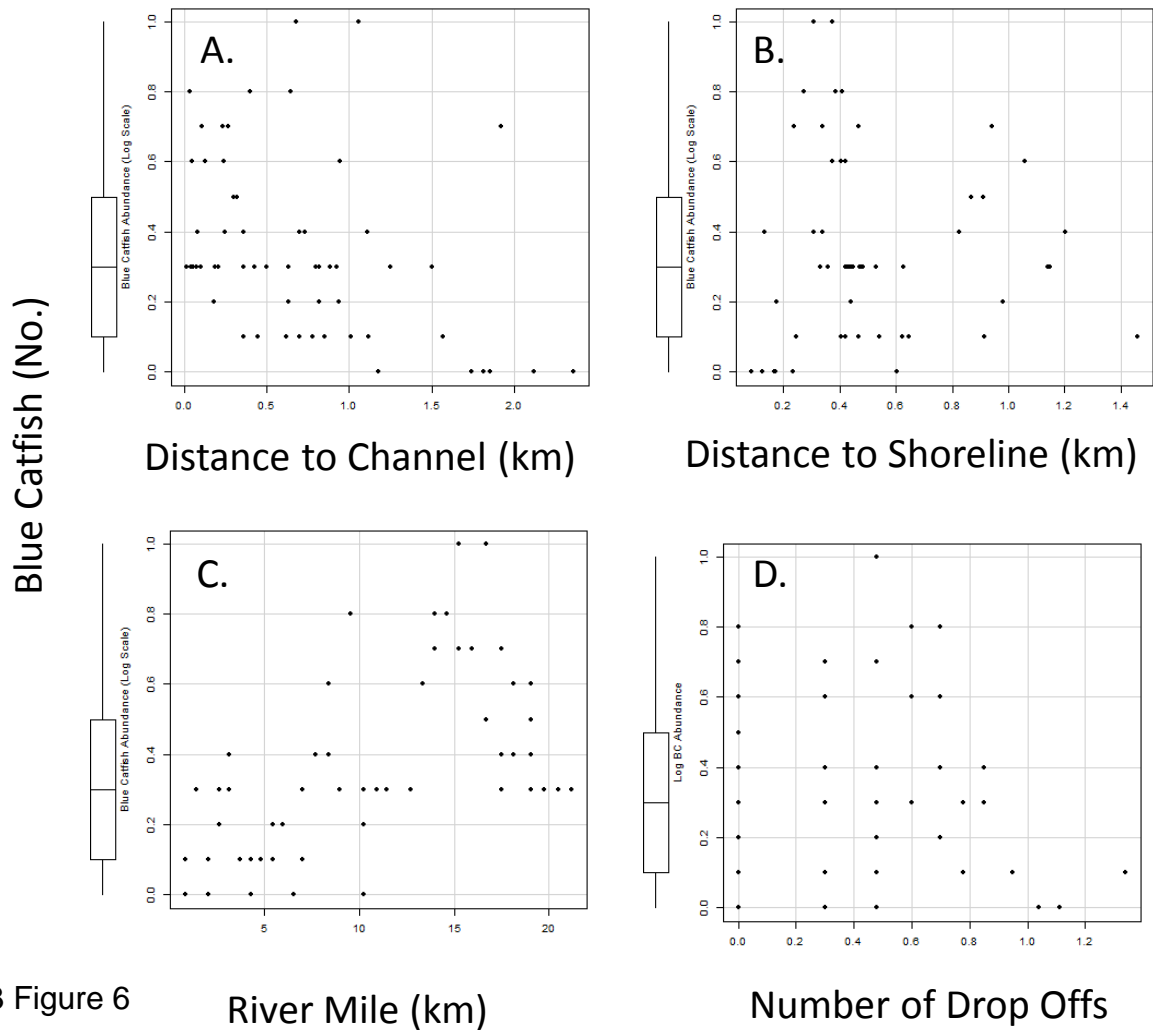
Chapter 3 Figure 4

HYPOTHESIS 1 – MICROHABITAT



Chapter 3 Figure 5

HYPOTHESIS 2 – MACROHABITAT

