

6-6-2014

The Relationship Between Water Level, Prey Availability and Reproductive Success in Roseate Spoonbills Foraging in a Seasonally-Flooded Wetland While Nesting in Florida Bay

Jerome J. Lorenz

Audubon Florida Tavernier Science Center, jlorenz@audubon.org

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Recommended Citation

Lorenz, J.J.. 2013. The Relationship Between Water Level, Prey Availability and Reproductive Success in Roseate Spoonbills Foraging in a Seasonally-Flooded Wetland While Nesting in Florida Bay. Wetlands DOI: 10.1007/s13157-012-0364-y

This material is based upon work supported by the National Science Foundation through the Florida Coastal Everglades Long-Term Ecological Research program under Cooperative Agreements #DBI-0620409 and #DEB-9910514. Any opinions, findings, conclusions, or recommendations expressed in the material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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24 Key Words; Roseate Spoonbill, Florida Bay, prey dependent nesting success, prey
25 concentration threshold, mangrove fishes.

26

27

INTRODUCTION

28 Gawlik (2002) best articulated a widely accepted and well-studied paradigm
29 regarding the function of ephemeral wetlands in determining nesting success of wading
30 birds. In short, during high water periods prey species are relatively less susceptible to
31 predation and their populations grow exponentially and during low water periods, prey
32 are concentrated into lower elevation habitats that provide refuge when ephemeral
33 wetlands are dry. Wading birds exploit the concentrations and time nesting and nest
34 location so that there is a readily available food source for the rapidly growing and
35 energetically demanding young and that this availability must be sustained through the
36 entire nesting cycle. While most components of this paradigm have been demonstrated
37 empirically (Kahl 1964, Higer and Kolipinski 1967, Kushlan 1976a, Kushlan 1978,
38 Kushlan 1980, Ogden et al. 1980, Loftus and Kushlan 1987, Powell 1987, Frederick and
39 Colopy 1989, Loftus and Eklund 1994, Bancroft et al. 1994, Frederick and Spalding
40 1994, DeAngelis et al. 1997, Lorenz 2000, Gawlik 2002, Herring et al. 2011) the
41 connection between water level/prey availability and nesting success has been somewhat
42 elusive. Because nesting sites and foraging locations are spatially distant and the location
43 of foraging sites changes temporally as a patch of concentrated prey is depleted, it is
44 difficult to determine prey abundance at specific sites where a particular pair of
45 successfully nesting birds foraged. Furthermore, there could be nesting failure unrelated
46 to food availability (e.g. predation, disease, weather, human disturbance etc.).

47 Another challenge in demonstrating this connection is that the relationship
48 between low water levels and prey availability is likely to be non-linear. For example,
49 high fish concentrations can arise when water levels are relatively high due to oxygen and
50 thermal stress that drive prey from wetlands into deeper water (e.g. Frederick and Loftus
51 1993). Conversely, prey availability can be low when water levels are low due to
52 depletion of prey from predation and/or effects of overcrowding (e.g. Gawlik 2002) or
53 hydrologically-limited productivity (e.g. Lorenz 2000). Although the linearity of the
54 relationships between water level, prey availability and nesting success are investigated
55 here, the analyses also focus on the concept of a Prey Concentration Threshold (PCT). I
56 propose that prey concentrations do not adhere to a strictly-linear relationship with water
57 level, rather, there is some water depth (the PCT) at which prey will abandon the
58 ephemeral wetlands and move to deep water refuges prior to the wetlands drying out
59 entirely. When water levels drop to this point, there is short-lived pulse in prey
60 concentrations as all the prey flee the drying wetland en masse. These concentrated prey
61 are then quickly depleted through predation and other mortality factors.

62 I address this paradigm using 22 years of Roseate Spoonbill (*Platalea ajaja*)
63 nesting data from colonies on islands in NEFB and water level and prey (demersal fish)
64 data from multiple foraging sites located in mainland mangrove wetlands specifically to
65 1) test the linearity of the relationships between water level, prey availability and nesting
66 success, 2) investigate the concept of the PCT, and 3) to investigate whether prey
67 availability has a direct impact on nesting success in a wading bird species.

68 Roseate Spoonbills were extirpated from Florida by the early 1900's due to
69 overhunting to provide feathers to the fashion industry (Allen 1942). Legal protection

70 resulted in population recovery and by the late 1970's the population had recovered to
71 more than 1200 nests in Florida Bay (Powell et al. 1989), more than half of which were
72 located in extreme northeastern corner of Florida Bay (Fig. 1; Lorenz et al. 2002). In
73 1984, the completion and operation of a series of canals and pumps (known as the South
74 Dade Conveyance System or SDCS) had a profound impact on the way fresh water
75 flowed into northeastern Florida Bay (NEFB). Prior to the SDCS, most of the fresh water
76 flowed from the Everglades into Florida Bay via Taylor Slough and associated creeks to
77 the east (Fig. 2). The SDCS diverted water away from Taylor Slough and into the C-111
78 canal (Fig. 2), fundamentally altering the hydrology of Taylor Slough and NEFB (Kotun
79 and Renshaw this issue). Since completion of the SDCS, notable changes have been
80 observed in the flora and fauna of Florida Bay, particularly in the northeastern region
81 (Lorenz, this issue) and spoonbill numbers in NEFB have been drastically reduced, with
82 <50 pairs in 2008-09 (Fig. 1; Lorenz and Dyer 2010).

83

84

METHODS

85 Wetland Site Description.

86 Spoonbills nesting in NEFB primarily forage in the seasonal ephemeral mangrove
87 wetlands north of the Bay from Taylor Slough eastward to Turkey Point (Fig. 2; Bjork
88 and Powell 1994, Lorenz et al. 2002, Lorenz unpublished satellite tracking data). The
89 mainland wetlands of NEFB are dwarf mangrove habitat, characterized by a centralized
90 creek ("creek" sub-habitat) that contains water throughout the year that is surrounded by
91 expansive shallow flats ("flats" sub-habitat) that are ephemerally inundated (Figure 2).
92 Vegetation consists of widely spaced (0.5-5.0 m) dwarf red mangrove (*Rhizophora*

93 *mangle*) trees (0.5-2.0 m tall) with varying amounts of herbaceous vegetation between
94 individual trees. Seasonal growth of *Eleocharis cellulosa*, *Utricularia* spp. and *Chara*
95 *hornimani* is common and the substrate is flocculent, unconsolidated, carbonate marl
96 (Browder et al. 1994).

