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Drying Times: Integrating Citizen Science to Examine Survival of Florida Largemouth Bass in a Coastal Refuge Habitat

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FLORIDA INTERNATIONAL UNIVERSITY

Miami, Florida

DRYING TIMES: INTEGRATING CITIZEN SCIENCE TO EXAMINE SURVIVAL OF FLORIDA LARGEMOUTH BASS IN A COASTAL REFUGE HABITAT

A thesis submitted in partial fulfillment of

the requirements for the degree of

MASTER OF SCIENCE

in

ENVIRONMENTAL STUDIES

by

Jessica A. Lee

2015

To: Dean Michael R. Heithaus
College of Arts and Sciences

This thesis, written by Jessica A. Lee, and entitled Drying Times: Integrating Citizen Science to Examine Survival of Florida Largemouth Bass in a Coastal Refuge Habitat, having been approved in respect to style and intellectual content, is referred to you for judgment.

We have read this thesis and recommend that it be approved.

Mahadev G. Bhat

Michael R. Heithaus

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Jennifer S. Rehage, Major Professor

Date of Defense: March 26, 2015

The thesis of Jessica A. Lee is approved.

Dean Michael R. Heithaus
College of Arts and Sciences

Dean Lakshmi N. Reddi
University Graduate School

Florida International University, 2015

DEDICATION

I would like to dedicate this thesis research to my family. I am thankful for all your love and support.

ACKNOWLEDGMENTS

I would first like to thank my advisor, Jennifer Rehage, for her support and providing me the opportunity to pursue such an amazing project. Through her mentoring I have developed the skills needed to be successful while also bringing out strength in my own abilities to chase my research goals with confidence. I would also like to thank the support of my committee members Michael Heithaus, Mahadev Bhat, and Matthew Lauretta. I especially thank Matt for all his help on this project and time spent going over MARK models with me.

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ABSTRACT OF THE THESIS

DRYING TIMES: INTEGRATING CITIZEN SCIENCE TO EXAMINE SURVIVAL OF FLORIDA LARGEMOUTH BASS IN A COASTAL REFUGE HABITAT.

by

Jessica A. Lee

Florida International University, 2015

Miami, Florida

Professor Jennifer S. Rehage, Major Professor

In aquatic systems refuge habitats increase resistance to drying events and are necessary for maintaining populations in disturbed environments. However, reduced water availability and altered flow regimes threaten the existence and function of these habitats. To test refuge function I conducted a capture-mark-recapture (CMR) study, integrating citizen science angler sampling into fisheries-independent methods. The objectives of this study were twofold: 1) To determine the contribution of citizen science anglers to improving CMR research, and 2.) to quantify apparent survival of Florida Largemouth Bass, *Micropterus salmoides floridanus*, in a coastal refuge habitat across multiple years of drying severity. The inclusion of angler sampling was determined to be an effective and feasible method for increasing capture probability. Apparent survival of Florida Bass varied among hydrologic periods with lowest survival when marshes functionally dried (< 10 cm). Overall mortality from drying events increased with the duration of marsh drying upstream.

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I. INTRODUCTION

Much of the world's freshwater flows are being altered as a result of anthropogenic demands for water resources (Mims & Olden 2013). Highly managed water flows have shifted the natural timing, quantity, and variability of freshwater delivery to altered and at times novel flow regimes (Poff et al. 1997; Poff & Zimmerman 2010; Beesley et al. 2014). Altered flows can directly influence disturbance regimes in aquatic habitats by interfering with the seasonal patterns of flood and drying events (Lytle & Poff 2004). In particular, the intensity and frequency of drying disturbances can be impacted by reduced water availability in conjunction with climate change (Lake 2011).

Disturbance regimes are fundamental components of ecosystems, affecting population dynamics and shaping ecological and evolutionary processes (Sousa 1984; Lake 2003; Turner 2010; Banks et al. 2013). However, despite their importance, there is little known about the impact of altered hydrology on mobile organisms such as fishes (Magalhães et al. 2002; Davey et al. 2006). This has left numerous gaps in our understanding of how fish populations respond to drying events exasperated by anthropogenic influences (Matthews & Matthews 2003).

The ability of fish to persist in the face of disturbance can be influenced by the availability and quality of refuge habitats (Sedell 1990; Lake 2003). Refuge habitats refer to those that decrease the negative effects of disturbance compared to the surrounding area and are necessary for maintaining populations in disturbed environments (Lancaster & Belya 1997; Magoulick & Kobza 2003). For example, Creek Chub, *Semotilus* *atromaculatus*, can escape drying in perennially interrupted Ozark streams by using seasonally-isolated pools that maintain high water quality via interstitial flows (Hodges & Magoulick 2011). Access to refuge habitats, such as dry season pools, buffer populations from drying events and are necessary for maintaining freshwater fish populations (Rolls et al. 2012; Robson et al. 2013; Avery-Gromm et al. 2014). Changing flow regimes threaten the existence and function of refuges (Perry & Bond 2009). Understanding the function of refuge habitats under altered flow regimes is vital for adaptation and management in a future of water scarcity and climate change (Robson et al. 2013; Davis et al. 2013).

A major component of refuge function for fishes and other aquatic biota is an increase in population resistance to drought events through a reduction in direct mortality (Magoulick & Kobza 2003). Thus, survival in refuge habitats is a fundamental measure of refuge quality and buffering capacity. Survival is a key determinant of population dynamics (Varley & Gradwell 1960; Buzby & Deegan 2004), and the ability for ecologists to link vital rates to environmental factors provides a powerful tool to investigate how natural populations respond to changing patterns of disturbance (Frederiksen et al. 2008; Frederiksen et al. 2013). Although a number of studies have begun incorporating variation in refuge quality to understand the interplay between disturbance and refuge habitats (Kobza et al. 2004; DeAngelis et al. 2010; Parkos et al. 2011; Bond et al. 2015), few directly quantify survival. Instead, most studies infer survival through changes in relative abundance over time, which can be problematic, as heterogeneity in the probability of individual detection across varying habitats creates an inherent bias (Williams et al. 2002). Further, studies that investigate drying effects on fishes are largely limited to dryland streams and Mediterranean climates, and often focus on small-bodied or juvenile fishes dwelling in small pool habitats (Matthews & Matthesws 2003; Magalhães et al. 2007; Labbe & Fausch 2000; Hodegs & Magoulick 2011; Robson et al. 2013).

In the Everglades, patterns of marsh flooding and drying regimes have been highly modified as a result of extensive draining, canalization, and redirection of water flow (Light & Dineen 1994). In the southern portion of the ecosystem, these hydrological modifications have resulted in an increased magnitude, frequency, and duration of marsh drying (Sklar 1999), particularly in Everglades National Park (ENP). Reductions in hydrological flows have likely increased the importance of refuge habitats such as solution-holes, alligator holes, and coastal mangrove creeks in maintaining fish populations (Rehage & Loftus 2007; Parkos et al. 2011; Rehage et al. 2014). In coastal habitats, reductions in freshwater inflow have resulted in increased salinity conditions and an overall introgression of the ecotone inland (Davis et al. 2005; Saha et al. 2011b). As upstream marshes dry, coastal mangrove creeks function as refuge habitats for important large-bodied mesoconsumers such as the Florida Largemouth Bass (*Micropterus salmoides floridanus*, here after Florida Bass), which support a highly-prized recreational sport fishery (Fedler 2009). Understanding how reduced freshwater flows, increased salinity and frequency of marsh drying influence the ability of these coastal mangrove creeks to buffer Florida Bass populations from drying events is crucial to fisheries management of ENP.

