Chapter 9: Kissimmee River Restoration and Other Kissimmee Basin Initiatives

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SUMMARY

The Kissimmee Basin experienced below average rainfall in Water Year 2020 (WY2020; May 1, 2019–April 30, 2020). Rainfall totals of 47.8 inches over the Upper Kissimmee Basin (UKB) and 47.0 inches over the Lower Kissimmee Basin (LKB) were 2.5 inches and 0.8 inches below their long-term averages, respectively. Despite overall normal conditions, operation of the S-65 water control structure faced challenges from periods of heavy rainfall and efforts to balance multiple and sometimes competing objectives. The IS-14-50.0 discharge plan for the S-65/S-65A water control structures was successfully implemented in the 2019 wet season; although it did not result in duration of floodplain inundation comparable to the reference period, it produced a single 49-day period with bankfull discharge or greater. Requests to moderate lake ascension and recession rates to the extent possible were implemented in Lakes Kissimmee, Cypress, and Hatchineha (Headwaters Lakes), Lake Tohopekaliga, and East Lake Tohopekaliga to benefit fish and wildlife.

The Kissimmee River Restoration Project (KRRP) entered the nineteenth year of an Interim Period that began with completion of the first phase of construction and is expected to continue until mid-2021, when construction and land acquisition are scheduled for completion and the Headwaters Revitalization Schedule (HRS) will be implemented.

Since 2005, this chapter has reported results of numerous monitoring studies being conducted in the Kissimmee River and floodplain in the LKB and the Headwaters Lakes as part of the Kissimmee River Restoration Evaluation Program (KRREP) by the South Florida Water Management District (SFWMD or District) and in the UKB by SFWMD and partner agencies. Results are reported as new data and analyses become available in a given water year. Brief abstracts of study findings are presented in this section; for results and other details such as study methods, refer to the corresponding subsections later in the chapter.

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LOWER KISSIMMEE BASIN

- **KRRP Construction Status.** Physical construction of the KRRP is predicted to be completed by the end of 2021. Reach 2 erosion repairs, and the S-69 weir at the terminus of the project are the last remaining construction features.
- **KRREP Hydrology**. Targets for KRREP Expectation 3: Hydroperiod Requirements for broadleaf marsh (BLM), the dominant and most characteristic wetland plant community of the pre-channelization floodplain, and Expectation 4: Recession Events, were evaluated in the Kissimmee River Basins Planning Window 2020 (PW2020; June 1, 2019–May 31, 2020). One floodplain inundation event met the depth criterion of at least 1 foot (ft); however, it lasted only 67 days, far shorter than the 210-day duration criterion. Two recession events occurred, one was due to discharge for flood control, instead of the single recession event that was typical of pre-channelization. One event had a recession rate less than the 1 ft per 30 days maximum recession rate criterion; the second had a rate of 1.21 ft per 30 days, which is in excess of the maximum rate criterion. Consequently, the targets were not met for either expectation. The targets for Expectations 3 and 4 have not been met in any year of the Interim Period (2001–2020). While it may not be possible to fully meet these targets prior to implementation of the HRS, performance can be improved now by implementation of discharge plans that use 1,400 cubic feet per second (cfs) as a minimum discharge when Headwaters Lakes stage is above a specified threshold.
- **KRREP Dissolved Oxygen.** Concentrations of daytime dissolved oxygen (DO) in the river channel of the Kissimmee River Phase I restoration area continued to be higher in WY2020 than pre-restoration levels. Three out of the four metrics used to evaluate DO response were met in WY2020. Mean daytime DO concentrations exceeded the dry season (November–May) and wet season (June–October) target ranges in WY2020. The third metric, frequency of DO concentration >1 milligram per liter (mg/L) within 1 meter (m) of the channel bottom, exceeded its 50% target annually. The fourth metric, frequency of concentrations > 2.0 mg/L, was 84% and did not meet its 90% target, because of two anoxia events. Two declines in DO concentration occurred, one in July 2019 when DO declined to zero for 10 days, resulting in a large fish kill, and another on August 4 when DO declined to 1 mg/L for 23 days.
- **Invasive Vegetation Mapping on the Kissimmee River Floodplain.** In the aftermath of river restoration, several invasive wetland vegetation species have appeared on the Kissimmee floodplain. In an effort to measure the impact of these invasions, a cell-based mapping method was tested in the last year that offered quicker results than can be obtained from normal vegetation mapping methods. The key to a quicker turnaround is in mapping dominant classes within predetermined hectare-size cells rather than doing more detailed polygon-based mapping.
- **KRREP Floodplain Vegetation Management.** In the past year, herbicide application and biocontrol agents were used to control invasive plants in the Kissimmee River floodplain. Post-treatment monitoring data are being collected to guide future management actions to control these invasive species. Populations of the brown lygodium moth (*Neomusotima conspurcatalis*) continue to be released to combat the invasive exotic old-world climbing fern (*Lygodium microphyllum*).
- **Non-native Apple Snails.** The non-native apple snail *Pomacea maculata* has become well established within the KRRP area. Although mean density of snails was highly variable, they remained abundant enough to support foraging and intermittent snail kite (*Rostrhamus*

sociabilis) nesting. The presence of this abundant, although exotic, prey item within the KRRP area may be a positive sign that could continue to benefit the endangered snail kite.

- **KRREP Fisheries.** During an anoxic event in June 2019, centrarchid abundance was reduced by 93% and included a total loss of largemouth bass (*Micropterus salmoides*). Six months later, centrarchid abundance was 20% greater than the pre-event conditions reported in May. However, virtually all of the increase in centrarchid abundance was due to small age-0 (young of the year) bluegill (*Lepomis macrochirus*) that likely were spawned after the anoxic event. Limiting or preventing access to the floodplain habitat during spawning season likely has negative impacts on the river's centrarchid community. Largemouth bass commonly spawn during January–April (dry season). Unfortunately, the floodplain has been inundated during bass spawning season only three of the past seven years. Bluegill can spawn during both the dry and wet season (summer). Thus, their extended spawning season may have helped them recover to some extent from the impacts of the anoxic event in 2019 more rapidly that largemouth bass.
- **KRREP Wading Bird Abundance.** Mean monthly wading bird abundance within the restored portions of the river during the 2019–2020 season was 14.2 ± 3.6 birds per square kilometer (km^2), bringing the three-year (2018–2020) running average to 43.9 ± 6.8; significantly greater than the restoration expectation of 30.6 birds/km^2. The long-term annual three-year running mean (2002–2020) is 42.9 ± 3.4 birds/km^2, significantly greater than the restoration expectation of 30.6 birds/km^2.
- **KRREP Waterfowl Abundance and Species Richness.** Waterfowl abundance during the 2019–2020 survey was 3.2 ± 0.7 ducks/km^2, bringing the three-year (2018–2020) running average to 26.6 ± 7.4 ducks/km^2, significantly greater than the restoration target of 3.9 ducks/km^2. The long-term mean annual three-year running average (2002–2020) of waterfowl abundance is 12.7 ± 1.5 birds/km^2, significantly greater than the restoration expectation of 3.9 birds/km^2. The three-year species total for 2018–2020 was 5, below the restoration target for waterfowl species richness of ≥ 13 (three-year species total).
- **KRREP Wading Bird Nesting.** Wading bird nesting colonies within the KRRP and the Headwaters Lakes were not surveyed during the 2019–2020 dry season due to weather and helicopter flight scheduling conflicts.

UPPER KISSIMMEE BASIN

- **Habitat Enhancement.** The Florida Fish and Wildlife Conservation Commission (FWC) conducted a lake drawdown habitat enhancement project on East Lake Tohopekaliga this water year. The goal was to counteract anthropogenic influences, namely stabilization of lake stages and nutrient enrichment, which have resulted in the dense growth of nuisance and exotic plants and excessive accumulation of organic sediments. Temporary pumps were deployed at S-59 and, starting in January 2020, they were used to lower water levels to 53 ft NGVD29, 2 feet below normal low pool. Lower water levels temporarily exposed approximately 875 acres (ac) of additional littoral zone around the lakeshore allowing the FWC contractor to scrape target plants and organic sediments, improving 105 ac on the east shore, and consolidating this material into two 3.5-ac spoil islands for long-term storage and deposit areas for future projects (South Florida Engineering and Consulting, LLC 2018). Additional management activities included herbicide application and prescribed burning of approximately 200 ac of cattail along the north and west shoreline.
- **Vegetation Monitoring.** SFWMD completed the fifth year of long-term vegetation monitoring data collection in East Lake Tohopekaliga, Lake Tohopekaliga, and Lake

Kissimmee. The sampling is intended to establish baseline conditions for comparison with data collected after completion of the KRRP, which will coincide with HRS implementation.

- **Fisheries.** FWC conducted electrofishing to collect fish community data and largemouth bass population data in fall 2018 and spring 2019, respectively. Community data showed more forage fish and fewer sunfish (*Lepomis* spp.) than average in samples from both Lake Kissimmee and Lake Tohopekaliga. Simpson's diversity and species richness were about average on Lake Tohopekaliga but, on Lake Kissimmee, Simpson's diversity was very low likely due to many threadfin shad (*Dorosoma petenense*) represented in the sample. Largemouth bass frequency distributions indicate a shift to a mostly adult bass population on Lake Kissimmee, whereas Lake Tohopekaliga shifted toward a much younger population.
- **Snail Kites.** Overall, the 2019 snail kite breeding season in South Florida saw a dramatic decrease in nesting effort from 2018. Nesting within the Kissimmee Chain of Lakes (KCOL) was close to average for the region but made up a significant proportion of overall nesting due to lack of nesting in other areas of the state. Lake Tohopekaliga rebounded from three consecutive years of declining nesting effort and success. Although nesting effort on Lake Kissimmee declined from 2018, the nesting effort in 2019 was still the second highest level on recent record.
- **Alligators.** FWC monitors American alligator (*Alligator mississippiensis*) populations using spotlight surveys at night and found high populations on Lakes Tohopekaliga, Kissimmee, and Hatchineha for the 2019 sampling period. Populations increased slightly from 2018 and continue to follow an increasing trend over the last 9 to 12 years. East Lake Tohopekaliga has a very small alligator population (91 individuals in 2018) compared to other lakes. East Lake Tohopekaliga and Lake Cypress alligators continue to show stable populations with modest decreases in this year's population compared to initial surveys in the early-2000s.

INTRODUCTION

SFWMD continues to coordinate with the United States Army Corps of Engineers (USACE) on KRRP construction and is integrating KRRP and KRREP with management activities throughout the Kissimmee Basin and Northern Everglades region. The primary goals of these efforts are to (1) restore ecological integrity to the Kissimmee River and its floodplain, (2) collect ecological data to evaluate river restoration and support water management decision making for river restoration and other goals, (3) enhance and sustain natural resource values in the KCOL, and (4) retain the flood reduction benefits of the Central and South Florida Flood Control Project (C&SF Project) in the Kissimmee Basin. In addition to projects under the KRREP, SFWMD also manages the KCOL and Kissimmee Upper Basin Monitoring and Assessment Project. See Koebel et al. (2018) for historical information about development of the KRRP and KRREP. The geographic scopes of projects in the Kissimmee Basin are shown in **Figure 9-1**.

This year's update on the KRREP evaluations includes analyses of newly available data from studies of hydrology, DO, apple snails, invasive vegetation, fish, wading birds, and waterfowl. This subset of restoration evaluation studies assesses the level of response of critical ecosystem components to physical restoration under Interim (pre-project completion) hydrologic conditions based on new data that have not been reported in previous *South Florida Environmental Report* (SFER) chapters. Results from these studies provide information for sound water management decision making as the KRRP progresses and will guide water management after the project is complete.

The Kissimmee Basin includes more than two dozen lakes in the KCOL, their tributary streams and associated marshes, and the Kissimmee River and floodplain (**Figures 9-2** and **9-3**). The basin forms the headwaters of Lake Okeechobee and the Everglades; together, they comprise the Kissimmee-Okeechobee-Everglades system. In the 1960s, the C&SF Project extensively modified the Kissimmee Basin's water resources by constructing canals and installing water control structures for flood control. In the LKB, construction of the 56-mile long C-38 canal through the Kissimmee River resulted in profoundly negative ecological consequences caused by elimination of flow in the original river channel, which also prevented seasonal inundation of the river's floodplain. These and other environmental losses led to legislation authorizing the federal-state KRRP, for which ground was broken for the first construction phase in 1999. The District has been working since the early 1990s to collect baseline data and to evaluate and operate completed phases of the KRRP through the KRREP. See Koebel and Bousquin (2014) for more details regarding environmental losses in the LKB.

This chapter is an update to Chapter 9 of the 2020 SFER – Volume I (Koebel et al. 2020). Its purpose is to report new results from Kissimmee Basin monitoring studies that were active in Planning Window 2019-2020 (PW2020; June 1, 2019–May 31, 2020), specifically those conducted under SFWMD's KRREP and several projects in the KCOL. The chapter also summarizes Kissimmee Basin hydrologic conditions and water management in PW2020, as well as construction and management activities and the status of various other projects throughout the Kissimmee Basin.

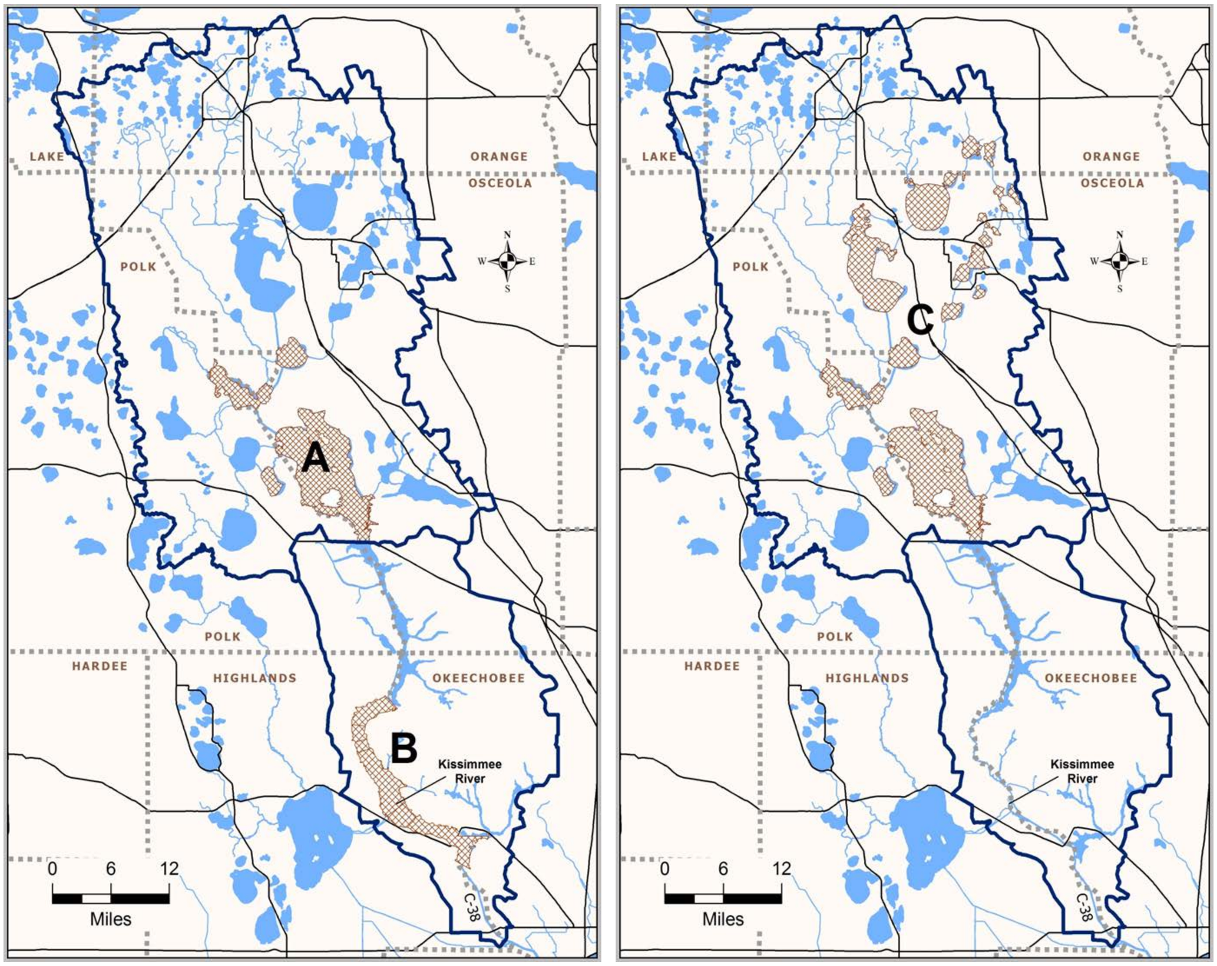


Figure 9-1. Geographic scopes (colored, hatched areas on maps) of major initiatives in the Kissimmee Basin including the (A) Headwaters Lakes components of the KRRP, (B) KRRP, and (C) KCOL and Kissimmee Upper Basin Monitoring and Assessment Project.

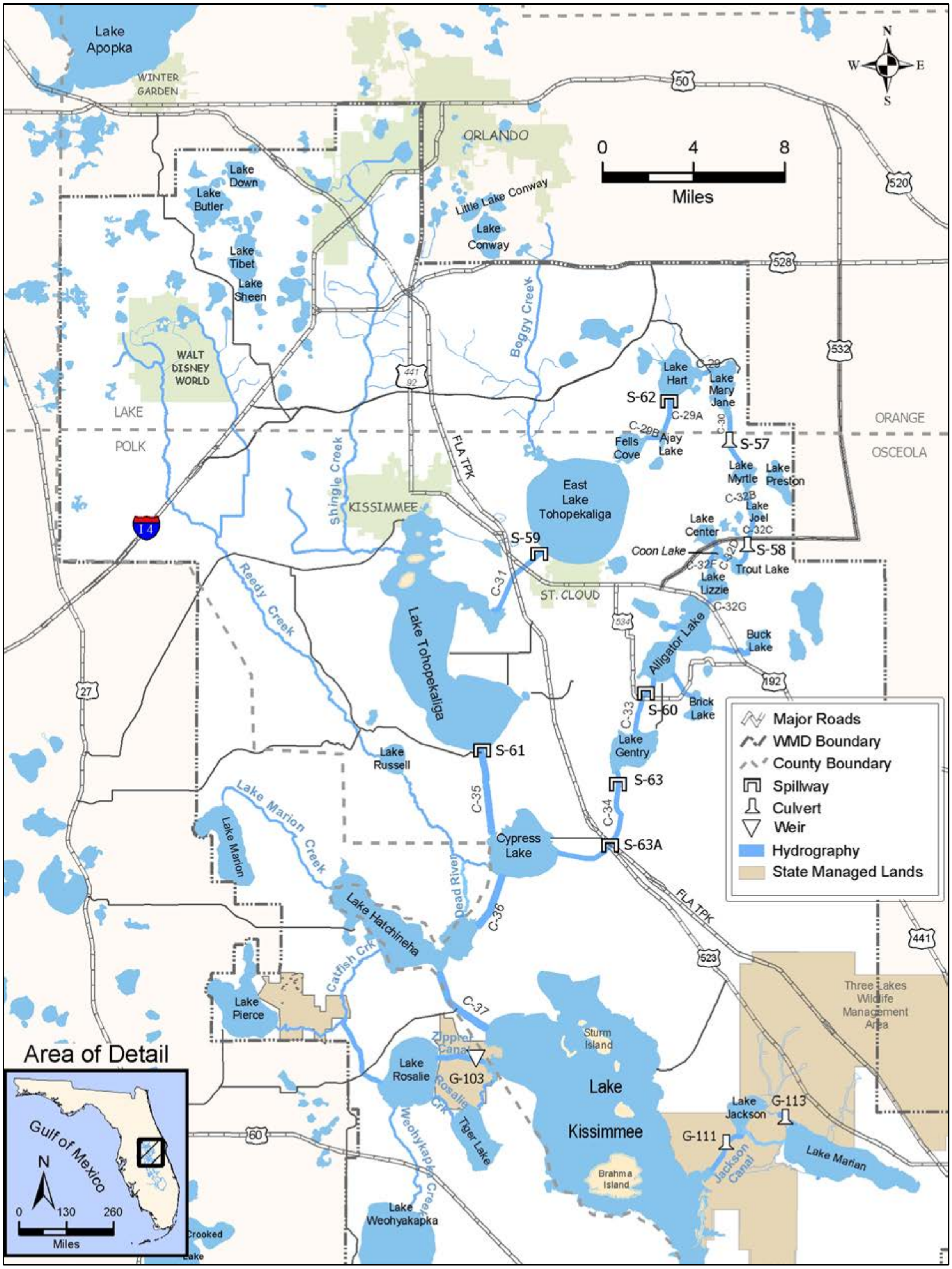


Figure 9-2. Upper Kissimmee Basin (UKB). (Note: WMD – South Florida Water Management District.)

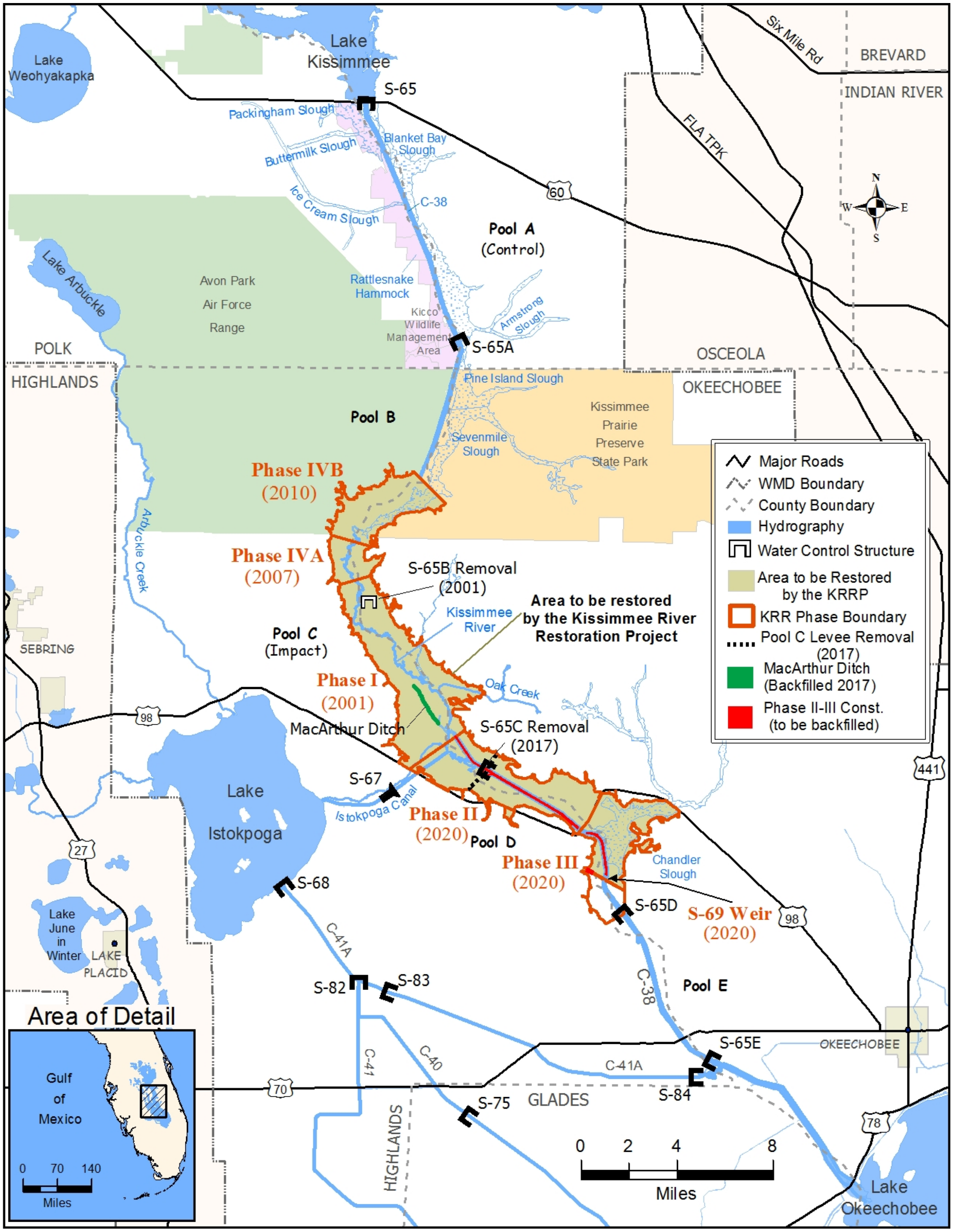


Figure 9-3. Lower Kissimmee Basin with actual and projected completion dates of construction phases. (Note: KRR – Kissimmee River Restoration Project.)

KISSIMMEE RIVER RESTORATION PROJECT UPDATE

Restoration components include (1) acquiring 65,603 ac of land in the LKB, (2) backfilling approximately 23 miles of the C-38 canal (over one-third of the canal's length) from the lower end of Pool D north to the middle of the former Pool B, (3) reconnecting the original river channel across backfilled sections of the canal, (4) recarving sections of river channel destroyed during C-38 canal construction, (5) removing the S-65B and S-65C water control structures and associated tieback levees, and (6) acquiring land and modifying portions of the river's Headwaters Lakes to allow the additional storage volume needed to meet the hydrologic criteria for restoration of the Kissimmee River. The material used for backfilling is that which was dredged during construction of the C-38 canal. Composed primarily of sand and coarse shell, this spoil material was deposited in large mounds adjacent to the canal.

Reconstruction of the river–floodplain's physical template is being implemented in four construction phases (**Figure 9-2**), currently projected for completion in 2021 (**Table 9-1**). Reaches 2 and 3 (Phases II and III), are the last major phases of construction. Reach 3 began in 2015 and was completed in 2016. The Reach 2 contract was awarded in January 2016 and is scheduled for completion in 2021. The S-69 weir that will serve as the terminus of the backfilled sections of canal is also projected for completion in 2021 (**Figure 9-4**).

Table 9-1. Sequence of backfilling construction reaches of the KRRP with selected benefits.

Construction Sequence	Name of Construction Phase	Timeline	Backfilled Canal (miles)	River Channel Recarved (miles)	River Channel to Receive Reestablished Flow (miles)	Total Area (ac)	Wetland Gained (ac)	Location and Other Notes
1	Reach 1 (Phase I) Project Area	1999–2001 (complete)	7.5	1	14	9,506	5,792	Most of Pool C, small section of lower Pool B
2	Reach 4A (Phase IVA) Project Area	2006–2007 (complete)	1.8	1	4	1,352	512	Upstream of Phase I in Pool B to Weir #1
3	Reach 4B (Phase IVB) Project Area	2008–2010 (complete)	3.9	4	6	4,183	1,406	Upstream of Phase IVA in Pool B (upper limit near location of Weir #3)
4	Reaches 2 and 3 (Phases II & III) Project Areas	2015-2021 (projected)	8.5	4	16	9,921	4,688	Downstream of Phase I (lower Pool C and Pool D south to the CSX Railroad bridge)
Restoration Project Totals			**21.7**	**10**	**40**	**24,963**	**12,398**	

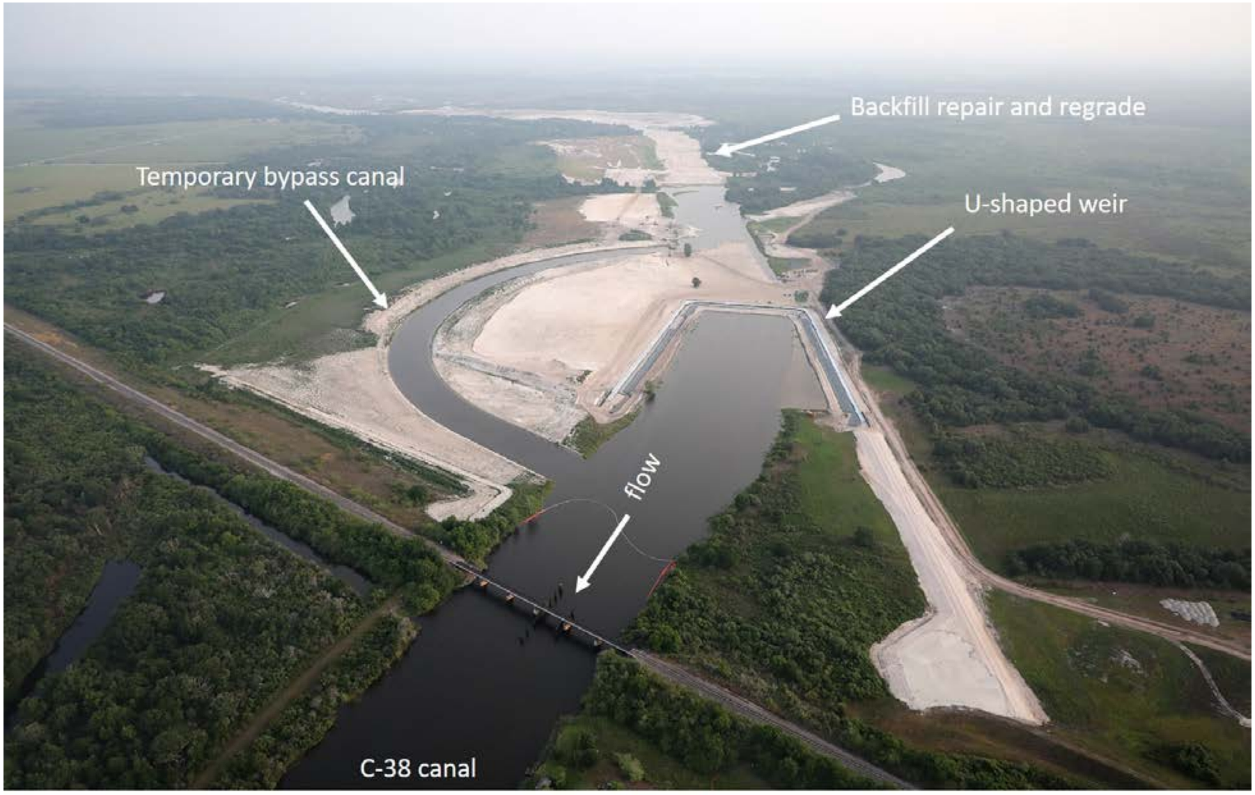


Figure 9-4 KRRP Reach 3 backfill repair work and S-69 weir construction.
Photo by Brent Anderson on February 13, 2020.

The KRRP will culminate with modification of the Kissimmee Basin water control structure operations including implementation of a new stage regulation schedule, called the Headwaters Revitalization Schedule (HRS), to operate the S-65 water control structure. The HRS will allow lake water levels to rise to 1.5 ft higher than the current S-65 schedule and will increase the water storage capacity of Lakes Kissimmee, Hatchineha, Cypress, and Tiger by approximately 100,000 acre-feet (ac-ft) allow storage of water to more closely approximate the historic flows needed for restoration of the Kissimmee River and its floodplain wetlands. Ninety-nine percent of the 36,612 ac of land in the UKB that will be affected by the higher water levels have been acquired, and all projects needed to increase the conveyance capacity of UKB canals and structures are in place to accommodate the larger storage volume. The few remaining land acquisitions are expected to be finalized in 2020.

Because of the time lag between completion of the first reach of the construction project and implementation of the HRS, in 2001 USACE authorized an interim regulation schedule for S-65 that allows SFWMD to make releases from S-65 when its headwater stage is within a certain range below the regulation line (termed “Zone B”). Zone B allows releases from S-65 for environmental purposes when flood control releases (stage above the regulation line or Zone A) are not needed. It is used to maintain flow in the reach of the restored river channel throughout the year and to allow seasonal variability. Environmental releases, according to this interim schedule, began in July 2001 after the Phase I construction was complete and lake levels began to rise following the 2000–2001 drought. Zone B releases have allowed continuous flow to the river since that time except for a 252-day period of drought in 2006–2007. Use of Zone B releases has been beneficial to the hydrology in completed sections of the KRRP, but does not provide the full benefits that the HRS is expected to provide when implemented.

CONSTRUCTION STATUS

The Reach 2 backfilling contract was awarded by USACE in 2016. Backfill of the C-38 canal in the Reach 2 area began in January 2017 and will continue into 2021. The $26.13 million Reach 2 contract is filling an additional seven miles of the C-38 canal and has removed water control structure S-65C, routing the flow of water to the native channel and floodplain of the Kissimmee River, which reestablishes hydrologic continuity between the river and floodplain in former Pools C and D for the first time since the C-38 canal was completed in 1971. Reach 2 backfill was nearly completed upon the event of Hurricane Irma when extremely high discharge and flooding throughout the Reach 2 construction area resulted in severe erosion of the recent backfill. The high water and discharge associated with the hurricane also caused erosion in the Reach 3 restoration area, which was previously completed in 2016. Both areas have been surveyed for erosion and evaluated for repair. Repairs consist of backfilling and regrading erosion damage areas. Armoring is also being installed at highly susceptible areas for future erosion, such as where backfill terminates at a river channel. Repair work in both Reach 2 and Reach 3 are ongoing and scheduled for completion in 2021. **Table 9-2** provides brief descriptions of remaining construction activities. A complete list of contracts can be found in Koebel et al. 2017.

Table 9-2. Remaining KRRP construction.
See Koebel et al. (2017) for a complete chronology of construction events.

Contract Number	Project Name and Description	Status	Construction		
			Projected or Actual Start Date	Projected or Actual End Date	Cost
10	Reach 2 Backfilling – New channels will be dredged, 6.5 miles of the C-38 canal will be backfilled, and the S-65C structure will be removed.	Under construction	January 2017	January 2021	$26.1 million
12A	S-69 Weir – The S-69 weir will serve as the terminus of the C-38 canal backfill, maximizing the area of wetlands to be rehydrated in the Kissimmee River floodplain. The weir will dissipate the energy of flood flows as they transition from the Kissimmee River floodplain to the remnant C-38 channel.	Awarded 2017	November 2018	October 2020	$15–$25 million

Note: Dates and costs do not include repair costs for erosion damages in Reach 2 Backfilling caused by Hurricane Irma.

KISSIMMEE BASIN HYDROLOGIC CONDITIONS AND WATER MANAGEMENT IN PLANNING WINDOW 2019-2020

This section describes hydrologic conditions in the UKB and LKB and their relationship to water management activities in PW2020. The planning window is used in this section and the following *Kissimmee River Restoration Evaluation Program* section in lieu of water year for alignment with KRREP operational planning, seasonal recommendations and ecological monitoring schedules, all of which are tied to the wet (June–October) and dry (November–May) seasons, whereas the water year is not. Lake regulation schedules in the UKB reach their low pool stages on May 31, coincident with the beginning of the wet season.

The discussion within this section focuses on the timing and quantity of rainfall in the Kissimmee Basin, environmental recommendations for water management in the basin, and the rainfall- and water management-driven temporal patterns of discharge and stage that resulted.

In the LKB, SFWMD uses water control structures S-65, S-65A, and S-65D to manage flow to and water levels in the Kissimmee River and its floodplain (**Figure 9-2**) within the KRRP. Operation of these structures is intended to allow restoration of the river-floodplain ecosystem with consideration of other authorized environmental and flood control project objectives in the LKB and UKB.

In the UKB, water control structures divide the KCOL into seven groups of one or more lakes interconnected by canals (**Figure 9-2**), each group with its own regulation schedule (**Figure 9-5**). Surface water from the northern UKB flows to the Headwaters Lakes before being discharged through water control structures S-65 and S-65A to the C-38 canal, which flows to reconstructed sections of the KRRP (**Figure 9-3**). Completion of restoration construction in 2021 and implementation of the HRS are expected to provide additional water storage for discharge to the Kissimmee River and its floodplain. However, appropriate water management during the Interim Period should realize substantial ecological benefits in the northern Phase I and Phase IV floodplain (**Figure 9-3**), where restoration construction has been completed.

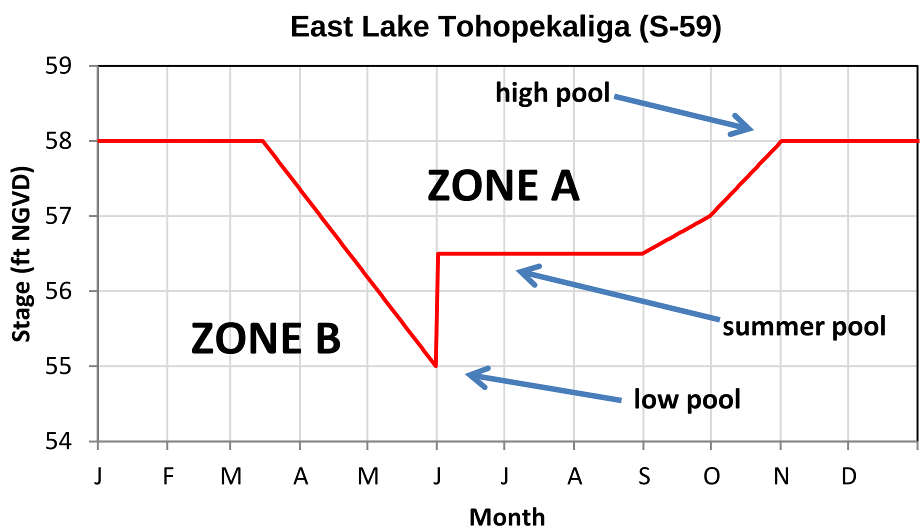


Figure 9-5. Example regulation schedule (East Lake Tohopekaliga) showing the regulation line (red) that separates Zone A (above the line) from Zone B (below the line). When lake stage is in Zone A, releases are mandatory for flood control; when stage is in Zone B, releases are discretionary for environmental purposes. All lakes in the KCOL have a similar schedule with a Zone A and Zone B.

Via S-65 and S-65A, the Headwaters Lakes are the main source of flow to reconstructed sections of the Kissimmee River and its floodplain. As water is released, stage in the Headwaters Lakes declines unless rainfall and runoff into the lakes offsets the volume of water released. Releases made from other water bodies upstream of the Headwaters Lakes, especially Lake Tohopekaliga and East Lake Tohopekaliga (e.g., for flood control in those lakes or to meet stage targets) also raise stages in the Headwaters Lakes. Therefore, discharge operations at S-65 and S-65A affect both stage in the Headwaters Lakes and flow to and stage in the Kissimmee River. Operation of structures for lake groups north of the Headwaters Lakes also affect stage in the Headwaters Lakes in addition to indirectly affecting water management operations for the KRRP.

One challenge in the management of flow to the Kissimmee River is limited storage in Pool A, the reach of the C-38 canal between S-65 and S-65A. This is due to the narrowness of the C-38 canal in Pool A (only 250 ft wide) and the limited range of headwater stage fluctuation that is currently allowed at S-65A (46.3-47.5 ft NGVD29). Consequently, direct rainfall and local basin runoff from even small, localized rainfall events can cause water levels in Pool A to rise rapidly, which can necessitate a reduction in the inflow at S-65 or a rapid increase in the outflow at S-65A, or both, to control rising water levels in Pool A. Increases in S-65A discharge must therefore often exceed the recommended maximum rates of discharge increases for KRREP (and similarly for rates of decrease). Because S-65A is the primary source of flow to the KRRP, this can have major consequences for restoration. If a rapid increase in discharge occurs after a period of low discharge, it can result in a rapid rise in water levels in the Kissimmee River causing or exacerbating the rate of depth increase and floodplain inundation, resulting in a "crash" in DO due to reduced photosynthesis and increased biological oxygen demand, which can cause a fish kill. The lack of storage in Pool A will continue to pose a challenge for water management after the KRRP is completed.

In addition to other divergent demands, in managing water operations for the KRRP, SFWMD must maintain the pre-KRRP level of flood control and work within the physical limitations of the system (e.g., the operational constraints and conveyance capacities of structures) and environmental conditions (e.g., rainfall) to achieve the best possible outcomes. Thus, the Kissimmee Basin is an ecosystem in which the progress and success of a federally-authorized $800 million ecosystem restoration project with mandated hydrologic and ecological goals (KRRP), nesting habitat for the endangered snail kite in the KCOL and Kissimmee River), and concerns about downstream ecosystems (including Lake Okeechobee and the St. Lucie and Caloosahatchee estuaries) are factors in water management decisions. In addition to the Kissimmee River, three of the UKB lake groups—the Headwaters Lakes, Lake Tohopekaliga, and East Lake Tohopekaliga—are a focus of discretionary environmental water management in the Kissimmee Basin, which may involve manipulation of discharge from these lakes. In some recent years, an additional factor has been in play with ongoing KRRP construction activities that at times can benefit from river flow rates that are less than required to inundate the floodplain.

THE 1,400-CFS DISCHARGE PLANS IN INTERIM AND FUTURE OPERATIONS

The 1,400- cfs discharge plans were originally developed to improve on the duration and continuity of floodplain inundation in the Kissimmee River during the Interim Period, but have also been adapted for the future system under HRS. Sustained floodplain inundation almost fully depends on discharge from S-65 then via S-65A because most of the volume of water passing through KRRP originates in the UKB and water levels cannot be maintained on the sloping Kissimmee River floodplain by the downstream water control structure (Anderson 2014). Prior to the use of the 1,400-cfs discharge plans, S-65 operations tended to alternate (often multiple times per year) between brief periods of high discharge for flood control as stage in the Headwaters Lakes rose to or above the regulation line, followed by rapid reductions in discharge to avoid subsequent stage declines in the lakes. The undesirable effect of such operations for the Kissimmee River, clearly visible in stage/discharge hydrographs (e.g., **Figure 9-6**), was sudden inundation of the floodplain followed by rapid termination of the flood event as discharge was reduced below river channel bankfull (approximately 1,400 cfs). The resulting pattern of intermittent, sudden floodplain inundation followed by rapid drying (often within a timeframe of weeks) was quite different from the single long, continuous flood event characteristic of the natural flood pulse, which occurred seasonally in the pre-channelized system (Koebel et al. 2019). Such operations affected floodplain water levels in both the wet and dry seasons. Rapid depth fluctuations in the Kissimmee River floodplain interfere with fish reproduction and recruitment, which depend on river channel/floodplain connectivity during the breeding season, disrupt wading bird foraging on the floodplain, and are unnatural and contrary to restoration goals, especially during the dry season (bird and centrarchid fish breeding season).