97 There is a characteristic seasonal pattern to the water level fluctuations on these
98 wetlands, with high water levels that inundate the ephemeral wetlands during the wet
99 season (June-Nov) and low water during the dry season (Dec-May) that exposes the
100 ephemeral wetland and results in only the central creeks being inundated (Lorenz 1999).
101 The principle drivers of this long-term cycle are the thermal expansion and contraction of
102 the Gulf of Mexico (Marmar 1954, Holmquist et al 1989) and wet season/dry season
103 rainfall patterns (Duever et al. 1994). Because the onset of the rainy season provides a
104 natural break in the cycle (Lorenz and Serafy 2006), “hydroyear” is defined from June 1
105 to May 31. Wind-driven tides can increase or decrease water levels (up to 40 cm) on the
106 wetlands very quickly and those conditions can be maintained until cessation of the wind
107 event (Holmquist et al. 1989). Upstream water management practices, such as pulse
108 releases from the C-111 canal (Fig. 2), can also result in rapid increases in water levels
109 (Kotun and Renshaw this issue, Lorenz this issue) that may endure for several days. The
110 southern Biscayne Bay wetlands are generally unaffected by these pulse releases as water
111 flow through the C-111 canal is blocked near US Highway 1 (US1; Fig. 2), so the
112 majority of water released through the C-111 flows southward from the canal on the west
113 side of US-1 toward Florida Bay (Kotun and Renshaw this issue, Lorenz this issue).
114 Finally, diurnal tides affect water levels on the wetlands of southern Biscayne Bay,

115 although the amplitude is relatively small (9-15 cm; Lorenz 1999); there are no diurnal
116 tides on the NEFB wetlands (Lorenz 1999).

117

118 Data Collection

119 **Water Level Records.** Water level recorders were placed at ten known spoonbill
120 foraging locations in the NEFB wetlands and west of southern Biscayne Bay (Fig. 2).

121 Hydrostations recorded depth (hourly) relative to the elevation of the flats (i.e., a reading
122 of 0 cm on the recorder indicated that the flats were completely dry while the creek was
123 flooded). Establishment of these sites was staggered through time but are identified as
124 long-term (established prior to 1992) mid-term (established in early 2000s) and short-
125 term (established after 2005; dates of the establishment of sites are presented in the ESM
126 1). Prior to 2000, data were collected using a Telog® 2108 potentiometric recorder with
127 a float and pulley design. After 2000, telemetered hydrostations (Remote Data Inc.,
128 using Hydrolab® pressure sensors to record water depth on a remotely-accessible
129 Campbell® data recorder) were established at each site in addition to the Telog®
130 recorders, thereby creating redundancy in water level data collection. Gaps in the data
131 were filled by using regression models between nearby hydrostations (see ESM 1 for
132 further details).

133 **Prey Fish Sampling.** Drop traps were used to collect fish according to the
134 methodology of Lorenz et al. (1997). Three 9-m² traps were used in each sub-habitat
135 (creek and flats) at each site. Each trap surrounded an individual dwarf mangrove tree,
136 thereby sampling both prop root habitat and the open area between trees (Fig. 2). Trees
137 were selected for sampling such that each site had a similar array of tree sizes with

138 roughly equivalent prop root density sampled between sites. Traps were set, left in place
139 overnight and deployed the following day within 2h after sunrise. Fish were cleared from
140 the trap using rotenone. Traps remained in place until the following day and any fish
141 found floating within the trap were added to the sample and their weights were estimated
142 from length-weight regressions generated from fishes from the initial collection (Lorenz
143 et al. 1997). Sample collections were targeted for June, September, and monthly from
144 November through April, however, logistical, economical and climatological problems
145 prevented complete sampling at some sites (presented in ESM 1). The majority of fish
146 collections were made during the dry season and transitional periods so that the impact of
147 fluctuations in water level could be assessed.

148 Although the drop traps were specifically designed to catch the small demersal
149 fishes that are the primary prey items of spoonbills (Lorenz et al., 1997), incidental
150 collections of larger fishes did occur. In some cases, a single large individual weighed
151 more than the entire sample of smaller fishes. Length-frequency distributions indicated
152 that all fish found on the flats were <6.5 cm TL (total length). The flats made up the
153 majority of the habitat, indicating that fish larger than 6.5 cm TL were not an integral part
154 of the demersal fish community. Based on this observation, all fish ≥ 6.5 cm TL (3.2% of
155 total fish collected) were omitted from analyses. The elimination of these large fish
156 limits the data to prey that spoonbills are likely to capture, as spoonbills' principle diet is
157 fish up to approximately 5 cm (Dumas 2000).

158 **Spoonbill nesting colony surveys.** Spoonbills typically nest in Florida Bay
159 between November and April (Powell et al. 1989). During this period, nest production
160 was estimated by repeated visits to a given colony on a 7-10 d cycle. Up to 65 nests were

161 marked with uniquely numbered nest tags during the late incubation period. An estimate
162 of the mean hatch day was made based on chick size and morphology when they were
163 first observed. At approximately 21 d, chicks begin to move out of the nest and spend
164 their time in adjacent trees (Allen 1942, Dumas 2000, Lorenz et al. 2002) and surveys
165 must be discontinued for the safety of the chicks (susceptible to falling out of the trees
166 when disturbed). Chicks that made it to 21d (from here referred to as the nestling
167 period) were considered successful even though some mortality does occur after they
168 leave the nest.

169 Spoonbill nest success surveys were performed at Tern Key (historically the
170 largest colony in NEFB) during every nesting cycle from 1987-88 to 2006-07 except for
171 1993-94. Beginning in 2007-08, the Tern Key colony failed to form so several smaller
172 colonies near Tern Key were surveyed in 2007-08 and 2008-09. No individual nest data
173 were available for the years 1988-89, 1991-92, 1992-93 and 1994-95 (for various
174 reasons), however, summary statistics for mean hatch date and mean nest production
175 were available. In most years a small number of spoonbills will nest a second time but in
176 1998-99, and from 2001-02 to 2005-06, the second nesting effort was sizable (almost as
177 large or larger than the first nesting). These second nestings were surveyed using the
178 above techniques as well, and treated the same as the first nestings.

179

180 Data Analysis

181 **Prey availability.** Average density and biomass of fish were calculated for each
182 sub-habitat (creeks and flats) at each site. The mean number of prey/trap from the sub-
183 habitat with the largest number of prey collected was considered the estimate of available

184 prey. The direct use of prey availability (i.e., abundance or biomass m^{-2}) is confounded
185 by the fact that each of the sites has a central creek that drains different sized watersheds
186 and sites with larger drainage basins tended to have higher concentrations of fishes than
187 smaller drainage basins. Concentration events would not be isolated to just the drainage
188 in which our sites are located but would be spread over a region that site represents. If
189 the simple estimate of fish density were used than sites with smaller basins would be
190 masked by those with larger ones and it would appear that concentration events never
191 occurred at the sites with smaller basins. In order to standardize the size of the catchment
192 area we relativized each sample to the maximum abundance and biomass for each site.
193 This created an index (on a 0-to-1 scale) for each site, hereby referred to as the fish
194 density availability index or DAI and the biomass availability index or BAI.

195 **Prey Concentration Threshold.** The mean and standard deviation for all DAI
196 estimates were calculated. All samples collected with a $DAI > \text{mean} + 1 \text{ SD}$ were
197 considered to be from a fish concentration event. June or September samples
198 experiencing a concentration event were removed from the estimate of the PCT because
199 the events were likely to be the result of thermal or oxygen stress rather than water level.
200 The tidal sites of southern Biscayne Bay (MB, BS, CS and TP) were also problematic to
201 estimating the PCT. This is because it takes up to 2h to deploy all six traps and water
202 level was only collected on an hourly basis so the actual depth at the time of trap
203 deployment is unknown. As a result, concentration events at these sites were also
204 removed from estimating the PCT. For the remaining concentration event samples, the
205 daily mean water level was calculated for the date of the samples. The PCT was defined
206 as the maximum depth at which a concentration event occurred.