In the present study, I used traditional capture-mark-recapture (CMR) methodology in conjunction with an angler citizen science program to estimate survival of Florida Bass across a range of drying severity. The objectives of this study were twofold: 1) to determine the contribution of citizen anglers to improving CMR fisheries research, and 2) to quantify variation in survival of Florida Bass in a coastal refuge habitat. I hypothesized that the inclusion of anglers through citizen science would improve CMR data by increasing capture probability, and thus better informing survival models. To test this hypothesis, I modeled monthly capture probabilities as a function of both electrofishing and angling sampling effort. I then tested alternative candidate open Cormack-Jolly-Seber (CJS) survival models (Cormack 1964; Jolly 1965; Seber 1965) derived from *a priori* hypotheses about the function of refuge habitat during seasonal hydrological periods and across years of varying severity. I hypothesized that apparent survival of Florida Bass in coastal mangrove habitats would be highest in the wet season when biotic and abiotic conditions in the refuge were less stressful. As upstream marshes dry I expected to see a decrease in survival in refuge mangrove creeks from a combination of fishing mortality and natural mortality (e.g., predation, salinity, etc.). I also hypothesized that apparent survival should be lowest at the peak of the dry season and expected mortality to vary as a function of duration of marsh drying.

II. METHODS

Focal species & study system

I quantified survival of Florida Bass in the upper Shark River Estuary (SRE), located in the southwestern region of ENP, Florida, USA (Figure 1). In the Everglades, Florida Bass reside throughout freshwater marshes and canals in periods of high water levels in the wet season (June-November) (Chick et al 2004; Rehage & Trexler 2006, Parkos & Trexler 2014). In the dry season (December-May), available marsh habitat contracts, often completely drying, particularly in the post-drainage system. In the coastal Everglades, in response to seasonal upstream marsh drying, Florida Bass move to refuge habitats in oligohaline mangrove creeks at the headwaters of coastal creeks. For instance, approximately 84 % of the Florida bass caught in the upper SRE were caught in the dry season (Rehage et al. 2015).

The SRE is one of the main drainages of the coastal Everglades into the Gulf of Mexico (Childers 2006). Marsh water levels are highly influenced by regional rainfall and water management decisions upstream, which result in seasonal and interannual variation in marsh inundation (Figure 2) (Sklar et al. 1999; Saha et al. 2011a). In contrast, the headwater creeks of the SRE remain inundated year round, and the combination of high hydrological connectivity between the marsh and estuarine habitats and their location at the southern end of the main drainage in the southern Everglades, the Shark River Slough (Childers et al. 2006), make the region an important refuge habitat for freshwater fishes in periods of seasonal marsh drying (Rehage & Loftus 2007).

The use of oligohaline reaches in coastal areas by Largemouth Bass, *Micropterus salmoides*, is well-established, but our understanding of these populations is limited (Norris et al. 2010). In the SRE, use of estuarine habitat and its function as refuge habitat for Florida Bass may be limited by increasing salinity levels as marshes dry. Salinity tolerance of Largemouth Bass varies through ontogeny as well as the origin of the population (e.g., inland vs. coastal), but there is a general preference for salinities < 3 ppt (Meador & Kelso 1989; Glover et al. 2013). Lethal limits for Largemouth Bass occur at 12 ppt (Meador & Kelso 1990), while the egg and larval stages cannot survive above 3.6

ppt and cessation of reproduction occurs at 3-4.5 ‰ (Meador & Kelso 1989). Florida Bass are a subspecies of *M. salmoides* and while salinity preferences may be similar, it is possible that Florida Bass may have lower tolerances to salinity (Glover et al. 2012). Thus, as marshes dry and salinity increases, Florida Bass in the SRE may experience mortality in the estuary under high salinity and fishing pressure. Once in the estuary, Florida Bass are an important recreational fishery in this region, and angler catch rates are strongly affected by the severity of marsh drying (Boucek & Rehage 2013b).

Study design

A capture-mark-recapture study was conducted between November 11, 2010 and June 2, 2014 at 10 fixed sites across the upper 12 km of the SRE (Figure 1). During this 3.5 year period, Florida Bass populations were sampled on 32 monthly sampling events during both the wet and dry seasons (Appendix A). Sampling was conducted using a boat-mounted generator-powered electrofisher (two anode, one-cathode Smith-Root® GPP 9.0 system), shown previously to be an effective means for sampling larger fishes including Florida Bass in the fresh and coastal Everglades (Chick et al. 1999; Boucek & Rehage 2013a). Fixed sites consisted of three 100 m replicate transects of shoreline each separated by 100 m buffer (see Rehage & Loftus 2007; Boucek and Rehage 2013a for additional details). For each transect, a randomly-selected side of the creek was sampled at idle speed for 5-minutes of shocking (Rehage & Loftus 2007). Power output was standardized to 1500 Watts per ambient temperature and conductance conditions (Burkhardt & Gutreuter 1995; Chick et al. 1999). Immobilized Florida Bass were collected by two netters at the bow of the boat and placed in a live-well for processing.

All Florida Bass >120 mm were tagged with a passive integrated transponder (PIT tags, 23 mm HDX, 0.6 g, Biomark®). PIT-tags are microchips encased in biocompatible glass, each encoding a unique number used to identify individuals (Gibbons & Andrews 2004). Before being tagged, every Florida Bass was scanned using a handheld tag reader to check for a previously-inserted tag. If a tag was detected it was noted as a recapture (Appendix A), and its unique identification number was recorded. If an individual was not previously marked, it was then tagged intraperitoneally with the PIT-tag (Baras et al. 1999). All captured fish were scanned and tagged on all sampling occasions and released promptly after processing at the location of capture. All fish were weighed and measured before tagging, and total length (mm) data was used to examine variation in size structure among years of varying drying severity. Two estimated age classes, age-1 and age-2+, were estimated from length frequency data using the Bhattacharya method (Ozen & Noble 2005) and known age-length relationships for Florida Bass (Allen et al. 2002).

Starting in 2011, an angler citizen science program called the Coastal Angler Science Team (CAST) was developed to increase recapture information on tagged individuals. This program was designed to incorporate anglers who targeted Florida Bass in the SRE region (Figure 1). Participating anglers were trained on how to properly scan and record recapture data and received data packets (Appendix B). Anglers scanned all catches before release and recorded any recapture tag numbers, as well as fish length and recapture location.

Classification of hydrologic periods

To compare survival across seasons, four distinct hydrologic periods were defined as a function of water levels in marshes upstream of the study region (e.g., Grossman et al. 1998; Figure 2). Hydrologic periods were defined as WET, when marsh water levels were >30 cm; DRYING when water levels were < 30 cm, but above >10 cm; and DRY when marsh levels dropped to < 10 cm. A 10 cm water depth was considered DRY since at this depth there is little standing water remaining and low connectivity of the landscape for large-bodied fishes such as Florida Bass (Chick et al. 2004; Parkos et al. 2011). Once marshes were DRY, a final REFLOOD period was designated for the re-inundation period when water levels were > 10 cm, but < 30 cm (Figure 2). Marsh water depths were obtained from the US Geological Survey hydrostation MO-215 (Figure 1). A range of DRY period severities were captured across the four years of the study, including: 132 days DRY in year 1, 25 days DRY in year 2, 0 days DRY in year 3, and 62 days DRY in year 4.

Survival model

Capture probability (p) and apparent survival (ϕ) were estimated using an open population CJS model (Cormack 1964, Jolly 1965, Seber 1965) in the program MARK® (White & Burnham 1999). Open models allow for changes in births, deaths, immigration, and emigration (Pine et al. 2003). Thus, apparent survival estimates (hereafter, survival) include mortality as well as permanent emigration (Williams et al. 2002). Multinomial encounter histories that included the presence or absence of tagged fish (0 = not captured, 1 = captured) across all 32 sampling events (Appendix C) were built and used as input for the CJS model (White & Burnham 1999, Cooch & White 2010). Both p and ϕ were estimated on monthly time steps, and sampling intervals were adjusted directly in MARK® (White & Burnham 1999) for the few instances when multiple months elapse between sampling events.