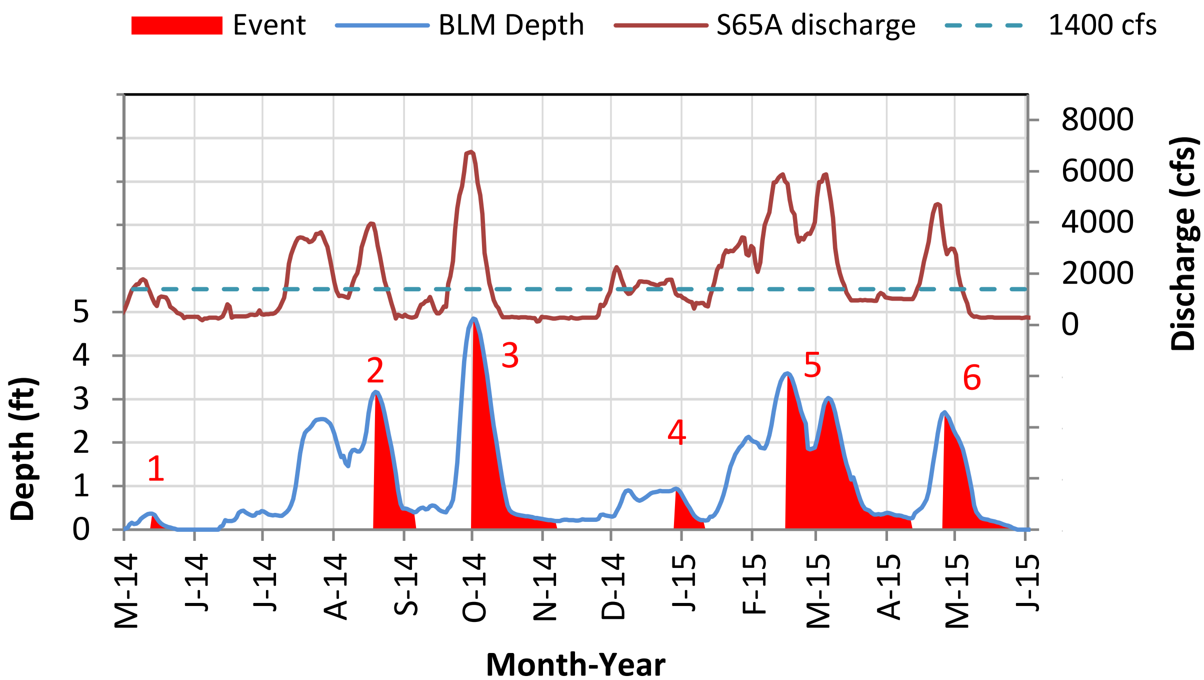


Figure 9-6. An example from PW2015 of unsuitable operations for Kissimmee River restoration. In this case, large, rapid increases in S-65A flood control levels of discharge driven by the regulation line in the Headwaters Lakes were followed by rapid reductions in discharge to maintain high stage in the lakes, causing six discrete floodplain inundation and recession events in the Kissimmee River. These events are described in more detail in Koebel et al. (2019) and other previous SFER chapters.

The rates of change in discharge and the range of discharges used in the discharge plans are conservative relative to the hydrologic needs of restoration, as discussed in Koebel et al. (2019) and previous SFER chapters. The maximum rates of discharge change used in the discharge plans (as shown in **Figure 9-7** lower left and **Table 9-3**) are known to be high relative to the hydrologic needs of restoration. They were originally defined to be as slow as feasible given operational realities, as a recognition of operational requirements (e.g., for flood control) and the need to approximate historic conditions for hydrologic restoration. The issue of dissolved oxygen (DO) sags during summer months, which is thought to be related to the rate of increase in flow and water depth, has highlighted this concern. For example, increases greater than 300 cubic feet per second per day (cfs/d) had an exceedance probability of 2.3% (8 times per year) in the Reference Period and 14.9% (54 times per year) in the Late Interim Period (**Figure 9-8**); the rate of increase in the discharge plans is typically four to five times higher than occurred on average in the Reference Period. On average, observed rates of increase in the Late Interim Period do not exceed the recommended rates (**Table 9-3**), although harmful exceedances of the preferred rates that are factors in DO declines may occur over short, critical periods that are not reflected in averages over a year. For example, rates of increase associated with DO crashes in June 2017 and June 2019 were as fast as 759 and 1,030 cfs/d, respectively, in both cases while discharge was less than 1,000 cfs, thus exceeding the recommended maximum rates of discharge increase. Both increases in discharge were followed by periods of anoxia (DO < 1 mg/L) that lasted at least 10 days. KRREP scientists and water managers are working to find operational solutions to this problem.

Stage and Discharge Guidance for Wet Season 2019.

Zone	KCH Stage (ft NGVD)	S-65/S-65A Discharge*
A	Above regulation schedule line.	Flood control releases as needed with no limits on the rate of discharge change.
B1	In flood control buffer zone (0.5 ft below the schedule line).	Adjust S-65 discharge so that S-65A discharge is between 1400 cfs at the buffer zone line and 3000 cfs at the schedule line.
B2	Between the Flood Control Buffer and the 50.0 ft line.	Adjust S-65 discharge to maintain at least 1400 cfs at S-65A. Use ± 0.2 ft buffer (gray band) above and below the 50.0 ft line to decide when to begin ramping up to 1400 cfs or down to 300 cfs; do not continue reducing discharge if stage rises back to or above the threshold stage line.
B3	Between the 50.0 ft line and 49 ft.	Adjust S-65 discharge to maintain at least 300 cfs at S-65A.
B4	Between 48.5 ft to 49 ft.	Adjust S-65 discharge to maintain S-65A discharge between 0 cfs at 48.5 ft and 300 cfs at 49 ft.
C	Below 48.5 ft.	0 cfs.

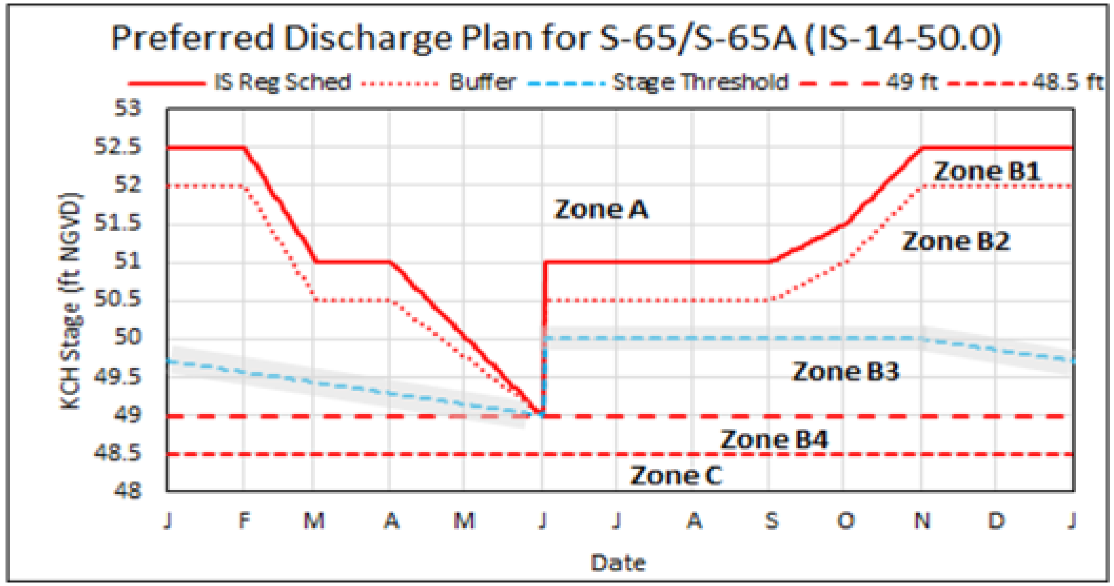
*Changes in discharge should not exceed limits in inset table below.

Discharge Rate of Change Limits for S65/S65A (revised 7/13/18).

Q (cfs)	Maximum rate of increase (cfs/day)	Maximum rate of decrease (cfs/day)
0-300	50	-50
301-650	75	-75
651-1400	150	-150
1401-3000	300	-600
>3000	1000	-2000

Revised 5/16/2019

Kissimmee Basin 2019 Wet Season



Other Considerations

- When possible, limit lake ascension rate in the Jun 1 - Aug 15 window to 0.5 ft per 14 days in Lakes Kissimmee, Cypress, Hatchineha (S-65), East Toho (S-59) and Toho (S-61).
- If outlook is for extreme dry conditions meet with KB staff to discuss modifications to this plan.

Figure 9-7. The IS-14-50.0 discharge plan for wet season 2019. The table insert specifies limits on rates of discharge increase and decrease at S-65 and S-65A. The plan uses the IS regulation line. Source: KB-2019-Wet Season Planning Presentation (April 11, 2019); the discharge rate of change limits table was modified on July 13, 2018, to allow faster rates of decrease when discharge is greater than 1,400 cfs. (Note: KB – Kissimmee Basin, KCH – Headwaters Lakes, and Toho – Tohopekaliga.)

Table 9-3. Comparison of observed rates of discharge increase during the Reference (1930–1962) and Late Interim (2015–2019) periods with the preferred maximum rates of discharge increase in the IS-14-50 discharge plan (**Figure 9-7,** lower left). Discharge was not managed during the Reference Period.

Discharge Rate of Change Limits for S-65/S-65A (revised 7/13/18)		Percent of Days at or Below the Maximum Rate of Increase		Mean Rate of Discharge Increase (cfs/day)	
Discharge (cfs)	**Maximum Rate of Increase (cfs/day)**	**Reference**	**Late Interim**	**Reference**	**Late Interim**
0–300	50	97	96	14	10
301–650	75	99	82	16	35
651–1,400	150	99	83	28	76
1,401–3,000	300	97	71	72	196
> 3,000	1000	98	93	210	429

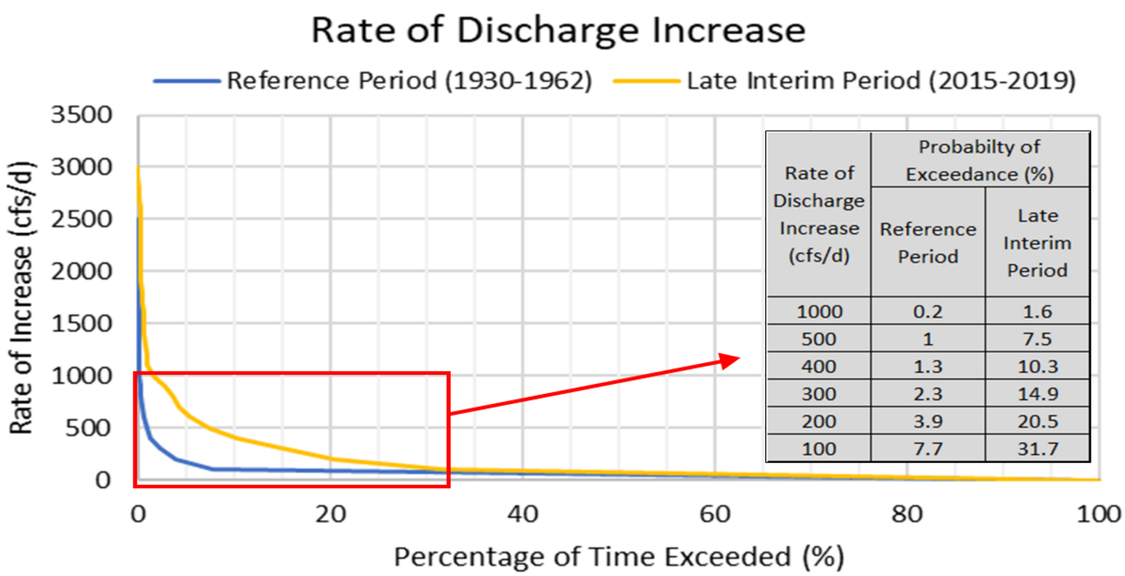


Figure 9-8. Exceedance curves for rate of increase in discharge in the Reference (1930–1962) and Late Interim (2015–2019) periods.

The 1,400-cfs discharge plans are weather-driven in that changes in discharge are linked to changes in stage in the Headwaters Lakes (i.e., discharge is increased only after rainfall has caused lake stage to rise above a threshold and is not reduced unless rainfall is insufficient to keep stage above the threshold). The plans include limits on the rate of discharge increase and decrease. The discharge plans are not intended to fully meet restoration targets for the Kissimmee River during the current Interim Period. However, variants of the 1,400-cfs discharge plans have been found to improve on prior operations, moving toward better performance in a crucial aspect of the hydrologic requirements for restoration and floodplain inundation. Because similar river/lake tradeoffs will also exist under the future HRS, a similar plan has been incorporated into planning for HRS implementation.

METHODOLOGY

Hydrologic conditions were quantified with data collected by SFWMD's hydrologic monitoring program at water control structures throughout the Kissimmee Basin (**Figures 9-2** and **9-3**) and stage monitoring locations distributed in the Kissimmee River channel and floodplain (**Figure 9-9**). The section follows the conventions of SFWMD and USACE water managers by reporting hydrologic variables in English units—inches for rainfall, ft NGVD29 for stage and depth, and cfs for discharge.

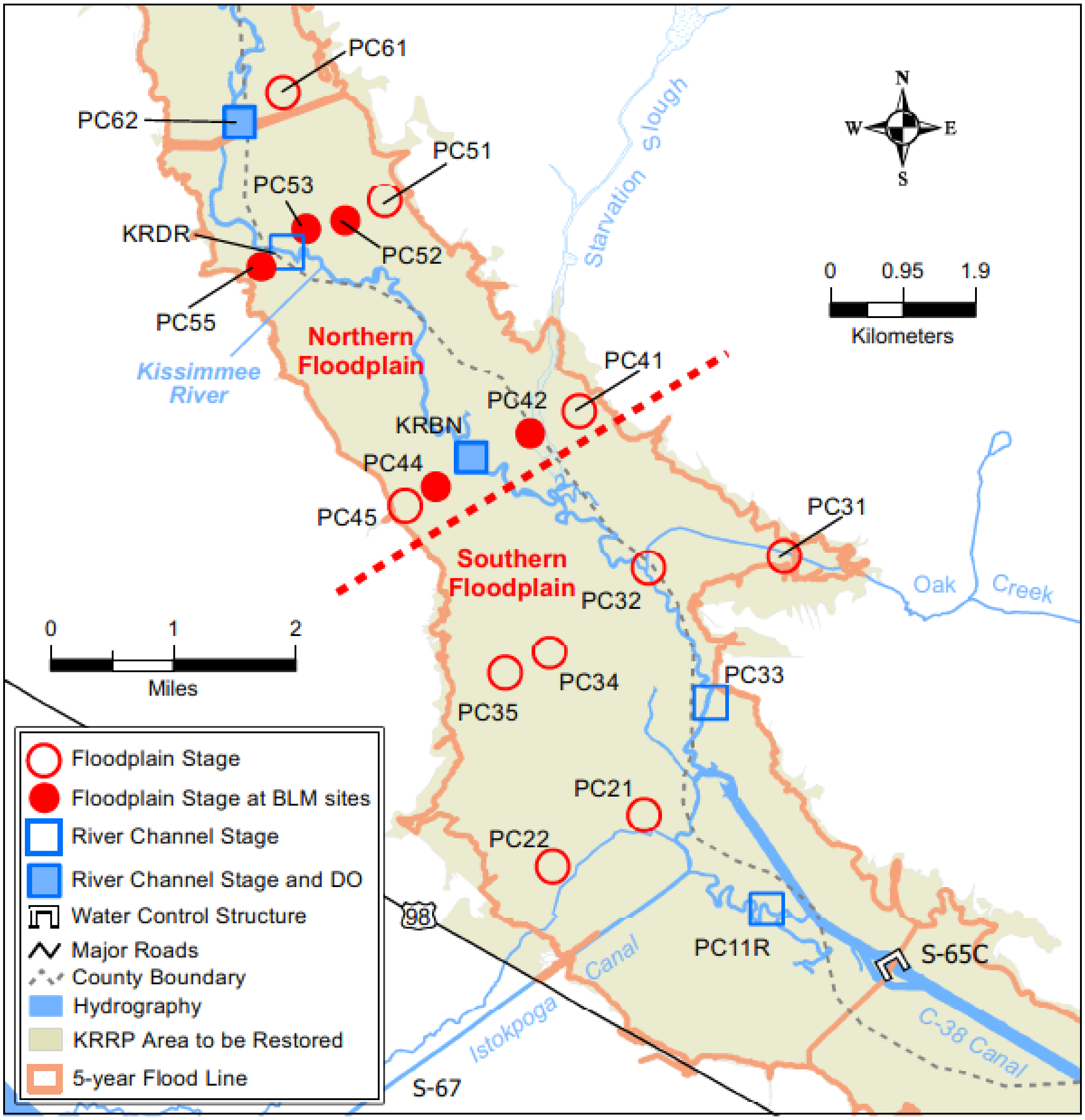


Figure 9-9. Locations of hydrologic monitoring sites in Pool C used to guide operations and evaluate restoration expectations.

Hydrology in the KRRP Phase I floodplain is complex; its dynamics were characterized for PW2020 using the metric "Mean depth at floodplain broadleaf marsh sites" (referred to as BLM Depth). BLM is a vegetation type with very long hydroperiod requirements (see the *Hydroperiod Evaluation (Expectation 3) in Planning Window 2019–2020 and the Interim Period* subsection of the *Lower Kissimmee Basin – Kissimmee River Restoration Evaluation Program* section). It was the dominant wetland plant community on the floodplain prior to channelization and is expected to expand to cover more than 50% of the Kissimmee River floodplain once historic hydroperiods are reestablished. Mean daily stage (water surface elevation) from recorders at each BLM site was converted to water depth by subtracting the average ground elevation within a 100-ft radius centered on the stage recorder in a surveyed digital elevation model.

BLM Depth was calculated as the average depth at five stations in the northern floodplain at which BLM vegetation occurred prior to regulation (pre-1962, i.e., before construction of the C-38 canal) and where BLM is expected to reestablish after restoration construction is completed and historic hydrology is restored (see *Hydrology* subsection of the *Kissimmee River Restoration Evaluation Program* section of this chapter). The five stations used for calculation of BLM Depth were selected because they are in the northern floodplain of the Phase I area and thus are outside the direct influence of the headwater stage of the former (through February 2017) downstream water control structure (S-65C), and for concurrence with Expectation 3, which is evaluated in the *Lower Kissimmee Basin – Kissimmee River Restoration Evaluation Program* section later in this chapter.

RAINFALL

Total rainfall for PW2020 approximated long-term averages with totals of 50 inches (99% of average) and 51 inches (106% of average) in the UKB and LKB, respectively. Both the UKB and LKB had large rainfall deficits in some wet season (September) and dry season (January and March) months (**Figure 9-10**); March is especially noteworthy because it was one of the driest for that month ever recorded. Rainfall deficits were offset by above average rainfall in other months, especially April and May, which resulted in near average or above average seasonal totals. Wet season rainfall was 31.9 inches (99% of average) in the UKB and 31.6 inches (99% of average) in the LKB. Dry season rainfall was 18.1 inches (100% of average) in the UKB and 19.2 inches (120% of average) in the LKB.

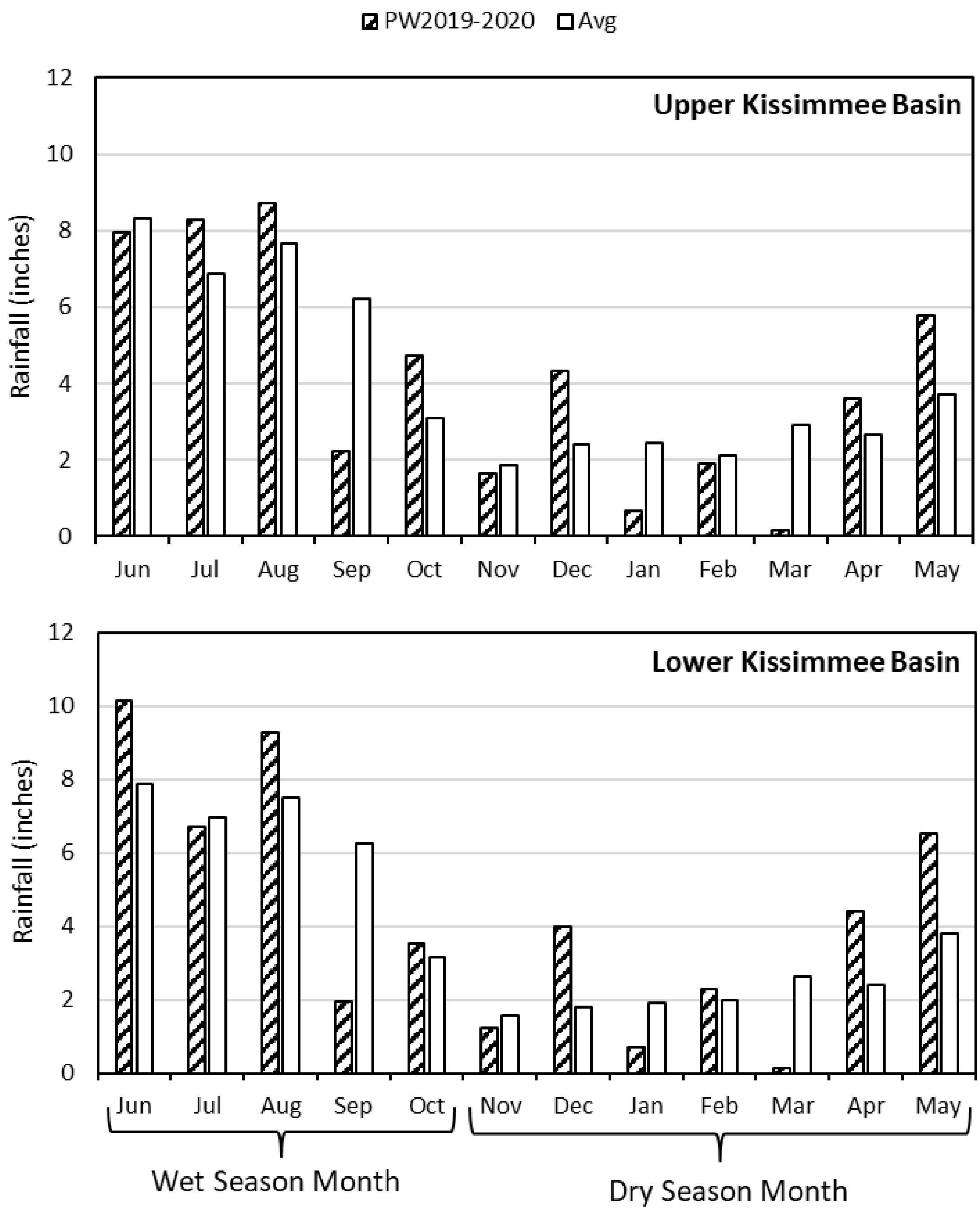


Figure 9-10. Monthly rainfall for PW2020 and average rainfall (1989–2018) in the UKB (top panel) and the LKB (bottom panel).

OPERATIONAL REQUESTS AND OUTCOMES

Seasonal Operational Planning

KRREP scientists collect input from partner agencies—SFWMD and USACE for the KRRP and FWC, United States Fish and Wildlife Service (USFWS), and SFWMD for the KCOL—to develop wet and dry season recommendations that balance KRRP needs with other considerations within the Kissimmee Basin. Throughout development and implementation of the recommendations, KRREP scientists work closely with SFWMD's water managers to implement the seasonal recommendations and coordinate Kissimmee Basin operations with other C&SF Project purposes.

KRREP wet and dry season planning typically involves modeling to determine how proposed operations are likely to affect water levels in the Headwaters Lakes, discharge to the Kissimmee River, and volumes of water originating in the UKB that are released to Lake Okeechobee via the Kissimmee River and C-38 canal. These analyses provide a better understanding of the tradeoffs among operational plans and the probable frequency of occurrence of desired conditions over long periods of time, rather than targeting goals to be met in years in which conditions may not be suitable to achieve them.

2019 Wet Season Water Management Outcomes

IS-14-50.0 Discharge Plan

Implementation of the IS-14-50.0 discharge plan (**Figure 9-7**) during the 2019 wet season resulted in a single period of discharge of at least 1,400 cfs that lasted 49 days (August 1 to September 18, 2019; **Figure 9-11B**). During this event, discharge was increased as stage in the Headwaters Lakes continued to rise and exceeded the regulation schedule, necessitating flood control releases. Discharge peaked at 6,733 cfs (August 21), which corresponded to a BLM Depth of just over 4 ft (**Figure 9-11C**). After stage in the Headwaters Lakes was reduced to the regulation schedule, S-65A discharge was reduced to and held at 1,400 cfs for 12 days (September 7 to 18) before ramping down to 300 cfs over 8 days (September 19 to 26). The ramp down began while stage was 0.6 ft above the 50 ft NGVD29 threshold in the discharge plan (**Figure 9-7**) for ramping down to 300 cfs and ended with stage still 0.4 ft above the threshold. Strictly following the plan and delaying the ramp down until stage declined to 50 ft NGVD29 would have extended the duration of discharge at or above 1,400 cfs, by 1 to 2 weeks. Discharge remained at 300 cfs through the remainder of the wet season.

An increase in S-65A discharge above 1,400 cfs lasted for two days (June 20–21) to provide flood protection by slowing the stage rise due to Pool A basin runoff. It was not the result of the discharge plan; the increase was made when stage in the Headwaters Lakes was still 0.5 ft below the 50 ft NGVD29 threshold for increasing discharge to 1,400 cfs. Discharge was increased from 300 cfs to 1,779 cfs over two days, which is about 5 times faster than the recommended maximum rates of increase in the discharge plan (**Figure 9-7**), underscoring concerns stated above about effects on the KRRP from limited storage in Pool A. As runoff declined, S-65A discharge was reduced in an attempt alleviate a severe DO crash (see **Figure 9-11D** and the *Wet Season Dissolved Oxygen* subsection below).

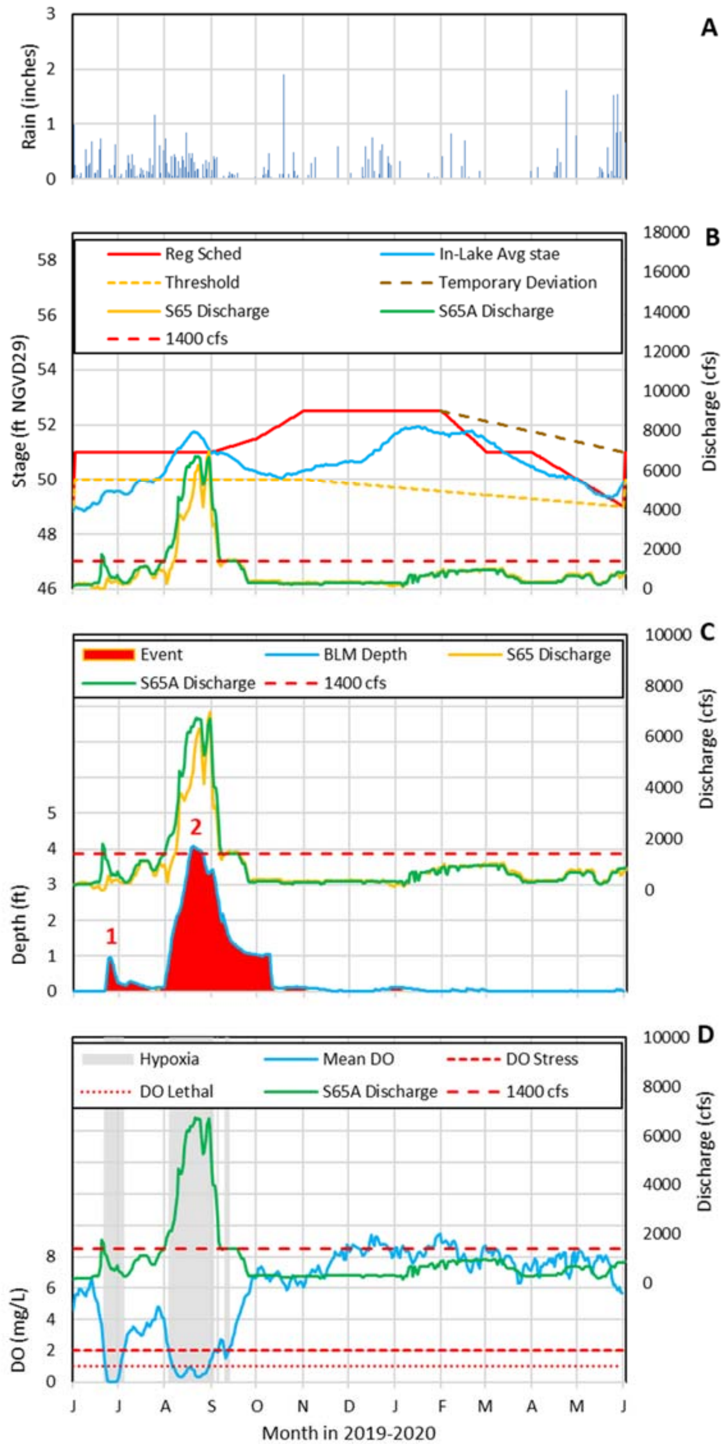


Figure 9-11. (A) Basin rainfall in the Headwaters Lakes, (B) regulation schedule, 2020 temporary deviation schedule, lake stage, and discharge from the Headwaters Lakes; (C) BLM Depth at five stations (PC52, PC55, PC53, PC44, and PC42) in the northern floodplain where BLM occurred pre-channelization and is expected to reestablish after restoration is completed in relation to mean daily discharge at S-65A; and (D) mean daily DO (calculated from 15-minute measurements) in the river channel at PC33 and PC62, and discharge at S-65A during June 2019–May 2020 planning window. Red numbers in Panel C identify two floodplain flood events that are described in the text. See **Figure 9-9** for locations of hydrologic monitoring sites and the *Lower Kissimmee Basin – Kissimmee River Restoration Evaluation Program* section's *Hydrology* subsection for more information.

Wet Season Floodplain Inundation

Two floodplain inundation (BLM Depth > 0.1 ft) events occurred in the 2019 wet season (**Figure 9-11C**). The first lasted for 30 days (June 22–July 21, 2019), had a maximum BLM Depth of 0.98 ft on June 25, 2019, and was the result of the increase in S-65A discharge above 1,400 cfs to provide flood control in Pool A. The second event lasted for 98 days (July 28–November 2, 2019), had a maximum BLM Depth of 4.08 ft, and was the result of implementing the IS-14-50.0 discharge plan. BLM Depth was as deep as 4 ft for approximately one week while S-65A discharge was at its peak (6,700 cfs) during this event. These events are treated as distinct because of their origin in two different flow events and because the reversal between the two events exceeded the 1.5 ft criterion used to identify a new recession event (see the *Hydroperiod Evaluation (Expectation 3) in Planning Window 2019–2020 and the Interim Period* subsection of the *Lower Kissimmee Basin – Kissimmee River Restoration Evaluation Program* section). Because one event closely followed the other and the duration at 300 cfs was brief, they resulted in a period of almost continuous inundation (BLM Depth > 0.1) of 134 days.

Wet Season Dissolved Oxygen

Two periods of anoxia (DO less than 1 mg/L) occurred during the 2019 wet season (**Figure 9-11C**). The first lasted 10 days (June 23–July 2, 2019) during which DO was 0 mg/L for five days; a large fish kill was associated with this event as described in more detail below in the *Fish* subsection of the *Lower Kissimmee Basin – Kissimmee River Restoration Evaluation Program* section. The second event occurred a month later and lasted 25 days (August 6–August 30, 2019); it was less extreme, with DO remaining above 0.3 mg/L. Further details are provided in the *Dissolved Oxygen* subsection of the *Lower Kissimmee Basin – Kissimmee River Restoration Evaluation Program* section later in this chapter.

Ascension Rates in the Kissimmee Chain of Lakes

Stage ascension rates were calculated daily for the June 1–August 15, 2019, window as the difference between current stage and stage 14 days prior. The preferred stage ascension rate of 0.5 ft per 14 days was exceeded on 8 days in East Lake Tohopekaliga, 1 day in Lake Tohopekaliga, and 21 days in the Headwaters Lakes. Most exceedances occurred in early August, resulting from above average rainfall in the UKB during July and August (**Figure 9-10**). As had been requested by FWC and USFWS in prior years, water was released from East Lake Tohopekaliga and Lake Tohopekaliga, as conditions permitted, to slow stage ascension so that it did not exceed the preferred rate (**Figure 9-7**). In June, releases were being made from the Headwaters Lakes per the IS-14-50.0 discharge plan (**Figure 9-7**) to provide flow to the Kissimmee River (**Figure 9-11B**); these releases were adequate to keep the stage ascension rate in those lakes below the preferred maximum rate, but later in the summer, even large flood control releases were not sufficient to prevent exceedances of the preferred maximum rate in early August.

2019-2020 Dry Season Water Management Outcomes

East Lake Tohopekaliga Drawdown

In October 2019, USACE approved a request by FWC for a temporary deviation to the regulation schedules for S-59 and S-61 for the 2019-2020 dry season. The purpose of the deviation was to provide lower lake stages to facilitate an environmental enhancement project in East Lake Tohopekaliga. The requested deviation was to lower stage in East Lake Tohopekaliga along a line that began at 57 ft NGVD29 on October 1, 2019, decreased to 53 ft NGVD29 by mid-February, 2020, and remained at or below that stage through the dry season. Thus, the East Lake Tohopekaliga stage was lowered 2 ft below the normal low pool. The requested deviation also lowered the stage in Lake Tohopekaliga from 55 ft NGVD29 on November 1, 2019, to 54.5 ft NGVD29 by mid-January, 2020, to enable gravity flow through the S-59 structure to continue to lower stage in East Lake Tohopekaliga as the stage difference between the two lakes declined. Flow through S-59 ended on January 20, 2020, when the gate was closed because stage was approximately the same in both lakes. Temporary pumps were used to lower stage in East Lake Tohopekaliga to 53 ft NGVD29 in late March 2020. Stage remained at or below 53 ft NGVD29 through the dry season as requested.

Lake Stage Recessions

East Lake Tohopekaliga was drawn down early in the dry season as described above, so that there was no request for a lake stage recession. In Lake Tohopekaliga, the recession began on February 7, 2020, as requested by FWC with lake stage at 54.9 ft NGVD29, and ended on June 1, 2020, at approximately the low pool of the regulation schedule. Recession rates did not exceed the preferred maximum of 0.2 ft per 7 days during most (96%) of the recession; all stage reversals were less than 0.2 ft.

In the Headwaters Lakes, a recession began earlier than usual, on January 8, 2020, to reduce the risk of high flow impacting construction for Reach 2 of the KRRP (see *Construction* subsection below). The objective was to begin lowering lake stage without exceeding a limit on discharge to protect downstream construction. Requested limits on discharge for construction varied between 700 and 900 cfs during the dry season. The recommendation was modified on March 24, 2020, to continue a recession to the low pool of 49 ft NGVD29 by June 1, 2020, and modified again on May 11, 2020, to slow the recession rate to less than 0.8 ft per 30 days. The resulting stage recession reflects the changing requests for construction limits on discharge over the dry season (**Figure 9-11B**). Most of the time, recession rates were less than 0.8 ft per 30 days and the only large stage reversal occurred at the very end of dry season.

Floodplain Inundation

No significant inundation of the floodplain occurred during the dry season. After S-65A discharge was reduced to 300 cfs in late September, 2019, flow was confined to the river channel and remained well below the bankfull discharge of 1,400 cfs (**Figure 9-11B**). BLM Depth responded to rainfall but did not exceed 0.1 ft during the dry season and was less than 0.01 ft for 60% of the time (**Figure 9-11C**).

Construction

Flow conditions below 900 cfs as requested by USACE during construction work for S-69 and Reach 2 of the KRRP were provided for most of the dry season. S-65A discharge was less than 900 cfs for 180 days, only exceeded 900 cfs for 33 days (February 8–March 12, 2020) and never exceeded 963 cfs. In April 2020, USACE approved a temporary deviation to the regulation schedule for S-65 (**Figure 9-11B**) to allow higher stages in the Headwaters Lakes to reduce the risk of flood control releases.

Summary of Planning Window 2019-2020 Water Management Operations

The IS-14-50.0 discharge plan was successfully implemented in the 2019 wet season, producing a single 49-day period with bankfull discharge or greater. The 2019 wet season is the fourth implementation of a version of a 1,400-cfs discharge plan since the 2015 wet season. The 2019 wet season, however, had the shortest duration of above bankfull discharge of the four implementations (**Table 9-4**). Two factors contributed to the relatively short duration in PW2020. First, the event was ended prematurely because discharge was reduced to 300 cfs while stage in the Headwaters Lakes was 0.6 ft above the ramp down threshold; delaying the ramp down until stage reached the threshold would have extended the event. Second, September 2019 rainfall was only about a third of average (**Figure 9-10**); most (80%) of the September rainfall fell in the first four days. The very dry conditions in the remainder of September were likely due to the passage of Hurricane Dorian parallel to the Florida coast. Closer to average rainfall in September would have extended the duration of bankfull discharge. Interestingly, the 2016 wet season, in which the plan was recommended but not implemented due to emergency operations (**Table 9-4**), would likely have resulted in a much longer interval of flow above 1,400 cfs; a spreadsheet simulation of the 2016 wet season indicated that following the recommended plan would have resulted in a single 182-day event (May 10–November,

2016) instead of the two widely separated events that resulted from flood control releases for 50 days (May 10–June 28, 2016) and 36 days (September 3–October 10, 2016) (Koebel et al. 2018).

Table 9-4. Outcomes of wet season recommendations to implement a 1,400-cfs discharge plan.

Year Recommended for Implementation	Recommended Plan	Outcome	Event Number	Above Bankfull Discharge Duration (days)
2015	IS-14-50.5	Produced a single wet season floodplain inundation event.	1	75
2016	IS-14-50.5	Not implemented due to non-standard emergency operations that attempted to hold as much water in the UKB to reduce flow to Lake Okeechobee and possibly the coastal estuaries. Flood control releases resulted in two widely separated events.	1 2	50 30
2017	HRS-14-50.0	Produced a single wet season floodplain inundation event. Event duration would have been longer. However, discharge was reduced to 300 cfs while the lake stage was almost 2 ft above the threshold stage.	1	75
2018	IS-14-50.0	Produced a single wet season floodplain inundation event.	1	108
2019	IS-14-50.0	Produced a single wet season floodplain inundation event (Event 2); flood control in Pool A resulted in a second event (Event 1).	1 2	2 49

The bankfull discharge event due to implementation of IS-14-50.0 was preceded by a two-day event that resulted from flood control releases at S-65A because of the lack of operational flexibility at S-65A. The resulting flashy discharge exemplifies the type of operations that the discharge plan was developed to avoid. The rapid increase in S-65A discharge limited the rise in stage in Pool A to about 1 ft but resulted in a stage rise of 4 to 5 ft in the much smaller river channel downstream, thus contributing to the DO crash and fish kill. KRREP staff are working to increase the operational flexibility at S-65A to reduce the frequency and severity of such events in the future.

The preferred maximum ascension rate was exceeded in the 2019 Wet Season by 8, 1, and 21 days in East Lake Tohopekaliga, Lake Tohopekaliga, and the Headwaters Lakes, respectively. Such exceedances are not unexpected; as reported in Chapter 9 of the 2016 SFER – Volume I (Koebel et al. 2016), attempts to control early wet season ascension rates can—and often will—be overwhelmed by rainfall; ascension rates exceeding 0.5 ft occurred frequently prior to regulation. Thus, a higher frequency of exceedances can be anticipated in all lakes, but particularly in the Headwaters Lakes because of interactions between East Lake Tohopekaliga and Lake Tohopekaliga and the effects of discharge from those lakes on stage in the Headwaters Lakes. Inflow into the Headwaters Lakes is increased by efforts to reduce ascension rates upstream in East Lake Tohopekaliga and Lake Tohopekaliga (S-59 and S-61, respectively) and complicates maintaining moderate rates of discharge change at S-65 and S-65A downstream to protect the KRRP from rapid increases in stage, which can cause DO declines in the Kissimmee River, and excessively fast reductions, which can strand aquatic organisms on the Kissimmee River floodplain. This illustrates the strong potential for operational conflicts among these three water bodies, to some extent complicating implementation of lake stage target requests, including both ascension and recession rates.

Below average dry season rainfall during the three preceding years have made it easier to manage lake stage recessions for fish and wildlife. The 2019-2020 dry season had approximately average rainfall and again experienced relatively gradual recessions in Lake Tohopekaliga and the Headwaters Lakes. Because

East Lake Tohopekaliga had been drawn down earlier in the dry season for the habitat enhancement project, there was no request for a fish and wildlife recession. The recession in Lake Tohopekaliga may have benefitted from the low water levels in East Lake Tohopekaliga because releases from upstream did not exacerbate reversals in Lake Tohopekaliga when it rained. The recession in the Headwaters Lakes was complicated by the limit on discharge to the Kissimmee River to protect construction and the temporary deviation to allow higher stages in the Headwaters Lakes; however, overall a fairly slow recession was managed and only in the last two weeks of the season did a reversal larger than 0.5 ft occur.

A key ecological driver of the Kissimmee River prior to channelization was a single, continuous floodplain inundation event in most years that typically began late in wet season and continued well into the dry season, and throughout the year in some years. The long period of floodplain inundation provided important foraging habitat for wading birds and waterfowl, nursery areas for important game fish in breeding season, and was necessary to meet the hydroperiod requirements of the dominant wetland vegetation type. Managing for a single, continuous floodplain inundation continues to be a focus of efforts to manage the Kissimmee River. Simulations suggest that consistent adherence to 1,400-cfs discharge plans will result in improvements in floodplain inundation while balancing benefits to the Headwaters Lakes.

LOWER KISSIMMEE BASIN – KISSIMMEE RIVER RESTORATION EVALUATION PROGRAM

A major component of the KRRP is assessment of restoration success by the Kissimmee River Restoration Evaluation Program (KRREP), a comprehensive ecological monitoring program (Bousquin et al. 2005, Williams et al. 2007, Koebel and Bousquin 2014) mandated and designed to evaluate the ongoing status and ultimate success of the KRRP in meeting its environmental goals. Restoration evaluation was identified as SFWMD’s responsibility in its cost-share agreement with USACE for the KRRP (Department of the Army and SFWMD 1994).