207 **Total colony nestling period.** The nestling period for each nesting cycle was
208 defined as the period from 2d before the first monitored nest hatched until 2d after the
209 last monitored nest had chicks reach 21d post-hatch. The nestling period had to be
210 estimated for years for which only the mean hatch date was available (Table 1). The
211 mean difference in days from the first hatch date to the mean hatch date was 9d and from
212 the mean hatch date until the last chick reached 21d was 40d (Table 1). For years with
213 only the mean hatch date available, the first hatch date and the date the last chick reached
214 21d were estimated by subtracting 9d and adding 40d, respectively.

215 **Mean water depth during the nestling period.** For years that individual nests
216 were monitored, the mean water level for the 21d post-hatch was calculated for each nest
217 from the long-term water level recording stations. The four years without individual nest
218 data could not be included in calculating mean water depth for individual nests but were
219 used to calculate mean depth for the entire nestling period.

220 **Mean DAI and BAI for the nestling period.** All fish samples that fell within the
221 nestling period (Table 2) were used to calculate mean DAI and BAI for each nesting
222 cycle. The number of samples collected during each cycle was highly variable with more
223 samples collected as the study went on and fish sampling sites were added. Also, there
224 were different sites used to estimate the DAI and BAI for each cycle, but bias caused by
225 intra-site variation was removed by scaling by the maximum for each site (0 to 1 scale).

226 **Statistical Analyses.** Regressions were used to compare the linearity of water
227 level with prey availability indices, water level with nest production and prey availability
228 indices with nest production. Analysis of variance (ANOVA) was used to compare water
229 levels with nest success (successful=a nest that produces ≥ 1 chick) and water levels with

230 nest production (chicks/nest or c/n) for individual nests. The difference between DAI and
231 BAI for failed and successful nesting cycles were also tested using ANOVA.

232

233

RESULTS

234 Negative relationships were detected between mean water level and both mean
235 nest production ($r^2 = 0.41$, $p < 0.001$) and nest success ($r^2 = 0.31$, $p < 0.001$; Fig. 3).

236 ANOVA between the number of chicks produced and the mean water level for the
237 nestling period of each individual nest were significant ($F_{4,700} = 39.20$, $p < 0.001$).

238 Individual nests produced between 0 and 4 c/n and for each incremental increase in
239 production water level was significantly lower (Fig. 4). All assumption for regression
240 models and ANOVA were met.

241 I observed marked inter- and intra-annual variation in water level and
242 corresponding prey abundance and biomass throughout this study's 811 prey sampling
243 events (results of individual collection are presented in the ESM 1). Regression models
244 between water level and fish concentrations were not statistically significant confirming
245 that the relationship between water level and prey availability was non-linear (Fig. 5).

246 The mean and standard deviation of the DAI for these samples was 0.182 and 0.187
247 respectively. There were forty samples with a DAI greater than the mean plus one
248 standard deviation (0.369) and qualified for use in estimating the PCT (Table 3). The
249 deepest water level that these concentration samples were collected in was 13.15 cm
250 (collected at JB in April 2000) thereby defined as the PCT.

251 Regressions of the relationship between chick production and prey availability
252 indices had mixed results (Fig. 6). There was a significant linear relationship between

253 DAI and chick production ($r^2 = 0.34$, $p < 0.001$) but not between BAI and chick production
254 ($r^2 = 0.12$, $p = 0.11$). ANOVA of DAI and BAI between failed (average $< 1c/n$) and
255 successful (average $> 1c/n$) nesting cycles were significant (DAI: $F_{(1,20)} = 7.78$, $p < 0.05$;
256 BAI: $F_{(1,20)} = 4.62$, $p < 0.05$), with successful nesting cycles having a significantly higher
257 degree of available prey (Fig. 7). All assumptions for regression models and ANOVA
258 were met.

259

260

DISCUSSION

261 Results presented here suggest that prey do not concentrate linearly with
262 decreasing water depth, rather, there is a depth threshold at which fish first become
263 concentrated. In the mangrove NEFB wetlands this appears to occur when water levels
264 drop below ~ 13 cm on the ephemeral wetland surface (i.e., the PCT). Previous studies
265 have suggested these concentrated prey are rapidly depleted, primarily through predation
266 (e.g., Kahl 1964, Master 1992, Gawlik 2002). These data also indicate that concentration
267 events can occur at water levels as low as 5 cm below the wetland surface and at
268 numerous depths in between (Table 3). As water levels continue to decline below the
269 PCT, prey that survive the initial concentration event become re-concentrated at lower
270 water, resulting in sequential concentration events at the same location (based on local
271 topography). The concept of thresholds that concentrate fish explains, at least in part,
272 why there is not a linear relationship between water level and fish prey availability. Kahl
273 (1964) presented data that support the concept of a water level threshold for
274 concentrating prey. He indicated that a 6 cm drop in water levels at a Wood Stork
275 (*Mycteria americana*) foraging site increased the density of prey fish from $50m^{-2}$ to ~ 2000

276 m². After dropping another 6 cm, the density remained about the same (2200 fish m²).
277 This suggests that, at some level between the first and second recession events fish were
278 forced to leave the adjacent wetland.

279 The regression results relating water level with nesting success concur with
280 numerous other studies that, in southern Florida, nesting wading birds have a greater
281 degree of nesting success at lower water levels (Kahl 1964, Frederick and Collopy 1989,
282 Powell et al. 1989, Ogden 1994, Hoffman et al 1994, Bancroft et al. 1994, Frederick and
283 Spaulding 1994, Lorenz et al. 2002). The estimation of the PCT at about 13 cm
284 augments the results of the ANOVA of water level and nest production (Fig. 4) since
285 failed nests had a mean water level and standard error above the PCT. Nests producing 1
286 c/n also had a mean just above the PCT but the standard error that spans below the PCT.
287 Nests that produced 2, 3 and 4 c/n were foraging under conditions where the mean water
288 level and standard error were below the PCT, and each incremental increase in
289 productivity had significantly lower water level.

290 There was a linear relationship between DAI and nest production but not BAI and
291 nest production (Fig. 6). Lorenz and Serafy (2006) documented that, at these sampling
292 locations, the assemblage of fishes present is a better determinant of biomass than the
293 density of fish present. Furthermore, they documented that salinity was the major
294 determinant of the community structure with communities from lower salinity
295 environments having larger biomass. Although it is intuitive that higher biomass should
296 be more important than the total density of available fish for determining nest
297 productivity, it is the density of fish that determines whether there is a concentration
298 event or not. The fact that fish are concentrated at these sites may suggest that fish

299 further upstream in lower salinity environments may be concentrated as well. These
300 would have higher biomass and would also be readily exploited by nesting spoonbills.
301 Thus, the fact that fish are concentrated may be a better indicator that foraging conditions
302 are better throughout the landscape than the biomass that is available at these particular
303 locations and times.