In order to incorporate both electrofishing and angling sampling from CAST, the capture probability model p(electrofishing + citizen science) was used. The logit-link function was used to incorporate sampling effort of each method to the capture probability model. Electrofishing effort was measured as the total number of days per month to complete sampling and angling effort was measured as the sum number of angling days per angler (Appendix A). In order to assess how incorporating citizen science influenced capture probability, predicted capture probability ($\hat{p}$) was modeled as a function of electrofishing effort and of angling effort using the equation:

(1) $$\hat{p}_{Electrofishing+Angling} = \frac{1}{1 + exp^{-(\beta_o + \beta_1 * E_{Electrofishing} + \beta_2 * E_{Angling})}}$$

where β_o is the intercept, β_1 is the coefficient of electrofishing effort, and β_2 is the coefficient of angler effort. Using these estimated coefficients, I assessed the efficiency of each sampling method (electrofishing vs angling) by comparing these estimated coefficients and comparing predicted capture probabilities ($\hat{p}$) for each method across a range of sampling efforts, using days as a common unit of effort.

To examine how survival of Florida Bass varied across the four hydrologic periods of interest, I developed four *a priori* models (Table 1). The models tested four hypotheses of interest that ranged from constant survival over time, heterogeneous survival among sampling events, variation in survival among hydrological periods, and as a function of both hydrological periods and years of the study (2011-2014). Final models was built to test effect of year 3 of the study, as marshes never fell below the 10 cm classification for DRY, but were low enough (12 cm) to have potential impacts on refuge function. Models were run using the iterative approach set forth by Lebreton et al. (1992). I then ranked models using Akaike's Information Criterion for small sample sizes (AICc). The lowest AICc value indicates the most parsimonious model within the set of candidate models (Burnham & Anderson 1998; Anderson 2007). I used goodness-of-fit (GOF) tests to test for the violation of model assumptions of equal probability of survival and recapture for all marked animals in the population (Lebreton et al. 1992; Williams et al. 2002) by using a parametric bootstrap and the RELEASE extension.

From the top ranking model, I obtained estimates of monthly survival rates for each of the four hydrologic periods. Model averaging, between the two top models was used to estimate survival in year 3, the non-dry year of the study. By multiplying the estimated monthly survival rates by the number of months each hydrologic period lasted (i.e., a two month DRY in year four equals($\phi_{dry} * \phi_{dry} = \phi^2$) I was able to compute a hydrologic period survival (HS) for each period of the study. I used the delta method to calculate variance for each HS (Powell 2007). For all hydrologic periods except DRY, survival was expected to be apparent survival, a combination of total mortality (fishing + natural mortality) and emigration. But, the study system was effectively 'closed' to migration during the DRY period, bounded by higher salinity downstream in the estuary and dry marshes upstream, and therefore estimates of apparent survival for this hydrologic period were assumed to be a function of fishing and natural mortality alone and were converted to DRY hydrologic period mortality estimates (Z) with the equation:

(2) $$Z = 1 - \phi_{HSdry}$$

where total mortality (Z) can be described as:

(3) $$Z = F + M$$

where F is the instantaneous fishing mortality and M is the instantaneous natural mortality (Kerns et al. 2012); however recaptures were too low to distinguish between the two. Tag loss and failure were assumed to be negligible, as demonstrated for PIT tagged Largemouth Bass in previous studies (Siepker et al. 2012 and references therein). Additionally, the volunteer nature of angler participation in CAST eliminated any tag reporting biases.

III. RESULTS

Over the 3.5 years, a total of 1,727 Florida Bass were marked and 146 were recaptured, 106 from electrofishing sampling and 43 from angler recaptures (Figure 3). The GOF fit test RELEASE showed that the global model (ϕ(Event), Table 3) had an adequate fit (χ^2 = 35.7, df = 60, P = 0.99). The second GOF test indicated slight overdispersion with a mean variance inflation factor of $\hat{C}$ = 1.13, which I addressed by using QAICc as our model selection criteria (Burnham & Anderson 2002, Table 3).

Electrofishing and angling sampling capture probabilities were not significantly different. Beta coefficients of capture probabilities from the model p(Electrofishing + Angling) were β_1 = 0.16 and β_2 =0.06 for electrofishing and angling respectively (Table 2). Capture probability was similar between sampling methods at low levels of effort (< 5 days), but at higher efforts electrofishing (unfeasible) surpassed angling in a nonlinear manner (Figure 5). However, overlapping confidence intervals indicate that there is no significant difference between the two methods. These results suggest that the inclusion of citizen science anglers to improve CMR capture probabilities can be just as good as electrofishing sampling.

Of the four candidate survival models, the best fit model was the ϕ(Hydrologic period) model, with a 0.77 probability of being the best model in the set (Table 3). The next best model was ϕ(Hydrologic Year 3), but this model contained less information, with a ΔQAICc of 2.7 and a model weight of 0.20. The model results suggest that hydrological period has an overwhelming effect on monthly. Additionally, interannual variation has little effect on the monthly estimates of each hydrologic period. From the top ranking model ϕ(Hydroperiod), parameter estimates indicated that monthly survival was 100% in DRYING periods (1.0; 95% CI: 0.99, 1.00). However, confidence intervals for the DRYING period are likely larger than reported as limitations of estimating standard errors for parameters at their boundary should be taken into consideration (Reboulet et al. 1999). Similarly, as a result of the seasonal nature of refuge use by Florida Bass, limited tagging data in the WET period make survival non-estimable in this time (Reboulet et al. 1999). In contrast, monthly survival was lower, but not different from each other in the DRY and REFLOOD periods, 0.73 (95% CI: 0.60, 0.84) and 0.58 (95% CI: 0.48, 0.68) respectively.

The estimated HS for the DRYING periods remained consistently at 1 for all years of the study, indicating reduced mortality under high water conditions. In contrast, HS was significantly lower in the DRY periods in the three years when minimal water levels in the DRY period fell < 10 cm (all years but 2013, Figure 5). The estimated mortalities for the DRY period were 79% in 2011, 27%, in 2012, 5% in 2013, and 46% in 2014. These mortalities were proportional to the duration of drying, 132 days in 2011 during the drought, vs. 25 in 2012, 0 in 2013, and 62 in 2014. Notable is the fact that mortality was estimated at only 5% when marshes remained above 10 cm and did not dry in 2013 (Figure 6).

The length frequency data indicated a dominance of two age classes in the SRE sites, and variation in age structure across the 4 years, which corroborates the survival estimates (Figure 7). In 2011, the frequency of age-1 and age-2+ classes was similar whereas in 2012 the 5-month drought the previous year was evident in the frequency data, with a truncated size distribution, with no age-1 fish present an absence of the largest individuals. This truncation in 2012 agrees with the highest mortality observed in the study. Post-drought, in 2013, the largest size distribution was detected, with a dominance of the age-1 size class, indicative of recovery. Lastly, 2014 was dominated by age-2+ with an overlap in size distribution with age-1 fish. Comparison of 2013 and 2014 length frequencies show that the 2013 cohort is intact in 2014 and most of it enters the next age class, corroborating the zero mortality estimated in the model in 2013.

IV. DISCUSSION

Understanding the ability of refuge habitats to buffer populations from disturbance is important to predicting how populations may respond to climate change and associated conservation efforts (Davis et al. 2013). Further, the need to understand the function of refuge habitats will only increase with growing demands on freshwater resources and forecasted declines in precipitation in many parts of the world (Lake 2011;

Avery-Gromm et al. 2014). In this study, I modeled Florida Bass survival across a range of seasonal hydrologic periods and years of drying severity and incorporated citizen science recapture data into CJS survival models. Inclusion of angler sampling improved recapture probabilities. Apparent survival of Florida Bass in the upper SRE varied among hydrologic periods, with the highest survival in periods of high water levels. As predicted, across years survival in coastal mangrove refuges was closely tied to the length of marsh drying upstream. Mortality over the DRY period peaked at 79% in the drought year when marshes were effectively dry for 132 days, but was 46% in a moderate year (62 day of dry), and 27% in a mild year (25 days dry). Below a marsh depth of 10 cm, the buffering ability of the coastal refuge habitat appeared to diminish and survival decreased. However, above 10 cm mortality was much lower, suggesting that only a small amount of water on the marsh surface can greatly reduce dry season mortality.