Only studies that collected new data in PW2020 are updated in this section. New results from studies of floodplain hydrology, DO, apple snails, invasive vegetation, fish, wading birds, and waterfowl document the status of these ecosystem components. Where applicable, results are evaluated in relation to the associated KRREP restoration expectations. An additional report is presented on floodplain vegetation management efforts. **Table 9-5** provides a directory of KRREP monitoring study updates that have been presented in the SFER since 2005.

Table 9-5. Directory of KRREP Phase I restoration response monitoring study updates in the 2005–2021 SFERs. [a]

KRREP Monitoring Study or Project	Expectation Number	Beginning Page Number in 2005–2021 SFERs – Volume I																
		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Kissimmee River Restoration Evaluation Program		11-8	11-37	11-22	11-28	11-36	11-26	11-25	9-16	9-19	9-20	9-22	9-27	9-29	9-27	9-27	9-22	9-25
Hydrology																		
Stage-discharge relationships	None	11-20																
Continuous river channel flow	1	**11-18**				**11-39**	**11-29**	**11-29**	**9-20**	**9-23**	**9-22**	**9-26**						
Variability of flow	2					**11-40**	**11-31**	**11-32**	**9-20**	**9-23**	**9-23**	**9-28**						
Stage hydrograph	3	**11-22**				**11-41**	**11-32**	**11-33**	**9-21**	**9-24**	**9-24**	**9-30**	**9-37**	**9-38**	**9-37**	**9-37**	**9-25**	**9-28**
Stage recession rate	4	**11-23**	11-23	11-16	11-19	**11-42**	**11-34**	**11-35**	**9-24**	**9-27**	**9-28**	**9-33**	**9-41**	**9-42**	**9-41**	**9-41**	**9-27**	**9-29**
Flow velocity	5	**11-25**					**11-35**	**11-37**	**9-24**									
Broadleaf marsh indicator	None					11-43						9-33	9-37					**9-28**
Geomorphology																		
River bed deposits	6	**11-26**						**11-70**										
Sandbar formation	7	**11-26**						**11-70**										
Channel monitoring	None					11-54		11-68										
Sediment transport	None							11-71										
Floodplain processes	None							11-72										
Dissolved Oxygen	8	**11-28**	**11-44**	**11-25**	**11-28**	**11-45**	**11-36**	**11-38**		**9-27**	**9-30**	**9-36**	**9-45**	**9-47**	**9-45**	**9-45**	**9-32**	**9-35**
River Channel Metabolism	None				11-35													
Phosphorus	None	11-33	11-52	11-30	11-32	11-51	11-43	11-43	9-25	9-31	9-34	9-40	9-50					
Turbidity	9	**11-30**	**11-48**	**11-27**														
Periphyton	None	11-46																
River Channel Vegetation																		
Width of littoral vegetation beds	10	**11-36**				**11-59**												
River channel plant community structure	11	**11-37**				**11-59**												
Floodplain Vegetation																		
Areal coverage of floodplain wetlands	12	**11-39**			**11-35**			**11-47**			**9-42**	**9-50**				**9-55**		**9-49**
Areal coverage of broadleaf marsh	13	11-40			**11-35**			**11-47**			**9-43**	**9-51**				**9-56**		9-49
Areal coverage of wet prairie	14	11-40			**11-35**			**11-47**			**9-43**	**9-51**				**9-56**		9-49

Table 9-4. Continued.

KRREP Monitoring Study or Project	Expectation Number	Beginning Page Number in 2005–2021 SFERs — Volume I																
		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Invertebrates																		
Macroinvertebrate drift composition	15	**11-45**	11-57															
Snag invertebrate community structure	16	**11-46**	11-55			11-62												
Aquatic invertebrate community structure in broadleaf marsh	17		11-57															
Benthic invertebrate community structure	18	**11-45**	11-58			11-62												
Native and nonnative bivalves	None							11-52										
Non-native apple snails	None																	9-52
Fish																		
Impact of hypoxic events on largemouth bass and bluegill	None															9-58		9-55
Herpetofauna																		
Floodplain reptiles and amphibians	19	11-48	Response data will be collected after implementation of the HRS.								9-47		Response data will be collected after implementation of the HRS.					
Floodplain amphibian reproduction and development	20	11-48	Response data will be collected after implementation of the HRS								9-47		Response data will be collected after implementation of the HRS					
Fish Communities																		
Small fishes in floodplain marshes	21	11-50					Response data will be collected after implementation of the HRS.											
River channel fish community structure	22	11-52	**11-59**			**11-66**			**9-29**									
Mercury in fish	None					11-20												
Floodplain fish community composition	23	11-50					Response data will be collected after implementation of the HRS.											
Birds																		
Wading bird abundance	24	**11-58**	**11-71**	**11-32**	**11-44**	**11-72**	**11-50**		**9-36**	**9-41**	**9-53**	**9-57**	**9-51**	**9-55**	**9-57**	**9-60**	**9-38**	**9-62**
Waterfowl	25		**11-67**	**11-35**		**11-73**	**11-52**		**9-37**	**9-42**	**9-55**	**9-59**	**9-54**	**9-57**	**9-59**	**9-64**	**9-42**	**9-66**
Shore birds	None	11-57																
Wading bird nesting	None		11-68		11-40	11-72	11-47		9-33	9-38	9-47	9-53	9-56	9-51	9-53	9-66	9-46	9-70
Wading bird and waterfowl prey availability	None														9-62		**9-46**	
Threatened and Endangered Species	None	11-60																9-84

a. Bolded page numbers indicate a major update in reference to the status of a restoration expectation (performance measure).

HYDROLOGY

This section evaluates metrics for Expectations 3 (hydroperiod) and 4 (recession events) in PW2020 and provides an overall assessment of progress towards meeting these expectations during the post-Phase I construction Interim Period (PW2002–PW2020). The reference conditions used to develop these expectations and the effect of channelization on BLM Depth and recession events were summarized in a previous *Hydrology* subsection (Koebel et al. 2019). These expectations have been especially challenging to address operationally in the Interim Period. The section concludes with recommendations for changes in discharge management that can improve performance for these expectations during the remainder of the Interim Period.

Hydroperiod Evaluation (Expectation 3) in Planning Window 2019-2020 and the Interim Period

Expectation 3 (Hydroperiod Requirements for Broadleaf Marsh)

Stage hydrographs that result in floodplain inundation frequencies comparable to pre-channelization hydroperiods, including seasonal and long-term variability characteristics.

- Component A: 59% of water years will have a BLM Depth ≥ 1 ft for 210 consecutive days.
- Component B: 40% of water years will have BLM Depth ≥ 1 ft for 210 consecutive days in the August–February window.

PW2020 had a single event with BLM Depth ≥ 1 ft (**Figure 9-12**). It lasted 67 days (August 4–October 9, 2019) and was associated with flood control releases during implementation of the IS-14-50.0 discharge plan. It was far shorter than the desired duration of 210 days and did not meet the criterion of BLM Depth ≥ 1 ft for 210 days for the water year (Component A) or the August–February window (Component B).

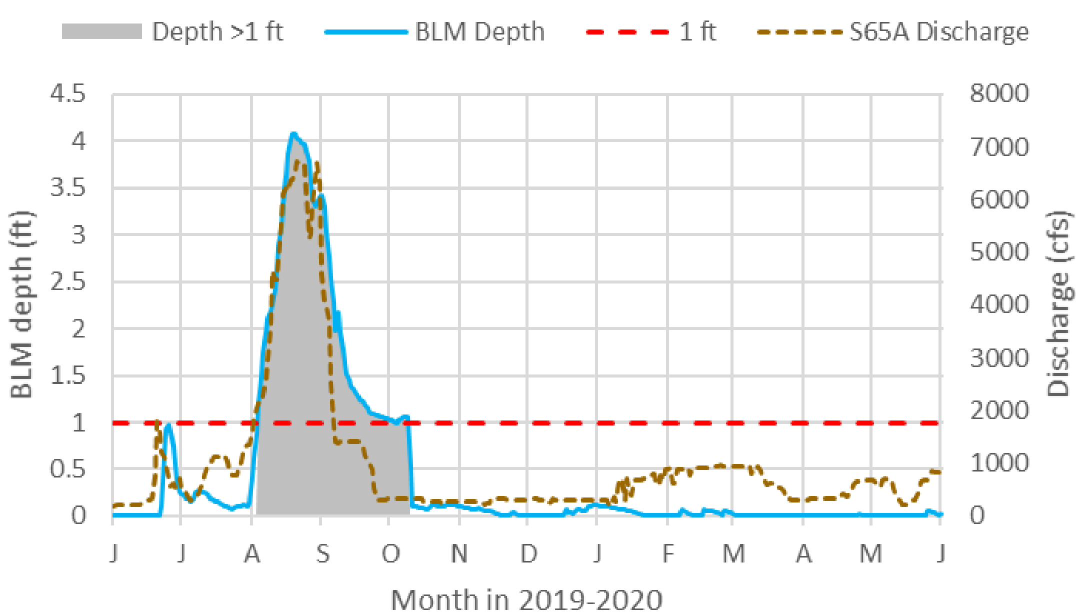


Figure 9-12. BLM Depth and S-65A discharge during PW2020. Gray shading indicates intervals of time when BLM depth was at least 1 ft. BLM depth is the average of mean depth at five stage recorders in the northern Phase I area floodplain.

None of the events in the Interim Period met the 210-day criterion (Component A) or the criterion for the more restrictive August–February window (Component B). Over the entire Interim Period, the longest duration event to date was only 169 consecutive days (range 6 to 169 days with a mean of 73 days), far short of the 210-day criterion, and barely exceeding the 25th percentile of years in the Reference Period (**Figure 9-13**). Only one year in the Interim Period (PW2006, in which Hurricane Wilma passed over the basin at the end of wet season), came close to meeting the criterion for that planning year (Component A) or the seasonal window (Component B). However, to meet the 210-consecutive day criterion for Component A in PW2006, the two longest periods of continuous BLM depth of at least 1 ft would have had to have been connected by disregarding a gap of 21 days (**Figure 9-13**). To meet the criterion during the August–February window (Component B), a second gap of 28 days also would have had to have been disregarded.

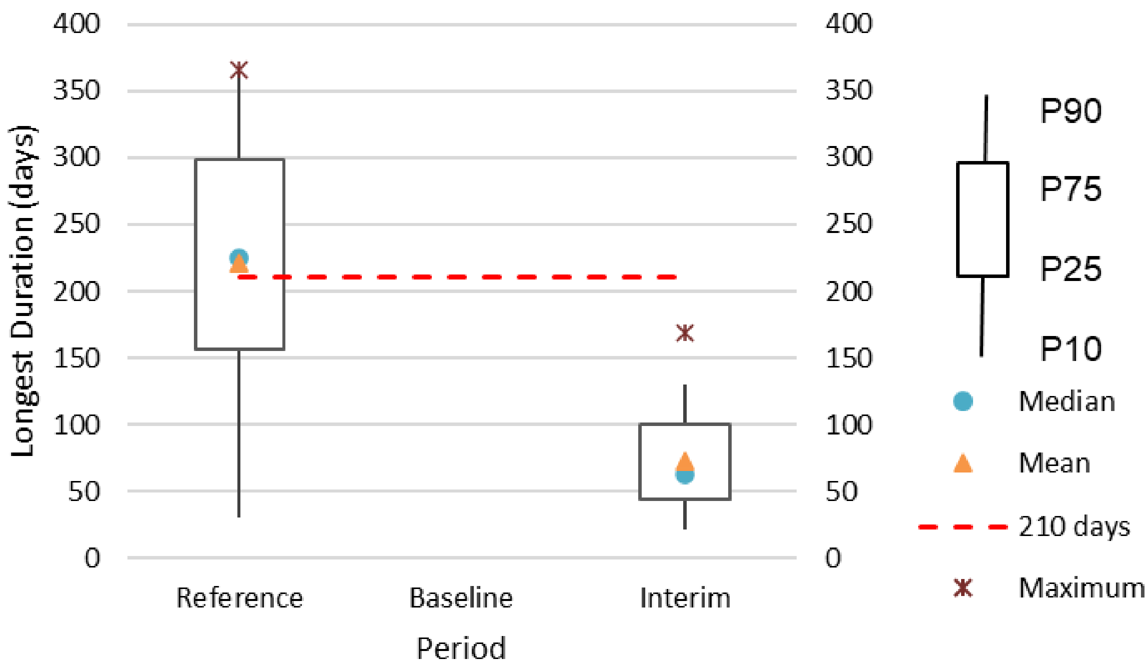


Figure 9-13. Longest duration (consecutive days) with BLM depth ≥1 ft in the Kissimmee River floodplain for 32 Reference Period years, 28 Baseline Period years, and 19 Interim Period years. No events occurred in the Baseline Period. Dashed red line indicates the 210-day criterion for the expectation. Box plots show the 90th, 75th, 25th and 10th percentiles.

Recession Events (Expectation 4) in the Interim Period

Expectation 4 (Recession Events)

Stage hydrographs that result in floodplain recession events with rates of water level decrease, duration, and timing that are comparable to pre-channelization events, including seasonal and long-term variability characteristics.

- Component A: 72% of recession events will have a mean recession rate < 1 ft per 30 days.
- Component B: 100% of recession events will have a mean recession rate < 2 ft per 30 days.

PW2020 had two recession events (**Figure 9-14**) that were associated with the two floodplain inundation events described in the *Kissimmee Basin Hydrologic Conditions and Water Management in Planning Window 2018-2019* section earlier in this chapter. The first event was the result of two days of flood control releases at S-65A, which resulted in peak BLM Depth of slightly less than 1 ft; the recession lasted 35 days and had a recession rate of 0.74 ft per day. The first event was followed closely by a second event, which was the result of implementing the IS-14-50.0 discharge plan. The second event had a peak BLM Depth of over 4 ft and exceeded the 1.5 ft criterion that is used to identify a new recession event. The second event's recession lasted 101 days and had a recession rate of 1.21 ft per 30 days. These two recession events brought the Interim Period total to 38 recession events, or an average of two events per year.

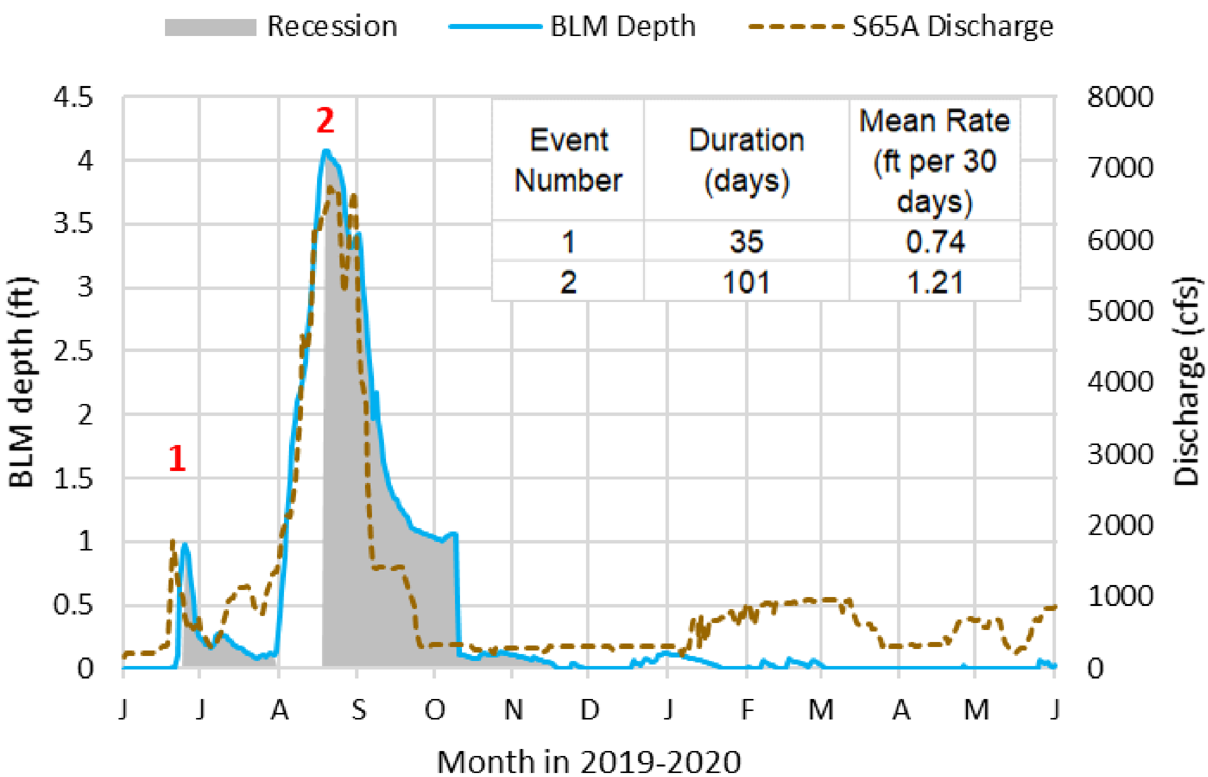


Figure 9-14. BLM Depth and S-65A discharge during PW2020. Two recession events are indicated by gray shading and identified by red numbers. Duration and mean recession rate for each event are shown in the table. BLM Depth is the average of mean depth at five stage recorders in the northern Phase I area floodplain.

During the Interim Period, mean recession rates for recession events ranged from 0.14 to 5.13 ft per 30 days, with a mean rate over all events of 1.82 ft (± 0.21 standard error [SE]) per 30 days (**Figure 9-15**). The duration of recession events ranged from 10 to 203 days and averaged 72 days (± 9 SE). Recession rates were < 1 ft per 30 days for 32% of the recession events and < 2 ft per 30 days for 69% of events; both values are well below their respective targets of 71% for Component A and 100% for Component B. As a result, Interim Period values to date for the two recession rate metrics did not meet the expectation targets based on the Reference Period data (**Figure 9-16**). More than a fourth of Interim Period recession events were faster than any that occurred in the Reference Period.

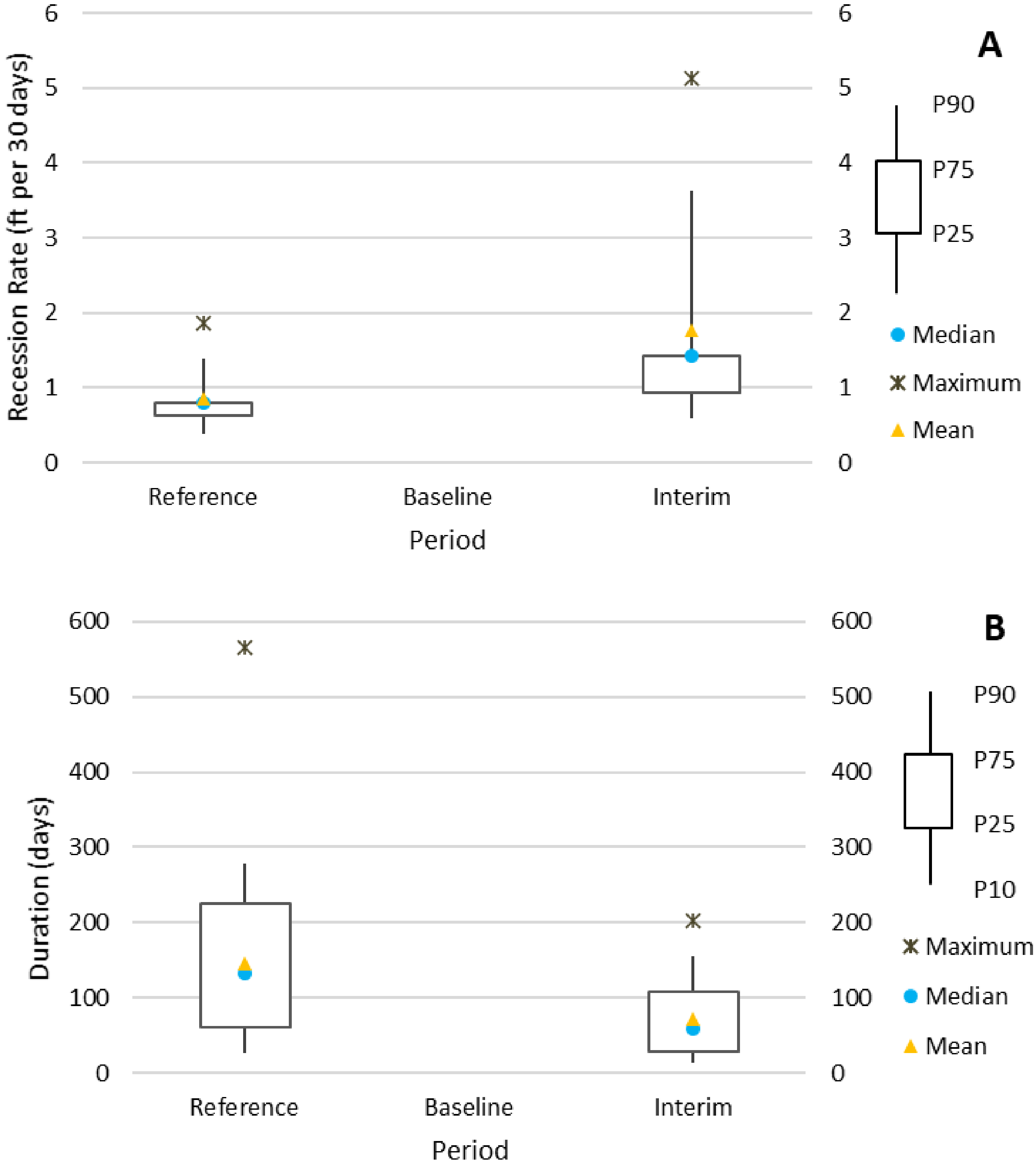


Figure 9-15. (A) Recession rates and (B) event duration for recession events during the Reference Period (PW1931–PW1962) and the Interim Period (PW2002–PW2020) in the Kissimmee River floodplain. No recession events occurred in the Baseline Period (PW1972–PW1999).

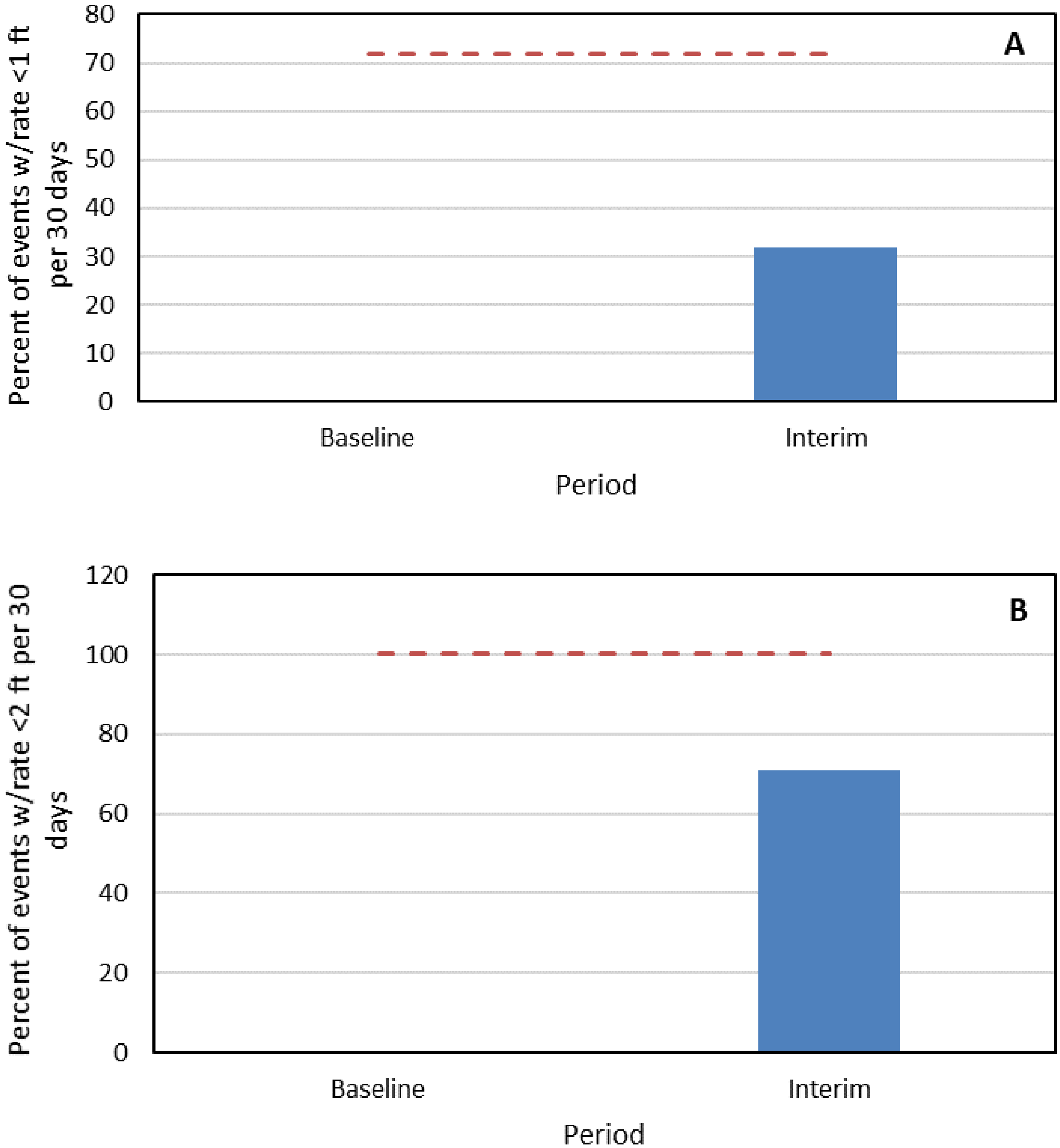


Figure 9-16. Comparison of percentage of Kissimmee River floodplain recession events having rates: (A) < 1 ft per 30 days (Component A) and (B) < 2 ft per 30 days (Component B) during Baseline (PW1972–PW1999) and Interim (PW2002–PW2020) periods. Dashed red lines are target percentages based on frequency of events during the pre-channelization Reference Period (PW1932–PW1962). Reductions to low discharge result in disjoined floodplain inundation events with periods of drying.

Discussion of Hydrologic Expectations

Reestablishment of flow through the river channel by backfilling the C-38 canal has allowed water levels to fluctuate in response to variable flow, providing intervals of floodplain inundation and recession during the Interim Period (Anderson 2014). While this is an improvement over the stabilized water levels of the channelized Baseline Period, we have not yet reestablished in even one year the single, long period of floodplain inundation followed by a slow stage recession that typified most years of the pre-channelization Reference Period. Evaluation of the hydrologic expectations show that even the longest period of inundation with BLM Depth ≥ 1 ft in the Interim Period is only about the 25th percentile of pre-channelization events; concomitantly recessions are too rapid.

Excessively fast floodplain stage recession rates have important implications for restoration success. A slow stage recession rate was an important characteristic of floodplain inundation events during the Reference Period and interacted with other aspects of the hydrologic regime to produce the long hydroperiods or flood pulses typical of the unregulated ecosystem (i.e., slow floodplain stage recession rates were a consequence of the characteristic gradual decline in flow from the headwaters lakes). Faster recession rates, as seen in the Interim Period and especially in recent years, are largely due to structure operations that impose unnatural demands on the system, disrupting the continuity and duration of flood pulses, with the consequence of pronounced intervals of dry conditions that are unsuitable for the floodplain's signature marshes (Spencer and Bousquin 2014). If continued, such operations will inhibit recovery of the Kissimmee River and floodplain.

Also characteristic of the Interim Period overall are extreme and rapid rises in Kissimmee River floodplain stage (stage reversals) due to rapid increases in discharge that may be made at the S-65 and S-65A structures for flood control (e.g., **Figures 9-6** and **9-14**). For example, during PW2019, large discharge increases for flood control twice interrupted the floodplain recession (Koebel et al. 2020). These reversals were a potential threat to snail kites that were nesting in the floodplain at the time. Such flood control releases can result from lake stage being at or near regulation schedule, often to maintain high lake stage, so that even minor rainfall events can trigger flood control releases. They are not a consequence of the 1,400-cfs discharge plan, which tends to keep lake stage below the regulation line. Large increases in discharge have been identified as a problem for restoration of the Kissimmee River (Cheek et al. 2014) and may now threaten snail kites nesting there. Floodplain reversals as small as 0.3 ft (much smaller than the 1.5-ft reversal used here to identify new recession events) have been associated with abandonment of nests by wading birds (Frederick and Collopy 1989, Smith et al. 1995).

Relationship of Hydroperiod and Recession Events to Discharge

BLM Depth is influenced, to a small extent, by direct rainfall and associated LKB runoff, but sustaining prolonged periods of inundation almost completely depends on inflow discharge through S-65 then S-65A (Anderson 2014). Thus, the way these structures are operated directly influences floodplain inundation characteristics in the Phase I area as evaluated by Expectations 3 and 4 and therefore, the extent to which the restoration expectations and hydrologic criteria can be met. Thus, recovery of the biota that depend on improvement in and eventual reestablishment of pre-regulation hydrology for recovery is strongly influenced by water management.

The outcome of implementation of the IS-14-50.0 discharge plan in the 2019 wet season was described in the *Kissimmee Basin Hydrologic Conditions and Water Management in Planning Window 2019-2020* section earlier in this chapter. Recommendations to use the 1,400-cfs discharge plan to address the hydroperiod and recession expectations to improve hydrologic performance for KRRP as required by USACE (1991, 1996) have been made for every wet season beginning in 2015. Although the plan is intended to improve hydrologic performance for Expectations 3 (hydroperiod) and 4 (recession events), it is not expected to fully meet the criteria for either expectation in the Interim Period. Similar discharge plans are being applied to the future HRS; how well the plan improves hydrologic performance before or after the HRS is implemented will be influenced by how consistently they are implemented.

Implementation of discharge plans during the 2015, 2017, 2018, and 2019 wet seasons resulted in single floodplain inundation and recession events during each wet season, with BLM hydroperiods of 76, 63, 63, and 67 days, respectively. Holding discharge at 1,400 cfs during these events extended the period BLM Depth was at least 1 ft, although the resulting durations were well short of the target duration of 210 days, partly due to rainfall. This underscores the importance of plan implementation across all years to capitalize on years of enough rainfall to provide both prolonged floodplain inundation and periods of higher stage in the Headwaters Lakes using balanced discharge plans when conditions are such that both objectives can be met. Despite shortfalls, implementation of the discharge plans suggests a promising direction for Kissimmee Basin operations to balance stage in the Headwaters Lakes against S-65 discharge to achieve benefits over time in both systems without harming either. In the same years, holding discharge at 1,400 cfs during the discharge ramp down also improved hydrologic performance for Expectation 4 by increasing the duration of the recession event and slowing the recession rate. No negative effects on the lakes have been noted except slightly lower stages over the period of implementation.

SFWMD will continue to evaluate, refine, and implement 1,400-cfs discharge plans in future years and with HRS implementation. The discharge plans are examples of hydrologically- and ecologically-balanced operations designed to link discharge for the KRRP to rainfall via upstream lake stage to achieve mutually beneficial operations for these two inextricably connected parts of the Kissimmee Basin ecosystem. For the Interim Period, the plan does not attempt to fully meet the KRRP expectations for hydroperiod and recession events, although implementations of 1,400-cfs discharge plans have demonstrated that substantial improvements in performance for the hydrologic expectations can be made if they are implemented consistently, even without the additional storage that will be provided by the HRS. Such operations will better approximate both the natural relationship of lake stages to flow to the river and the natural variability in lake stage that is characteristic of healthy lakes (NRC 1992).

Extension of Discharge Plans through the Dry Season

Implementation of 1,400-cfs discharge plans during the 2015, 2017, 2018, and 2019 wet seasons resulted in promising improvements in the performance of Expectations 3 and 4 that could have been enhanced by continuing to follow the plan into the dry season. For example, the simulation of PW2019 presented in the *Kissimmee Basin Hydrologic Conditions and Water Management in Planning Window 2018-2019* section in last year’s chapter (Koebel et al. 2020) showed that continuing to follow the plan into the dry season would have greatly increased the duration of inundation during the dry season and might have allowed snail kites that were present on the floodplain early in the nesting season to nest (discharge was reduced, draining the floodplain, before mating and nesting began).

Extension of discharge plans through the dry season will help address another issue identified in previous years: rapid changes in discharge to manipulate stage in the Headwaters Lakes can result in harmful depth fluctuations in the Kissimmee River and floodplain. Current KRREP operational guidelines allow maximum rates of discharge decrease and increase that are relaxed to consider realistic operational needs; however, the specified rates of change are much faster than occurred in the Reference Period. Operations to achieve and maintain high stages near the regulation line in the Headwaters Lakes (and to a lesser extent in East Lake Tohopekaliga and Lake Tohopekaliga), or to precisely follow dry season stage recession lines without stage reversals in these lakes, create conditions under which all or most inflow from rainfall events must be quickly discharged to the river, rather than balancing the stage reversals that inevitably result from rainfall between the lakes and the river. The resulting abrupt reductions and increases in depth on the Kissimmee River floodplain are harmful, inhibiting improvements in performance of the KRRP hydrologic goals, as well as directly impacting wading bird foraging and nesting and fish breeding, among other components of the system. Modeling suggests that such operations may also inhibit a more natural range of stage fluctuation in the Headwaters Lakes.

Summary

The performance of hydrologic Expectations 3 (hydroperiod) and 4 (recession events) in PW2020 was influenced by the implementation of the IS-14-50.0 during the 2019 wet season and the large September 2019 deficit in what was otherwise above average rainfall for the wet season.

Expectation 3

- The targets for Expectation 3 (hydroperiod) were not met in PW2020 or in any year of the Interim Period thus far (PW2002–PW2020).
- Performance for Expectation 3 (hydroperiod) can be improved by implementing operations designed to increase the number of consecutive days that inflow discharge of 1,400 cfs or greater is maintained.

Expectation 4

- The targets for Expectation 4 (recession events) were not met in PW2020 or in any year of the Interim Period thus far (PW2002–PW2020).
- Performance for Expectation 4 (recession events) can be improved by slowing the rate of recession, especially by eliminating the practice of decreasing discharge to low levels to hold the Headwaters Lakes stable at high stages for extended periods.

Use of discharge plans such as the one implemented in PW2020 can improve hydrologic conditions for Expectations 3 (hydroperiod) and 4 (recession events) and create conditions for recovery of the biotic components of the river/floodplain ecosystem.

DISSOLVED OXYGEN

Dissolved oxygen (DO) directly affects aquatic life through oxygen (O_2) availability and the metabolism of aquatic ecosystems (Hauer and Lamberti 2007, Colangelo 2007). DO concentration can influence the growth, distribution, and structural organization of aquatic communities and thereby impact the productivity of aquatic ecosystems (Wetzel 2001). For these reasons, DO was chosen as one of the metrics used in the KRREP expectations for evaluation of the status and success of the KRRP (Colangelo and Jones 2005).

DO in the Kissimmee River channel is a function of the balance between primary production, reaeration, and respiration (Chen 2019), which are influenced by many factors including temperature, water depth, stage, and discharge at water control structures S-65A and the former S-65C (Chen et al. 2016). Operation of these structures thus has important implications for reduction of the severity and/or duration of hypoxic (< 2 mg/L) and anoxic events in partially restored sections of the Kissimmee River.

Evaluation of Expectation 8

Expectation Components: *Mean daytime concentration of DO in the Kissimmee River channel at 0.5 to 1.0 m depth will increase [a] from < 1 to 2 mg/L to 3 to 6 mg/L during the wet season (June–October) and [b] from 2 to 4 mg/L to 5 to 7 mg/L during the dry season (November–May). [c] Mean daytime DO concentrations within 1 m of the channel bottom will exceed 1 mg/L more than 50% of the time. [d] Mean daily (24-hour) DO concentrations will be > 2 mg/L more than 90% of the time (updated from Colangelo and Jones 2005).*

Reference (Pre-channelized Period) and Baseline (Channelized Period) Data

Based on reference and baseline data, restoration of the Kissimmee River is expected to improve DO concentrations in the river channel primarily by reintroducing flow, which is expected to reduce the amount of organic matter that accumulates on beds of non-flowing (remnant) channels after construction of the C-38 canal (Colangelo and Jones 2005). DO data from the Kissimmee River were not available prior to channelization. For this reason, available daytime DO data from nearby free-flowing blackwater streams where DO had been measured frequently from 1973 to 1999 were used to estimate reference (pre-channelization) conditions for the Kissimmee River (**Table 9-6**). For some of these streams, more than 10 years of data were available (Colangelo and Jones 2005). Baseline (channelized period) DO data were obtained from monitoring stations in non-flowing remnant river runs of the Kissimmee River and the C-38 canal prior to Phase I construction. For these data, grab samples were collected monthly within a time window between 10 am and 2 pm from WY1996 to WY1999. Expectation 8 Components [a], [b], and [d] were developed based on these reference and baseline data. Component [c] was developed based on weekly DO depth profiles sampled in Micco Bluff Run and Montsdeoca Run in the Phase I project area of the Kissimmee River from May to October 1999. Details and summaries of reference and baseline data and expectation development are available in Colangelo and Jones (2005).

Table 9-6. Reference, baseline, and post-construction DO sampling for performance evaluation in the KRRP.

Period	Sampling Type and Frequency	Depth	Dates Collected	Location	Purpose
Reference (represents pre-channelization condition)	Grab, daytime; Monthly	0.5–1.0 m	1973–1999	Reference nearby free-flowing blackwater streams	Expectation and target development
Baseline	Grab, daytime; Monthly	0.5–1.0 m	1996–1999	Non-flowing remnant runs in Kissimmee River	Establish baseline for comparison with restored condition
Post-Phase I Construction – Interim and Final	Sonde: continuous	0.5–1.0 m	2002–present	Kissimmee River Phase I area	Expectation evaluation; hypoxia/anoxia investigations
Post-Phase I Construction Interim and Final	Grab, daytime; Monthly	0.5–1.0 m and within 1 m of channel bottom	2002–present	Remnant runs in Kissimmee River	Expectation evaluation

Interim (Post-Phase I Construction) Data

DO monitoring continued in the Phase I Interim Period (post-Phase I construction) at some of the stations used to establish reference and baseline DO conditions. The same or similar grab sampling methods have been used to provide data for evaluating changes in DO before and after restoration construction (**Table 9-6**). Grab samples used for evaluation of Components [a] and [b] were collected monthly from sampling stations KREA91, KREA92, and KREA97 in Pool A and KREA93, KREA94, and KREA98 in the Phase I area between 10 am and 2 pm. Daytime DO concentrations within 1 m of the channel bottom were also measured at stations KREA94 and KREA98 in the Phase I area for evaluation of Component [c]. Daytime-only measurements were used for compatibility with the available reference data as described earlier and in Colangelo and Jones (2005).

For evaluation of Component [d] during the Interim Period, continuous monitoring of daily (24-hour) DO at stations PC33 and PC62 was conducted using stationary DO sondes at a depth of 0.5 to 1.0 m from the water surface in the Phase I river channel (**Table 9-6**). The data were collected continuously at

15-minute intervals day and night. Data from these stations also are used to provide technical guidance for adaptive management of discharge at water control structures S-65 and S-65A.

For statistical evaluations of a restoration effect on DO, the difference (ICd) between the Impact (Pool BC of the Phase I area where flow was reestablished in 2001) and Control (Pool A, which was not altered by restoration construction) area means was calculated for daytime DO collected monthly at the KREA stations using a before-after-control-impact paired series (BACIPS) sampling design (Osenberg et al. 2006, Bousquin and Colee 2014). The ICd data were tested for autocorrelation using a Durbin-Watson test, which indicated no significant autocorrelation. A t-test was used to test the difference between the ICd means for daytime DO in the Before (Baseline) and After (Interim) periods (Stewart-Oaten et al. 1992). Statistical significance was evaluated at significance level (α) = 0.05.

Post-Construction Dissolved Oxygen from WY2002 to WY2020

Since completion of Phase I construction (WY2002–WY2020), DO in the Phase I Impact area (Pool BC) has averaged 2.87 ± 0.11 mg/L (1 SE) during the wet season and 6.59 ± 0.08 mg/L during the dry season (**Figure 9-17**). By comparison, post-construction DO in the Control area (Pool A) was significantly lower at 1.92 ± 0.10 and 3.64 ± 0.12 mg/L during the wet and dry seasons, respectively (probability factor [p] < 0.01). Mean annual daytime DO has been significantly higher in the Phase I area (5.04 ± 0.17 mg/L) than in Pool A (2.92 ± 0.20 mg/L) for the 18 water years following completion of Phase I construction ($p < 0.01$) (**Figure 9-18**).

A t-test on the ICd means of Baseline and Post-Phase I Construction samples indicated that DO greatly improved in the Phase I impact area during the Post-Phase I Construction period compared to the control area. The ICd for DO was significantly higher for the post-construction period (2.12 ± 0.16 mg/L) than for the baseline period (-0.18 ± 0.19 mg/L; $p < 0.01$).

In WY2020, three of the four expectation components were met (**Table 9-7**). Mean daytime DO concentration in the wet season in the Phase I area increased from 3.10 mg/L in WY2019 to 3.51 mg/L in WY2020 ($p < 0.01$), meeting the Component [a] target of 3 to 6 mg/L. Mean daytime DO concentration in the dry season in the Phase I area continued to be high in WY2020, meeting Component [b] of 5 to 7 mg/L. The percentage of time that mean daytime DO concentrations within 1 m of the channel bottom were > 1 mg/L, was 96% in WY2020, exceeding its 50% target [c]. For Component [d], the percentage of time that mean daily DO concentrations were > 2 mg/L in the river channel in WY2020 was 84%, not meeting the Component [d] target of > 90% of the time annually.

Table 9-7. Restoration expectation component metrics and WY2020 values for DO.