304 The ANOVA of DAI and BAI between failed and successful nesting cycles
305 demonstrated that prey were more available during nesting cycles that resulted in an
306 average of greater than 1 c/n than those that produced less than 1c/n (Fig. 7). These
307 results, in addition to the DAI regression model (Fig. 6) support the relationship between
308 available prey on the primary foraging grounds with the ability of spoonbills nesting on
309 islands in NEFB to raise chicks through the critical 21 d post hatch period.

310 Studies that relate water level to nesting success express or imply that this is the
311 result of prey becoming more available to wading birds at lower water levels (Ogden et
312 al. 1980, Powell, 1987, Frederick and Collopy 1989, Frederick and Spalding 1994, Ogden
313 1994) however, few studies present any prey availability data. Conversely, many studies
314 demonstrate that wading birds forage more successfully in areas where fish have been
315 concentrated (Kahl 1964, Kushlan 1976b, Master 1987, Master 1989, Gawlik 2002), but
316 rarely can this foraging success be related back to the success or failure of a specific
317 colony or population although it is commonly inferred. Previous studies have
318 demonstrated that spoonbills nesting in NEFB primarily forage in the wetlands where I
319 measured water levels and collected prey samples (Bjork and Powell 1994, Lorenz et al.
320 2002, Lorenz unpublished satellite tacking data). By surveying spoonbill colonies so as
321 to know nest production and identify the nestling period and by using numerical indices

322 of prey collected on their primary foraging grounds during the nestling phase, links
323 between lower water levels, greater prey availability and higher nest production were
324 demonstrated.

325 Lorenz et al. (2002) demonstrated that, prior to anthropogenic alterations to the
326 foraging habitats of Florida Bay, spoonbills produced an average of 2.25 c/n, resulting in
327 an exponential increase in the number of spoonbill nests in Florida Bay. Since the
328 completion of the SDCS in 1984, the average production has been 0.98 c/n (Table 1). De
329 le Court and Aguilera (1997) indicated that Eurasian Spoonbills (*Platalea leucordia*)
330 exhibit nesting fidelity to their natal colony location and that there is only a small degree
331 of gene flow between discrete nesting populations. Similarly, I have found that Roseate
332 Spoonbills in Florida likely occur in discrete nesting populations that are largely insular
333 when it comes to immigration and emigration (unpublished banding and tracking data). It
334 appears that the conditions that result in a production rate of <1 c/n are not able to sustain
335 NEFB's population thereby explaining the striking decline in nest numbers (Fig. 1).

336 Results indicate that if water management practices result in a reversal of the dry
337 down process such that PCT is exceeded during the nestling period, prey will disperse
338 and become unavailable to higher trophic levels. The high energetic demands of rapidly
339 growing wading bird chicks (e.g. Kahl 1964) suggest that nesting attempts will likely fail
340 if prey are unavailable for even a relatively brief period (2-3d). Such reversals have
341 occurred with regularity since the completion of the SDCS (Lorenz 2000), but in the last
342 decade water management practices began to take into account environmental impacts
343 and efforts were made to avoid such reversals. Spoonbill nesting success has been higher
344 since this has happened (Lorenz and Dyer 2010).

345 Kotun and Renshaw (this issue) indicate that current operation of the SDCS have
346 lowered wet season and increased dry season water levels in Taylor Slough and that this
347 had similar hydrologic repercussions throughout NEFB. Data presented here indicate
348 these conditions should result in lower prey production during the wet season and less
349 prey availability during the nesting season. Therefore, the water management practices
350 of recent decades likely had a significant role in the depressed nesting success and the
351 declining population of spoonbills in Florida Bay. Given that numerous other species
352 have been similarly affected (Lorenz, this issue) and that spoonbills are an indicator of
353 ecosystem integrity for Florida Bay and the southern Everglades (Lorenz et al. 2009), the
354 current efforts to restore natural flows are necessary and justified.

355 In conclusion, this study demonstrated that the relationship between water level
356 and prey abundance was not linear but rather there is likely a threshold, or series of
357 thresholds, in water level that result in prey concentrations. Furthermore, the study
358 indicates that spoonbills require water level-induced concentrated prey in order to have
359 enough food available to successfully raise young.

360

361

ACKNOWLEDGEMENTS

362 I would like to thank Shawn E. Liston (National Audubon Society) for intellectual
363 contributions as well for the final review. Peter C. Frederick (University of Florida) Dale
364 E. Gawlik (Florida Atlantic University) and the late John C. Ogden also contributed
365 intellectually. I would also like to express gratitude to the myriad dedicated and hard
366 working staff members at TSC that participated in the collection of these data over the
367 last 20 years.

368

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470

471 Tables

472 Table 1. Dates of first hatch, mean hatch and last chick to 21d for each nesting cycle.

473 “B” indicates a second nesting cycle in the given hydrologic year.

474 Table 2. Nestling period; mean depth (calculated from the 4 long term data sets), prey
475 Density Availability Index (DAI), prey Biomass Availability Index (BAI) and number
476 of prey samples collected (i.e., number of collections used to calculate the DAI and
477 BAI) for the nestling period; nest production and percent of nests successful.

478 Table 3. Fish collections that were classified as concentration events because they had a
479 DAI greater than the mean + 1 standard deviation for all samples collected.

480

481 Figures

482 Fig. 1. The number of spoonbill nests found for each primary nesting cycle at Tern Key
483 and for all of the colonies in northeastern Florida Bay combined showing the steady
484 decline in nests since the completion of water management infrastructure in 1984.

485 Fig. 2. Top: map showing locations of sites and pertinent landmarks. Bottom: Aerial
486 photo of JB site showing creeks and flats sub-habitats and the fish traps used.

487 Fig. 3. Regression results comparing mean water level from the long-term sites with the
488 nest production (A) and percent of nest successful (B) for each nesting cycle.

489 Fig. 4. ANOVA results comparing mean water levels during the nesting cycle with nest
490 production for each individual nest that was monitored in this study. Number of nests
491 used are provided along the x-axis.

492 Fig. 5. Regression results comparing mean water level from the long-term sites with the
493 DAI (A) and the BAI (B) for each nesting cycle.

494 Fig. 6. Regression results comparing the DAI (A) and the BAI (B) with nest production
495 for each nesting cycle.

496 Fig. 7. ANOVA results comparing DAI and BAI between failed (mean <1 c/n) and
497 successful (mean > 1 c/n) nesting cycles (n=12 successful cycles and 10 failed cycles).