Citizen science

When designing and implementing a CMR tagging, several key aspects must be considered. These include tag-shedding, tag-reporting rates, and low capture probabilities (Pine et al. 2012). The design of this study aimed to overcome these common pitfalls in several ways. The choice of PIT-tags eliminated any tag-shedding bias, as these tag types are known to have very high retention rates, low tagging mortality, and last the lifetime of the individual tagged (Boucek & Adams 2011). Additionally, the use of PIT-tags in conjunction with citizen science eliminated bias arising from reporting rates as tag reporting was done exclusively by CAST volunteers actively scanning their catches for recaptures. In open systems it is often difficult to overcome low recapture rates (Hewitt et al. 2010) and most fisheries studies result in capture probabilities of 0.2 and lower (Pine et al. 2012). Like other studies capture probabilities were low for both methods however the inclusion of angler citizen science was shown to match capture probabilities for electrofishing methods and provided direct estimates of their potential to increase capture rates.

My findings showed that the addition of citizen science into CMR research has the ability to improve monthly capture probabilities of tagged fish. This finding supports results from forest and avian monitoring programs, where the inclusion of citizen science was a powerful complement to conventional monitoring programs (Danielsen et al. 2007; Ryder et al. 2010). At low effort, electrofishing and angling sampling were similar; however at higher efforts electrofishing capture probability surpassed angling effort and increased further in a nonlinear pattern. Model results indicate that angler sampling days were not significantly different than electrofishing days and produced more consistent capture probabilities. This high consistency by anglers may result from increased spatial effort relative to sampling at fixed sites by electrofishing, in addition to anglers specifically targeting Florida Bass. Each angler has the ability to cover most of the study region in a single day (pers. comm. with CAST members, Figure 1), while electrofishing covers much smaller spatial domains per sampling day. Increased spatial and temporal coverage is a major advantage for research programs that use citizen science data (Devictor et al. 2010), particularly in fisheries research (Fairclough et al. 2014). For example, Thorson et al. (2014) built demographic models to analyze previously-untapped spatiotemporal data collected solely by citizen science participants, which resulted in important information on demographic trends and habitat associations for two critically-endangered fish species.

In CMR studies, increases in capture probabilities are extremely important and efforts should be made to increase these (Hewitt et al. 2010). In addition to increasing capture probability, the feasibility of increasing sampling effort is greater through angler sampling than routine electrofishing sampling. Additional angler days can be gained by increasing the number of angler participants and overlapping angling trips. In contrast, increasing the number of electrofishing sampling days within a monthly event may not be feasible for most research programs. Furthermore, as the number of sampling days increase, the duration of sampling events are no longer discrete relative to the interval between sampling events (Pollock et al. 1990). This is a promising result as citizen science participants have been shown to collect large amounts of high-quality data at low cost in previous studies (Danielsen et al. 2011). Under ever increasing budgetary constraints, the application of citizen science can potentially be a cost-effective solution to supplement fisheries research (Danielsen et al. 2007; Fairclough et al. 2014). Furthermore, recreational anglers are key stakeholders in the conservation and management of coastal resources, including the Everglades. Examples from other areas in Florida have shown that the exclusion or alienation of stakeholders in resource management can lead to stakeholder frustration and a lack of acceptance and compliance with management decisions (Suman et al. 1999). The creation of citizen science programs similar to this study has the potential to better integrate anglers into restoration and conservation efforts (Nelson et al. 2013), with clear benefits in the form of public support and improved research results.

Variation in survival

The observed decreases in survival during DRY periods are likely driven by a number of biotic and abiotic factors known to affect fish concentrations in refuge habitats (Magoulick & Kobza 2003). Concentrated Florida Bass in the upper SRE may experience predation from marine and freshwater predators that take advantage of marsh drying and accompanying prey pulses. This includes Bull sharks, *Carcharhinus leucas* (Matich & Heithaus 2014), American Alligators, *Alligator mississipiensis* (Rosenblatt & Heithaus 2011), Bottlenose dolphins, *Tursiops truncates* (Sarabia 2012; pers. obs.), and intraguild predators such as Common Snook, *Centropomus undecimalis* (Boucek & Rehage 2013). In addition to predation, the concentration of fishes in coastal refuges also increases their susceptibility to fishing pressure (Boucek & Rehage 2013b), potentially increasing fishing catch-and-release and harvest mortality (e.g., Kerns et al. 2012). Lastly, salinities increase rapidly in DRY periods likely intensify concentration by reducing the extent of suitable coastal refuge habitats and eventually leading to direct mortality when levels exceed lethal limits of salinity. For instance during the 2011 drought, salinities during the DRY season reached 13.9 ppt at the most upstream sites and 25 ppt downstream, well above the 12 ‰ lethal limit (Meador & Kelso 1990).

Severity of drying has been shown to be an important hydrological attribute of flow regimes that influence ecosystem function (Rolls et al. 2012). In this study, mortality from varying durations of DRY periods (Z) ranged as high as 79% in the severe 5-month 2011 drought, to 27% - 46% in years of moderate drying conditions. These mortality estimates agree with previous work in this region indicating that an increased duration of marsh drying limits the abundance of large fish species, including Florida

Bass (Chick et al 2004; Trexler et al. 2005; Parkos et al. 2011). I expect these estimations of DRY period mortality to be a close approximate of increased mortality from seasonal drying. In many CMR studies, biases of apparent survival estimates can arise from emigration out of the study area (Pollock et al. 1991). In this study, however, emigration was not expected to occur during the DRY period, as fish movement out of the study area was constrained by high salinity downstream and dried marshes upstream. Conversely, the estimated decrease in apparent survival during the REFLOOD period (58%) was likely a result of emigration out of refuge habitats back into marshes upon reconnection (unpub. acoustic data).

Yearly differences in DRY period mortality were supported by the length frequency data. For instance, the effects of high mortality in 2011 were clearly evident in the disappearance of the smallest and largest size classes in 2012. Similarly, estimates of zero mortality in 2013 are seen in the intact cohort shown in 2014 with age-1 fish in 2013 becoming age-2+ in 2014 (Figure 7). While, I was unable to incorporate size-specific mortality in the models, these length frequency data shows that there may be a disproportionate impact of dry events on larger (and presumably older) individuals. This would support previous work on *M. salmoides* in other estuarine systems that report a decreased salinity tolerance in larger fish due to ontogenetic differences in osmoregulation (Glover et al. 2012). Other drivers such as susceptibility to fishing pressure and increased biotic interactions (Kerns et al. 2012; Magoulick & Kobza 2003), could also be responsible for this size-selective mortality.

The estimated 5% mortality in the DRYING period in 2013, the year marshes did not functionally dry (when water levels remained >10 cm) were surprising. I expected that increasing abiotic and biotic stressors driven by marsh drying would have an effect even in years when marshes did not fully dry. This result gives us insight into how hydrological variation influences refuge habitat. Abrupt decreases in survival once marshes fell below 10 cm point to the notion of a critical level at which the buffering capacity of refuge habitat drops and mortality from seasonal drying increases. Anthropogenic reductions in water availability have altered disturbance patterns by increasing the frequency of dry-down events in the Everglades (McVoy et al. 2011). However, it is possible that the intensity of such events have also changed over time, not just by increasing frequency and duration, but through alterations of coastal refuges. In arid freshwater rivers of Australia, freshwater inputs through groundwater sources can decouple refuge habitats from local precipitation patterns, increasing the buffering capacity of these habitats for fishes (Davis et al. 2013). In the Everglades, reduced water availability has resulted in saltwater intrusion resulting in brackish groundwater discharge in the mangrove ecotone (Saha et al. 2011a). Shifts from fresh to saline groundwater discharge in the coastal zone have been further documented through shifts in coastal vegetation from saline intolerant communities to more saline tolerant species (Saha et al. 2011b). Groundwater discharge is a significant component of the water budget, with peak discharges late in the dry season (May-July, Saha et al. 2011a). In the pre-drainage Everglades it is possible freshwater groundwater discharge later in the dry season could have potentially prevented dramatic increases in salinity. While restoration efforts may decrease the frequency of disturbance by increasing freshwater flows, unless increased water flow can reverse saltwater intrusion, the elimination of freshwater sources from groundwater discharge may have permanently altered ecotonal refuge habitats.