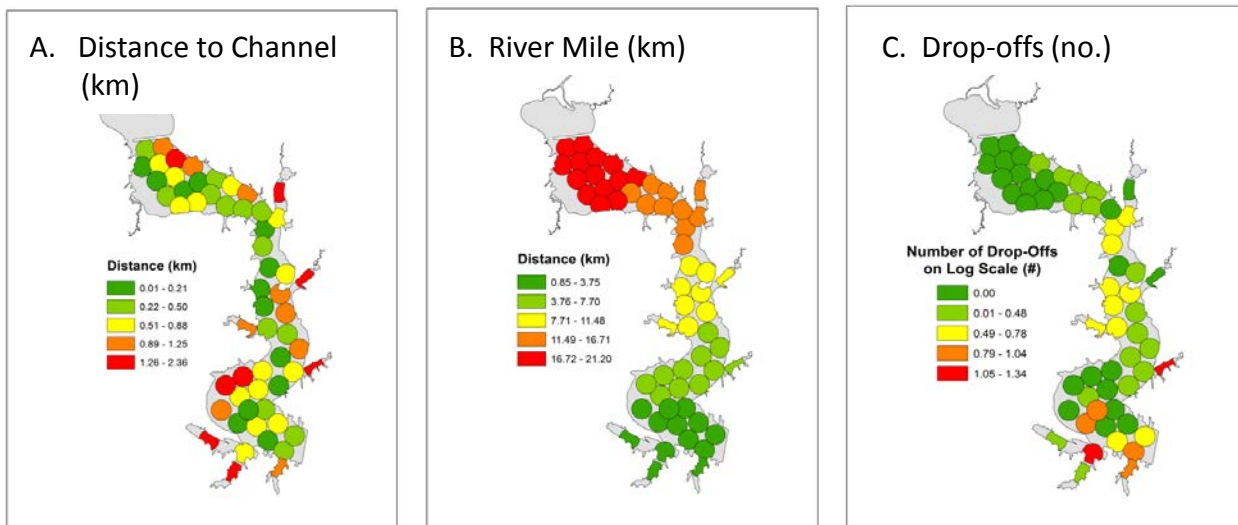


Chapter 3 Figure 6

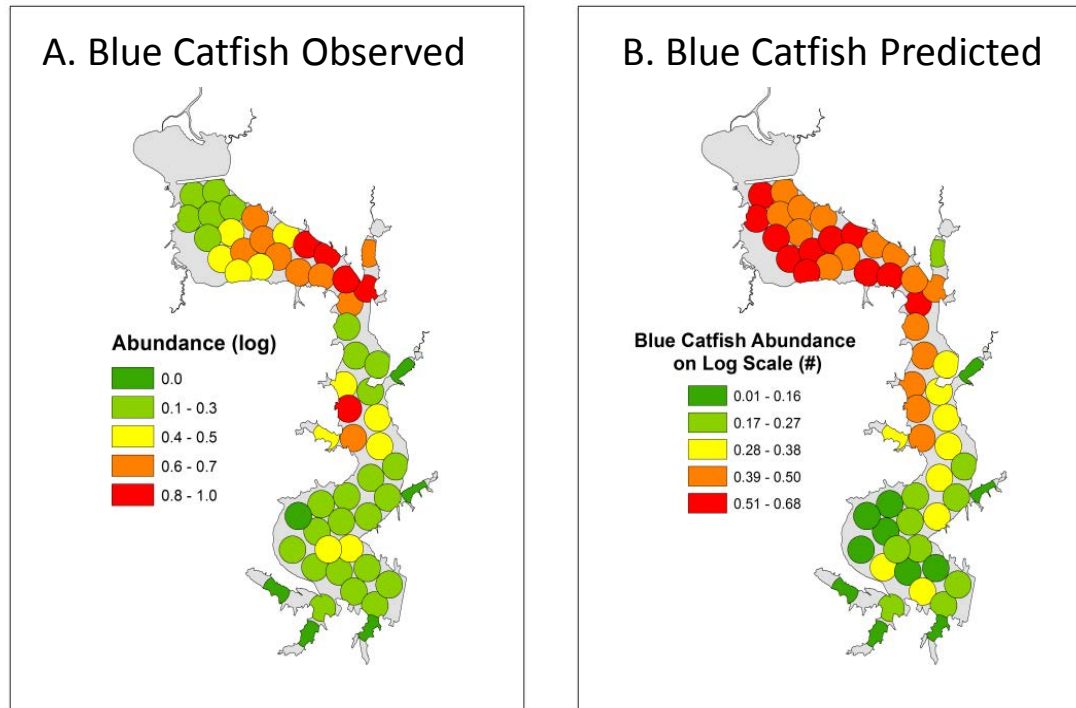
River Mile (km)