Expectation Components	WY2020 Value	Metric Achieved in WY2020	Data Source
[a]. Mean daytime DO concentration in the river channel at 0.5- to 1.0-m depth will increase from < 2 mg/L to 3 to 6 mg/L during the wet season (June–October).	3.51 ± 0.42 mg/L	Yes	KREA93, KREA94, and KREA98 (grabs)
[b]. Mean daytime DO concentration in the river channel at 0.5- to 1.0-m depth will increase from 2 to 4 mg/L to 5 to 7 mg/L during the dry season (November–May).	7.42 ± 0.10 mg/L	Yes	KREA93, KREA94, and KREA98 (grabs)
[c]. DO concentrations within 1 m of the channel bottom will be > 1 mg/L more than 50% of the time annually.	96%	Yes	KREA94 and KREA98 (grabs)
[d]. Mean daily DO concentrations in the river channel will be > 2 mg/L for more than 90% of the time annually.	84%	No	Sondes at PC33 and PC62 (continuous)

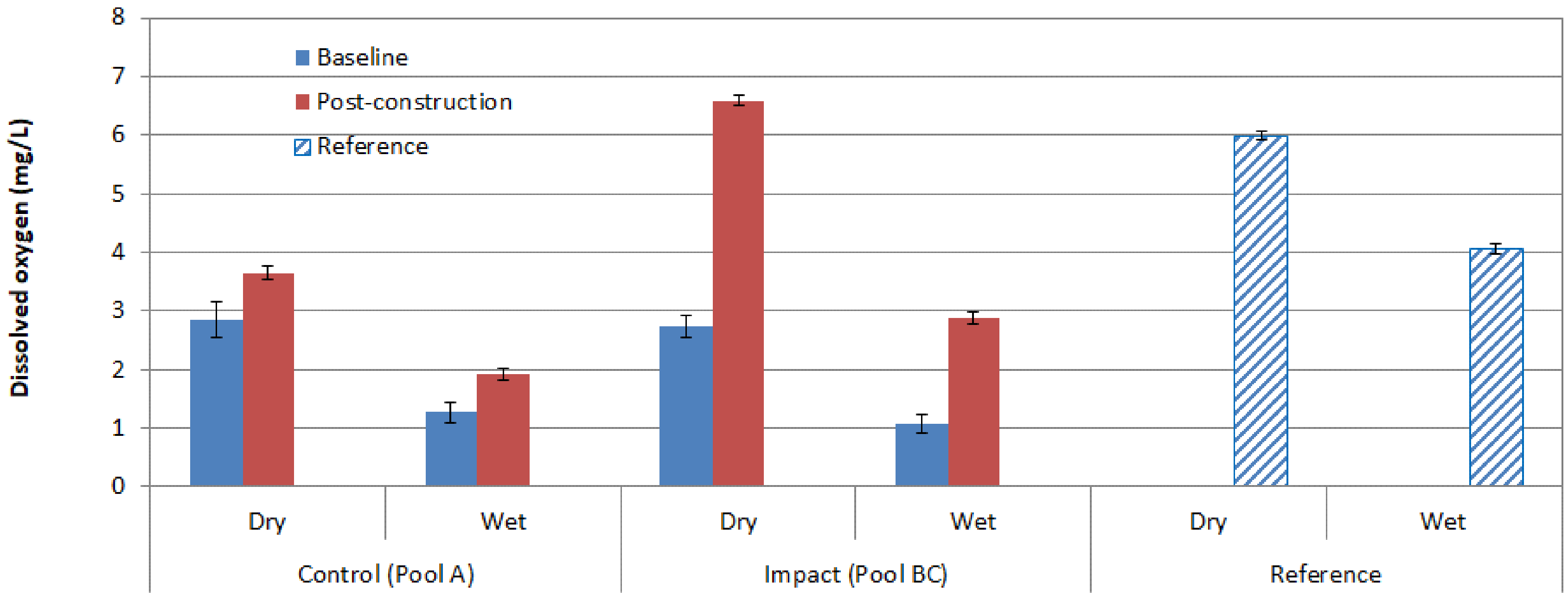


Figure 9-17. Daytime DO concentrations (mean ± SE) in reference streams (period of record WY1973–WY1999) and Control and Impact areas in wet and dry seasons during the baseline (WY1997–WY1999) and Post-Phase I Construction (WY2002–WY2020) periods. Impact areas in Pool BC have had reestablished flow since Phase I construction was completed in 2001; Control areas in Pool A have not been altered by KRRP construction activities and therefore, remain non-flowing.

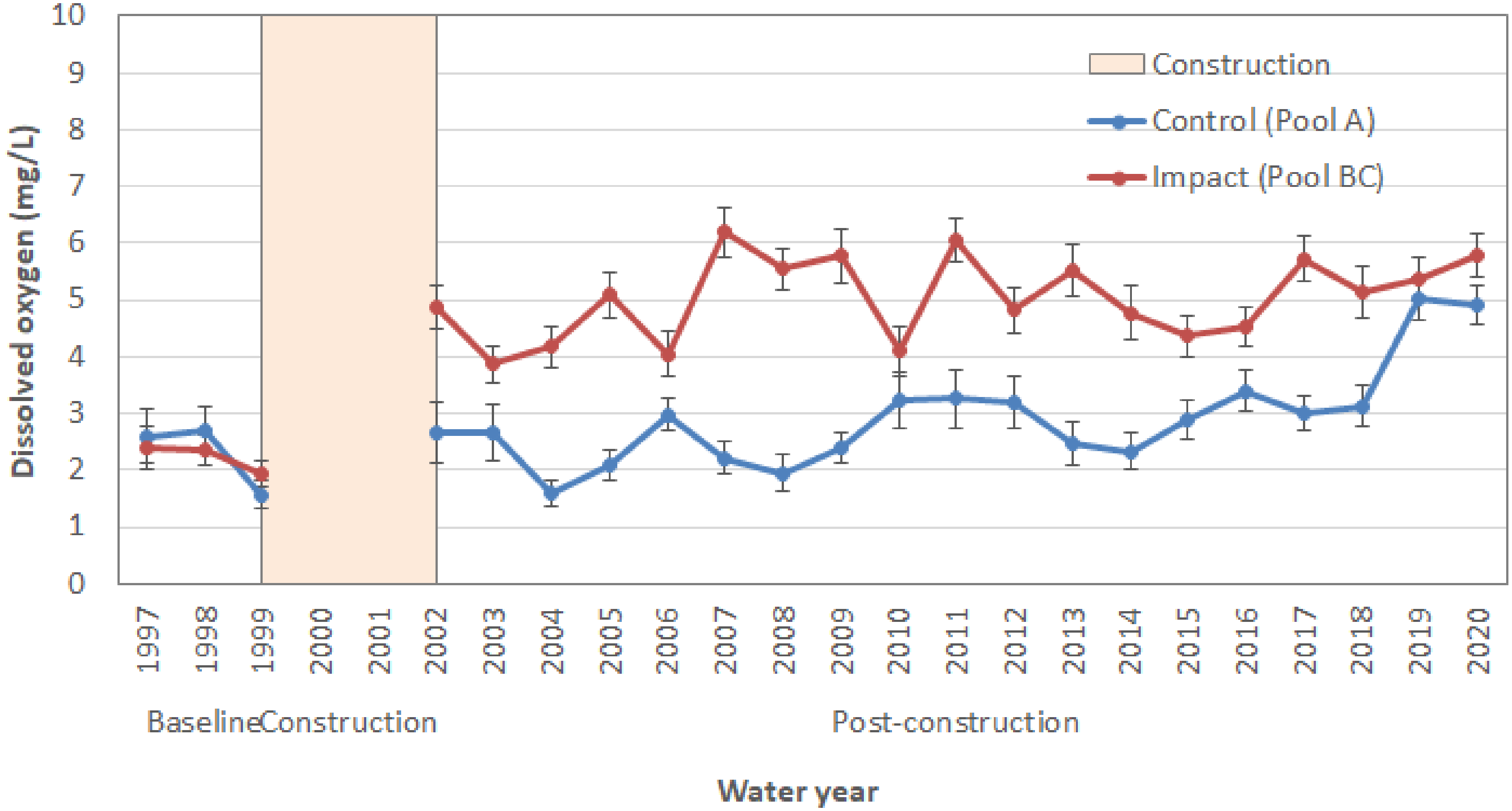


Figure 9-18. Daytime DO concentrations (mean ± SE) of sampling stations KREA91, KREA92, and KREA97 in Pool A and sampling stations KREA93, KREA94, and KREA98 in the Phase I Impact area (Pool BC) of the Kissimmee River for each water year during the baseline (WY1997–WY1999) and post-Phase I construction periods (WY2002–WY2020).

We note that the Component [d] target may be met in a year in which the river still experiences deep DO sags, as happened last year (Koebel et al. 2020). The current target would be met with a 36-day period of DO less than 2 mg/L that is capable of harming fish populations in the river. We are developing a new DO target based on a more recent reference DO data set, that targets “mean daily DO concentrations in the Kissimmee River channel at 0.5 to 1.0 m below the water surface will be > 2 mg/L for more than 95% of the time annually, and/ or > 1 mg/L more than 98% of the time”. This newly proposed DO target has not yet been finalized and published.

As in previous years, monthly daytime and daily mean DO concentrations in WY2020 showed a seasonal pattern with high DO levels in the dry season and lower DO in the wet season (**Figures 9-19** through **9-21**), a pattern that was not seen prior to reestablishment of flow (Chen et al. 2016). DO in the river channel was low in the 2019 wet season (June through October) and higher in the 2019-2020 dry season (November–May).

2019 Anoxia Events

Following a large rainfall event directly over the Pool A basin, which led to rapid increases in discharge for flood control at S-65A in late June and early July 2019, DO concentration in the Kissimmee River rapidly declined to 0 mg/L (“crashed”). The anoxic condition lasted 10 days (June 22–July 1, 2019) and resulted in a very substantial fish kill throughout Pool BCD as described in the *Fish Population Monitoring* subsection later in this chapter. This DO crash was associated with heavy rainfall over Pool A (**Figure 9-22**), which necessitated the rapid increase in flow that disrupted photosynthesis in the river downstream. The proximate cause of the DO crash was likely a combination of factors related to this, including rapidly increased water depth, disruption of aquatic photosynthesis, mobilization of nutrients on the suddenly-inundated Kissimmee River floodplain, and reduced light availability in the water column.

Another DO crash occurred during August 4 to September 13, 2019 when DO declined to 1 mg/L for 23 days (August 8–30, 2019). Following heavy rainfall in the Kissimmee Basin and increasing S-65A discharge in late July and early August 2019, DO concentration in the Kissimmee River rapidly declined to below 1 mg/L (**Figure 9-23**).

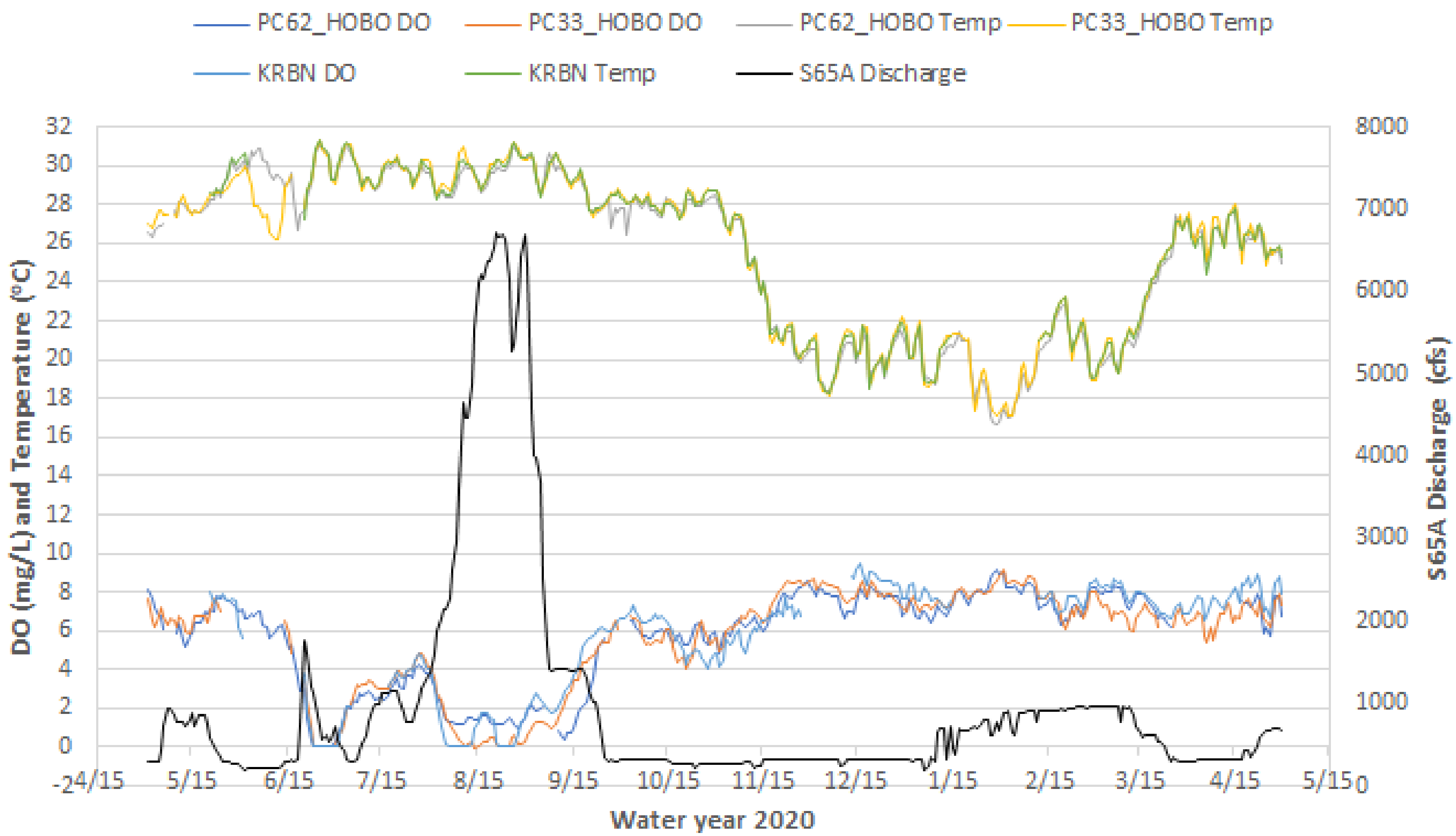


Figure 9-19. Daily mean DO concentrations from sampling stations KRBN, PC33, and PC62 in the river channel of the Phase I Impact area (Pool BC) in WY2020 for evaluation of Expectation 8, Component [d]. See **Figure 9-20** for locations of DO stations.

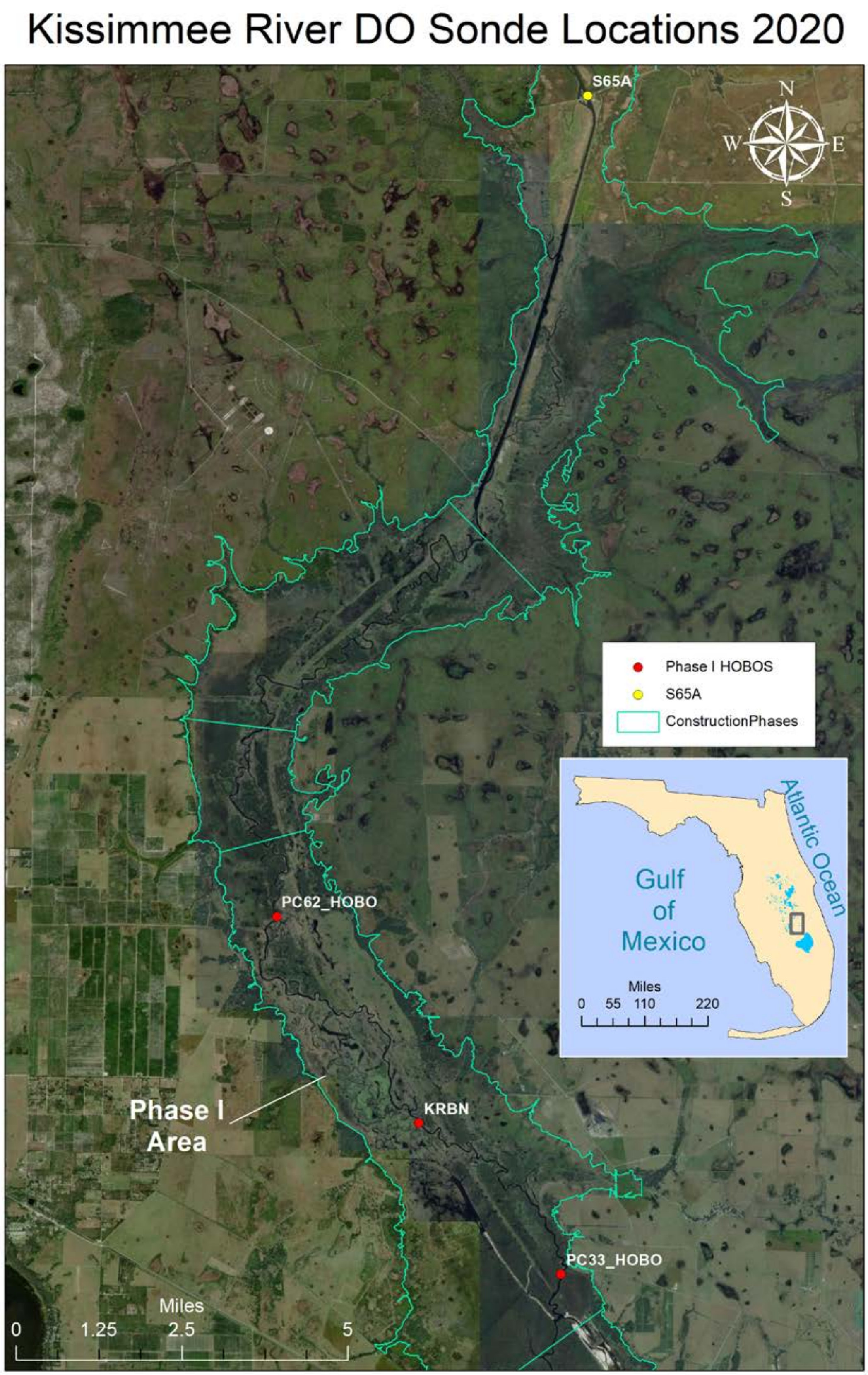


Figure 9-20. Locations of the Phase I river channel DO stations used in **Figure 9-19**.

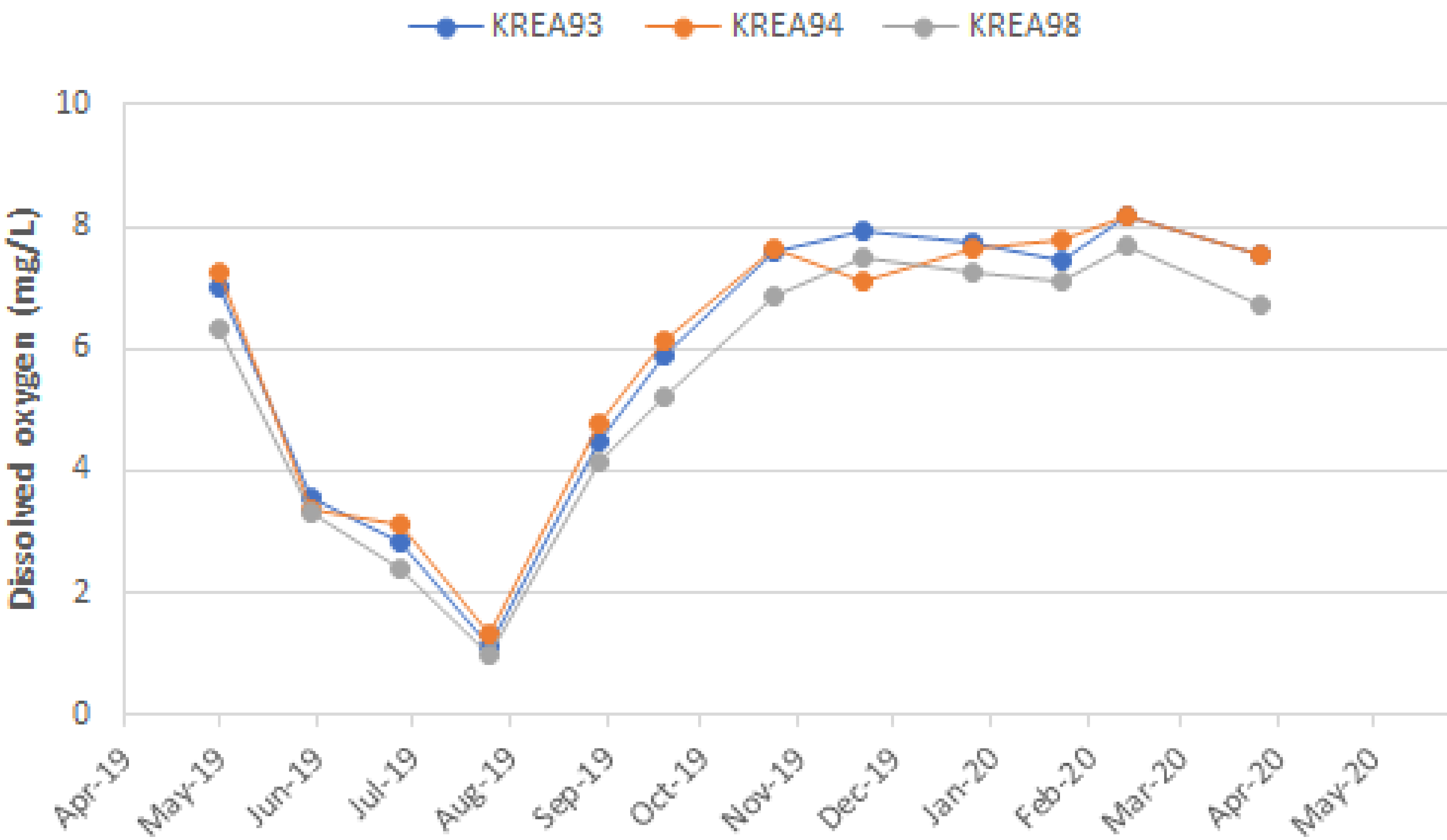


Figure 9-21. Monthly daytime DO concentrations from sampling stations KREA93, KREA94, and KREA98 in the river channel of the Phase I Impact area (Pool BC) in WY2020.

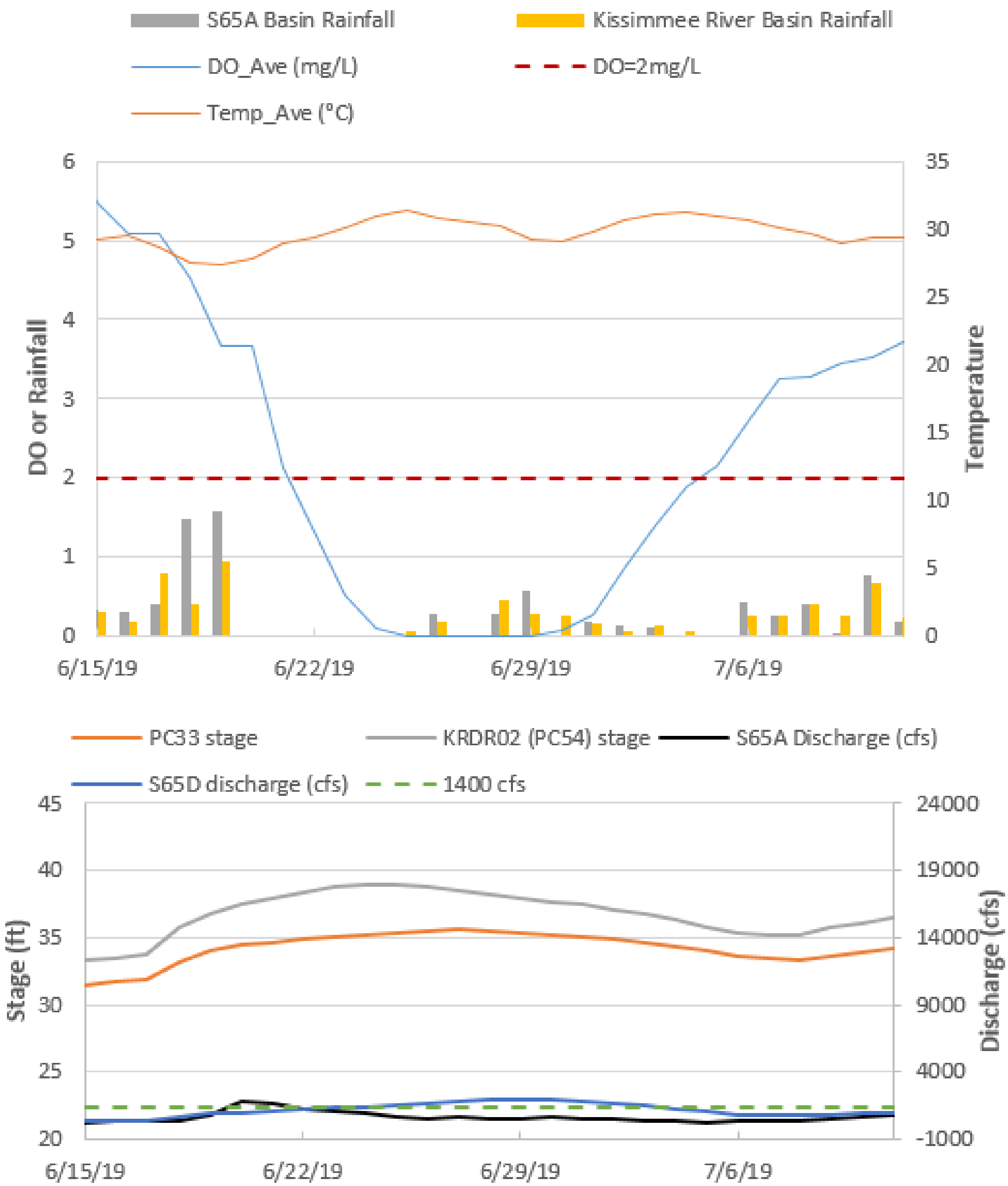


Figure 9-22. Average DO concentrations (DO_Ave) at sampling stations KRBN, PC62, and PC33 in the river channel of the Phase I Impact area (Pool BC) along with average water temperature (Temp_Ave) in degrees Celsius (°C) and rainfall in inches at S6A and for the Kissimmee River Basin (top) and daily stage at PC33 and KRDR02 and daily discharge from S65A and S65D (bottom) in June and July 2019.

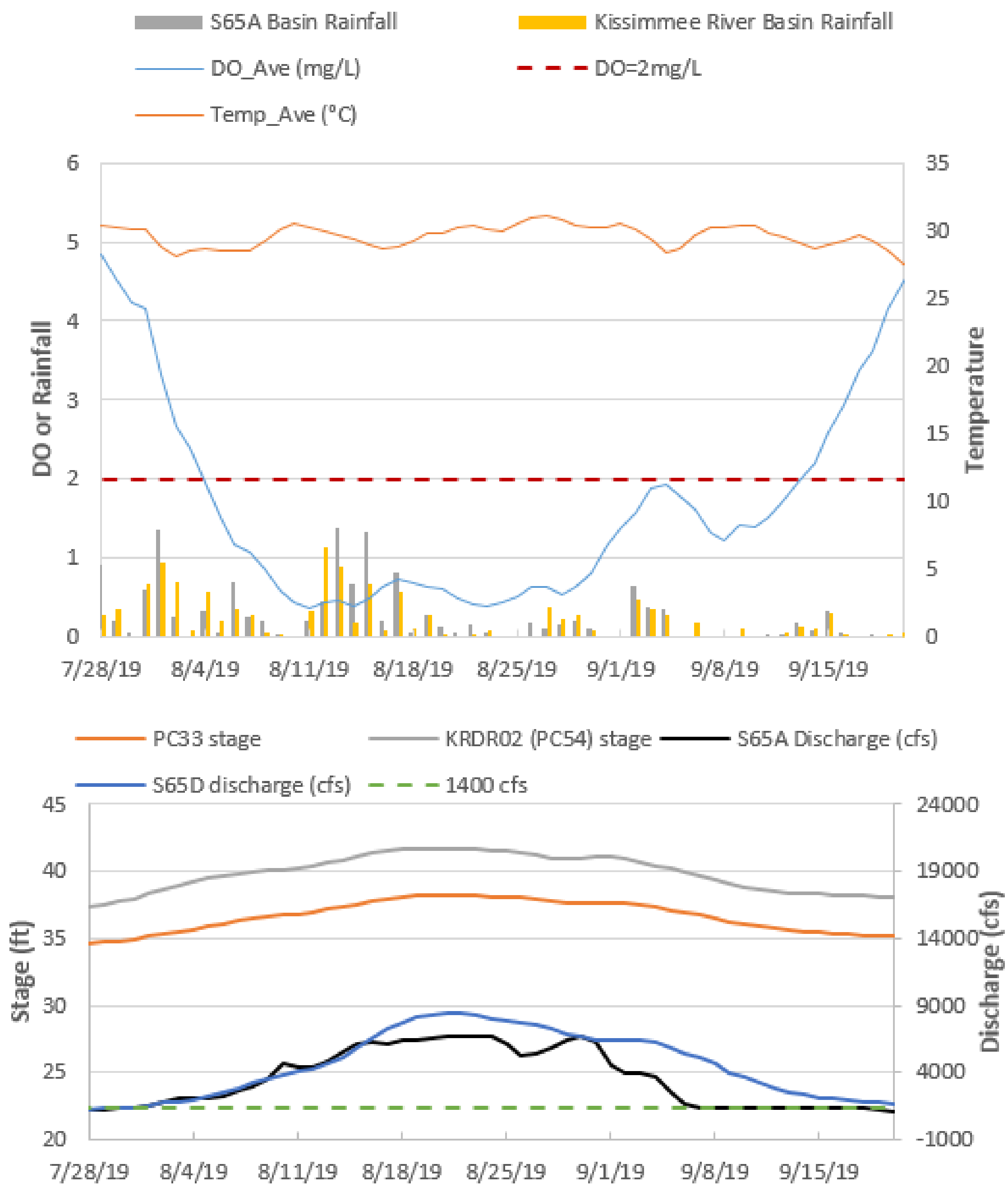


Figure 9-23. Mean daily DO concentrations (DO_avg) at sampling stations KRBN, PC62, and PC33 in the river channel in the Phase I Impact area (Pool BC) along with water temperature in degrees Celsius (°C) and rainfall in inches (top) and daily stage at PC33 and KRDR02 and daily discharge from S65A and S65D (bottom) in July to September 2019.

INVASIVE VEGETATION ON THE KISSIMMEE RIVER FLOODPLAIN

As noted in previous SFER reports, wetland vegetation on the Kissimmee River floodplain is expected to return to historical areal coverage and species densities when the hydrologic conditions of the floodplain are restored to the approximate antecedent conditions. With this in mind, KRREP scientists developed expectations predicting coverage of wetland vegetation communities on the restored floodplain (Carnal 2005a, b, c) based on historical areal coverage.

Hydrologic restoration is not yet complete and will not be until the HRS is implemented, anticipated in late 2021. Despite this, much progress has been made during the interim period in reestablishing wetland vegetation on the floodplain. Indeed, wetland vegetation overall, all but eradicated during the channelized period between 1970 and 1999, now makes up more than 80% of the floodplain, and has reached its historic levels in overall coverage. However, native species densities have not returned to historic levels. In fact, the species makeup on the floodplain is very different now than the historic floodplain before channelization. In the years since the restoration project began, populations of invasive wetland plants have spread onto the floodplain and pose a threat to the restoration of the native wetlands to the area.

Exotic wetland grasses, including para grass (*Urocloa mutica*), West Indian marsh grass (*Hymenachne amplexicaulis*), and limpo grass *(Hemarthria altissima*) have expanded in wet prairie areas, which occupy areas that were historically dominated by BLM and native Wet Prairie grasses in the historic system.

The largest vegetation coverage increase over the period between 2011 and 2015 was in the category Wetland Shrub, which increased its area by about 6% in that period, mostly because of expansion of Carolina willow (*Salix caroliniana*) populations, especially within the northern to central parts of the Phase I area (**Figures 9-24** and **9-25** and **Table 9-8**). This expansion may be due to natural expansion of the established populations of mature willows within this area, but the pressure on surrounding native populations is disquieting.

In an effort to measure the impact of these invasions and to give scientists a snapshot of the locations and densities of exotic plant populations, a cell-based mapping method was tested that offered quicker results than can be obtained from the normal vegetation mapping methods. The key to a quicker turnaround is in mapping dominant classes within pre-determined hectare-size cells rather than doing more detailed polygon-based mapping.

In 2018, more than 3,800 100- by 100-meter-sized cells were established across the Phase I floodplain area using Geographic Information System (GIS) functions. The initial photo interpretation was then carried out by selecting the dominant vegetation class where possible within each cell. Cells where the class was uncertain or indeterminate were visited by helicopter or airboat to confirm class type. These trips were carried out in 2018 and 2019. In addition, several cells were visited as random accuracy assessment samples. Class types within each cell were revisited after field trips to apply any applicable revisions and confirm interpreted vegetation types. Final editing and accuracy assessment resulted in the maps in **Figures 9-24** and **9-25** and **Table 9-8**. The resultant maps have overall accuracy of about 88%. This is a slightly lower accuracy measure than previous mapping efforts, which may be due to the use of cell-based mapping methods while at the same time increasing the number of classes mapped.

The maps and table show that, although wetland habitat still makes up a large percentage of the Phase I floodplain, 23% of the floodplain area is now covered with exotic Wet Prairie grasses (**Table 9-8**), while also showing a small reduction in coverage of BLM plants since the 2015 mapping effort. Note that in previous mapping efforts, there was no attempt to divide Wet Prairie into exotic and native types, so comparisons with previous maps are not possible. However, going forward, such comparisons will be possible.

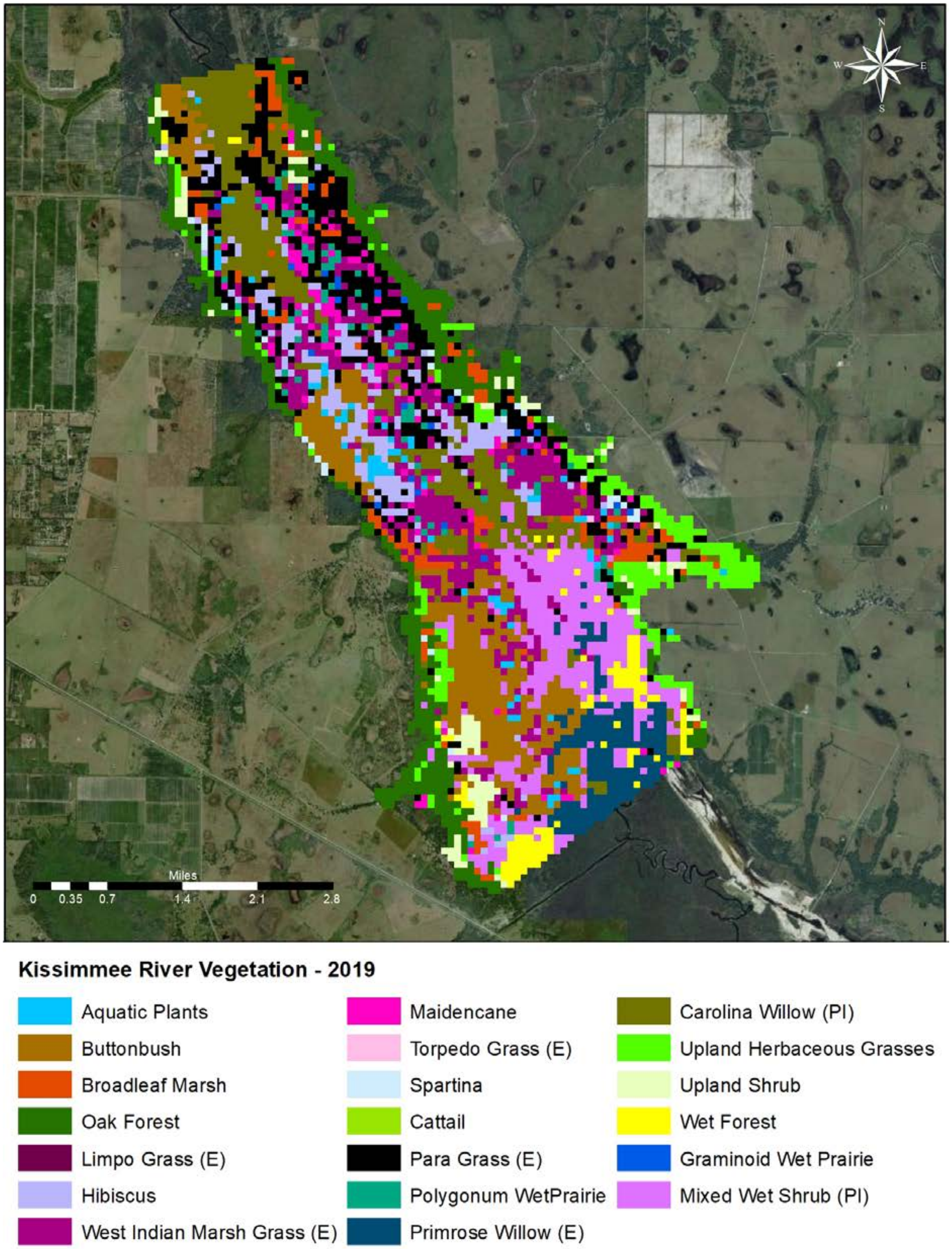


Figure 9-24. Vegetation map of Kissimmee River floodplain Phase I area showing detailed map classes including invasive and exotic communities. (Note: E – Exotic invasive class and PI – potentially invasive class.)

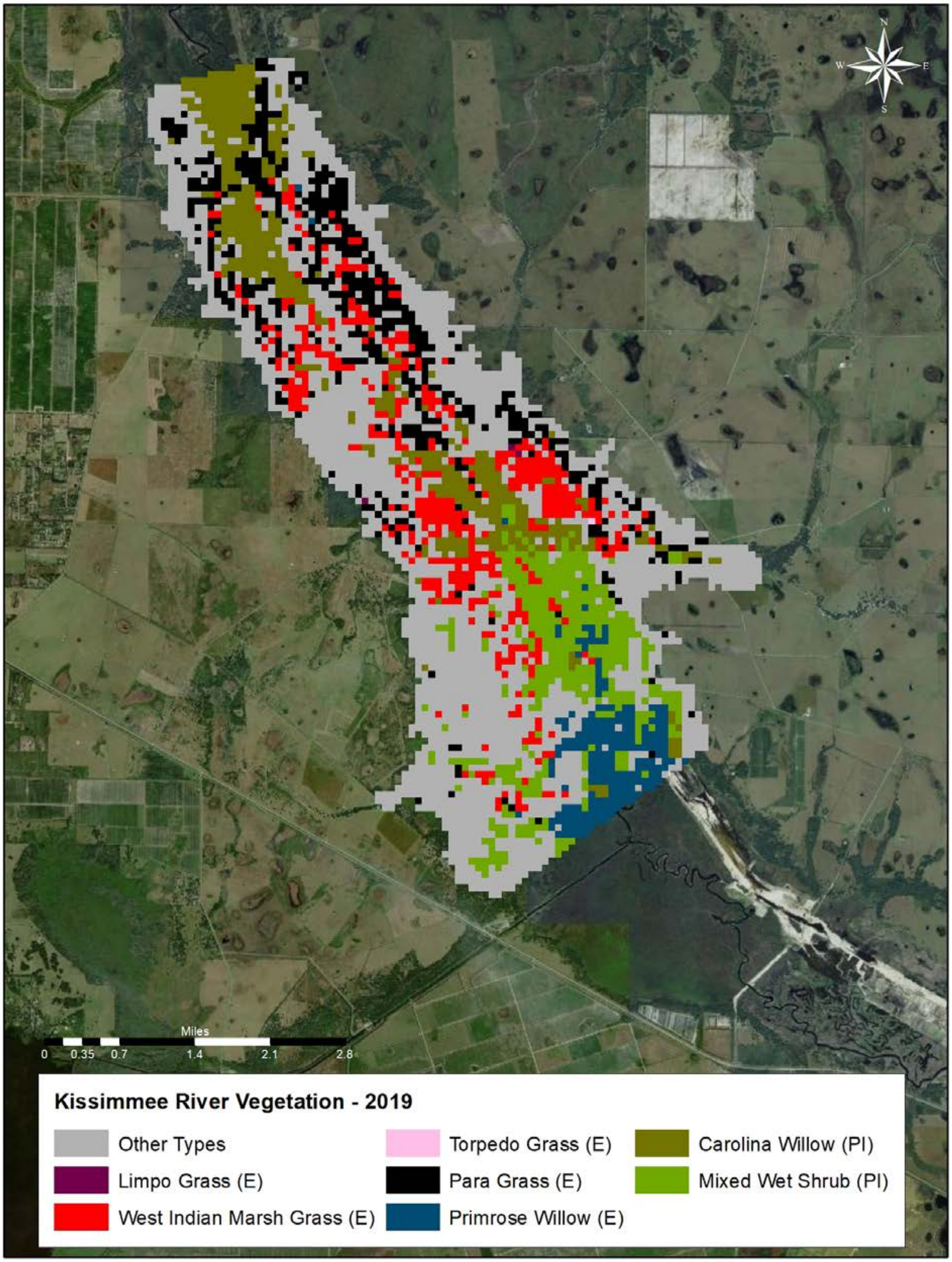


Figure 9-25. Vegetation map of Kissimmee River floodplain Phase I area showing exotic or potentially invasive map classes. (Note: E – exotic invasive class and PI – potentially invasive class.)

Table 9-8. Area of vegetation types within the Phase I restoration area over six time periods. Break-out of Native and Exotic Wet Prairie are only available for the most recent mapping effort. Note that most populations of Wet Shrub are considered potentially invasive.

