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INTRODUCTION AND BACKGROUND

The Water Resources Development Act (WRDA) of 2000 authorized the Comprehensive Everglades Restoration Plan (CERP) as a framework for structural and operational changes to the Central and Southern Florida Project that are needed to restore the south Florida ecosystem. Provisions within WRDA 2000 authorized the establishment of an adaptive assessment and monitoring program; the REstoration, COordination and VERification (RECOVER) team developed a Monitoring and Assessment Plan (MAP) as the primary tool to assess system-wide performance of CERP (RECOVER 2004). The MAP describes monitoring efforts and enhancement of scientific information and technology needed to measure responses of the south Florida ecosystem.

The MAP also imparts system-wide performance measures, representative of south Florida's natural systems, which will be evaluated to help determine responses to CERP. The performance measures address responses of the south Florida ecosystem that CERP is explicitly designed to improve, correct, or otherwise directly affect. A separate Performance Measure Documentation Report prepared by RECOVER (RECOVER 2007) provides scientific, technical, and legal bases for performance measures. The four broad objectives of the MAP are as follows:

1. Establish pre-CERP reference state including variability for each of the performance measures
2. Determine status and trends in performance measures
3. Detect unexpected responses of ecosystem to changes in stressors resulting from CERP activities
4. Support scientific investigations designed to increase ecosystem understanding, cause-and-effect, and interpret unanticipated results

Because not everything within an ecosystem can be monitored, it is important to select ecological indicators that 1) are representative of the system, 2) integrate system responses, 3) show clear responses to system change, 4) can be effectively and efficiently monitored, and 5) are easily communicated (Schiller et al. 2001, Doren 2006, Doren et al. 2009). Crocodilians (alligators and crocodiles) are one of the indicators that meet these criteria within Everglades ecosystems (Mazzotti et al. 2009).

Crocodilians are present throughout virtually all Everglades freshwater wetlands and estuarine areas. These areas include the following RECOVER & Science Coordination Group (SCG) regional modules: Greater Everglades, Florida Bay and Southern Estuaries, Big Cypress, Lake Okeechobee, and the Kissimmee River Basin. Crocodilians are included as attributes in the following conceptual ecological models: Total System, Everglades Ridge and Slough, Southern Marl Prairies (Rocky Glades), Everglades Mangrove Estuaries, and Biscayne Bay.

Crocodilians integrate biological impacts of hydrological operations, affecting them at all life stages (Mazzotti and Brandt 1994, Mazzotti 1999, Rice et al. 2005, Mazzotti et al. 2007a), through three key aspects of Everglades ecology:

1. Food webs: Top predators such as crocodilians are dependent on prey density, especially aquatic and semi-aquatic organisms (Barr 1997). Crocodilians are critical in the food web as top predators, influencing abundance and composition of prey (Mazzotti and Brandt 1994).
2. Diversity and productivity: Drier (nests) and wetter (trails and holes) conditions created by ecosystem engineers like alligators provide habitat for plants and animals that otherwise would not be able to survive. This variation in hydrologic conditions created by alligators increases diversity and productivity of Everglades marshes (Kushlan and Kushlan 1980, Campbell and Mazzotti 2004, Palmer and Mazzotti 2004).
3. Freshwater flow: Distribution and abundance of crocodilians in estuaries are directly dependent on timing, amount, and location of freshwater flow (Dunson and Mazzotti 1989, Mazzotti and Dunson 1989). The American crocodile, a federally threatened flagship species, represents the importance of freshwater inflow to estuarine health and productivity (Mazzotti et al. 2007a).

Responses of crocodilians are directly related to suitability of environmental conditions and hydrologic change (Mazzotti and Brandt 1994, Rice et al. 2005, Mazzotti et al. 2007a). Restoration success or failure can be evaluated by comparing recent and future trends and status of crocodilian populations with historical or reference population data and model predictions, as stated in the CERP hypotheses related to alligators and crocodiles (RECOVER 2004, sections 3.1.2.5 and 3.1.2.6).

The alligator performance measures and components of the system-wide crocodilian indicator are relative abundance (reported as an encounter rate), body condition, and occupancy rates of alligator holes. The crocodile performance measures and components for the system-wide crocodilian indicator are juvenile growth and hatchling survival. We hypothesize that these parameters are correlated with the following hydrologic conditions: depth, duration, and timing and water quality (Rice et al. 2006, Mazzotti et al. 2009); and salinity in estuarine habitats (Dunson and Mazzotti 1989; Mazzotti and Dunson 1989).

The MAP poses three hypotheses for alligators:

1. Restoration of hydropatterns (depth, duration, distribution, and flow) in Southern Marl Prairies/Rocky Glades will expand the distribution and abundance of reproducing alligators and active alligator holes and will restore the keystone role of alligator holes as refugia for aquatic fauna.
2. Restoration of estuarine salinity regimes will expand the distribution and abundance of reproducing alligators into oligohaline portions of estuaries.
3. Restoration of hydropatterns in ridge and slough landscape will sustain populations of reproducing alligators.

The MAP poses one hypothesis for crocodiles:

1. Restoration of freshwater flows to estuaries and salinity regimes will increase growth and survival of crocodiles.

Objectives and Organization

Objectives for the alligator and crocodile MAP project are:

1. Design and develop monitoring programs for both species
2. Monitor changes in alligator and crocodile performance measures over different temporal and spatial scales

The report is organized into two main sections: American Alligator and American Crocodile. Each species section is divided into three sections: "Design and Development," which describes monitoring methods used for each of the performance measures, "Application," which describes how the methods were applied to collect monitoring data and to address the four primary objectives of the MAP, and "Summary and Recommendations," which provide a brief summary of the results and suggest future areas of investigation.

For alligators, the sections Design and Development and Application are further divided into subsections for each of the alligator performance measures:

1. Relative abundance (encounter rate)
2. Body condition (Fulton's K)
3. Alligator hole occupancy (proportion occupied)

The crocodile section of this report focuses on the two crocodile performance measures:

1. Growth (cm/day)
2. Juvenile survival (proportion of hatchlings that survive for six months)

This report summarizes and presents data collected on MAP alligator and crocodile project tasks from 2004-2009 and is divided into two volumes. Volume I is the Final Summary Report and Volume II contains the appendices.

AMERICAN ALLIGATOR

Design and Development

Distribution and Relative Abundance

Prior to 1998 there were limited systematically collected data on alligators within Everglades marshes. Previous alligator surveys were conducted within limited marsh areas in Everglades National Park (ENP) and in canals as part of the Florida Fish and Wildlife Conservation Commission's assessment of areas to support a potential public alligator hunt (Hines and Abercrombie 1987, Woodward et al. 1987, Wiley and Jennings 1990).

In 1998, the Everglades Protection District (EPD) funded a two-year study to conduct an ecological characterization of alligator holes and to initiate development of a network of alligator

survey routes that could be used to monitor the effects of restoration on alligators throughout Everglades ecosystems (Mazzotti et al. 1999). Four marsh, five canal, and two estuarine routes were established during that effort and were surveyed quarterly following common protocols used in alligator surveys statewide (Woodward and Moore 1990). Additional funding was provided through the National Park Service Critical Ecosystems Study Initiative (CESI); data and survey routes developed during those efforts provided the starting point for the current monitoring program. Since the time of those initial surveys, protocols and areas surveyed have been refined to fulfill requirements of the system-wide monitoring program and to address CERP and RECOVER MAP hypotheses related to crocodilians.

Our methodology (see Volume II. Appendix 1) has evolved over the years and now includes nine marsh, one estuary, and nine canal routes. Marsh and estuary routes are surveyed twice in the spring and twice in the fall of each year (four surveys per year). Because they were developed at different times, routes were not initially all the same length, but we have standardized them so now each marsh and estuary route consists of two 10-km transects with 1-km separation. With this current design we have the power to detect a 5% annual trend in relative abundance (as measured by encounter rate) over five years based on power analysis done with data collected in LOX from 1998-2002 (Rice and Mazzotti 2006). Before this reporting period, we presented trend information based on route data (instead of transect data) because we did not have at least five years of transect data in all areas. In this report we present results for trend analysis based both on routes and transects.

Canal routes each consist of one 10-km transect (except for the L-39 which has two transects to make it comparable with data collected between 1971 and 1987). Currently canals are surveyed only in the spring (two surveys) to assess densities in the dry season. These spring surveys provide supporting information for marsh surveys and a baseline for potential future studies examining effects of canal removal on alligators. Because of high variability of canal counts and low alligator densities in the fall, there is low power to detect trends using the sampling design that is used in the marsh. Since system-wide canal densities are not a performance measure and it is not cost-efficient to conduct the necessary number of surveys to efficiently detect trends, we eliminated the fall surveys (Rice and Mazzotti 2006).

Although our survey protocols have been standardized to minimize variation in counts, we recognized that there were some specific areas of uncertainty that could affect detectability of alligators and hence our ability to compare survey results across years and among areas. Thus, we conducted two studies investigating detectibility of animals under different conditions. The first study evaluated environmental factors that affect whether an alligator is visible to be counted (Bugbee 2008) and the second evaluated the effect of habitat type and structure on alligator detection probabilities (Carter 2010).

Bugbee (2008) confirmed that many of the standards currently applied in our survey protocols are appropriate. Conclusions included that the best time for conducting surveys is in low wind, in half- or full-moon phases, and on clear, cloud-free nights with relatively high air and water temperatures and relatively low water depths (Bugbee 2008). Based on the results from this study, we will examine effects of additional covariates such as moonlight, moon phase, and time after sunset in our future analyses.

Carter (2010) found that visual obstruction was the variable with the greatest effect on detection rates, followed by distance from transect, vegetation height, water depth, and seat height. Detectability functions varied slightly among the different habitats by variables included in the optimum model. These functions are most applicable if there is a need to convert encounter rates to population estimates. However, Carter (2010) cautioned against using detectability functions broadly without further validation. Based on results of this study we will standardize airboat seat height as much as possible and we will investigate using data from the RECOVER vegetation map as covariates in our future analyses.

Multiple regression analysis has been used to determine trends in abundance for data from 1998-2005 (Rice and Mazzotti 2006), 1999-2008 (Rice et al. 2009), and 2004-2009 (this report). Trends in alligators per km are examined for four size categories: juvenile (0.50 to <1.25 m), sub-adult (1.25 to <1.75 m), adult (≥1.75 m), and total non-hatchling population (≥0.50 m). Our current model regresses log-transformed counts of alligators per km in each size class (dependant variable) on year, season (fall and spring), average water depth (AWD), and average water temperature (AWT) using the following:

Route Data:
Marsh: log((n+1)/route length) = year + season + AWD + AWT
Estuary: log((n+1)/route length) = year + season + AWT

Transect Data:
Marsh: log((n+1)/transect length) = year + season + AWD + AWT
Estuary: log((n+1)/transect length) = year + season + AWT

where n is the count of alligators per km and AWD and AWT are the average of the values measured on the survey.

Now that we have a longer period of record (≥8 years in several areas) we are exploring other methods of trend analysis that will allow us to identify when trends occur, rather than simply if there was a trend in a set time period. In addition, we conducted a preliminary analysis using a two-stage hierarchical model comprising abundance and detection probability to examine recent abundance trends (Fujisaki, *In Review*). Using such a modeling method allows us to improve inferences made from alligator nightlight surveys.

Body Condition

Fifteen alligators ≥ 1.25 m are captured twice a year (spring and fall) in marshes and estuaries for calculation of body condition (see Volume II. Appendix 1). Earlier capture efforts targeted animals 1.0 m or larger. However, because of variability in body condition of smaller animals, and to allow a direct comparison of body condition trends within the same size classes we use for abundance, we increased the minimum size to 1.25 m.

Body condition is calculated as Fulton's K using either of the following equations: $K= (Wt/HL^3)*10^4$ or $K= (Wt/SVL^3)*10^5$, where Wt is the weight of the animal in kg, HL is head

length in cm and SVL is snout-vent length in cm. In previous reports we calculated K using HL following recommendations of Zweig (2003). In the future, we will calculate K using SVL instead of HL as it will allow us to compare body condition of crocodilians in the Everglades to crocodilians sampled elsewhere around the world where SVL (but not HL) is routinely measured (Webb and Messel 1978, Verdade 2001, Santos et al. 1994, Dalrymple 1996, Seijas 1998, Fujisaki et al. 2009). The use of SVL rather than HL should not affect the estimates of trends or the estimates of covariates (Zweig 2003). In this report we present results using both equations.

Rice and Mazzotti (2006) conducted a preliminary power analysis on body condition data collected through 2005 and determined that with a sample of at least 15 animals, we are able to detect a 5% per season (10% per year) decline in body condition over both three- and five-year periods. Because not all areas being sampled at that time had adequate sample sizes, we reran the power analysis using 2004-2009 data. Results of this power analysis showed that even in the most variable of the areas (standard deviation of 1.69) we should be able to detect trends when average condition is high (11.40) or low (9.56) with a power of 0.99 and an alpha of 0.05 in three years.

Multiple regression analysis has been used to determine trends in body condition for data for all areas from 1999-2005 (Rice and Mazzotti 2006), 1999-2008 (Rice et al. 2009), and 2004-2009 (this report). In this report we regress body condition of individual alligators (dependent variables) on year, with size class, sex, season, and average water depth 10-49 days prior to capture (from Everglades Depth Estimation Network, EDEN) as covariates using the following two models:

Marsh: K = year + size class + sex + season + EDEN10-49
Estuary: K = year + size class + sex + season

We used average water depth 10-49 days prior to capture because this was the timeframe identified by Fujisaki et al. (2009) as having the greatest effect on body condition of animals in Shark Slough.

Alligator Hole Occupancy

Occupancy of alligator holes is determined by flying transects in three areas (Northeast Shark Slough, Rocky Glades, and Shark Slough) using modified Standard Reconnaissance Flights (SRF) protocols (Volume II. Appendix 1). These areas were selected because they are areas where occupancy of alligator holes is expected to change with restoration and because alligator holes were identified there during mapping efforts (Rice and Mazzotti 2006, 2007, 2008; Rice et al. 2009).

Flights are conducted in the morning during the spring (May-June). Holes are considered occupied if there is an alligator in the hole or located a short distance away (e.g., in a trail or basking next to the hole). Occupancy rates are calculated as the percentage of observed holes that have alligators. We are currently working to incorporate detection probabilities and environmental factors into trend analysis for alligator hole occupancy.

Application

In the following section we report on data collected on alligator relative abundance, body condition, and hole occupancy from 2004-2009 in the context of the major objectives of the MAP.

Distribution and Relative Abundance

We have 6 to 12 years of alligator abundance data within marshes and estuaries for defining pre-CERP baseline conditions. Targets for relative abundance of non-hatchlings/km were developed based on the distribution of encounter rates from all night surveys conducted in the Everglades from 1999-2006 (individual replicates of 10 areas over 4 to 8 years; Rice and Mazzotti 2006). This distribution was divided into quartiles: first and second quartiles (density $\leq$ 1.47 animals/km), third quartile (1.47 < density $\leq$ 2.70 animals/km), and fourth quartile (density > 2.70 animals/km). Quartiles were assigned colors based on a stoplight scheme to illustrate relationship to restoration targets with the first and second quartiles red, the third quartile yellow, and the fourth quartile green (Mazzotti et al. 2009).

During the period from fall 2004 to spring 2009, relative abundance of non-hatchling alligators in marshes (measured along routes) ranged from a low of 0.1 non-hatchlings/km in Fall 2004 in Big Cypress National Preserve (BICY) to a high of 9.54 non-hatchlings/km in Spring 2007 in A.R.M. Loxahatchee National Wildlife Refuge (LOX). Seventy-two percent of surveys fell within the first and second quartiles (red) and 1% percent fell within the fourth quartile (green). All fourth quartile surveys were from LOX (Figures 1 to 10).

Trends in relative abundance were detected in three areas using route data. WCA2A marsh had negative trends in juvenile, adult, and non-hatchlings/km. WCA3A-N41 marsh and WCA3A-TW marsh had a negative trend in juveniles/km. Season effects were detected in two areas. In BICY, numbers of juvenile, adult, and non-hatchlings/km were higher in spring. In WCA3A-HD marsh, numbers of adult, and non-hatchlings/km were higher in spring. We found no effects of water depth on any size classes. Water temperature effects were detected in four areas. Negative effects of water temperature were detected for number of juveniles/km in ENP-FC, for number of adults/km in ENP-SS and ENP-EST, and for number of non-hatchlings/km in ENP-SS. A positive effect of water temperature was detected for number of non-hatchlings/km in WCA3A-HD marsh and ENP-EST (Table 1).

Trends in relative abundance were detected in five areas with transect data. WCA3A-N41 marsh, WCA3B marsh, ENP-EST, and WCA2A marsh all had negative trends in number of juveniles/km, and WCA2A marsh also had negative trend in adults/km. In WCA3A-HD marsh positive trends were detected in number of juveniles and non-hatchlings/km. Season effects were detected in three areas with transect data. In BICY, numbers of juveniles, adults, and non-hatchlings/km were higher in spring. In WCA2A marsh, numbers of non-hatchlings/km were higher in fall. In WCA3A-HD spring had higher numbers of adult/km as did spring in WCA3A-N41 for number of adults and non-hatchlings/km. Water depth effects were detected in four areas. In ENP-FC, there was a negative effect of water depth on numbers of sub-adults and non-hatchlings/km. In WCA2A marsh and WCA3A-N41, water depth had a negative effect on

number of non-hatchlings/km, and in WCA3A-HD it had a positive effect on number of adults/km. Water temperature effects were detected in four areas: a negative effect on number of sub-adults/km in BICY, a negative effect on number of juveniles/km in ENP-FC and ENP-SS, and a positive effect on number of adults and non-hatchlings/km in WCA3A-HD (Table 2).

