Chapter 9: Kissimmee River Restoration and Other Kissimmee Basin Initiatives

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Phase II Kissimmee River Restoration Project at Riverwood Run looking upstream.

Highlights

The chapter reports new results from Kissimmee Basin monitoring studies that were active in Planning Window 2021-2022 (PW2022; June 1, 2021–May 31, 2022), specifically those conducted under the South Florida Water Management District's (SFWMD's or District's) Kissimmee River Restoration Evaluation Program (KRREP) and several projects in the Kissimmee Chain of Lakes (KCOL). Since 2005, this chapter has reported results of numerous monitoring studies being conducted in the Kissimmee River and floodplain in the Lower Kissimmee Basin (LKB) and the Headwaters Lakes as part of the KRREP by SFWMD and in other lakes in the Upper Kissimmee Basin (UKB) by SFWMD and partner agencies. Results are reported as new data and analyses become available for 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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The chapter also summarizes Kissimmee Basin hydrologic conditions and water management in PW2022, as well as construction and management activities and the status of various other projects throughout the Kissimmee Basin. The Kissimmee River Restoration Project (KRRP) entered the twenty-first year of an Interim Period of restoration evaluation that began with completion of the first phase of construction and is expected to continue for five years after the Headwaters Revitalization Schedule (HRS) is fully implemented. Construction and backfilling for the project were completed in July 2021 and land acquisition is scheduled for completion in 2022. The HRS will be implemented in phases over several years starting in 2023.

BASIN-LEVEL RAINFALL AND LAKE STAGE

To be consistent with Chapter 2A of this volume, rainfall is reported for Water Year 2022 (WY2022; May 1, 2021–April 30, 2022). The Kissimmee Basin experienced below average rainfall in WY2022. Rainfall totals of 43.7 inches over the UKB and 41.9 inches over the LKB were 7.2 inches and 6.3 inches below their long-term averages, respectively. Despite overall drier conditions, operation of the S-65 water control structure was complex due to periods of heavy dry season 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 implemented in the 2021 wet season; although it did not result in a duration of floodplain inundation for the Kissimmee River comparable to the reference period, it produced a single 96-day period with bankfull discharge or greater. From early October to early November 2021, dry conditions, outflow to the Kissimmee River, and discontinuation of inflow from Lakes Tohopekaliga and Gentry resulted in a decline in stage in the Headwaters Lakes (Lakes Kissimmee, Cypress, and Hatchineha) to below 50 feet (ft) National Geodetic Vertical Datum of 1929 (NGVD29) by the beginning of the 2021-2022 dry season. Over the dry season, requests to moderate lake recession rates were implemented in Lake Tohopekaliga and East Lake Tohopekaliga to benefit fish and wildlife. A low stage target was successfully implemented for the Headwaters Lakes in late dry season and early 2022 wet season, resulting in the lakes' stages being below the usual low pool of 49 ft NGVD29 for 64 days.

LOWER KISSIMMEE BASIN

KRRP Status. July 2021 marked the completion of KRRP construction after nearly 22 miles of C-38 Canal backfilling, removal of two water control structures, installation of the S-69 Weir, and numerous additional construction efforts. This milestone sets the stage for gradual implementation of the new HRS stage regulation schedule for the S-65 water control structure. Following finalization of the last remaining land acquisitions, HRS will be incrementally implemented in several phases currently projected to start in spring 2023. The phased increments will allow successively higher stages in the Headwaters Lakes until approximately 2026, when the HRS is currently projected to be fully implemented. The objective of the HRS is to provide sufficient water storage to reestablish historical (pre-channelization) flow patterns to the Kissimmee River. The higher stages allowed by the schedule are also expected to improve littoral zone habitat in the Headwaters Lakes.

U-shaped weir and backfill at the terminus of KRRP looking upstream towards the restored part of the river.

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 PW2022. Two floodplain inundation events met the depth criterion of at least 1 ft; however, they lasted only 54 and 8 days, respectively, both far shorter than the 210-day duration criterion. Two recession events occurred with recession rates of 0.5 and 0.88 ft per 30 days. Although both were less than the maximum recession rate criterion of 1 ft per 30 days, this expectation was not considered met in PW2022 because there were two events instead of the single long recession event that was typical of pre-channelization. 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 (2001–2022). 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.

Inundated Riverwoods floodplain and the restored Kissimmee River near the Phase II KRRP restoration area.

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 on average in PW2022 than prior to construction of the project. New provisional Expectation 8 components were developed based on new continuous DO data collected from reference streams. Two out of the four provisional expectation components used to evaluate DO response were met in PW2022. With the completion of construction on the Phase II/III area, continuous DO data from two sondes located there were included in expectation calculations for the first time. Mean daily DO concentrations met the wet season (June–October) target range and the dry season (November–May) target range in PW2022. The third metric, frequency of DO concentration > 1 milligram per liter (mg/L) was 89%, which did not meet its new 98% target annually. The fourth metric, frequency of concentrations > 2.0 mg/L, was 82% and did not meet its new 95% target due to an anoxia event. A sag in DO concentration occurred in June 2020 when DO declined below 2 mg/L and stayed there for 70 days except for a short 8-day period in September in which DO rose no higher than 2.4 mg/L. An expanded network of 21 floodplain sonde sites collected continuous DO data during the 2021 wet season. This data along with additional continuous water quality parameters from two new river sondes are providing new insights into the DO dynamics of the river and floodplain.

KRREP Floodplain Vegetation Management. In the past year, herbicide applications 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). Three prescribed burns were conducted within the KRRP area, covering a total of 1,771 acres in the Oak Creek/ Starvation Slough and Fort Basinger areas. A critical emerging issue for recovery of the Kissimmee River floodplain is invasion and establishment of exotic grasses, especially West Indian marsh grass (*Hymenachne amplexicaulis*), which do not provide quality habitat and are displacing native plant species. KRREP has received new funding to adaptively implement long-term management programs to address these invasions.

KRREP Fish Studies. Winter centrarchid abundance, measured as catch per unit effort (CPUE), increased by 60% in Phase I due mostly to an increase in bluegill sunfish (Lepomis macrochirus) and other sunfish (Lepomis spp.). In Phase IV, the abundance of largemouth bass (LMB; Micropterus salmoides) increased during winter but a decline in sunfish resulted in an overall reduction of centrarchid abundance. The mean winter biomass catch rate, measured as biomass per unit effort (BPUE), increased in both phases and LMB accounted for more than 70% of the total centrarchid biomass. Limiting or preventing access to the floodplain habitat during spawning season likely has negative impacts on the river's centrarchid community. LMB commonly spawn during January–April (dry season), a period during which the floodplain has only been inundated three of the past eight years. Bluegill and other sunfish can spawn during both the dry and wet season (summer) and that extended spawning season may help them recover to some extent from the impacts of anoxic events more rapidly than LMB.

Wading Bird Abundance. Mean monthly wading bird abundance within the restored portions of the river during the 2021-2022 dry season was 25.1 ± 7.9 birds per square kilometer (km2), bringing the three-year (2019–2022) running average to 25.3 ± 5.1; not significantly greater than the restoration expectation of 30.6 birds/km2. Only two of the seven surveys (29%) in the 2021-2022 dry season recorded ≥ 30.6 birds/km2, well below the restoration expectation of at least 85%.

Roseate spoonbills in the Phase II KRRP restoration area.

Waterfowl Abundance. Waterfowl abundance during the 2021-2022 dry season was 10.0 ± 7.7 ducks/km^2, bringing the three-year (2020-2022) running average to 8.1 ± 3.1 ducks/km^2, not significantly greater than the restoration target of 3.9 ducks/km^2. Since 2001, annual duck abundance has ranged from 42.0 ± 11.2 ducks/km2 to 1.3 ± 1.3 ducks/km2 (mean for 2002-2022 = 13.6 ± 1.8 birds/km2). Two of the five monthly surveys (November and January) during winter 2021-2022 were above the restoration target of 3.9 ducks/km2, but this was not enough to bring the seasonal average above the restoration target. This dry season also did not meet the secondary restoration expectations that at least 80% of the monthly surveys will record ≥ 3.9 ducks/km2 and species richness will be ≥ 11 (three-year species total).

UPPER KISSIMMEE BASIN

Vegetation Monitoring. The District completed the fifth year of data collection in long-term vegetation monitoring plots in East Lake Tohopekaliga, Lake Tohopekaliga, and Lake Kissimmee. The plots are intended to establish baseline conditions for comparison with data collected after completion of the KRRP, which will coincide with HRS implementation.

Fisheries. The Florida Fish and Wildlife Conservation Commission (FWC) conducted electrofishing sampling to collect fish community data (fall 2021) and LMB population data (spring 2021). Community data showed a decline in gamefish on Lake Kissimmee since 2017, coinciding with Hurricane Irma. Annual relative abundance of juvenile LMB on Lake Kissimmee have also been very low following trends in submerged aquatic vegetation.

Snail Kites. Snail kite nesting effort was below average on the Kissimmee Chain of Lakes (KCOL) in 2021, attributed to kites shifting to better nesting conditions in Lake Okeechobee and southern impoundments. Nesting success on East Lake Tohopekaliga may have been affected by large stage reversals due to unseasonable rainfall in early spring. Statewide nesting effort was much higher than the past two years.

Conducting apple snail, the preferred food of the snail kite, surveys in Riverwoods floodplain. Inset: closer view of survey team.

Alligators. FWC alligator monitoring showed very high populations on Lakes Tohopekaliga, Kissimmee, and Hatchineha for the 2021 sampling period compared to the start of sampling in the 1990s. Populations have been stable with slight increases over the last few years. East Lake Tohopekaliga has a very small alligator population (106 estimated individuals in 2021) 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.

American alligator in the KRRP Phase I restored area.

INTRODUCTION

SFWMD continued 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 Southern 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 KRREP evaluations includes analyses of newly available data from studies of hydrology, DO, vegetation management, fish, wading birds, waterfowl, and lake vegetation. This subset of restoration evaluation studies assesses the level of response of critical ecosystem components to physical restoration under Interim Period (pre-project completion) hydrologic conditions based on new data and analyses that have not been reported in previous *South Florida Environmental Report* (SFER) – *Volume I* chapters. Results from these studies provide information for sound water management decision making as the recovery of the ecosystem progresses and will help evaluate project success and guide water management decisions.

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, these regions 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 because of earlier channelization of the river.

This chapter is an update to Chapter 9 of the 2022 SFER – Volume I (Koebel et al. 2022). Its purpose is to report new results from Kissimmee Basin monitoring studies that were active in PW2022, 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 PW2022, as well as construction and management activities and the status of various other projects throughout the Kissimmee Basin.

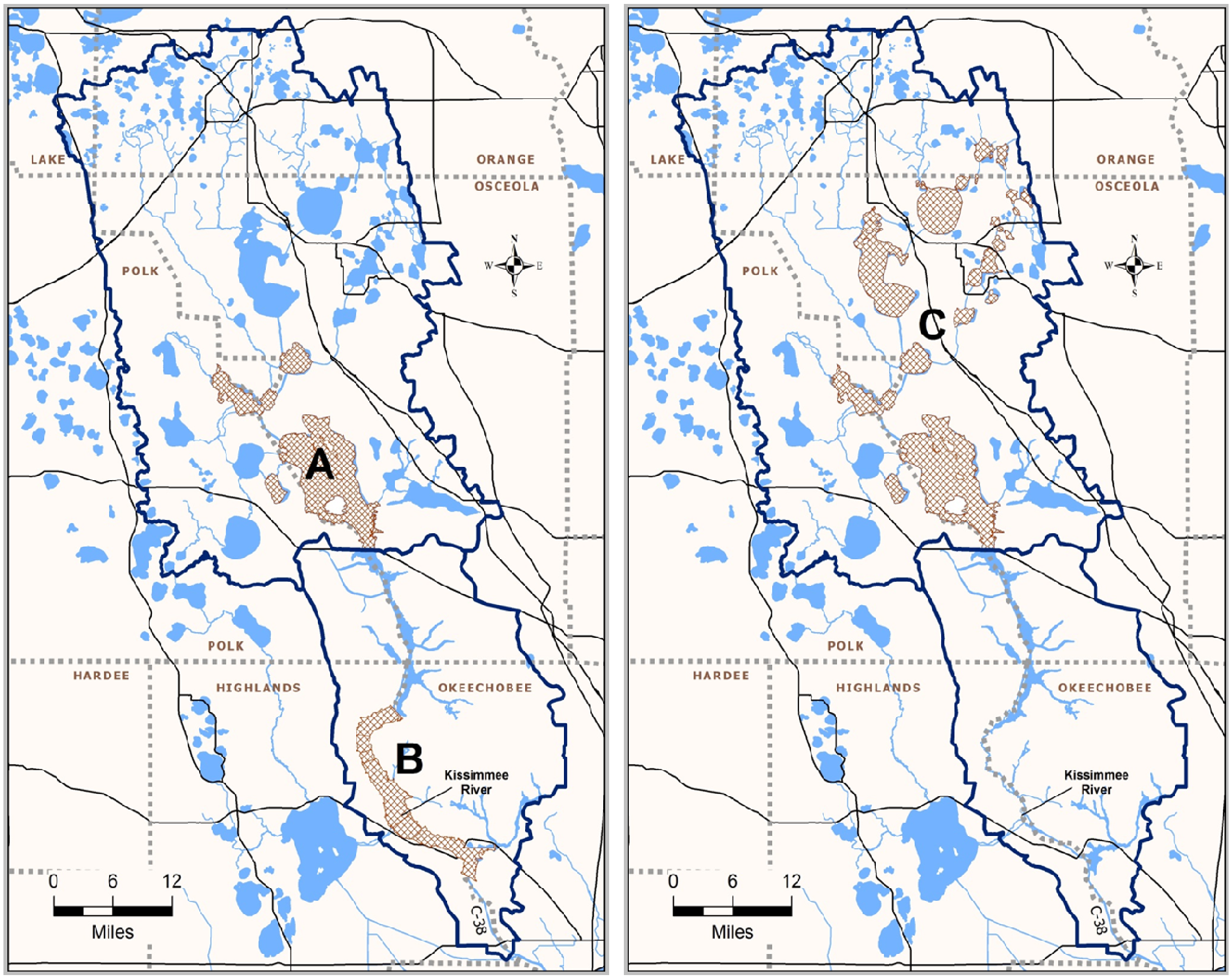


Figure 9-1. Geographic scopes (colored, hatched areas on maps) of major initiatives in the Kissimmee Basin including the (A) Headwaters Lakes components of the KRRP, (B) KRRP, and (C) KCOL and Kissimmee Upper Basin Monitoring and Assessment Project.

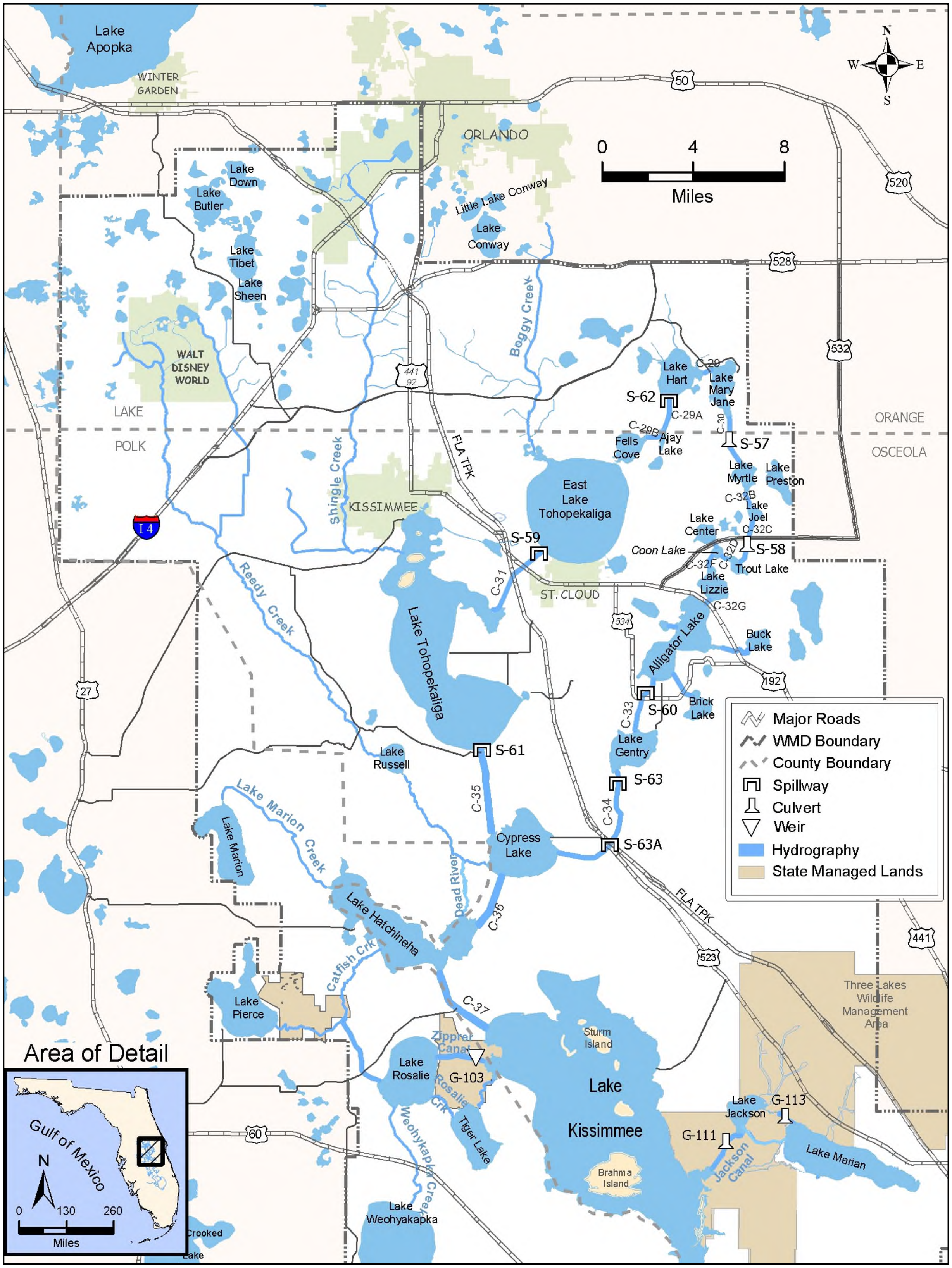


Figure 9-2. Map showing the major features of the Upper Kissimmee Basin (UKB). (Note: WMD –Water Management District.)

Figure 9-3. Map showing the major features of the Lower Kissimmee Basin (LKB) with completion dates of construction phases and other construction work. (Note: WMD –Water Management District).

KISSIMMEE RIVER RESTORATION PROJECT UPDATE

KRRP construction was completed in July 2021. The new regulation schedule (HRS) for the S-65 water control structure will be incrementally implemented in several phases currently projected to begin in 2023. These increments will successively raise maximum permissible stages in the Headwaters Lakes over several years. Once fully implemented (currently projected for 2026), the HRS will allow lake water levels to rise up to 1.5 ft higher than the current S-65 Interim Schedule and will increase the water storage capacity of Lakes Kissimmee, Hatchineha, Cypress, and Tiger by approximately 100,000 acre-feet (ac-ft) to allow sufficient storage of water to more closely approximate the historic flows needed for restoration of the Kissimmee River and its floodplain wetlands; the HRS is also expected to improve littoral zone conditions in Headwaters Lakes due to the higher water levels it allows. Ninety-nine percent of the land in the UKB that will be affected by the higher water levels has been acquired, and all projects needed to increase the conveyance capacity of UKB canals and structures are in place or in the final stages to accommodate the larger storage volume. The few remaining land acquisitions are expected to be finalized in 2023.

The HRS is fundamentally different from previous regulation schedules. Releases from S-65 will not only be based on the water level in the Headwater Lakes approaching the flood control regulation line but also to meet flow targets for the reconstructed portion of the Kissimmee River. The acquisition of lands surrounding the lakes and the raising of the maximum regulation stage from 52.5 to 54.0 ft NGVD29 was precisely to be able to store more water in the Headwater Lakes for release to the Kissimmee River during the dry season and to meet the KRREP expectations of delivering variable and continuous flow downstream at volumes and frequencies comparable to the pre-channelized system. Users of the lakes for recreational and commercial purposes may experience water levels that are different from previous years and will likely observe discharge from S-65 during times of the year when it previously was uncommon.

Construction components for the entire KRRP in the LKB included (1) acquiring 65,603 acres (ac) of land in the LKB and 36,612 ac of land in the UKB, (2) backfilling approximately 22 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 S65B 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 was implemented in four construction phases (**Figure 9-3**) and completed 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, after some weather-related setbacks, was completed in 2021. The S-69 weir that will serve as the terminus of the backfilled sections of canal was also completed in 2021.

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 (Interim Schedule) 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 (when stage is above the regulation line or Zone A) are not needed. Zone B is used to maintain flow in the reach of the reconstructed river channel throughout the year and to allow seasonal variability in flow. Environmental releases under this Interim Schedule began in July 2001 after Phase I construction was completed and lake levels began to rise following a drought in 2000–2001. 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.

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 Recon-structed (miles)	Connector Channels (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	2.9	1.0	13.9	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	0	0	3.9	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	4.4	0.2	5.9	4,184	1,406	Upstream of Phase IVA in Pool B (upper limit near location of Weir #3)
4	Reaches 2 and 3 (Phases II & III) and S-69 Weir Project Areas	2015–2021 (complete)	8.5	3.7	0.2	16.4	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**	**11.0**	**1.4**	**40.1**	**24,963**	**12,398**	

CONSTRUCTION STATUS

All backfilling and other mandated construction work for the KRRP was completed by July 2021 and was announced in a ribbon-cutting ceremony at the river on July 29, 2021. The two final contracts completed in 2021 were Reach 2 Backfilling and the S-69 weir (**Figure 9-4**). **Table 9-2** provides brief descriptions of these final construction activities. A complete list of contracts can be found in Koebel et al. 2017. The Reach 2 Backfilling contract was originally awarded by USACE in 2016. Work in Reach 2 began in January 2017 and was completed in 2019, although two major storm events including Hurricane Irma in 2017 resulted in extremely high discharge and flooding throughout the Reach 2 construction area, causing severe erosion of the recent backfill. The high water and discharge associated with the storm events also caused erosion in the Reach 3 restoration area, which had been previously completed in 2016. Both areas were surveyed for erosion and evaluated for repair. Repairs consisted of backfilling and regrading of erosion damage areas. Armoring was also installed at highly susceptible areas for future erosion, such as where backfill terminates at a river channel crossing. Repair work in both Reach 2 and Reach 3 were completed July 2021.

During the final phases of construction repair work in Reach 2 and 3, SFWMD staff discovered two areas of concern that were left out of the original KRREP construction plans. The first aera of concern is a hidden berm on the downstream side of US Highway 98 running parallel to the highway that will restrict sheet flow of the floodplain as water flows downstream through the previously constructed culverts under the highway. A contract will be awarded in 2022 and work is mandated to be completed within one year. The second area of concern is a berm and ditch further downstream of the US Highway 98 bridge in the Reach 3 construction area. This berm runs north to south along the western edge of the floodplain, restricting floodplain expansion and potentially conveying water directly into the nearby residential boat basin in the Hidden Acres community. Contracts were awarded in 2022 to degrade portions of the berm and plug sections of the ditch that parallels the berm. Both contracts are scheduled to be completed in 2023.