Vegetation Type	Area (hectares and percent area)						
	1952	1974	2003	2008	2011	2015	2019
Broadleaf (including Buttonbush) Marsh	1,913 (49.7%)	175 (4.6%)	304 (7.9%)	658 (17.1%)	793 (20.6%)	639 (16.6%)	668 (17.3%)
Wet Prairie	1,186 (30.8%)	525 (13.6%)	1,270 (33.0%)	1,513 (39.3%)	1,167 (30.3%)	1,136 (29.5%)	1,073 (27.9%)
Native Wet Prairie							188 (4.9%)
Exotic Wet Prairie							885 (23.0%)
Wetland Shrub	36 (0.9%)	104 (2.7%)	637 (16.6%)	706 (18.3%)	734 (19.1%)	1,002 (26.0%)	1,014 (26.4%)
Other Wetland	82 (2.1%)	68 (1.8%)	341 (8.9%)	331 (8.6%)	508 (13.2%)	470 (12.2%)	465 (12.1%)
Aquatics	61 (1.6%)	36 (0.9%)	136 (3.5%)	241 (6.3%)	173 (4.5%)	109 (2.8%)	74 (2.3%)
Miscellaneous Wetlands	9 (0.2%)	26 (0.7%)	76 (2.0%)	25 (0.6%)	298 (7.8%)	264 (6.9%)	270 (7.0%)
Wet Forest	12 (0.3%)	6 (0.1%)	129 (3.3%)	65 (1.7%)	37 (0.9%)	97 (2.5%)	121 (3.1%)
Total Wetlands	**3,216 (83.6%)**	**872 (22.7%)**	**2,553 (66.4%)**	**3,208 (83.4%)**	**3,201 (83.2%)**	**3,247 (84.4%)**	**3,220 (83.7%)**
Other Classes	631 (16.4%)	2,975 (77.3%)	1,294 (33.7%)	639 (16.6%)	646 (16.9%)	600 (15.6%)	627 (16.8%)
Total Area	**3,847**	**3,847**	**3,847**	**3,847**	**3,847**	**3,847**	**3,847**

As it did in previous maps, the invasive exotic primrose willow (*Ludwigia peruviana*), dominates the central floodplain in the southern portion of the Phase I area, closest to the former location of the S-65C water control structure (**Figure 9-25** and **Table 9-8**). Relatively stable water levels associated with the structure may have allowed this invader to out compete native species in this area. This structure was removed in 2017. Once the HRS is implemented, conditions may be less favorable for *L. peruviana* and native vegetation may return to this area (Spencer and Bousquin 2014).

Carolina willow, a native shrub, seems to be expanding in the floodplain and is considered potentially invasive, taking over former Wet Prairie and BLM areas by expanding on the margins of already established populations in the northern to central areas of the Phase I floodplain (**Figures 9-24** and **9-25**). The current mapping approach offers a way, going forward, of documenting expansions of this type, giving scientists a more effective way to view changes in floodplain vegetation dynamics.

To reverse the expansions of invasive species using adaptive management, SFWMD personnel have been testing vegetation management techniques in some parts of the floodplain, including herbicide and fire used in different combinations to test their efficacy. So far, such treatments have been promising, but measurable reductions of invasive species over the long term will require further testing and application of an integrated approach. Beneficial changes in the coverage of invasive species may also come about when restoration construction is completed and the HRS is implemented in 2021. Although near continuous flow has been maintained in the river channel and the floodplain has been inundated intermittently during the 14 years that have elapsed between completion of Phase I and the 2015 imagery, historical hydroperiods may not be closely approximated until the HRS is implemented. The changes in hydrology that will follow implementation of HRS are expected to drive further changes in the coverage of vegetation types and these conditions should favor BLM vegetation in lower elevations of the floodplain.

Funding for control of invasive exotic grasses on the Kissimmee River floodplain has not been available from the customary sources in recent years, but a District-funded initiative starting in Fiscal Year 2022 (FY2022; October 1, 2021–September 30, 2022) has been proposed.

FLOODPLAIN VEGETATION MANAGEMENT ACTIVITIES

During the Interim Period, several significant vegetation management issues arose that required adaptive management action. The primary vegetation management issues within the KRRP management area are as follows:

- Invasion of floodplain wet prairie and BLM habitat by exotic grasses on the Florida Exotic Pest Plant Council's List of Invasive Plant Species 2019 (FLEPPC 2019). These grasses are primarily paragrass (Category II), limpo grass (Category I) and West Indian marsh grass (Category I) and they are displacing native species.
- Invasion of former spoil areas, the backfilled C-38 canal, and other disturbed soils by Carolina willow and Peruvian primrosewillow.
- Invasion of Wet Prairie and former BLM habitat by wax myrtle (*Myrica cerifera*) and other facultative shrubs (Rule 62-340.450, Florida Administrative Code [F.A.C.]; available online at https://floridadep.gov/water/submerged-lands-environmental-resources-coordination/content/wetland-delineation-vegetative.).

The long-term management goal for the KRRP area is to rely primarily on hydrologic change and prescribed fire to restore and maintain the reestablished floodplain marshes, only using herbicide and mechanical treatments when necessary to achieve maintenance control as needed to reach restoration goals. No single management tool is used in isolation and each management unit is evaluated individually to determine which combination and sequence of management actions may best achieve the goals for floodplain vegetation. Management actions to address the abovementioned vegetation issues will be a combination of the following, again with the focus being to supplement rather than replace hydrologic change and prescribed fire:

- Hydrologic change through HRS implementation HRS. Expected changes include longer hydroperiods, greater stage amplitude, slower rates of stage change, and a more natural seasonality in discharge to the river from its headwaters lakes.
- Prescribed fire through a well planned and documented prescribed burning program that focuses on early lightning season burning, when possible, to promote the return of historic Wet Prairie and BLM habitats.
- Herbicide treatments of target species to reduce and control exotic and invasive infestations and encourage recruitment of native species. Treatments are documented and coordinated with other management activities.
- Mechanical treatments such as mowing, roller-chopping, and shredding to reduce facultative and/or invasive shrubs and trees as needed in Wet Prairie and BLM habitats.
- Biological control using host-specific natural enemies from the native range of the invasive exotic species and introducing them to SFWMD lands to provide a natural regulation of the pest plant. Examples of state- and federally-approved biocontrol agents include the melaleuca weevil (*Oxyops vitiosa*), white lygodium moth (*Austromusotima camptozonale*), waterhyacinth planthopper (*Megamelus scutellaris*), and waterhyacinth weevils (*Neochetina* spp.).

In PW2020, while no prescribed burns were conducted (see below), herbicide applications and biocontrol agents were used to begin to address the vegetation management issues described above.

Prescribed Fire

SFWMD is using prescribed fire as a management tool to help reach the goal of restoring ecological integrity within the KRRP area. It is hoped that well timed prescribed burns in the late spring and early summer will help reduce coverage of exotic grasses and invasive shrubs by direct consumption and will increase the competitive advantage of native Wet Prairie and BLM species. Native wet prairie and BLM species are adapted to lightning season fires just prior to wet season inundation. Lightning season wildfires are one of the historic ecological processes that helped shape the vegetation structure of the river floodplain and its associated fauna. However, no prescribed burns were conducted during this reporting period, due in part to the COVID-19 pandemic-related restrictions, which began in Florida starting at the end of March 2020.

Fire effects on vegetation are being monitored by SFWMD using permanent photo monitoring points (see **Figures 9-26** and **9-27** as examples), aerial photography, and vegetation plots. Ground photo points and vegetation plots are monitored at 3, 6, 12, and 24 months post-burn, and subsequently every 5 years. Longer-term monitoring of vegetation will be conducted via aerial photo interpretation approximately every 3 to 5 years. The results of this monitoring will be used to determine what other vegetation management activities will be required to manage invasive exotic grasses and shrubs within the floodplain. Activities may include hydrological manipulations, herbicide, and mechanical treatments such as roller-chopping and shredding. It is known from other study areas throughout the state that prescribed fire alone will not eliminate or even reduce invasive exotic grasses over the long-term; it needs to be used in conjunction with hydrological management and oftentimes herbicide applications prior to burning.

Figure 9-26. Starvation Slough Prescribed Burn Photo Point 2, pre-burn on April 22, 2019. The trees in the background are the live oak hammock indicating roughly the 100-year floodline, the shrubs behind the graduated PVC pole are mostly native swamp rose-mallow (*Hibiscus grandiflorus*), and the herbaceous species are dominated by the invasive exotic grasses limpo grass and paragrass.

Figure 9-27. Starvation Slough Prescribed Burn Photo Point 2 three days post-burn on June 27, 2019. The oak hammock was not burned, the swamp rose-mallow was scorched aboveground, and the exotic grasses were partially consumed, being slightly reduced in height from approximately 60 centimeters (cm) to 20 cm (see graduated PVC pole in 10-cm increments). The lighter-colored grass laid over is indicative of scorched limpo grass.

Herbicide Treatments

District herbicide treatments targeting Old World climbing fern (*Lygodium microphyllum*), Brazilian pepper (*Schinus terebinthifolia*), tropical soda apple (*Solanum* sp.), strawberry guava (*Psidium cattleianum*) and other SFWMD priority invasive species were conducted within the floodplain during WY2020. Most treatments occurred south of the current restoration construction of the S-69 Weir between the CSX railroad bridge and the S-65D structure (i.e., outside the KRRP boundary), but aerial treatment of Old World climbing fern did occur in Pool A and in the vicinity of where the Istokpoga Canal meets the main river channel. For a more comprehensive summary of SFWMD herbicide treatments along the Kissimmee River, refer to Chapter 7: Status of Nonindigenous Species of this volume (Rodgers et al. 2021).

Results of the experimental treatment of approximately 60 ac of the invasive exotic West Indian marsh grass conducted during PW2019 (November 15, 2018) are still forthcoming. The treatment was part of a research project led by Dr. Stephen Enloe of the University of Florida examining the efficacy and selectivity of the grass-specific herbicides sethoxydim and fluazifop-butyl compared to standard non-selective treatments (e.g., Glyphosate + imazapyr) (Enloe 2017). Post-treatment data has been collected at 30, 60, and 90 days after treatment. The experimental treatment of approximately 30 ac of Carolina willow that was conducted near Oak Creek on March 30, 2018, was monitored for two years post-treatment and monitoring results are still being summarized and will be presented in next year's SFER. Funding for control of invasive exotic grasses on the Kissimmee River floodplain has not been available in recent years, but a District-funded initiative starting in FY2022 has been proposed. Herbicide treatments are costly, and funding is oftentimes inadequate to effectively address the invasive vegetation management issues occurring within the KRRP area. Planning and funding for invasive vegetation management within the KRRP area was not considered when the project was first initiated decades ago, thus aggressive expansion of invasive grasses and shrubs has remained uncontrolled. Therefore, continued, enhanced interagency coordination and funding is vital to achieving the floodplain vegetation component of the KRRP.

Biocontrol

Populations of the brown lygodium moth were released in two general locations along the Kissimmee River totaling 212,271 individuals. A mix of approximately 118,941 adult moths and caterpillars were released on November 13, 2019, along the main river channel between the old S-65C locks access road and just north of the Istokpoga Canal. Another 93,330 adult moths and caterpillars were released on June 1, 2020 along the main river channel between the CSX railroad bridge and the S-65D structure. The United States Department of Agriculture monitors moth introduction sites at other locations outside of the LKB.

NON-NATIVE APPLE SNAILS IN THE KISSIMMEE RIVER

While it is unclear exactly when the non-native apple snail *Pomacea maculata* (formerly *P. insularum*) was introduced into Central Florida water bodies, it was first documented in the Kissimmee Basin in 2003 where it was confined to a single area known as Goblets Cove on Lake Tohopikaliga (Desa 2008). By 2006, it had spread to nearly 45% of the lake, nearly doubling to over 80% of the lake in 2007 (Desa 2008). Although there is no detailed timeline describing the geographic expansion of *P. maculata* throughout the Kissimmee Basin, Cattau et al. (2016) indicate that by 2008, *P. maculata* had become well established throughout the Kissimmee River Valley including East Lake Tohopekaliga, Lake Hatchineha, Lake Kissimmee, Lake Istokpoga, and Lake Jackson. It also appears that adults colonized the C-38 canal and reestablished sections of the Kissimmee River and were transported downstream, as *P. maculata* had become well established in Lake Okeechobee by this time.

This rapid increase in geographic coverage is largely due to the snail's ability to rapidly reproduce. *P. maculata* egg masses are large with an average clutch size of over 2,000 eggs and a field hatching success rate of approximately 70% (Barnes et al. 2008). Although year round reproduction has been suggested for *P. maculata,* data are lacking to verify this. It is clear that *P. maculata* has an extended reproductive period in the southeast United States, beginning in early spring and extending through the warm autumn months. Paired with the ability of mature females to lay a new clutch every 7 to 10 days, it is not difficult to see how this species could rapidly expand its distribution. By contrast, the native Florida apple snail (*Pomacea paludosus*) is considered an annual breeder with an average clutch size of between 10 to 80 eggs.

Adult *P. maculata* were first collected from the KRRP area in March 2014 as part of a wading bird and waterfowl food availability study (Koebel et al. 2020). Individual sample density across samples from 2014 to 2019 was highly variable across years, ranging from 0 to 1,194 individuals per square meter (/m^2). Annual sample period density was also highly variable, ranging from < 1 to nearly 40 individuals/m^2 (**Figure 9-28**). Mean monthly density was also variable but generally did not exceed 20 individuals/m^2 in most months (**Figure 9-29**). No native apple snails were collected in the KRRP area during this study.

Snail kites were first observed actively foraging within the KRRP area as early as 2013, and snail kite nesting was first observed in 2016 after inundation of the northern Pool D floodplain for the first time in 50 years after Reach 2 backfilling of the C-38 canal. During 2016, a total of 21 active snail kite nests were observed. Of those active nests, two were successful with a total of four fledglings (Fletcher et al. 2017). No active nests were reported within the KRRP area in 2017. Formal surveys in 2018 found a total of 95 active nests, of which, 26 (27%) were successful, producing 53 fledglings (Fletcher et al. 2019). No active nests were observed in 2019.

As described above, no native apple snails have been collected within the KRRP area since the beginning of the food availability study in 2010. This suggests that snail kites that have nested and successfully fledged young in the KRRP area are relying on the exotic species exclusively. It is unclear whether the absence of native apple snails is a result of direct or indirect competition with *P. maculata.* Conner et al. (2008) found that the presence of adult *P. maculata* or *P. paludosus* decreased growth and juvenile survival of native snails and that the presence of one adult *P. maculata* had the same effect as three or four native adults. Posch et al. (2013) found similar reduced growth rates when juvenile *P. maculata* were in the presence of native juvenile snails. Although mean density of exotic snails was quite variable over the period from 2014 to 2019, they remained abundant enough to support foraging and intermittent snail kite nesting over that time. The presence of an abundant, albeit exotic, prey source within the KRRP area is a positive sign that may continue to benefit the snail kite population.

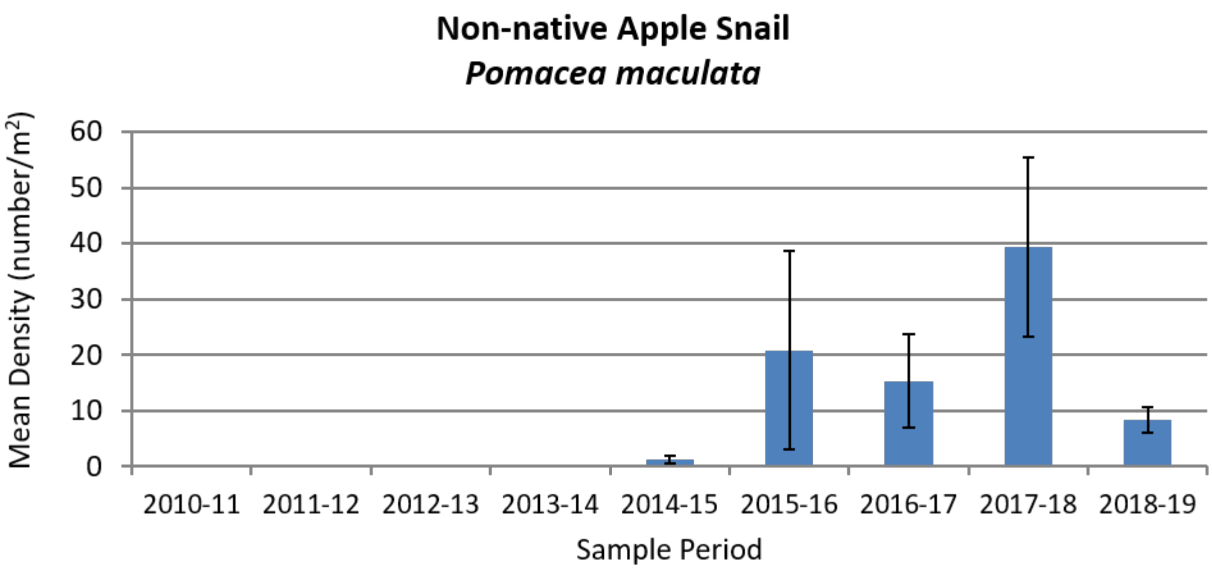


Figure 9-28. Mean sample period density + SE for non-native apple snails in the KRRP Phase I area.

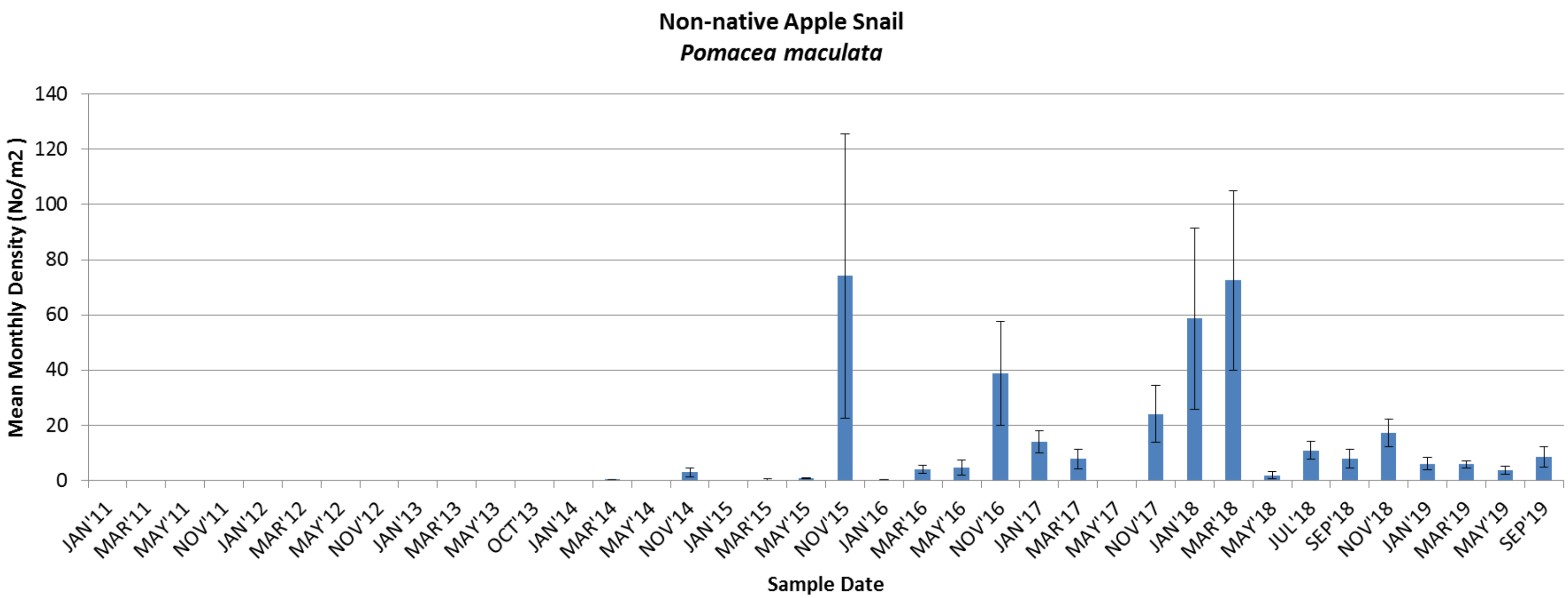


Figure 9-29. Mean monthly density + SE of *P. maculata*.

IMPACT OF THE 2019 ANOXIC EVENT ON FISH IN THE KISSIMMEE RIVER

In the Kissimmee River, fish, especially gamefish, can be stressed when the concentration of DO decreases below 2 mg/L (hypoxia) and may die when DO is < 1 mg/L (anoxia) (Furse et al. 1996). Since KRRP Phase I construction was completed in 2001, DO concentrations have generally improved (see the *Dissolved Oxygen* subsection earlier in this chapter), but prolonged periods of anoxic conditions do continue to occur in the wet season. In 2014, KRREP began a new study to quantify fish populations in the river channel and their response to restoration construction and water management. Early in the 2019 wet season, there was an anoxic event that was associated with a significant fish kill. In this section, the impact of this event on fish is summarized, focusing on centrarchids (sunfish), an important group of gamefish that includes largemouth bass and bluegill sunfish, and compare this event to a similar event that occurred in 2017.

The two centrarchid species examined in this report, largemouth bass and bluegill sunfish, have been the most common centrarchids and account for most of the centrarchid biomass collected in the Kissimmee River since 2014. The centrarchid community and other fish species in the Phase I area experienced substantial challenges in the 2019 wet season when exposed to a prolonged period of anoxic conditions.

Methods

Fish were sampled annually beginning in 2014 on randomly selected transects in the Phase I (sample size [n] = 12) and Phase IV (n = 10) restoration areas, in which flow was restored in 2001 and 2009, respectively. Sampling was conducted during periods of within-bank flow in May–June. Each transect was a 150-m segment of river shoreline. Fish were sampled by electrofishing along each transect for approximately 15 minutes (900 seconds). The exact duration of each transect was used to calculate the number (catch per unit effort [CPUE]) and biomass (biomass per unit effort [BPUE]) for all species and two groups that included hypoxia-tolerant versus hypoxia-intolerant species using the classification of Trexler (1995) for Kissimmee River fishes. All stunned fish were identified, measured to the nearest millimeter of total length (TL), weighed to the nearest gram and released alive. Additional sampling was conducted during summer months following anoxic events and during December 2017 through December 2019 to better understand how hypoxic and anoxic events affect fish populations in the Kissimmee River.

To evaluate the effect of the most recent (2019) anoxic event on the river's fishery, analyses were focused on the centrarchid community in Phase I and the two important gamefish species within the group, largemouth bass and bluegill sunfish. The annual spring sampling event that occurred in May was followed by an anoxic event in June that lasted for approximately seven days. The fish community was sampled again in early July, just days after the anoxic event and again in December. The average CPUE and BPUE calculated for the May 2019 (pre-anoxic event) sample was compared with the post-event samples using the means of samples collected in July and December 2019 (post-anoxic event).

Results and Discussion

During the anoxic event in June, centrarchid abundance (CPUE) was reduced within days by 93%, bluegill abundance by 91% and largemouth abundance by 100% (**Figure 9-30**). See the *Dissolved Oxygen* subsection earlier in this chapter for more information on these hypoxic and anoxic events. In December, approximately 6 months after the anoxic event, centrarchid abundance was 20% greater than the pre-event conditions reported in May. Much of the increase in centrarchid abundance was due to small, young of the year, bluegill that likely were spawned after the event (**Figure 9-31**).

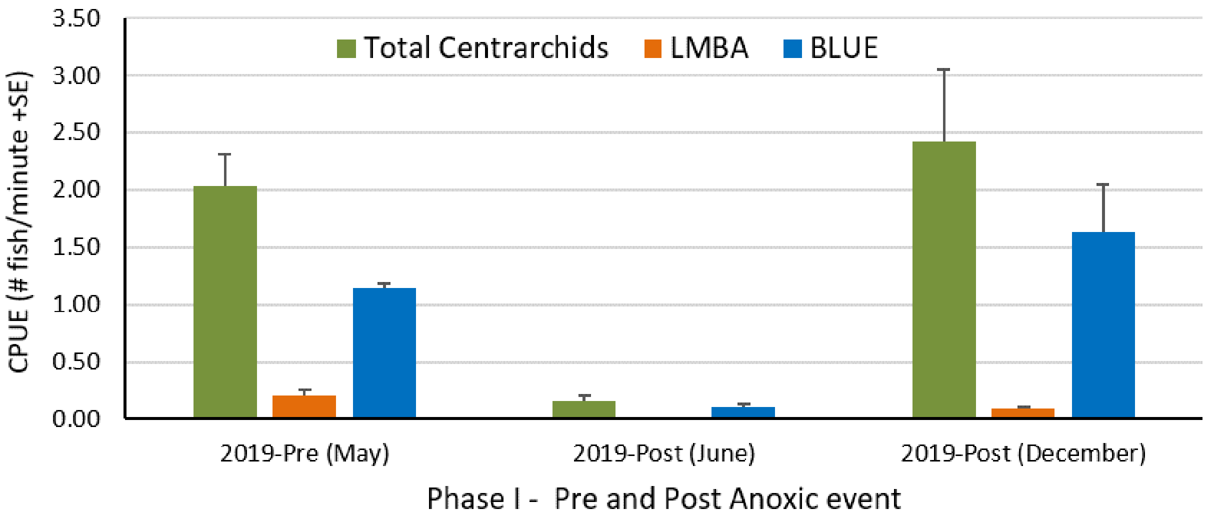


Figure 9-30. Mean CPUE (abundance) of all centrarchid species (green bar), largemouth bass (LMBA, orange bar) and bluegill sunfish (BLUE, blue bar) collected in Phase I prior to and after an anoxic event in June 2019. Centrarchid abundance was reduced 93% following the event and included a 100% reduction in largemouth bass and a 91% reduction in bluegill sunfish.

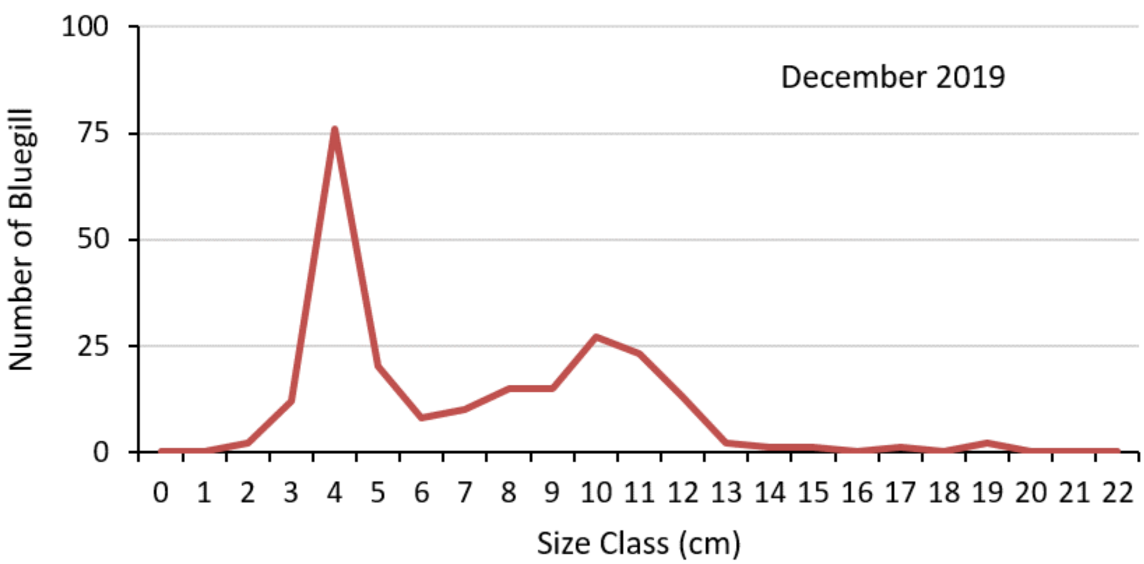


Figure 9-31. Number and size class (cm) of bluegill sunfish collected in December 2019. Most of the bluegill were likely spawned after the anoxic event in June.

Mean BPUE for all centrarchids decreased significantly from 10.2 kilograms per hours (kg/hr) prior to the anoxic event to 0.34 kg/hr (±0.1 SE) following the event (analysis of variance [ANOVA], $F = 45.03$, $p < 0.01$). The reduction in biomass included the total loss of largemouth bass and a significant reduction in bluegill biomass from 3.7 to 0.27 kg/hr (ANOVA, $F = 45.88$, $p < 0.01$) **(Figure 9-32)**. The reductions in mean BPUE observed in 2019 were similar to reductions reported following the anoxic events in 2017.

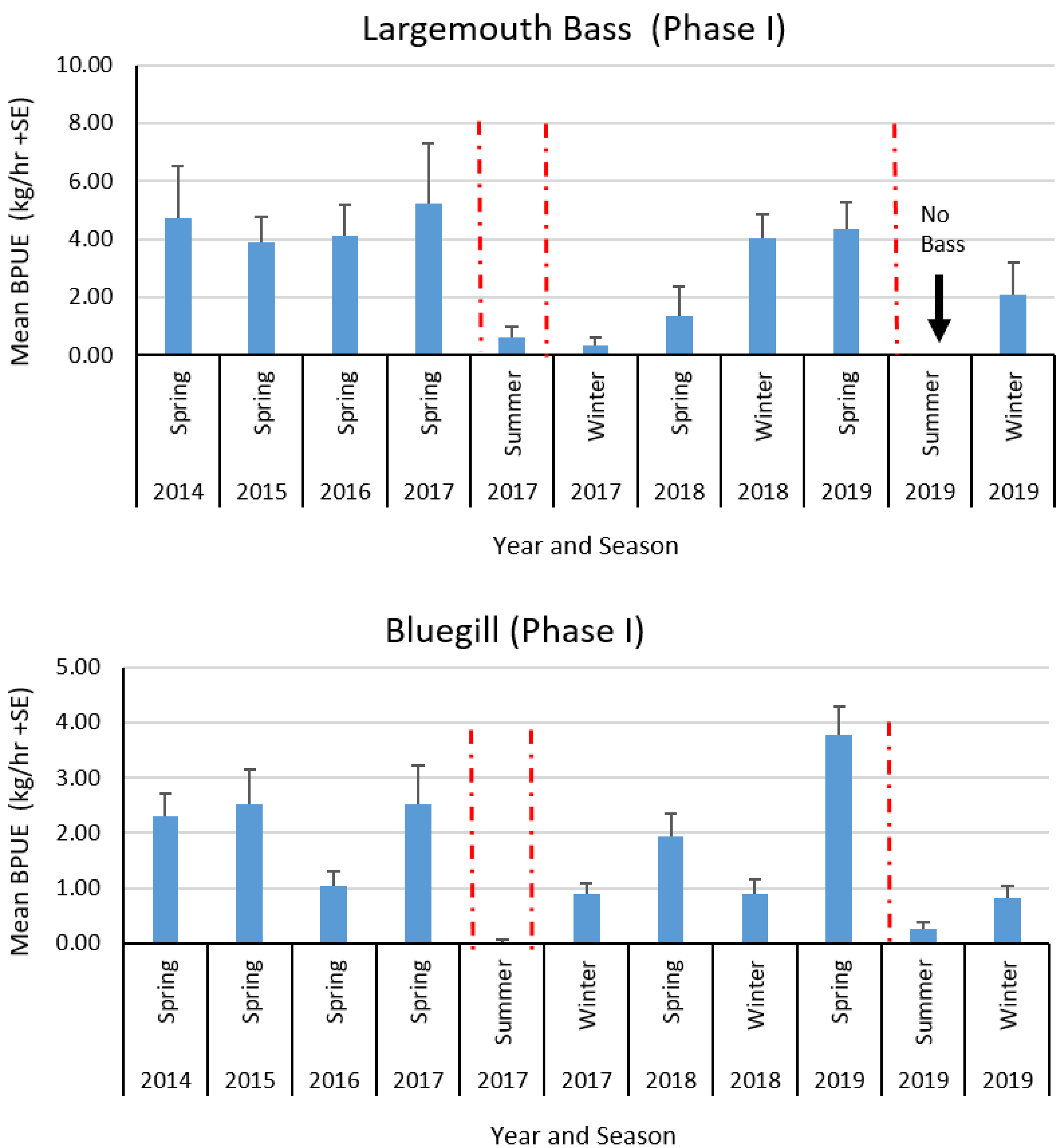


Figure 9-32. Mean biomass of largemouth bass (upper panel) and bluegill (lower panel) collected prior to and after anoxic events (DO crash) that occurred during summer 2017 and summer 2019. The vertical red lines indicate the occurrence of an anoxic event. Data were collected from 12 monitoring sites in the restored region (Phases I) of the Kissimmee River.

The centrarchid community in Phase I appears to have recovered somewhat during the two-year period between anoxic events (**Figure 9-33**). However, due to the extreme loss in fish abundance and biomass that occurred in the 2017 anoxic event, it is probable that some of the increase in centrarchid biomass reported prior to the anoxic event in 2019 was due to fish migrating into Phase I from other connected regions of the river and/or lakes. We are investigating the prevalence of migration in a separate three-year tracking study.

To further evaluate the impacts of the anoxic events on the river's fishery, fish species were divided into two groups based on their tolerance to low DO. We found that both groups, the intolerant (centrarchids) and tolerant (rough fish including Florida gar (*Lepisosteus platyrhincus*) (FGAR), bowfin (*Amia calva*) and exotics) experienced large reductions in mean BPUE during summer 2017 and summer 2019 following anoxic events. That low DO tolerant species declined suggests that they too were impacted, possibly due to the rapid and extreme reduction in DO at the onset of the anoxic event. Prior to the 2019 event, mean BPUE values for the tolerant and intolerant groups were 53.3 kg/hr (± 4.7 SE) and 10.2 kg/hr (± 1.0 SE), respectively. Following the anoxic events, mean BPUE for the tolerant group was reduced to 17.1 kg/hr (± 3.8 SE) while the intolerant group fell to 2.4 kg/hr (± 0.43 SE). Both values were significantly less than the pre-event means. In 2017, the tolerant group began to recover more rapidly than the intolerant group. A similar response occurred in 2019. Compared to the pre-event biomass reported for May, the tolerant species biomass was 8% greater during the post event December sampling event while the biomass of intolerant species was 64% less than pre-event biomass (**Figure 9-34**).

In addition to requiring an adequate concentration of DO to survive, preferably 2 mg/L or greater, many fish species found in the Kissimmee River use floodplain habitat for both reproduction and feeding (Lee et al. 1980). The large bodied species, including largemouth bass and bluegill, depend on shallow floodplain areas for spawning. Bass and bluegill are nest builders that prefer relatively shallow, open areas with sandy substrate. Limiting or preventing access to floodplain habitat during spawning season likely has negative impacts on the river's centrarchid community. Largemouth bass commonly spawn January–April (dry season). Unfortunately, the floodplain has been inundated during bass spawning season in only three of the past seven years (**Figure 9-35**). Bluegill sunfish can spawn during both the dry (spring) and wet (summer) seasons when the floodplain is inundated. Thus, their extended spawning season may have helped them recover to some extent from the impacts of anoxic events of summer 2017 and summer 2019 more rapidly the largemouth bass.

SFWMD continues to work to reduce the severity and duration of Kissimmee River hypoxic/anoxic events to the extent possible. In 2019, the river was anoxic for about 33 days (not continuous). It will be difficult for the river's fishery to show long-term improvement until DO conditions improve and proper floodplain inundation depths and frequencies that allow access to floodplain habitat during breeding season are established.

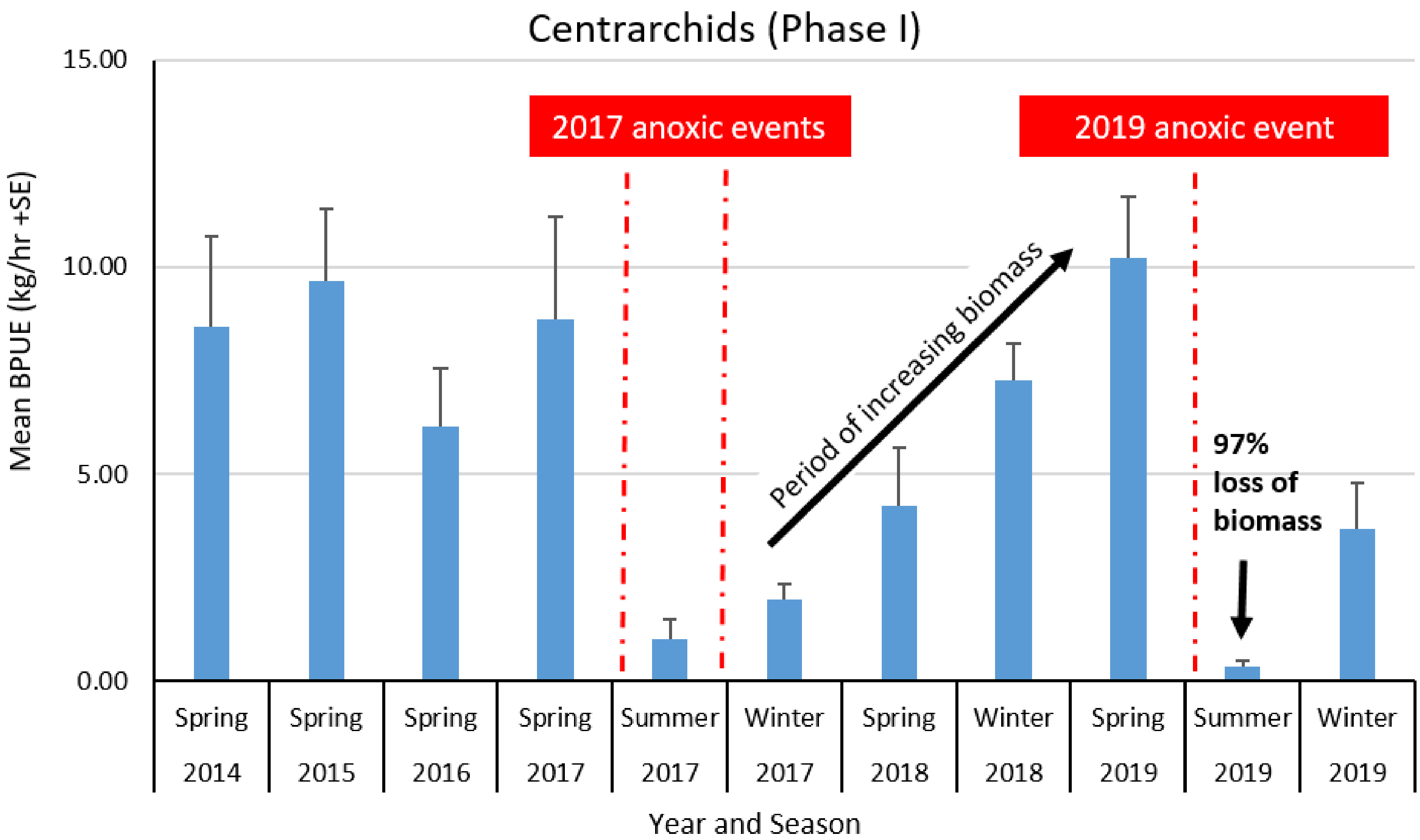


Figure 9-33. Mean biomass of all centrarchid species (kg/hour ± S.E.) collected prior to and after anoxic events (dissolved oxygen crash) that occurred during summer 2017 and summer 2019. The vertical red lines indicate the occurrence of an anoxic event. Data were collected from 12 monitoring sites in the restored region (Phases I) of the Kissimmee River.

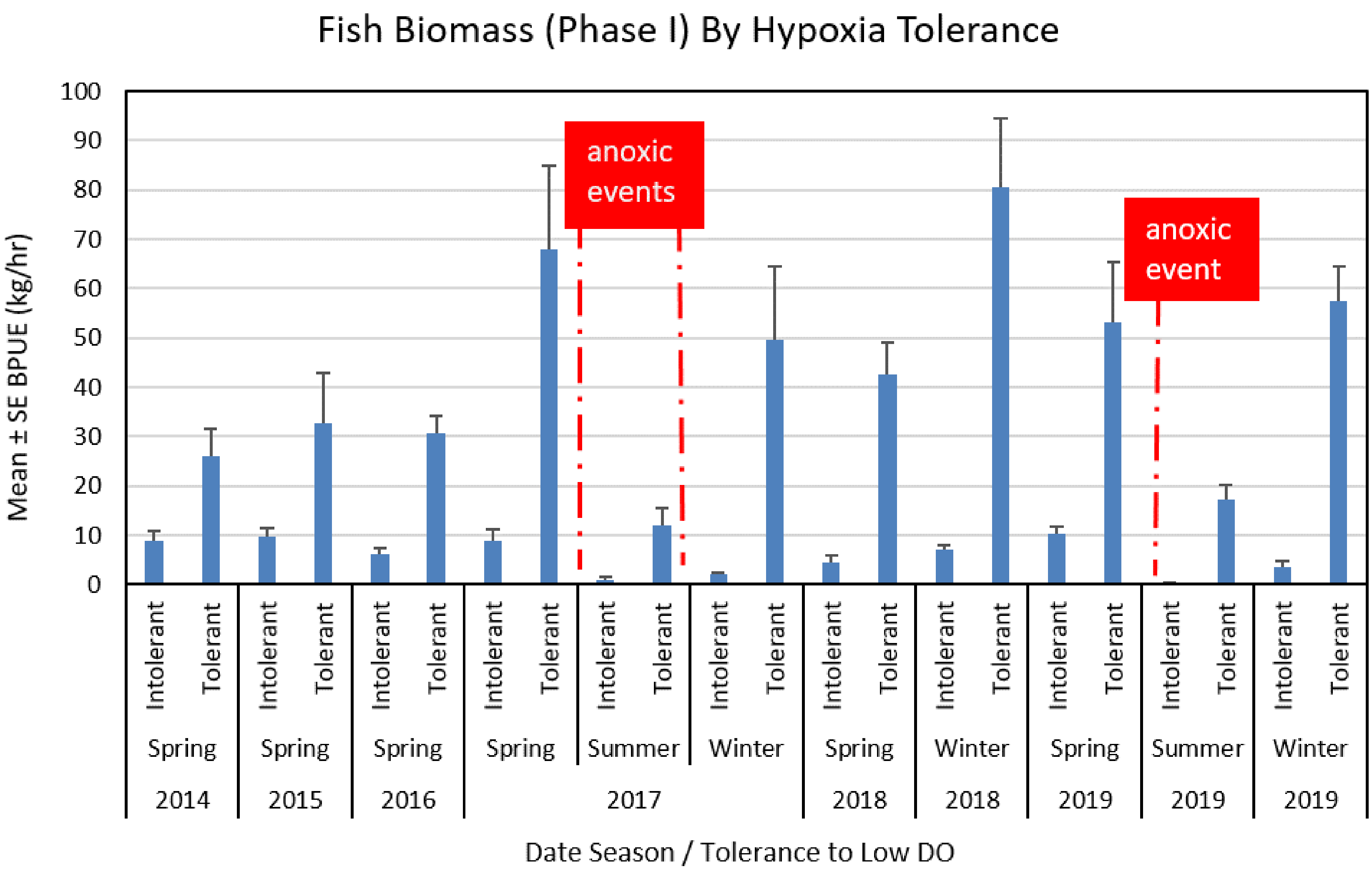


Figure 9-34. Biomass of low DO intolerant centrarchids and low DO tolerant Florida gar, bowfin, and exotic species by season and year (2014–2019).