Body Condition

We have 6 to 11 years of body condition data to define pre-CERP baseline conditions. Targets for body condition were developed based on the distribution of body condition (Fulton's K) of all alligators captured and assessed in the Everglades from 1999-2006 (n=1755). This distribution was divided into quartiles: first quartile (Fulton's $K \leq 9.31$), second and third quartiles ($9.31 <$ Fulton's $K \leq 11.27$), and fourth quartile (Fulton's $K > 11.27$) (Rice and Mazzotti 2006). Quartiles were assigned colors based on a stoplight scheme to illustrate relationship to restoration targets with the first quartile red, second and third quartiles yellow, and the fourth quartile green (Mazzotti et al. 2009).

During the period from fall 2004 to spring 2009, average body condition in marshes ranged from a low of 8.79 in fall 2008 in WCA-3B to a high of 11.51 in spring 2009 in WCA-3B. Ninety percent of mean body condition values fell within the second and third quartiles (yellow) and 3% percent fell within the fourth quartile (green) (Figures 11 to 20).

WCA3A TW marsh was the only area that showed a negative trend in body condition from 2004-2009 when Fulton's K was calculated with head length. In six of 10 areas there was an effect of size on body condition, with larger animals having higher body condition values than smaller animals. We also found an effect of sex in six areas with females having higher body condition values than males (Table 3).

When Fulton's K was calculated using snout-vent length, ENP-FC was the only area showing a positive trend in body condition and WCA3A-N41 was the only area showing a negative trend. There was an effect of size on body condition in five areas, with larger animals having higher body condition values than smaller animals. There was an effect of sex in three areas, with females having higher body condition scores than males (Table 4).

Alligator Hole Occupancy

We have three years of alligator hole occupancy data to define pre-CERP baseline conditions for Northeast Shark Slough, the Rocky Glades, and Shark Slough. As this component was assessed for the first time in 2005, we used additional data sources to develop targets: (1) data from 2005 in ENP; (2) data from a study of alligator holes in WCA 3 by Campbell and Mazzotti (2004); and (3) historical information from Craighead (1968). Values were set as low occupancy ($\leq 30\%$; stoplight = red), medium occupancy ($30\% <$ occupancy $\leq 70\%$; yellow), and high occupancy ($> 70\%$; green) (Rice and Mazzotti 2006, Mazzotti et al. 2009).

Occupancy rates were 56%, 39%, and 34% in Northeastern Shark Slough in 2007, 2008, and 2009, respectively. In the Rocky Glades occupancy was 44%, 86%, and 17%, and in Shark Slough it was 45%, 38%, and 50% over the same three-year time period. The only "low" occupancy value was 17% (Rocky Glades in 2009) and the only "high" value was 86% (Rocky Glades in 2008); the remainder of the occupancy values fell in the "medium" category. The

variability in Rocky Glades from 2008 to 2009 could be due to a wildfire that burnt the majority of vegetation in the spring of 2009. For all areas combined, hole occupancy averaged 48%, 54%, and 33% for 2007, 2008, and 2009, respectively.

Summary and Recommendations

We now have a minimum of six years of data on alligator relative abundance and body condition and three years of data on alligator hole occupancy, which can be used to define pre-CERP reference conditions for these performance measures. We are beginning to document pre-CERP variability across years, among areas, and in relation to environmental factors. We have also been able to document current status and relationship to restoration targets and identify trends toward or away from those targets.

In over 70% of our abundance surveys, values for number of non-hatchling alligators/km were well below restoration targets and in no case showed improvement during this reporting period (2004-2009). Continuing negative trends in number of juveniles/km in areas that experience dry-downs almost every year (WCA2A and WCA3A-TW) illustrate the need to restore multi-year hydroperiods to these areas. It is expected that areas with repeated declines in numbers of juveniles will eventually show declines in numbers of adults as there will be fewer animals moving into that size class. Currently, we are conducting linear trend analysis on set time increments (five years). However, in the next five years we will refine our trend analysis by exploring other methods that will allow us to identify when trends occur, rather than simply identifying whether a trend was present in a set time period. In addition, in future analyses we will explicitly address factors that affect alligator detectability. These advances in our analytical approach will strengthen our ability to make inferences about patterns of alligator abundance and the effects of restoration. We will also begin to link our survey information with data from other MAP projects such as vegetation mapping and aquatic sampling, and continue to explore the applicability of EDEN for understanding hydrological effects on alligators.

The majority (90%) of our values for body condition fell below restoration targets and 7% fell well below restoration targets. There was only one positive trend in body condition (ENP FC marsh). The other areas remained stable or declined (WCA3A-N41 marsh). This is not surprising since restoration actions have not yet been implemented that greatly affect the Greater Everglades module. In the next five years we will refine our body condition analysis by exploring the use of metrics other than average body condition. For example, the number of animals per capture effort that fall in the lowest quartile may be more informative than an average body condition value.

The majority of our values for alligator hole occupancy fell in the medium occupancy category. We did not conduct trend analysis because we only have three years of data. However, in the next five years we will continue to collect pre-CERP baseline data and further explore the use of EDEN data for explaining observed patterns in alligator hole occupancy.

Basic biology of alligators in the Everglades and methods to monitor their responses to hydrologic management are relatively well understood. Continued work is needed to improve reliability of monitoring techniques in all habitats, to calibrate existing models and develop new

ones, and to better understand implications of canals and levees for improved assessments of de-compartmentalization. Existing monitoring programs and projects need to continue to develop time-series information about these animals that can be used in impact assessment. Current monitoring techniques for relative density of alligators use airboats in freshwater habitats. While these techniques are excellent for much of the Everglades, there are limitations. In particular, neither technique can be used effectively in the Rocky Glades during the dry season, in cypress swamps, or in any wilderness area. Use of helicopters and other techniques for sampling in these landscapes need to be developed, especially for occupancy rates of alligator holes. Techniques to survey alligator nests in marshes of Everglades National Park have been established but may not be suitable for use in other parts of the Greater Everglades ecosystems. This is unfortunate because access to these areas is critical for research and monitoring of alligators and crocodiles, and is invaluable for assessment and evaluation.

Data presented here support the hypotheses for the effects of diminished freshwater flow on body condition and for abundance of alligators in estuaries; however, they do not prove direct relationships among the variables. Additional data are needed to evaluate condition, relative density, movements, and habitat use of alligators and crocodiles in relation to salinity gradients and food supply. Recent advances in GPS/VHF telemetry and the ability to describe temporal and spatial changes in salinity may provide an opportunity to strengthen linkages between alligator performance measures and salinity in the Everglades.

Although not included in conceptual models, exotic plant and animal species may impact populations of crocodilians. Exotic plants may affect alligators by altering native vegetation and hydrological characteristics of wetland areas. For example, melaleuca can replace open grassy wetlands with forest, and may raise soil levels, thus reducing the area of inundation and water flow. Exotic plants may affect crocodiles by limiting access to nesting substrate. Largely restricted to manmade bodies of water, the nonnative spectacled caiman (*Caiman crocodilus*) has not yet posed any threat to alligators or crocodiles. Prior to the establishment of exotic pythons, alligators were the only large, abundant, and widespread aquatic predators in Greater Everglades ecosystems. However, Burmese pythons (*Python molurus bivittatus*) are now breeding in Everglades National Park and adjacent areas and there have been five reported encounters between pythons and alligators. The results of these encounters have been mixed (Snow et al. 2006), and the long-term effect of interaction between these two top predators is unknown. Research is needed to determine what the long-term relationship will be.

To date we have focused successfully on the basic MAP objectives of determining pre-CERP baseline conditions, detecting trends, and relating performance measures to hydrological parameters. With additional spatial sampling we should also be able to relate alligator performance measures to those for wading birds, fish, and periphyton.

AMERICAN CROCODILE

Design and Development

Crocodile surveys have been conducted in south Florida since the 1970s (Kushlan and Mazzotti 1989, Moler 1992, Mazzotti 1999, Mazzotti et al. 2007a) for the purposes of assessing crocodile and crocodile nesting distribution and habitat use. Over that time survey protocols and purposes have evolved to include methods that explicitly address the crocodile growth and survival performance measures outlined in the MAP.

Juvenile Crocodile Growth and Survival

Spotlight surveys were performed quarterly to estimate juvenile growth and survival from Key Largo and Biscayne Bay west along most of the accessible coastal and estuarine shoreline to Cape Sable in ENP (Volume II. Appendix 1). In an effort to streamline effort required to detect trends through spotlight surveys, we compared results based on four surveys per year to those based on three surveys per year (without third quarter data), and found the same trends with reduced survey frequency. Therefore, in the future we will reduce survey frequency to three times annually. In addition, we plan to expand our monitoring parameters to include growth and survival for all size classes, which will increase our sample size and ability to quantitatively determine changes in growth and survival for all crocodiles.

Absolute growth and minimum survival over the first six months are the indices we use to measure relative growth and survival. Growth rates are based on changes in total length (TL) for crocodiles marked as hatchlings and recaptured as juveniles (less than 1.5 m TL); we calculate rates separately for all three nesting areas (ENP, Crocodile Lake National Wildlife Refuge [CLNWR] and Turkey Point). Minimum survival is defined as proportion of hatchling crocodiles known to have survived for at least six months and also is calculated separately for the three nesting areas. We recognize that minimum survival does not differentiate among death, dispersal, and wariness and hence is an underestimate of true survival. We are currently using linear regression models to examine trends based on data from two reference sites, ENP-Buttonwood Canal (BWC) and Key Largo-CLNWR. Data from these areas have been examined for trends in the periods 1998-2004 (Mazzotti et al. 2009), and 2004-2008 (this report). Trends in additional areas, such as Cape Sable, northeastern Florida Bay and Biscayne Bay, will be examined as sufficient data become available. In the near future, we will perform data analyses in Program MARK to incorporate variability in detection by size class and variability in survival by recapture effort, addressing limitations with current methods.

Application

Juvenile Crocodile Growth and Survival

We have over 25 years of growth and survival data that can be used to determine pre-CERP baseline conditions. Targets for growth and survival, were developed based on the distribution of the growth and survival values from between 1978 and 2006 (Mazzotti et al. 2007a, Mazzotti et al. 2009). This distribution was divided into quartiles for growth: first quartile (growth 0 – 0.068

cm/day), second and third quartiles (0.068 < growth ≤ 0.15 cm/day), fourth quartile (growth > 0.15 cm/day). It was also divided into quartiles for survival: first quartile (survival 0 – 65%), second and third quartiles (65% < survival ≤ 85%), fourth quartile (survival > 85%). Quartiles were assigned colors based on a stoplight scheme to illustrate relationship to restoration targets with the first quartile red, second and third quartiles yellow, and the fourth quartile green (Mazzotti et al. 2009).

During the period from fall 2004 to spring 2009, juvenile growth ranged from 0.01 - 0.17 cm/day at CLNWR with all yearly average values falling within the first quartile (red). At BWC growth ranged from 0.09 - 0.14 cm/day with yearly average values all falling within the second and third quartiles (yellow, Figure 21). No trend in annual growth was detected at either BWC (P=0.3618, R^2 =0.4073) or CLNWR (P= 0.8871, R^2 =0.0311).

During this same period survival ranged from 0% - 89% at CLNWR and from 73% – 88% at BWC (Figure 22). No trends were observed in annual survival at either BWC (P=0.3346, R^2 =0.1856) or CLNWR (P= 0.3129, R^2 =0.2011).

Summary and Recommendations

We now have over 30 years of growth and survival data that can be used to define pre-CERP conditions. We are documenting the pre-CERP variability across years, among areas, and in relation to environmental factors. We have been able to calculate current status and relationship to restoration targets and identified trends toward, neutral, or away from those targets.

During the period 2004-2009 we found no trends in either juvenile growth or juvenile survival of crocodiles. While components for crocodiles are below restoration targets (Figures 1-2), they appear stable at this time. This is not unexpected because significant restoration efforts that might affect these areas have not yet been implemented and are expected to improve with restoration of timing and amount of freshwater flow to estuaries. Our ability to monitor growth and survival will improve, given that more than 50% of crocodiles captured annually are recaptures (Rice and Mazzotti, 2006); this high rate of recapture is without precedent in a crocodilian study. Once we move toward examining growth across all size classes and analyzing survival data in program MARK (and incorporating variability in detection by size class and variability in survival by recapture effort), we will be able to examine data from additional areas such as Cape Sable, northeastern Florida Bay and Biscayne Bay, areas possibly affected by restoration efforts.

Crocodile nesting (numbers of nests/year) is not currently a performance measure. However, we routinely collect these data as part of determining growth and survival. Mazzotti et al. (2007b) reported a fivefold increase in crocodile nesting in ENP from 1978 to 2004; while a slight increase occurred in the core nesting area of northeastern Florida Bay, most of this increase occurred on artificial substrates in new Cape Sable/Flamingo nesting area. Mazzotti et al. (2007a) hypothesized that plugging canals in the Cape Sable/Flamingo area in the 1980s and 1990s to reduce saltwater intrusion and retain fresh water provided more suitable habitat for nesting for the few crocodiles present in the area and for growth and survival of hatchling crocodiles. The rapid increase in numbers of crocodiles nesting in the Cape Sable/Flamingo area

since 2000 may be the result of offspring of the original nesting crocodiles entering the breeding population. These recent increases in crocodile nesting patterns (Figure 23) showcase the importance of long-term datasets for evaluating population trends and they demonstrate a species' response to ecosystem restoration.

Crocodile relative abundance and body condition also are not currently being used as system-wide performance measures. However, we collect the necessary information to calculate these attributes when we survey for growth and survival; we perform systematic surveys for abundance while recapturing individual crocodiles. Relative abundance and body condition could be used for crocodiles as they are for alligators, to determine ecological responses at a shorter temporal scale (i.e., quicker) than growth and survival.

Although the data presented here support the hypotheses for the effects of diminished freshwater flow on growth, survival, and abundance of crocodiles, they do not prove a direct relationship. Additional data are needed to evaluate growth, survival, movements, and habitat use of crocodiles in relation to salinity gradients and food supply. Recent advances in GPS/VHF telemetry and the ability to describe temporal and spatial changes in salinity may provide an opportunity to strengthen the linkage between crocodiles and salinity in the Everglades.

Potential effects of sea-level rise (SLR) on crocodiles have not been evaluated, which concerns us because of the vulnerability of natural nest sites to increases in water levels (Mazzotti 1999). A long-time ''Glades'' explorer, Glenn Simmons, observed that creek nest sites have already been adversely affected by SLR (Simmons and Ogden 1998). Thus, urgent research priorities include identifying and mapping all potential crocodile-nesting habitat in south Florida and developing a forecasting model to evaluate spatial and temporal patterns of nesting habitat loss in response to SLR and ecosystem restoration.

LITERATURE CITED

Barr, B. 1997. Food habits of the American alligator, *Alligator mississippiensis*, in the southern Everglades. Dissertation, University of Miami, Miami, FL.

Bugbee, C.D. 2008. Emergence dynamics of American alligators (*Alligator mississippiensis*) in Arthur R. Marshall Loxahatchee National Wildlife Refuge: life history and application to statewide alligator surveys. Thesis, University of Florida, Gainesville, FL.

Campbell, M.R. and F. J. Mazzotti. 2004. Characterization of natural and artificial alligator holes. Southeastern Naturalist 3(4):583-594.

Carter, C.B. 2010. Effects of habitat type and structure on detection probabilities of American alligator (*Alligator mississippiensis*) during night-light counts. Thesis, University of Florida, Gainesville, FL

Craighead, F.C., Sr. 1968. The role of the alligator in shaping plant communities and maintaining wildlife in the Southern Everglades. Florida Naturalist. 41:2-7, 69-74, 94.

Dalrymple, G.H. 1996. Growth of American alligators in the shark valley region of Everglades National Park. Copeia 1996(1): 212-216.

Doren, R.F. , 2006. Indicators for restoration: south Florida ecosystem restoration. Report to the South Florida Ecosystem Restoration Task Force.

_____, Trexler, J.C., Harwell, M., and Best, G.R. (eds). 2009. System-wide indicators for Everglades restoration 2008 assessment. Unpublished Technical Report. Crocodilian portion of: System-wide Indicators for Everglades Restoration 2008 Assessment.

Dunson, W.A. and F.J. Mazzotti. 1989. Salinity as a limiting factor in the distribution of reptiles in Florida Bay: a theory for the estuarine origin of marine snakes and turtles. Bulletin of Marine Science 44:229-244.

Fujisaki, I., F.J. Mazzotti, R.M. Dorazoi, K.G. Rice, M. Cherkiss and B. Jeffery. *In review*. Estimating trends in alligator populations from nightlight surveys. Wetlands.

_____, K. G. Rice, L. G. Pearlstine and F. J. Mazzotti. 2009. Relationship between body condition of American alligators and water depth in the Everglades, FL. Hydrobiologia 639:329-338.

Hines, T.C. and C.L. Abercrombie. 1987. The management of alligators in Florida USA. *In***:** J.W. Webb, S.C. Manolis, and P.J. Whitehead (eds.). Wildlife management: crocodiles and alligators. Chipping Norton, N.S.W. Australia: Surrey Beatty and Sons Pty. Ltd. p. 43-47.