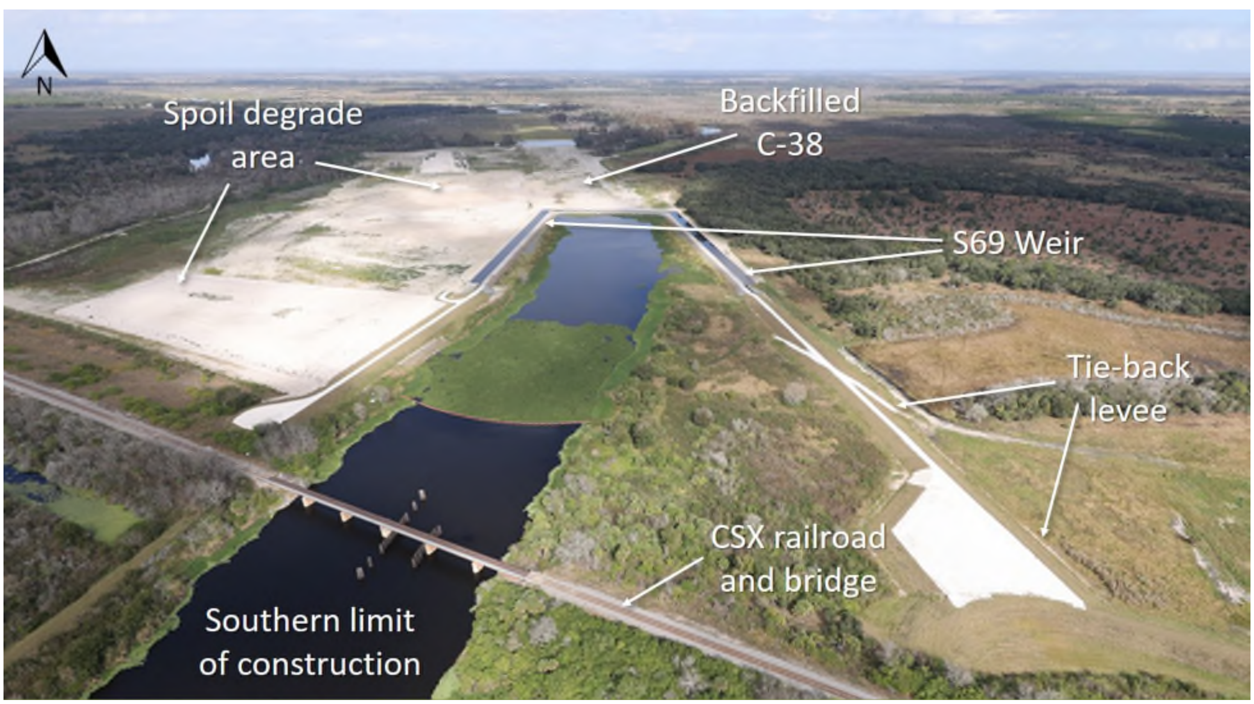


Figure 9-4 S-69 weir completed construction features. Photo by Brent Anderson on January 4, 2022.

Table 9-2. Final KRRP construction activities. 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 dredged, 6.5 miles of the C-38 Canal backfilled, and the S-65C structure removed.	Completed	January 2017	July 2021	$26.1 million
	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.	Completed	November 2018	July 2021	$15–$25 million

Note: Dates and costs do not include repair costs for erosion damages in Reach 2 and 3 Backfilling caused by Hurricane Irma.

KISSIMMEE BASIN HYDROLOGIC CONDITIONS AND WATER MANAGEMENT IN PLANNING WINDOW 2021-2022

This section describes hydrologic conditions in the UKB and LKB and their relationship to water management activities in Planning Window 2021-2022 (PW2022; June 1, 2021–May 31, 2022). The planning window is used in this section and the following *Lower Kissimmee Basin – 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. Lake regulation schedules in the UKB reach their low pool stages on June 1, coincident with the official beginning of the wet season. This section focuses on the timing and quantity of rainfall in PW2022 in the Kissimmee Basin, environmental recommendations made 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 or from, and water levels in, the Kissimmee River and its floodplain (**Figure 9-3**) within the KRRP footprint. Operation of these structures is intended to advance 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 (for an example see **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 will be followed by phased implementation of the HRS, currently projected to last from 2022 to 2025. Full implementation of the HRS, projected for 2026, is expected to provide additional water storage for discharge to the Kissimmee River and its floodplain. However, even during phased implementation, coordinated and flexible water management for the remainder of the Interim Period can realize ecological benefits for the KRRP before full implementation of the HRS.

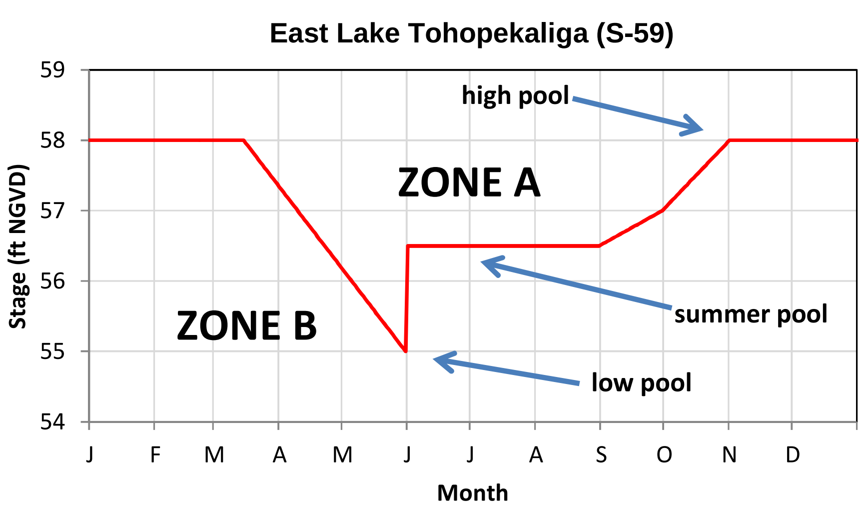


Figure 9-5. The regulation schedule for East Lake Tohopekaliga is an example of the regulation schedules for lakes in the UKB. The diagram shows the regulation line (red) that separates Zone A (above the line) from Zone B (below the line). When lake stage is in Zone A, releases are mandatory for flood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

Via structures 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 inflow, rainfall, and runoff into the lakes offsets the volume of water released. Thus, discharge operations at S-65 and S-65A affect both stage in the Headwaters Lakes and flow to and stage in the Kissimmee River. 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. Operation of structures for lake groups north of the Headwaters Lakes indirectly affect water management operations for the KRRP because they affect stage in the Headwaters Lakes; but northern lake groups are generally not operated to raise stage in the Headwaters Lakes for the purpose of meeting flow targets to the Kissimmee River.

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 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 relatively small but localized rainfall events can cause water levels in Pool A to rise rapidly, which can necessitate a reduction in the inflow from 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 rate of change for discharge increases for KRREP, and similarly for rates of decrease. Because S-65A is the primary source of flow to the KRRP, these constraints to its operation can have major consequences for restoration. If a rapid increase in discharge from S-65A occurs, it results in a rapid rise in water levels in the Kissimmee River; when this happens after a period of low discharge and dry floodplain conditions, the resulting high rate of depth increase and floodplain inundation can result in a "crash" in DO due to reduced photosynthesis and increased biochemical oxygen demand (BOD), which can cause a fish kill. This lack of storage in Pool A will continue to pose a challenge for water management now that construction for 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 depends on other factors affecting water management decisions, including endangered snail kite (*Rostrhamus sociabilis*) nesting activity in the KCOL and Kissimmee River, concerns about water levels or flows in downstream ecosystems (Lake Okeechobee and St. Lucie and Caloosahatchee estuaries), navigation and resident concerns in the LKB and UKB, and flood control. 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, which often involves establishing rates of stage decrease in the dry season. In recent years, especially PW2021, river flow rates have been held low to accommodate KRRP construction activities (now complete), which also affected how often and the extent to which the floodplain was inundated.

DISCHARGE PLANS IN INTERIM AND FUTURE OPERATIONS

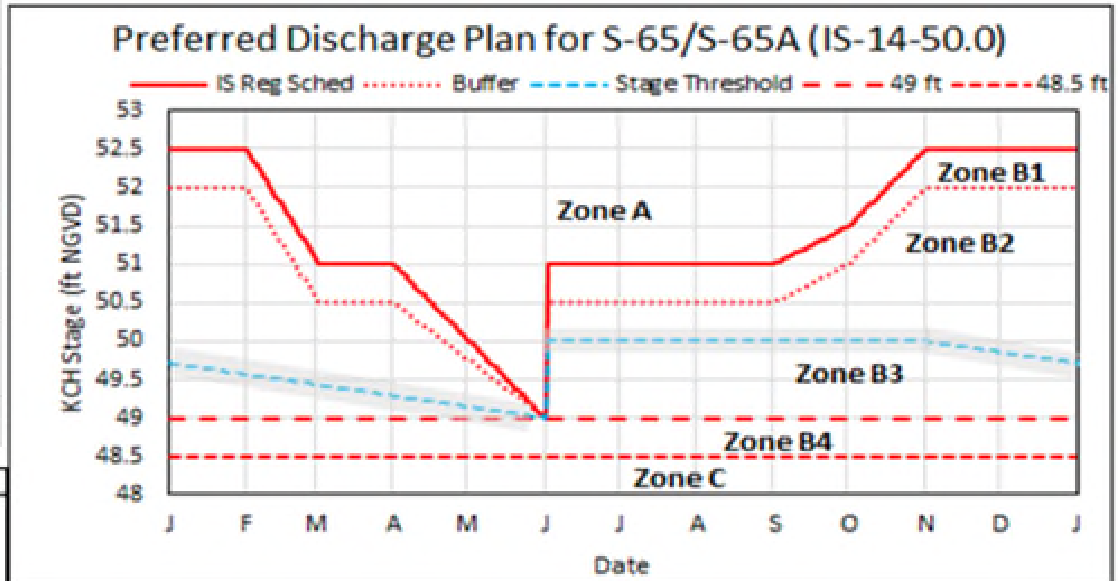
Several variations of discharge plans under the Interim Schedule (IS) have been partially implemented in recent years to improve the duration and continuity of floodplain inundation in the Kissimmee River during the Interim Period. These plans superimpose discharge specifications linked to stage in the Headwaters Lakes on the pre-established Interim Schedule flood regulation line. These discharge plans are called IS-14-50 (the plan name refers to Interim Schedule – 1,400-cfs minimum discharge while stage is above 50 ft NGVD29 in the Headwaters Lakes). The most recent configuration of IS-14-50 is shown in **Figure 9-6**. See the *2021 Wet Season Water Management Outcomes* subsection below for additional information. The approach has been or will be adapted for future operations under the first increment of HRS, any additional phased increment(s), and is being used in planning for implementation of HRS itself.

Stage and Discharge Guidance for 2019-2020.

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.

2019-2020 Discharge Plan S-65/S-65A



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

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.

Revised 5/16/2019

Figure 9-6. The IS-14-50.0 discharge plan for wet season 2021. The table insert in the lower left recommends limits on rates of discharge increase and decrease at S-65 and S-65A. The plan shown uses the IS Reg Sched line. 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. (Notes: KB – Kissimmee Basin, KCH – Headwaters Lakes, and Toho – Tohopekaliga. Source: KB-2021-Wet Season Planning Presentation on May 13, 2021.)

Sustained floodplain inundation almost fully depends on discharge from S-65 through S-65A because most of the volume of water passing through the KRRP originates in the UKB and water levels cannot be maintained on the sloping Kissimmee River floodplain by the downstream water control structure (previously S-65C, now S-65D) (Anderson 2014). Prior to use of the IS-40-50 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 or to minimize flow to the south. The undesirable effect of such operations for the Kissimmee River, clearly visible in stage/discharge hydrographs (e.g., **Figure 9-7**), was sudden inundation of the floodplain followed by rapid termination of the flood event as discharge was reduced below river channel bankfull discharge (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 duration 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). In the wet season, such "flashy" operations are a substantial factor in DO declines

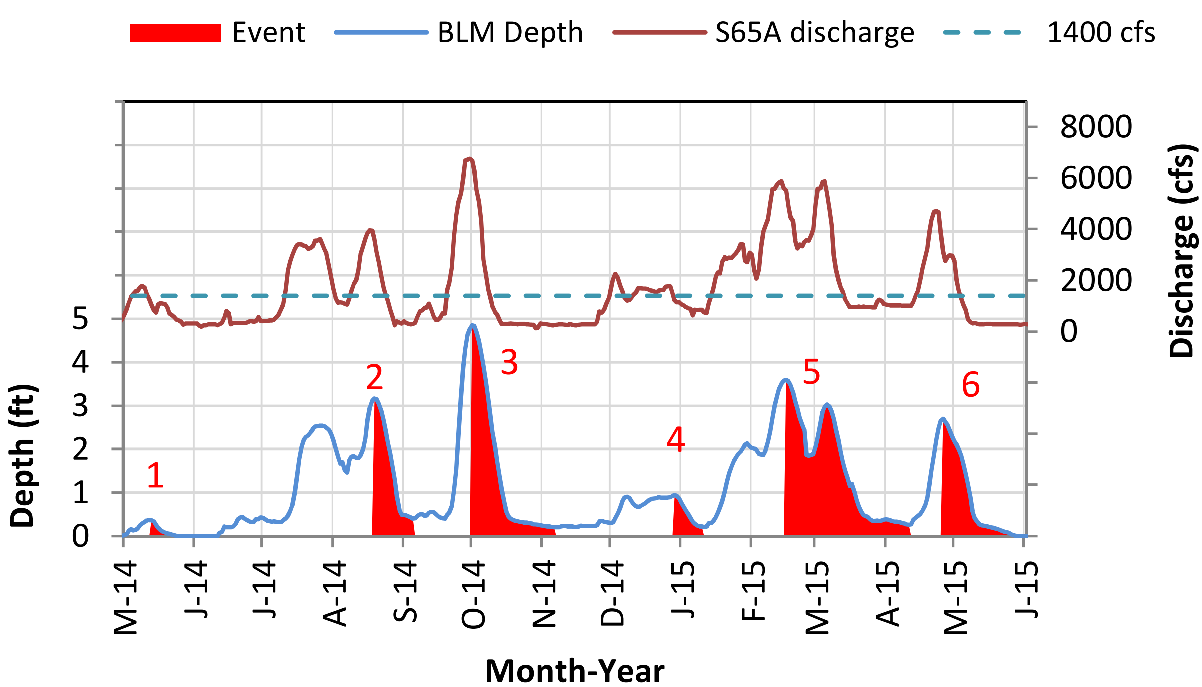


Figure 9-7. An example from PW2015 of unsuitable operations for Kissimmee River restoration. In this case, large, rapid increases in S-65A flood control levels of discharge driven by the regulation line in the Headwaters Lakes were followed by rapid reductions in discharge to maintain high stage in the 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 9-6** 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 other operational requirements (e.g., flood control) balanced against the need to approximate historic conditions for hydrologic restoration.

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 9-6,** 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/d)	
Discharge (cfs)	Maximum Rate of Increase (cfs/d)	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

The issue of DO sags during summer months in the Kissimmee River, which is thought to be related to the rate of increase in flow and water depth, has highlighted concerns that the current rates of change are too fast. Comparing the currently recommended rates to the pre-regulation system, 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 (which 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, while discharge was less than 1,000 cfs; thus, exceeding the recommended maximum rates of discharge increase. Both periods of increase 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.

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 HRS implementation.

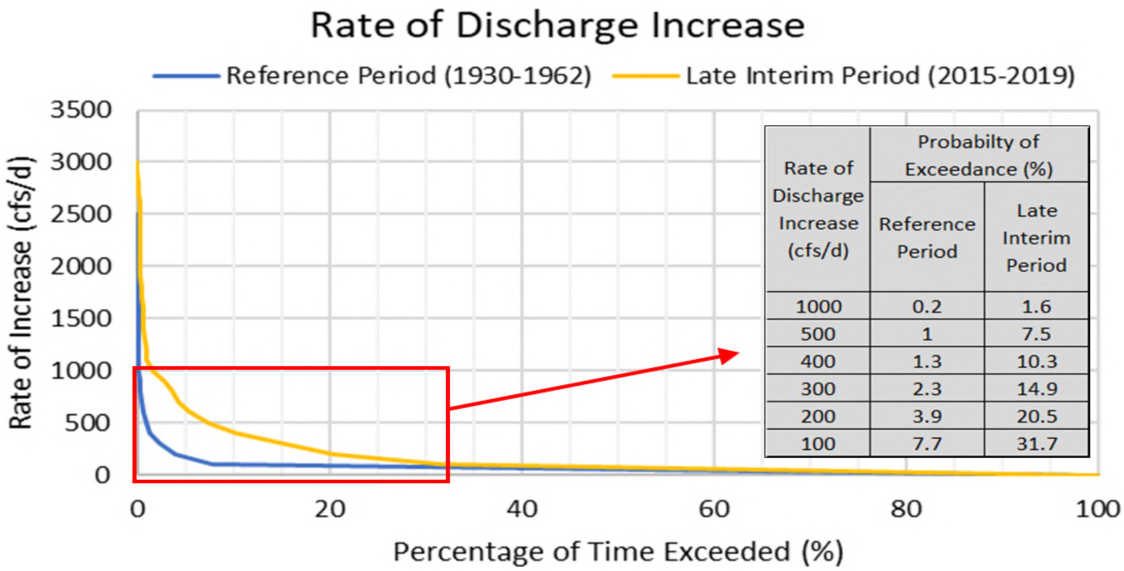


Figure 9-8. Exceedance curves for rate of increase in discharge in the Reference (1930–1962) and Late Interim (2015–2019) periods.

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.

Hydrology in the KRRP Phase I floodplain is complex; its dynamics were characterized for PW2022 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 PW2022 and Over the Interim Period* subsection of the *Lower Kissimmee Basin – Kissimmee River Restoration Evaluation Program* section below). 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 of five historically BLM sites 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 complete and historic hydrology is reestablished (see *Hydrology* subsection of the *Lower Kissimmee Basin – Kissimmee River Restoration Evaluation Program* section later in 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.

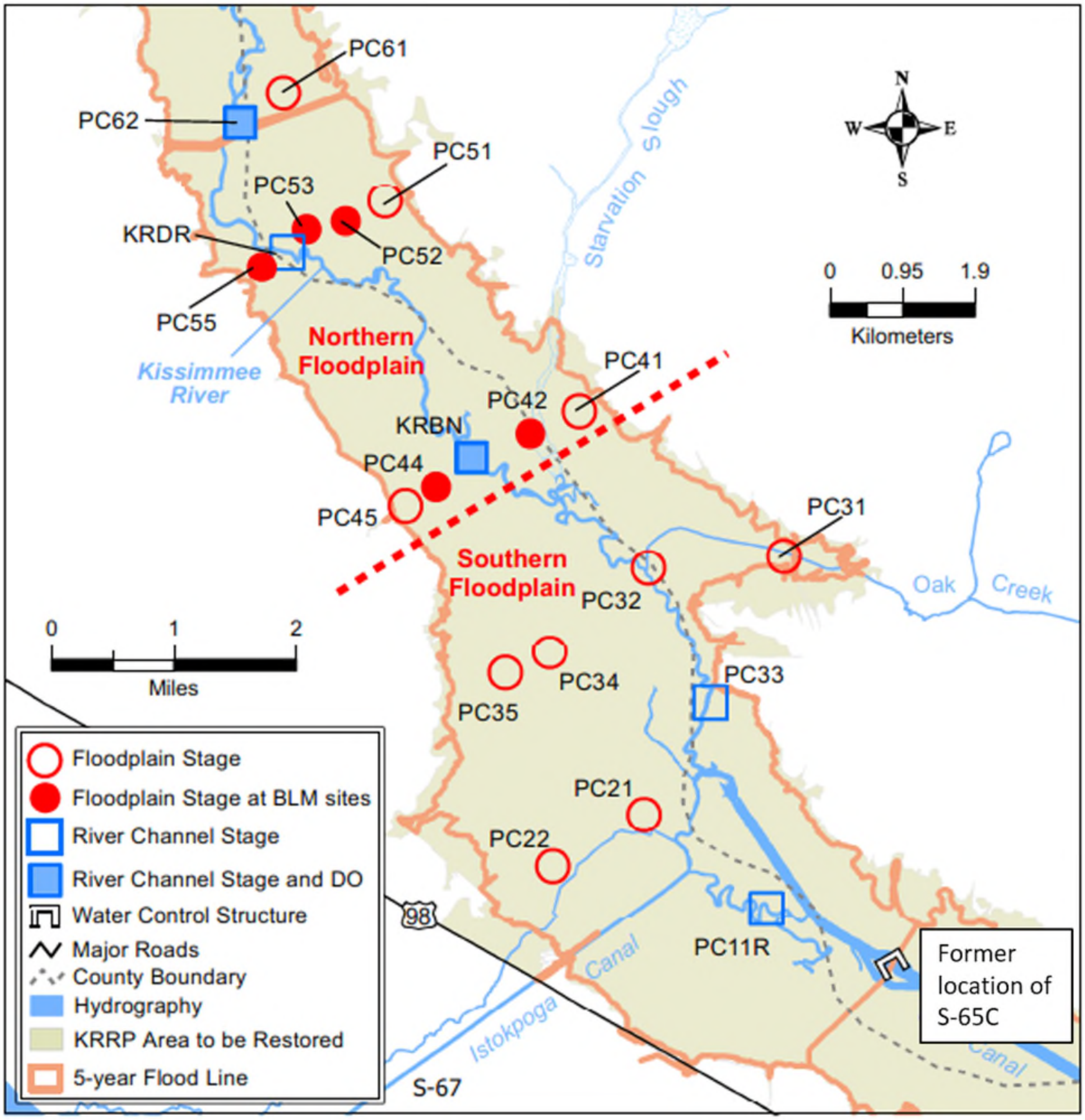


Figure 9-9. Locations of hydrologic monitoring sites in Pool C used to guide operations and evaluate restoration expectations.

RAINFALL

Total rainfall for PW2022 was below long-term averages with totals of 46 inches (90% of average) and 44 inches (90% of average) in the UKB and LKB, respectively. In the UKB, monthly rainfall totals were at or below average except for November, March, and April resulting in wet and dry seasons totals that were 87 and 94% of the long-term averages (**Figure 9-10**). In the LKB, monthly rainfall totals exceeded long-term averages in July, September, and November resulting in rainfall totals that were 100% of the long-term average for the wet season and only 71% for the dry season.