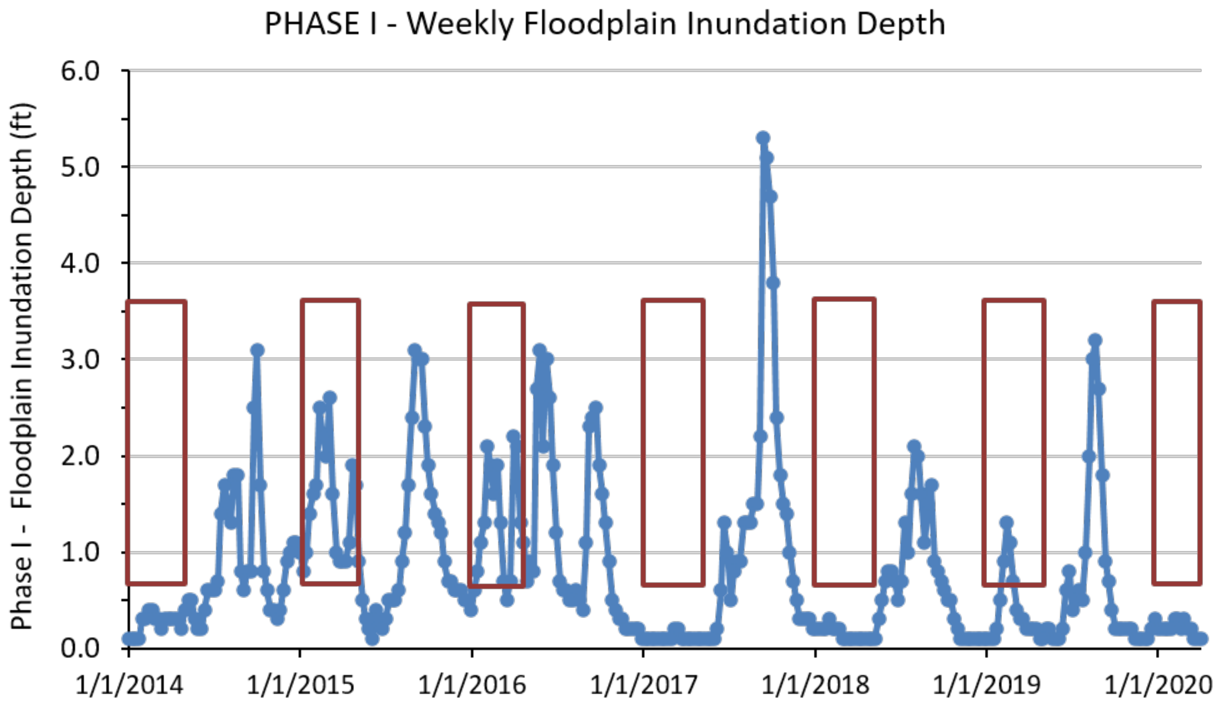


Figure 9-35. Hydrograph (blue line) showing the weekly average inundation depth of the Phase I floodplain (2014–2020). Red boxes represent the approximate spawning season (January–April) of largemouth bass. The floodplain was inundated only during the 2015 and 2016 spawning season and for part of the 2019 spawning season.

WADING BIRDS AND WATERFOWL

Birds are integral to the Kissimmee River floodplain ecosystem and highly valued by the public. While quantitative pre-channelization data are sparse, available data and anecdotal accounts suggest that the system supported an abundant and diverse bird assemblage (National Audubon Society 1936–1959, FGFWFC 1957). Restoration of the Kissimmee River and floodplain is expected to reproduce the necessary conditions to support such an assemblage once again. Because many bird groups (e.g., wading birds and waterfowl) exhibit a high degree of mobility, they are likely to respond rapidly to restoration of appropriate habitat (Weller 1995). Detailed information regarding the breadth of the avian evaluation program and the initial response of avian communities to Phase I restoration can be found in Chapter 11 of the 2005 SFER – Volume I (Williams et al. 2005) and a research article published in the journal *Restoration Ecology* (Cheek et al. 2014). The objective of this section is to highlight portions of the avian evaluation studies for which data were collected during the 2019-2020 dry season within PW2020 and compare recent data to the KRREP avian restoration expectations. Statistical significance was evaluated at $\alpha = 0.05$.

Wading Bird Abundance

Expectation 24

*Mean annual dry season density of long-legged wading birds (excluding cattle egrets [*Bubulcus ibis*]) on the restored floodplain will be ≥ 30.6 birds/km^2 (Williams and Melvin 2005b).*

Monthly aerial surveys were used to estimate foraging wading bird abundance. Prior to the restoration project, dry season abundance of long-legged wading birds in the Phase I restoration area averaged (±SE) 3.6 ± 0.9 birds/km^2 in 1997 and 14.3 ± 3.4 birds/km^2 in 1998. Since completion of Phases I, IVA, and IVB of restoration construction in 2001, 2007, and 2009, respectively, annual abundance has ranged from 102.3 ± 31.7 birds/km^2 to 11.0 ± 1.9 birds/km^2 (mean for 2002–2020 = 40.0 ± 5.4 birds/km^2; **Figures 9-36** and **9-37**). The long-term annual three-year running mean (2002–2020) is 42.9 ± 3.4 birds/km^2, significantly greater than the restoration expectation of 30.6 birds/km^2 (t-test, $p < 0.001$, Williams and Melvin 2005b). All three-year running means for the period 2002–2020 were significantly greater than the restoration target of 30.6 birds/km² except for 2007-2009. Mean monthly wading bird abundance within the restored portions of the river during the 2019-2020 season was 14.2 ± 3.6 birds/km^2, bringing the three-year (2018–2020) running average to 43.9 ± 6.8; significantly greater than the restoration expectation of 30.6 birds/km^2 (t-test, $p > 0.008$, **Figure 9-37**).

Rainfall during the 2019-2020 dry season was approximately average, and in the preceding wet season rainfall was also average in the UKB and LKB (99% and 100% of average, respectively). However, discharge to the river out of S-65A dropped to approximately 300 cfs (well below bankfull) by September 25, 2019, and water levels in the floodplain marshes began to recede quickly to less than 0.10 ft deep by October 12, 2019 (**Figure 9-38**). This fast recession of water levels on the floodplain began over one month before the end of the wet season. Water levels did not ascend again above floodplain elevation throughout the dry season. Therefore, there was very little shallow water foraging habitat available for wading birds on the floodplain for most of the dry season, as reflected in their below average abundance in 2019-2020 following the initial survey on November 22, 2019.

As in previous years, white ibis (*Eudocimus albus*) dominated the surveys numerically (284, 30.5%), followed in order of abundance by great blue heron (*Ardea herodias*; 195, 21.0%), great egret (*A. alba*; 158, 17.0%), small white herons (snowy egrets [*Egretta thula*] and juvenile little blue heron [*Egretta caerulea*]; 78, 8.4%), glossy ibis (*Plegadis falcinellus*; 69, 7.4%), wood stork (*Mycteria americana*; 57, 6.1%), black-crowned and yellow-crowned night herons (*Nycticorax violacea* and *Nyctanassa violacea*, respectively; 41, 4.4%), small dark herons (tri-colored herons [*Egretta tricolor*] and adult little blue heron; 39, 4.1%), and roseate spoonbill (*Platalea ajaja*; 9, 1.0%).

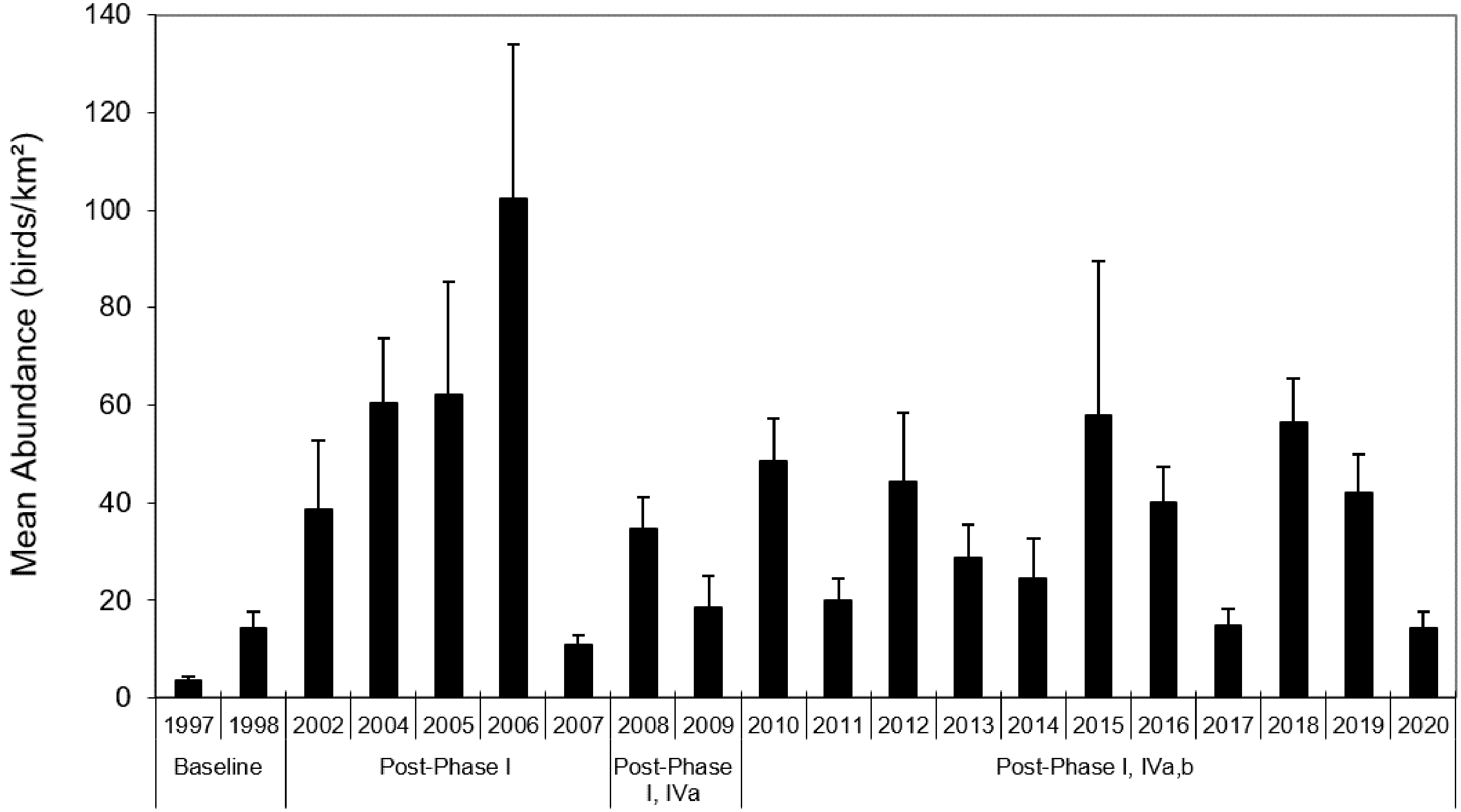


Figure 9-36. Baseline and post-Phases I, IVA, and IVB mean abundance ± SE of long-legged wading birds/km^2, excluding cattle egrets, during the dry season (December–May) within the 100-year flood line of the Kissimmee River.

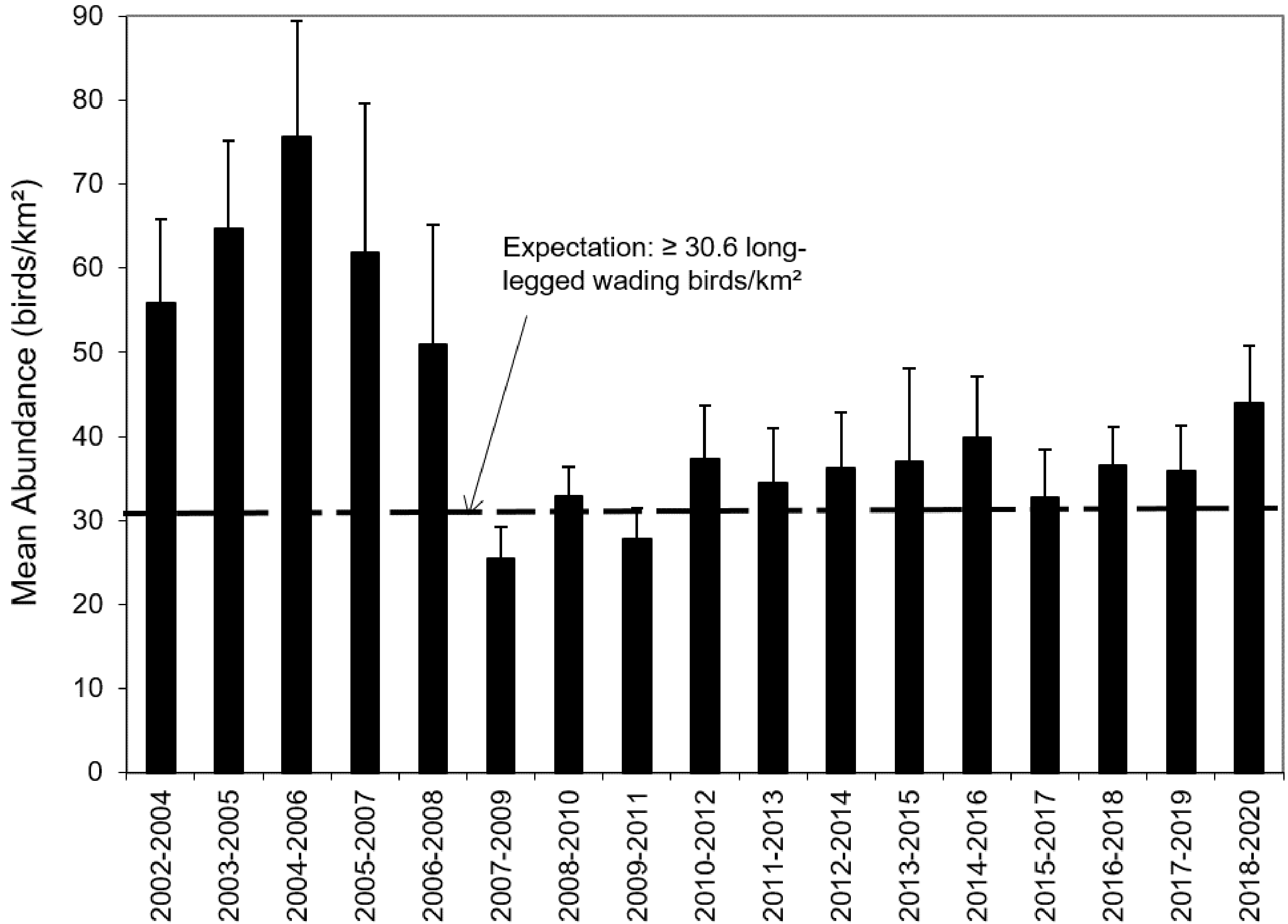


Figure 9-37. Post-restoration abundance as three-year running averages ± SE of long-legged wading birds/km^2, excluding cattle egrets, during the dry season (December–May) within the Phase I, IVA, and IVB restoration areas of the Kissimmee River. All three-year periods are significantly greater than the restoration expectation of 30.6 birds/km^2 except for 2007-2009 (t-test).

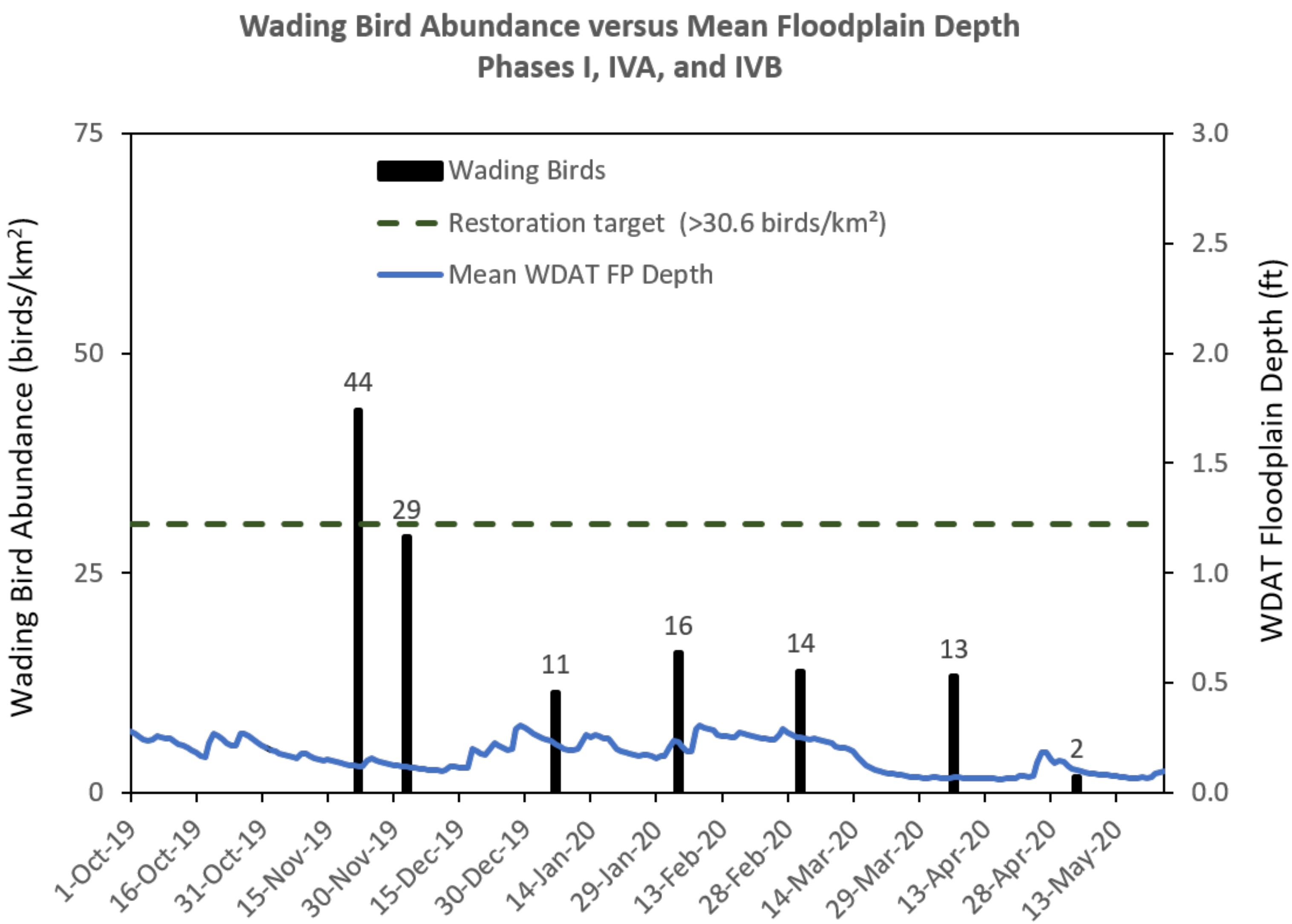


Figure 9-38. Wading bird abundance versus mean floodplain (FP) depth in the KRRP (Phases I, IVA, and IVB) area during the 2019-2020 dry season (December–May). Floodplain depth is obtained from the South Florida Water Depth Assessment Tool (WDAT; Godin 2012).

Waterfowl Abundance and Species Richness

Expectation 25

Winter densities of waterfowl within the restored area of the floodplain will be ≥ 3.9 ducks/km^2. Species richness will be ≥ 13 (Williams et al. 2005).

Four duck species, blue-winged teal (*Anas discors*), green-winged teal (*A. crecca*), mottled duck (*A. fulvigula*), and hooded merganser (*Lophodytes cullulatus*), were detected during baseline aerial surveys. During the same period, casual observations of wood ducks (*Aix sponsa*) were made during ground surveys for other projects (Williams and Melvin 2005a). Mean annual abundance ± SE was 0.4 ± 0.1 ducks/km^2 in the Phase I area during the Baseline Period, well below the restoration expectation of 3.9 ducks/km^2. The long-term mean annual three-year running average (2002–2020) of waterfowl abundance is 12.7 ± 1.5 ducks/km^2, significantly greater than the restoration expectation of 3.9 ducks/km^2 (t-test, $p < 0.002$). All three-year running means for the period 2002–2020 were significantly greater than the restoration target of 3.9 ducks/km^2 (t-test, p-values < 0.05).

Waterfowl abundance during the 2019-2020 survey was 3.2 ± 0.7 ducks/km^2, bringing the three-year (2018–2020) running average to 26.6 ± 7.4 ducks/km^2, significantly greater than the restoration target of 3.9 ducks/km^2 (t-test, p-value < 0.008; **Figures 9-39** and **9-40**). Since 2001, annual duck abundance has ranged from 42.0 ± 11.2 to 1.3 ± 1.3 ducks/km^2 (mean for 2002–2020 = 12.1 ± 2.4 ducks/km^2). Only two (December and March) of the seven surveys during winter 2019-2020 were above the restoration target of 3.9 ducks/km^2, and this was not enough to bring the seasonal average above the restoration target (**Figure 9-41**).

As mentioned in the *Wading Bird Abundance* section above, discharge to the river out of S-65A dropped to approximately 300 cfs (well below bankfull) before the end of the wet season and water levels in the floodplain marshes were 0.29 ft deep or less for the entire dry season (**Figure 9-41**). Therefore, there was very little shallow water foraging habitat available for waterfowl on the floodplain for most of the dry season, as reflected in their below average abundance in 2019-2020.

As in previous years, teal (*Anas* sp.) dominated the surveys numerically (130, 78.8%), followed by mottled duck (35, 21.2%). No other duck species were observed this year on the floodplain. The three-year species total for 2018–2020 was 5, below the restoration target for waterfowl species richness of ≥ 13.

Although the American wigeon (*Mareca americana*), northern pintail (*Anas acuta*), northern shoveler (*A. clypeata*), ring-necked duck (*Aythya collaris*), and black-bellied whistling-duck (*Dendrocygna autumnalis*) were not detected during the 2019-2020 baseline surveys, they have been present following restoration construction. However, these species are not regularly observed; therefore, the restoration target for waterfowl species richness (≥ 13 species) has yet to be reached on an annual or cumulative basis. Based on reference data, black-bellied whistling-ducks were never observed prior to channelization and it is unclear how abundant American wigeon, northern pintail, northern shoveler, and ring-necked duck were on the floodplain since survey data were combined with the Upper Kissimmee Basin lakes (Florida Game and Fresh Water Fish Commission 1957). American wigeon populations have generally trended downward since the 1950s and only a small proportion of the their population winters in the Atlantic flyway and Florida, so it is possible that it was never common on the Kissimmee River floodplain (Mini et al. 2020). Ring-necked ducks were not likely common on the river floodplain as these diving ducks are more commonly found on open water and lakes with deeper water. Observations of northern pintail and northern shoveler likely remain low due to the lack of suitable foraging habitat during the overwintering period from December through March, when water levels remain relatively shallow and unpredictable compared to the historical reference period. This reduced dry season hydroperiod also prevents the establishment of important overwintering food sources such as submerged and emergent aquatic vegetation and aquatic invertebrates. Blue-winged teal and mottled duck remain the two most observed species, accounting for more than 94% of observations since 2001 (79.9% and 14.1%, respectively).

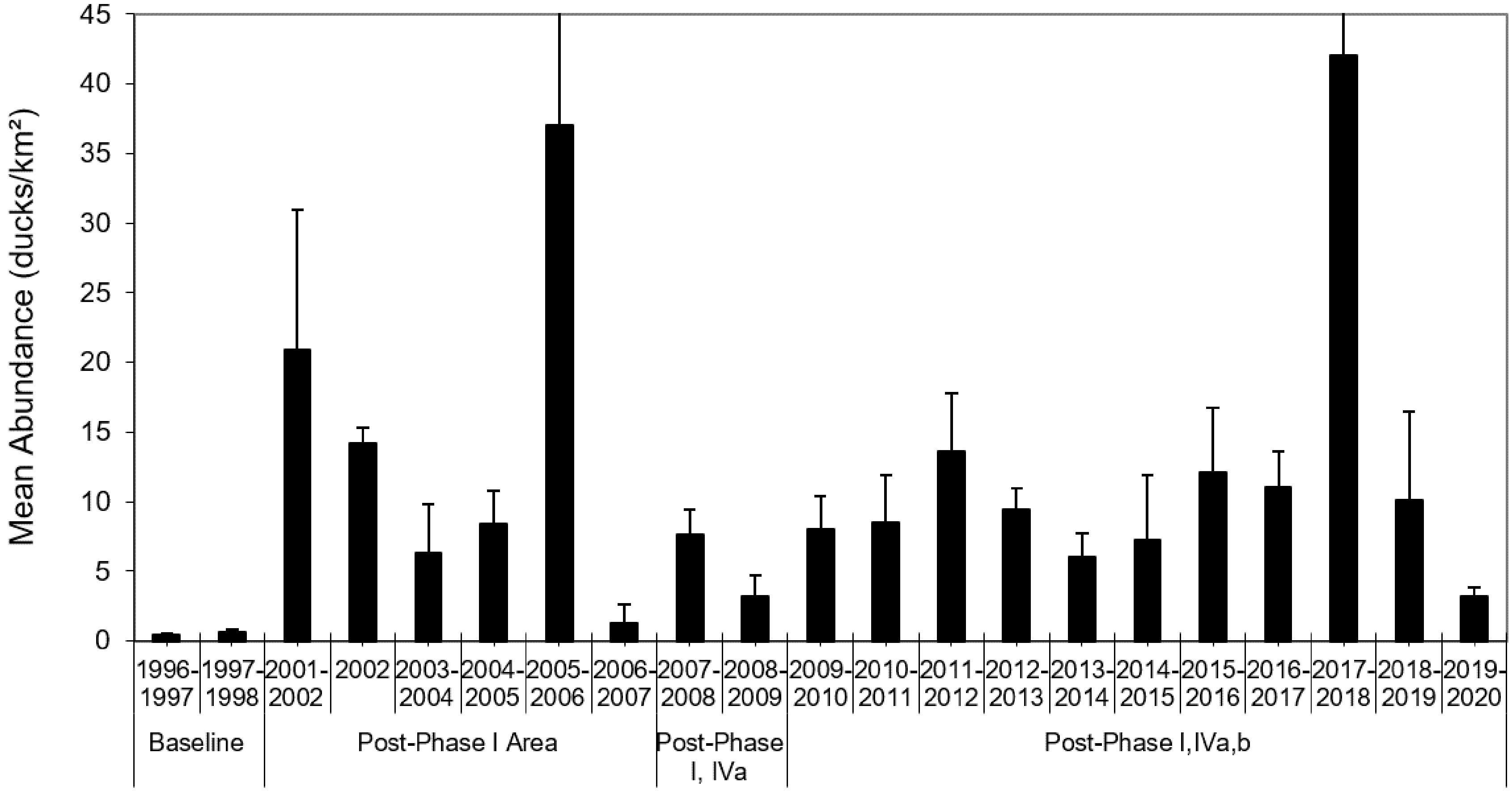


Figure 9-39. Baseline and post-Phases I, IVA, and IVB mean abundance ± SE of waterfowl during winter (November–March) within the 100-year flood line of the Kissimmee River. Baseline abundance was measured in the Phase I area prior to restoration. Measurement of post-restoration abundance began approximately nine months following completion of Phase I.

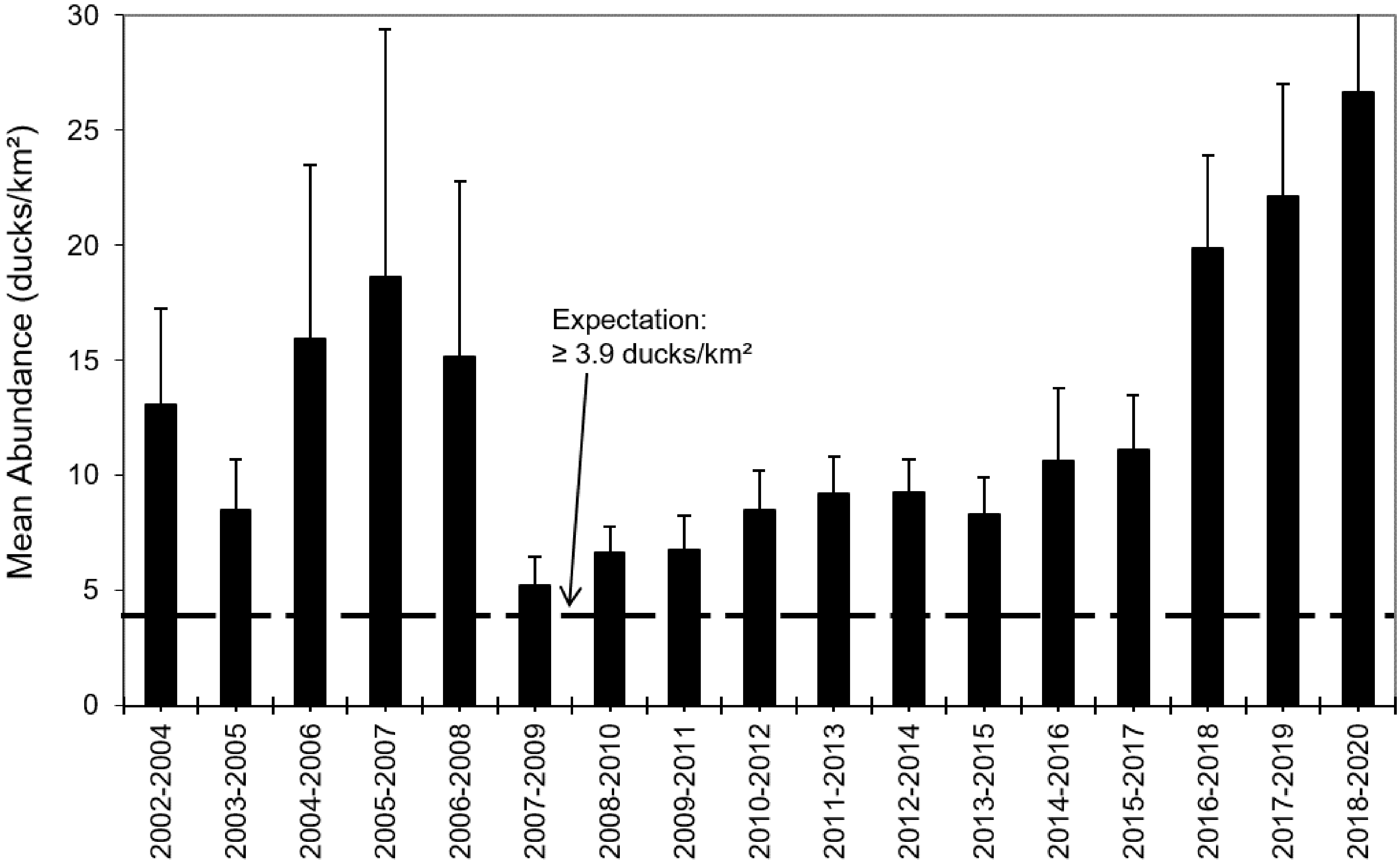


Figure 9-40. Post-restoration abundance as three-year running averages ± SE of waterfowl (ducks/km^2) during the winter (November–March) within the Phase I, IVA, and IVB restoration areas of the Kissimmee River. All three-year periods are significantly greater than the restoration expectation of 3.9 ducks/km^2 [t-test]).

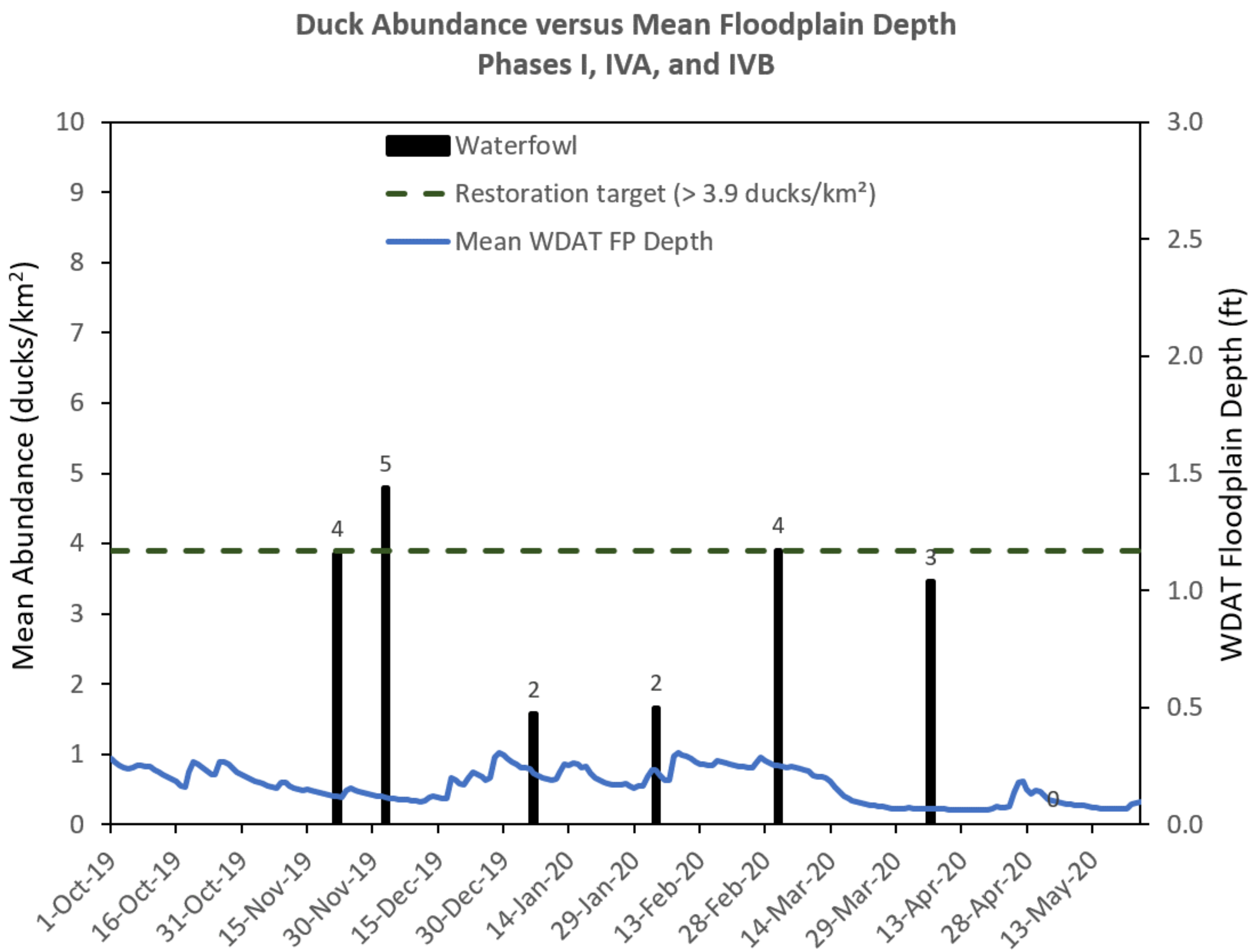


Figure 9-41 Waterfowl abundance versus mean floodplain depth in the KRRP area (Phases I, IVA, and IVB) during the 2019-2020 dry season (November 2019–May 2020). Source of floodplain depth data is the South Florida Water Depth Assessment Tool (WDAT; Godin 2012).

Restoration of the physical characteristics of the Kissimmee River and floodplain, along with improvements in the hydrologic characteristics of inflows under the HRS, are expected to produce hydropatterns and hydroperiods that will lead to the development of extensive areas of wet prairie and BLM, two preferred waterfowl habitats (Chamberlain 1960, Bellrose 1980). Changes in the species richness and abundance of waterfowl within the KRRP area are likely to be directly linked to the development of floodplain plant communities and the faunal elements they support, particularly populations of aquatic invertebrates (Harris et al. 1995). Extrinsic factors such as annual reproductive output on summer breeding grounds and local and regional weather patterns also may play a role in the speed of recovery of the waterfowl community.

Wading Bird Nesting Colonies

Expectation

No formal expectation has been established for wading bird nesting colonies.

UPPER KISSIMMEE BASIN – KISSIMMEE RIVER RESTORATION EVALUATION PROGRAM

The KCOL and UKB Monitoring and Assessment Project involves data collection, evaluation, and reporting to support SFWMD’s mission to manage and protect water resources. The monitoring also contributes to the assessment of the KRRP, which—under the HRS—will increase storage in the Headwaters Lakes to improve timing and volume of flow to ensure the ecological and hydrologic success of the KRRP. This monitoring is part of the KRREP, which includes goals for littoral zone improvement in the Headwaters Lakes. Together, these products support management decisions and are used to determine whether management intervention is required or whether the ecosystem is responding as intended to management actions. Key focus areas include the following:

- Data collection and evaluations to define relationships between hydrology and the lake littoral vegetation response to seasonal water level conditions.
- Coordination with agency and environmental stakeholders to ensure non-redundant and complementary data collection and evaluation; to annually report on ecological conditions within the KCOL and UKB; and to facilitate information sharing and identification of emerging issues and concerns.

The scope of this year’s KCOL and UKB reporting includes an overview of watershed assessment, monitoring, and research results. The results provide an overview of ecological conditions and water quality trends in the UKB by combining data and information from SFWMD’s monitoring activities with those of KCOL partner agencies.

VEGETATION MONITORING

The HRS was designed to increase storage in the Headwaters Lakes to provide appropriate flow patterns to the Kissimmee River and floodplain upon completion of KRRP construction. The increased storage that results due to higher maximum regulatory stages are expected to improve the quantity and quality of littoral habitat in the Headwaters Lakes. The HRS will increase regulatory stages and change the operating schedule for S-65, which controls discharge from and stage of the Headwaters Lakes.

Monitoring vegetation within the existing littoral zones and up to future lake regulation elevations is necessary to estimate the effects of the HRS in the Headwaters Lakes on the quantity and quality of littoral habitat and document vegetation changes (USACE 1996). The need for vegetation monitoring was also identified in the Kissimmee Upper Basin Monitoring and Assessment Project (initiated in October 2010) to address data gaps and knowledge uncertainties that were identified during the development of the *Kissimmee Chain of Lakes Long-Term Management Plan* (SFWMD et al. 2011). By combining monitoring efforts between these projects, expected improvements from the HRS can be better isolated from other management activities in the basin, and monitoring efforts can be expanded to include wildlife responses in the future, as well.

Currently, there are two vegetation monitoring studies on the KCOL that will fill these needs. The first is an SFMWD project and involves tracking changes in specific plant community types over time and documenting any distributional shifts up or down slope if they occur. The second is an FWC project and involves quantifying specific littoral communities via aerial imagery on a three- to five-year rotation in the major KCOL water bodies. Currently, FWC is considering new methods for this project including the use of satellite imagery. Updated methods will be described, and any new results will be presented in future versions of this report.

Objectives

This study monitors plant communities along shoreline gradients in the Headwater Lakes to assess changes in distribution or composition of indicator species and functional groups and relate those results to corresponding hydrology. The results will be used to partially fulfill monitoring requirements in the Headwaters Lakes as part of the KRREP, better assess the level of effort required to confirm changes from HRS implementation versus climatic variability, and to quantify effects throughout the entire HRS footprint.

Through repeated sampling of permanent quadrat and transect sites over time, changes in vegetation composition in Deep Water Emergent, Floating Leaf, BLM, Freshwater Marsh, and Wet Prairie communities will be documented and compared to lake stage characteristics. The objectives of the study are as follows:

- Determine whether plant communities are moving up or down the depth gradient or changing composition over time or in response to major disturbances, such as hurricanes or changes in stage regulation schedules
- Determine whether littoral habitat expands or contracts as a result of HRS implementation and extrapolate observations throughout the project footprint to estimate quantity of impacts.

Methods

Long-term, permanent monitoring stations were established on three of the major water bodies in the KCOL in 2015: East Lake Tohopekaliga, Lake Tohopekaliga, and Lake Kissimmee. Lake Kissimmee is the only lake that will have a different regulation schedule under the HRS, while Lake Tohopekaliga and East Lake Tohopekaliga will serve as control lakes for comparison. The permanent monitoring stations include circular plots that are stratified by water depth and community type throughout the littoral zone, as well as belt transects set perpendicular to shore in the upper reaches of the littoral zone.

Depth Plots

Circular plots were established using a stratified-random sampling approach (Baker et al. 1987), placing sampling stations randomly within selected communities and depth strata (Day et al. 1988, Walker et al. 2003). This approach focuses sampling within clear patterns of plant zonation, allowing the monitoring of responses of vegetation along the depth gradient (Dale 1999). Using repeated measures, i.e., resampling the same monitoring stations over time, focuses variance *within* sites to detect trends or differences more effectively in impact *between* sites (Green 1993).

Using the above methodology, sampling stations were placed in communities from medium (Shallow Marsh) and long hydroperiod (BLM) depth classes, as well as two deep water (5 to 7 ft when lake is at high pool) communities (Floating Leaf and Deep Grasses) that represent different "energy" environments (**Figure 9-42**). For example, lilies and floating leaf aquatics are representative of more stabilized water levels or sheltered/lower-energy areas (Day et al. 1988, Wisheu and Keddy 1992), whereas deep water grasses and emergents are more representative of dynamic water levels and higher energy environments (Johnson et al. 2007). Additionally, these two communities respond differently to periodic lake drawdowns, and can be an indicator of long-term drying cycles (Moyer et al. 1989, Paillisson and Marion 2006, Johnson et al. 2007). The cluster analysis and indicator species analysis (ISA; Tichý and Chytrý' 2006) confirmed the four distinct communities determined a priori to monitor changes in those specific communities over time (**Table 9-9**).