Kushlan, J.A. and F.J. Mazzotti. 1989. Population biology of the American crocodile. Journal of Herpetology 23:7-21.

_____ and M.S. Kushlan. 1980. Everglades alligator nests: nesting sites for marsh reptiles. Copeia 4:1930-1932.

Mazzotti, F.J. 1999. The American crocodile in Florida Bay. Estuaries 22:552-561.

_____ and L A. Brandt. 1994. Ecology of the American alligator in a seasonally fluctuating environment. In: S.M. Davis and J.C. Ogden (eds.). Everglades, the ecosystem and its restoration. Delray Beach, FL: St. Lucie Press. p. 485-507.

_____ , L A. Brandt, M. Campbell and M. Palmer. 1999. An ecological characterization of Everglades alligator holes. University of Florida, Everglades Research Center, Belle Glade, FL.

_____, L.A. Brandt, P.E. Moler and M.S. Cherkiss. 2007a. American crocodile (*Crocodylus acutus*) in Florida: recommendations for endangered species recovery and ecosystem restoration. Journal of Herpetology 41:121-131.

_____, M.S. Cherkiss, M.W. Parry and K.G. Rice. 2007b. Recent nesting of the American crocodile (*Crocodylus acutus*) in Everglades National Park, Florida, USA. Herpetological Review 38(3): 285-289.

_____, G.R. Best, L.A. Brandt, M.S. Cherkiss, B.M. Jeffery and K.G. Rice. 2009. Alligators and crocodiles as indicators for restoration of Everglades ecosystems. Ecological Indicators. 9(6)S1: S137-S14.

_____ and W.A. Dunson. 1989. Osmoregulation in crocodilians. American Zoologist. 29:903-920.

Moler, P.E. 1992. American crocodile population dynamics. Final report to the Florida Game and Fresh Water Fish Commission Bureau of Wildlife Research. Gainesville (FL): Florida Game and Fresh Water Fish Commission.

Palmer, M.L. and F.J. Mazzotti. 2004. Structure of Everglades alligator holes. Wetlands 24(2):115-122.

RECOVER. 2004. CERP monitoring and assessment plan. Part I. Monitoring and supporting research. Comprehensive Ecosystem Restoration Project. South Florida Water Management District. West Palm Beach, and U.S. Army Corps of Engineers, Jacksonville.

_____. 2007. Final 2007 system status report. Restoration, coordination, and verification Leadership Group Final Report. U.S. Army Corps of Engineers, Jacksonville, FL and South Florida Water Management District, West Palm Beach, FL.

Rice, K.G. and F.J. Mazzotti. 2006. American alligator distribution, size, and hole occupancy and American crocodile juvenile growth and survival. University of Florida, Fort Lauderdale Research and Education Center, Fort Lauderdale, FL.

_____ and F.J. Mazzotti. 2007. American alligator distribution, size, and hole occupancy and American crocodile juvenile growth and survival. University of Florida, Fort Lauderdale Research and Education Center, Fort Lauderdale, FL.

_____ and F.J. Mazzotti. 2008. American alligator distribution, size, and hole occupancy and American crocodile juvenile growth and survival. University of Florida, Fort Lauderdale Research and Education Center, Fort Lauderdale, FL.

_____, F.J. Mazzotti and L.A. Brandt. 2005. Status of the American alligator (*Alligator mississippiensis*) in southern Florida and its role in measuring restoration success in the Everglades. *In*: W.E. Meshaka, Jr. and K.J. Babbitt (eds.). Status and Conservation of Florida Amphibians and Reptiles. Melbourne, FL: Krieger Publishers. p. 145-153.

_____, F.J. Mazzotti and K. Hart. 2009. American alligator distribution, size, and hole occupancy and American crocodile juvenile growth and survival. University of Florida, Fort Lauderdale Research and Education Center, Fort Lauderdale, FL.

Santos, S.A., M.J.S. Nogueira, M.S. Pinheiro, G.M. Mourao and Z. Campos. 1994. Condition factor of *Caiman crocodiles yacare* in different habitats of Pantanal Mato-Grossense Proceedings of the 12th Working meeting of Crocodile Specialists Group.

Seijas, A.E. 1998. The Orinoco Crocodile (*Crocodylus intermedius*) in the Cojedes River System, Venezuela: population status and ecological characteristics. Doctoral dissertation. University of Florida, Gainesville, FL.

Simmons, G. and L. Ogden. 1998. Gladesmen. University Press of Florida, Gainesville, FL

Schiller, A., C.T. Hunsaker, M.A. Kane, A.K. Wolfe, V.H. Dale, G.W. Suter, C.S. Russell, G. Pion, M. Hadley and V.C. Konar. 2001. Communicating ecological indicators to decision-makers and the public. Conservation Ecology. 5(1):19

Snow, R.W., L. Oberhofer and F.J. Mazzotti. 2006. *Alligator mississippiensis:* Feeding. Herpetological Review. 37(1):80-81.

Verdade, L.M. 2001. Allometry of reproduction in broad-snouted caiman (*Caiman latirostris*). Brazilian Journal of Biology. 61(3):431-435.

Wiley, E.N. and M. Jennings. 1990. An overview of alligator management in Florida. Proceedings of the 10th Working Meeting of the Crocodile Specialists Group. Gainesville, FL. p. 274-285.

Webb, G.J.W. and H. Messel. 1979. Wariness in *Crocodylus porpsus* (Reptilia: Crocodilidae). Australian Wildlife Research 6:227-234.

Woodward, A.R., T.C. Hines, C.L. Abercrombie and J.D. Nichols. 1987. Survival of young American alligators on a Florida lake. Journal of Wildlife Management. 51(4):931-937.

Woodward, A.R. and C. T. Moore. 1990. Statewide alligator surveys. Florida Game and Fresh Water Fish Commission, Tallahassee, FL.

Water Resources Development Act of 2000. Public Law 106-541. 106th Cong., 11 December 2000.

Zweig, C.L. 2003. Body condition factor analysis for the American alligator (*Alligator mississippiensis*). Thesis, University of Florida, Gainesville, FL.

Table 1. Summary of trends along **routes** and effects of covariates from multiple regression analysis of log-transformed counts of alligators/km in each size class (dependant variable) on year, season (fall and spring), average water depth, and average water temperature. Values in trend columns indicate if there is a trend and if so if it is positive or negative. Effects for season, water depth, and water temperature are indicated followed by the direction and size class(s) for which that effect was significant. For example, there were no significant trends in BICY Marsh, but there was a significant season effect with the number of juvenile, adult, and non-hatchling alligators higher in spring than in fall.

Area	Trend (2004-2009) Juvenile (J)	Trend (2004-2009) Sub-adult (S)	Trend (2004-2009) Adult (A)	Trend (2004-2009) Non-hatchling (NH)	Season Effect	Water Depth Effect	Water Temperature Effect
BICY Marsh	No	No	No	No	Yes S>F; J,A,NH	No	No
ENP FC Marsh	No	No	No	No	No	No	Yes (-) J
ENP SS Marsh	No	No	No	No	No	No	Yes (-) A, NH
LOX Marsh	No	No	No	No	No	No	No
WCA 2A Marsh	Yes (-)	No	Yes (-)	Yes (-)	No	No	No
WCA 3A HD Marsh	No	No	No	No	Yes S>F; A,NH	No	Yes (+) NH
WCA 3A N41 Marsh	Yes (-)	No	No	No	No	No	No
WCA 3A Tower Marsh	Yes (-)	No	No	No	No	No	No
WCA 3B Marsh	No	No	No	No	No	No	No
ENP Estuary	No	No	No	No	No	NA	Yes (+) A, NH

Table 2. Summary of trends along **transects** and effects of covariates from multiple regression analysis of log-transformed counts of alligators/km in each size class (dependant variable) on year, season (fall and spring), average water depth, and average water temperature. Values in trend columns indicate if there is a trend and if so if it is positive or negative. Effects for season, water depth, and water temperature are indicated followed by the direction and size class(s) for which that effect was significant. For example, there were no significant trends in BICY Marsh, but there was a significant season effect (number of juvenile, adult, and non-hatchling alligators higher in spring than in fall) and a negative effect of water temperature on number of sub-adults.

Area	Trend (2004-2009) Juvenile (J)	Trend (2004-2009) Sub-adult (S)	Trend (2004-2009) Adult (A)	Trend (2004-2009) Non-hatchling (NH)	Season Effect	Water Depth Effect	Water Temperature Effect
BICY Marsh	No	No	No	No	Yes S>F; J,A,NH	No	Yes (-) S
ENP FC Marsh	No	No	No	No	No	Yes (-) S,NH	Yes (-) J
ENP SS Marsh	No	No	No	No	No	No	Yes (-) J
LOX Marsh	No	No	No	No	No	No	No
WCA 2A Marsh	Yes (-)	No	Yes (-)	No	Yes F>S;NH	Yes (-) NH	No
WCA 3A HD Marsh	Yes (+)	No	No	Yes (+)	Yes S>F;A	Yes (+) A	Yes (+) A,NH
WCA 3A N41 Marsh	Yes (-)	No	No	No	No	Yes (-) NH	No
WCA 3A Tower Marsh	No	No	No	No	No	No	No
WCA 3B Marsh	Yes (-)	No	No	No	No	No	No
ENP Estuary	Yes (-)	No	No	No	No	NA	No

Table 3. Summary of trends in body condition and effects of covariates from regression of body condition using **head length (HL)** of individual alligators (dependent variables) on year, with size class, sex, season, and average water depth 10-49 days prior to capture (from EDEN) as covariates. Values in trend columns indicate if there is a trend and if so if it is positive or negative. Effects of size, sex, season, and water depth are indicated followed by the direction for which that effect was significant. For example, there was not a significant trend in body condition in BICY Marsh, but there were significant size, sex, season and water depth effects. Juveniles had lower body condition than adults, females were in better condition than males, animals were in better condition in fall than spring, and there was a negative effect of water depth 10-49 days prior to capture on condition.

Area	Trend in Body Condition (2004-2009; HL)	Size Effect	Sex Effect	Season Effect	Water Depth Effect
BICY Marsh	No	Yes; J<A	Yes; F>M	Yes; F>S	Yes(-)
ENP FC Marsh	No	No	Yes; F>M	No	No
ENP SS Marsh	No	No	No	No	No
LOX Marsh	No	J<A	Yes; F>M	No	No
WCA 2A Marsh	No	Yes; J<A; S<A	Yes; F>M	Yes; S>F	No
WCA 3A HD Marsh	No	Yes; J<A	No	No	No
WCA 3A N41 Marsh	Yes(-)	Yes; J<A; S<A	Yes; F>M	No	No
WCA 3A Tower Marsh	No	Yes; J<A; S<A	Yes; F>M	No	No
WCA 3B Marsh	No	No	No	No	No
ENP Estuary	No	No	No	No	NA

Table 4. Summary of trends in body condition and effects of covariates from regression of body condition using **snout-vent length (SVL)** of individual alligators (dependent variables) on year, with size class, sex, season, and average water depth 10-49 days prior to capture (from EDEN) as covariates. Values in trend columns indicate if there is a trend and if so if it is positive or negative. Effects of size, sex, season, and water depth are indicated followed by the direction for which that effect was significant. For example, there was not a significant trend in body condition in BICY Marsh, but there were significant season and water depth effects. Animals were in better condition in fall than spring, and there was a negative effect of water depth 10-49 days prior to capture on condition.

Area	Trend in Body Condition (2004-2009)	Size Effect	Sex Effect	Season Effect	Water Depth Effect
BICY Marsh	No	No	No	Yes; F>S	Yes(-)
ENP FC Marsh	Yes (+)	No	No	Yes; F>S	Yes(-)
ENP SS Marsh	No	No	No	No	No
LOX Marsh	No	No	Yes; F>M	No	No
WCA 2A Marsh	No	Yes; J<A;S<A	No	No	No
WCA 3A HD Marsh	No	Yes; J<A;S<A	No	No	No
WCA 3A N41 Marsh	Yes (-)	Yes; J<A;S<A	Yes; F>M	No	No
WCA 3A Tower Marsh	No	Yes; J<A;S<A	Yes; F>M	No	No
WCA 3B Marsh	No	Yes; S<A	No	No	No
ENP Estuary	No	No	No	No	NA

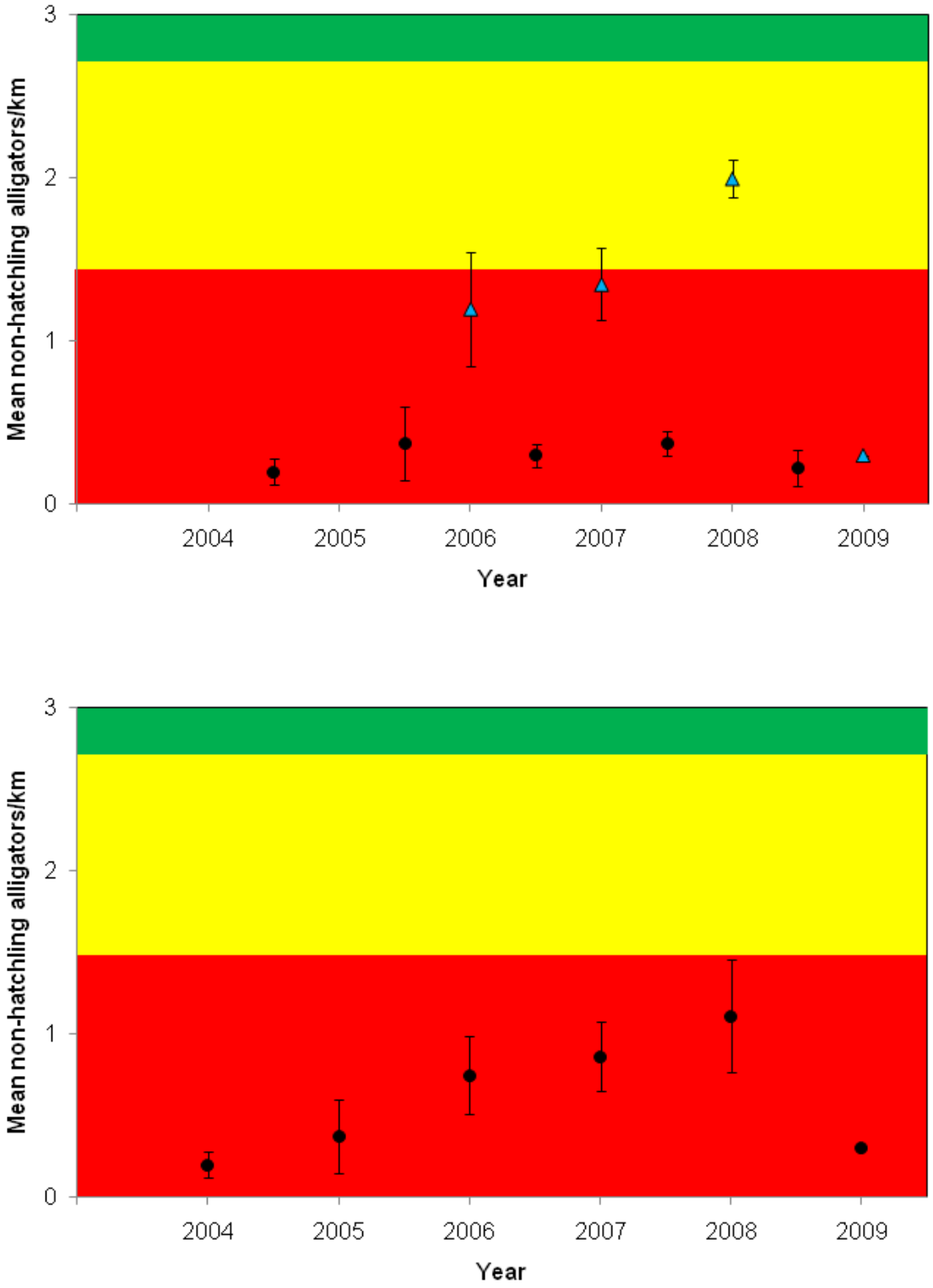

Figure 1. Relative abundance of mean non-hatchling alligators/km (standard error bars) in Big Cypress National Preserve for season (top; spring triangles, fall circles) and annual (bottom). Red (first and second quartiles, density ≤ 1.47 animals/km), yellow (third quartile, 1.47 < density ≤ 2.70 animals/km), and green (fourth quartile, density > 2.70 animals/km).