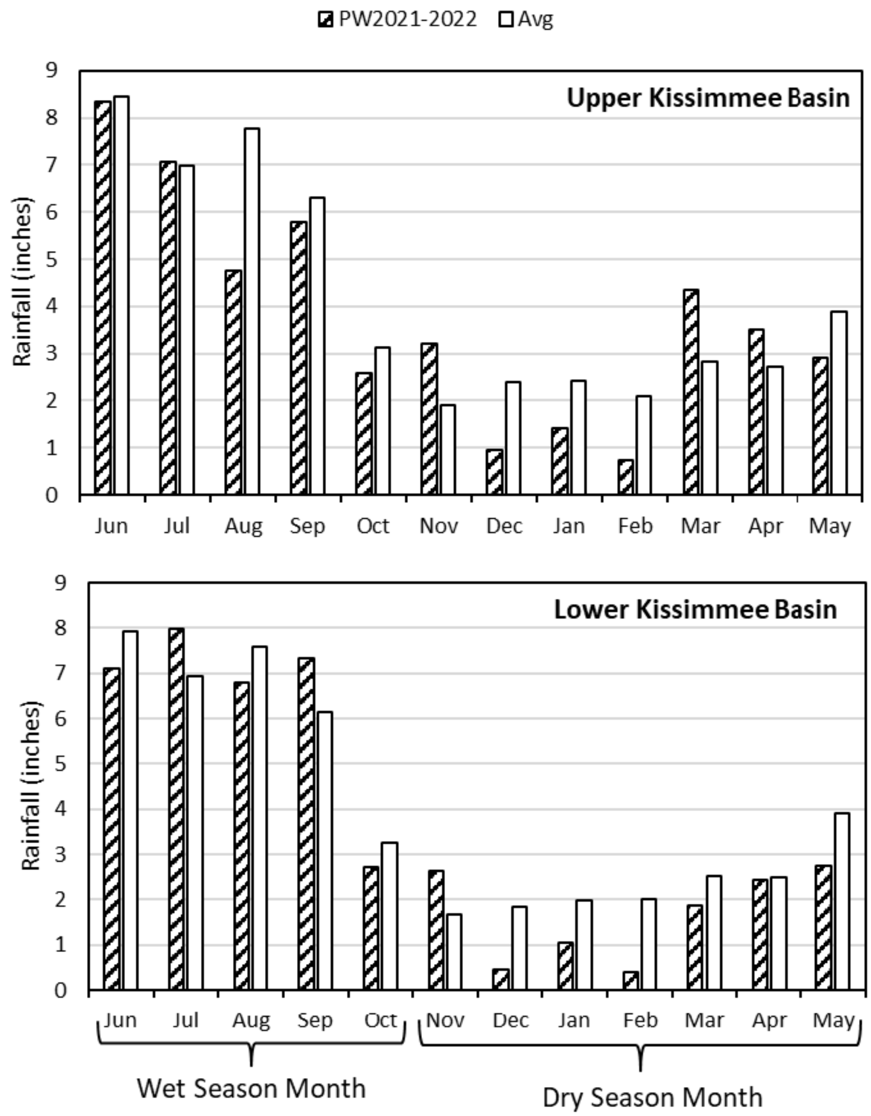


Figure 9-10. Monthly rainfall for PW2022 and average (Avg) rainfall (1991–2020) in the UKB (top panel) and the LKB (bottom panel).

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 in 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 can 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.

2021 Wet Season Water Management Recommendations

- Use the IS-14-50 discharge plan through the 2021 wet season. The discharge rate of change limits for S-65/S-65A may be adjusted for individual events after consultation with KRREP staff.
- To the extent possible, attempt to control the ascension rate in East Lake Toho, Lake Toho, and Lakes Kissimmee-Cypress-Hatchineha to be less than 0.25 ft/7 days (d) during the June 1–August 15 window.
- Continue to follow the USACE request to hold S-65A discharge below 800 to 900 cfs to facilitate construction for the KRRP.

2021 Wet Season Water Management Outcomes

IS-14-50.0 Discharge Plan

Note that operations in part of PW2022 were affected by a discharge limit requested by USACE to facilitate KRRP construction in the Pool D area, and an associated temporary deviation that raised the flood regulation line in the later months of the preceding dry season in the Headwaters Lakes. The 2021 wet season thus began with stage in the Headwaters Lakes above 50 ft NGVD29 due to the temporary deviation (**Figure 9-11B**). Under the IS-14-50 discharge plan, S-65A discharge would have been increased to 1,400 cfs (**Figure 9-6**) at 50 ft NGVD29, but discharge was held at or below 800 to 900 cfs until July 6, 2021, which allowed the completion of construction. Headwaters Lakes stage began to rise in response to approximately average rainfall totals for June and July in the UKB (**Figure 9-10**). S-65A discharge was increased gradually to slow the rise in stage. S-65A discharge was maintained at or above 1,400 cfs for 96 continuous days (July 16–October 19, 2021). Discharge of 1,400 to 2,000 cfs for Kissimmee River floodplain inundation was sufficient to keep the Headwaters Lakes stage close to the regulation schedule line because of below average UKB rainfall totals for August and September, and the absence of larger discharges for flood control kept BLM Depth < 2 ft (**Figure 9-11C**). Continued low rainfall in October caused Headwaters Lakes stage to decline more than 1.5 ft, resulting in a reduction in S-65A discharge from 1,400 cfs to minimum discharge (300 cfs) over a 37-day period (October 20—November 25, 2021); this resulted in an average rate of change of -30 cfs/day for S-65A discharge and -0.14 ft/7 days for BLM Depth.

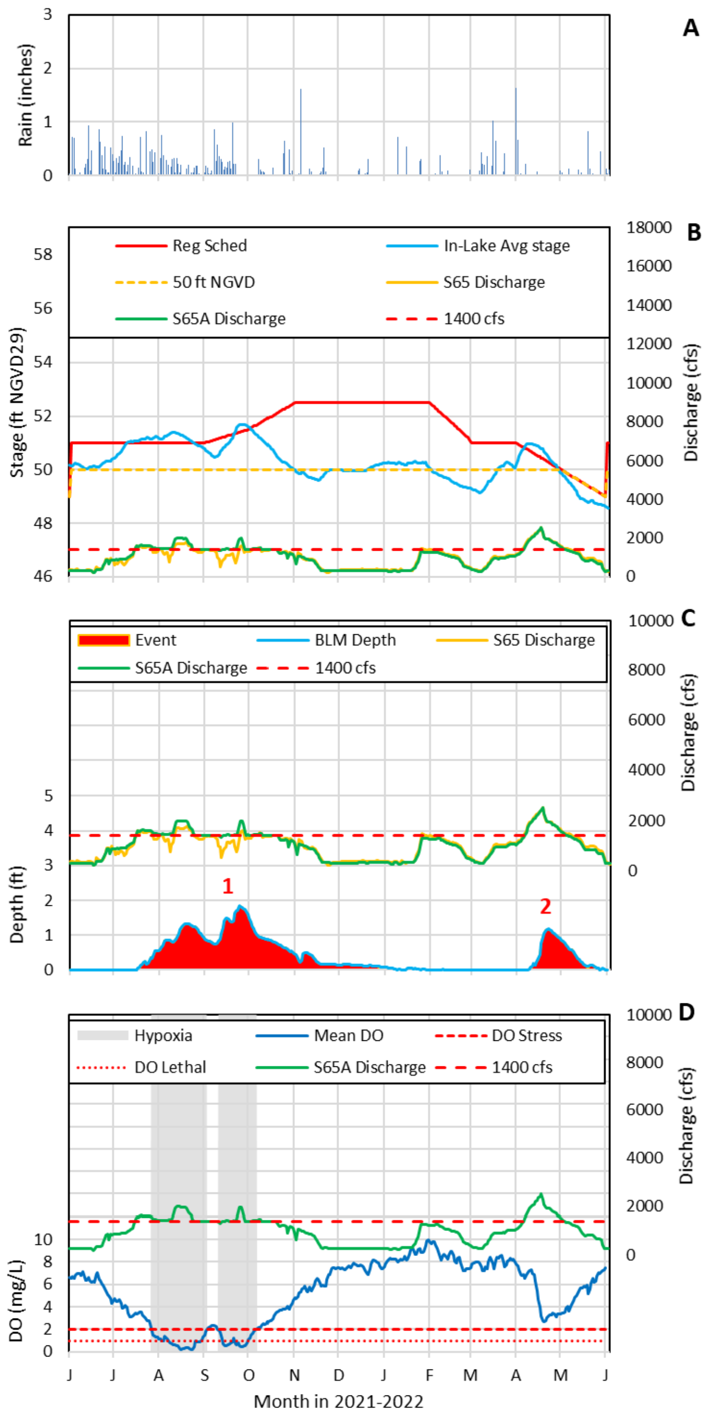


Figure 9-11. A) Basin rainfall in the Headwaters Lakes, (B) regulation (Reg) schedule, lake stage (In-Lake Avg stage), and discharge from the Headwaters Lakes; (C) BLM Depth at five stations (PC52, PC55, PC53, PC44, and PC42) in the northern floodplain where BLM occurred pre-channelization and is expected 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 PC62, PC33, KRBN, PD62R, PD42R, and discharge at S-65A during PW2022. Red numbers in Panel C identify two floodplain flood events that are described in the text. See **Figure 9-9** above for locations of hydrologic monitoring sites and the *Hydrology* subsection of the *Lower Kissimmee Basin – Kissimmee River Restoration Evaluation Program* section for more information.

Wet Season Floodplain Inundation

A single floodplain inundation event (BLM Depth > 0.1 ft) occurred in the 2021 wet season (**Figure 9-11C**), lasting for 162 days (July 19–December 27, 2021). BLM Depth varied over this event with a maximum of 1.84 ft on September 24, 2021 and was at least 1 ft for 54 days (August 14–October 6, 2021) although depth dipped below 1 ft but not below 0.74 ft for 12 days (August 30–September 11, 2021) and discharge remained above 1,400 cfs. S-65A discharge was reduced from 1,400 to 300 cfs over 36 days (October 20–November 24, 2021). During the 36-day ramp down of S-65A discharge from 1,400 to 300 cfs, BLM Depth declined from 0.75 to 0.17 ft or at a rate of 0.11 ft/week, which is within the preferred range of recession rates used for lakes in the region (0 to 0.18 ft/week).

Wet Season Dissolved Oxygen

Two periods of anoxia (DO < 1 mg/L) occurred during the 2021 wet season (**Figure 9-11D**). The first lasted 22 days (August 8–29, 2021) during which DO was as low as 0.20 mg/L. The second event occurred two weeks later and lasted 17 days (September 14– 30, 2021). During this event, DO was as low as 0.44 mg/L. Further details are provided in the *Dissolved Oxygen* and *Impact of the 2021 Anoxic Events on Fish in the Kissimmee River* subsections within 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, 2021, window as the difference between current stage and stage 14 days prior for East Lake Tohopekaliga, Lake Tohopekaliga, and the Headwaters Lakes. Stage ascension rates exceeded the preferred rate of 0.5 ft/14 d on 8 days in East Lake Tohopekaliga (**Figure 9-12**), 14 days in Lake Tohopekaliga (**Figure 9-13**), and 10 days in the Headwaters Lakes (**Figure 9-14**).

Most exceedances occurred early in the 2021 wet season, resulting from average rainfall in the UKB during June and July (**Figure 9-10**). Such exceedances were to be expected given the rainfall because previous analyses have shown that attempts to control early wet season ascension rates can**—**and often will**—**be overwhelmed by rainfall, and ascension rates exceeding 0.5 ft/14 days occurred frequently prior to regulation (Koebel et al. 2016).

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 rates in those lakes so that they did not greatly exceed the preferred maximum ascension rate (**Figures 9-12** and **9-13**). These releases, in turn, impacted the ascension rate in the Headwaters Lakes. Releases from the Headwaters Lakes were constrained by the 900-cfs limit on S-65A discharge for construction. Once releases from the Headwaters Lakes to the Kissimmee River were increased to 1,400 cfs (**Figure 9-11B**) per the IS-14-50.0 discharge plan (**Figure 9-6**), the releases were adequate to keep the stage ascension rate in the Headwaters Lakes below the preferred maximum rate (**Figure 9-15**).

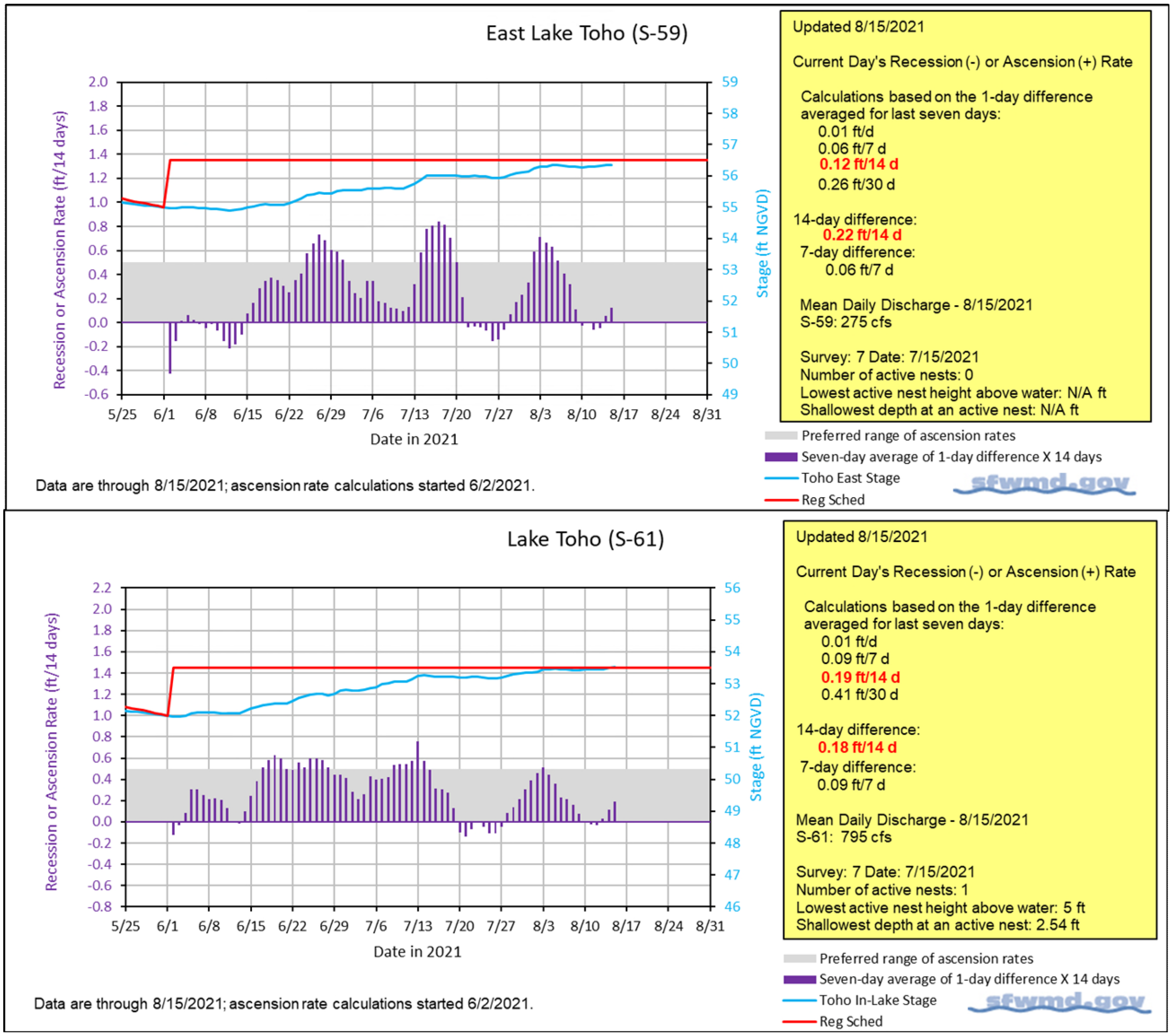


Figure 9-12. Ascension rates in East Lake Tohopekaliga and Lake Tohopekaliga during the 2021 wet season.

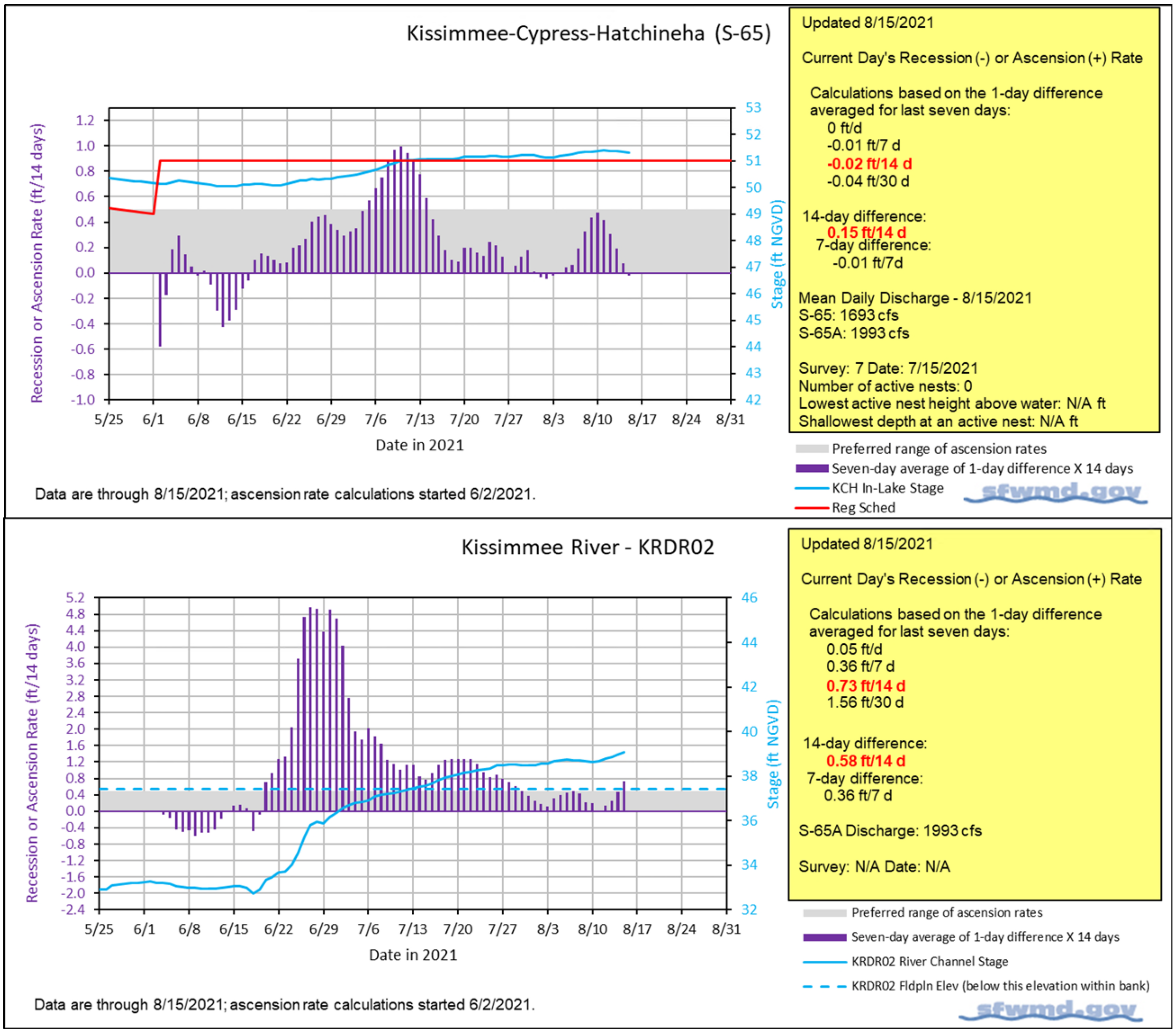


Figure 9-13. Ascension rates in the Headwaters Lakes and the Kissimmee River (stage monitoring station KRDR02) during the 2021 wet season.

2021-2022 Dry Season Water Management Recommendations

- Reduce stage in Lake Tohopekaliga to 54.5 ft NGVD29 by January 14, 2022, in preparation for managed stage recessions for snail kite nesting season. Begin managed stage recessions for snail kite nesting season in East Lake Tohopekaliga and Lake Tohopekaliga on January 15, 2022. Maintain stage recessions in East Lake Tohopekaliga, Lake Tohopekaliga, and the Headwaters Lakes to stay below the preferred maximum rate of 0.18 ft/7 d.
- Adjust discharge at S-65/S-65A using the discharge rate of change limits in the IS-14-50 discharge plan. The discharge rate of change limits for S-65/S-65A may be adjusted for individual events after consultation with KRREP staff.
- If possible, lower stage in the Headwaters Lakes to < 49 ft NGVD29 and remain there for 60 or more days.

2021-2022 Dry Season Water Management Outcomes

Lake Stage Recessions

In preparation for managed stage recessions for snail kite nesting season, stage in Lake Tohopekaliga was lowered from 54.90 ft NGVD29 on December 17, 2021, to 54.5 ft NGVD29 by January 12, 2022 per request from USFWS and FWC. In East Lake Tohopekaliga and Lake Tohopekaliga, stage recessions began on January 15, 2022, as requested by USFWS and FWC, with the lake stages at 57.90 and 54.49 ft NGVD29, respectively; both recessions ended on June 1, 2021, at approximately the low pool of the regulation schedules (**Figures 9-14** and **9-15**). The resulting recession lines had target rates of -0.15 ft/7 d in East Lake Tohopekaliga and -0.13 ft/7 d in Lake Tohopekaliga. Managed recessions were steady in both lakes with recession rates less than the preferred maximum of 0.18 ft/7 d for 65% of the time in East Lake Tohopekaliga and 83% in Lake Tohopekaliga. The higher percentage of time that Lake Tohopekaliga did not exceed the preferred maximum recession rate was likely due, in part, to having lowered stage before the recession began. East Lake Tohopekaliga had small stage reversals of 0.26 ft in early March and 0.37 ft in early April; Lake Tohopekaliga also had small reversals of 0.24 ft in early March and 0.28 ft in early April.

IS-14-50.0 in the Dry Season and Recession in the Headwaters Lakes

In the 2021-2022 dry season, the Headwaters Lakes were managed with the IS-14-50.0 discharge plan rather than a fixed recession line like East Lake Tohopekaliga and Lake Tohopekaliga. As recessions began in East Lake Tohopekaliga and Lake Tohopekaliga, their outflows (and unseasonably high rainfall in March and April) caused stage to rise in the Headwaters Lakes above the regulation schedule; discharge was increased from the Headwaters Lakes to limit the rise in lake stage and begin a decline to the low pool (49 ft NGVD) by June 1 as required by the regulation schedule (**Figure 9-14**). The increase in S-65A discharge was limited to 1,300 cfs to avoid causing a reversal on the floodplain that could disrupt wading bird foraging by dispersing their prey over a larger area. S-65A discharge was increased slowly at an average rate of 50 cfs per day.

At the start of dry season, FWC and the District began to explore the possibility of lowering stage in the Headwaters Lakes to 48.0 ft NGVD29 by April 1 and to hold at that stage for the remainder of the dry season (~60 days) to benefit littoral emergent vegetation (Kissimmee Grass, *Paspalidium geminatum*). The target elevation of 48 ft NGVD29, however, is outside the range of normal operations for the Headwaters Lakes, and the request would have required a temporary deviation from USACE to continue flow after stage declined below 48.5 ft. Because this authorization had not been obtained, the operation was not pursued further. In addition, modeling indicated that had minimum flow been continued after stage declined to 48 ft, without additional inflow from East Lake Tohopekaliga and Lake Tohopekaliga, stage would have continued declining to unacceptable levels. As a compromise for the benefit of the Headwaters Lakes, the

District planned to attempt to lower stage in the Headwaters Lakes below 49 ft NGVD29, conditions permitting, which might be possible under existing authorization without discontinuing flow to the river. This period of low stage would provide benefits for vegetation in the Headwaters Lakes and might allow the District to continue at least minimum flow (300 cfs) to the Kissimmee River.