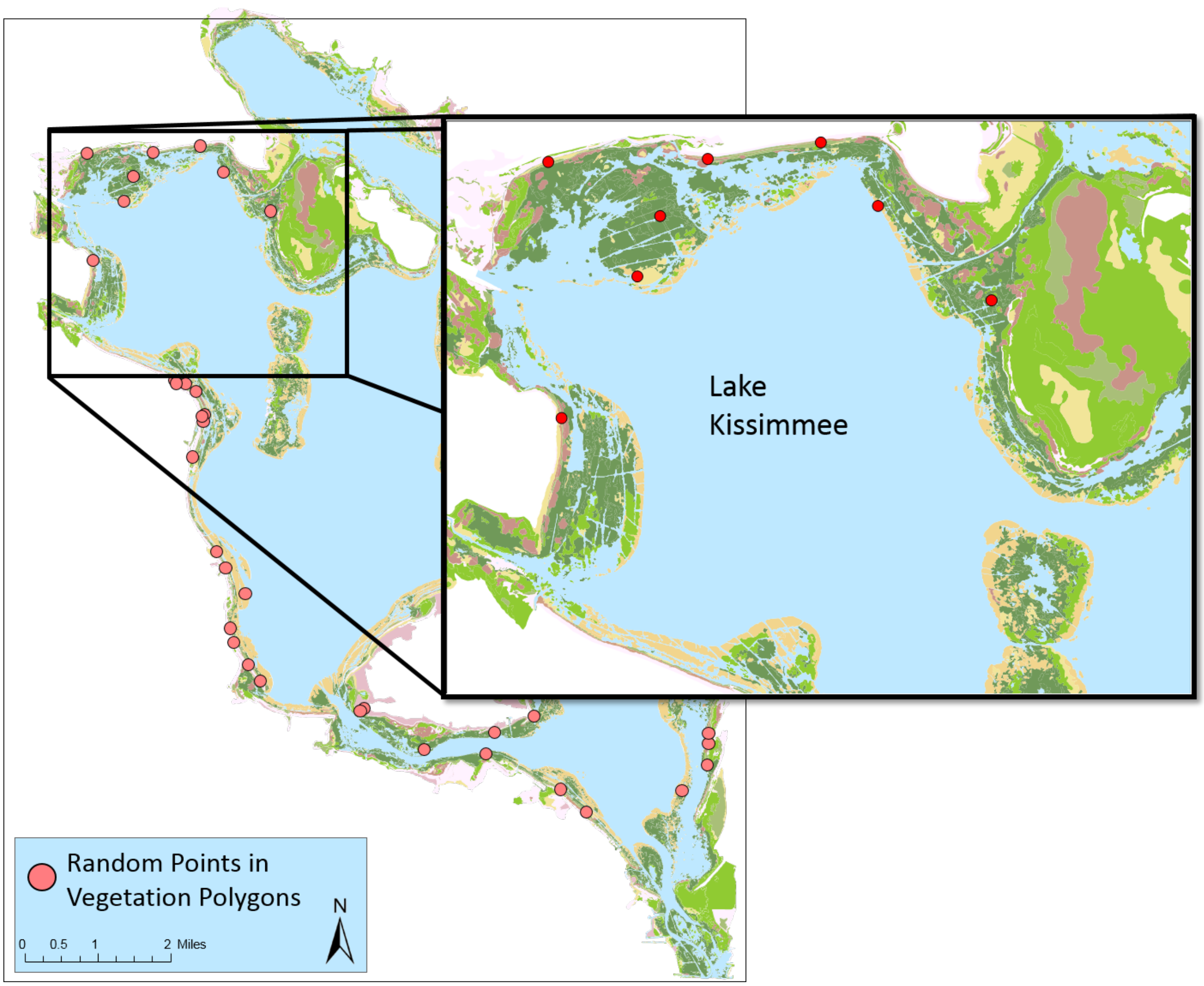


Figure 9-42. Examples of randomly generated sample locations (red circles) in different depth categories (colored polygons), which were used to select permanent monitoring stations for percent cover estimates.

Table 9-9. Groups identified by cluster analysis using plot data from 2015, 2016, 2018, and 2019, and indicator species for each group.

Plot Type	Indicator Species	
	Common Name	**Scientific Name**
Deepwater Grasses	maidencane	*Panicum hemitomon*
Floating Leaf	spatterdock water lilies	*Nuphar advena*) *Nymphaea* spp.
Broadleaf Marsh	pickerelweed bulltongue arrowhead	*Pontederia cordata* *Sagittaria lancifolia*
Freshwater Marsh	southern watergrass torpedograss marshpennyworts buttonweed alligator weed waterhyssops piedmont primrosewillow spikerushes	*Luziola fluitans* *Panicum repens* *Hydrocotyle* spp. *Diodia virginica* *Alternanthera philoxeroides* *Bacopa* spp. *Ludwigia arcuate* *Eleocharis* spp.

Within each of the four depth categories described above, ten sample locations (40 per lake) are monitored annually in the late summer–early fall, which coincides with the peak of the growing season and when many species are flowering, aiding identification (Toth 2005). Percent cover is visually estimated at each location for a 5 m^2 circular quadrat, using Daubenmire (1959) cover classes (Bousquin and Colee 2014).

Transects with Quadrats

In addition to the percent cover plots, three interrupted belt transects (Baker et al. 1987) have been established perpendicular to shore between the low and high water elevations of the current lake regulation schedules and, on Lake Kissimmee, they extend upslope to what will be the high water elevation under the HRS (**Figure 9-43**). Perpendicular to each transect, two rectangular, 1- by 2-m quadrats (Bousquin and Colee 2014) are sampled one meter from the transect at each half-foot elevation break (e.g., Frahn et al. 2014), resulting in a total of seven sampling locations on each transect, an equal sampling effort regardless of total length (**Figure 9-43**). Plant species abundance is visually estimated using Daubenmire (1959) cover classes (Bousquin and Colee 2014) in the late summer/fall each year.

Samples from 2015 to 2019 were grouped via cluster analysis, using the Sorenson distance measure and a flexible Beta of -0.25. Note that plots were not sampled in 2017 and transects were not sampled in 2019. Species representative of each cluster were identified via ISA (Tichý and Chytrý' 2006). ISA identifies species that are most frequently found in one group and rarely in other groups but are not necessarily dominant in terms of areal coverage. The number of clusters was chosen based on the ISA with the lowest average p-values and highest number of significant indicator species (McCune and Grace 2002). For analyses, species were grouped within a genus according to their wetland indicator status (e.g., *Rhynchospora* species (spikerushes) were grouped as *Rhynchospora* facultative wet or *Rhynchospora* obligate species) to reduce variability, and others were grouped at genus level because of dominance of one species and no differences in wetland indicator status among the genera (e.g., Fimbries [*Fimbristylis* spp.]). The relative dissimilarity of the plot samples in terms of species composition were displayed via a nonmetric multidimensional scaling ordination, with individual samples color-coded to the groups identified in the cluster analyses. The cluster and ISA analyses of transect data suggested four distinct communities for the lakes distributed along a depth gradient, described in **Table 9-10**, with indicator species and average hydroperiod calculated from the number of days lake stage was at or above the elevation of the quadrats.

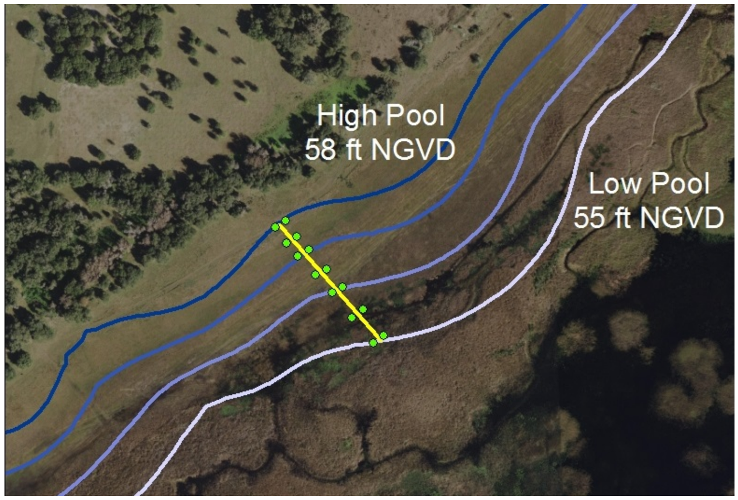


Figure 9-43. Example of line transects (yellow) and subsamples (green circles) are shown to demonstrate approximate locations spanning the 58 to 55 ft NGVD29 elevation contours on East Lake Tohopekaliga, or the maximum and minimum of the annual regulation schedule.

Table 9-10. Groups identified by cluster analysis using transect data from 2015 to 2018, along with their general location on the shoreline elevation gradient, average annual hydroperiod (± SE), and indicator species for each group are also included.

Elevation	Average Hydroperiod (% of time ± SE)	Indicator Species	
		Common Name	Scientific Name
Upland	1 ± 0.06	bahiagrass sweetbroom rough Mexican clover flatsedges thoroughworts rustweed witchgrasses	*Paspalum notatum* *Scoparia dulcis* *Richardia scabra* *Cyperus* spp. [a] *Eupatorium* spp. *Polypremum procumbens* *Dichanthelium* spp.
Short Hydroperiod	23 ± 1.24	big carpetgrass rattlebox bluestems beaksedges Indian cupscale	*Axonopus furcatus* *Sesbania punicea* *Andropogon* spp. *Rhynchospora* spp. [a] *Sacciolepis indica*
Medium Hydroperiod	74 ± 1.12	torpedograss southern watergrass	*Panicum repens* *Luziola fluitans*
Long Hydroperiod	93 ± 0.47	pickerelweed cattails alligatorweed spatterdock	*Pontederia cordata* *Typha* spp. *Alternanthera philoxeroides* *Nuphar lutea* [b]

a. Faculative wetland.

b. Along with other floating leaf species.

Results

Analysis of plot data presented here focuses on Lake Kissimmee, which experienced a decrease in major plant communities following Hurricane Irma in 2017. **Table 9-11** reports average abundances for each plant community, showing the decline between 2015–2016 and 2018. Data from 2019 indicated most groups are recovering with a slight increase in abundance over the last year.

Analysis of transect data for this report is based on the four distinct plant communities identified using cluster and ISA analyses, which are distributed along a depth gradient (**Table 9-10**). The shallowest group's indicator species were pasture grass (*Paspalum notatum*), several upland grassy and herbaceous weeds typical of pastures, and flatsedges (*Cyperus* spp.) in the facultative wetland functional group. The community nearest the top of the regulation schedule (i.e., the least frequently inundated zone) includes common weedy grasses, an exotic legume (rattlebox, *Sesbania punicea*) and faculative wetland beaksedges (*Rhynchospora* spp.). Mid-elevations were represented by two common grasses, and plants typical of BLM along with floating leaf species were associated with the lowest elevations where conditions are wettest.

As shown in previous reports (e.g., Koebel et al. 2019), consistent patterns among the lakes are revealed when species are grouped by wetland indicator status, with groups characteristic of drier conditions having peak abundance at higher elevations and wetter groups peaking at lower elevations (Lichvar et al. 2012; **Table 9-12**). for additional evaluation of each lake (**Table 9-13**). Abundances of each wetland indicator status group were compared to further evaluate the effect of hydroperiod on littoral vegetation. Transect data were separated by wetland indicator status.

Table 9-11. Average abundance of indicator species within each depth plot type by sample year.

Plot Type	Species Type Present	Abundance ± SE (percent cover)			
		2015	2016	2018	2019
Deepwater Grasses	Deepwater Grass Species	53.75 ± 6.55	51.50 ± 6.94	28.75 ± 4.28	30.25 ± 4.20
	Floating Leaf Species.	5.50 ± 5.61	6.75 ± 4.11	6.25 ± 1.77	3.25 ± 2.28
Floating Leaf	Deepwater Grass Species	2.75 ± 1.61	3.25 ± 2.28	2.75 ± 1.61	4.50 ± 5.53
	Floating Leaf Species	69.75 ± 6.44	73.50 ± 8.07	30.00 ± 7.47	21.25 ± 7.80
	Freshwater Marsh Species	2.50 ± 0.00	5.50 ± 1.54	3.75 ± 2.17	3.00 ± 0.00
	Broadleaf Marsh Species	80.50 ± 8.70	75.00 ± 11.95	38.50 ± 9.35	49.00 ± 7.60

Table 9-12. Wetland indicator status and percent occurrence. Reproduced from Lichvar et al. (2012).

Indicator Status	Percent Occurrence in Wetlands
Obligate – occur almost always under natural conditions in wetlands	99%
Facultative wetland – usually occur in wetlands but occasionally found in non-wetlands	67% to 99%
Facultative – equally likely to occur in wetlands and non-wetlands	34% to 66%
Facultative upland – Usually occur in non-wetlands but occasionally found in wetlands	1% to 33%
Upland – occur in wetlands in another region but occur almost always under natural conditions in non-wetlands in the region specified	1

Table 9-13. Species observed during depth plot and transect sampling by wetland indicator status. (Note: An asterisk (*) indicates the species is exotic.)

Common Name	Scientific Name	Common Name	Scientific Name
Faculative			
tropical carpetgrass	*Axonopus compressus*	peppervine	*Nekemias arborea*
thistles	*Cirsium* spp.	sour paspalum	*Paspalum conjugatum*
Columbian waxweed	*Cuphea carthagenensis**	thin paspalum	*Paspalum setaceum*
Baldwin's flatsedge	*Cyperus croceus*	vaseygrass	*Paspalum urvillei**
yellow nutgrass	*Cyperus esculentus**	turkey tangle fogfruit	*Phyla nodiflora*
roadside flatsedge	*Cyperus sphacelatus*	cabbage palm	*Sabal palmetto*
blanket crabgrass	*Digitaria serotina*	Indian cupscale	*Sacciolepis indica**
thalia lovegrass	*Eragrostis atrovirens**	sweetbroom	*Scoparia dulcis*
prairie fleabane	*Erigeron strigosus*	rattlebox	*Sesbania punicea*
wax myrtle	*Morella cerifera*	casarweed	*Urena lobata**
Faculative Upland			
common ragweed	*Ambrosia artemisiifolia*	bahiagrass	*Paspalum notatum* var. *notatum**
sensitive pea	*Chamaecrista nictitans* var. *aspera*	rustweed	*Polypremum procumbens*
Bermuda grass	*Cynodon dactylon**	pink purslane	*Portulaca pilosa*
southern crabgrass	*Digitaria ciliaris*	blackroot	*Pterocaulon pycnostachyum*
rough buttonweed	*Hexasepalum teres*	Malaysian false pimpernel	*Torenia crustacea**
Faculative Wetland			
blue maidencane	*Amphicarpum muehlenbergianum*	whitehead bogbutton	*Lachnocaulon anceps*
bushy bluestem	*Andropogon glomeratus* var. *hirsutior*	climbing hempvine	*Mikania scandens*
common carpetgrass	*Axonopus fissifolius*	torpedograss	*Panicum repens**
false nettle	*Boehmeria cylindrica*	field paspalum	*Paspalum laeve*
spadeleaf	*Centella asiatica*	sweetscent	*Pluchea odorata*
redtop panicum	*Coleataenia rigidula*	West Indian medowbeauty	*Rhexia cubensis*
Leavenworth's tickseed	*Coreopsis leavenworthii*	pale meadowbeauty	*Rhexia mariana*
shortleaf spikesedge	*Cyperus brevifolius**	meadowbeauties	*Rhexia* spp.
poorland flatsedge	*Cyperus compressus*	starrush whitetop	*Rhynchospora colorata*
fragrant flatsedge	*Cyperus odoratus*	fascicled beadsedge	*Rhynchospora fascicularis*
flatsedges	*Cyperus* spp.	bunch beaksedge	*Rhynchospora microcephala*
tropical flatsedge	*Cyperus surinamensis*	fairy beaksedge	*Rhynchospora pusilla*
Virginian buttonweed	*Diodia virginiana*	beaksedges	*Rhynchospora* spp.
clustered mille graines	*Edrastima uniflora*	sugarcane plumegrass	*Saccharum giganteum*
ditch fimbry	*Fimbristylis schoenoides**	netted nutrush	*Scleria reticularis*
white twinevine	*Funastrum clausum*	yellow bristlegrass	*Setaria parviflora*
limpograss	*Hemarthria altissima**	sand cordgrass	*Spartina bakeri*
dwarf St. John's-wort	*Hypericum mutilum*	swamp fern	*Telmatoblechnum serrulatum*
shore rush	*Juncus marginatus*	paragrass	*Urochloa mutica**
Obligate			
alligatorweed	*Alternanthera philoxeroides**	herb-of-grace	*Bacopa monnieri*
big carpetgrass	*Axonopus furcatus*	bermarigold	*Bidens laevis*
American waterfern	*Azolla filiculoides*	smallfruit beggarticks	*Bidens mitis*
lemon bacopa	*Bacopa caroliniana*	Long's sedge	*Carex longii*

Table 9-13. Continued.

Common Name	Scientific Name	Common Name	Scientific Name
Obligate (continued)			
common buttonbush	*Cephalanthus occidentalis*	marsh seedbox	*Ludwigia palustris*
Browne's savory	*Clinopodium brownei*	creeping primrosewillow	*Ludwigia repens*
Florida tickseed	*Coreopsis floridana*	southern watergrass	*Luziola fluitans*
jointed flatsedge	*Cyperus articulatus*	American lotus	*Nelumbo lutea*
Cuban bulrush	*Cyperus blepharoleptos**	spatterdock	*Nuphar advena advena*
haspan flatsedge	*Cyperus haspan*	American white waterlily	*Nymphaea odorata*
Leconte's flatsedge	*Cyperus lecontei*	big floatingheart	*Nymphoides aquatica*
manyspike flatsedge	*Cyperus polystachyos*	maidencane	*Panicum hemitomon*
flatsedges	*Cyperus* spp.	Kissimmee grass	*Paspalidium geminatum*
coast cockspur	*Echinochloa walteri*	brook crowngrass	*Paspalum acuminatum**
waterhyacinth	*Eichhornia crassipes**	mudbank crowngrass	*Paspalum distichum*
Baldwin's spikerush	*Eleocharis baldwinii*	Florida reimargrass	*Paspalum eglume*
Gulf Coast spikerush	*Eleocharis cellulosa*	early paspalum	*Paspalum praecox*
yellow spikerush	*Eleocharis flavescens*	water paspalum	*Paspalum repens*
knotted spikerush	*Eleocharis interstincta*	denseflower knotweed	*Persicaria glabra*
slender fimbry	*Fimbristylis autumnalis*	hairy smartweed	*Persicaria hirsuta*
Carolina fimbry	*Fimbristylis caroliniana*	swamp smartweed	*Persicaria hydropiperoides*
forked fimbry	*Fimbristylis dichotoma*	swampweeds	*Persicaria* spp.
marsh fimbry	*Fimbristylis spadicea*	water-lettuce	*Pistia stratiotes*
fimbries	*Fimbristylis* spp.	pickerelweed	*Pontederia cordata*
saltmarsh umbrellasedge	*Fuirena breviseta*	mermaidweed	*Proserpinaca* spp.
southern umbrellasedge	*Fuirena scirpoidea*	Chapman's beaksedge	*Rhynchospora chapmanii*
swamp rosemallow	*Hibiscus grandiflorus*	spreading beaksedge	*Rhynchospora divergens*
West Indian marshgrass	*Hymenachne amplexicaulis**	narrowfruit horned beaksedge	*Rhynchospora inundata*
Virginia marsh St. John's wort	*Hypericum virginicum*	southern beaksedge	*Rhynchospora microcarpa*
clustered bushmint	*Hyptis alata*	shortbeak beaksedge	*Rhynchospora nitens*
soft rush	*Juncus effusus solutus*	beaksedges	*Rhynchospora* spp.
Carolina redroot	*Lachnanthes caroliana*	American cupscale	*Sacciolepis striata*
southern cutgrass	*Leersia hexandra*	bulltongue arrowhead	*Sagittaria lancifolia lancifolia*
American spongeplant	*Limnobium spongia*	broadleaf arrowhead	*Sagittaria latifolia*
Savannah false pimpernel	*Lindernia grandiflora*	giant bulrush	*Schoenoplectus californicus*
Piedmont primrosewillow	*Ludwigia arcuata*	gaping panicum	*Steinchisma hians*
largeflower primrosewillow	*Ludwigia grandiflora*	cattails	*Typha* spp.
angelstem primrosewillow	*Ludwigia leptocarpa*		
Upland or Undetermined			
ragweeds	*Ambrosia* spp.	crabgrasses	*Digitaria* spp.
bluestems	*Andropogon* spp.	spikerushes	*Eleocharis* spp.
Florida hammock sedge	*Carex vexans*	lovegrasses	*Eragrostis* spp.
Gambian dayflower	*Commelina gambiae*	thoroughworts	*Eupatorium* spp.
dayflowers	*Commelina* spp.	clustered sedge	*Fimbristylis glausescens*
rushfoil	*Croton michauxil*	fimbries	*Fimbristylis* spp.
flatsedges	*Cyperus* spp.	umbrellasedges	*Fuirena* spp.
witchgrasses	*Dichanthelium* spp.	marshpennyworts	*Hydrocotyle* spp.
slender crabgrass	*Digitaria filiformis* var. *filiformis*	St. John's worts	*Hypericum* spp.

Table 9-13. Continued.

Common Name	Scientific Name	Common Name	Scientific Name
Upland or Undetermined (continued)			
bogbuttons	*Lachnocaulon* spp.	Mexican clovers	*Richardia* spp.
primrosewillows	*Ludwigia* spp.	crimson bluestem	*Schizachyrium sanguineum*
dewflowers	*Murdannia* spp.	Wright's nutrush	*Scleria lacustris**
common yellow woodsorrel	*Oxalis corniculata*	sesbans	*Sesbania* spp.
woodsorrels	*Oxalis* spp.	fanpetals	*Sida* spp.
crowngrasses	*Paspalum* spp.	tropical soda apple	*Solanum viarum**
rough Mexican clover	*Richardia scabra*	yelloweyed grasses	*Xyris* spp.

The mean cover of wetland indicator species for individual sample years was compared along the elevation gradient to identify significant changes in **Figure 9-44**. East Lake Tohopekaliga and Lake Kissimmee both had elevations where abundance differed significantly over time ($p < 0.05$; **Figure 9-44**). On East Lake Tohopekaliga, changes occurred at quadrats located at the driest part of the transects, 3 feet above regulation low stage (58 ft NGVD29); facultative upland plant abundance was significantly higher in 2015 than in 2016 or 2018 (Tukey Honestly Significant Distance [HSD], $p = 0.0236$), and conversely, facultative wetland plant abundance was significantly higher in 2018 than in 2015 (Tukey HSD, $p = 0.0257$). On Lake Kissimmee, changes occurred in the obligate group at 2 feet above normal low pool stage (51 ft NGVD29) where, in 2018, average abundances climbed to 94% from 58% and 49%, respectively (Tukey HSD, $p = 0.0141$ and 0.0446, respectively).

Subsequent analysis of water levels for the years prior to each significantly different sample illustrates the connection between hydroperiod and species abundance when plants are divided into functional groups. For example, on East Lake Tohopekaliga, there were two considerably drier years (2012-2013 and 2013-2014) at elevations coincident with the change in functional groups described above, followed by a moderately wet year in 2014-2015. In 2018, stage rose above 58 ft NGVD29 for more than a month (**Figure 9-45**). The change in obligate plant abundance on Lake Kissimmee followed two very wet years where water levels were 6 inches or greater at 51 ft NGVD29 for over 3 months.

Discussion and Conclusions

The lack of inter- and intra-annual water level fluctuation is a major concern on these managed lakes, which often show an increase in low-dynamic communities, such as floating leaf pads, and a subsequent decline in deepwater emergent grasses. Plot data show how major disturbances like hurricanes can help regulate the growth of dense areas of vegetation, and that more desirable communities (e.g., deep water grasses) were also apparently impacted. More research is needed, such as analysis of satellite imagery pre- and post- Hurricane Irma to understand plant community impacts more fully.

The increase in obligate and facultative wetland abundances at higher elevations is likely temporary and related to short-term hydrology, but demonstrates the study's ability to detect changes that will be used to assess the effects of HRS implementation over time; i.e., to determine whether changes in hydrology under the new regulation schedule are significant enough to affect littoral vegetation distributions long term. Future changes in the HRS should be reflected in the trends shown through permanent shifts in where peak abundance occurs on the shoreline elevation gradient, shown as significantly different abundances of functional groups at higher or lower elevations maintained over several years. Comparing abundances of these groups over time using current data shows that few shifts were detected under moderate changes in water levels typical of routine hydrological management (**Figures 9-44**), and serves as evidence that detectable shifts will occur with the implementation of HRS.

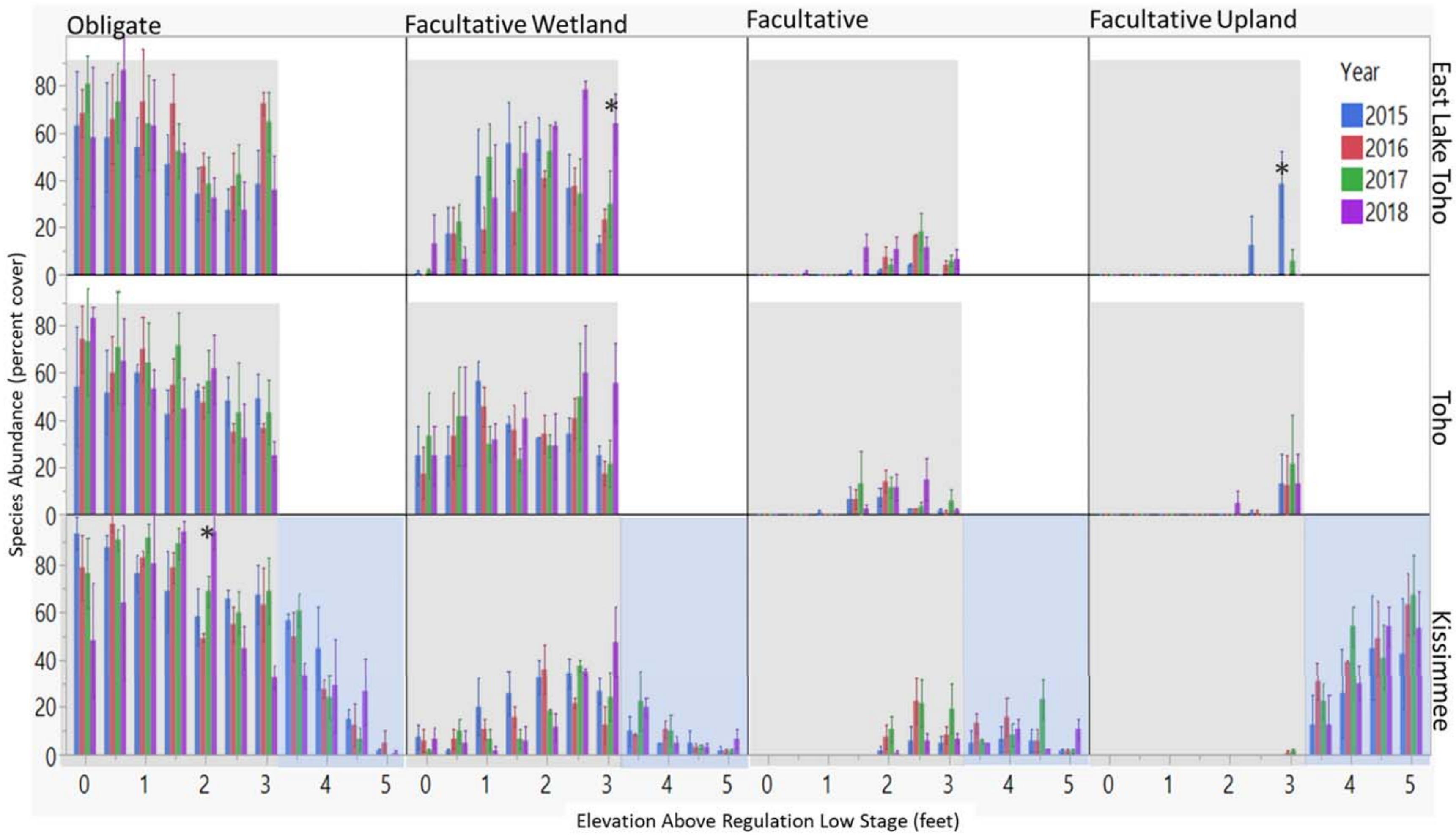


Figure 9-44. Mean (± SE) abundance of species grouped by wetland indicator status along elevation gradients on the lakes during annual samples from 2015 to 2018. Indicator status, from wet to dry, is obligate, facultative wetland, facultative, and facultative upland. Gray boxes represent the elevations of the current regulation schedule, and blue represents the future regulation expansion on Lake Kissimmee upon completion of Kissimmee River Restoration. An asterisk (*) denotes areas along the transects where abundance was significantly different in separate years. (Note: Toho – Tohopekaliga.)

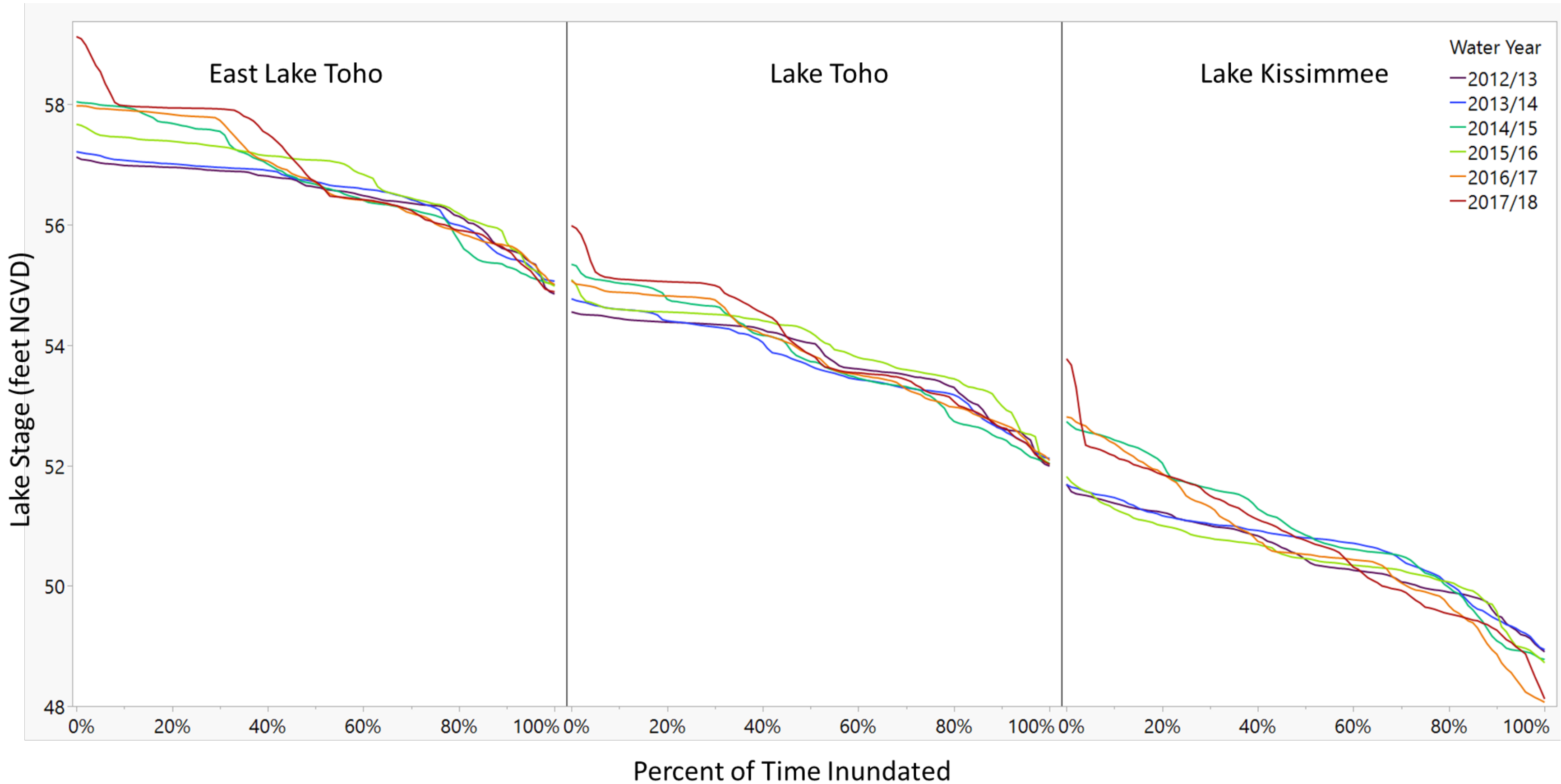


Figure 9-45. Stage duration curves for East Lake Tohopekaliga (Toho), Lake Tohopekaliga, and Lake Kissimmee for 2012-2013 through 2017-2018. Note on East Lake Tohopekaliga and Lake Kissimmee, the wide range in hydroperiod at the higher elevations with broad divergence between years.

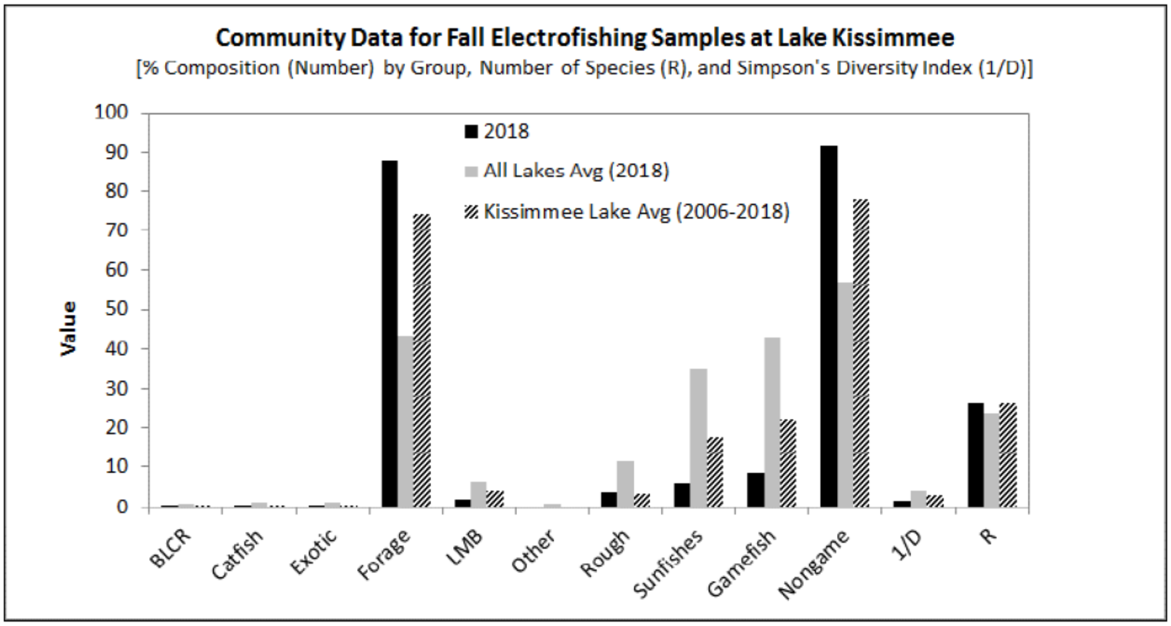
FISH POPULATION MONITORING

The status of the fishery in the KCOL is monitored on a regular basis by FWC via electrofishing and creel surveys. Electrofishing surveys use a standardized sampling protocol implemented in 2007, where random transects are sampled for 15 minutes each. Electrofishing surveys occur in the fall and spring every 2 to 3 years on the major lakes in the KCOL. Fall surveys provide community data with number of fish per functional group: black crappie (*Pomoxis nigromaculatus*), catfish, exotic species, small forage fish, largemouth bass, rough fish, sunfish, game fish, and nongame fish. The rough functional group contain bowfin (*Amia calva*), Florida gar (*Lepisosteus platyrhincus*), and similar species. Game fish and nongame fish are larger breakdowns of the other 7 groups; the fish on these lists also appear in another functional group. Spring surveys provide an assessment of the size distribution and abundance of largemouth bass populations. The most recent summaries were tallied for fall 2018 and spring 2019 on Lakes Kissimmee and Tohopekaliga.

Community data are summarized in **Figure 9-46** to provide a more complete understanding of the diversity and type of fish present in KCOL lakes. Samples from fall 2018 include 26 and 25 species on Lakes Kissimmee and Tohopekaliga, respectively. A large majority of the fish population, both number of individuals and number of species, is composed of small native forage fishes, such as topminnows, killifish, and shiners. As the name implies, this group is also an important component of lake food webs, sustaining predators including other fish. FWC cautions against interpreting differences between yearly samples and averages as real indications of increases and decreases in populations, explaining that results are greatly affected by habitat conditions such as water levels or amount of submerged aquatic vegetation, making it hard to directly compare samples. The relatively low diversity, measured using Simpson's reciprocal index of diversity, on Lake Kissimmee this year is attributed to a very large number of threadfin shad, which constituted over 82% of the total catch. These fish tend to form large schools or baitballs and can result in very large numbers of individuals in one electrofishing sample.

Catch per unit effort (CPUE) is one metric used to assess the annual abundance of largemouth bass, though catch rates can vary some with density of vegetation, water clarity, inclement weather, or an abundance of small size classes. CPUE was approximately 22 and 29 bass/hour on Lakes Kissimmee and Tohopekaliga, respectively, which is down from 2018 when values were 47 and 35 bass/hour.

The annual size distributions generally show a bimodal peak if the population is doing well, with a peak in subadults (< 25 centimeters [cm]) indicating good production of young and a second peak in larger size classes indicating good recruitment of young into the population (**Figure 9-47**). When there are few to no subadults found in a given year, there typically is a subsequent decline in larger size classes within 2 to 3 years after, and the opposite can be found as well. In 2019, the frequency distribution data from Lake Kissimmee show a peak in the adult population with very small numbers of subadult fish. Lake Tohopekaliga data show a bimodal pattern, with a large proportion of subadult fish relative to past years and a very small adult peak.



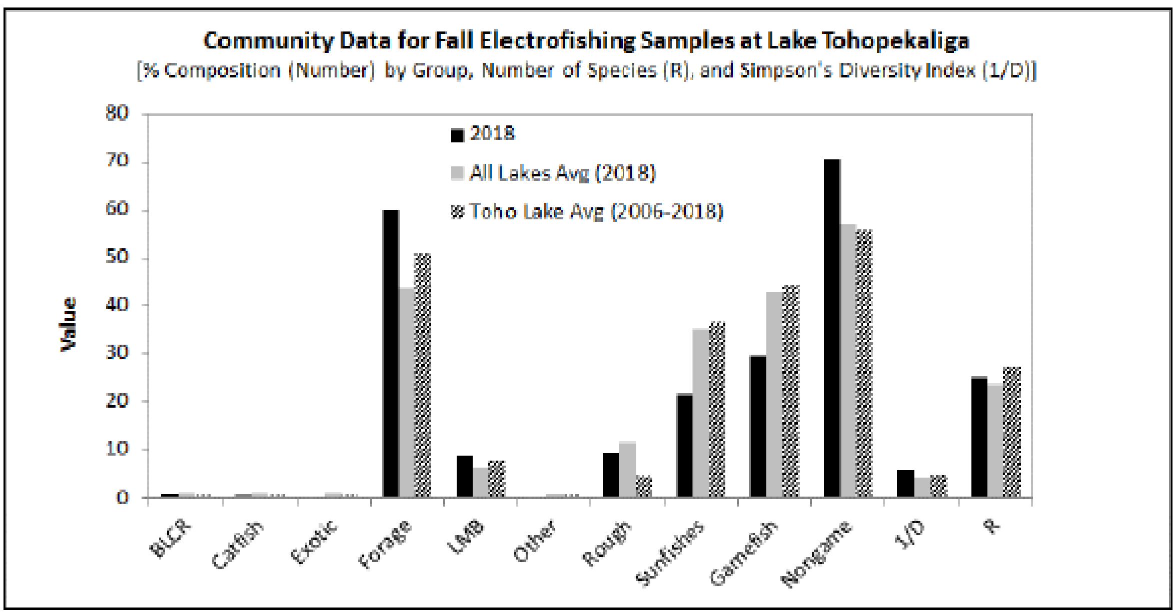
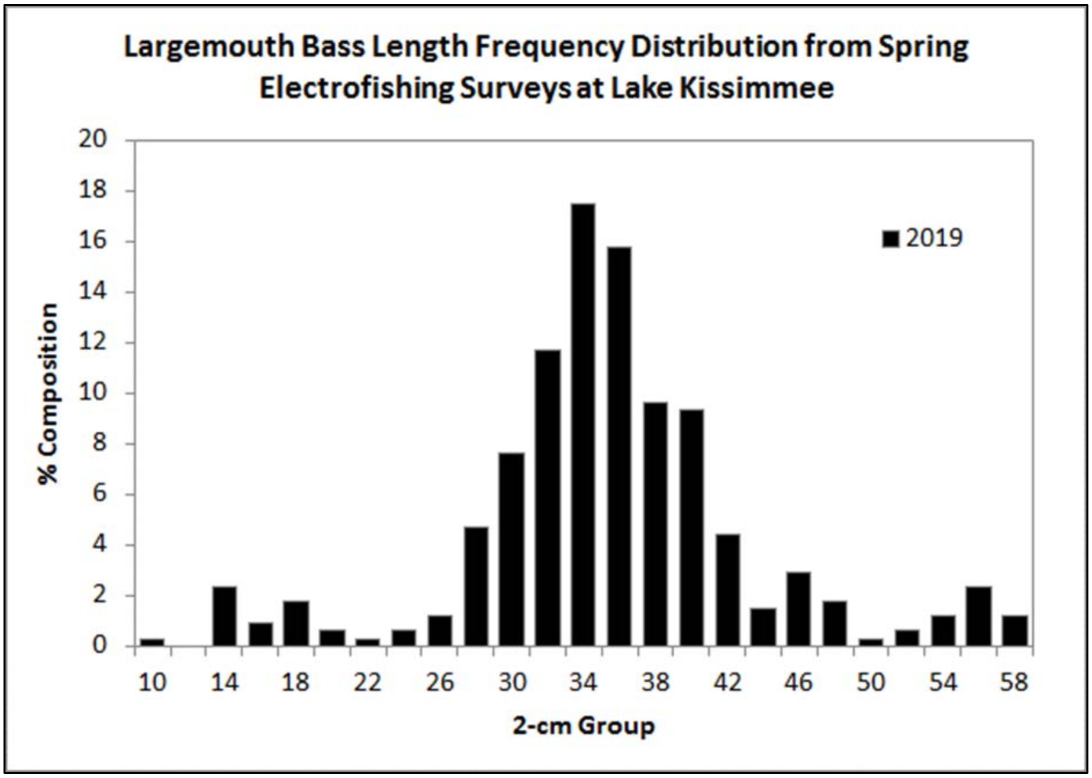


Figure 9-46. Percent composition of the fish community including functional groups, species richness, and Simpson's Diversity, for fish collected by electrofishing at Lakes Kissimmee (top) and Tohopekaliga (bottom) during fall 2018. (Note: BLCR – black crappie and LMB – largemouth bass.)