Number of Drop Offs

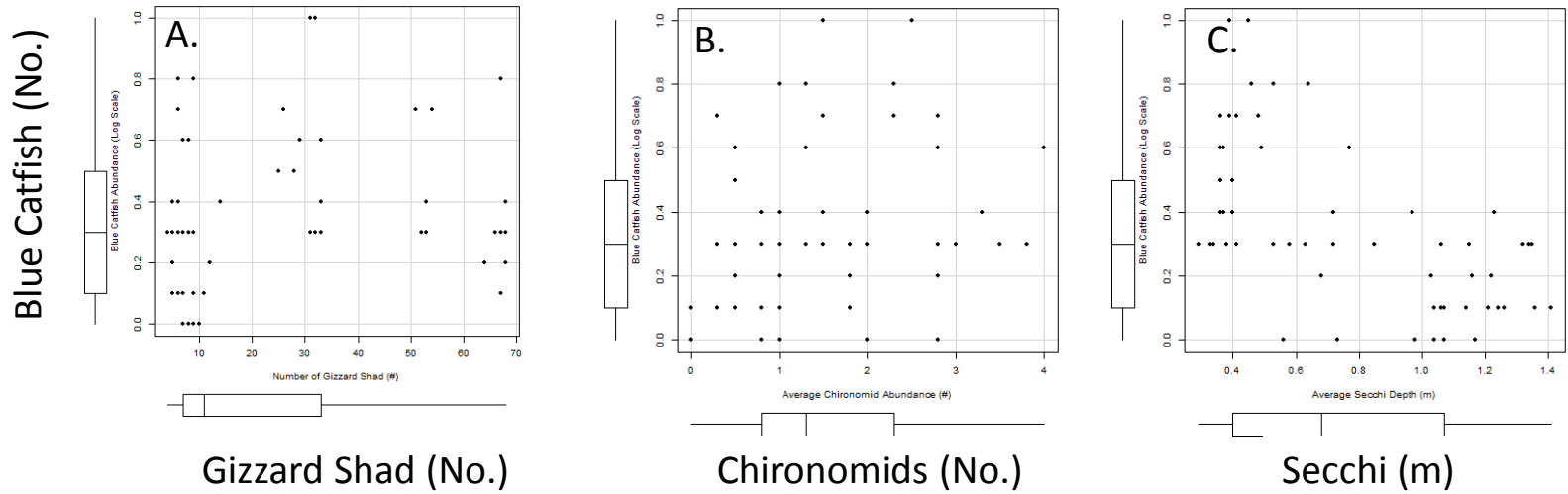
HYPOTHESIS 2 - MACROHABITAT



HYPOTHESIS 2 – MACROHABITAT