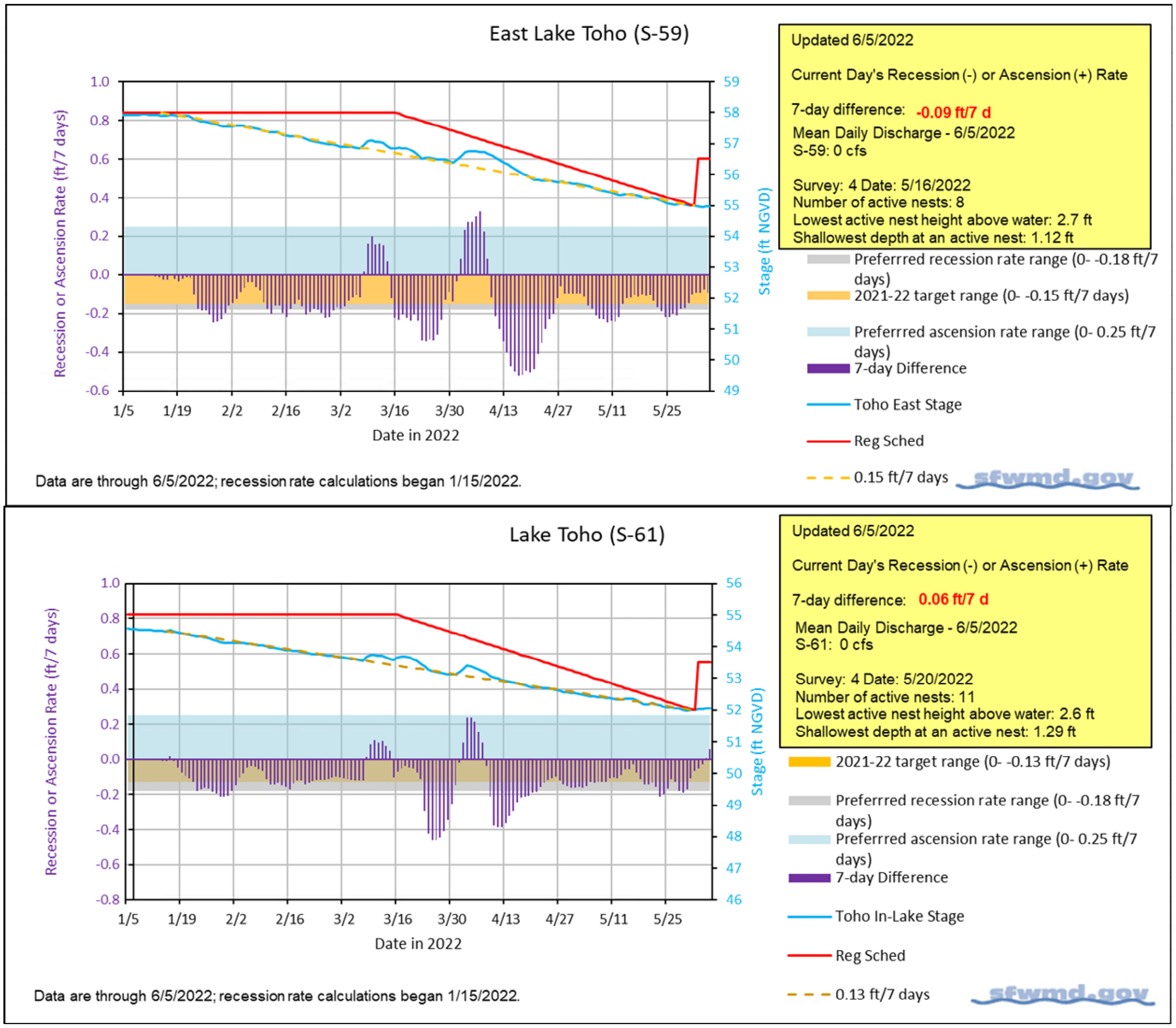


Figure 9-14. Recession rates during the 2021-2022 dry season in East Lake Tohopekaliga with S-59 discharge and Lake Tohopekaliga with S-61 discharge.

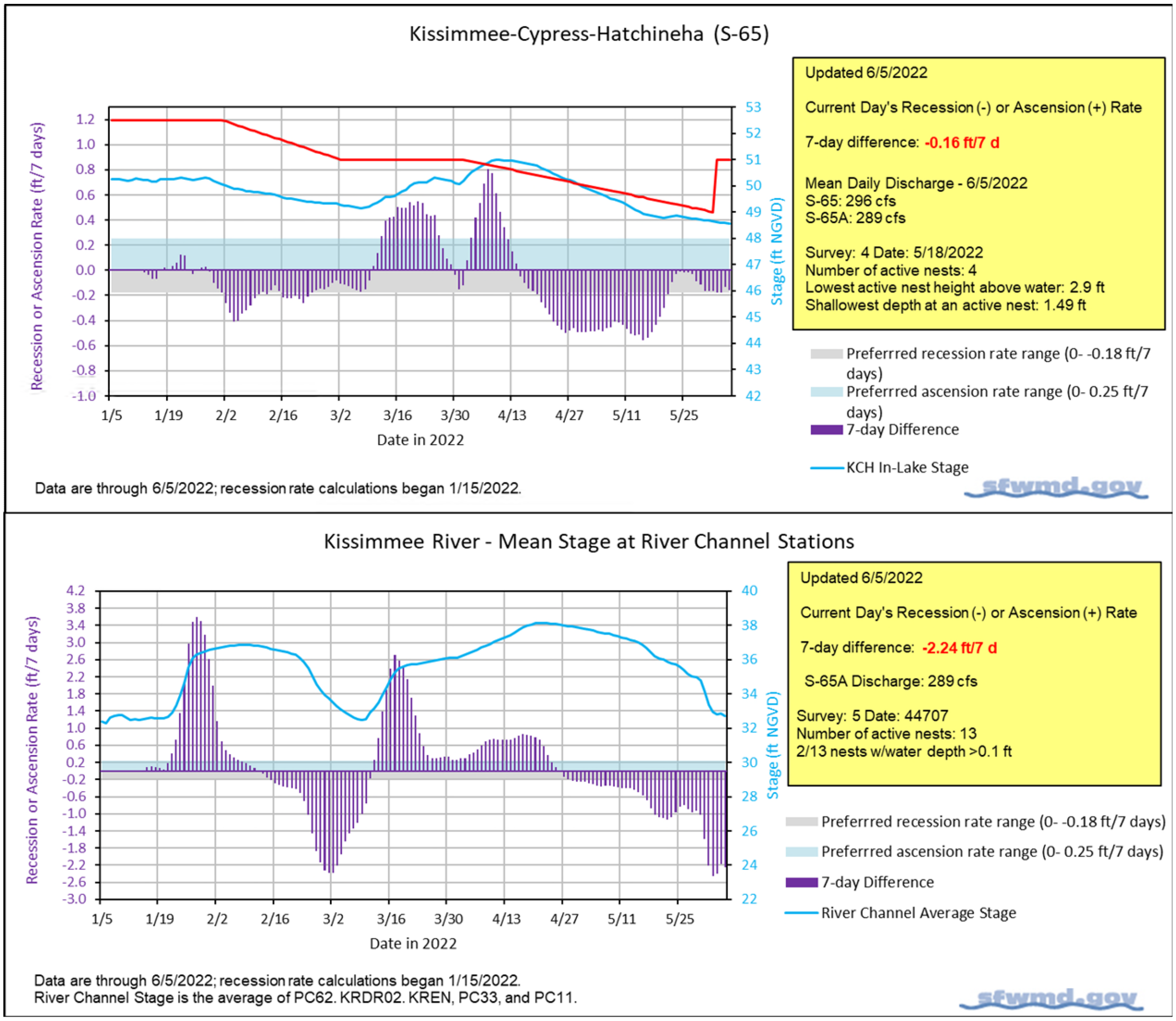


Figure 9-15. Recession rates during the 2021-2022 dry season in the Headwaters Lakes and Kissimmee River with S-65A/S-65A discharge.

Stage in the Headwaters Lakes had been lowered to 49.15 ft NGVD29 by March 7, 2022, but then rose in response to high rainfall and increased inflows to control reversals in East Lake Tohopekaliga and Lake Tohopekaliga (**Figures 9-14** and **9-15**). Stage in the Headwaters Lakes increased by 1.83 to 50.98 ft NGVD29 from March 7 to April 9, 2022. During the stage reversal, 60% of the input volume to the Headwaters Lakes came from East Lake Tohopekaliga and Lake Tohopekaliga via S-61, 21% from Lake Gentry and the Alligator Chain of Lakes via S-63A to control reversals in those lakes, and only 19% from direct rainfall over the Headwaters Lakes and local basin rainfall. Thus, most of the large reversal in the Headwaters Lakes was the result of discharging water from East Lake Tohopekaliga and Lake Tohopekaliga to manage their respective reversals.

To protect the Kissimmee River, gradual increases in discharge at S-65A to a maximum of 2,528 cfs were made, and the reversal in the Headwaters Lakes was controlled after stage had exceeded the regulation schedule line (**Figure 9-15**). Despite the gradual increases in discharge, the concentration of DO in the river sagged by > 4 mg/L over a week in mid-April to 2.65 mg/L (**Figure 9-11D**), very close to the threshold for harm to native sunfish of 2 mg/L. The DO decline was arrested by reducing S-65A flow rapidly by > 400 cfs over two days, which allowed DO to rise to pre-decline levels within about five weeks. DO remained above the 2 mg/L threshold for hypoxia over the remainder of April and May. Overall, the S-65A discharge reductions were managed with an average rate of -50 cfs/d for the period after the reversal ended, including the > 400-cfs reduction. Following the reversals, S-65A discharge was adjusted to maintain minimum flow (300 cfs) to the Kissimmee River, which provided another opportunity to lower stage below the usual low pool (49 ft NGVD29) during the final weeks of dry season.

After an unusually dry start to the 2022 wet season, stage continued to decline below 48.5 ft in the Headwaters Lakes after June 1 even at minimum flow levels, and S-65 discharge was stopped on June 23, 2022. From this point, the only flow to the Kissimmee River was from local Pool A runoff discharged via S-65A. These events happened in PW2023 and therefore will be discussed more fully in next year's SFER. Stage in the Headwaters Lakes was below 49 ft NGVD29 from May 15, 2022, through July 17, 2022, for a total of 64 days.

In the Headwaters Lakes, recession rates were below the preferred maximum rate of 0.18 ft/7 d for 72% of the time between January 15, 2022, when recessions began in East Lake Tohopekaliga and Lake Tohopekaliga, and March 9, 2022, when the stage reversal began (**Figure 9-15**). The Headwaters Lakes also had a single stage reversal of 1.83 ft that corresponded to the two reversals observed in East Lake Tohopekaliga and Lake Tohopekaliga (**Figure 9-14**). As described above, the reversal in the Headwaters Lakes was primarily due to increased discharge to control the reversals in the upstream lakes. The recession in the Headwaters Lakes was also complicated by limits on the maximum rates of discharge from S-65 and S-65A to prevent harm to the Kissimmee River. After the reversal ended, stage in the Headwaters Lakes was lowered quickly to get below the regulation line and later to attempt to meet the lake management desire to be below 49 ft NGVD for at least 60 days. Recession rate in the Headwaters Lakes exceeded the preferred maximum rate 69% of the time and were as fast as -0.56 ft/7 d.

Dry Season Floodplain Inundation

A brief floodplain inundation event occurred in late dry season, which was the second inundation event of PW2022. When the Headwaters Lakes stage exceeded its regulation schedule in March (**Figure 9-11B**), discharge at S-65 and S-65A were increased above 1,400 cfs to a maximum of 2,528 cfs. This inundation event, indicated by BLM Depth of at least 0.1 ft, lasted 43 days (April 11–May 23, 2022), during which time BLM Depth reached a maximum of 1.19 ft (**Figure 9-11C**).

Brief, isolated periods of inundation such as occurred in the 2021-2022 dry season are not consistent with the restoration project's goal of reestablishing pre-channelization patterns of floodplain inundation that could extend well into the dry season as part of a single long event. Such brief periods of inundation are likely of little value and may be harmful. For example, as this inundation event was ending, the endangered snail kite established 13 nests in the Kissimmee River floodplain by May 26, 2022, in the same general area where kites had nested previously during the 2018 wet season (Koebel et al. 2020). Within three weeks, more than two-thirds of the nests had failed possibly due to the lack of water depth to serve as a barrier to terrestrial predators. Such brief periods of inundation, especially near the beginning of the wet season, may provide a false signal of an early start to the wet season and a longer period of inundation and induce fish and birds to waste energy on spawning or nesting behaviors with low probability of success.

Summary of PW2022 Water Management Operations

The 2021 wet season marked the sixth implementation of a variation of the IS-14-50.0 discharge plan since the 2015 wet season. Implementation of the plan in PW2022 resulted in a single 96-day period with bankfull discharge or greater, the third longest duration of bankfull discharge (**Table 9-4**) since reestablishment of flow in 2001. The duration of bankfull discharge would have been even longer if implementation of the plan had not been delayed by the 900-cfs limit on discharge for construction.

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 an additional, previous event (Event 1).	1 2	2 49
2020	IS-14-50.0	Produced a single wet season floodplain inundation event. Event duration would have been longer if the limit for construction had not delayed implementation of the plan and if discharge had not been reduced to 300 cfs while the lake stage was more than 2 ft above the threshold stage.	1	106
2021	IS-14-50.0	Produced a single wet season floodplain inundation event. Event duration would have been longer if the limit for construction had not delayed implementation of the plan.	1	96

As in previous years, PW2022 reflected the difficulties of trying to limit rates of stage ascensions and recessions in a series of connected water bodies, where achieving targets upstream can complicate downstream conditions. PW2022 highlights the tradeoffs and complexity of such operations, both among the lakes and between the lakes and the Kissimmee River. Water management in PW2022 was further complicated by the need to limit flows for KRRP construction early in the 2021 wet season, and to lower stage in the Headwaters Lakes below low pool in the 2021-2022 dry season. The consequences are illustrated by the challenges that were experienced in controlling rates of stage ascension (**Figures 9-12** and **9-13**) and recession (**Figure 9-14** and **9-15**) in the lakes, and the cumulative impacts on discharge to and stage in the Kissimmee River. For example, peak ascension rates in the Kissimmee River were nearly five times the maximum rates in the lakes (**Figure 9-15**). Similarly, efforts to control recessions in the lakes resulted in adjustments to discharge that caused stages to rise and fall repeatedly in the river (**Figure 9-15**).

During PW2022, an effort was made to slow the rates of discharge change below the recommended maximum rates of change in the IS-14-50.0 discharge plan (**Figure 9-6**). While this undoubtedly resulted in slower rates of change in stage in the Kissimmee River, the observed rates were still faster than the preferred maximum rates of stage ascension and recession typically recommended for the UKB lakes. This is especially clear after the reversal in the dry season when reductions in S-65A discharge averaged 50 cfs/d and the Kissimmee River recession rates had a maximum of -1.58 ft/7 d, an average of -0.6 ft/7 d, and 94% of the time exceeded the preferred rate of -0.18 ft/7 d requested for the Headwaters Lakes (**Figure 9-15**). Preliminary analysis for the Kissimmee River indicates that rates of stage ascension and recession during the pre-channelization Reference Period were slower than the preferred maximum rates for ascension (0.25/7 d) and recession (-0.18 ft/ 7 d) recommended for the lakes. Analysis of Reference Period stage data for the Kissimmee River is ongoing to better define target rates of ascension and recession and corresponding limits on the rates of change for discharge.

Rapid changes in discharge from the Headwaters Lakes will continue to cause rapid changes in flow and stage in the Kissimmee River, which can cause DO declines during rapid increases in discharge and can strand aquatic organisms on the floodplain during rapid decreases in discharge. These interactions illustrate the strong potential for operational tradeoffs among the lakes in the UKB (including the Headwaters Lakes) and the Kissimmee River, which can complicate implementation of lake stage target requests, including both preferred ascension and recession rates, while attempting to accomplish restoration goals.

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 the wet season, continued well into the dry season, and extended throughout the year in some years. These long periods of floodplain inundation provided important foraging habitat for wading birds and waterfowl, nursery areas for important native fish in the breeding season and were necessary to meet the hydroperiod requirements of the dominant wetland vegetation type (BLM) of the Kissimmee River floodplain. Managing for single, continuous floodplain inundation events continues to be a focus of efforts to manage releases for 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 PW2022 are updated in this section. New results from studies of floodplain hydrology, DO, 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 2007; updates were also provided in the 2005 SFER.

Table 9-5. Directory of KRREP Phase I restoration response monitoring study updates in the 2007–2023 SFERs. [a, b]

KRREP Monitoring Study or Project	Expectation Number	Beginning Page Number for Each Subsection in 2007–2023 SFERs — Volume I																
		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Beginning page number for KRREP Section:		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	9-27	9-30
Hydrology																		
Stage-discharge relationships	None																	
Continuous river channel flow	1			**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			**11-41**	**11-32**	**11-33**	**9-21**	**9-24**	**9-24**	**9-30**	**9-37**	**9-38**	**9-37**	**9-37**	**9-25**	**9-28**	**9-30**	**9-33**
Stage recession rate	4	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**	**9-31**	**9-34**
Flow velocity	5				**11-35**	**11-37**	**9-24**											
BLM indicator	None			11-43						9-33	9-37					**9-28**		
Geomorphology																		
Riverbed deposits	6					**11-70**												
Sandbar formation	7					**11-70**												
Channel monitoring	None			11-54		11-68												
Sediment transport	None					11-71												
Floodplain processes	None					11-72												
Dissolved Oxygen	8	**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**	**9-37**	**9-41**
River Channel Metabolism	None		11-35															
Phosphorus	None	11-30	11-32	11-51	11-43	11-43	9-25	9-31	9-34	9-40	9-50							
Turbidity	9	**11-27**																
Periphyton	None																	
River Channel Vegetation																		
Width of littoral vegetation beds	10			**11-59**														
River channel plant community structure	11			**11-59**														
Floodplain Vegetation																		
Areal coverage of floodplain wetlands	12		**11-35**			**11-47**			**9-42**	**9-50**				**9-55**		**9-49**		
Areal coverage of broadleaf marsh	13		**11-35**			**11-47**			**9-43**	**9-51**				**9-56**		9-49		
Areal coverage of wet prairie	14		**11-35**			**11-47**			**9-43**	**9-51**				**9-56**		9-49		

Table 9-5. Continued.

KRREP Monitoring Study or Project	Expectation Number	Beginning Page Number of Subsection in 2007–2023 SFERs — Volume I																
		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Invertebrates																		
Macroinvertebrate drift composition	15																	
Snag invertebrate community structure	16			11-62														
Aquatic invertebrate community structure in BLM	17																	
Benthic invertebrate community structure	18			11-62														
Native and nonnative bivalves	None					11-52												
Non-native apple snails	None															9-52		
Fish																		
Impact of hypoxic events on LMB and bluegill	None													9-58		9-55	9-53	9-62
Herpetofauna																		
Floodplain reptiles and amphibians	19	9-47								Response data will be collected after implementation of the HRS.								
Floodplain amphibian reproduction and development	20	9-47								Response data will be collected after implementation of the HRS								
Fish Communities																		
Small fishes in floodplain marshes	21																	
River channel fish community structure	22			**11-66**			**9-29**											
Mercury in fish	None			11-20														
Floodplain fish community composition	23																	
Birds																		
Wading bird abundance	24	**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**	**9-62**	**9-75**
Waterfowl	25	**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**	**9-66**	**9-78**
Shore birds	None																	
Wading bird nesting	None		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	9-71	
Wading bird and waterfowl prey availability	None												9-62		**9-46**			
Threatened and Endangered Species	None															9-84	9-77	

a. Bolded page numbers indicate a major update in reference to the status of a restoration expectation (performance measure).
b. Reporting on the KRREP began in the 2005 SFER – Volume I.

HYDROLOGY

This section evaluates metrics for Expectations 3 (hydroperiod) and 4 (recession events) in PW2022 and provides an overall assessment of progress toward meeting the expectations during the post-Phase I construction Interim Period (PW2002–PW2022). The reference conditions used to develop these expectations and the effect of channelization on BLM Depth (mean depth at floodplain BLM sites) 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 PW2022 and Over the Interim Period

Expectation 3 (Hydroperiod Requirements for BLM)

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

PW2022 had two events with BLM Depth ≥ 1 ft (**Figure 9-16**). The first had a maximum BLM Depth of 1.84 ft and lasted 54 days (August 14–October 6, 2021) and was associated with implementation of the IS-14-50.0 discharge plan. The second event had a maximum BLM Depth of 1.05 ft and lasted only 8 days (April 20–27, 2022). The 54 days was approximately the 25th percentile of the duration of BLM Depth ≥1 ft in the Interim Period (**Figure 9-17**), so neither event was very long. Both events were far shorter than the desired duration of 210 days, and neither met the criterion of BLM Depth ≥ 1 ft for 210 days for the water year (Component A) or the August–February window (Component B).

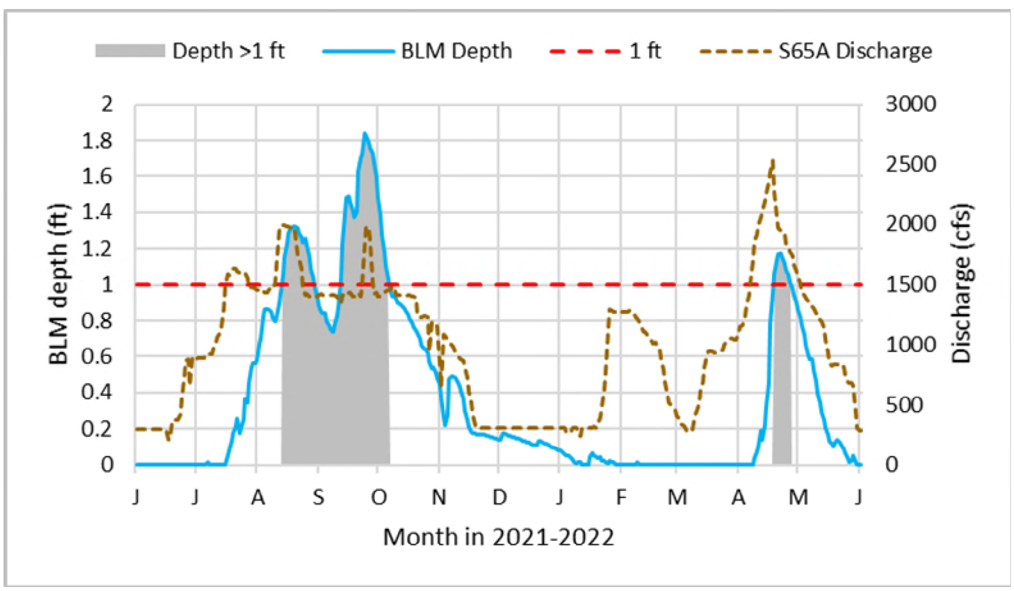


Figure 9-16. BLM Depth and S-65A discharge during PW2022. Gray shading indicates intervals of time when BLM Depth was at least 1 ft. BLM Depth is the average of mean depth at five stage recorders in the northern Phase I area floodplain.

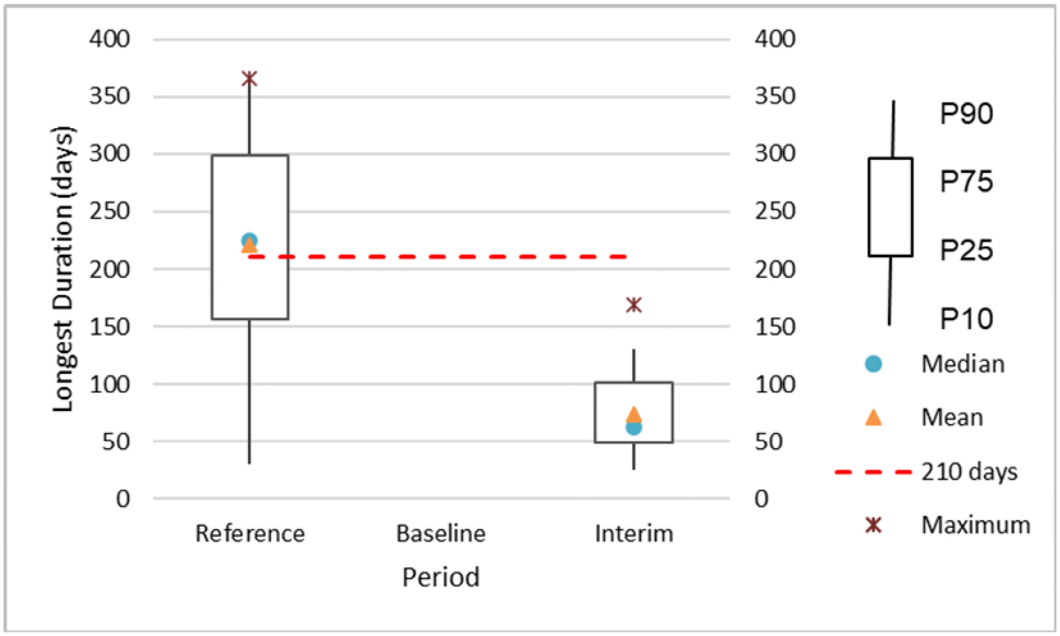


Figure 9-17. Longest duration (consecutive days) with BLM Depth ≥ 1 ft in the Kissimmee River floodplain for 32 Reference Period years, 28 Baseline Period years, and 21 Interim Period years. No events occurred in the Baseline Period. The dashed red line indicates the 210-day (target for 59% years) criterion for the expectation. The box plots show the 90th, 75th, 25th and 10th percentiles.