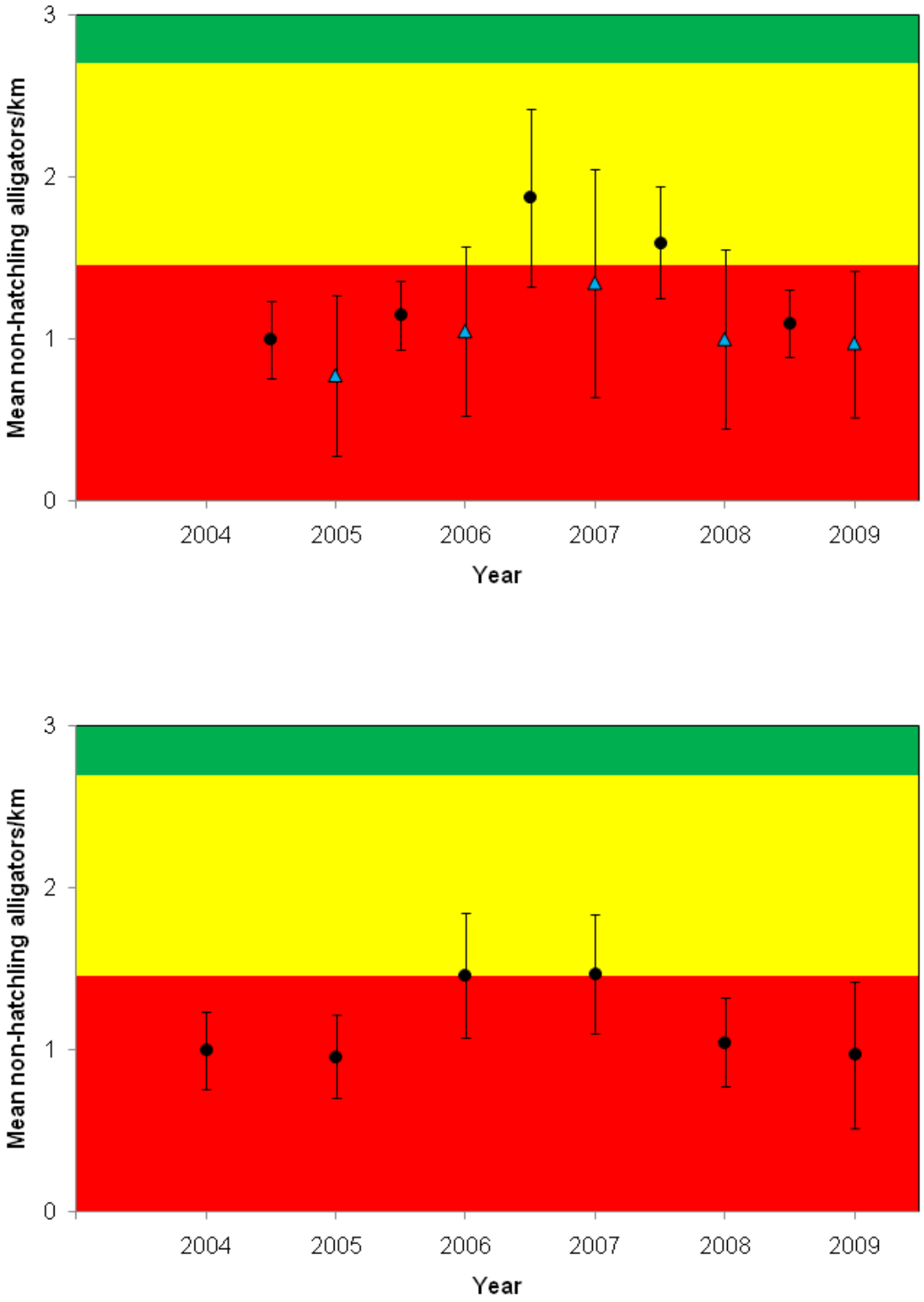

Figure 2. Relative abundance of mean non-hatchling alligators/km (standard error bars) in Everglades National Park Estuary for season (top; spring triangles, fall circles) and annual (bottom). Red (first and second quartiles, density ≤ 1.47 animals/km), yellow (third quartile, 1.47 < density ≤ 2.70 animals/km), and green (fourth quartile, density > 2.70 animals/km).

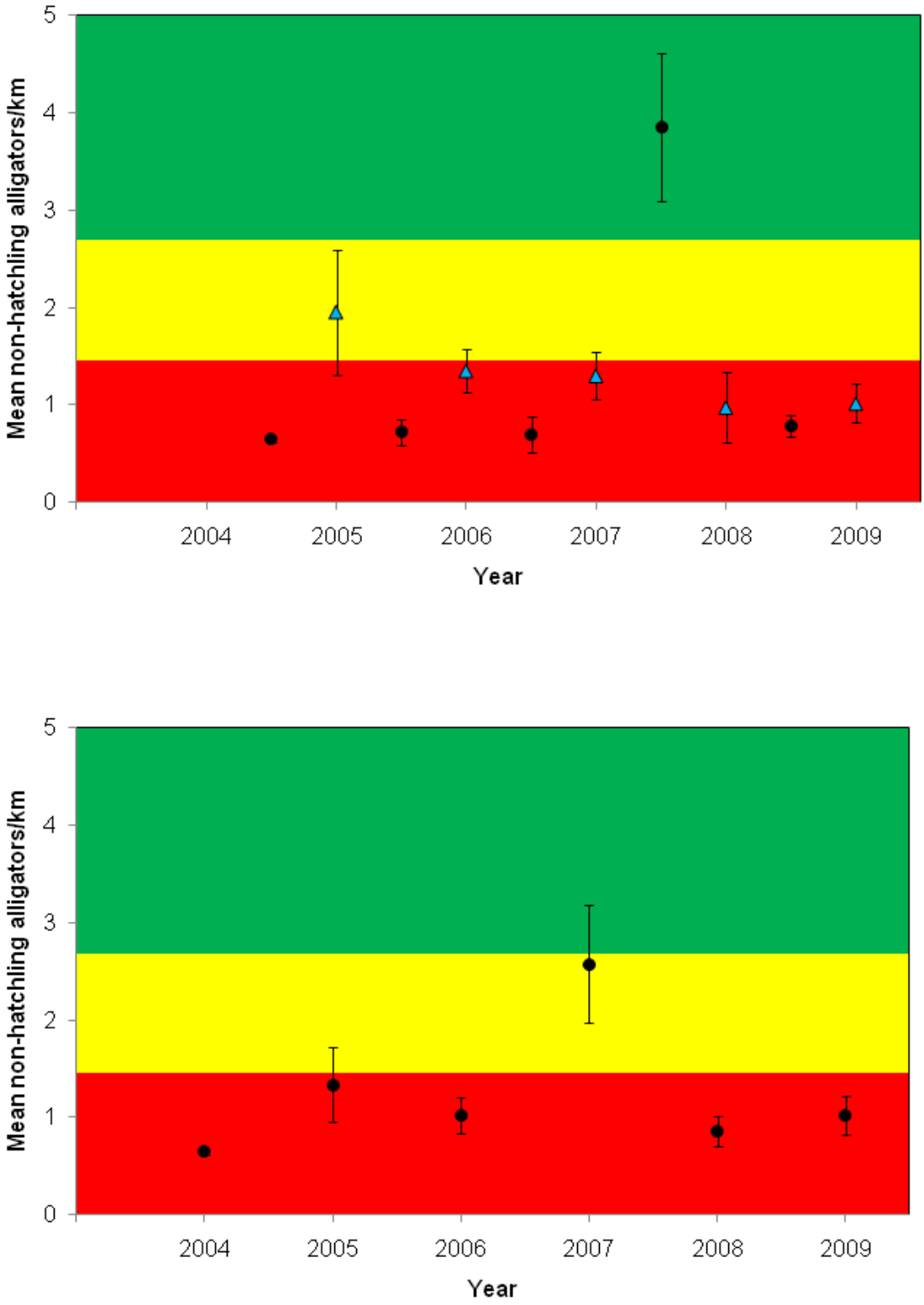

Figure 3. Relative abundance of mean non-hatchling alligators/km (standard error bars) in Everglades National Park Frog City for season (top; spring triangles, fall circles) and annual (bottom). Red (first and second quartiles, density ≤ 1.47 animals/km), yellow (third quartile, 1.47 < density ≤ 2.70 animals/km), and green (fourth quartile, density > 2.70 animals/km).

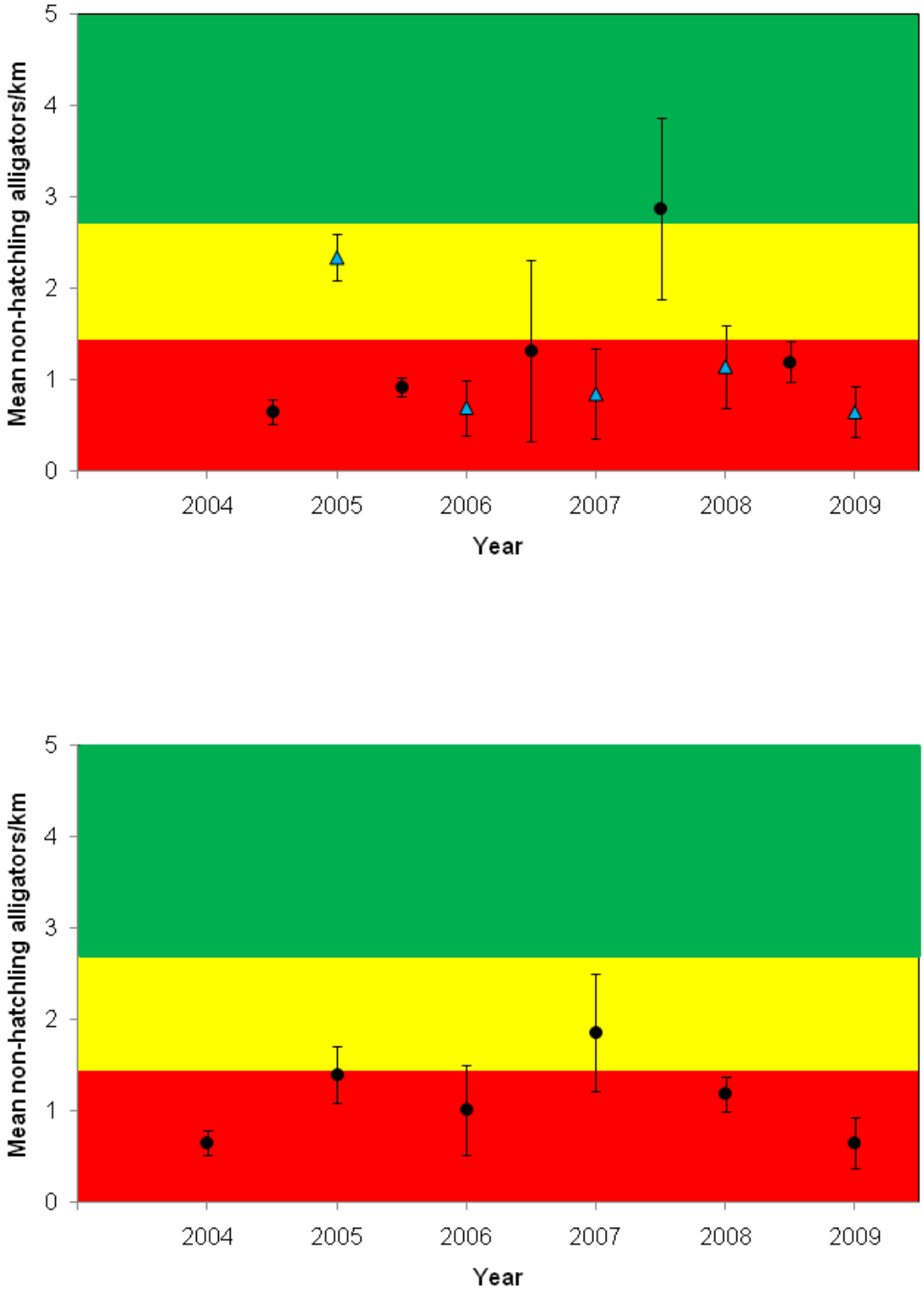

Figure 4. Relative abundance of mean non-hatchling alligators/km (standard error bars) in Everglades National Park Shark Slough for season (top; spring triangles, fall circles) and annual (bottom). Red (first and second quartiles, density ≤ 1.47 animals/km), yellow (third quartile, 1.47 < density ≤ 2.70 animals/km), and green (fourth quartile, density > 2.70 animals/km).

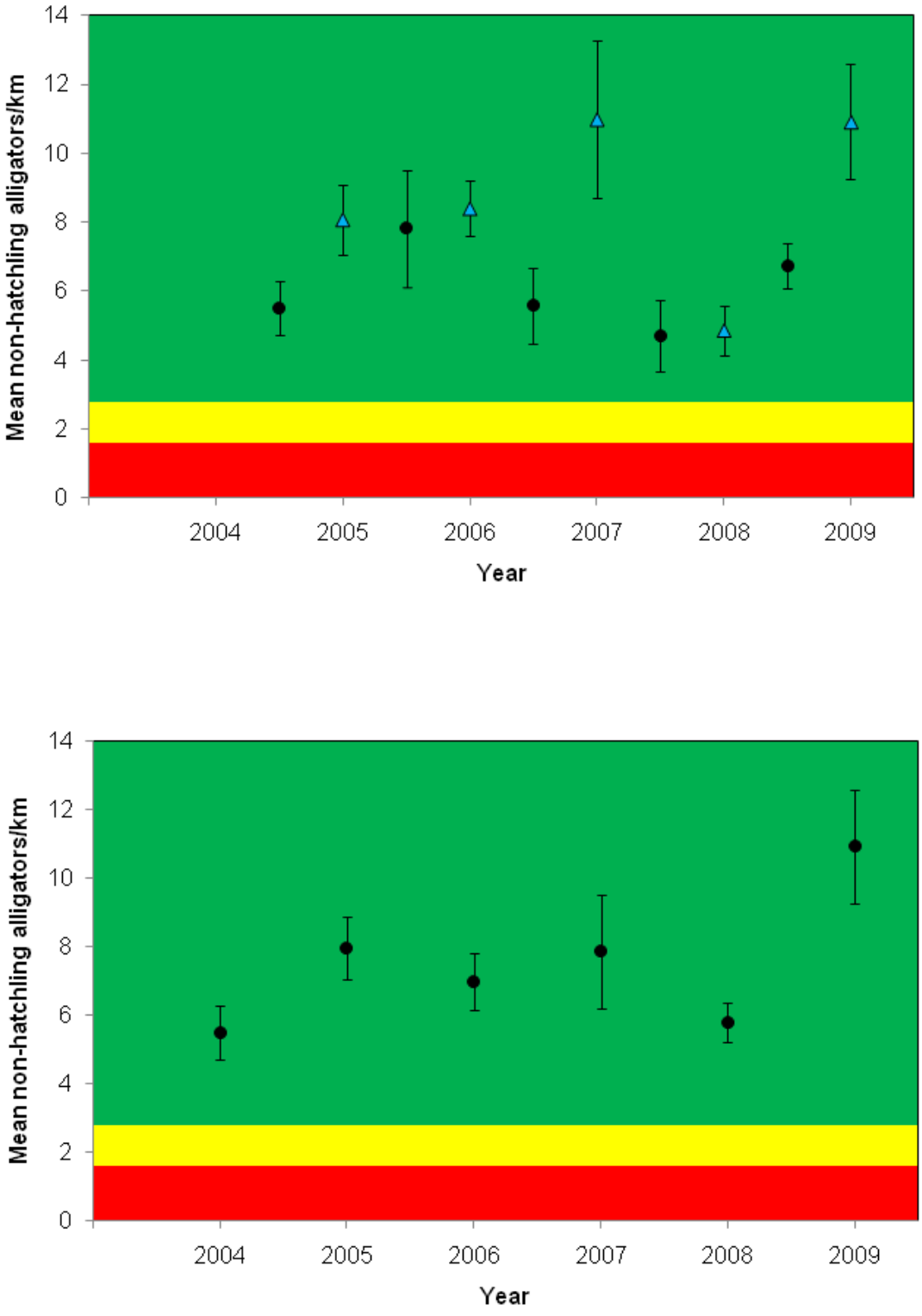

Figure 5. Relative abundance of mean non-hatchling alligators/km (standard error bars) in A.R.M. Loxahatchee National Wildlife Refuge for season (top; spring triangles, fall circles) and annual (bottom). Red (first and second quartiles, density ≤ 1.47 animals/km), yellow (third quartile, 1.47 < density ≤ 2.70 animals/km), and green (fourth quartile, density > 2.70 animals/km).