Furthermore, without restored water flows, sea level rise may further promote trends of increasing salinity (Karamperidou et al. 2013), potentially shifting coastal refuges into sinks and functionally eliminating coastal creeks as dry season refuge.

Survival while in a refuge habitat can vary greatly depending on the quality of the habitat. Labbe and Fuasch (2000) calculated that survival of the threatened Arkansas Darter, *Etheostoma cragini*, varied from 81% in high quality upstream pools connected to groundwater flows to only 5% downstream in poor quality pools disconnected from freshwater inputs. In the SRE, low survival rates in refuge habitats are likely to have important implications for Florida Bass populations. Modeling efforts by Bond et al. (2015) on Golden Perch, *Macquaria ambigua*, in Australian dryland rivers showed that variation in survival rates from drought events had a far greater effect on population size when compared to effects on fecundity and dispersal. The deleterious effect of low survival rates on population persistence is further aggravated as the frequency of disturbance events increases (Bond et al. 2015). Thus, currently low survival rates of Florida Bass are likely to threaten the long-term persistence of these populations under forecasted scenarios of increasing drought disturbance and lower rainfall regimes in the Everglades with climate change (Obeysekera et al. 2011).

In summary, Florida Bass populations in the Everglades currently experience frequent pressure from seasonal drying as marshes functionally dried (< 10 cm) three out of the four years of the study. However, restoration efforts underway in the Everglades aim to reduce the severity of seasonal drying by restoring periods of marsh inundation to pre-drainage scenarios (McVoy et al. 2011). The findings of a critical level of 10 cm for refuge function has promising implications, as this may be a feasible goal for restoration efforts that should directly reduce mortality over the DRY season. Fisheries in Florida contribute $7.5 billion dollars to the economy annually, with 21% of Florida fishermen targeting the Greater Everglades Ecosystem (Fedler 2009). Largemouth Bass are the most targeted freshwater species (FWC 2011), thus Everglades restoration will have important economic impacts on recreational fisheries. Reduction in seasonal drying may increase the number of large or trophy-sized Florida Bass in this system, potentially improving angler perceptions and recreational activities. The perceived improvement of resource quality by stakeholders has been shown to bolster the economic benefits of ecological services through an increase in recreational demand (Bhat 2003). A promising area of research is better understanding the economic benefits of such reductions in mortality and the accompanying benefits to recreational fisheries.

TABLE 1. Model structure and description of *a priori* candidate models for estimating survival for Florida Bass in the SRE

Model notation	Hypotheses
ϕ(Constant)	Monthly survival was constant across the study
ϕ(Event)	Monthly survival differed between each sampling event
ϕ(Hydrologic period)	Monthly survival differed between defined hydrological periods
ϕ(Hydrologic period*Year)	Monthly survival differed between defined hydrological periods and years
ϕ(Hydrologic Year 3)	Monthly survival differed between defined hydrologic periods, with the lowest water month in year 3 classified as DRY

TABLE 2. Estimated beta parameters, standard error, and $\pm$ 95% CI of capture probability model p(Electrofishing + Angling) of Florida Bass for electrofishing and angling sampling methods. See equation (1)

	Coefficient estimate	Standard error	Lower	Upper
β_o(intercept)	-5.24	0.31	-5.84	-4.64
β_1(Electrofishing)	0.16	0.10	-0.03	0.35
β_2(Angling)	0.06	0.01	0.03	0.09

TABLE 3. Model structure for the four monthly survival (ϕ) models considered, showing number of parameters (K), loglikehoood (LL), the difference between the model adjusted Akaike's information criteria, $QAIC_C$, and the top model ($\Delta QAIC_C$), and the model weight (w_i). Models were ranked based on the minimum $\Delta QAIC_C$. Goodness of fit was tested for the global model ϕ(Event).

Survival Model	K	LL	$\Delta QAIC_C$	w_i
ϕ(Hydrologic period)	7	1580.72	0.00	0.78
ϕ(HydrologicYear3)	7	1583.77	2.70	0.20
ϕ(Hydrologic period*Year)	16	1568.24	7.19	0.02
ϕ(Constant)	4	1609.82	19.72	0.00
ϕ(Event)	34	1560.25	37.14	0.00

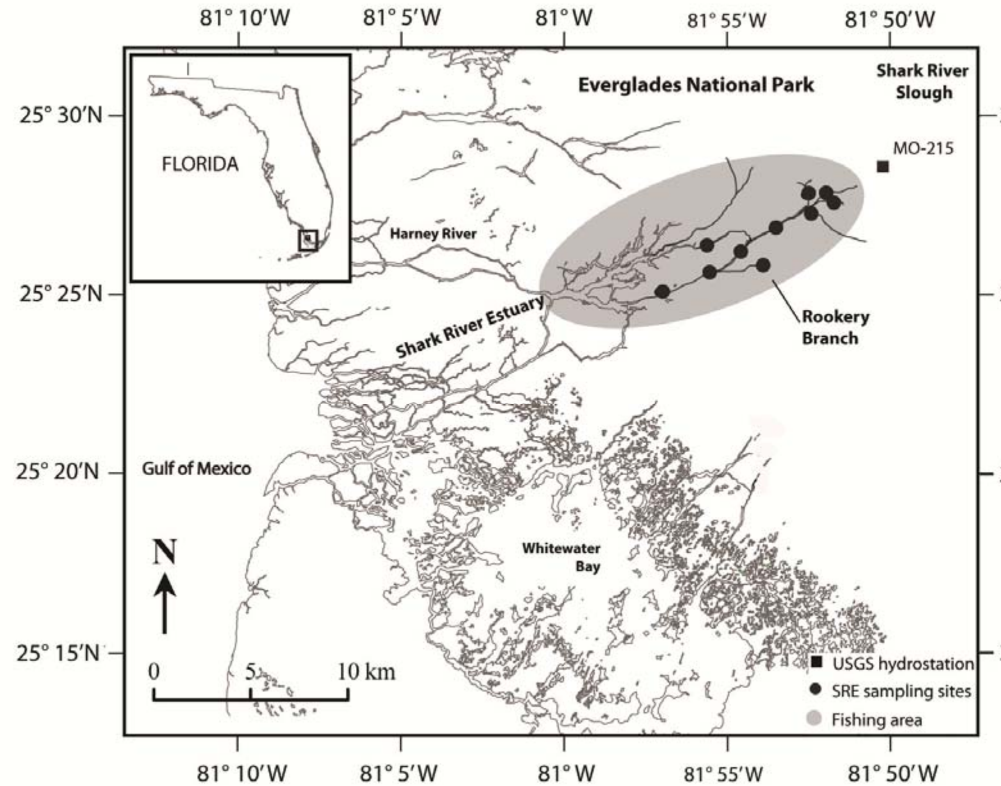

FIGURE 1. Map of study region in the Florida Everglades showing the upper SRE. Ten fixed coastal riverine sites (circles), were sampled via electrofishing and the larger area (grey shading) was sampled by anglers. Marsh water depths were obtained from USGS marsh hydrostation MO-215 (square) located in freshwater marshes upstream of study sites.