None of the events in the Interim Period (2001–present) have met the 210-day criterion (Component A) or the more restrictive criterion for the August–February window (Component B). Over the entire Interim Period, the longest duration event to date was only 169 consecutive days (range 13 to 169 days with a mean of 75 days), far short of the 210-day criterion, and barely exceeds the 25th percentile of years in the Reference Period (**Figure 9-17**). 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 either the planning window (Component A) or the seasonal window (Component B). To have met 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 9-17**). 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.

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/30 d.*
- *Component B: 100% of recession events will have a mean recession rate < 2 ft/30 d.*

PW2022 had two recession events (**Figure 9-18**) corresponding to the two floodplain inundation events described in the *Kissimmee Basin Hydrologic Conditions and Water Management in Planning Window 2021-2022* section earlier in this chapter. The first recession event began in September when BLM Depth crested at 1.84 ft and then declined to 0 ft over 111 days for an average recession rate of 0.5 ft/30 d. It occurred during implementation of the IS-14-50.0 discharge plan, but the peak in BLM Depth was associated with increased discharge to provide flood control in the Headwaters Lakes. BLM Depth declined to 0 ft after S-65A discharge was reduced to the minimum level (300 cfs) to hold water in the Headwaters Lakes.

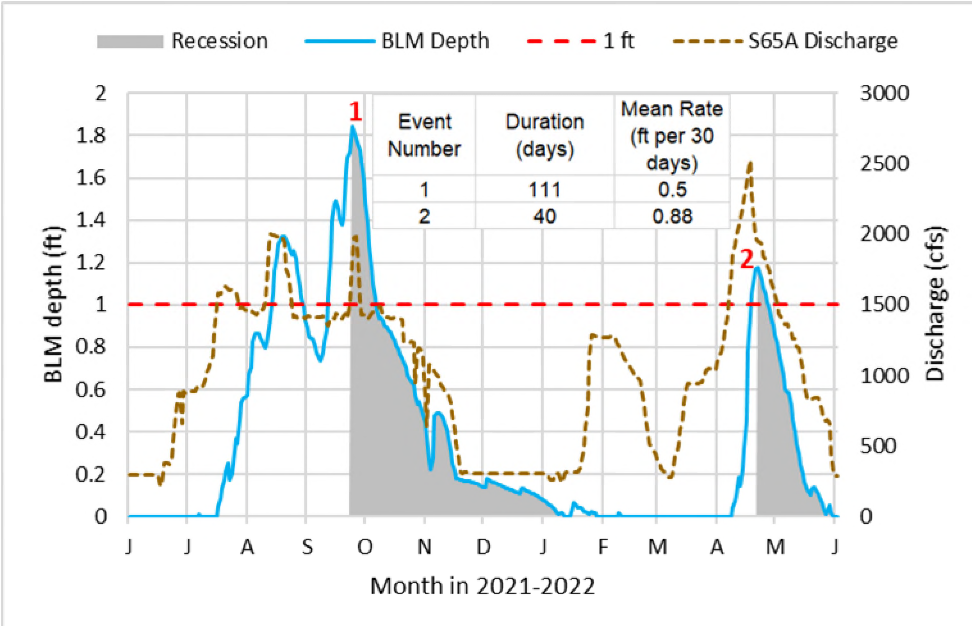


Figure 9-18. BLM Depth and S-65A discharge during PW2022. Two recession events are indicated by gray shading and identified by red numbers. Duration and mean recession rate for each event are shown in the inset table. BLM Depth is the average of mean depth at five stage recorders in the northern Phase I area floodplain.

The second recession event occurred in April, when BLM Depth crested at 1.18 ft and decreased to 0 ft over 40 days for an average recession rate of 0.88 ft/30 d. BLM Depth crested in response to increased discharge to provide flood control in the Headwaters Lakes; it declined to 0 ft as S-65A discharge was reduced to the minimum level (300 cfs) to hold water in the Headwaters Lakes. When the second event began, BLM Depth had been 0 ft for about 3 months after discharge had been reduced to 300 cfs, well below bankfull discharge; although the increase in BLM Depth did not exceed the 1.5-ft reversal criterion, stage in the river channel increased by more than 5 ft, well in excess of the 1.5-ft criterion.

Although both recession events in PW2022 had recession rates less than 1 ft per 30 days, the season is not considered a success because there were two events instead of the single event that was typical of the pre-channelization Reference Period, and because the second event was a response to flood control and not an attempt to maintain floodplain inundation. These two recession events brought the Interim Period total to 43 recession events, or an average of two events per year.

The slower recession rates observed in PW2022 compared to previous years were the result, in part, of adhering to slower reductions of S-65A discharge than the maximum rates recommended in the IS-14-50.0 discharge plan, as discussed in *the Kissimmee Basin Hydrologic Conditions and Water Management in Planning Window 2021-2022* section earlier in this chapter. This suggests that a modification to IS-14-50.0 should be considered for future implementation.

During the Interim Period, mean recession rates for recession events ranged from 0.14 to 5.13 ft/30 d, with a mean rate over all events of 1.71 ft (± 0.18 standard error or SE)/ 30 d (**Figure 9-19**). The duration of recession events ranged from 10 to 203 days and averaged 70 days (± 8 SE). Recession rates were < 1 ft/30 d for 35% of the recession events and < 2 ft/30 d for 70% 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 components did not meet the expectation targets (**Figure 9-20**). More than a third of Interim Period recession events were faster than any that occurred in the Reference Period, on which the targets were based.

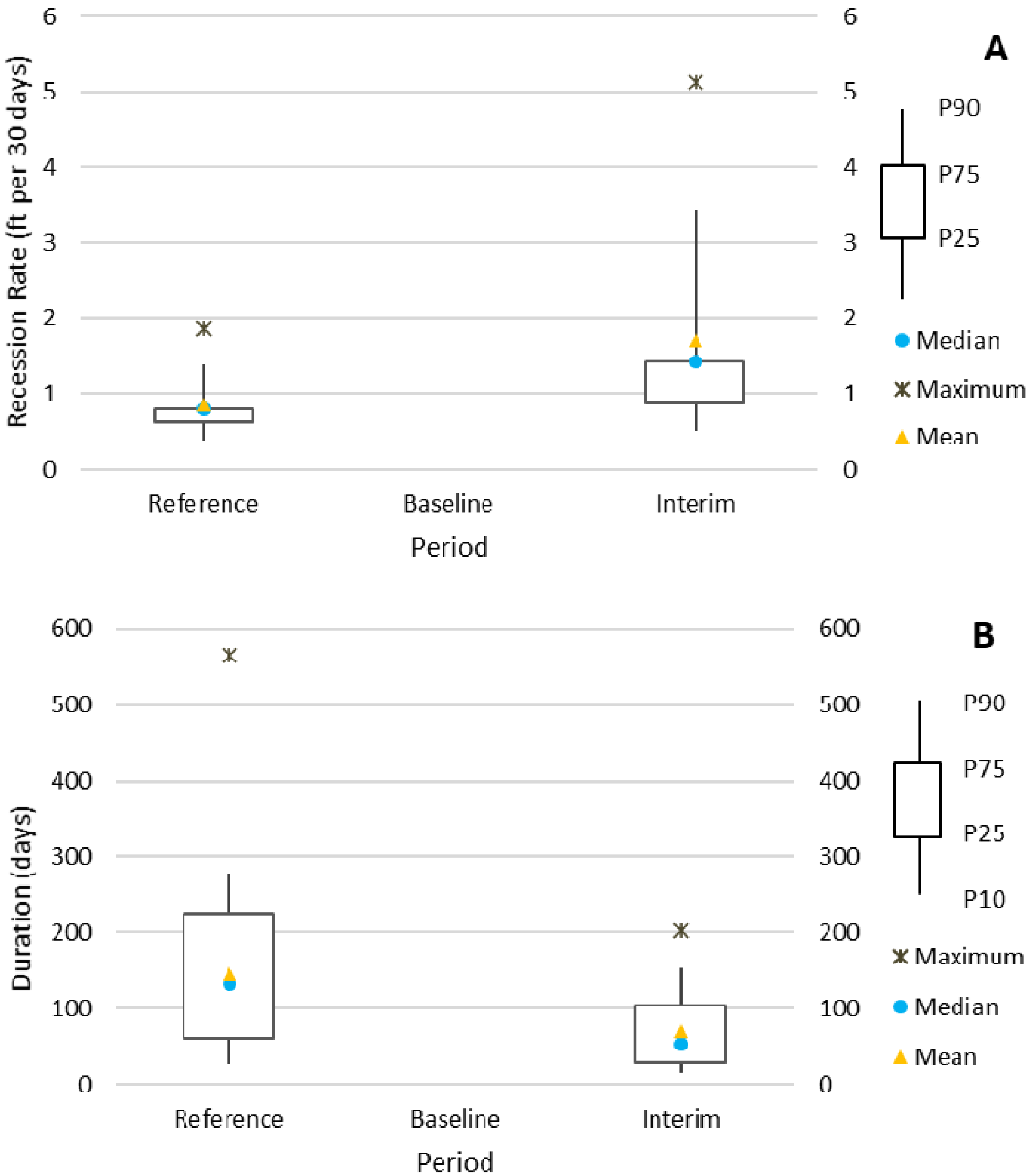


Figure 9-19. (A) Recession rates and (B) event duration for recession events during the Reference Period (PW1931–PW1962) and the Interim Period (PW2002–PW2022) in the Kissimmee River floodplain. No recession events occurred in the Baseline Period (PW1972–PW1999).

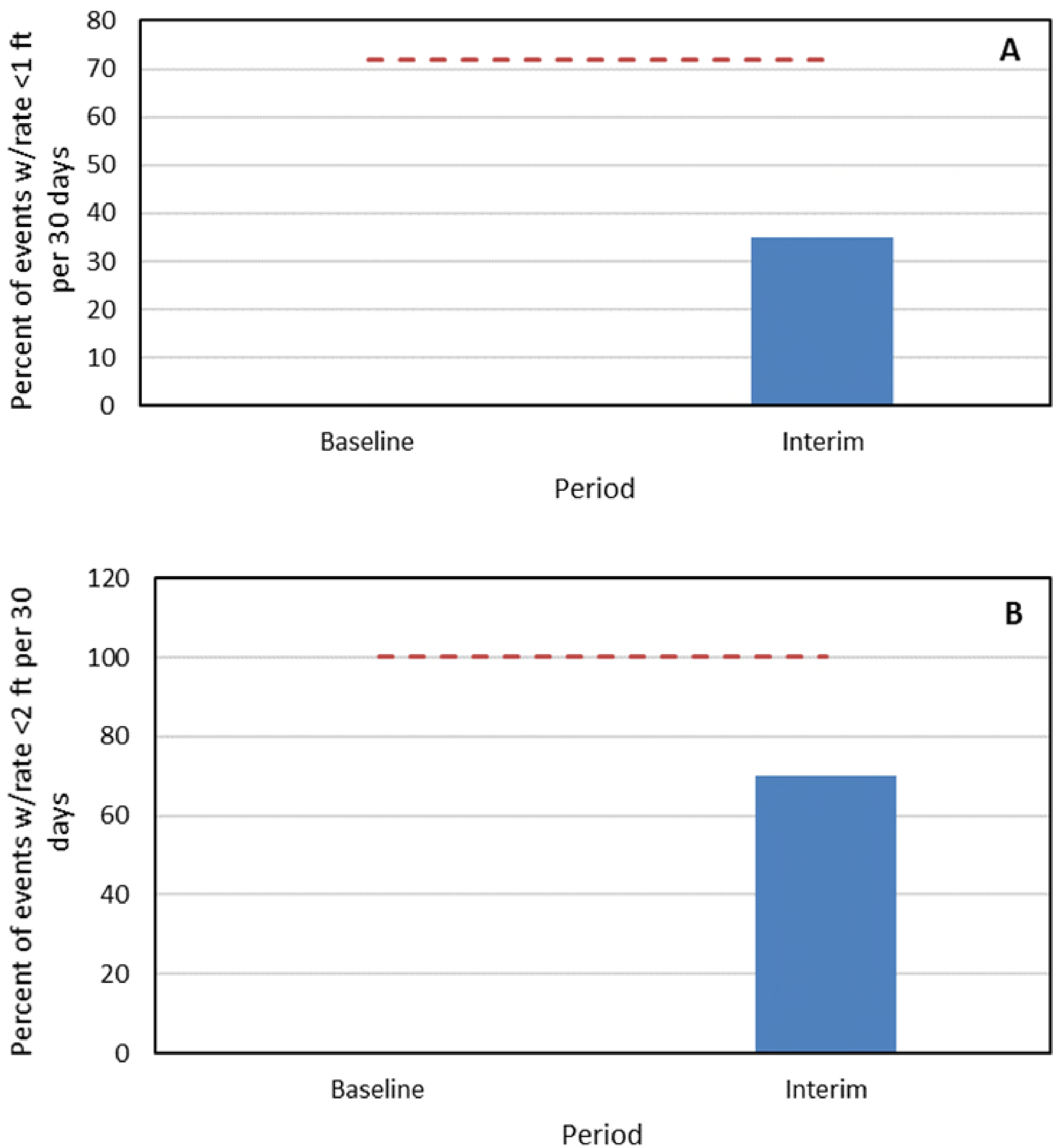


Figure 9-20. Comparison of percentage of Kissimmee River floodplain recession events having rates: (A) < 1 ft/30 d (Component A) and (B) < 2 ft/30 d (Component B) during Baseline (PW1972–PW1999) and Interim (PW2002–PW2022) periods. The dashed red lines are target percentages based on frequency of events during the pre-channelization Reference Period (PW1932–PW1962). Reductions to low discharge result in disjoined floodplain inundation events with periods of drying.

Discussion of the Hydrologic Expectations in the Interim Period

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 25^{th} percentile of pre-channelization events; it follows then that recessions are currently too rapid. The slower (< 1 ft/30 d) recession rates observed in PW2022 indicate that meeting the recession rate expectation in the future will depend, in part, on slowing maximum discharge rates of decrease to ~50 cfs/d, at least between bankfull and minimum discharges.

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 long hydroperiod marshes (Spencer and Bousquin 2014). If continued, such operations will prevent 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 at the S-65 and S-65A structures for flood control (e.g., **Figures 9-7** and **9-18**). 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 when lake stage is held at or near the regulation schedule line 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 attempts to keep lake stage well below the regulation line (0.5 ft). Large and rapid increases in discharge have been identified as a problem for restoration of the Kissimmee River (Cheek et al. 2014). In addition to the threat to snail kites nesting, 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). As the 2021-2022 dry season demonstrated, moderate increases in discharge that create favorable conditions (e.g., water depths) in the floodplain for snail kite nesting can pose a problem if conditions cannot be sustained for sufficient time for eggs to hatch and young to fledge.

Relationship of Hydroperiod and Recession Events to Discharge

BLM Depth is influenced, to a small extent, by direct rainfall and associated runoff from within the LKB but sustaining prolonged periods of inundation almost completely depends on inflow discharge through S-65 through 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 dependent on appropriate water management.

Recommendations to use 1,400-cfs discharge plans to address the hydroperiod and recession expectations to improve hydrologic conditions as required by USACE (1991, 1996) have been made for every wet season beginning in 2015. Although the plans are intended to improve hydrologic performance for Expectations 3 (hydroperiod) and 4 (recession events), they are not expected to fully meet the criteria for either expectation until the Interim Period ends and the Headwaters Revitalization Schedule (HRS) implementation can begin. Similar discharge plans are being applied to the future HRS; how well these plans improve hydrologic performance before or after the HRS is implemented will be strongly influenced by how consistently they are implemented.

Implementation of discharge plans during the 2015, 2017, 2018, 2019, 2020 and 2021 wet seasons resulted in single floodplain inundation events during each wet season, with BLM hydroperiods of 76, 63, 63, 67, 101 and 54 days, respectively. The approach used in the plans of holding discharge at 1,400 cfs during these events has in all cases 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, regardless of rainfall conditions, to ensure capitalization on years with enough rainfall to provide both prolonged floodplain inundation and periods of higher stage in the Headwaters Lakes by using balanced discharge plans.

Implementation of the discharge plans indicates a promising direction for Kissimmee Basin adaptive management to achieve a balance between stage goals in the Headwaters Lakes and S-65 discharge goals for the river, 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 similar discharge plans in future years both during phased implementation of HRS and after full HRS implementation. The discharge plans are examples of hydrologically- and ecologically-balanced operations designed to link discharge for the KRRP to rainfall via linkage to 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 between lake stages and 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, 2019, 2020, and 2021 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, a simulation of PW2019 presented in the *Kissimmee Basin Hydrologic Conditions and Water Management in Planning Window 2018-2019* section in 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 but 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. For example, current KRREP operational guidelines allow maximum rates of discharge decrease and increase that are often relaxed in consideration of other operational needs; however, the specified maximum rates of change are much faster than occurred in the Reference Period. Other examples include 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); precisely follow dry season stage recession lines by controlling all 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, and directly impact wading bird foraging and nesting and fish breeding, among other components of the system. Further, operating for similar dry season stages year after year in the Headwaters Lakes could reduce inter-annual variability, which is widely viewed as a desirable characteristic of healthy lakes (Perrin et al. 1982, USFWS 1994, Hill et al. 1998, Keddy and Fraser 2000).

Summary

The performance of hydrologic Expectations 3 (hydroperiod) and 4 (recession events) in PW2022 was influenced by the implementation of the IS-14-50.0 in the 2021 wet season. Outcomes were also affected by average rainfall early in wet season and constraints on operations early in the wet season to limit discharge for construction, as well as operations designed to lower stage in the Headwaters lakes below 49 ft NGVD29 for an extended period in the dry season (as described in the *Kissimmee Basin Hydrologic Conditions and Water Management in Planning Window 2021-2022* section earlier in this chapter).

Expectation 3

The targets for Expectation 3 (hydroperiod) were not met in PW2022 or in any year of the Interim Period thus far (PW2002–PW2022). Performance for Expectation 3 (hydroperiod) can be improved by consistently 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 PW2022 or in any year of the Interim Period thus far (PW2002–PW2022). Performance for Expectation 4 (recession events) can be improved by slowing the rate of recession in the Kissimmee River, 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 PW2022 can improve hydrologic conditions for Expectations 3 (hydroperiod) and 4 (recession events) and create conditions for the reestablishment of historic hydrology to initiate recovery of the biotic components of the river/floodplain ecosystem.

DISSOLVED OXYGEN

Dissolved oxygen (DO) directly affects aquatic life through oxygen availability and the metabolism of aquatic ecosystems (Colangelo 2007, Hauer and Lamberti 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 is a function of the balance between primary production, reaeration, and respiration (Chen 2019), which are influenced by many factors including temperature, rainfall, water depth, floodplain interactions, and discharge at water control structure S-65A (Chen et al. 2016). Calculations in this report for expectation evaluation and control/impact comparisons are made for the PW2022 (June 1 2021–May 31, 2022); please note this might affect direct comparisons to information presented in some previous SFERs, which made calculations using the water year (May 1–April 30).

Evaluation of Expectation 8

New Provisional Expectation 8 Components

To better capture the diurnal patterns of dissolved oxygen levels, we have developed new provisional expectation components based on continuous data from reference streams, which will be evaluated with continuous data being collected from the Kissimmee River channel. Details on the methods of their development can be found in the *Development of New Expectation 8 Components* subsection below.

Provisional Expectation 8 Components:

> *[a] Mean daily concentration of DO in the Kissimmee River channel will increase from < 1.0 to 2.0 mg/L to 2.5 to 6.0 mg/L during the wet season (June–October).*
>
> *[b] Mean daily concentration of DO in the Kissimmee River channel will increase from 2 to 4 mg/L to 4.5 to 7.5 mg/L during the dry season (November–May).*
>
> *[c] Mean daily concentration of DO in the Kissimmee River channel will exceed 1.0 mg/L more than 98% of the time annually.*
>
> *[d] Mean daily concentration of DO in the Kissimmee River channel will exceed 2.0 mg/L more than 95% of the time annually.*

Methods

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

Based on analyses of reference and baseline data, restoration of the Kissimmee River was expected to improve DO concentrations in the river channel primarily by reintroducing flow, which reduces the amount of organic matter that accumulated 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, continuous 30-minute DO data were collected from five nearby free-flowing blackwater streams (Arbuckle, Josephine, Fisheating, Catfish, and Marion creeks) and used to estimate reference (pre-channelization) conditions for the Kissimmee River (**Table 9-6**). Data was collected from 2015 to 2016, and additional data collection has been ongoing since 2021. Note this is an updated methodology for establishing the expectation targets (reference data) compared to previous evaluations of Phase I DO response. To learn more about the previous methodology, which was based on daytime grab samples to establish reference conditions, see Koebel et al. (2022). For Baseline (channelized) Period data, 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 10:00 am and 2:00 pm from PW1996 to PW1999. Expectation 8 Components [a], [b], [c], and [d] were updated as of this report based on these reference and Baseline Period data.

Interim (Post-Phase I Construction) Data

DO monitoring has continued in the Phase I Interim Period (post-Phase I construction) at some of the stations used to establish Reference and Baseline DO conditions. Grab samples used for comparing control and impact areas were collected monthly from sampling stations KREA91, KREA92, and KREA97 in Pool A and KREA93, KREA94, and KREA98 in the Phase I area between 10:00 am and 2:00 pm. Prior to this report, these grab samples were also used for evaluating Components [a], [b], and [c], but going forward, continuous data will be used to better capture the range of diurnal variation in DO levels. For the previous methodologies, please see Koebel et al. (2022).

Table 9-6. Reference, Baseline, and Post-construction periods DO sampling for performance evaluation in the KRRP.

Period	Sampling Type and Frequency	Depth	Dates Collected	Location	Purpose
Reference (represents the pre-channelized condition)	Sonde; continuous	0.5–1.0 meters (m)	2015–2016 2021–present	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 the 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	KRRP Phase I and Phase II/III areas	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 the channel bottom	2002–present	Remnant runs in the Kissimmee River	Control/impact comparisons

For statistical evaluations of a restoration effect on DO, the difference between the impact (Phase I area where flow was reestablished in 2001) and control (Pool A, which was not altered by restoration construction) area means, or the difference between impact and control area means (ICd) 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.

For evaluation of all Expectation 8 components during the Interim Period, continuous monitoring of daily mean DO (based on 24 hours of data collected at 30-minute intervals) at stations KRBN, PC33, and PC62 in Phase I and PD62 and PD42 in Phase II/III was conducted using stationary DO sondes in the river channel (**Figure 9-21**). Phase II/III sonde data has been newly added to this evaluation as construction was finished on this phase with the completion of the canal backfilling and S-69 weir in summer 2021. Data from all these stations also are used to provide technical guidance for adaptive management of discharge at water control structures S-65 and S-65A.