<i>Nesting cycle</i>	<i>Number of nests surveyed</i>	<i>First Hatch</i>	<i>Mean Hatch</i>	<i>Last to chick to 21d</i>	<i>first hatch to mean hatch (d)</i>	<i>mean hatch to last chick to 21d</i>
1987-88	60	30-Dec-87	20-Jan-88	21-Feb-88	22	53
1988-89			12-Dec-88			
1989-90	50	20-Dec-89	23-Dec-89	18-Jan-90	3	29
1990-91	37	27-Nov-90	2-Dec-90	1-Jan-91	5	35
1991-92			16-Dec-91			
1992-93			1-Jan-93			
1994-95			5-Mar-95			
1995-96	38	14-Dec-95	19-Dec-95	16-Jan-96	6	33
1996-97	24	21-Dec-96	7-Jan-97	9-Feb-97	18	50
1997-98	35	17-Dec-97	22-Dec-97	21-Jan-98	6	35
1998-99	38	17-Dec-98	22-Dec-98	20-Jan-99	6	34
1998-99B	18	21-Mar-03	30-Mar-03	2-May-03	9	42
1999-00	24	8-Dec-99	11-Dec-99	5-Jan-00	3	28
2000-01	32	28-Dec-00	31-Dec-00	28-Jan-01	3	31
2001-02	31	31-Dec-01	3-Jan-02	13-Feb-02	4	44
2001-02B	14	21-Feb-02	27-Feb-02	29-Mar-02	6	36
2002-03	35	13-Dec-02	26-Dec-02	22-Jan-03	14	40
2002-03B	16	26-Jan-03	7-Feb-03	19-Mar-03	12	52
2003-04	38	30-Dec-03	12-Jan-04	21-Feb-04	14	53
2003-04B	27	4-Apr-04	7-Apr-04	1-May-04	3	27
2004-05	15	10-Jan-05	15-Jan-05	7-Feb-05	5	28
2004-05B	7	31-Mar-05	2-Apr-05	24-Apr-05	3	24
2005-06	54	7-Dec-05	17-Dec-05	28-Jan-06	11	52
2005-06B	12	3-Apr-06	11-Apr-06	12-May-06	8	39
2006-07	56	14-Dec-06	24-Dec-06	20-Jan-07	11	37
2007-08	23	29-Nov-07	17-Dec-07	23-Jan-08	18	55
2008-09	21	17-Dec-08	30-Dec-08	1-Mar-09	14	74
Mean					9	40

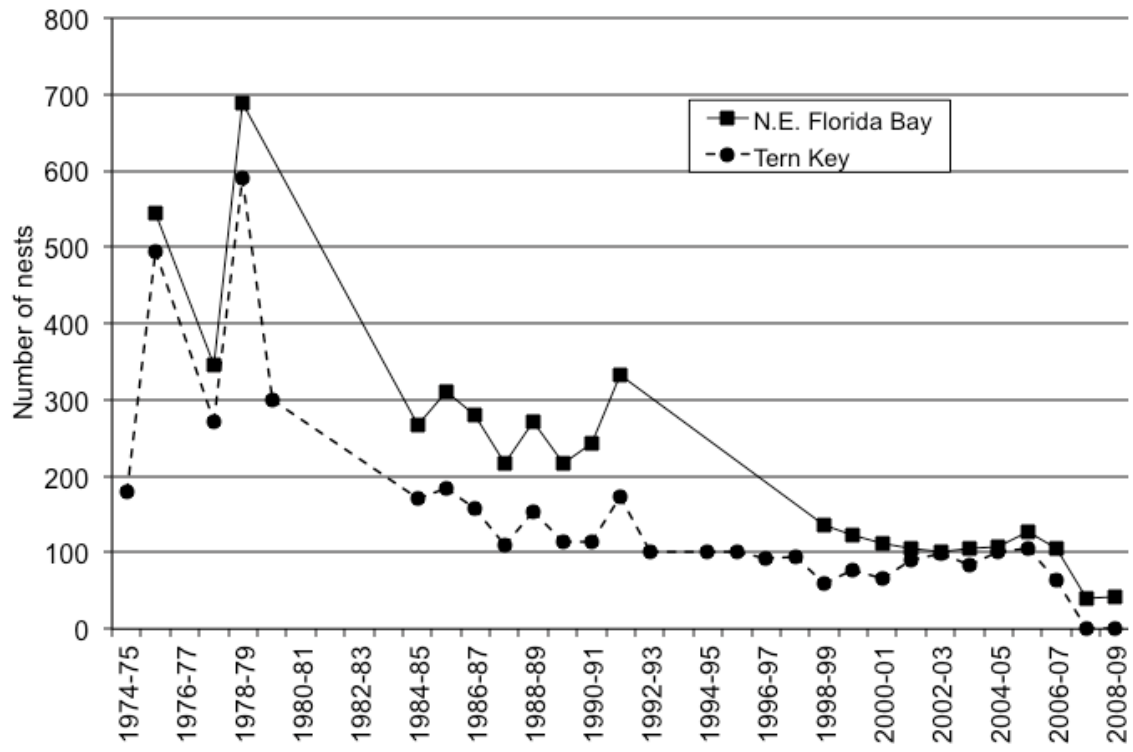
500 Table 2

<i>Nesting Cycle</i>	<i>Start Nestling Period</i>	<i>End nestling period</i>	<i>Length of nestling period (d)</i>	<i>Mean WL during nestling period</i>	<i># prey samples collected during nestling period</i>	<i>Mean DAI during nestling period</i>	<i>Mean BAI during nestling period</i>	<i>Mean Production (Chicks/nest)</i>	<i>% of nest that produced chicks</i>
1987-88	28-Dec-87	23-Feb-88	57	16.12				1.2	0.66
1988-89	1-Dec-88	14-Jan-89	44	11.18				1.9	
1989-90	18-Dec-89	20-Jan-90	33	-0.50				2.4	0.86
1990-91	25-Nov-90	3-Jan-91	39	5.67				2.2	0.77
1991-92	5-Dec-91	18-Jan-92	44	12.91	3	0.13	0.31	1.3	
1992-93	21-Dec-92	3-Feb-93	44	18.20	5	0.09	0.07	0	0
1994-95	22-Feb-95	7-Apr-95	44	15.34	6	0.14	0.17	0	0
1995-96	12-Dec-95	18-Jan-96	37	19.58	0			0.26	0.24
1996-97	19-Dec-96	11-Feb-97	54	15.34	4	0.21	0.27	0.25	0.25
1997-98	15-Dec-97	23-Jan-98	39	16.64	4	0.15	0.20	0.81	0.6
1998-99	15-Dec-98	22-Jan-99	38	19.36	4	0.18	0.16	0.35	0.38
1998-99B	19-Mar-03	4-May-03	46	12.61	7	0.34	0.24	2.17	0.69
1999-00	6-Dec-99	7-Jan-00	32	19.09	4	0.06	0.09	0.64	0.32
2000-01	26-Dec-00	30-Jan-01	35	8.52	4	0.13	0.27	0.92	0.44
2001-02	29-Dec-01	15-Feb-02	48	11.69	7	0.11	0.07	1.26	0.68
2001-02B	19-Feb-02	31-Mar-02	40	8.72	5	0.09	0.14	0.61	0.39
2002-03	11-Dec-02	24-Jan-03	44	13.07	10	0.16	0.24	0.88	0.33
2002-03B	24-Jan-03	21-Mar-03	56	2.23	11	0.24	0.21	0.9	0.5
2003-04	28-Dec-03	23-Feb-04	57	14.24	14	0.17	0.17	0.14	0.08
2003-04B	2-Apr-04	3-May-04	31	6.68	5	0.17	0.17	1.86	0.83
2004-05	8-Jan-05	9-Feb-05	32	13.49	9	0.14	0.19	0.18	0.07
2004-05B	29-Mar-05	26-Apr-05	28	12.65	7	0.11	0.08	0.37	0.36
2005-06	5-Dec-05	30-Jan-06	56	12.05	19	0.23	0.19	1.54	0.63
2005-06B	1-Apr-06	14-May-06	43	15.22	12	0.17	0.20	0.06	0.06
2006-07	12-Dec-06	22-Jan-07	41	14.74	14	0.23	0.30	0.96	0.54
2007-08	27-Nov-07	25-Jan-08	59	12.19	21	0.29	0.29	1.6	0.96
2008-09	15-Dec-08	3-Mar-09	78	7.03	22	0.25	0.23	1.7	0.77
Mean								0.98	0.46