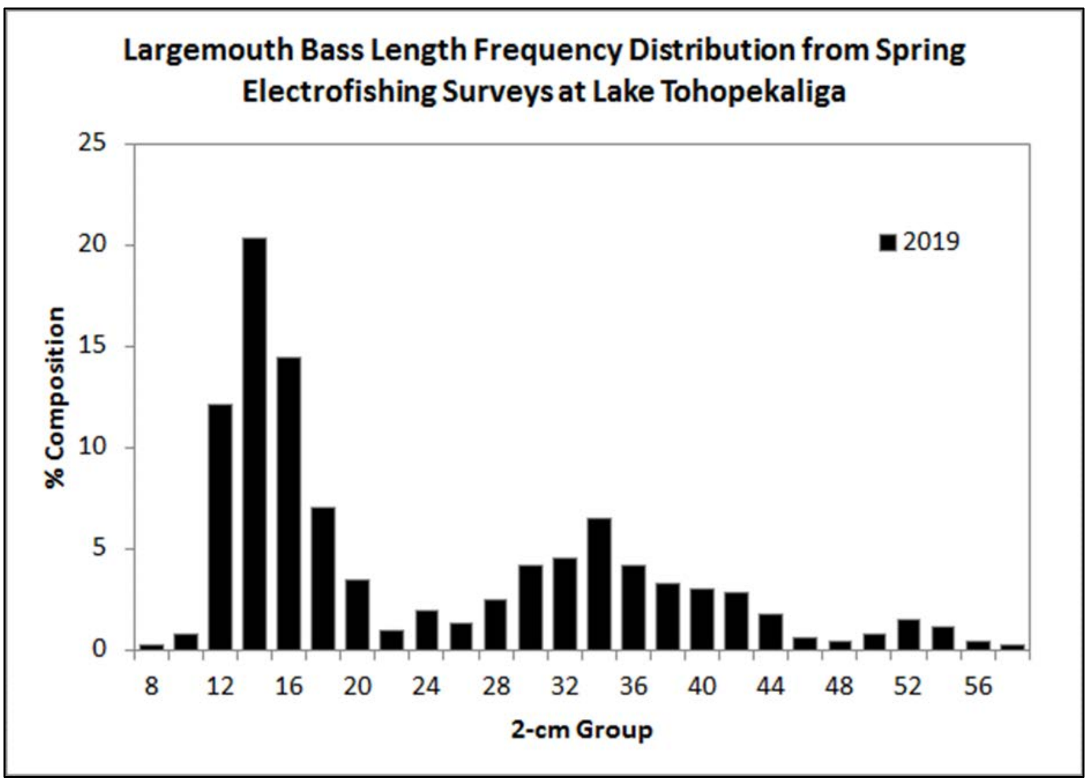


Figure 9-47. Length-frequency distribution (bars) for largemouth bass collected by electrofishing at Lakes Kissimmee (top; n = 343) and Tohopekaliga (bottom; n = 527) during spring 2019. Fish lengths were placed into 2-cm groups (e.g., 10 cm group = 10.00 through 11.99 cm total length).

SNAIL KITE POPULATION MONITORING

Statewide snail kite (*Rostrhamus sociabilis*) nesting effort, distribution, and population size are systematically monitored by the University of Florida on an annual basis (see Fletcher et al. [2020] for details). This monitoring effort covers most wetlands statewide in which snail kite breeding activity has been observed within the last decade or more. In the KCOL region, surveyed water bodies include East Lake Tohopekaliga and Lake Runnymede (grouped as East Lake Tohopekaliga); Lake Tohopekaliga; Lake Kissimmee; and Lakes Jackson, Cypress, Hatchineha, and Marian (grouped as Other). Surveys begin in January and crews record nesting information including the location, status (incubating, nestlings, failed, successful, or unknown), leg bands of parents if possible, and other important characteristics. Following the first survey in January, each nest is revisited at about 3-week intervals until the nest is no longer active. Alphanumeric leg bands are put on most nestlings when they are 24 days old for future identification and for estimating population size. The number of snail kites observed in each water body is counted and identified by their alphanumeric leg bands if possible.

In 2019, survey crews located 275 active nests (i.e., containing eggs or nestlings) throughout the snail kite's Florida range. This represents a dramatic decrease in nesting effort from 2018 (732 active nests).

Nesting in the KCOL made up 44% of statewide snail kite nesting in 2019, its highest contribution since 2012 (57%). This high contribution of nesting effort in the KCOL is mostly attributed to the low nesting effort in other areas of the state, especially Lake Okeechobee (**Figure 9-48A**). Lake Okeechobee did not have any active nests in 2019, which was the first time this occurred since 2009. The Everglades had 31 active nests, 16 of which were successful. Most of the nesting in the Everglades occurred in Water Conservation Area 3A (28 nests, 15 successful). The upper St. John's River basin had 30 active nests, 13 of which were successful. Most of the nesting in the upper St. John's River basin occurred in Three Forks Marsh Conservation Area (25 nests, 10 successful). The "Other" region had the second highest nest effort (91) and successful nests (37) than any other region. Most of this nesting occurred in Payne's Prairie Preserve State Park in Alachua County (74 nests, 29 successful).

For the first time since at least 2015, the most snail kite nests were found in the KCOL region (**Figure 9-48A**). Within the KCOL in 2019, there were 58 nests located on Lake Tohopekaliga (21% of the statewide nesting effort), 60 nests were located on Lake Kissimmee (22% of the statewide nesting effort), and 4 nests were located on East Lake Tohopekaliga (1% of the statewide nesting effort) (**Figure 9-48C**). There was no nesting documented on any other KCOL water body (**Figure 9-48C**). Of the 122 nests in the KCOL, 43 nests (35%) were observed to be successful (**Figure 9-48D**).

In summary, despite a poor snail kite nesting year in most regions, the KCOL nesting effort was near its average from the previous 12 years. Lake Tohopekaliga rebounded from three consecutive years of declining nesting effort and success. Although nesting effort on Lake Kissimmee declined from 2018, the nesting effort in 2019 was still the second highest level on recent record. Like 2018, many of these nests occurred on floating islands covered in woody vegetation. These islands may have appeared on Lake Kissimmee due to disturbance from Hurricane Irma in 2017. Apparent success rate on Lake Kissimmee (30%) also declined from 2018 (46%) but was still above average, suggesting the kites still benefitted from the security of nesting on floating islands.

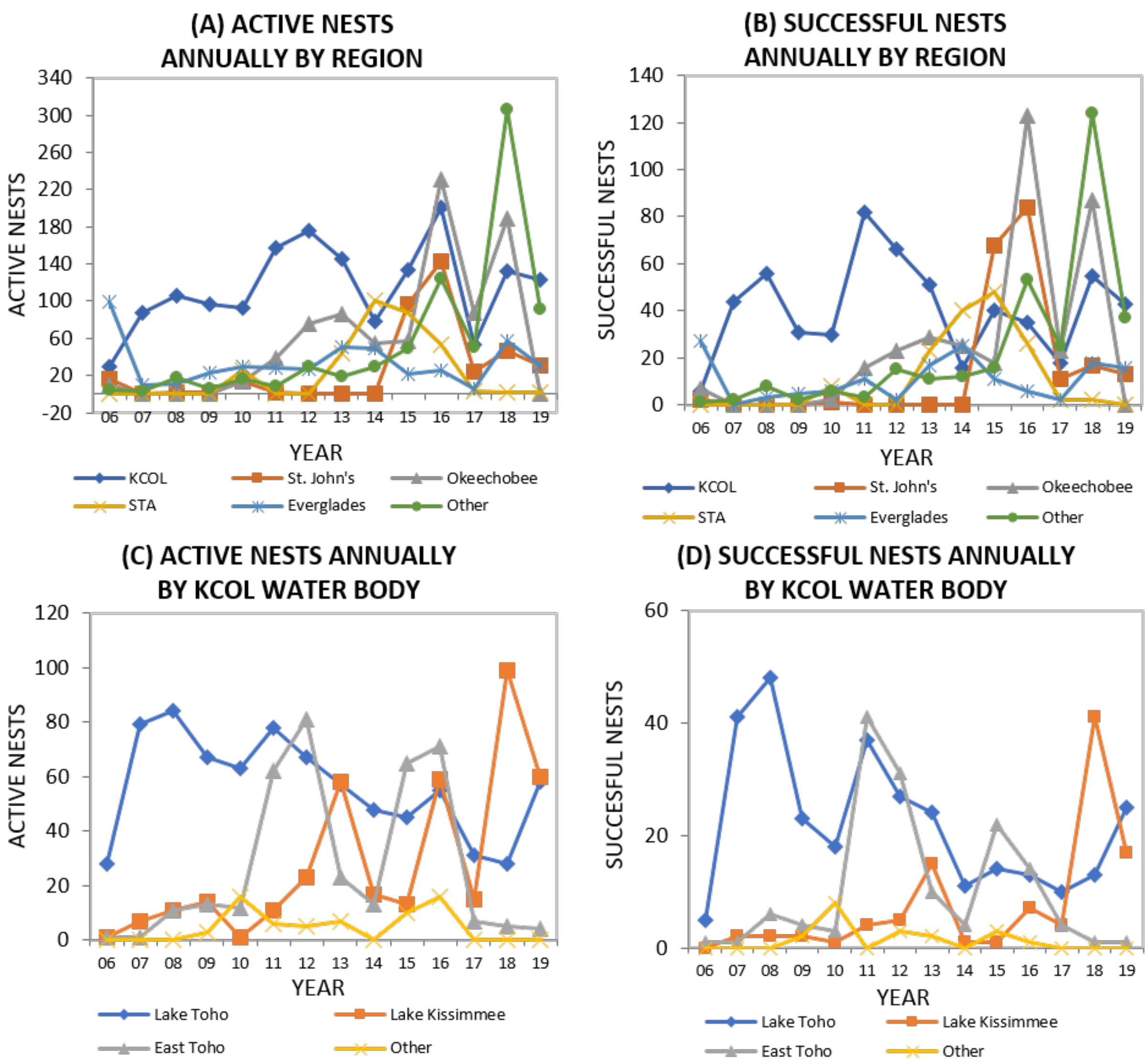


Figure 9-48. (A) Active snail kite nests for each region from 2006 to 2019 and (B) the total number successful. (C) Active snail kite nests for each major water body in the KCOL region and (D) the total number successful from 2006 to 2019.

ALLIGATOR POPULATION MONITORING

FWC conducts American alligator (*Alligator mississippiensis*) monitoring studies in many public water bodies throughout the state to obtain relative abundance of their populations (Hutton and Woolhouse 1989). Alligator activities vary seasonally (Lutterschmidt and Wasko 2006), so night light surveys are conducted from May through mid-June (spring surveys) and July through mid-August (summer surveys) and are analyzed separately. Survey routes are standardized and follow the perimeter of a lake along the open water-shoreline/marsh interface (Woodward and Marion 1978), or middle/centerline of a river/canal section, depending on width. Spotlights (200,000 candlepower) are used to locate alligator eye reflections and sizes are estimated to the nearest 1 ft, if possible. When the exact size cannot be determined, broader size categories (0–2 ft, 2–4 ft, 4–6 ft, ≥ 4 ft, ≥ 6 ft, and ≥ 9 ft) are used, or they are recorded as unknown size.

For trend analysis by year, counts are summed in each size category. Average date, water level, and water temperature within replicates are determined for each year. FWC uses Turnbull's (1976) approach for interval-censored data via the "%ice" SAS macro (So et al. 2010) to allocate counts into size categories. A modified version of this macro is used to produce an overall probability distribution function, describing the estimated proportions of unit-interval lengths for each replicate-unit-year sample. The probability distribution function is summed for specified portions of the alligator size range to produce the cumulative distribution function for each replicate-unit-year. Standard errors and 95% confidence intervals for cumulative distribution function are determined via the macro as well, and these are multiplied by the total number of all alligators counted for each replicate-unit-year sample to estimate the total count, along with SE and confidence limits.

FWC models year trends in the natural logarithms of the estimated counts using the generalized additive modeling package of the R statistical environment (Hastie 2009). Akaike's information criterion is used to select the best of six models from some combination of year and water level as predictors, modeled as either linear or spline (piecewise) regressions with four knots or separations (de Boor 2001). The predictors in the six models are (1) linear year effect; (2) four-knot spline for year; (3) linear year and linear water level; (4) linear year and four-knot spline for water level; (5) linear water level and four-knot spline for year; and (6) four-knot spline for year and four-knot spline for water level. A fixed detectability coefficient of 0.14 is applied to survey counts to generate population estimates from the generalized additive modeling analyses (Woodward et al. 1996).

In absence of historic (pre-C&SF) population data, FWC-based target levels (green zones on the graphs below) on population levels at the time monitoring surveys were initiated on each lake, which coincided with managed harvesting of alligators and eggs. It is likely that the current populations are greater than historic populations, reflecting habitat conditions that are more suitable for supporting alligators. For example, stabilization of the water levels has allowed for increased plant growth in the littoral zone and over time the formation of more mature tussocks, which can serve as productive substrates for alligator nesting. Increasing trends on most lakes indicate that populations continue to respond to favorable habitat conditions. Ramifications of allowing alligator populations to grow too large for a waterbody could include an increase in nuisance alligator complaints from the public, increased cannibalism as a result of increased densities of larger alligators, or a diminished food base eventually leading to poorer body conditions. Adults and eggs are routinely harvested on these lakes, which helps to keep the populations at more ecologically-sustainable levels.

Lake Kissimmee

Total alligator population estimates on Lake Kissimmee have continued to trend upward in recent years. The 2019 estimated population was 14,454 alligators, which is an increase of approximately 214% since population monitoring began in 1991 (**Figure 9-49a**). The estimated number of juvenile (1–4 ft) alligators was 7,974 individuals, which is a 391% increase over the 1991 estimated population. The adult (6 ft and larger) portion of the alligator population also increased and was estimated at 3,515 individuals, a 49% increase since 1991.

Lake Tohopekaliga

Alligator population estimates on Lake Tohopekaliga have continued to trend upward. Because of unusually high total counts during the two most recent years, data from 2018 and 2019 were identified as outliers and omitted from the trend analysis. The latest total alligator population estimate on Lake Tohopekaliga remains unchanged from the 2017 estimate, which was 7,826 alligators and an increase of 263% since population monitoring began in 1994 (**Figure 9-49b**). The estimated number of juvenile (1–4 ft) alligators was 4,917 individuals, a 184% increase over the 1994 estimated population. The adult (6 ft and larger) portion of the alligator population also increased and was estimated at 1,603 individuals, an 118% increase over the 1994 estimated population.

East Lake Tohopekaliga

The 2019 estimated population was 91 alligators, a decrease of approximately 7% since population monitoring began in 2003. Despite this apparent decrease, the variation in survey counts is relatively high and there is no significant trend. The estimated number of juvenile (1–4 ft) alligators was 22 individuals, a 27% decline from the 2003 estimated population. The adult (6 ft and larger) portion of the alligator population was 37 individuals, a 29% decrease from the 2003 estimated population.

Lake Hatchineha

Total alligator population estimates on Lake Hatchineha have continued an upward trend. The 2019 estimated population was 3,937 alligators, an increase of approximately 226% since population monitoring began in 1988 (**Figure 9-49c**). The estimated number of juvenile (1–4 ft) alligators was 2,140 individuals, a 241% increase since 1988. The adult (6 ft and larger) portion of the alligator population also increased and was estimated at 1,141 individuals, a 180% increase over the 1988 estimated population.

Cypress Lake

The 2019 estimated population on Cypress Lake was 648 alligators, a 34% decrease since population monitoring began in 2000. The estimated number of juvenile (1–4 ft) alligators was 181 individuals, while the estimated number of adult alligators was 348 individuals. Those estimates represent 26% and 20% declines, respectively, from the 2000 estimated population.

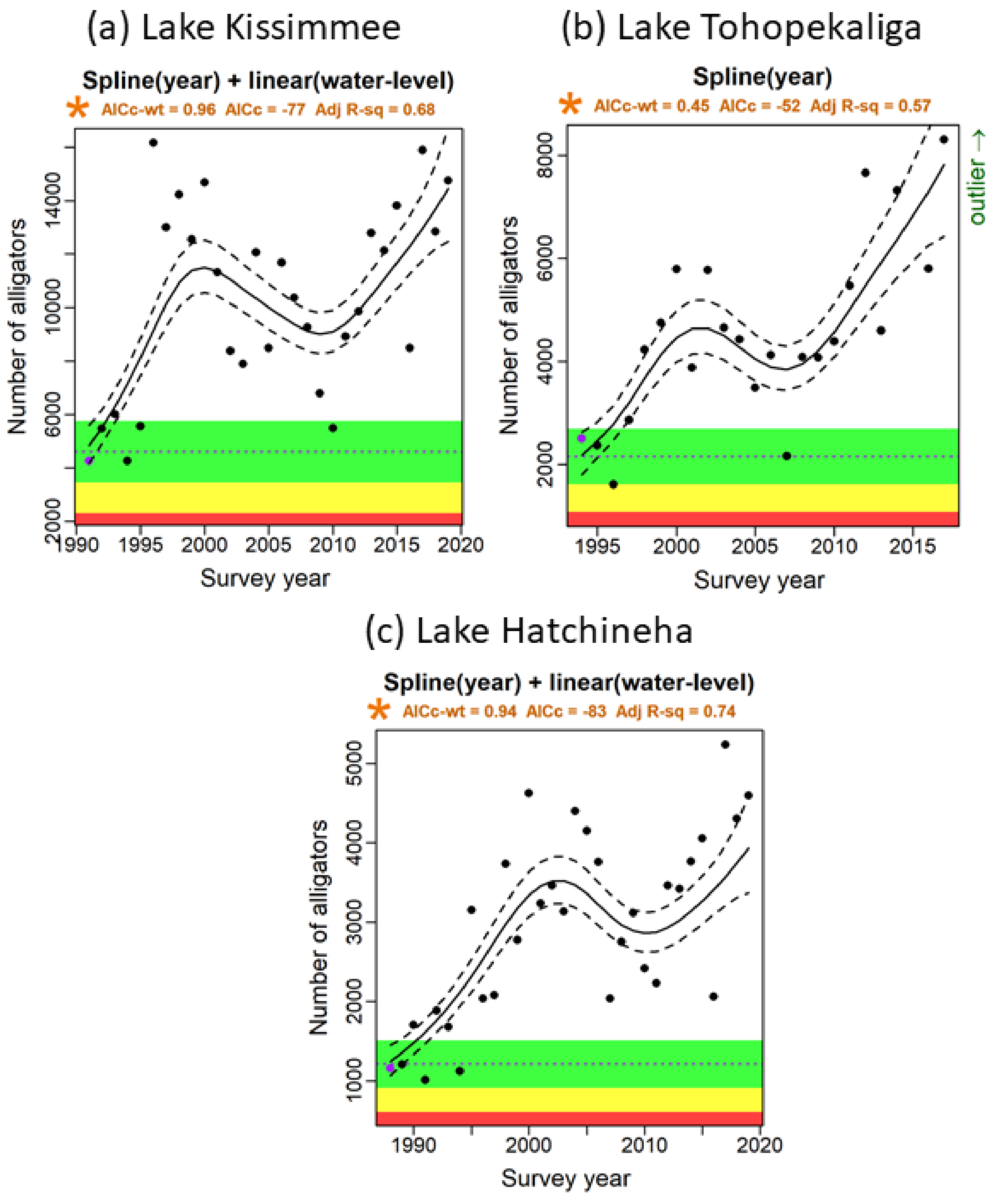


Figure 9-49. Alligator population trends on (a) Lake Kissimmee, (b) Lake Tohopekaliga, and (c) Lake Hatchineha based on night light surveys conducted between 1988 and 2019. The green-shaded area represents ± 25% of the population management target; the yellow-shaded area represents 25–50% of the target; and the red-shaded area represents ≤ 50% of the target. Dashed lines represent 70% confidence intervals around the solid trend line. Note that both the x- and y-axes scales vary between figures. (Note: Adj R-sq – adjusted R-squared; AICc – Akaike information criterion with a correction for small sample sizes and AIC_c-wt – Akaike weights.)

Summary

Alligator populations on the three largest lakes within the KCOL (Kissimmee, Tohopekaliga, and Hatchineha) have shown increases in juvenile, adult, and total populations over the period for which monitoring surveys were conducted. Increases in the number of juveniles could be an indication of sufficient nesting habitat, favorable nesting conditions, high hatching success, and sufficient habitat for hatchlings and juveniles. Likewise, increases in the number of adults possibly are due to high survival of juveniles and subsequently high recruitment of younger alligators into the adult size classes.

Trend analyses for East Lake Tohopekaliga and Cypress Lake indicate declines for juveniles, adults, and total populations. Despite the declines observed over the period of monitoring, all the size classes on both lakes remain within the acceptable range of population estimates. The decline of adults might reflect the harvest from recreational and nuisance trappers. The declines noted for the juveniles is unclear but might reflect changes in the available habitat for smaller alligators. The removal of dense emergent vegetation and hydrilla (*Hydrilla verticillata*) can reduce the amount of available cover and foraging area for juvenile alligators. The drawdown on East Lake Tohopekaliga could have further negative effects on juvenile populations because of the reduction in nesting and foraging habitats, as well as available cover. Continued monitoring should allow assessment of the effects of the drawdown on alligator populations.

LITERATURE CITED

Anderson, D.H. 2014. Interim hydrologic responses to Phase I of the Kissimmee River Restoration Project, Florida. *Restoration Ecology* 22(3):353-366.

Baker, J.M., J.P. Hartley, and B. Dicks. 1987. Planning Biological Surveys. Pages 1–26 in: J.M. Baker and W.J. Wolff (eds.), *Biological Surveys of Estuaries and Coasts*, Cambridge University Press, Cambridge, United Kingdom.

Barnes, M.A., R.K. Fordham, R.L. Brooks, and J.J. Hand. 2008. Fecundity of the exotic apple snail *Pomacea insularum*. *Journal of the North American Benthological Society* 27(3):738-745.

Bellrose, F.C. 1980. *Ducks, Geese, and Swans of North America, Third Edition*. Stackpole Books, Harrisburg, PA.

Bousquin, S.G., and J. Colee. 2014. Interim responses of littoral river channel vegetation to reestablished flow after Phase I of the Kissimmee River Restoration Project. *Restoration Ecology* 22(3):388-396.

Bousquin, S.G., D.H. Anderson, G.W. Williams, and D.J. Colangelo (eds.). 2005. *Kissimmee River Restoration Studies, Volume I – Establishing a Baseline: Pre-restoration Studies of the Channelized Kissimmee River*. Technical Publication ERA 432, South Florida Water Management District, West Palm Beach, FL.

Carnal, L. 2005a. Expectation 12: Areal Coverage of Floodplain Wetlands.. Pages 12-1 through 12-4 in: D.H. Anderson, S.G. Bousquin, G.W. Williams and D.J. Colangelo (eds.), *Kissimmee River Restoration Studies Volume II – Defining Success: Expectations for Restoration of the Kissimmee River*. Technical Publication ERA 433, South Florida Water Management District, West Palm Beach, FL.

Carnal, L. 2005b. Expectation 13: Areal Coverage of Broadleaf Marsh. Pages 13-1 through 13-4 in D.H. Anderson, S.G. Bousquin, G.W. Williams, and D.J. Colangelo (eds.), *Kissimmee River Restoration Studies Volume II – Defining Success: Expectations for Restoration of the Kissimmee River.* Technical Publication ERA 433, South Florida Water Management District, West Palm Beach, FL.

Carnal, L. 2005c. Expectation 14: Areal Coverage of Wet Prairie. Pages 14-1 through 14-4 in D.H. Anderson, S.G. Bousquin, G.W. Williams, and D.J. Colangelo (eds.), *Kissimmee River*

Restoration Studies Volume II – Defining Success: Expectations for Restoration of the Kissimmee River. Technical Publication ERA 433, South Florida Water Management District, West Palm Beach, FL.

Cattau, C.C., R.J. Fletcher Jr, B.E. Reichart, and W.M. Kitchens. 2016. Counteracting effects of a non-native prey on the demography of a native predator culminates in positive population growth. *Ecological Applications* 26(7):1952-1968.

Chamberlain, E.B. 1960. *Florida Waterfowl Populations, Habitats, and Management*. Technical Bulletin 7, Florida Game and Fresh Water Fish Commission, Tallahassee, FL.

Cheek, M.D., G.E. Williams, S.G. Bousquin, J. Colee, and S.L. Melvin. 2014. Interim response of wading birds (Pelecaniformes and Ciconiiformes) and waterfowl (Anseriformes) to the Kissimmee River Restoration Project, Florida, U.S.A. *Restoration Ecology* 22(3):426-434.

Chen, H., S.G. Bousquin, and D.H. Anderson. 2016. Dissolved Oxygen Dynamics in the Post-Phase I Kissimmee River Channel and Implications for Discharge Management. Poster presented at the 2016 National Conference on Ecological Restoration, Fort Lauderdale, FL, April 18–22, 2016.

Chen, H., 2019. Responses of River Metabolism to Phase I of the Kissimmee River Restoration Project. Presentation at the 2019 Greater Everglades Ecosystem Restoration Conference, Coral Springs, FL, April 24, 2019.

Colangelo, D.J. 2007. Response of river metabolism to restoration of flow in the Kissimmee River, Florida, U.S.A. *Freshwater Biology* 52:459-470.

Colangelo, D.J., and B. Jones. 2005. Expectation 8: Dissolved Oxygen Concentrations in the River Channel. Pages 8-1 through 8-6 in: D.H. Anderson, S.G. Bousquin, G.W. Williams, and D.J. Colangelo (eds.) *Kissimmee River Restoration Studies, Volume II – Defining Success: Expectations for Restoration of the Kissimmee River*, Technical Publication ERA 433, South Florida Water Management District, West Palm Beach, FL.

Conner, S.L., C.M. Pomory, and P.C. Darby. 2008. Density effects of native and exotic snails on growth in juvenile apple snails *Pomacea paludosus* (Gastropoda: Ampullariidae): A laboratory experiment. *Journal of Molluscan Studies* 74:355-362

Dale, M.R.T. 1999. *Spatial Pattern Analysis in Plant Ecology*. Cambridge University Press, New York, NY.

Daubenmire, R. 1959. A canopy-coverage method of vegetation analysis. *Northwest Science* 33:43-64.

Day, R.T., P.A. Keddy, J. McNeill, and T. Carleton. 1988. Fertility and disturbance gradients: A summary model for riverine marsh vegetation. *Ecology* 69(4):1044-1054.

de Boor, C. 2001. *A Practical Guide to Splines (Revised Edition)*. Springer-Verlag, New York, NY.

Department of the Army and SFWMD. 1994. *Project Cooperation Agreement between the Department of the Army and South Florida Water Management District for Construction of the Kissimmee River, Florida, Project*. United States Department of the Army, Washington, DC, and South Florida Water Management District, West Palm Beach, FL.

Desa, M.A. 2008. *How aquatic fauna responded to large scale management on Lake Tohopekaliga, FL*. Master's Thesis, University of Florida, Gainesville, FL

Enloe, S. 2017. *Field Demonstrations of Selective Control of Invasive Aquatic Grasses*. Full Proposal for NUMBER 17-SOI-0008, Gulf Coast Region. University of Florida, Gainesville, FL.

FGFWFC. 1957. Appendix B: Waterfowl Ecological Studies. In: *Recommended Program for Kissimmee River Basin*, Florida Game and Fresh Water Fish Commission, Tallahassee, FL.

FLEPPC. 2019. *List of Invasive Plant Species*. Florida Exotic Pest Plant Council. Available online at http://bugwoodcloud.org/CDN/fleppc/plantlists/2019/2019_Plant_List_ABSOLUTE_FINAL.pdf.

Fletcher, R., C. Poli, E. Robertson, B. Jeffery, S. Dudek, and B. Reichert. 2017. *Snail Kite Demography 2016 Annual Report*. United States Geological Survey, Florida Cooperative Fish and Wildlife Research Unit, Department of Wildlife Ecology and Conservation, University of Florida, Gainesville, FL.

Fletcher, R., E. Robertson, S. Dudek, C. Poli, and B. Jeffery. 2019. *Snail Kite Demography 2019 Annual Report on the 2018 Breeding Season*. United States Geological Survey, Florida Cooperative Fish and Wildlife Research Unit, Department of Wildlife Ecology and Conservation, University of Florida, Gainesville, FL.

Fletcher, R., C. Poli, B. Jeffery, B. Reichert, F. Potash, E. Robertson, and A. Gonzalez. 2020. *Snail Kite Demography 5 Year Final Report and Update on the 2019 Breeding Season*. Department of Wildlife Ecology and Conservation, Florida Cooperative Fish and Wildlife Research Unit, Department of Wildlife Ecology and Conservation, University of Florida, Gainesville, FL.

Florida Game and Fresh Water Fish Commission. 1957. Waterfowl Ecological Studies. Appendix B in *Recommended Program for Kissimmee River Basin*. Florida Game and Fresh Water Fish Commission, Tallahassee, Florida, USA.

Frahn, K., S. Gehrig, J. Nicol, and K. Marsland. 2014. *Lower Lakes Vegetation Condition Monitoring – 2013/2014*. Report Number 795, South Australian Research and Development Institute, Adelaide, South Australia.

Frederick, P.C., and M.W. Collopy. 1989. Nesting success of five ciconiiform species in relation to water conditions in the Florida Everglades. *The Auk* 106:625-634.

Furse, J.B., L.J. Davis, and L.A. Bull. 1996. Habitat use and movements of largemouth bass associated with changes in dissolved oxygen and hydrology in Kissimmee River, Florida. *Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies* 50:12-25.

Godin, J. 2012. Appendix 1-6: South Florida Water Depth Assesssment Tool (SFWDAT). In: *2012 South Florida Environmental Report – Volume I*, South Florida Water Management District, West Palm Beach, FL. Available online at https://apps.sfwmd.gov/sfwmd/SFER/2012_SFER/v1/appendices/v1_app1-6.pdf.

Green, R.H. 1993. Application of repeated measures designs in environmental impact and monitoring studies. *Austral Ecology* 18(1):81-98.

Harris, S.C., T.H. Martin, and K.W. Cummins. 1995. A model for aquatic invertebrate response to Kissimmee River restoration. *Restoration Ecology* 3(3):181-194.

Hastie, T. 2009. *R Package Version 1.01*. Palo Alto, CA.

Hauer, F.R. and G.A. Lamberti. 2007. *Methods in Stream Ecology, 2nd Edition*. Academic Press, San Diego, CA.

Hutton, J.M., and M.E.J. Woolhouse. 1989. Mark-recapture to assess factors affecting the proportion of a Nile crocodile population seen during spotlight counts at Ngezi, Zimbabwe, and the use of spotlight counts to monitor crocodile abundance. *Journal of Applied Ecology* 26:381-395.

Johnson, K.G., M.S. Allen, and K.E. Havens. 2007. A review of littoral vegetation, fisheries, and wildlife responses to hydrologic variation at Lake Okeechobee. *Wetlands* 27:110−126.

Koebel, J.W., and S. Bousquin. 2014. The Kissimmee River Restoration Project and Evaluation Program, Florida, U.S.A. *Restoration Ecology* 22(3):345-352.

Koebel, J.W., S.G. Bousquin, D.H. Anderson, Z. Welch, M.D. Cheek, H. Chen, R.T. James, J. Zhang, B.C. Anderson, R. Baird, T. Beck, A. Brunell, D.J. Colangelo, T. Coughlin, K. Lawrence, and C. Mallison. 2016. Chapter 9: Kissimmee River Restoration and Basin Initiatives. In: *2016 South Florida Environmental Report – Volume I*, South Florida Water Management District, West Palm Beach, FL.

Koebel, J.W., S.G. Bousquin, D.H. Anderson, Z. Welch, M.D. Cheek, H. Chen, B.C. Anderson, R. Baird, T. Beck, A. Brunell, T. Coughlin, and C. Mallison. 2017. Chapter 9: Kissimmee River Restoration and Basin Initiatives. In: *2017 South Florida Environmental Report – Volume I,* South Florida Water Management District, West Palm Beach, FL.

Koebel, J.W., S.G. Bousquin, D.H. Anderson, M.D. Cheek, Z. Welch, H. Chen, B.C. Anderson, L. Spencer, T. Beck, A. Brunell, T. Coughlin, and C. Mallison. 2018. Chapter 9: Kissimmee River Restoration and Basin Initiatives. In: *2018 South Florida Environmental Report – Volume I*, South Florida Water Management District, West Palm Beach, FL.

Koebel, J.W., S.G. Bousquin, D.H. Anderson, M.D. Cheek, C. Carroll, H. Chen, C. Hanlon, Z. Welch, B.C. Anderson, L. Spencer, T. Beck, T. Coughlin, and C. Mallison. 2019. Chapter 9: Kissimmee River Restoration and Basin Initiatives. In: *2019 South Florida Environmental Report – Volume I*, South Florida Water Management District, West Palm Beach, FL.

Koebel, J.W., S.G. Bousquin, D.H. Anderson, M.D. Cheek, C. Carroll, H. Chen, B.C. Anderson, T. Beck, and A. Brunell. 2020. Chapter 9: Kissimmee River Restoration and Basin Initiatives. In: *2020 South Florida Environmental Report – Volume I*, South Florida Water Management District, West Palm Beach, FL.

Lee, D.S., C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister, and J.R. Stauffer, Jr. 1980. *Atlas of North America Freshwater Fishes*. North Carolina State Museum of Natural History, Raleigh, NC.

Lichvar, R.W., N.C. Melvin, M.L. Butterwick, and W.N. Kirchner. 2012. *National Wetland Plant List Indicator Rating Definitions*. ERDC/CRREL TR-12-1, United States Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory, Hanover, NH.

Lutterschmidt, W.I., and D.K. Wasko. 2006. Seasonal activity, relative abundance, and size-class structure of the American alligator (*Alligator mississippiensis*) in a highly disturbed inland lake. *The Southwestern Naturalist* 51:346-351.

McCune, B., and J.B. Grace. 2002. *Analysis of Ecological Communities.* MjM Software Design, Gleneden Beach, OR.

Mini, A.E., E.R. Harrington, E. Rucker, B.D. Dugger, and T.B. Mowbray. 2020. American Wigeon (*Mareca americana*), version 1.0. In: A.F. Poole (ed.), *Birds of the World*, Cornell Lab of Ornithology, Ithaca, NY.

Moyer, E.J., M.W. Hulon, R.S. Butler, and R.W. Hujik. 1989. *Kissimmee Chain of Lakes Studies: Study 1. Lake Tohopekaliga Investigations*. Florida Game and Freshwater Fish Commission, Tallahassee, FL.

National Audubon Society. 1936–1959. Audubon Warden Field Reports. Everglades National Park, South Florida Research Center, Homestead, FL.

NRC. 1992. *Restoration of Aquatic Ecosystems*. National Research Council, National Academy Press, Washington, DC.

Osenberg, C.W., B.M. Bolker, J-S. S. White, C.M. St. Mary, and J.S. Shima. 2006. Statistical Issues and Study Design in Ecological Restoration: Lessons Learned from Marine Reserves. Pages 280–302 in: D.A. Falk, M.A. Palmer, and J.B. Zedler (eds.), *Foundations of Restoration Ecology*, Island Press, Washington, DC.

Paillisson, J-M., and L. Marion. 2006. Can small water level fluctuations affect the biomass of *Nymphaea alba* in large lakes? *Aquatic Botany* 84(3):259-266.

Posch, H., A.L. Garr, and E. Reynolds. 2013. The presence of an exotic snail, *Pomacea maculata*, inhibits growth of juvenile Florida apple snails, *Pomacea paludosus. Journal of Mulluscan Studies* 79:383-385.

Rodgers, L., C. Mason, M. Kirkland, R. Brown, K. Quincy, E. Metzger, P. Tipping, M. Miller, F. Mazzotti, S. Funck, A. Peters, J. Lane, Chelsea Bohaty, and F. Laroche. 2021. Chapter 7: Status of Nonindigenous Species. In: *2021 South Florida Environmental Report – Volume I*, South Florida Water Management District, West Palm Beach, FL.

SFWMD, FWC, FDEP, FDACS, USACE, USFWS, and Osceola County. 2011. *Kissimmee Chain of Lakes Long-Term Management Plan*. South Florida Water Management District, West Palm Beach, FL; Florida Fish and Wildlife Conservation Commission, Vero Beach, FL; Florida Department of Environmental Protection, Tallahassee, FL; Florida Department of Agriculture and Consumer Services, Tallahassee, FL; United States Army Corps of Engineer, Jacksonville, FL; United States Fish and Wildlife Service, Vero Beach, FL; and Osceola County, Kissimmee, FL.

Smith, J.P., J.R. Richardson, and M.W. Collopy. 1995. Foraging habitat selection among wading birds (Ciconiiformes) at Lake Okeechobee, Florida, in relation to hydrology and vegetative cover. *Archiv für Hydrobiologie Special Issues Advances in Limnology* 45:247-285.

So, Y., G. Johnston, and S.H. Kim. 2010. *Analyzing Interval-censored Survival Data with SAS Software*. SAS Institute Inc., Cary, NC.

South Florida Engineering and Consulting, LLC. 2018. *East Lake Toho Drawdown and Habitat Enhancement Final Biological Assessment.* Prepared for United States Army Corps of Engineer, Jacksonville, FL, by South Florida Engineering and Consulting, LLC, West Palm Beach, FL.

Spencer, L., and S. Bousquin. 2014. Interim responses of floodplain wetland vegetation to Phase I of the Kissimmee River Restoration Project: Comparisons of vegetation maps from five periods in the river's history. *Restoration Ecology* 22(3):397-408.

Stewart-Oaten, A., J.R. Bence, and C.W. Osenberg. 1992. Assessing effects of unreplicated perturbations: No simple solutions. *Ecology* 73(4):1396-1404.

Tichý, L., and M. Chytrý. 2006. Statistical determination of diagnostic species for site groups of unequal size. *Journal of Vegetation Science* 17:809-818.

Toth, L.A. 2005. Plant community structure and temporal variability in a channelized subtropical floodplain. *Southeastern Naturalist* 4(3):393-408.

Trexler, J. C. 1995. Restoration of the Kissimmee River: A conceptual model of past and present fish communities and its consequences for evaluating restoration success. *Restoration Ecology* 22(3):195-210.

Turnbull, B.W. 1976. The empirical distribution function with arbitrarily grouped, censored and truncated data. *Journal of the Royal Statistical Society* Series B (Methodological):290-295.

USACE. 1991. *Final Integrated Feasibility Report and Environmental Impact Statement for the Restoration of the Kissimmee River, Florida*. United States Army Corps of Engineers, Jacksonville, FL.

USACE. 1996. *Central and Southern Florida Project, Kissimmee River Headwaters Revitalization Project: Integrated Project Modification Report and Supplement to the Final Environmental Impact Statement*. United States Army Corps of Engineers, Jacksonville, FL.

Walker, S., J.B. Wilson, J.B. Steel, G.L. Rapson, B. Smith, W. McG. King, and Y.H. Cottam. 2003. Properties of ecotones: Evidence from five ecotones objectively determined from a coastal vegetation gradient. *Journal of Vegetation Science* 14:579-590.

Weller, M.W. 1995. Use of two waterbird guilds as evaluation tools for the Kissimmee River restoration. *Restoration Ecology* 22(3):211-224.

Wetzel, R.G. 2001. *Limnology, 3rd Edition*. Academic Press, San Diego, CA.

Williams, G.E. and S.L. Melvin. 2005a. Chapter 14: Studies of Bird Assemblages and Federally-Listed Bird Species of the Channelized Kissimmee River, Florida. Pages 14-1 through 14-30 in: D.H. Anderson, S.G. Bousquin, G.W. Williams, and D.J. Colangelo (eds.), *Kissimmee River Restoration Studies Volume II – Defining Success: Expectations for Restoration of the Kissimmee River*, Technical Publication ERA 433, South Florida Water Management District, West Palm Beach, FL.

Williams, G.E. and S.L. Melvin. 2005b. Expectation 24: Density of Long-legged Wading Birds on the Floodplain. Pages 24-1 through 24-5 in: D.H. Anderson, S.G. Bousquin, G.W. Williams, and D.J. Colangelo (eds.), *Kissimmee River Restoration Studies, Volume II – Defining Success: Expectations for Restoration of the Kissimmee River*, Technical Publication ERA 433, South Florida Water Management District, West Palm Beach, FL.

Williams, G.E., Jr., J.W. Koebel Jr., D.H. Anderson, S.G. Bousquin, D.J. Colangelo, J.L. Glenn, B.L. Jones, C. Carlson, L. Carnal, and J. Jorge. 2005. Chapter 11: Kissimmee River Restoration and Upper Basin Initiatives. In: *2005 South Florida Environmental Report – Volume I*, West Palm Beach, FL.

Williams, G.E., D.H. Anderson, S.G. Bousquin, C. Carlson, D.J. Colangelo, J.L. Glenn, B.L. Jones, J.W. Koebel Jr., and J. Jorge. 2007. Chapter 11: Kissimmee River Restoration and Upper Basin Initiatives. In: *2007 South Florida Environmental Report – Volume I*, South Florida Water Management District, West Palm Beach, FL.

Wisheu, I.C., and P.A. Keddy. 1992. Competition and centrifugal organization of plant communities: Theory and tests. *Journal of Vegetation Science* 3:147-156.

Woodward, A.R. and W.R. Marion. 1978. An evaluation of factors affecting night-light counts of alligators. *Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies* 32:291-302.

Woodward, A.R., K.G. Rice, and S.B. Linda. 1996. Estimating sighting proportions of American alligators during night-light and aerial helicopter surveys. *Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies* 50:509-519.