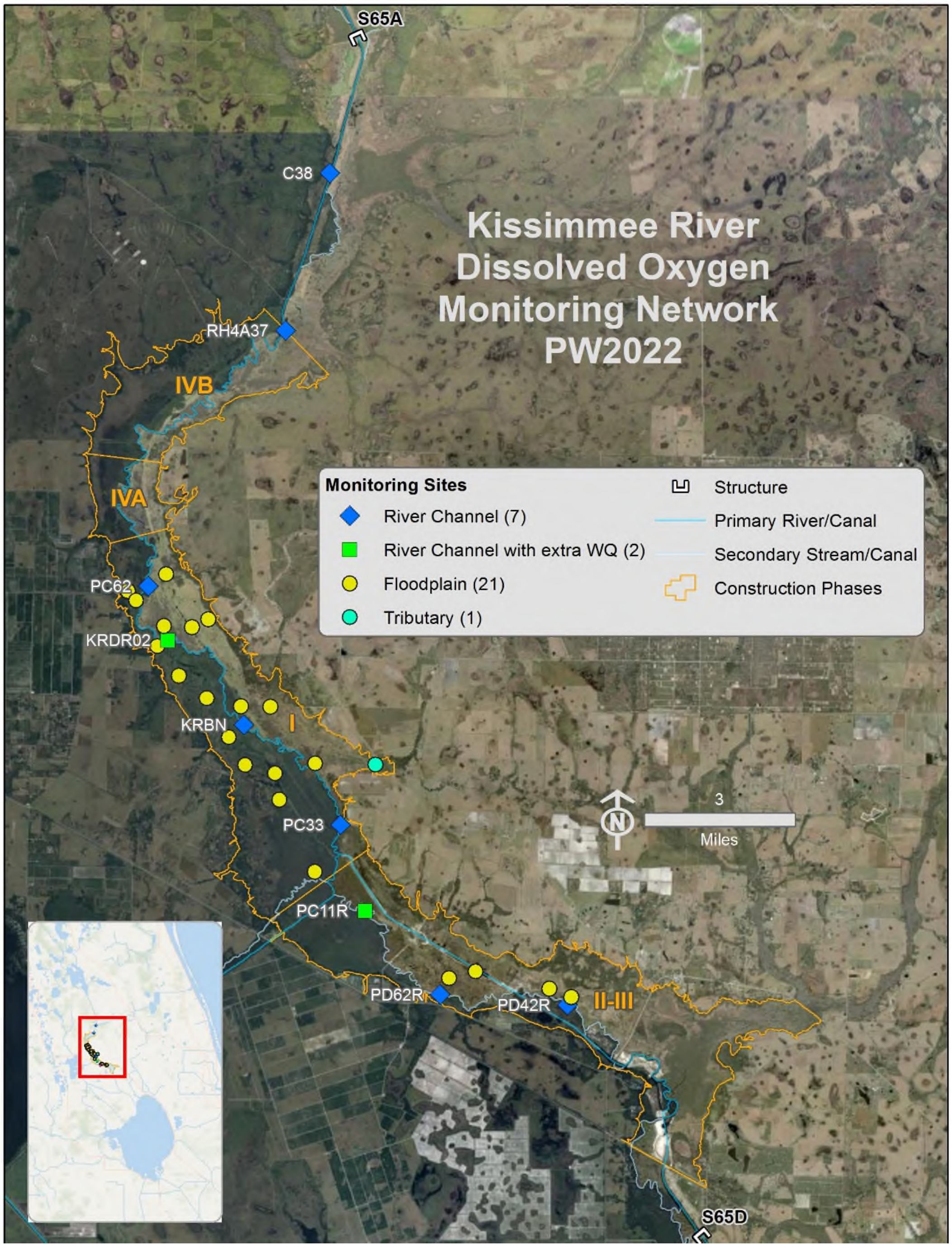


Figure 9-21. Sampling plan as deployed for the PW2022. The legend indicates sonde location type (River Channel, Floodplain, or Tributary) and number of sondes. Floodplain sites are seasonal deployments to coincide with the wet season and floodplain inundation. River channel with extra water quality (WQ) indicates two locations where extra continuous water quality parameters are collected including chlorophyll and fluorescent dissolved organic matter.

Results

Evaluation of Expectation 8: Post-Construction Dissolved Oxygen from PW2002 to PW2022

Since completion of Phase I construction (PW2002–PW2022), mean daytime DO in the Phase I impact area has averaged 2.80 ± 0.10 mg/L (1 SE) during the wet season and 6.64 ± 0.08 mg/L during the dry season (**Figure 9-22**). By comparison, post-construction DO in the control area (Pool A) was significantly lower at 2.00 ± 0.11 and 3.76 ± 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 (5.03 ± 0.17 mg/L) than in Pool A (2.98 ± 0.20 mg/L) for the 21 planning windows following completion of Phase I construction ($p < 0.01$) (**Figure 9-23**).

A comparison of Baseline and Post-Phase I construction data indicated that overall, 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 (t-test) for the Post-Construction period (2.03 ± 0.15 mg/L) than for the Baseline period (-0.18 ± 0.19 mg/L; $p < 0.01$).

In PW2022, two of the four provisional expectation components were met in the combined Phase I and Phase II/III area (**Table 9-7**). When averaged separately, Phase II/III DO levels were somewhat lower than those in Phase I during the wet season (2.8 mg/L compared to 3.0 mg/L) but were similar during the dry season. The component evaluations for the combined Phase I and Phase II/III areas are discussed here, while the values for each area averaged separately can be found in **Table 9-7**. Mean daily DO concentration in the wet season in the combined Phase I and Phase II/III area was 2.9 mg/L, meeting the Component [a] target of 2.5 to 6 mg/L. Mean daily DO concentration in the dry season was 7.0 mg/L, meeting Component [b], which requires 4.5 to 7.5 mg/L. The percentage of time during PW2022 that mean daily DO concentrations were > 1 mg/L was only 89%, thus not meeting its Component [c] target of > 98%. The percentage of time that mean daily DO concentrations were > 2 mg/L in the river channel in PW2022 was 82%, not meeting the Component [d] target of > 95% of the time.

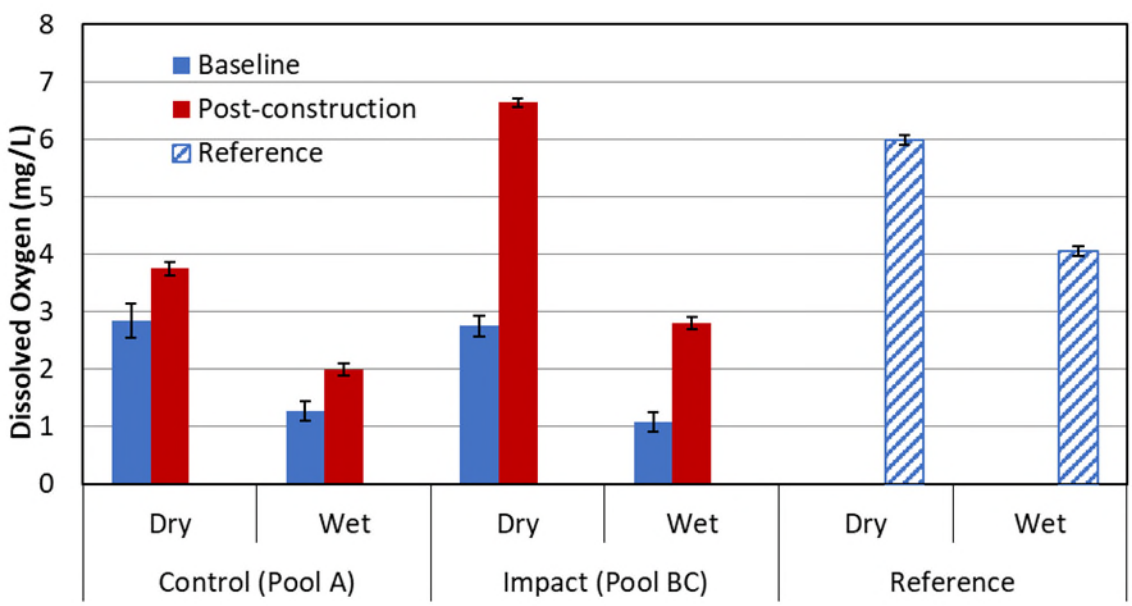


Figure 9-22. Daytime DO concentrations (mean ± SE) in reference streams for period of record PW1973–PW1999 and control and impact areas in wet and dry seasons during the Baseline (PW1997–PW1999) and Post-Phase I Construction (PW2002–PW2022) periods. Impact areas in Phase I have had reestablished flow since construction was completed in 2001. Control areas in Pool A have not been altered by KRRP construction activities and therefore, remain non-flowing.

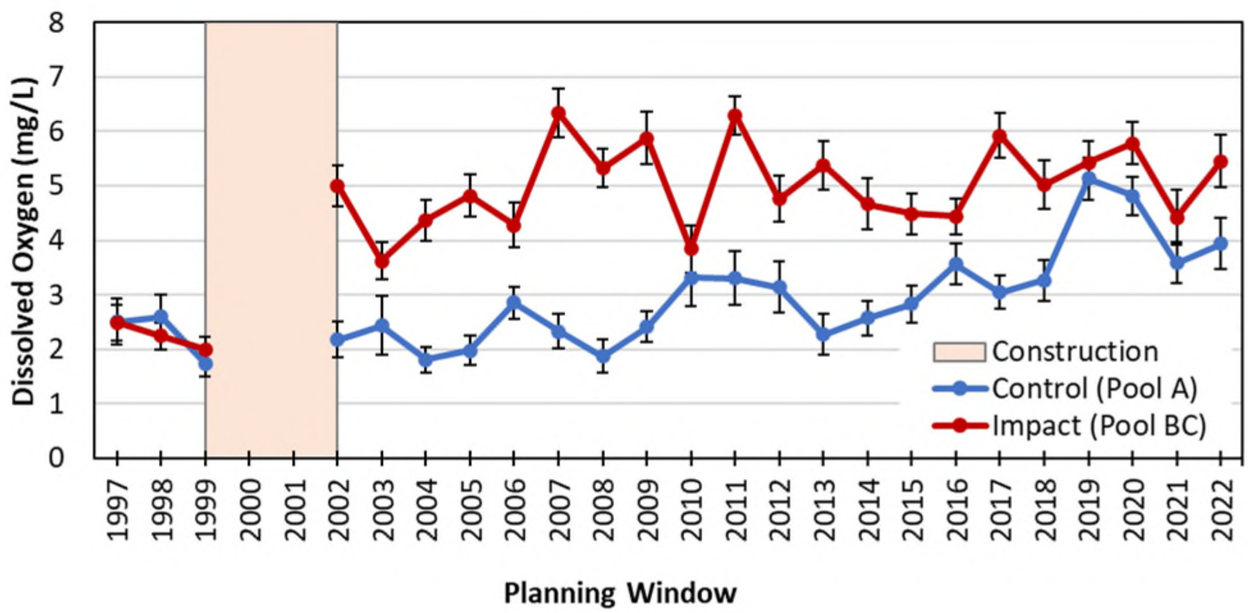


Figure 9-23. Daytime DO concentrations (mean ± SE) of sampling stations KREA91, KREA92, and KREA97 in the Pool A control area and sampling stations KREA93, KREA94, and KREA98 in the Phase I impact area of the Kissimmee River for each planning window during the baseline (PW1997–PW1999) and post-Phase I construction periods (PW2002–PW2022).

Table 9-7. Restoration expectation component metrics and PW2022 values for DO.

Expectation Components	Phase I PW2022 Value	Metric Achieved in Phase I in PW2022	Phase II/III PW2022 Value	Metric Achieved in Phase II/III in PW2022	Phase I & Phase II/III PW2022	Metric Achieved in Phase I & Phase II/III in PW2022
[a] Mean daily DO of 2.5 to 6.0 mg/L during the wet season (June–October).	3.0	Yes	2.8	Yes	2.9	Yes
[b] Mean daily DO of 4.5 to 7.5 mg/L during the dry season (November–May).	7.0	Yes	6.9	Yes	7.0	Yes
[c] Mean daily channel DO will be > 1 mg/L more than 98% of the time annually.	92%	No	86%	No	89%	No
[d] Mean daily channel DO will be > 2 mg/L more than 95% of the time annually.	84%	No	79%	No	82%	No

Development of New Expectation 8 Components

Previously, evaluation of Components [a], [b], and [c] of Expectation 8 used DO measurements from monthly grab samples that are exclusively collected during the daytime, when DO is the highest. This was done to match the methods of the reference data on which the DO expectation was originally based. However, continuous 30-minute interval DO data are now available in the river channel from multiple deployed sondes, which better capture daily fluctuations in DO due to varying rates of photosynthesis and respiration. These continuous data can also capture changes in DO levels that occur during the month-long period between grab samples. To improve evaluations, we are developing new mean daily DO targets for all Expectation 8 components, and are changing Components [a], [b], and [c] to use mean daily DO concentrations instead of mean daytime DO concentrations. This will enable DO to be evaluated using a full year of continuous 30-minute data. To see the effect of these changes, the results of using the original expectation components and the water year period was compared to using the provisional expectation components and the planning window period (**Table 9-8**). Phase II/III data was excluded from the provisional components in this table to make a more accurate comparison.

To determine the specific values of the new targets, new continuous DO data are being gathered from five of the original reference creeks that were used to develop the previous target values: Arbuckle, Josephine, Fisheating, Catfish, and Marion. We currently have more than a full year of continuous data from these creeks and will be gathering more data during PW2023. New provisional components were developed based on a preliminary analysis of the data already collected. The analysis suggests that the target ranges of DO concentrations for Component [a] should be broadened to from 3–6 mg/L to 2.5–6 mg/L and Component [b] should be broadened from 5–7 mg/L to 4.5–7.5 mg/L. This analysis also indicated that the target percentages of time that DO should be above 1 mg/L for Component [c] should increase from 50% to 98% and time above 2 mg/L for Component [d] should be increased from 90% to 95%. The part of Component [c] referring to DO at 1 m from the channel bottom was removed from the expectation, as the continuous sondes in the reference streams and the Kissimmee River do not necessarily capture this data. Increasing these target percentages will help address the issue noted in Koebel et al. (2021) of there being the potential for fish kills even when Component [d] was met because it allowed for up to 36 days of DO concentrations below 2 mg/L, a period sufficient to impact sensitive native species such as largemouth bass and bluegill. These specific target values are still provisional and will be updated as needed as more data is gathered from reference streams.

Table 9-8. Comparison of evaluation of DO Expectation 8 previous and provisional expectation components

Previous Expectation Components	Reference	WY 2004	WY 2005	WY 2006	WY 2007	WY 2008	WY 2009	WY 2010	WY 2011	WY 2012	WY 2013	WY 2014	WY 2015	WY 2016	WY 2017	WY 2018	WY 2019	WY 2020	WY 2021	WY 2022	Total Years Met
[a] Mean Daytime DO of 3 – 6 mg/L during the wet season (Jun–Oct).	2.4 - 6.0	3.3	3.0	2.9	3.1	3.2	3.3	2.5	na*	2.5	3.7	2.8	3.9	2.7	3.4	2.4	3.1	3.5	1.0	2.9	10
[b] Mean Daytime DO of 5 – 7 mg/L during the dry season (Nov–May).	3.7 - 7.4	6.1	6.0	5.9	6.2	6.4	6.6	6.2	na	7.0	7.3	7.1	4.9	5.9	7.3	7.1	7.0	7.4	7.1	7.2	17
[c] Mean Daytime DO concentrations within 1 m of the channel bottom will be >1 mg/L more than 50 percent of the time annually.	na	>50%	>50%	>50%	>50%	>50%	>50%	97%	na	96%	na	na	92%	92%	100%	83%	100%	96%	78%	87%	16
[d] Mean Daily channel DO at 0.5 to 1.0 m depth will be >2 mg/L more than 90 percent of the time annually.	> 90 %	85%	80%	70%	87%	81%	80%	84%	na	78%	82%	79%	81%	95%	82%	78%	95%	84%	65%	83%	2
All Expectation Components achieved?		No	No	No	No	No	No	No	na	No	No	No	No	No	No	No	Yes	No	No	No	1

Provisional Expectation Components	Reference	PW 2004	PW 2005	PW 2006	PW 2007	PW 2008	PW 2009	PW 2010	PW 2011	PW 2012	PW 2013	PW 2014	PW 2015	PW 2016	PW 2017	PW 2018	PW 2019	PW 2020	PW 2021	PW 2022	Total Years Met
[a] Mean Daily DO of 2.5 – 6.0 mg/L during the wet season (Jun–Oct).	2.7 - 5.7	2.9	2.7	2.2	na	na	na	na	na	2.5	2.8	2.4	2.7	3.7	3.1	2.2	3.1	3.6	1.2	3.0	10
[b] Mean Daily DO of 4.5 – 7.5 mg/L during the dry season (Nov–May).	4.6 - 7.5	5.9	6.1	5.1	na	na	na	na	na	5.9	7.4	7.0	6.1	5.5	7.8	6.8	6.6	7.5	7.0	7.0	14
[c] Mean Daily channel DO will be >1 mg/L more than 98 percent of the time annually.	97.9%	97%	88%	93%	na	na	na	na	na	93%	92%	92%	93%	87%	94%	92%	100%	91%	75%	92%	1
[d] Mean Daily channel DO will be >2 mg/L more than 95 percent of the time annually.	95.5%	92%	83%	78%	na	na	na	na	na	82%	83%	81%	82%	83%	85%	78%	96%	86%	65%	84%	1
All Expectation Components achieved?		No	No	No	na	na	na	na	na	No	No	No	No	No	No	No	Yes	No	No	No	1

*Green cells met expectation components, orange cells did not; 'na' means there was not sufficient data to accurately assess the expectation component that year

Planning Window 2022 Anoxia Events

Following a large rainfall event over the Kissimmee River Basin, average daily river channel DO levels (measured at PC62, KRBN, PC33, PD62R, and PD42R; **Figure 9-21**) dropped to hypoxic levels of less than 2 mg/L (DO sag) on July 28, 2021; at 1.9 mg/L this was 0.7 mg/L lower than the day prior (**Figure 9--24**). This event lasted 70 days, with only 8 days from September 3-10 that rose to no higher than 2.4 mg/L. Initiation of the DO sag event appeared to be associated with increased discharge to bankfull (1,400 cfs at S-65A) as well as localized rainfall leading to increased average depth on the floodplain. This event led to 62 days below 2 mg/L, with two events of potential anoxic conditions (daily average under 1 mg/L) at 22 and 18 days of length; the lowest daily average was 0.2 mg/L on August 24–25. Potential causes of the DO sags are likely be a combination of factors associated with a presence of a higher volume of water in the system, including rapidly increased water depth, disruption of aquatic photosynthesis, mobilization of nutrients on the newly inundated Kissimmee River floodplain, and reduced light availability in the water column. No large-scale fish kill was observed on the Kissimmee River in PW2022, though see the *Fish Studies* subsection below for more information about the effects of these events on the native centrarchid population.

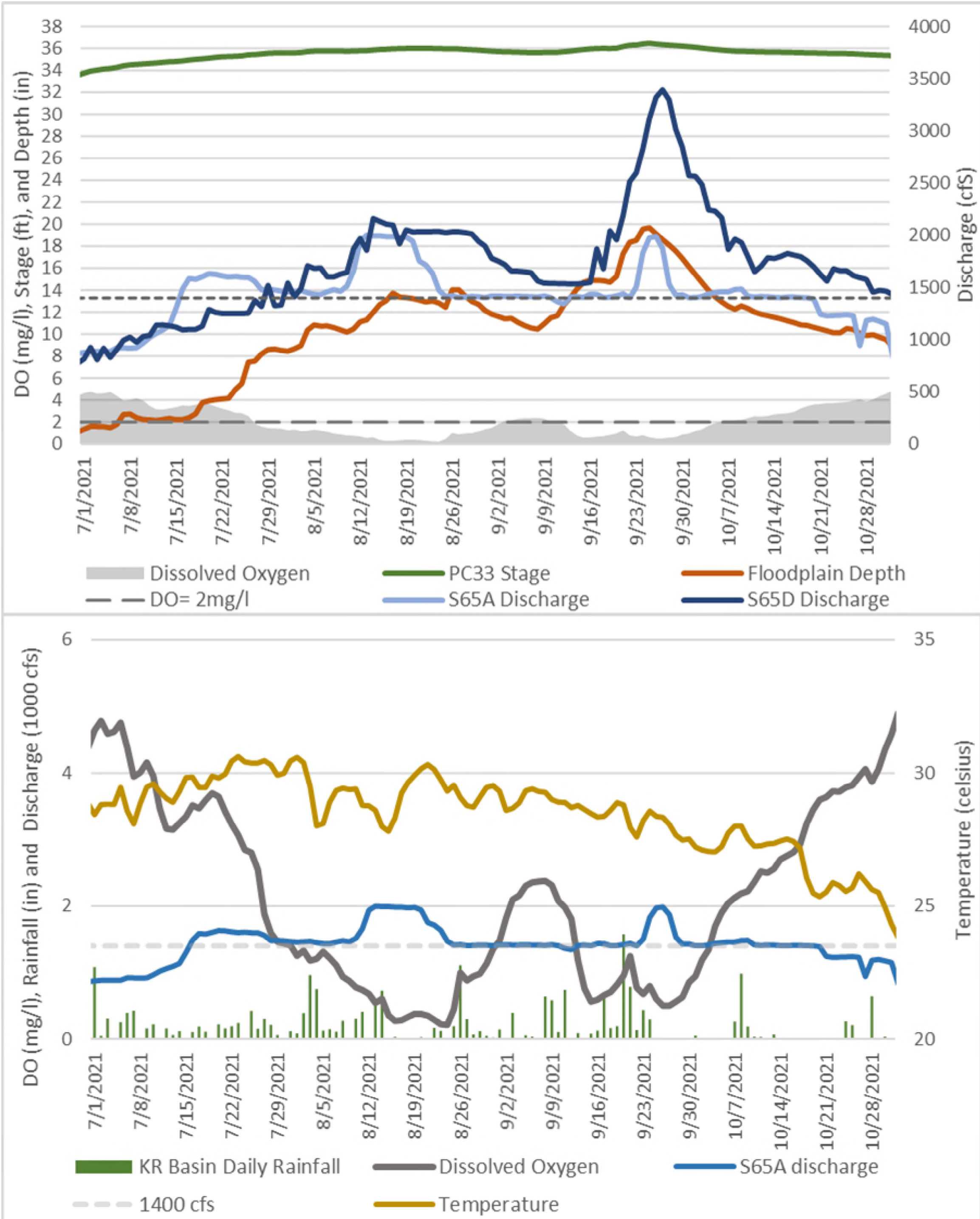


Figure 9-24. Average dissolved oxygen (DO) concentrations at sampling stations PC62, KRBN, PC33, PD62R, and PD42R in the Kissimmee River channel of the Phases I and II-III, daily stage at PC33, estimated average floodplain depth for Phase I in inches, and daily discharge from S-65A and S-65D (top), along with average water temperature in degrees Celsius and rainfall in inches for the Kissimmee River Basin (bottom) during the PW2022 sag event (DO < 2 mg/L). The 1,400 cfs (estimated flow when river is over bank) and DO at 2 mg/L (level at which sportfish are negatively impacted) lines are provided for reference.