501 Table 3

<i>Hydro yr</i>	<i>month</i>	<i>site</i>	<i>Depth</i>	<i>DAI</i>	<i>Hydro yr</i>	<i>month</i>	<i>site</i>	<i>Depth</i>	<i>DAI</i>
08-09	1	SB	-4.70	0.74	07-08	12	SB	5.90	0.65
07-08	3	WJ	-1.76	1.00	96-97	2	TR	6.50	0.52
06-07	2	SB	-1.63	0.89	03-04	3	HC	6.65	0.51
04-05	2	SB	-1.58	0.89	04-05	3	TR	6.80	0.45
98-99	3	HC	-1.50	0.95	04-05	12	HC	7.30	0.49
00-01	2	TR	-1.28	0.51	06-07	12	HC	7.60	0.52
03-04	1	HC	0.17	0.47	96-97	2	JB	8.00	0.46
03-04	4	HC	0.42	0.50	96-97	3	TR	8.20	0.85
91-92	4	HC	0.50	0.38	06-07	1	EC	8.30	0.39
00-01	3	TR	0.74	0.53	04-05	3	SB	8.71	0.63
07-08	12	HC	0.96	0.41	05-06	11	SB	9.05	0.46
90-91	12	HC	1.07	0.39	98-99	1	HC	9.30	0.41
93-94	1	HC	1.40	0.74	98-99	12	HC	9.70	0.38
95-96	3	TR	1.72	0.47	07-08	2	EC	10.05	0.49
07-08	3	EC	2.10	0.87	96-97	4	TR	10.20	1.00
06-07	2	EC	2.88	1.00	08-09	12	SB	10.78	0.37
97-98	4	HC	3.00	0.39	96-97	1	TR	10.80	0.38
00-01	4	TR	3.58	0.40	98-99	3	JB	11.20	0.49
07-08	3	SB	4.70	0.42	06-07	1	SB	11.92	0.41
01-02	4	HC	5.05	0.44	05-06	4	JB	13.15	1.00

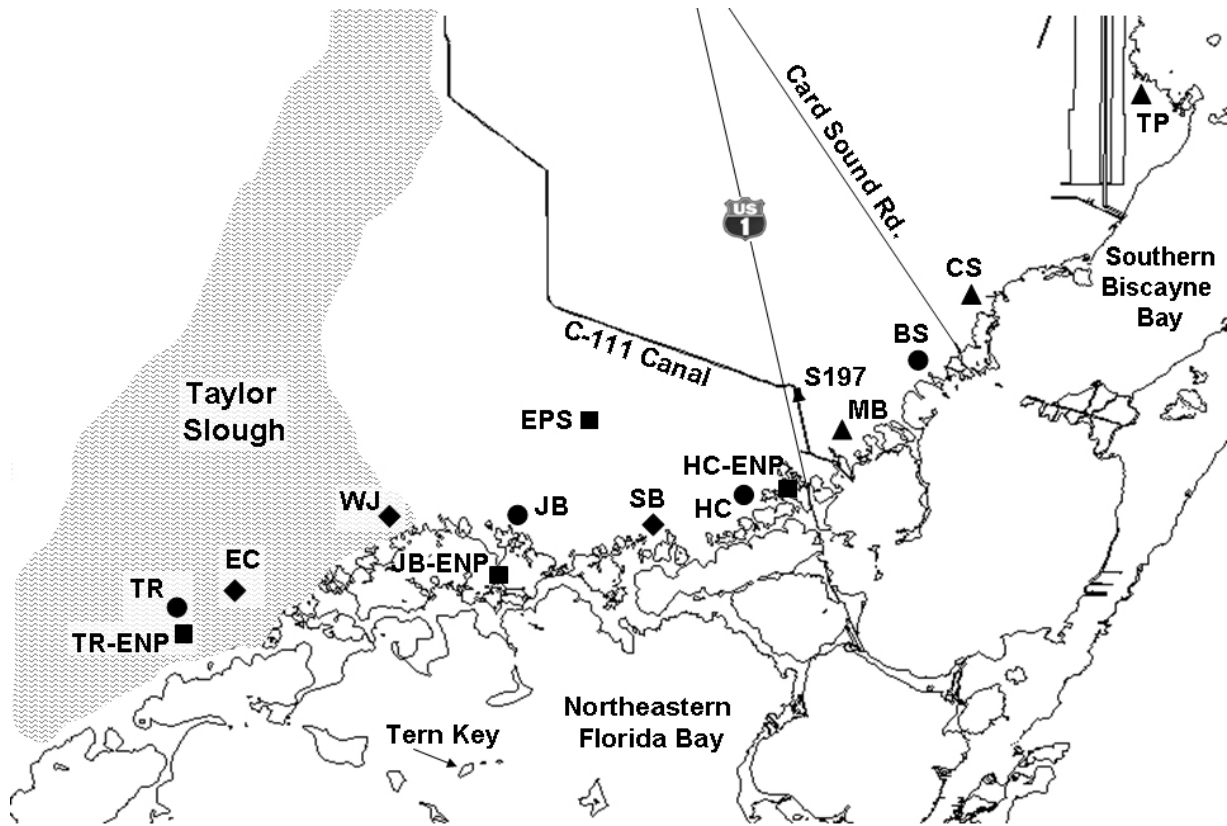
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Fig. 1