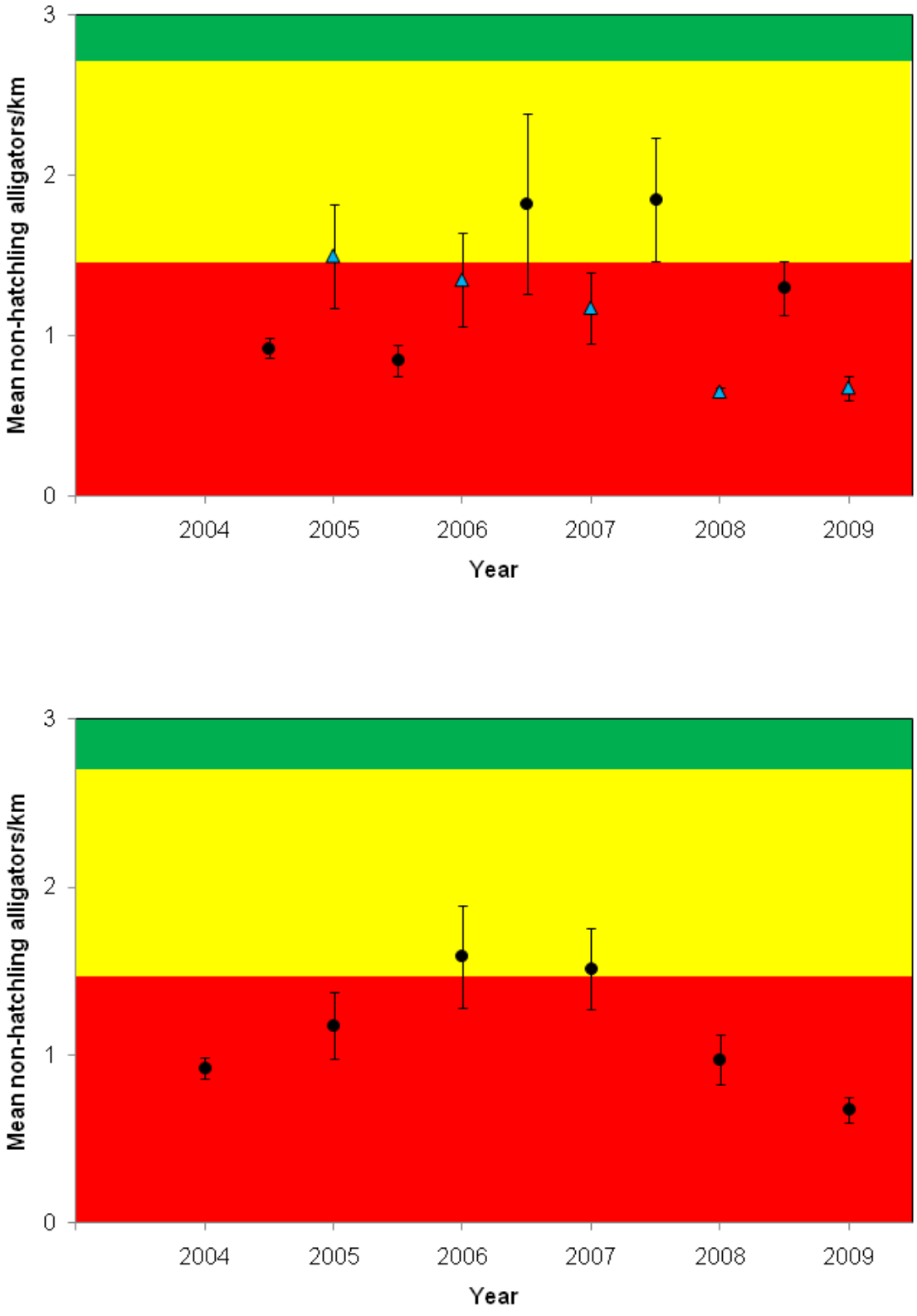

Figure 6. Relative abundance of mean non-hatchling alligators/km (standard error bars) in Water Conservation Area 2A for season (top; spring triangles, fall circles) and annual (bottom). Red (first and second quartiles, density ≤ 1.47 animals/km), yellow (third quartile, 1.47 < density ≤ 2.70 animals/km), and green (fourth quartile, density > 2.70 animals/km).

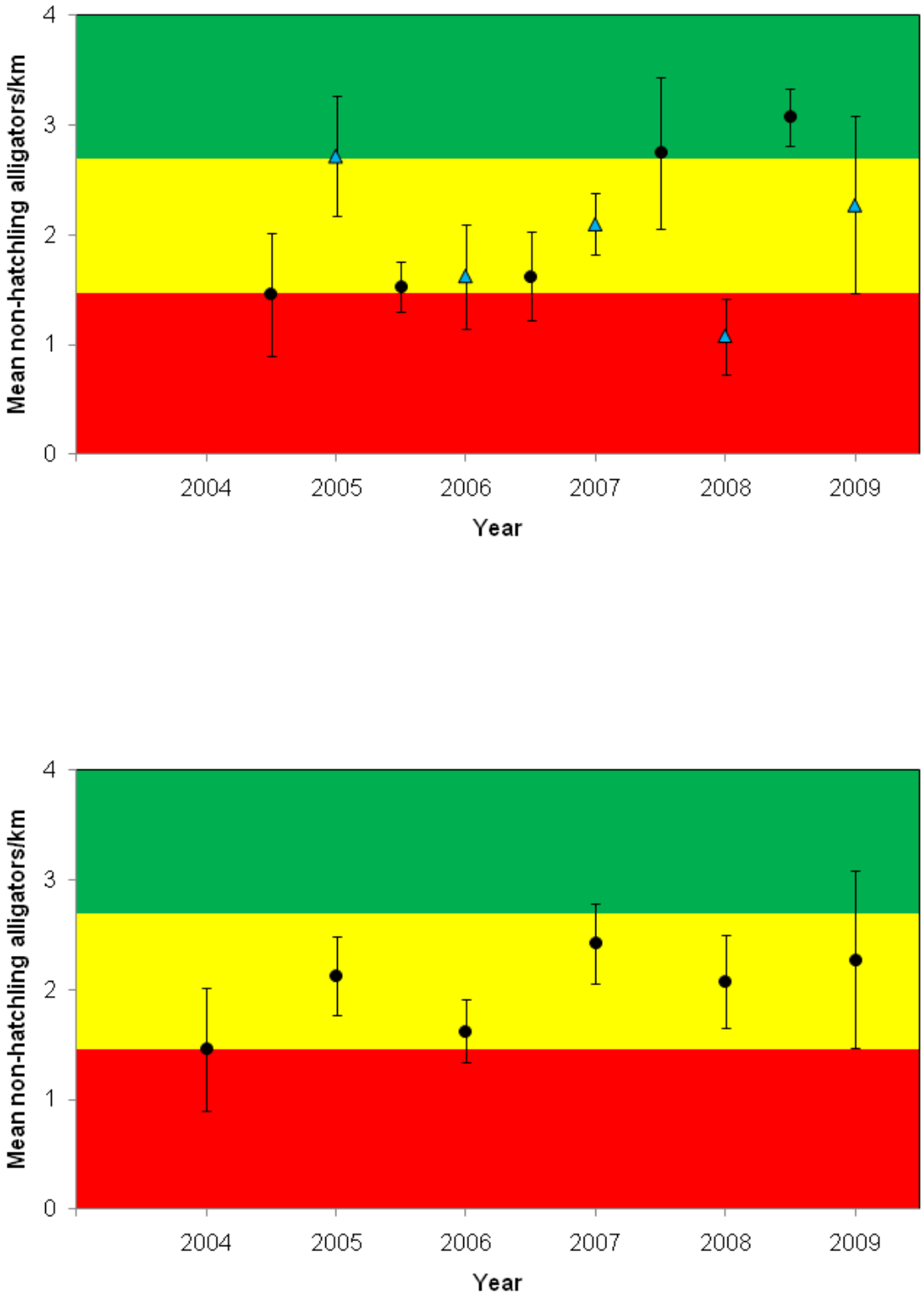

Figure 7. Relative abundance of mean non-hatchling alligators/km (standard error bars) in Water Conservation Area 3A Holiday Park for season (top; spring triangles, fall circles) and annual (bottom). Red (first and second quartiles, density ≤ 1.47 animals/km), yellow (third quartile, 1.47 < density ≤ 2.70 animals/km), and green (fourth quartile, density > 2.70 animals/km).

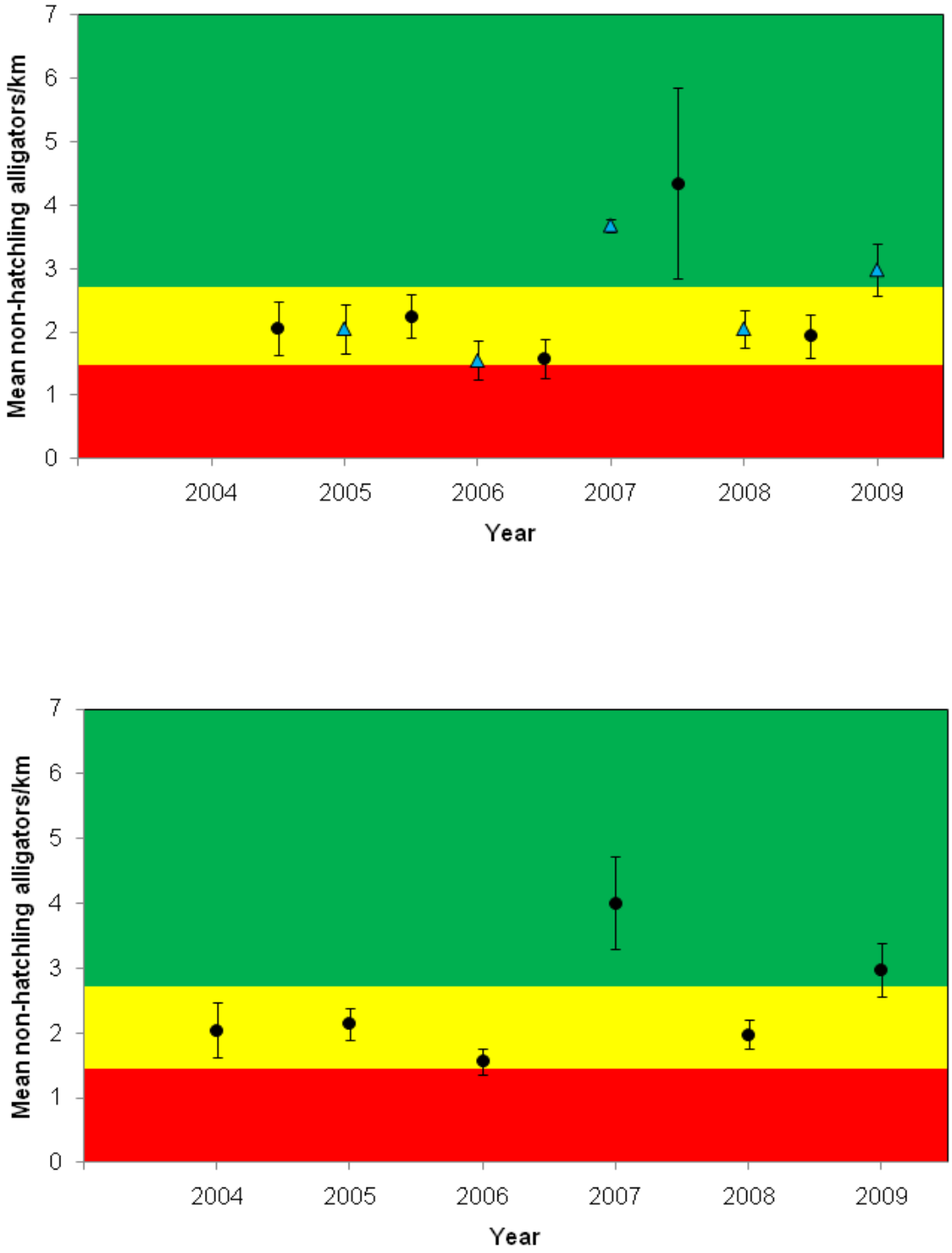

Figure 8. Relative abundance of mean non-hatchling alligators/km (standard error bars) in Water Conservation Area 3A North 41 for season (top; spring triangles, fall circles) and annual (bottom). Red (first and second quartiles, density ≤ 1.47 animals/km), yellow (third quartile, 1.47 < density ≤ 2.70 animals/km), and green (fourth quartile, density > 2.70 animals/km).

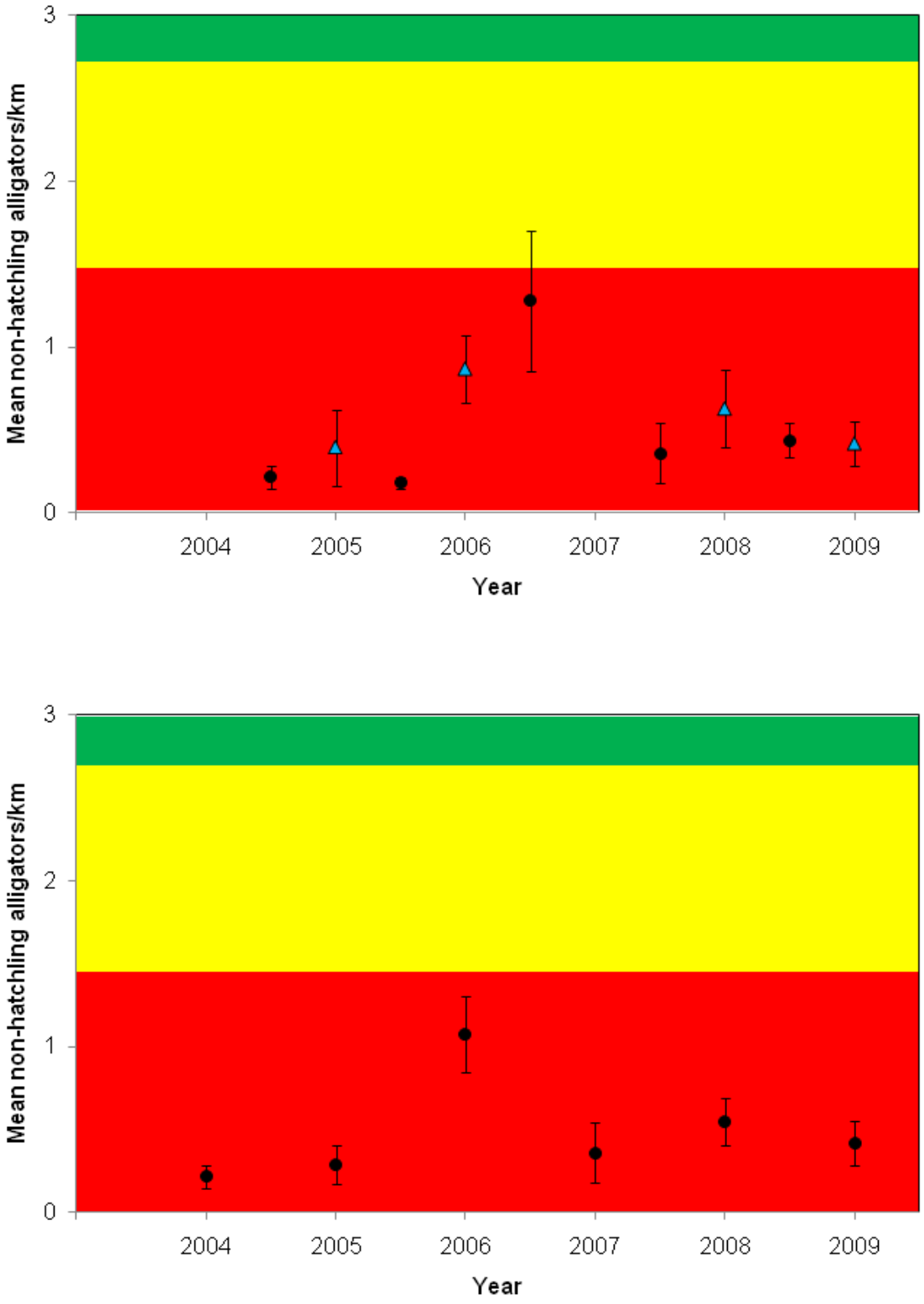

Figure 9. Relative abundance of mean non-hatchling alligators/km (standard error bars) in Water Conservation Area 3A Tower for season (top; spring triangles, fall circles) and annual (bottom). Red (first and second quartiles, density ≤ 1.47 animals/km), yellow (third quartile, 1.47 < density ≤ 2.70 animals/km), and green (fourth quartile, density > 2.70 animals/km).

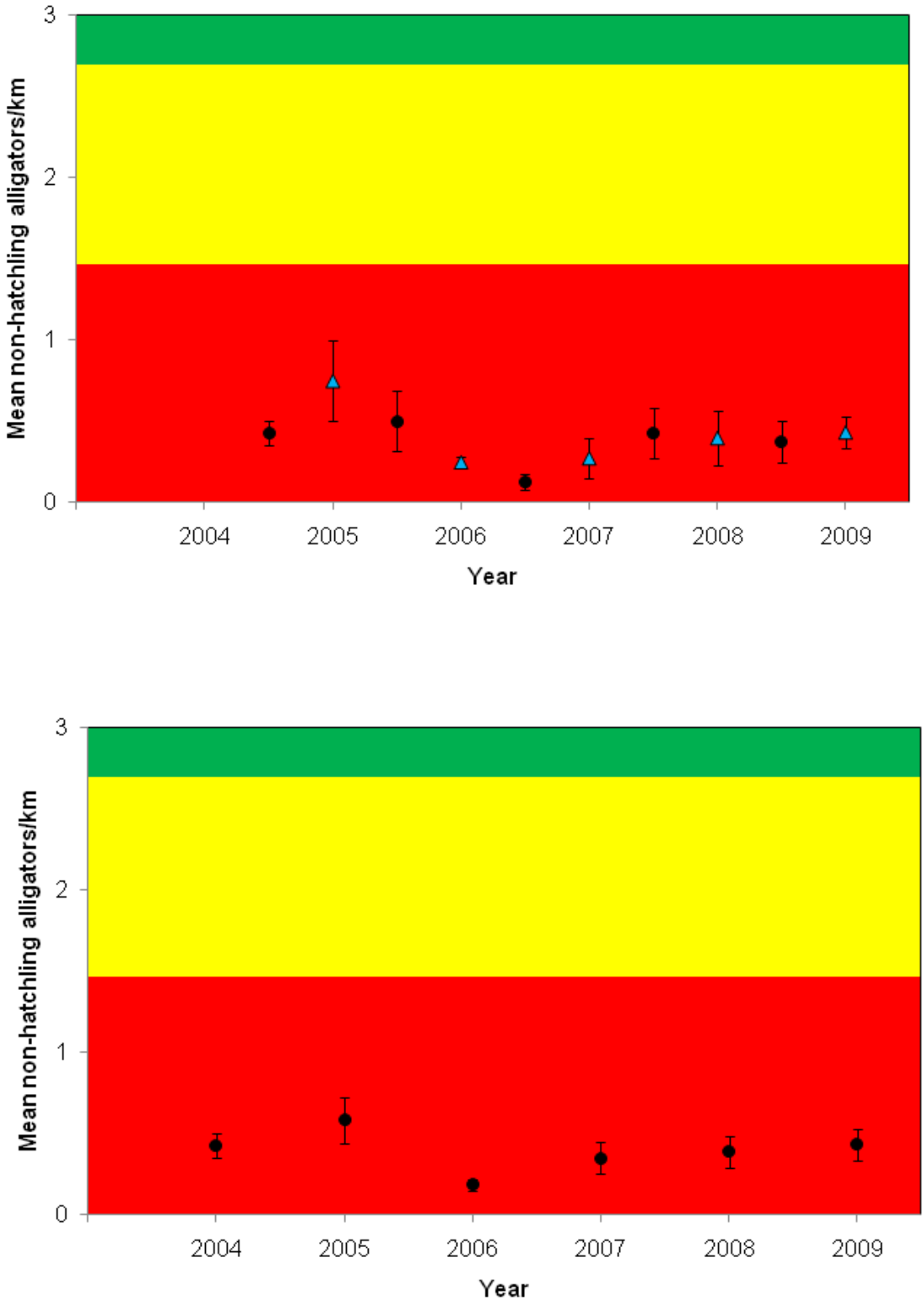

Figure 10. Relative abundance of mean non-hatchling alligators/km (standard error bars) in Water Conservation Area 3B for season (top; spring triangles, fall circles) and annual (bottom). Red (first and second quartiles, density ≤ 1.47 animals/km), yellow (third quartile, 1.47 < density ≤ 2.70 animals/km), and green (fourth quartile, density > 2.70 animals/km).