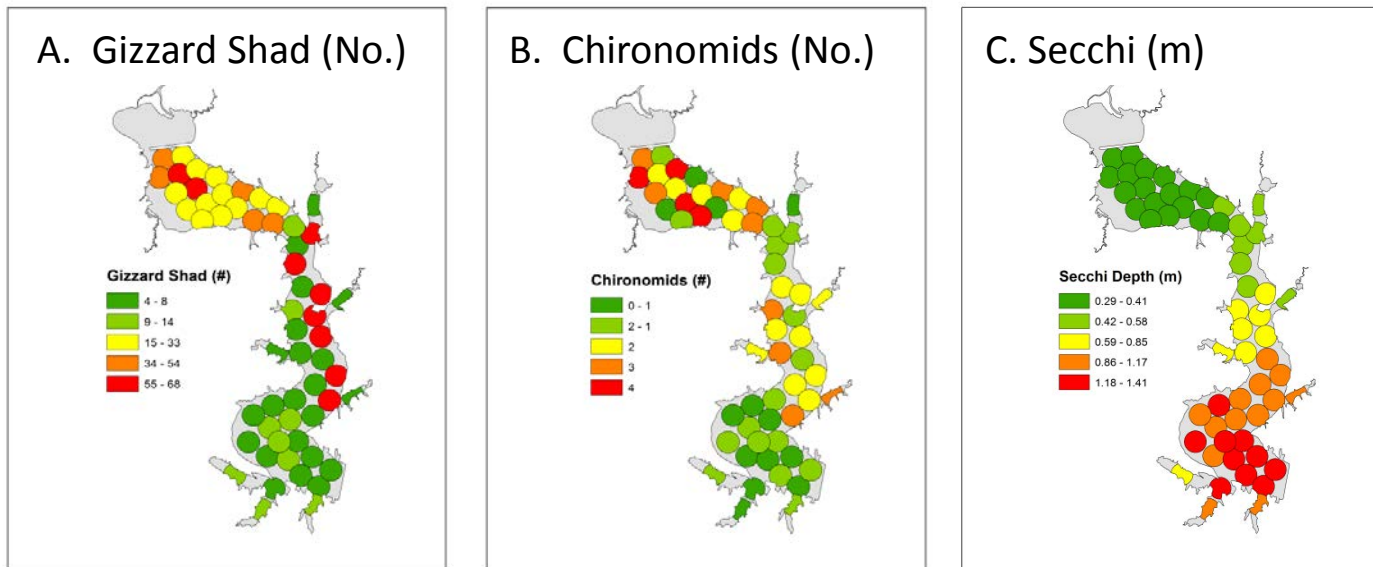


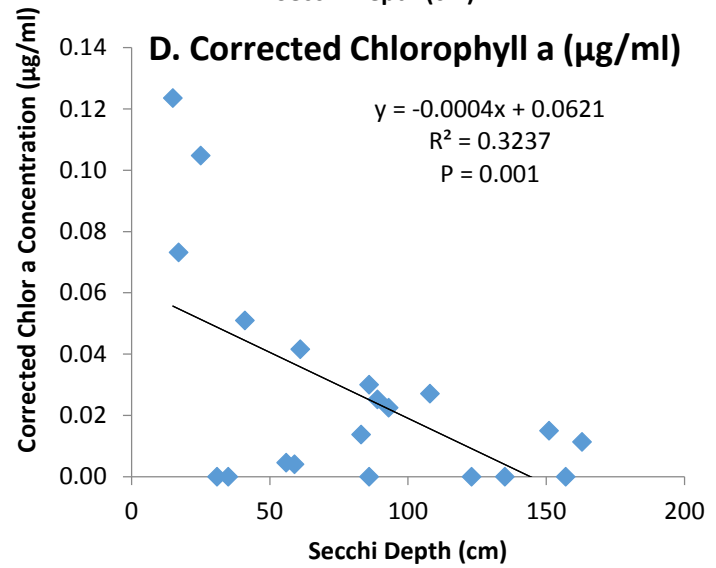
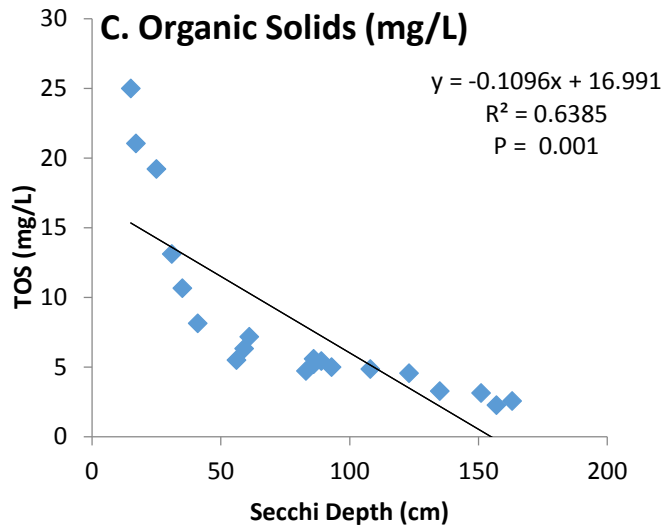