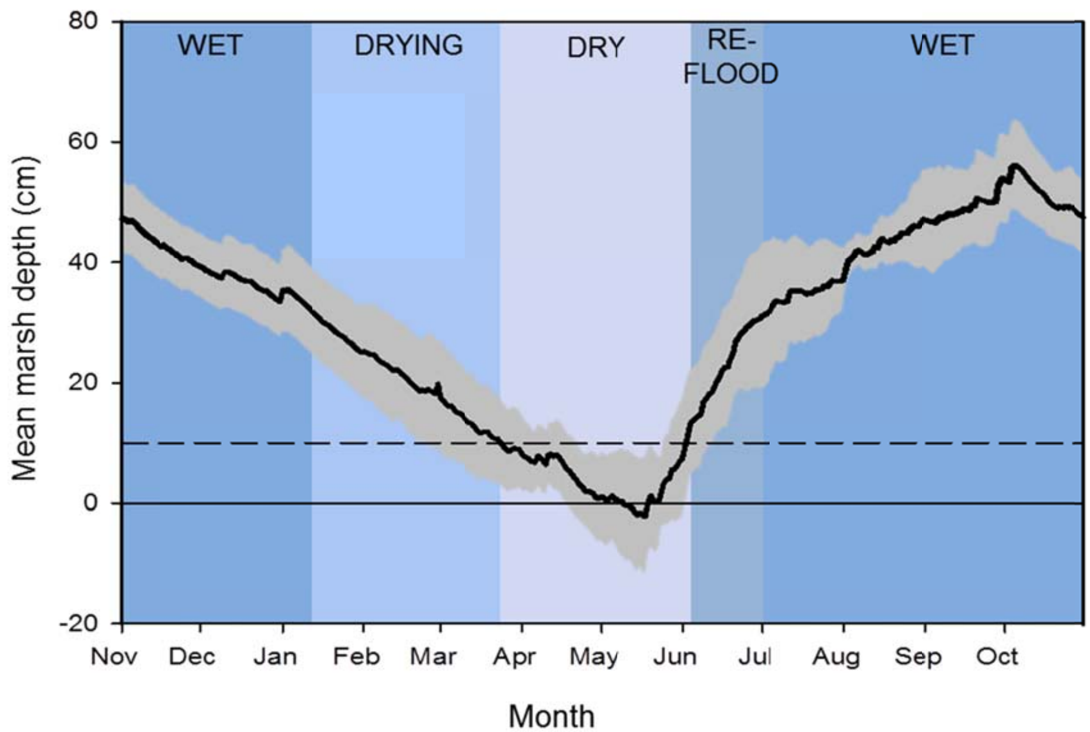

FIGURE 2. Mean daily marsh water depth (black line and in cm) and 95% confidence interval (grey shading) at hydrostation MO-215 from 2000-2010 (see Figure 1). Four hydrologic periods of interest (blue shading) were identified: WET (water levels above 30 cm), DRYING (water recession period when water levels are between 30 cm and 10 cm, DRY (minimal water levels, <10cm), and REFLOOD (re-inundation period when water levels are above 10 cm, but below 30 cm).

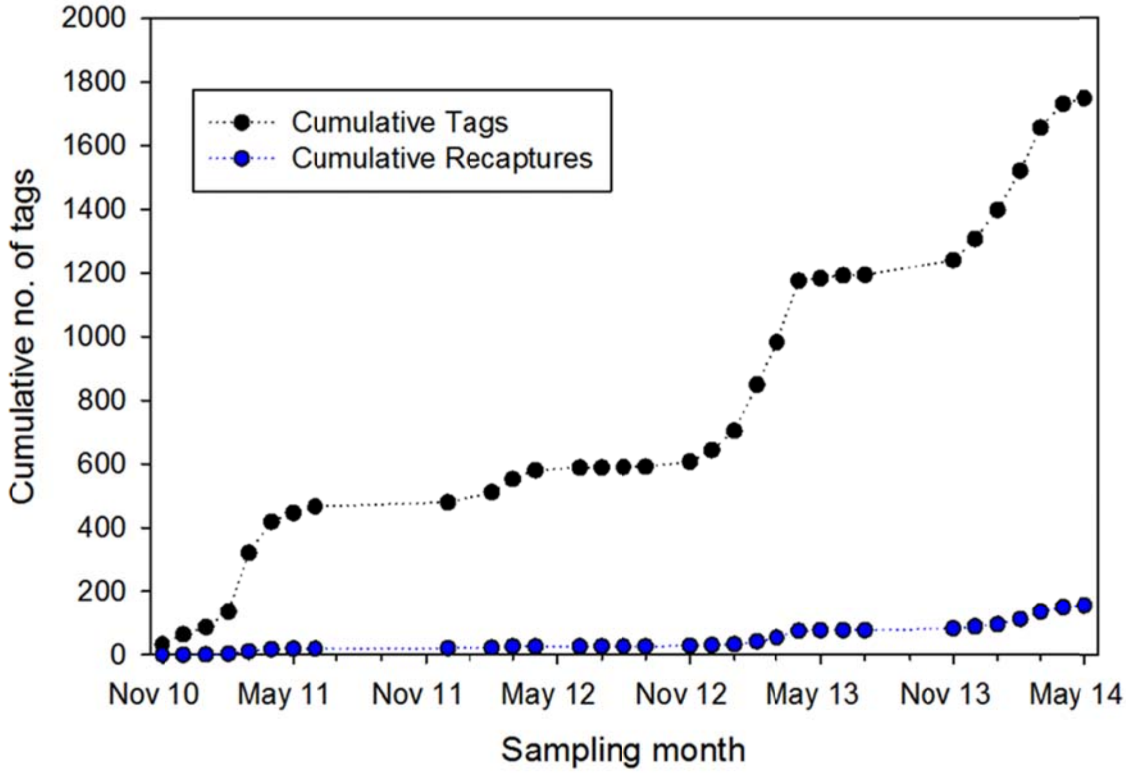

FIGURE 3. The cumulative number of PIT-tagged and recaptured Florida Bass for each sample month of the study (November 2011- May 2014) in the SRE. Electrofishing and angling recaptures are combined.