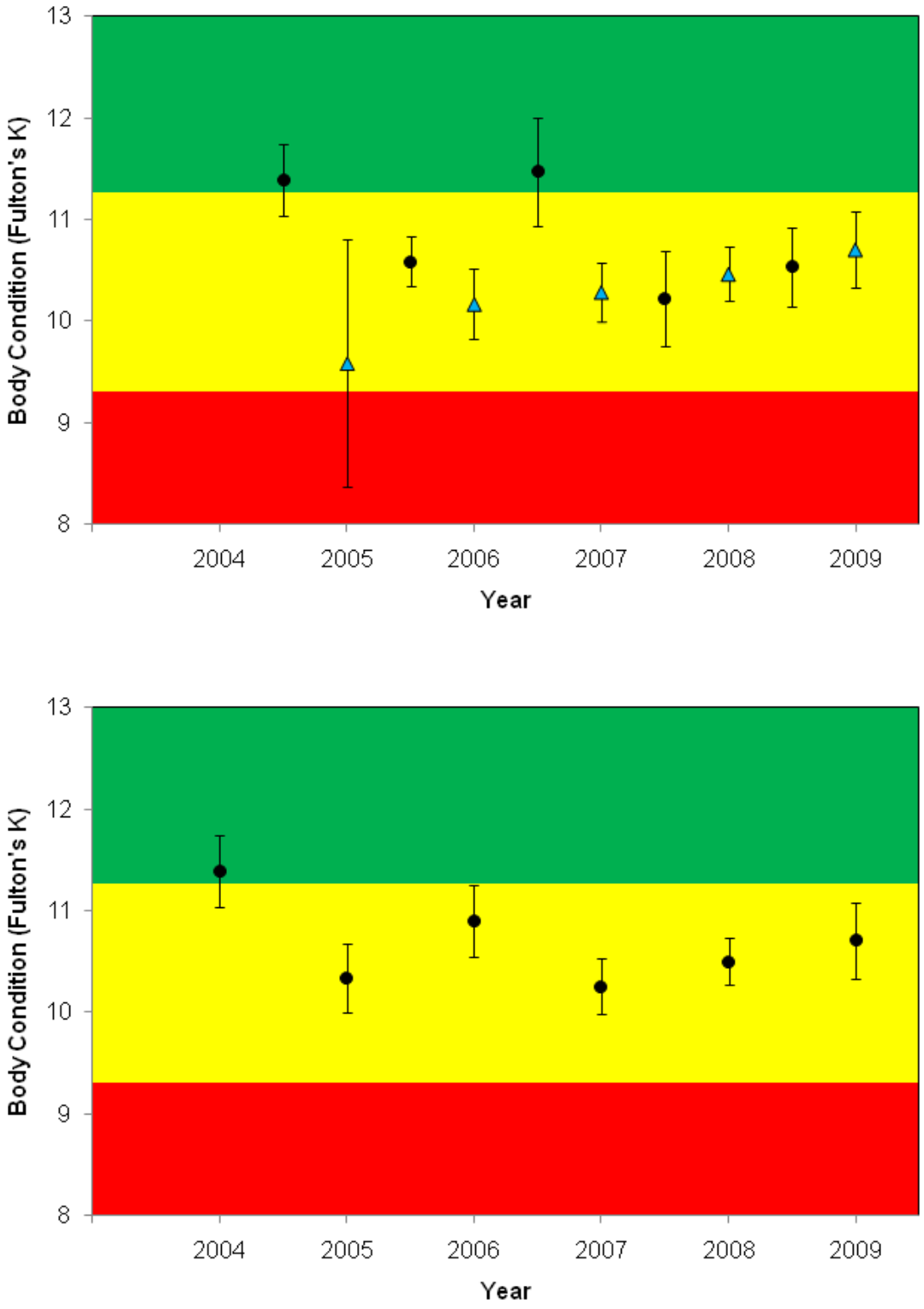

Figure 11. Mean body condition (Fulton's K, standard error bars) in Big Cypress National Preserve for season (top; spring triangles, fall circles) and annual (bottom). Red (first quartile Fulton's K ≤ 9.31), yellow (second and third quartiles 9.31 < Fulton's K ≤ 11.27), and green (fourth quartile Fulton's K > 11.27).

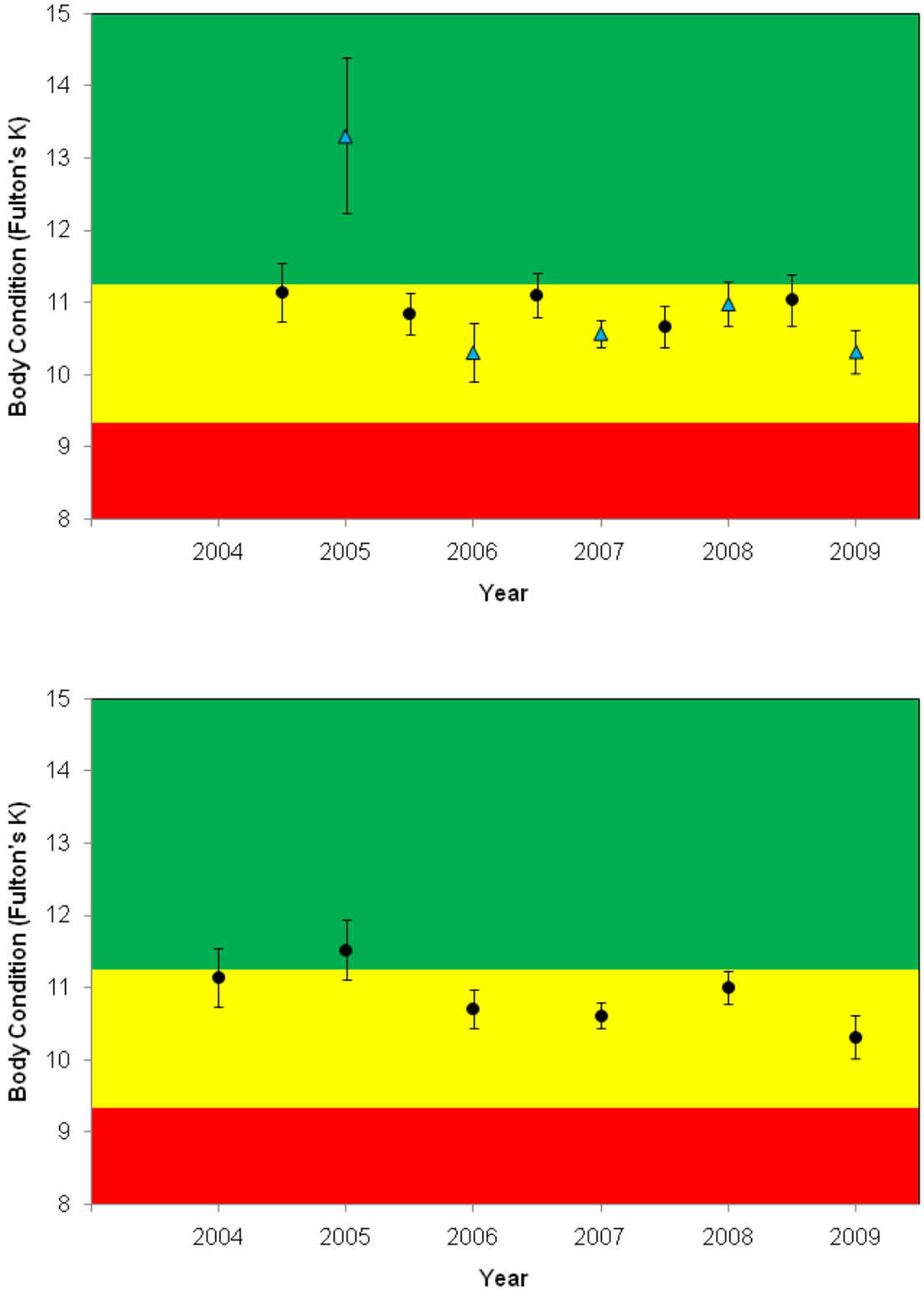

Figure 12. Mean body condition (Fulton's K, standard error bars) in Everglades National Park Estuary for season (top; spring triangles, fall circles) and annual (bottom). Red (first quartile Fulton's K ≤ 9.31), yellow (second and third quartiles 9.31 < Fulton's K ≤ 11.27), and green (fourth quartile Fulton's K > 11.27).

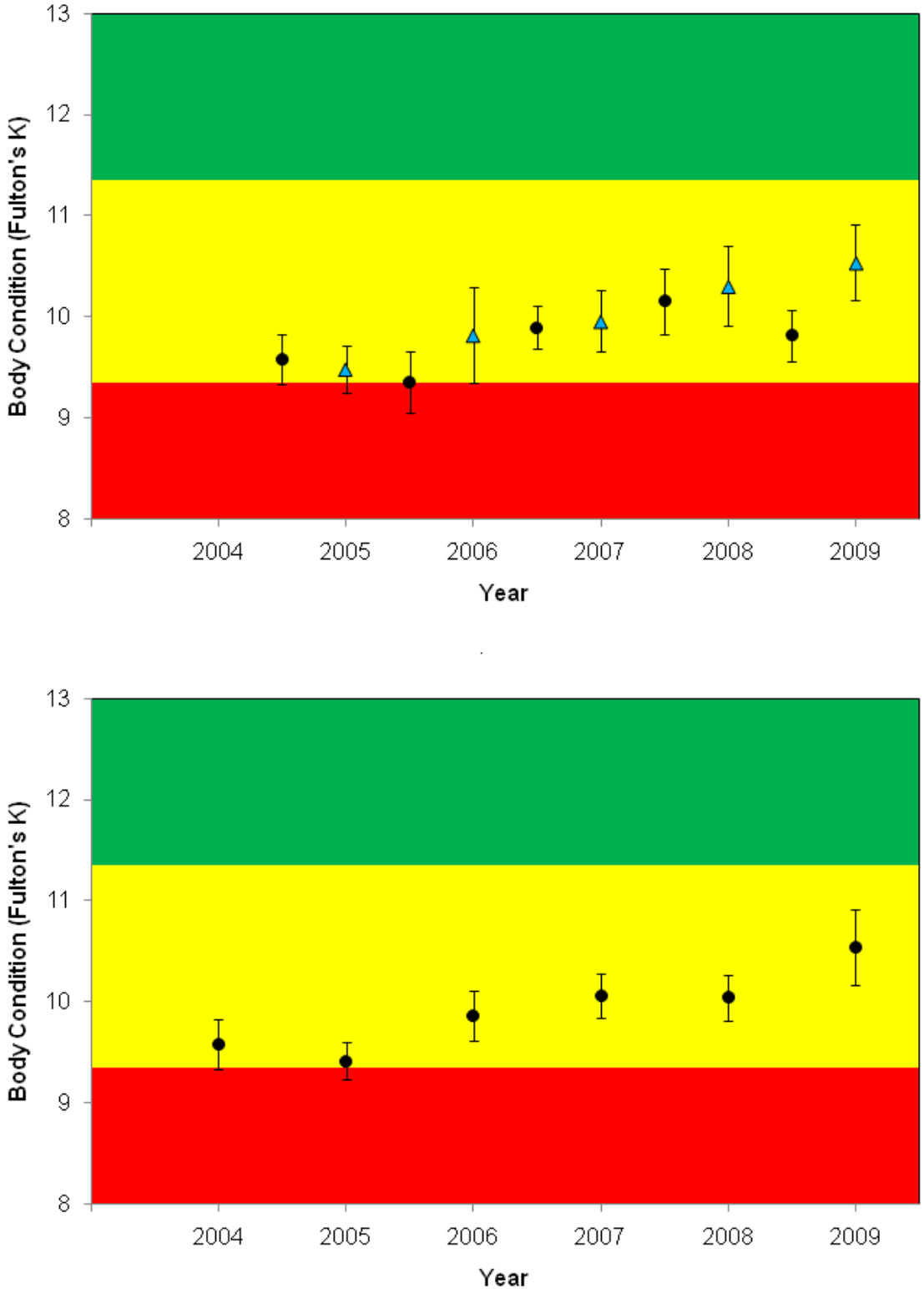

Figure 13. Mean body condition (Fulton's K, standard error bars) in Everglades National Park Frog City for season (top; spring triangles, fall circles) and annual (bottom). Red (first quartile Fulton's K ≤ 9.31), yellow (second and third quartiles 9.31 < Fulton's K ≤ 11.27), and green (fourth quartile Fulton's K > 11.27).

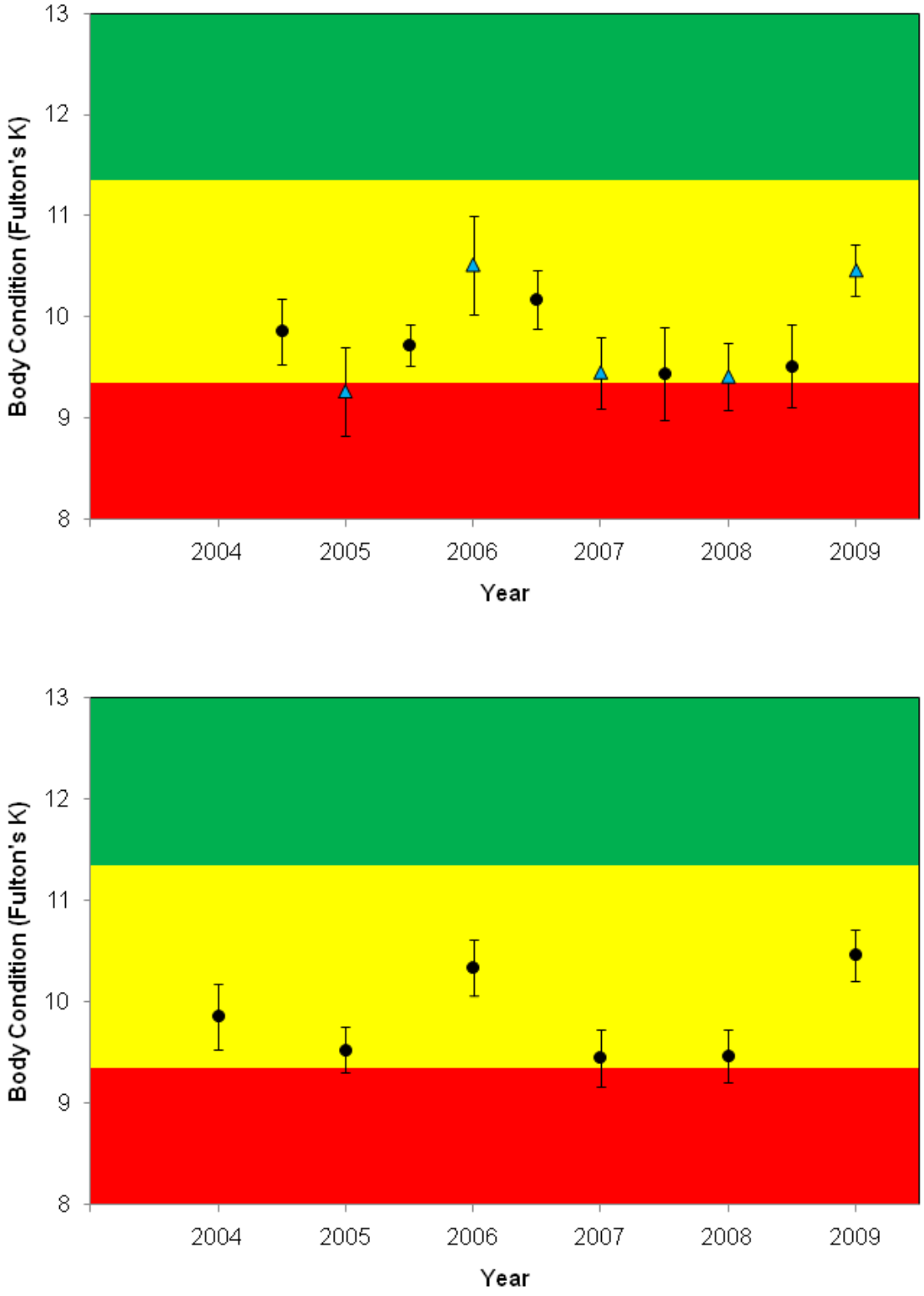

Figure 14. Mean body condition (Fulton's K, standard error bars) in Everglades National Park Shark Slough for season (top; spring triangles, fall circles) and annual (bottom). Red (first quartile Fulton's K ≤ 9.31), yellow (second and third quartiles 9.31 < Fulton's K ≤ 11.27), and green (fourth quartile Fulton's K > 11.27).