Research on Kissimmee River Dissolved Oxygen Dynamics

Preliminary Evaluation of Replacement Hypothesis

One of the initial hypotheses proposed in the 2015 SFER about the cause of consistent wet season DO sag events was that low DO water was flowing into the river from the C-38 Canal (Cheek et al. 2015) to the north of the restoration area. We now have data from several cases generally showing that the C-38 Canal is not a significant driver in severe DO sag events. While DO levels in the C-38 Canal decline in the wet season along with levels in the river to an extent, this can likely be attributed to increased temperature reducing the capacity of water to hold oxygen. Further, there usually comes a point where the canal's DO levels stabilize at their new wet season levels, while in severe crashes, DO levels in the river are observed to continue dropping (mid-July in 2021), demonstrating a disconnect in water quality between the two areas (**Figure 9-25**).

Another period that supports the idea that river DO sags are independent of C-38 Canal influence was the drought in 2007 when flow was completely restricted from the upstream S-65A gate, yet river DO levels still reached anoxic (< 1mg/L) levels (**Figure 9-26**). Ultimately, it seems that while lower wet season DO levels in the C-38 Canal may contribute to lower DO levels in the river to an extent, they do not typically get low enough to cause the hypoxic river DO levels of < 2 mg/L that we see most years. Hypoxic and anoxic events appear to occur independently of C-38 Canal influence, driven by factors that occur after water enters the restoration area river and floodplain system. We will continue to investigate this hypothesis and assess the magnitude of its contribution to DO sags, but the current data supports that there are alternative causes that drive river DO levels to severely low values.

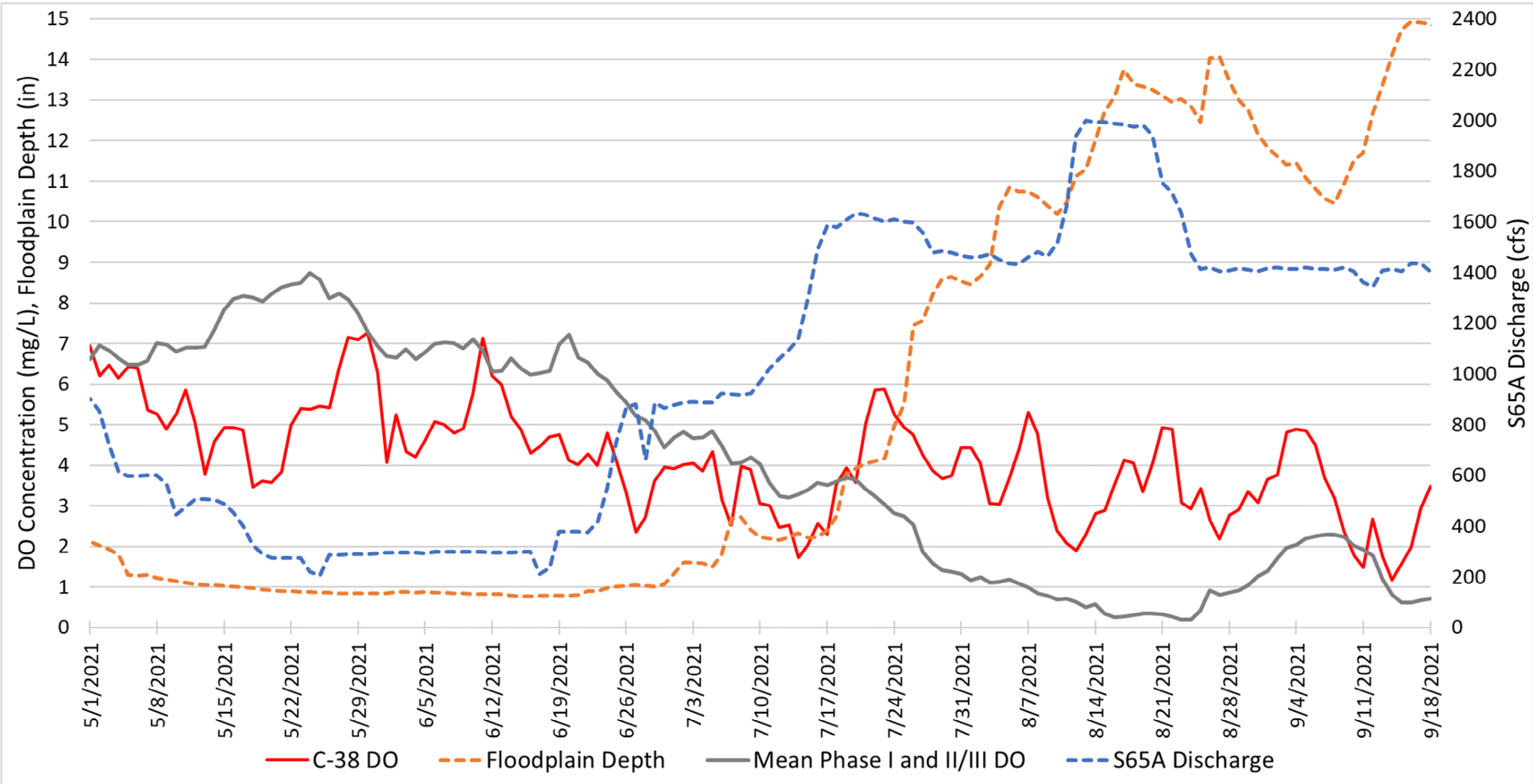


Figure 9-25. Time series of C-38 Canal DO and river channel DO along with S-65A discharge and floodplain depth in inches (in) during PW2022 wet season. Note that in mid-July C-38 Canal DO continues to stay high while river channel DO continues to decline.

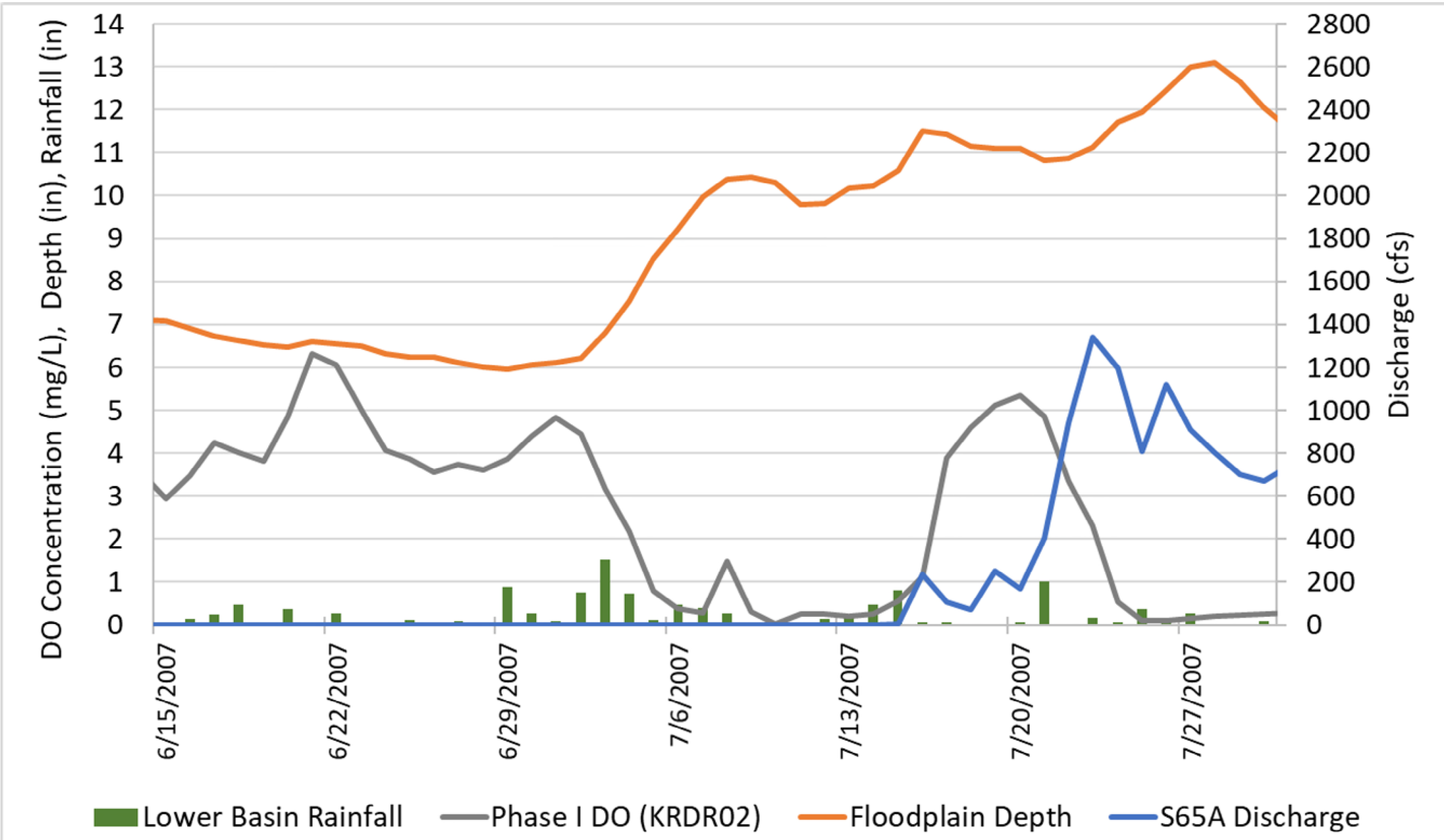


Figure 9-26. Time series of river channel DO at KRDR02 during a drought in 2007 wet season when flow from S-65A was shut down so there is minimal upstream influence on the river yet DO is still seen to sag in July.

Exploration of Floodplain Inundation Hypothesis

Floodplain Dissolved Oxygen and Expanded River Channel Monitoring

Another hypothesis about the cause of DO sags in the river and floodplain is mobilization of accumulated organic matter and the associated biochemical oxygen demand (BOD) as the floodplain is inundated by rain and/or high flow events and becomes hydrologically connected to the river (Cheek et al 2015). This mobilized organic matter may cause an increase in decomposition that could result in the consumption of DO by respiration outpacing the addition of DO by photosynthesis and diffusion from the atmosphere. Even during periods of low (within-bank) flow, organic matter may be transported directly to the river channel in floodplain runoff and cause increased BOD once there.

To further explore DO dynamics and associated sag events within the river channel and floodplain, an enhanced network of floodplain DO recorders was deployed for continuous floodplain monitoring starting in the PW2022 wet season (**Figure 9-21**). This expansion is intended to increase the spatial extent of DO data collection on the floodplain, with 21 locations deployed prior to the wet season. This monitoring will be ongoing, but specific locations may change to address evolving research priorities. Additional recorders were deployed in the river channel upstream and downstream of Phase I and in the C-38 Canal north of the project area. Two of the new sites in the river channel will collect additional water quality parameters including turbidity, chlorophyll, and fluorescent dissolved organic matter (fDOM) near the north end of the Phase I area and just downstream of its south end. Grab samples are also being collected at these two new river sites to validate their continuous data and create relationships between fDOM data and the more widely used parameter of total organic carbon (TOC).

Preliminary Floodplain Dissolved Oxygen Observations and Results

A total of 21 DO sites were deployed in the Kissimmee River floodplain (**Figure 9-21**) prior to the PW2022 wet season. Three different response types to sonde submergence were observed during a flood event: (1) 11 sites rapidly declined to 0 mg/L DO and remained there for an extended period, (2) 5 sites declined substantially but still occasionally rose above 0 mg/L in the daytime, and (3) 5 sites continued to see substantial diurnal fluctuations for an extended period of time after submersion; individual sites representative of each response type are shown in **Figure 9-27**. Locations that continued to have substantial fluctuations (see FPCW_012 in **Figure 9-27**) were either less vegetatively dense due to recent earth movement during hydrologic restoration in Phase II/III or more open wet prairie habitat with less cover of invasive grasses such as West Indian marsh grass in Phase I. Investigations and floodplain DO sampling will continue in upcoming wet seasons and results will be presented in future SFERs.

Very low wet season DO levels at most floodplain sites seem to provide support for the floodplain inundation hypothesis. These low DO levels likely reflect a high BOD brought on by floodplain inundation, causing a system in which respiration outweighs photosynthesis. As flow rises above 1,400 cfs, the river channel and floodplain come into hydrologic contact. This mixing effect may have been captured in mid-July 2021 when river channel DO levels declined below the levels seen upstream in the C-38 Canal shortly after S-65A discharge was increased above 1,400 cfs (**Figure 9-25**).

With inundation of the floodplain, total organic carbon (TOC) grab sample values in the restored area (KREA93, near KRBN) and downstream of it (S-65D) started to diverge in mid-August from values measured upstream of the restored area (S-65A) suggesting an influence of floodplain inundation (**Figure 9-28**). On August 16, TOC values at S-65D (19.8 mg/L) were 44% higher than they were at S-65A (13.1 mg/L); this coincided with a river daily DO average of 0.3 mg/L where the grab sample of DO at S-65A was 4.29 mg/L as compared to 0.93 mg/L at S-65D. These increased channel TOC levels could be causing an increase in BOD and in turn causing the observed decline in channel DO levels. Investigation into previous events is ongoing as well as the addition of new equipment for collection of continuous data for a surrogate measure of TOC, fDOM, at two sites (PC11 and KRDR02). The floodplain inundation hypothesis will continue to be explored as this new data is collected and analyzed.

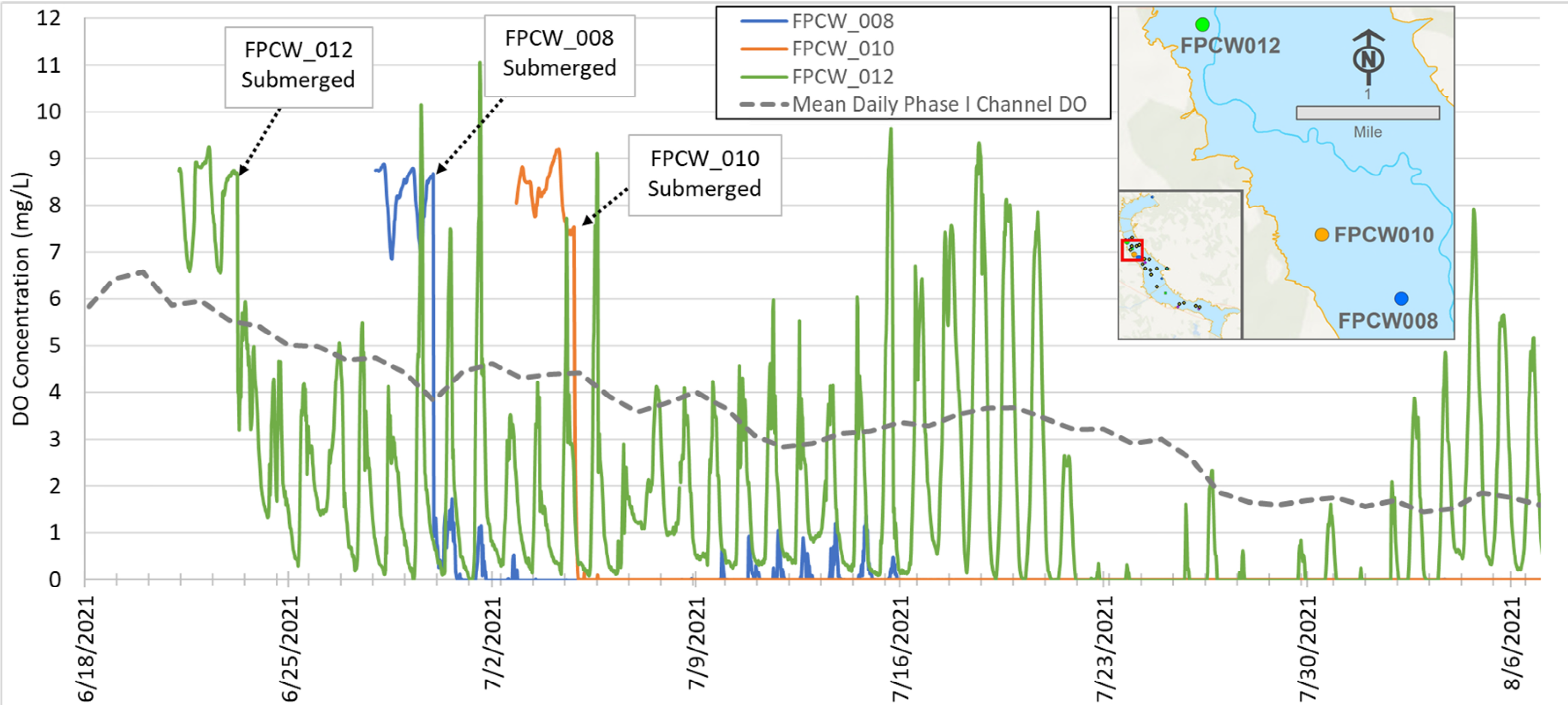


Figure 9-27. DO on the Kissimmee River and selected floodplain (FPCW) sites during the June 2021 hypoxic/anoxic events (floodplain site locations shown in the inset map). Arrows point to when sondes became submerged and switched from readings of ambient air to DO concentrations in the water. FPCW_010 demonstrates the rapid decline to 0 mg/L DO as seen in 11 of the sites, FPCW_008 shows a rapid decline followed by occasional increases above zero as seen at 5 sites, and FPCW_012 shows continued substantial diurnal fluctuations in DO as seen at 5 sites.

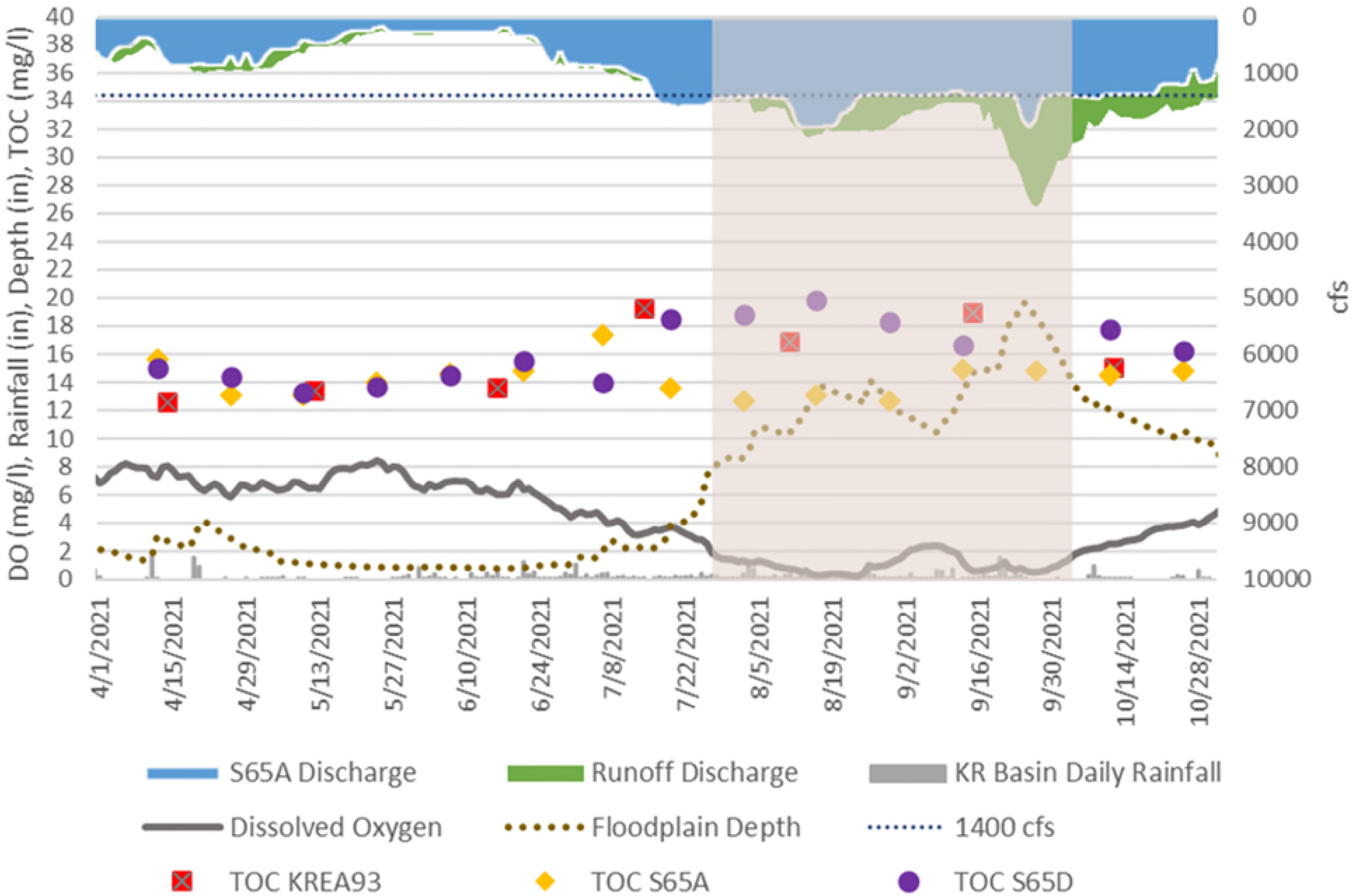


Figure 9-28. Average DO concentrations at sampling stations PC62, KRBN, PC33, PD62R, and PD42R in the Kissimmee River channel of the Phases I and III–IV. Runoff cfs is calculated as the difference between S65D cfs and S65A cfs and floodplain depth is average water depth in inches (in) for Phase I. Shaded area is the time the river was in a DO sag during PW2022. TOC grab samples are depicted before the restored area (S-65A), in Phase I (KREA93, near KRBN), and after the restored area (S-65D). Notice the divergence in TOC values as floodplain depth increases, possibly showing connectivity between the floodplain and river channel.

FLOODPLAIN VEGETATION MANAGEMENT ISSUES AND ACTIVITIES

During the Interim Period of the KRRP (the period since 2001 when Phase I construction was completed through present), several significant vegetation management issues have arisen that require adaptive management action. The primary vegetation management issues within the KRRP are as follows:

- Invasion of floodplain wet prairie and broadleaf marsh (BLM) habitat by exotic grasses listed on the *2019 FLEPPC's* (Florida Exotic Pest Plant Council's) *List of Invasive Plant Species* (FLEPPC 2019). These are primarily West Indian marsh grass (*Hymenachne amplexicaulis;* Category I), paragrass (*Urochloa mutica*; Category II), and limpo grass (*Hemarthria altissima*; Category I), all of which are displacing native species.
- Invasion of former spoil areas, the backfilled C-38 Canal, and other disturbed soils by the native Carolina willow (*Salix caroliniana*) and the exotic Peruvian primrosewillow (*Ludwigia peruviana*).
- Invasion of wet prairie and former BLM habitat by wax myrtle (*Myrica cerifera*) and other facultative shrubs. For more information on facultative plants, see Rule 62-340.450, Florida Administrative Code (F.A.C.) and https://floridadep.gov/water/submerged-lands-environmental-resources-coordination/content/wetland-delineation-vegetative.

The long-term management goal for the KRRP is to rely primarily on hydrologic change and prescribed fire to reestablish and maintain pre-channelization floodplain marshes; using herbicide and mechanical treatments only when necessary to achieve 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 will 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 primarily on hydrologic change and prescribed fire:

- Hydrologic change through implementation of the Headwaters Regulation Schedule (HRS) is expected to begin in 2026. Expected changes include longer hydroperiods, greater stage amplitude, slower rates of stage change, and a more natural seasonality in discharge to the river from the 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*), water hyacinth planthopper (*Megamelus scutellaris*), and water hyacinth weevils (*Neochetina* spp.). See Chapter 7 of this volume for more information on biocontrol agents used on SFWMD lands.
- In PW2022, three prescribed burns were conducted (see below) and herbicide application and biocontrol agents were used toto continue to address the vegetation management issues described above.

Prescribed Fire

The District 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 lightning season (late spring and early summer) will help reduce coverage of exotic grasses and invasive shrubs by direct consumption and enhancing 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.