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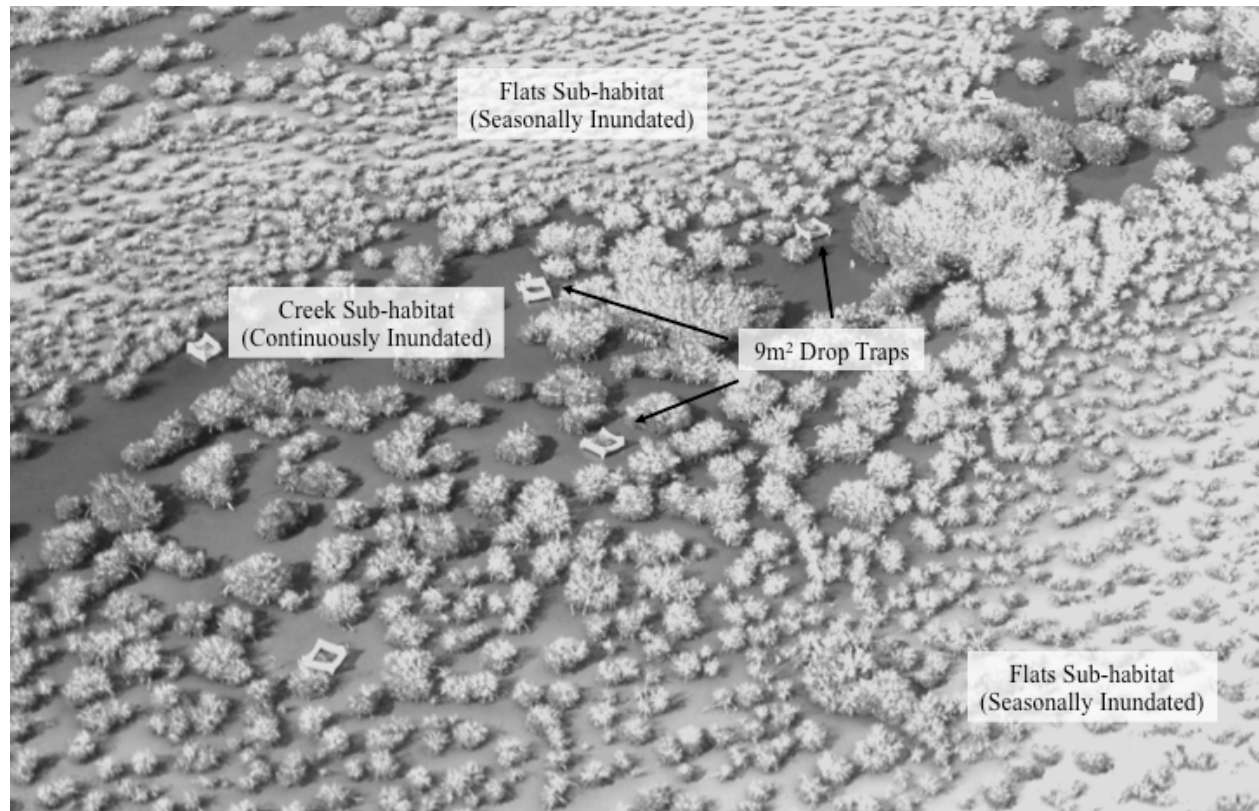
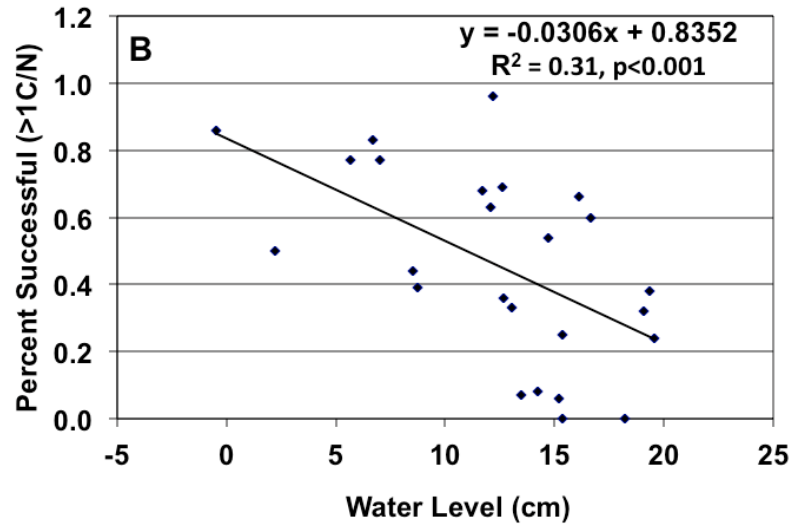
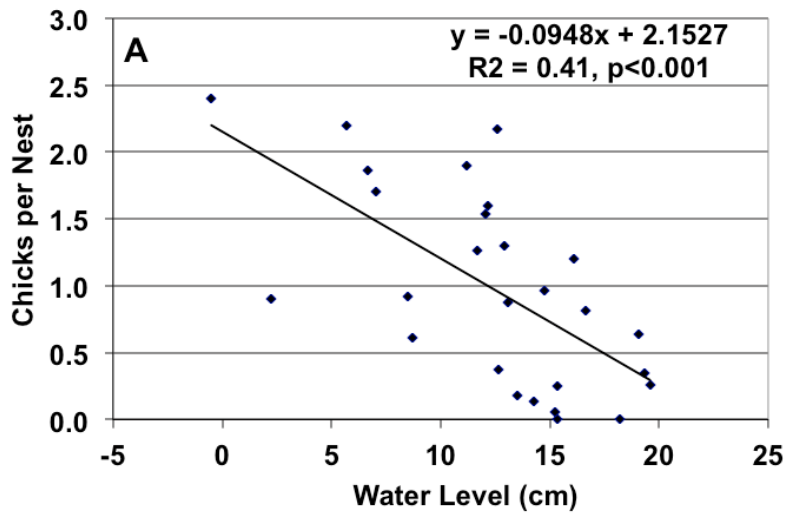


Fig. 2

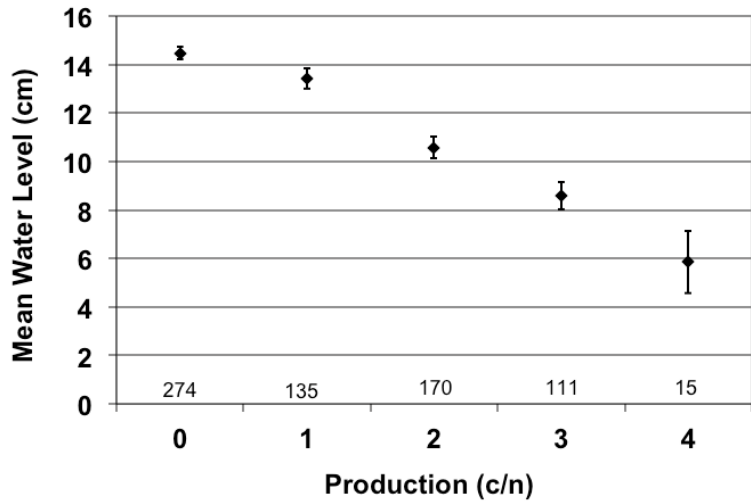
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Fig. 3