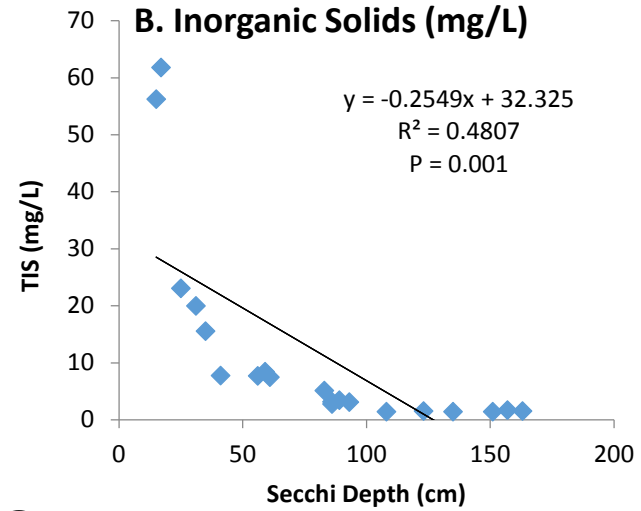
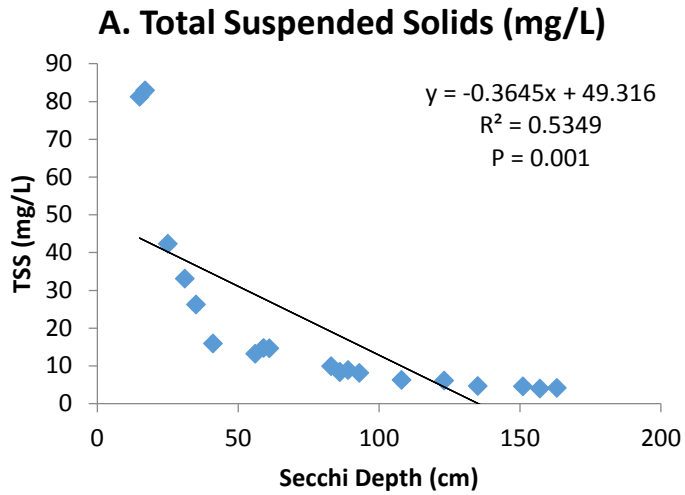
HYPOTHESIS 4 – BIOTIC