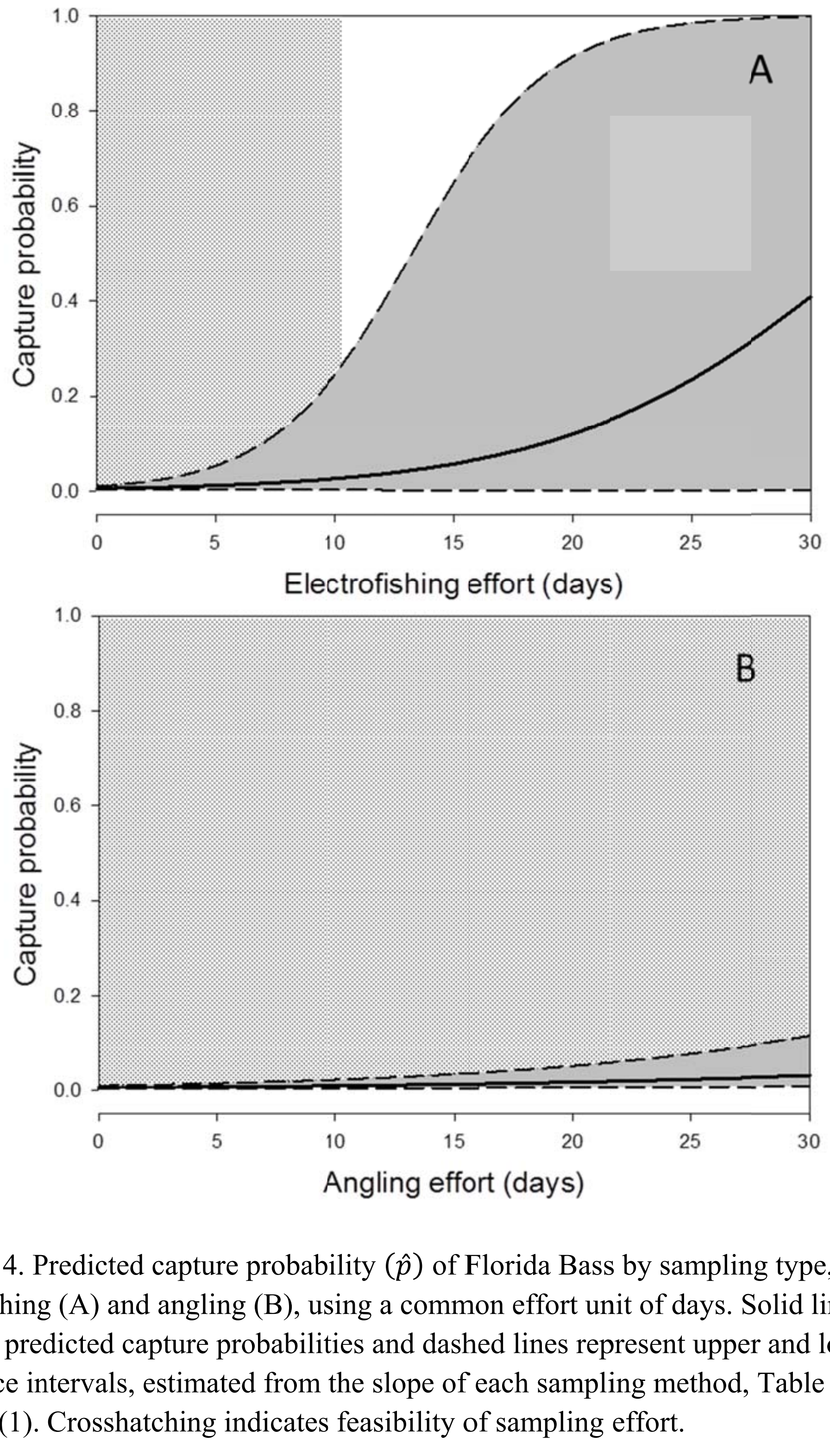

FIGURE 4. Predicted capture probability $(\hat{p})$ of Florida Bass by sampling type, electrofishing (A) and angling (B), using a common effort unit of days. Solid lines represent predicted capture probabilities and dashed lines represent upper and lower 95% confidence intervals, estimated from the slope of each sampling method, Table 2, using equation (1). Crosshatching indicates feasibility of sampling effort.

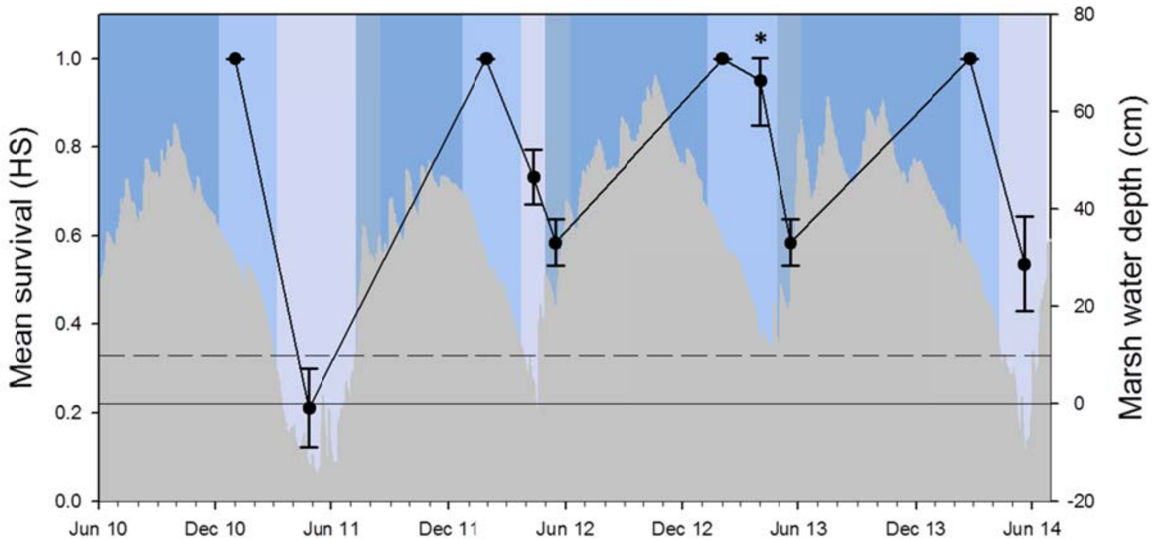

FIGURE 5. Estimated HS of Florida Bass (black symbols) for each hydrologic period across years of the study. Blue shading corresponds to the four hydrological periods of interest: WET, DRYING, DRY and REFLOOD (from dark to lighter shades, see Figure 2). In year 3 (*), marshes never dropped below 10 cm and model averaging was used to estimate the lowest water month . WET periods were not estimated. Grey shading shows daily water depth in upstream marshes (MO-215 hydrostation in Figure 1) from 2010-2014.

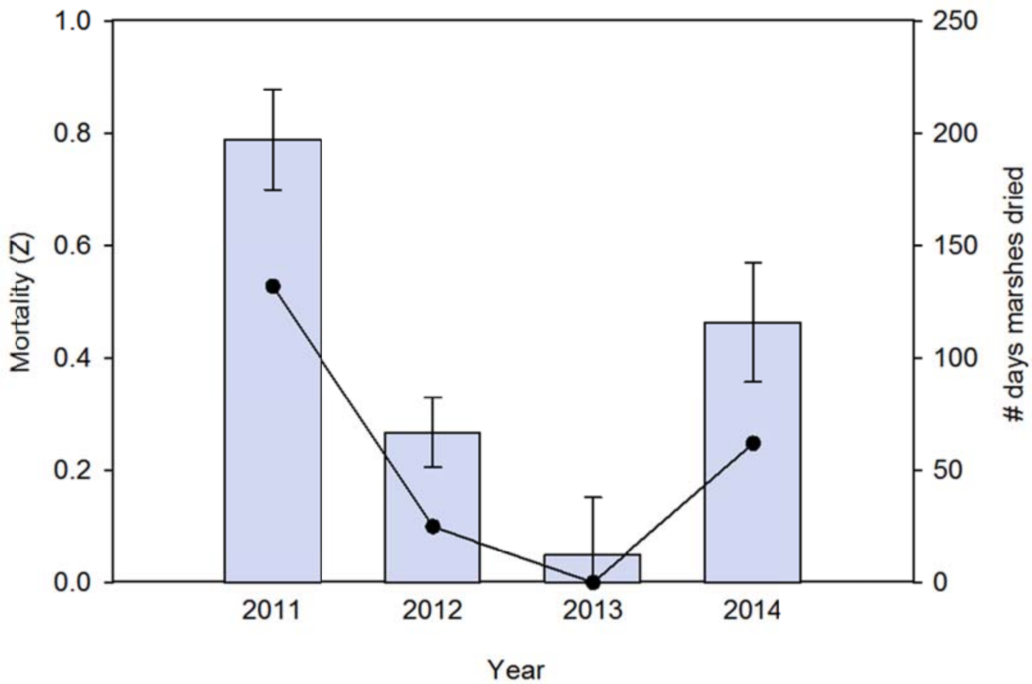

FIGURE 6. Predicated DRY season mortality (Z) given the predicted monthly DRY period survival, see equation (2), and standard errors (bar graphs) for Florida Bass in the SRE. Estimates during this hydrologic period are likely a result of a combination of fishing mortality (F) and natural mortality (M) as emigration in this period is unlikely. Lines indicate the severity of drying in each year in days.