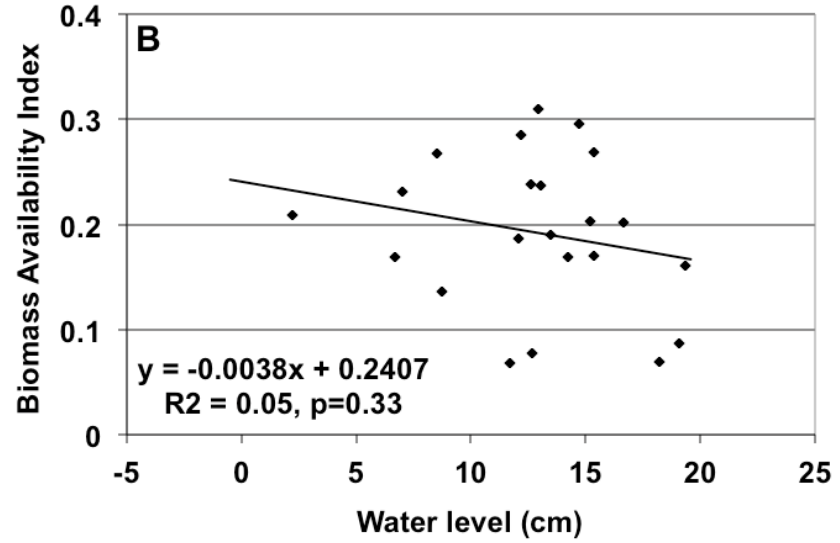
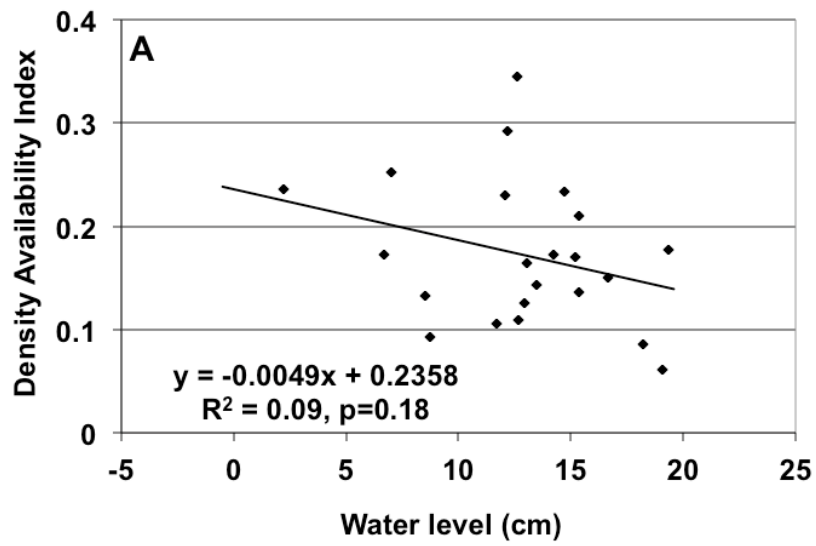


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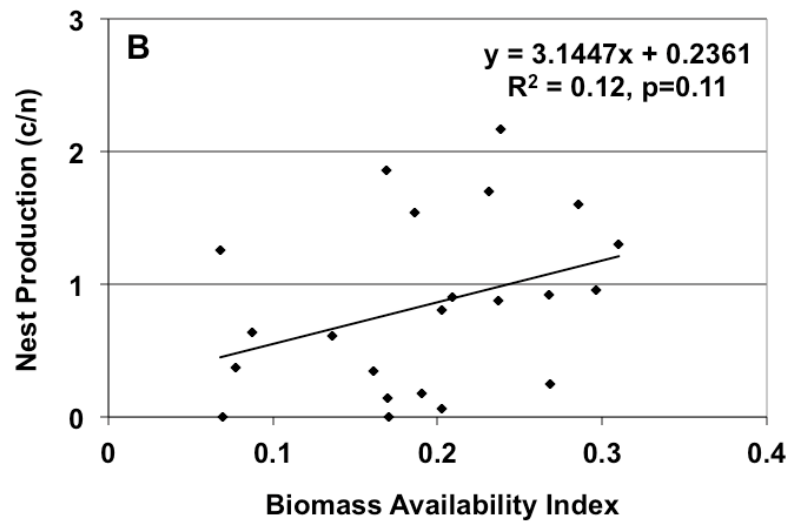
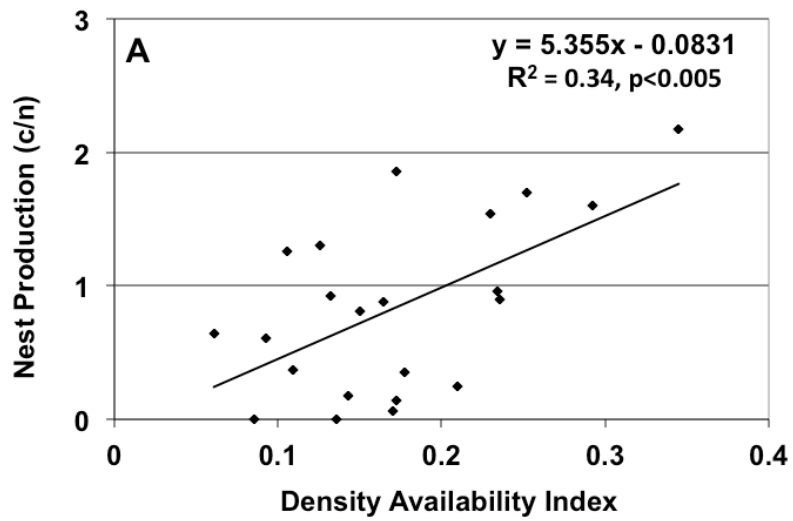
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Fig. 4



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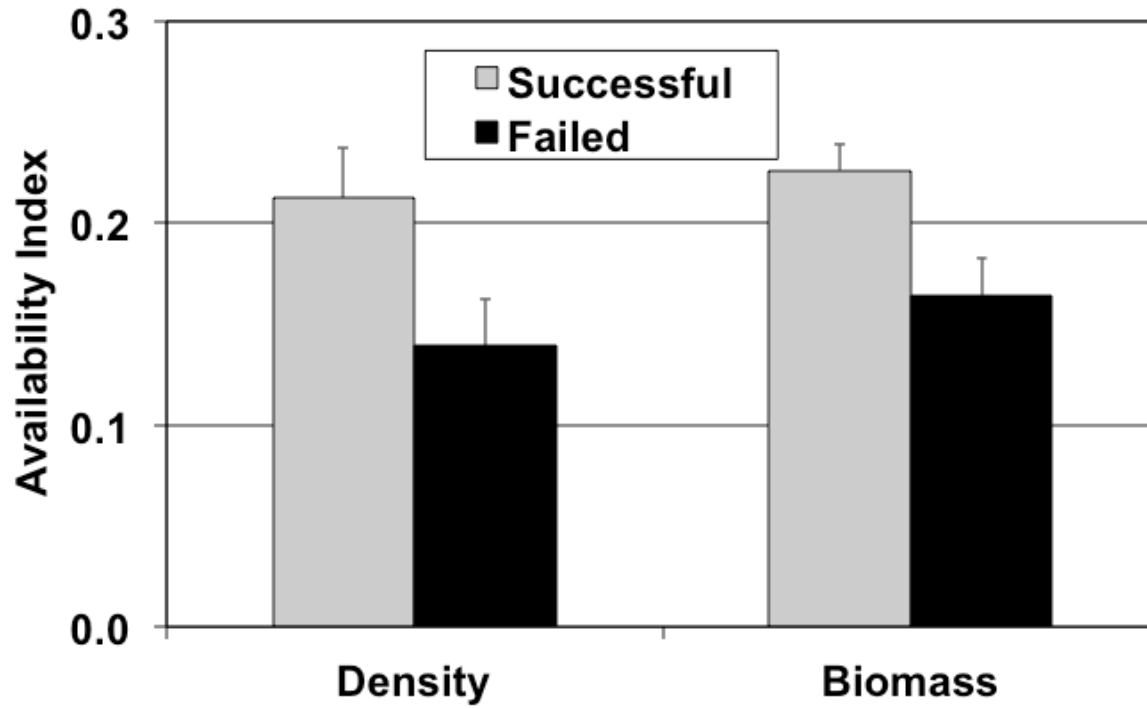
Fig. 5.



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Fig. 6

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