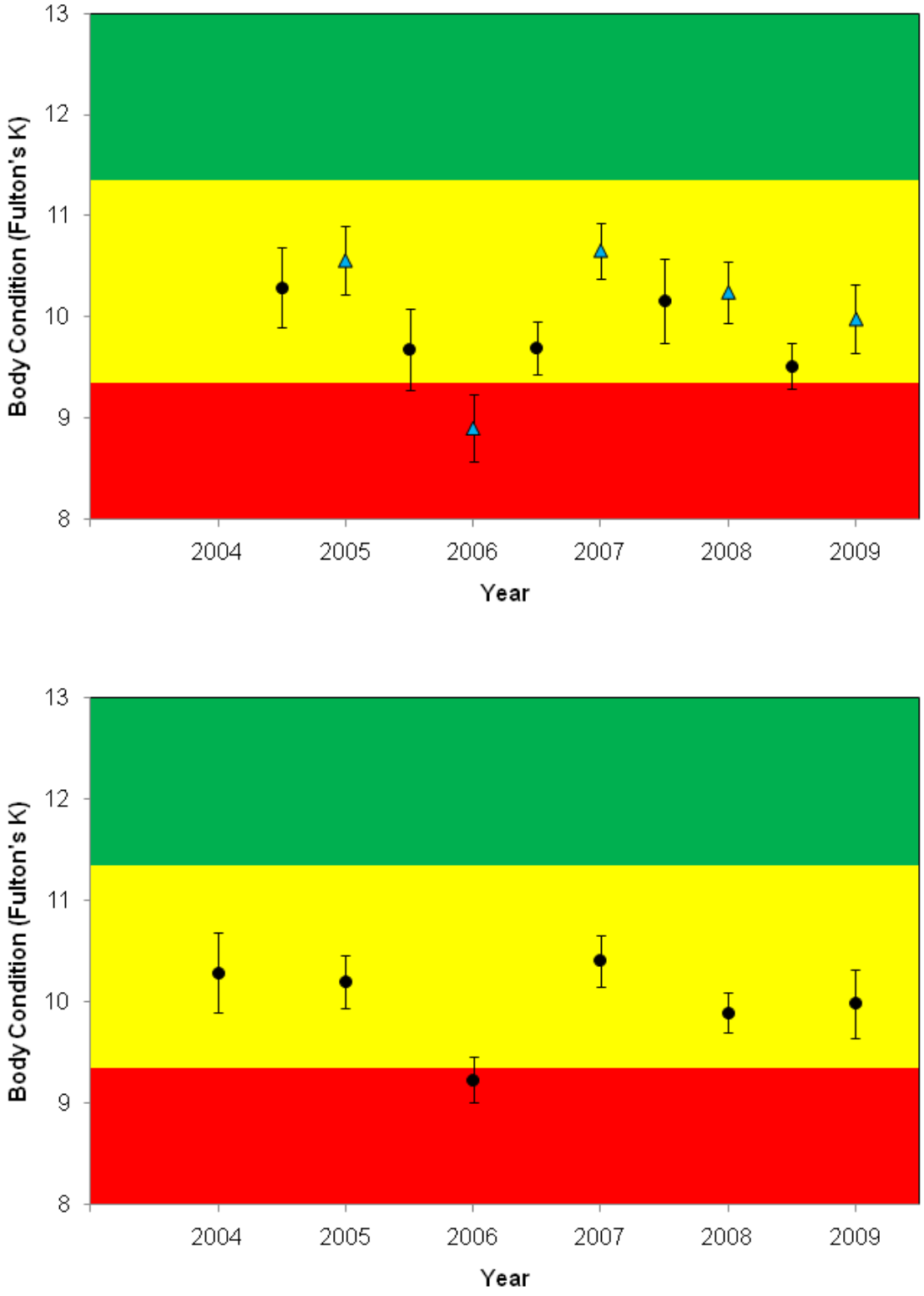

Figure 15. Mean body condition (Fulton's K, standard error bars) in A.R.M. Loxahatchee National Wildlife Refuge for season (top; spring triangles, fall circles) and annual (bottom). Red (first quartile Fulton's K ≤ 9.31), yellow (second and third quartiles 9.31 < Fulton's K ≤ 11.27), and green (fourth quartile Fulton's K > 11.27).

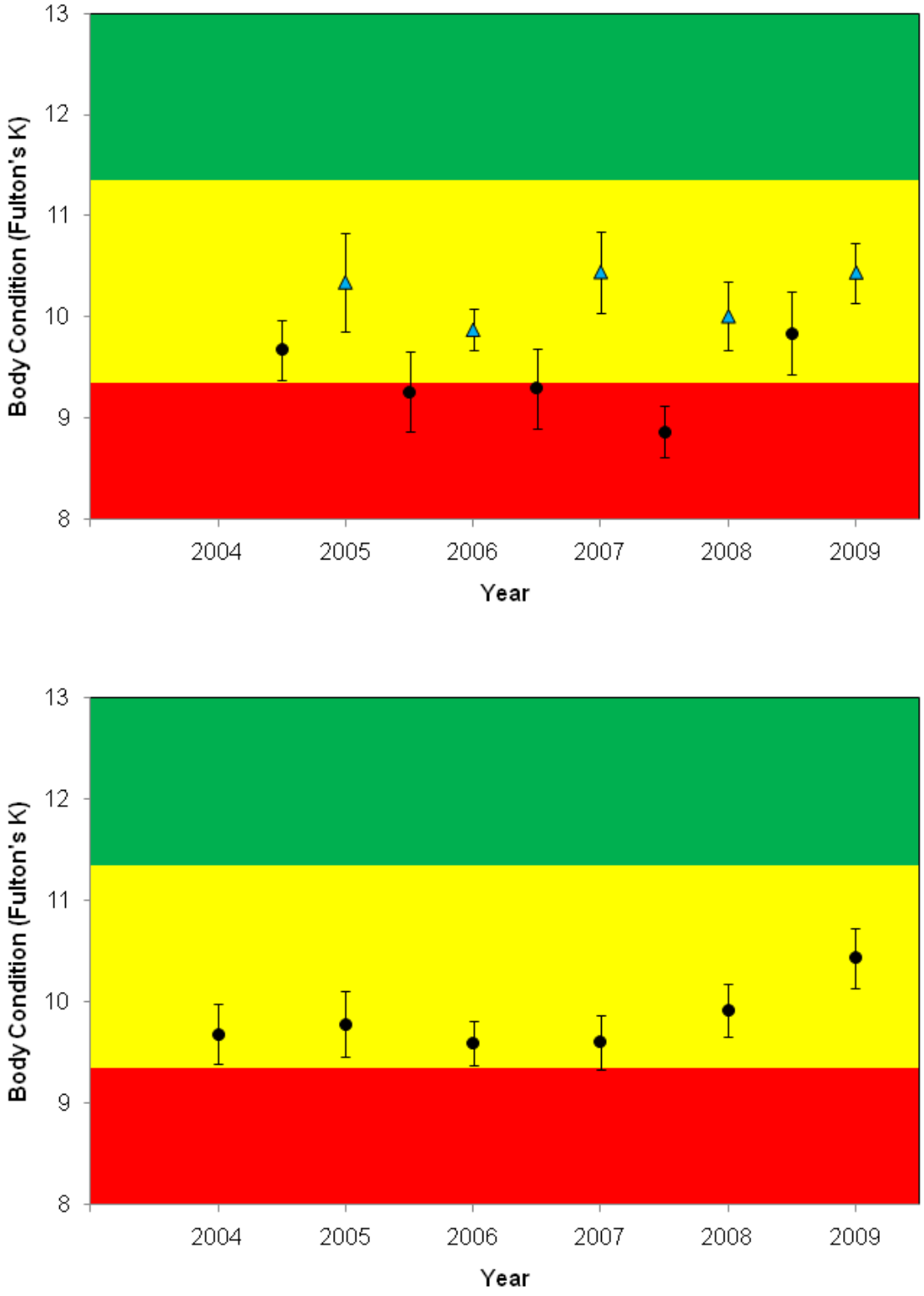

Figure 16. Mean body condition (Fulton's K, standard error bars) in Water Conservation Area 2A for season (top; spring triangles, fall circles) and annual (bottom). Red (first quartile Fulton's K ≤ 9.31), yellow (second and third quartiles 9.31 < Fulton's K ≤ 11.27), and green (fourth quartile Fulton's K > 11.27).

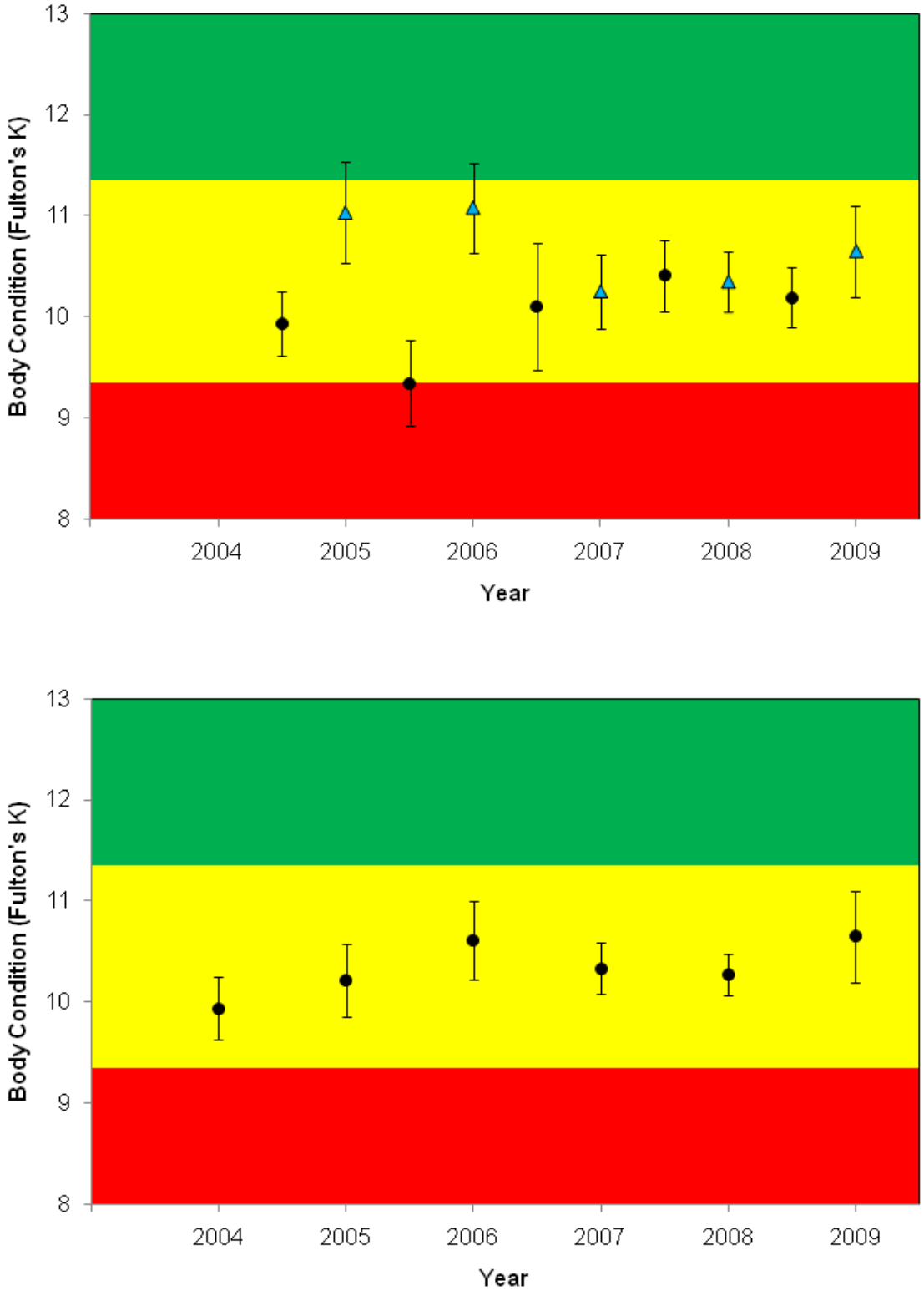

Figure 17. Mean body condition (Fulton's K, standard error bars) in Water Conservation Area 3A Holiday Park for season (top; spring triangles, fall circles) and annual (bottom). Red (first quartile Fulton's K ≤ 9.31), yellow (second and third quartiles 9.31 < Fulton's K ≤ 11.27), and green (fourth quartile Fulton's K > 11.27).

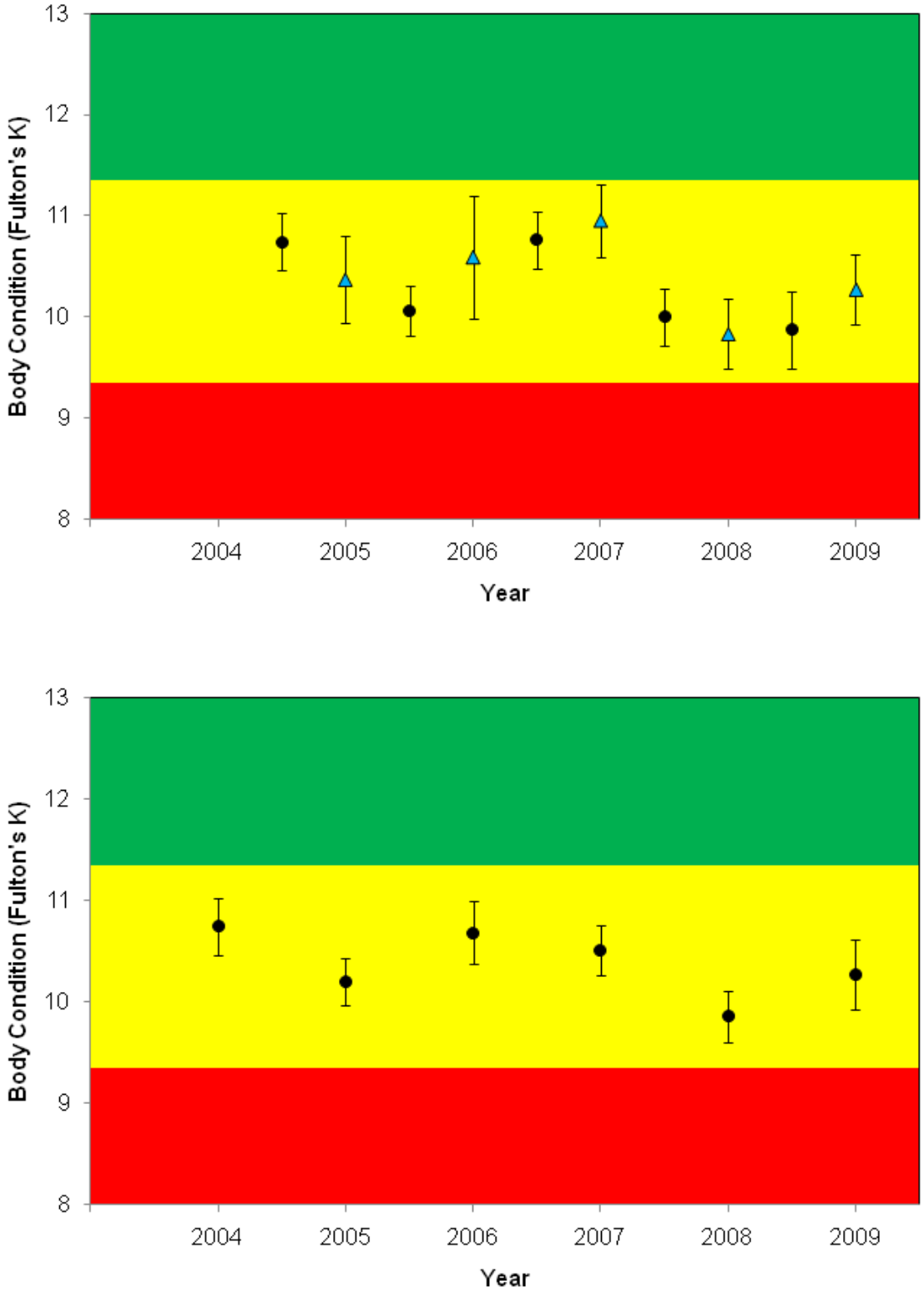

Figure 18. Mean body condition (Fulton's K, standard error bars) in Water Conservation Area 3A North 41 for season (top; spring triangles, fall circles) and annual (bottom). Red (first quartile Fulton's K ≤ 9.31), yellow (second and third quartiles 9.31 < Fulton's K ≤ 11.27), and green (fourth quartile Fulton's K > 11.27).