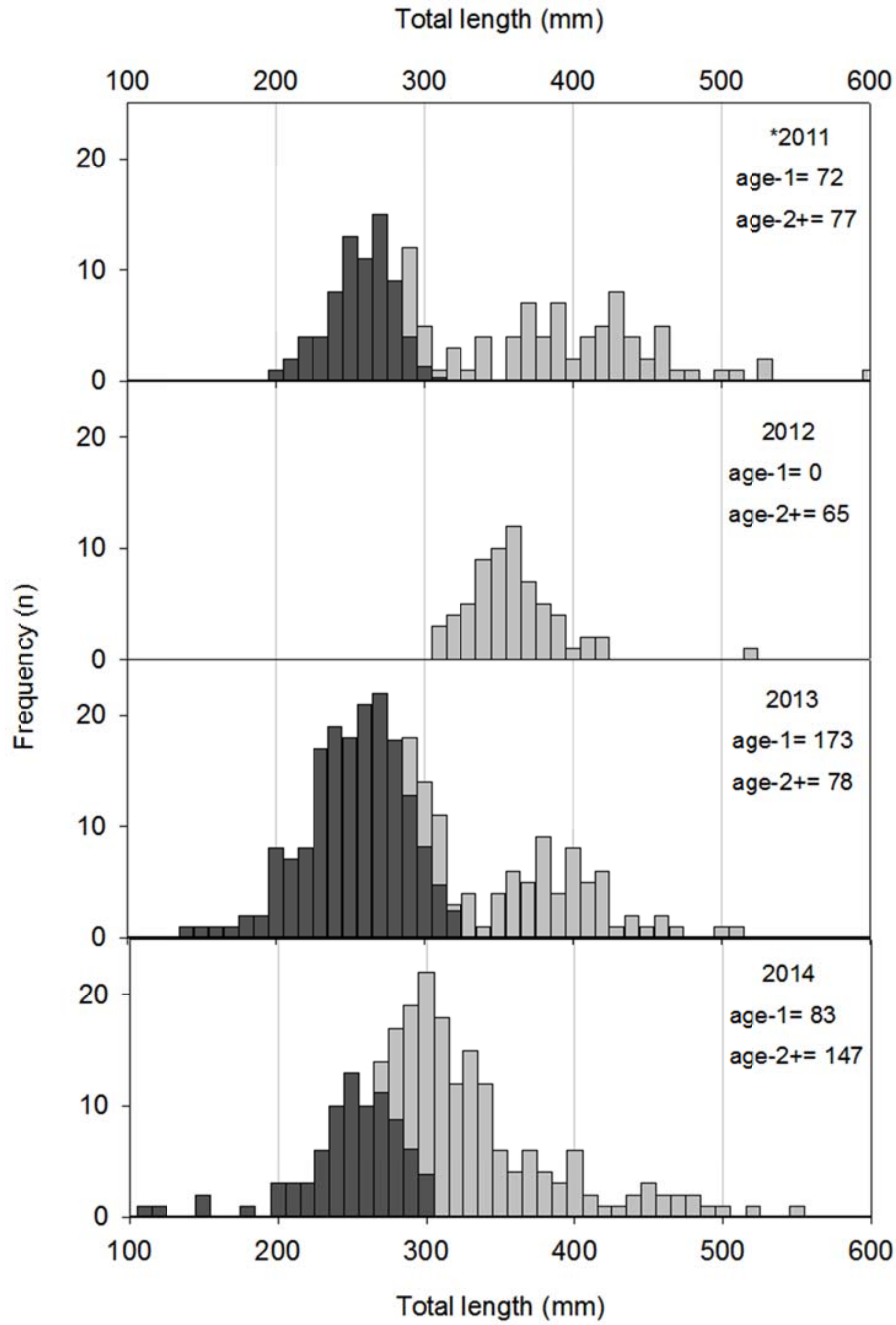

FIGURE 7. Length-frequency histogram (10-mm length groups) of Florida Bass in the SRE. Age-1 (dark grey) and age-2+ (light grey) were separated using the Bhattacharya method and known age-length relationships for Florida Bass in Florida (see text).

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APPENDIX A. Details on the 32 sampling events between 2011 and 2014 for this Florida Bass CMR study. Sampling events include electrofishing and citizen science angling sampling.

Event	Start date	End date	Interval adjustment (1-month)	Total marks	Recapture (Electro-fishing)	Recapture (Angling)	Effort: Electro-fishing days	Effort: angler days	Average marsh depth (cm)	Hydrological classification
1	11 Nov 10	19 Nov 10	START	33	-	-	5	0	START	START
2	16 Dec 10	18 Dec 10	1	31	0	NA	3	0	37.7	WET
3	22 Jan 11	23 Jan 11	1	23	1	NA	2	0	28.9	DRYING
4	10 Feb 11	13 Feb 11	0.7	49	2	NA	5	0	24.8	DRYING
5	4 Mar 11	28 Mar 11	1.4	185	8	NA	7	0	6.3	DRY
6	15 Apr 11	22 Apr 11	0.8	97	6	NA	4	0	-7.5	DRY
7	10 May11	15 May 11	0.7	28	2	NA	4	0	-13	DRY
8	5 Jun 11	6 Jun 11	0.8	20	0	NA	2	0	-7	DRY*
9	6 Dec 11	8 Dec 11	6.2	13	1	0	3	2	31.4	WET
10	19 Feb 12	25 Feb 12	2.6	32	2	0	4	4	22.3	DRYING*
11	18 Mar 12	19 Mar 12	0.8	41	4	0	2	6	19.1	DRYING
12	13 Apr 12	15 Apr 12	0.9	28	0	0	5	2	8.4	DRY
13	26 Jun 12	26 Jun 12	2.4	8	0	0	1	0	27.2	REFLOOD*
14	26 Jul 12	27 Jul 12	1.0	0	0	0	2	2	49.9	WET
15	23 Aug 12	23 Aug 12	0.9	2	0	0	1	2	48.3	WET
16	25 Sep 12	29 Sep 12	1.2	1	0	0	2	0	55.4	WET
17	11 Nov 12	12 Nov 12	1.5	16	2	0	2	1	62.4	WET
18	9 Dec 12	10 Dec 12	0.9	36	1	1	2	2	50.9	WET
19	21 Jan 13	26 Jan 13	1.6	61	2	1	2	1	43.3	WET
20	23 Feb 13	1 Mar 13	1.1	145	5	4	4	8	30	DRYING
21	15 Mar 13	17 Mar 13	0.5	133	7	5	3	15	24.7	DRYING
22	16 Apr 13	21 Apr 13	1.2	193	7	14	5	23	14.9	DRYING**

23	28 May 13	7 Jun 13	1.6	8	0	2	3	2	28.8	REFLOOD
24	26 Jun 13	1 Jul 13	0.8	9	0	0	2	3	46.3	WET
25	23 Jul 13	29 Jul 13	0.9	2	0	0	2	2	55.3	WET
26	17 Nov 13	18 Nov 13	3.7	46	4	2	2	8	52.1	WET
27	15 Dec 13	20 Dec 13	1.1	67	5	1	3	4	48.2	WET
28	21 Jan 14	23 Jan 14	1.1	91	6	1	3	6	41.1	WET
29	22 Feb 14	4 Mar 14	1.3	123	11	5	4	19	33	WET
30	22 Mar 14	31 Mar 14	0.9	135	23	1	3	13	23	DRYING
31	27 Apr 14	5 May 14	1.2	75	7	7	5	22	10	DRY
32	31 May14	2 Jun 14	0.9	18	3	2	2	4	-4.6	DRY

* Hydrological transition occurred between missed sampling months. Highest or lower water levels were used for hydrological classification.
** Marshes did not fall below 10cm, indicates the lowest water level of year
NA= time before CAST began
Interval adjustment= time between samples/30, all intervals were scaled to 1-month

APPENDIX B. CAST data packets for collecting recapture data. A) handheld tag scanner, B) data collection sheets, C) zone map of study region, D) tape measure, extra batteries, pencils, etc., E) Test PIT-tags

APPENDIX C. *m*-array summary of capture-recapture histories for each sampling occasion.

Occ	. R(i)	j = 2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	***22***	23	24	25	26	27	28	29	30	31	32	Total
1	33	0	0	1	2	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	6
2	31		1	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
3	24			1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3
4	51				2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	4
5	190					3	2	0	0	1	2	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	1	0	1	1	0	0	15
6	103						0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
7	30							0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
8	20								0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
9	14									0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	34										1	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	5
11	45											0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2
12	28												0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
13	8													0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2
14	0														0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	2															0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2
16	1																0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	18																	1	0	1	0	2	0	0	0	1	0	0	0	0	0	0	5
18	35																		2	1	1	0	0	0	0	1	0	0	1	0	0	0	6
19	64																			4	1	3	0	0	0	1	0	1	0	2	1	0	13
20	145																				3	3	0	0	0	0	1	1	3	1	1	1	14
21	144																					1	0	0	0	1	1	1	3	3	1	0	11
22	211																						1	0	0	1	1	0	0	1	1	0	5
23	10																							0	0	0	0	0	0	0	1	0	1
24	9																								0	0	1	1	1	0	0	0	3
25	2																									0	0	0	0	0	0	0	0
26	52																										1	1	0	2	0	1	5
27	61																											2	3	4	0	0	9
28	98																												4	3	2	0	9
29	137																													7	3	2	12
30	159																														3	0	3
31	87																															1	1