Chapter 3 Figure 9

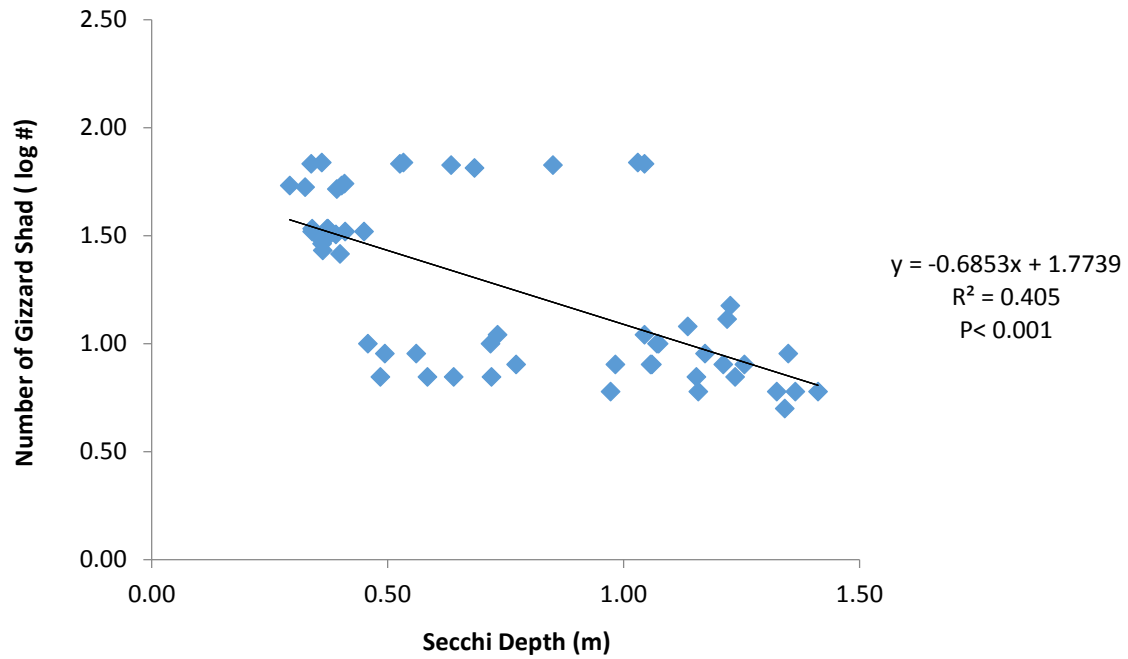
HYPOTHESIS 4 – BIOTIC



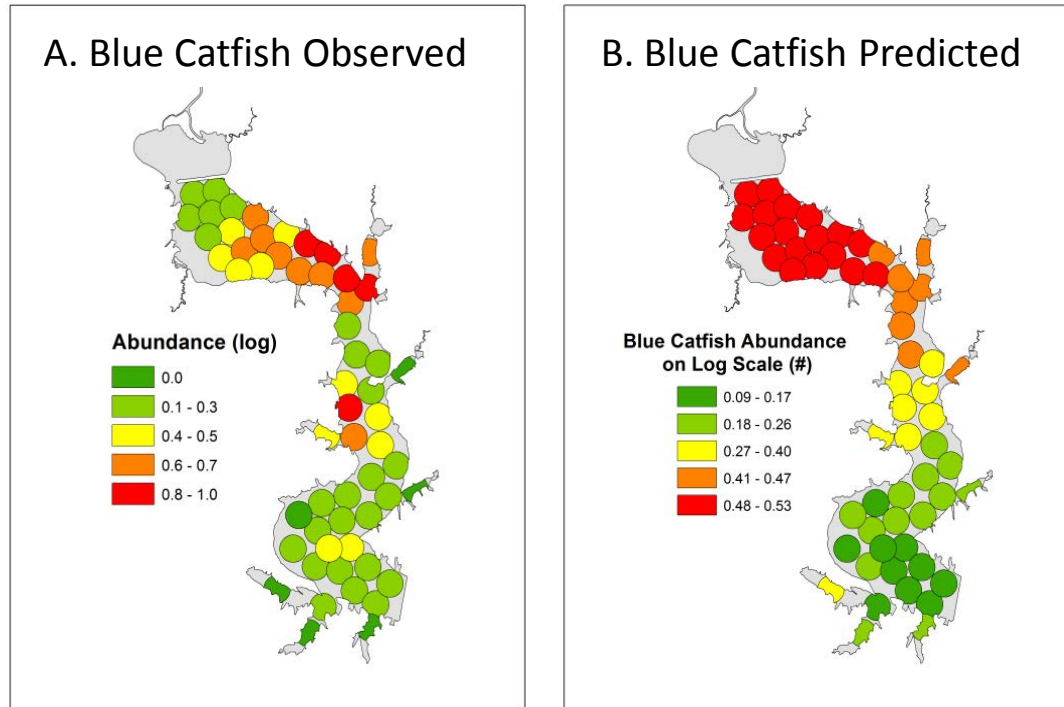


Chapter 3 Figure 11

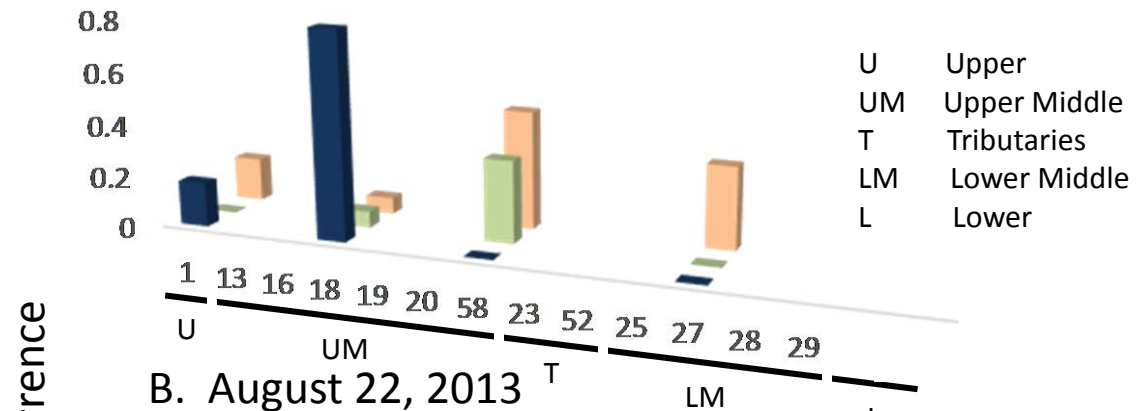
Secchi Depth (m) and Gizzard Shad (No)