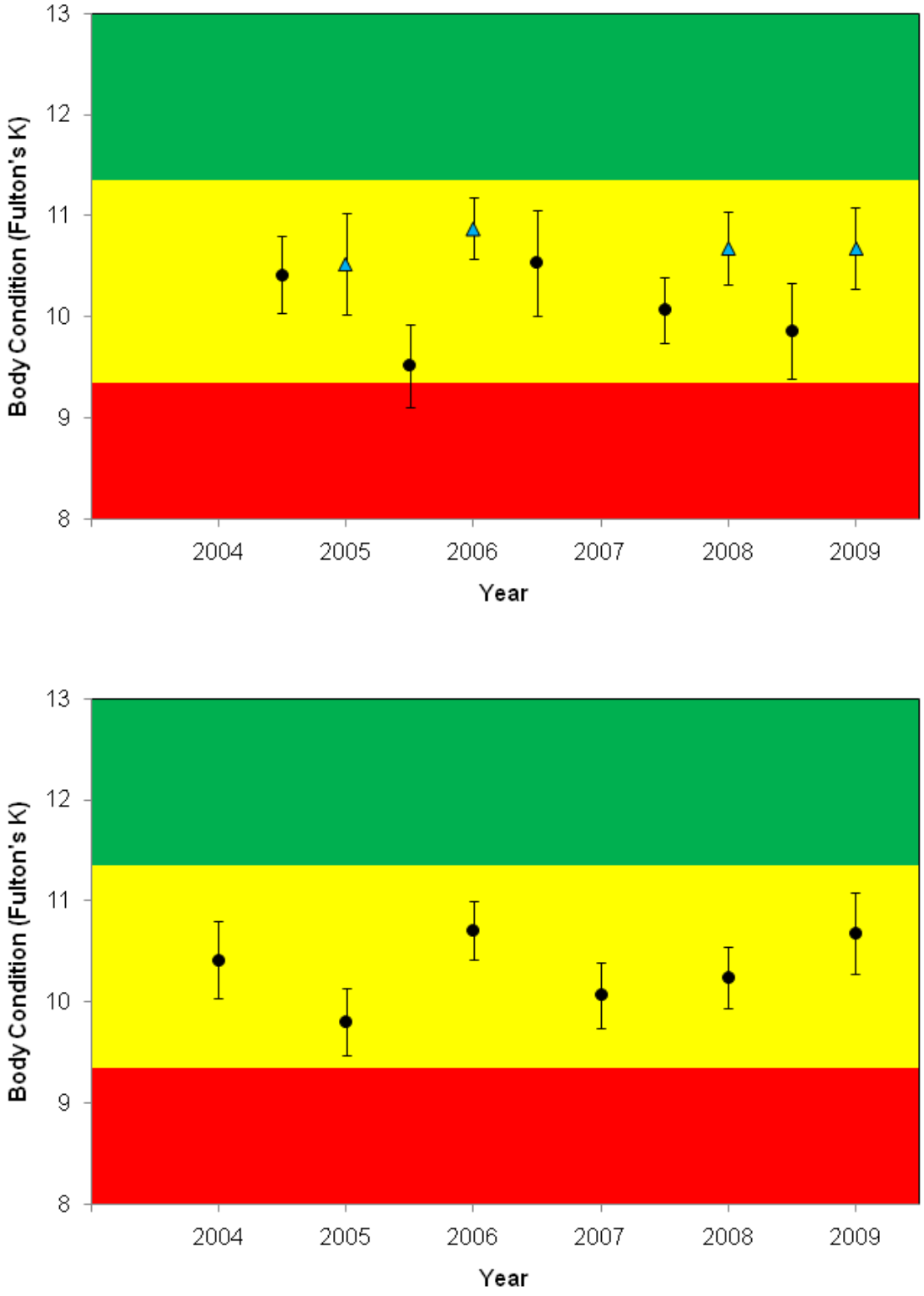

Figure 19. Mean body condition (Fulton's K, standard error bars) in Water Conservation Area 3A Tower for season (top; spring triangles, fall circles) and annual (bottom). Red (first quartile Fulton's K ≤ 9.31), yellow (second and third quartiles 9.31 < Fulton's K ≤ 11.27), and green (fourth quartile Fulton's K > 11.27).

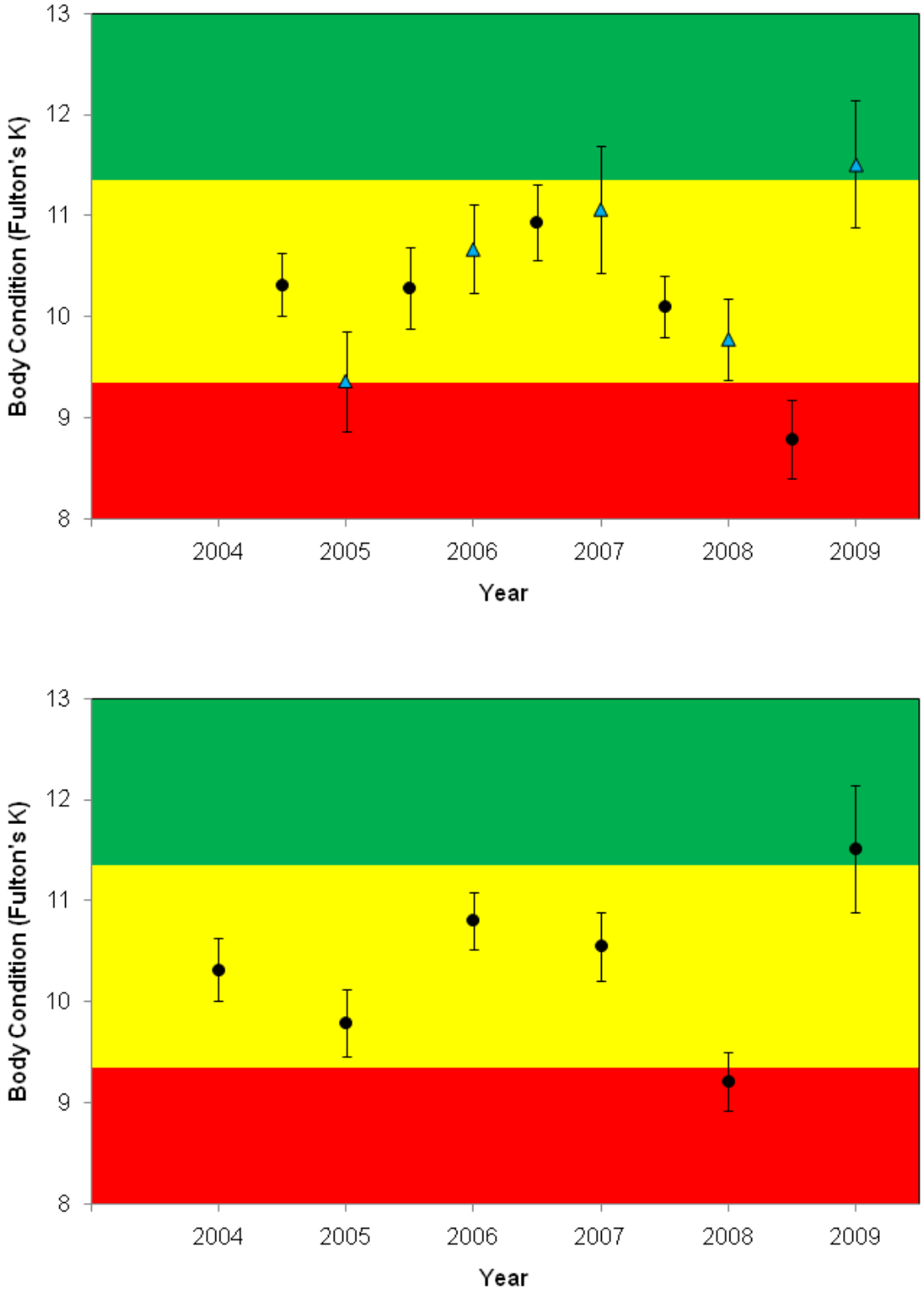

Figure 20. Mean body condition (Fulton's K, standard error bars) in Water Conservation Area 3B for season (top; spring triangles, fall circles) and annual (bottom). Red (first quartile Fulton's K ≤ 9.31), yellow (second and third quartiles 9.31 < Fulton's K ≤ 11.27), and green (fourth quartile Fulton's K > 11.27).

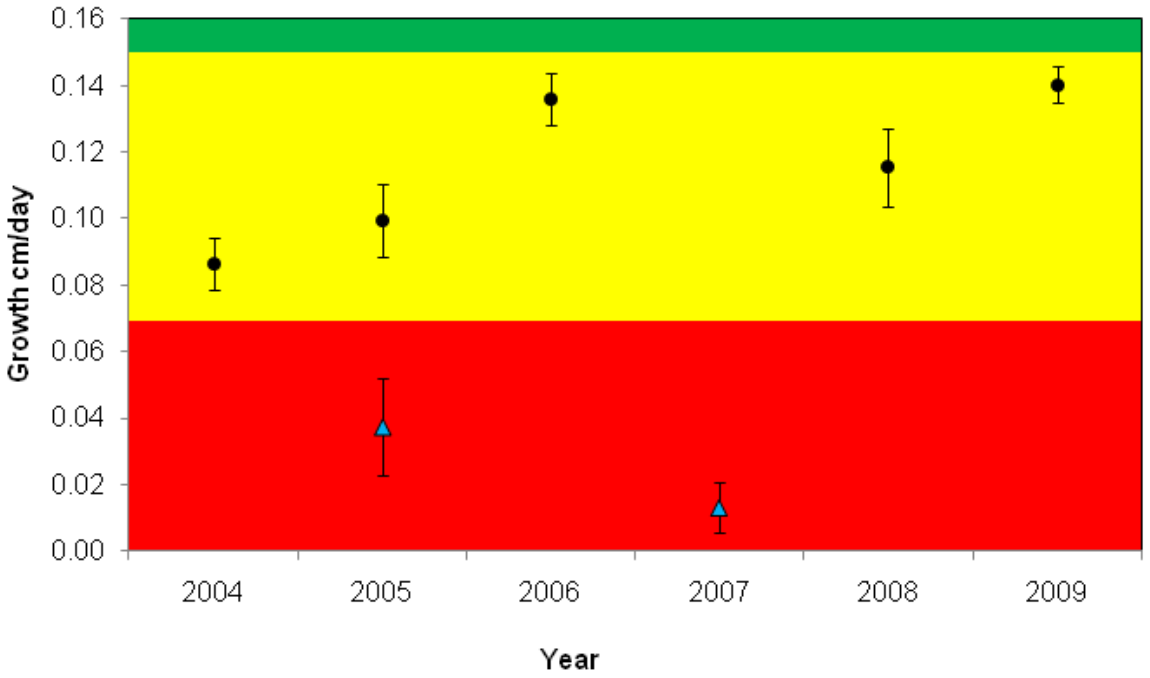

Figure 21. Plots of average juvenile crocodile growth (cm/day) over time by area (BWC-circles, CLNWR-triangles) with standard error bars.

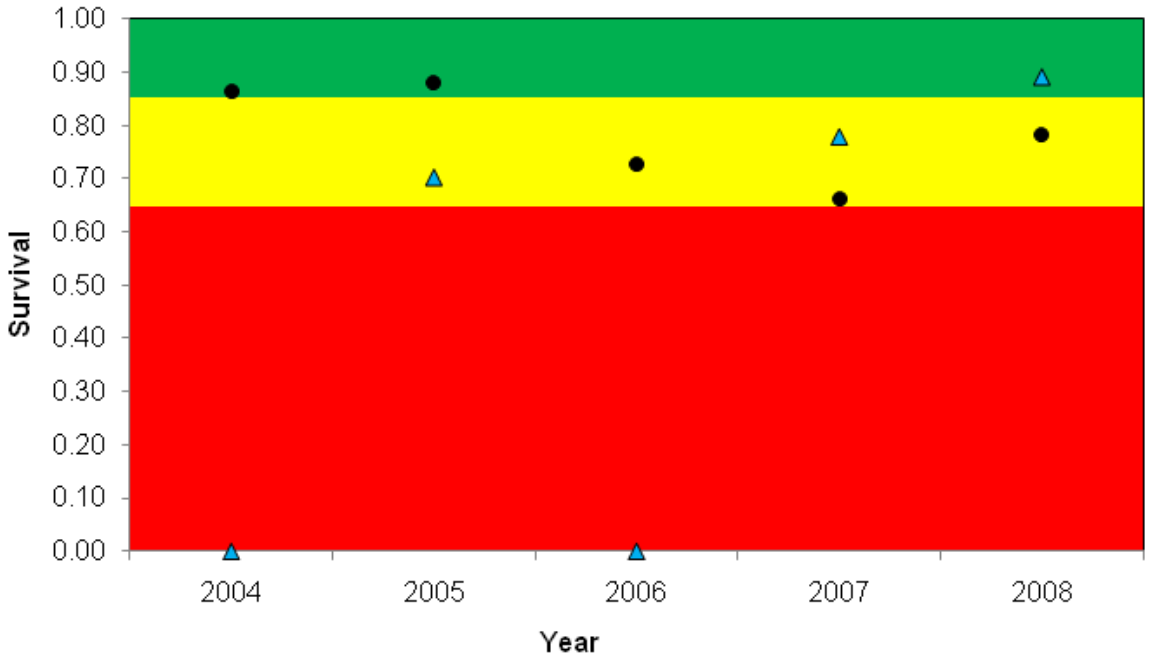

Figure 22. Plots of juvenile crocodile survival (% survival first six months) over time by area (BWC-circles, CLNWR-triangles).

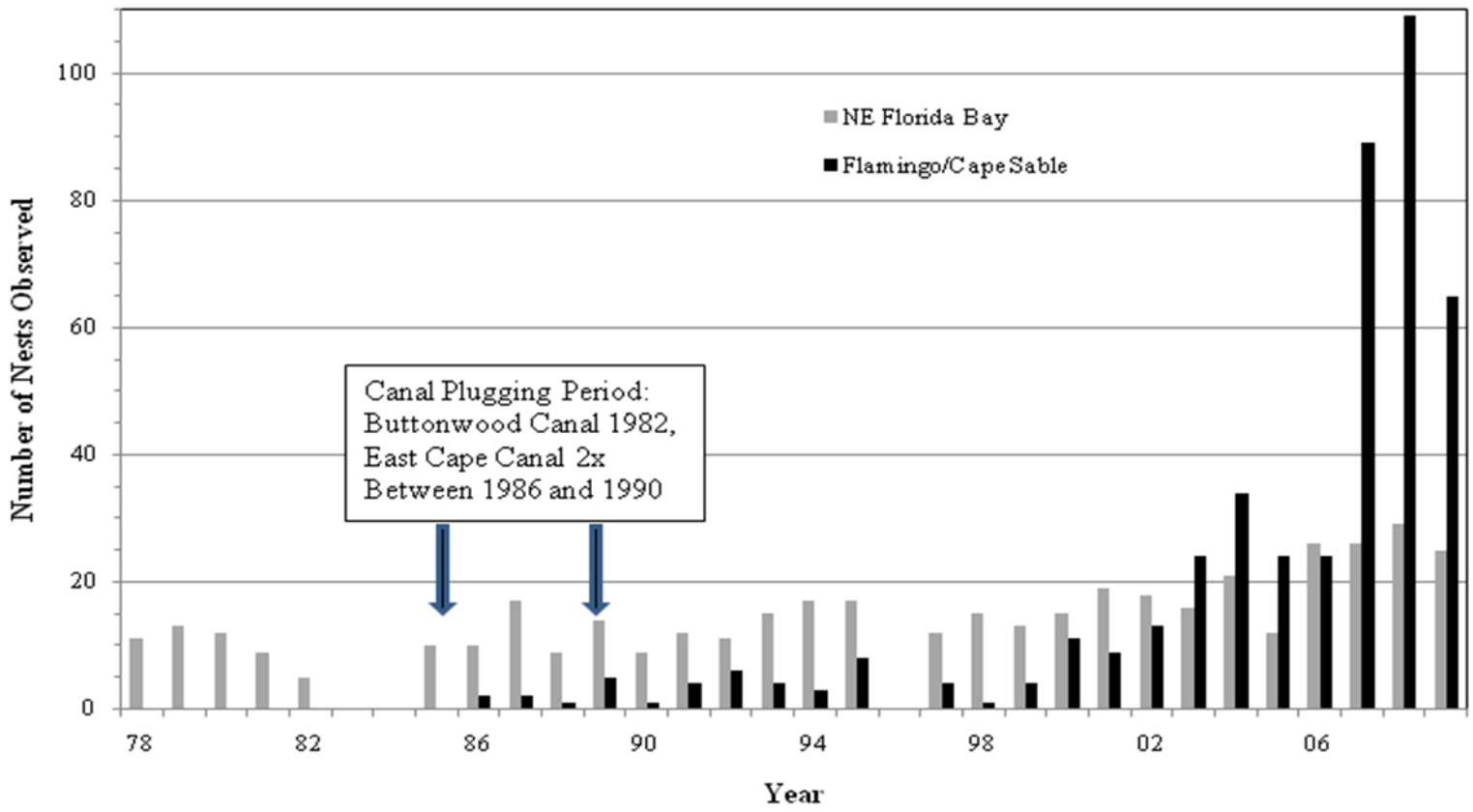

Figure 23. Distribution of crocodile nesting between NE Florida Bay and the Flamingo/Cape Sable area between 1978 and 2009.