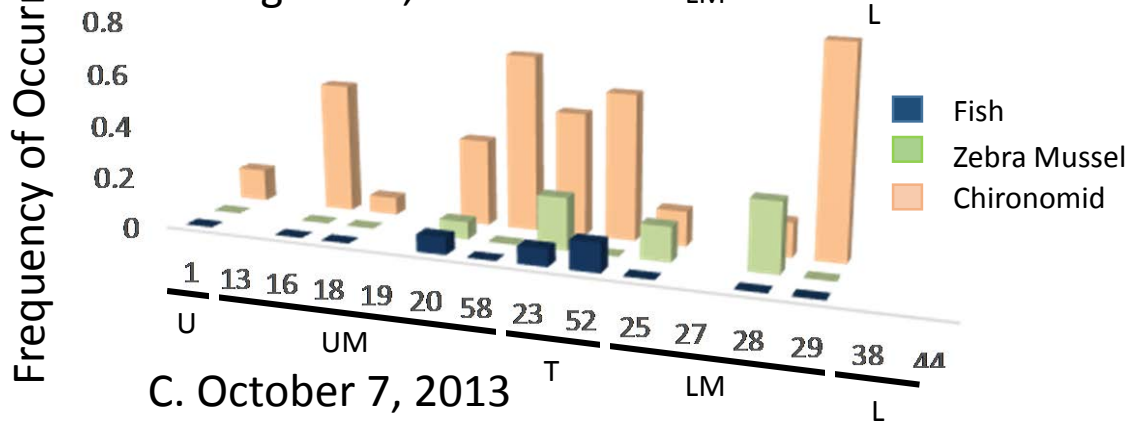
HYPOTHESIS 4 - BIOTIC



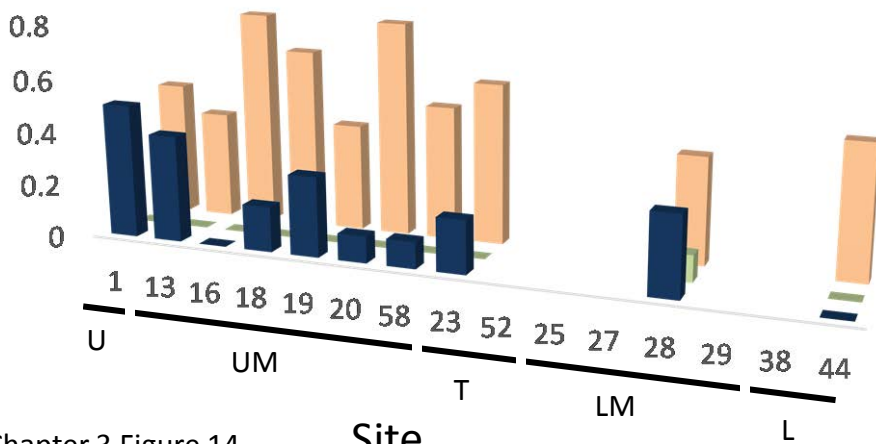
A. July 11, 2013



B. August 22, 2013



C. October 7, 2013



Chapter 3 Figure 14

Site

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