In PW2022, three prescribed burns were conducted within the KRRP area in Oak Creek, Starvation Slough, and Fort Basinger Management Areas (**Figure 9-29**). Prior to the burns, colder than normal conditions led to a frost that damaged many grasses, including exotics such as paragrass and West Indian marsh grass, in this region. The Fort Basinger burn covered approximately 173 ac and was conducted on February 18, 2022, with the burn mostly in adjacent upland habitats. The other burns were conducted in the area near Starvation Slough and Oak Creek. On February 23 and 24, approximately 1,240 ac were burned with efficient dispersion from the adjacent uplands all the way to the river's edge (**Figure 9-30**). Much of the floodplain had substantial invasions of exotic grasses, also top-killed by the frost, which led to increased fuel for the fire. This likely aided the spread of the controlled burn to carry to the river channels' edge and into denser areas of Carolina willow on the floodplain, which normally does not burn well but had a dense understory of paragrass. On March 22, 2022, the third burn was conducted over approximately 358 ac. This burn was a continuation of the previous month's effort, intended to extend it further south into the Oak Creek Management Area, and it had similar efficacy.

Fire effects on vegetation are being monitored by SFWMD using permanent photo-monitoring points (examples can found in Chapter 9 of the 2022 SFER – Volume I; Koebel et al. 2022), aerial photography, and vegetation plots. Ground photo monitoring points and vegetation plots are monitored at 3-, 6-, 12-, and 24-months post-burn. Longer-term monitoring of vegetation will be conducted via aerial photo interpretation approximately every 3 to 5 years. Vegetation plots consist of a 3-meter radius circular plot centered on a permanent photo point where each species is identified and assigned a Daubenmire cover class (Daubenmire 1959). These data are used to estimate vegetation height, species richness, composition, diversity, and coverage of native versus exotic vegetation before and after management actions such as prescribed burns. The results of this monitoring will be used to assess the effects of fire on floodplain vegetation and help 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.

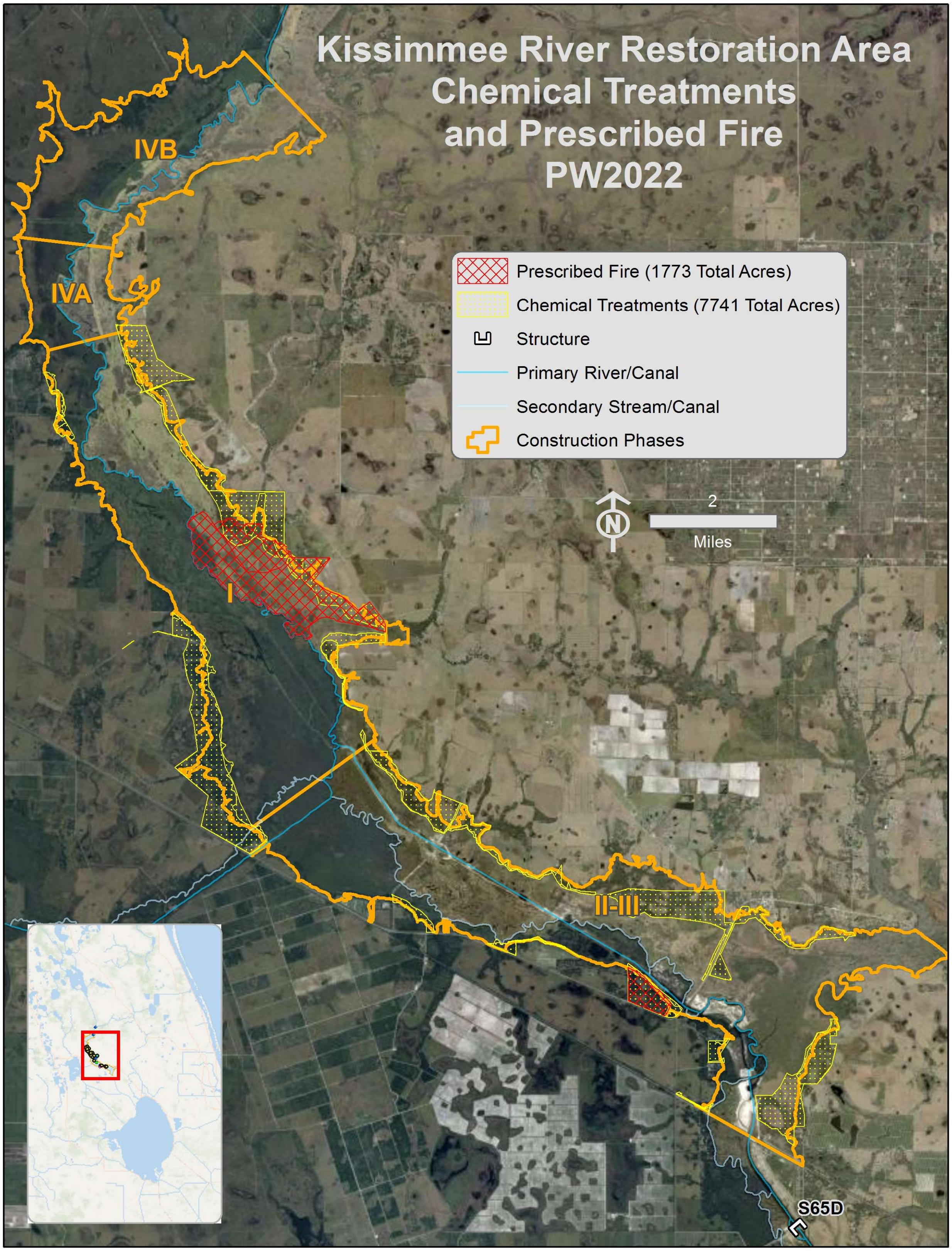


Figure 9-29. Map of locations of prescribed fire and chemical treatments within the KRRP area and directly adjacent District lands.

Figure 9-30. Photos from the edge of the Kissimmee River in Phase I near Starvation Slough during the February 24, 2022, prescribed burn (top) and approximately 1 week after (bottom).

Herbicide Treatments

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. Continued and enhanced interagency cooperation, coordination, and funding is vital to the long-term outcome of the KRRP. District funding for a long-term program of control and experimentation to find suitable methods will begin in PW2023, as detailed below.

Carolina Willow Treatments

The expansion of the native shrub Carolina willow in the Kissimmee River floodplain has resulted in replacement of herbaceous wetland communities and has become a hindrance in the restoration of these natural communities. State agencies, water management districts, and conservation groups that manage natural areas have experienced similar encroachment of Carolina willow elsewhere, and although there has been research into the management of this species in wetlands, no previous research has been conducted in the Kissimmee River floodplain where hydrologic conditions and restoration efforts are unique. To determine the best management practices to reduce Carolina willow populations while promoting desired native plant community recovery and establishment, experimental trials were developed and implemented in Pool B/C north of the Istokpoga Canal, and east of Hickory Hammock Wildlife Management Area. The experimental herbicide trials were designed to evaluate the efficacy and non-target impacts of three herbicide treatments that target Carolina willow. Preliminary results showed that all treatments under saturated conditions were successful with visual determination of defoliation and mortality of Carolina willow upwards of 90%. Additional details of experimental treatments and plots can be found in Chapter 9 of the 2022 SFER – Volume I (Koebel et al. 2022). Research is ongoing and additional results will be forthcoming in a future SFERs.

West Indian Marsh Grass Treatments

The primary vegetation management issue to be addressed during the remainder of the Interim Period and into the 5-Year Post-Construction Restoration Evaluation Period is the invasion of floodplain wet prairie and BLM habitat by several exotic grasses listed on the *FLEPPC's 2019 List of Invasive Plant Species*: primarily paragrass (Category II), limpo grass (Category I), and West Indian marsh grass (Category I) (FLEPPC 2019). While a combination of glyphosate and imazapyr is effective at killing invasive exotic grasses such as paragrass and torpedograss in Florida (Enloe et. al. 2020), as well as West Indian marsh grass in Australia (Cooperative Research Center for Australian Weed Management 2003), we do not have comprehensive information about its effect on West Indian marsh grass in Florida (Sellers et.al. 2008, Quincy and Enloe 2020). Starting in PW2023, the District is funding a contract with University of Florida to (1) address when is the best time to apply herbicide to this community in south-central Florida (wet season versus dry season) and (2) determine which infestation density and treatment combination provides the most rapid recovery of desirable native wetland species.

Twenty-four herbicide plots, 12 treatment and 12 control, will be established by the District prior to the start of monitoring. Each plot will be between 25 and 35 ac, totaling approximately 720 ac. The contractor will establish 10 permanent study quadrats with field markers in each treatment plots for a total of 240 quadrats (**Figure 9-31**). Specific locations and acreages are subject to change dependent on environmental conditions during study implementation. Once established, vegetation will be monitored within each permanent survey quadrat before each herbicide treatment, wet season (sample size [n] = 120 quadrats) versus dry season (n = 120 quadrats), and at 1, 3, 6, 9, and 12 months following each treatment. Field sampling will be staggered based on the initial dry season and wet season treatment dates. This will provide estimates of percent cover to statistically compare the herbicide treatment efficacy of (1) wet versus dry season and (2) exotic monoculture versus mixed vegetative communities.

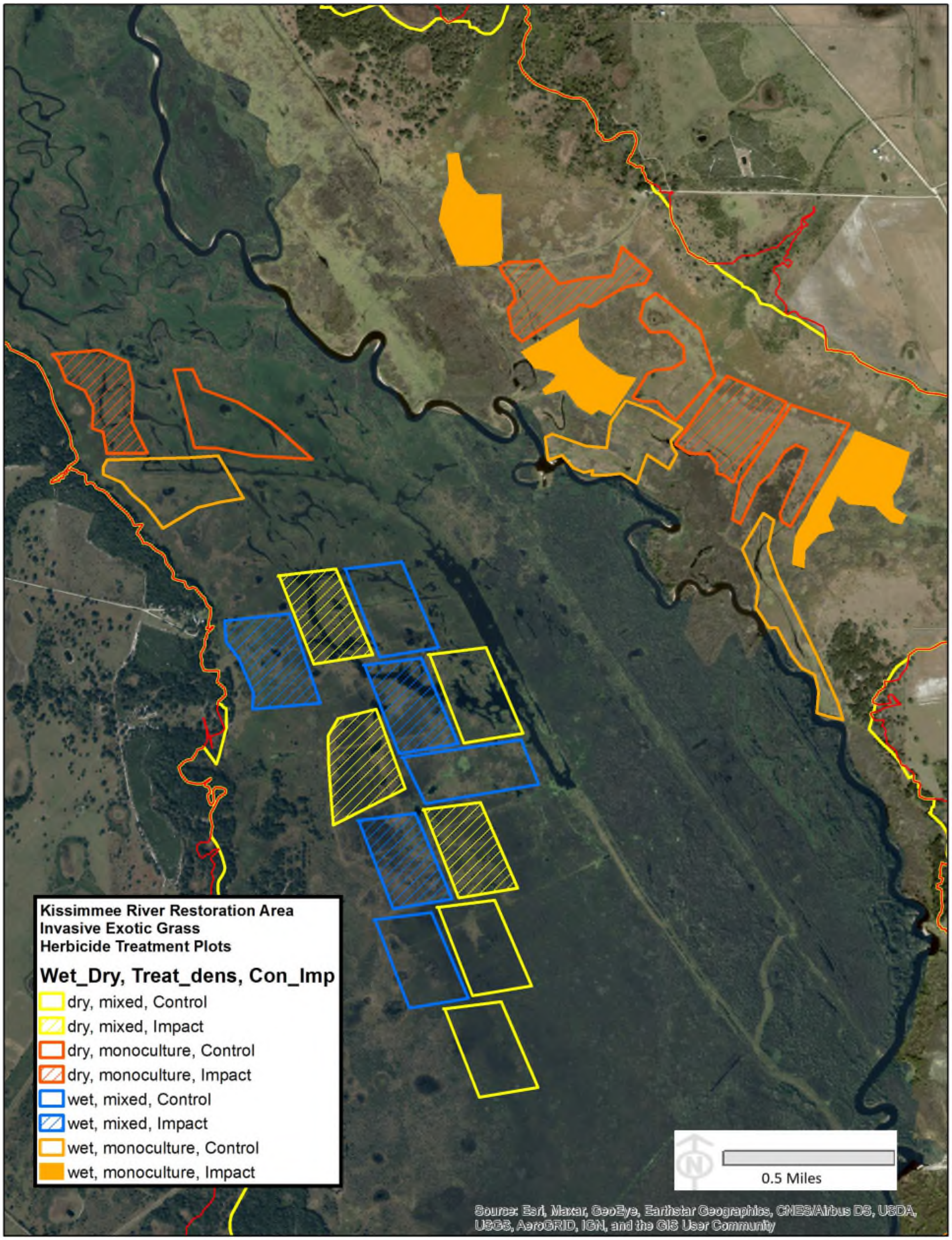


Figure 9-31. Location map and experimental plots for the invasive exotics grass study to commence in PW2023. Specific locations are subject to change dependent on environmental conditions during study implementation.

Knowledge of how West Indian marsh grass responds to treatment on the floodplain under different conditions will aid in developing optimal control strategies and improving treatment efficacy. Validation of these approaches and herbicides as viable tools for control of West Indian marsh grass will be of value to land managers at SFWMD as well as numerous stakeholders including other public and private land managers and farmers. This study will directly impact the decisions for operational herbicide treatments on the Kissimmee River in upcoming years to help achieve long-term management goals. Detailed methods and results will be presented in a future SFERs.

Upland Species 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 but mostly in associated uplands during PW2022 (**Figure 9-29**). The total area of these treatments was approximately 7,741 ac. For a more comprehensive summary of SFWMD herbicide treatments along the Kissimmee River, refer to Chapter 7 of this volume.

Biocontrol

To combat Old World climbing fern, populations of the brown lygodium moth (*Neomusotima conspurcatalis*) and eriophyid (*Floracarus perrepae)* mites have been introduced in general locations near Chandler Slough. Additional introductions and monitoring are ongoing. The United States Department of Agriculture monitors moth introduction sites at other locations outside of the LKB.

FISH STUDIES

Impact of the 2021 Anoxic Events and Other Environmental Conditions on Fish in the Kissimmee River

In the Kissimmee River, fish, especially gamefish, can experience physiological stress 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 Phase I and Phase IV of construction for KRRP were completed in 2001 and 2009, respectively, DO concentrations have generally improved (see the *Dissolved Oxygen* subsection above), 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, water management, and DO declines. The impacts of anoxic events that occurred in 2017, 2019, and 2020 have been reported previously (Koebel et al. 2018, 2020, 2021).

Low DO events in PW2022 occurred during the 2021 wet season when hypoxic and anoxic conditions persisted for 29 and 35 days, respectively. In this section, we summarize the impacts the low DO events had on fish, focusing on centrarchids (sunfish), an important group of gamefish that includes largemouth bass (LMB; *Micropterus salmoides*) and bluegill sunfish (*Lepomis macrochirus*), and compared this event to similar events that occurred in 2017, 2019, and 2020.

Methods

Beginning in 2014, fish were sampled annually by electrofishing in spring (May to June) during a period of within-bank flow (no floodplain inundation). Winter sampling began in 2017 and summer sampling was conducted in 2017 and 2019 to evaluate more closely how the river's fishery responds to large and sometimes prolonged declines in DO that are common during the wet season (summer months). Fish were sampled along randomly selected transects in the Phase I (n = 12) and Phase IV (n = 10) restoration areas at low speed using a double-boom electrofishing boat. Each transect followed a 150-meter (m) segment of river shoreline and was sampled for approximately 15 minutes (900 seconds). The exact sampling duration of each transect was used to calculate the catch per unit effort (CPUE) and biomass per unit effort (BPUE) for all species. All stunned fish were identified, measured to the nearest millimeter of total length (TL), weighed to the nearest gram, and released alive.

Spring sampling occurred during the two-week period from May 12 to May 26, 2021. No sampling occurred during the summer. Winter samples were collected January 6–January 13, 2022. Both sampling events occurred while DO concentrations were favorable for centrarchids (> 5 mg/L) (**Figure 9-32**).

Centrarchids and other fish species experienced substantial challenges when exposed to prolonged periods of anoxic conditions. To evaluate the effect of the most recent (summer 2021) anoxic events on the river's fishery, average CPUE and BPUE calculated for the May 2021 (pre-anoxic event) sample was compared with the means of samples collected during the post-anoxic period (winter 2021). Analyses focused on the centrarchid community as a whole and two important gamefish species within that group, LMB and bluegill sunfish. Bluegill sunfish is the most common centrarchid species observed in the river and when combined with LMB, these species account for most of the centrarchid biomass collected in the Kissimmee River since 2014.

Results and Discussion

During spring 2021, LMB were more abundant in Phase I (8.4 LMB per hour or LMB/hr) compared to Phase IV (6.8 LMB/hr). Following anoxic events in August and September 2021, the abundance of LMB declined to 5.4 LMB/hr in Phase I while the abundance of small bluegill sunfish, spotted sunfish (*Lepomis punctatus*), and warmouth (*Lepomis gulosus*) increased causing the overall abundance of all centrarchids to increase by 60%. In Phase IV, winter abundance of LMB increased to 11.2 LMB/hr while the abundance of most sunfish decreased, causing total centrarchid abundance to decline by 8 % (**Figure 9-33**). Neither of the measured changes in abundance were significant (Phase I, analysis of variance or ANOVA, variance between sample means or $F = 1.2$, $p > 0.25$ and Phase IV, ANOVA, $F = 0.5$, $p > 0.8$) likely due to a large variance between sampling locations in both phases of the river (**Figure 9-34**).

Centrarchid biomass (BPUE) increased during winter 2021 in both restored phases of the river, from 5.3 kg/hr (± 0.6) to 7.6 kg/hr (± 1.6) in Phase I (**Figure 9-35**), and from 5.9 kg/hr (± 1.4) to 10.9 kg/hr (± 3.4) in Phase IV (**Figure 9-36**). Although the increases in biomass were relatively large, 43 and 85% in Phase I and Phase IV, respectively, the changes were not significant (Phase I ANOVA $F = 1.86$, $p > 0.18$ and Phase IV ANOVA $F = 1.84$, $p > 0.19$), likely because of the large variability between sampling locations observed during the winter season (**Figure 9-37**).

In Phase I, LMB accounted for 77 and 71 % of the spring and winter biomass, respectively. LMB biomass increased from 4.1 kg/hr (± 0.7) in spring to 5.4 kg/hr (± 1.6) in winter. Small but additional increases in winter bluegill sunfish, spotted sunfish, and warmouth biomass added to the overall increase in biomass. In Phase IV, bluegill sunfish, spotted sunfish, and warmouth biomass all declined slightly while LMB biomass more than doubled to 8.3 kg/hr (**Figure 9-38**).

The increases in winter biomass observed in 2021 were opposite of the changes observed in 2017, 2019, and 2020 when centrarchid biomass declined between spring and winter samples following summer anoxic events (Koebel et al. 2018, 2020, 2021). Increases in winter LMB biomass in Phase I (**Figure 9-38**) and Phase IV (**Figure 9-39**) accounted for much the observed increases in total centrarchid biomass. The increase in LMB biomass was largely due to bass being larger during the winter season. In spring, bass averaged 319 mm and 317 mm TL in Phase I and Phase IV, respectively, and had an average weight of less than 0.5 kg. Average bass length and weight increased in winter to 377 mm and 1.02 kg in Phase I and 336 mm and 0.74 kg in Phase IV. It's likely that some of these larger fish were preparing to spawn and migrated into the area during the winter season.

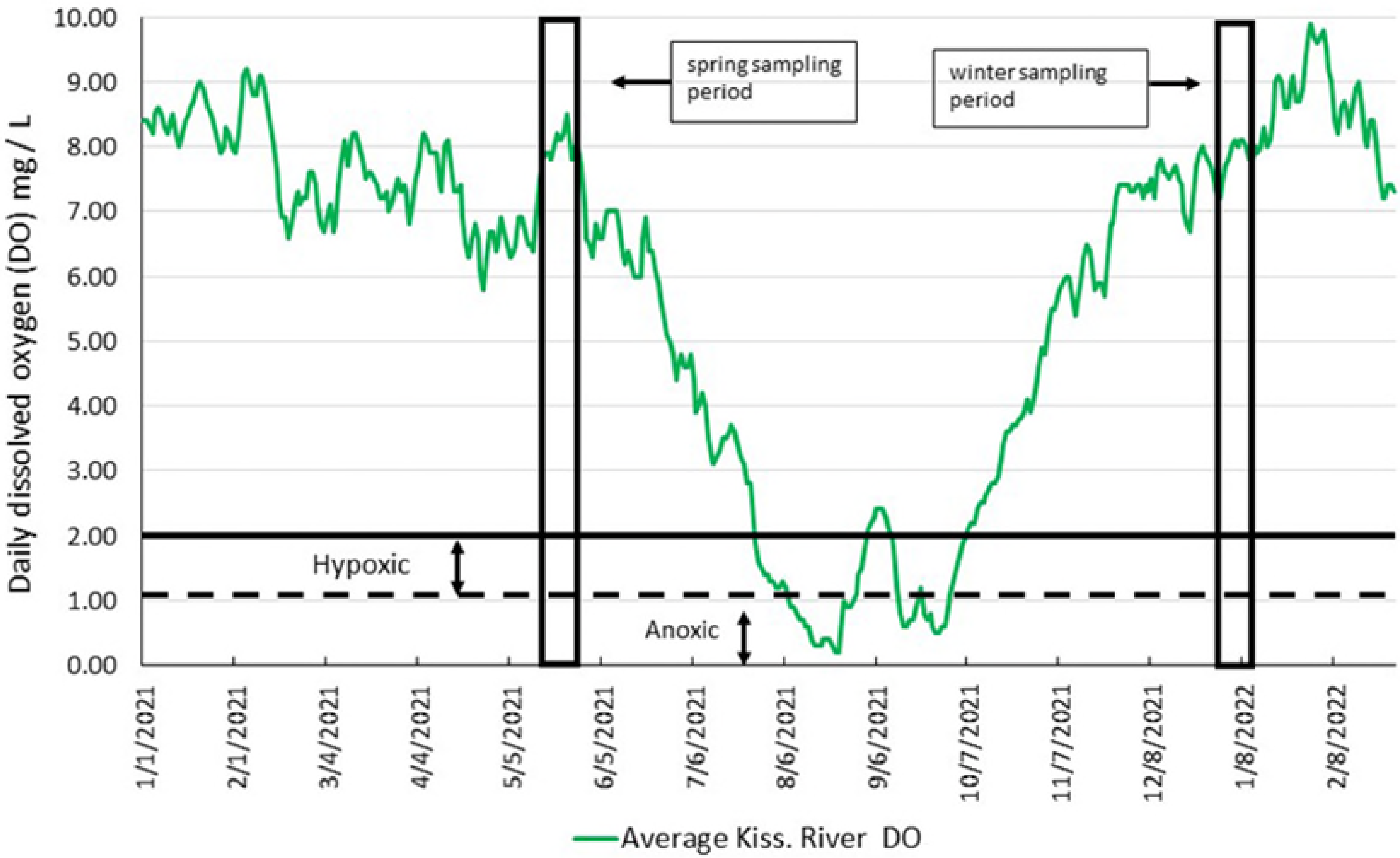


Figure 9-32. Daily dissolved oxygen (DO) concentrations (green line) in sections of the Kissimmee River with reestablished flow (January 1, 2021 – February 28, 2022) during the spring and winter sampling events. Black rectangular boxes indicate the period of fish sampling (spring and winter) and the corresponding DO at the time of sampling. Dissolved oxygen concentrations less than 1 mg/L are considered anoxic and will likely result in fish death.

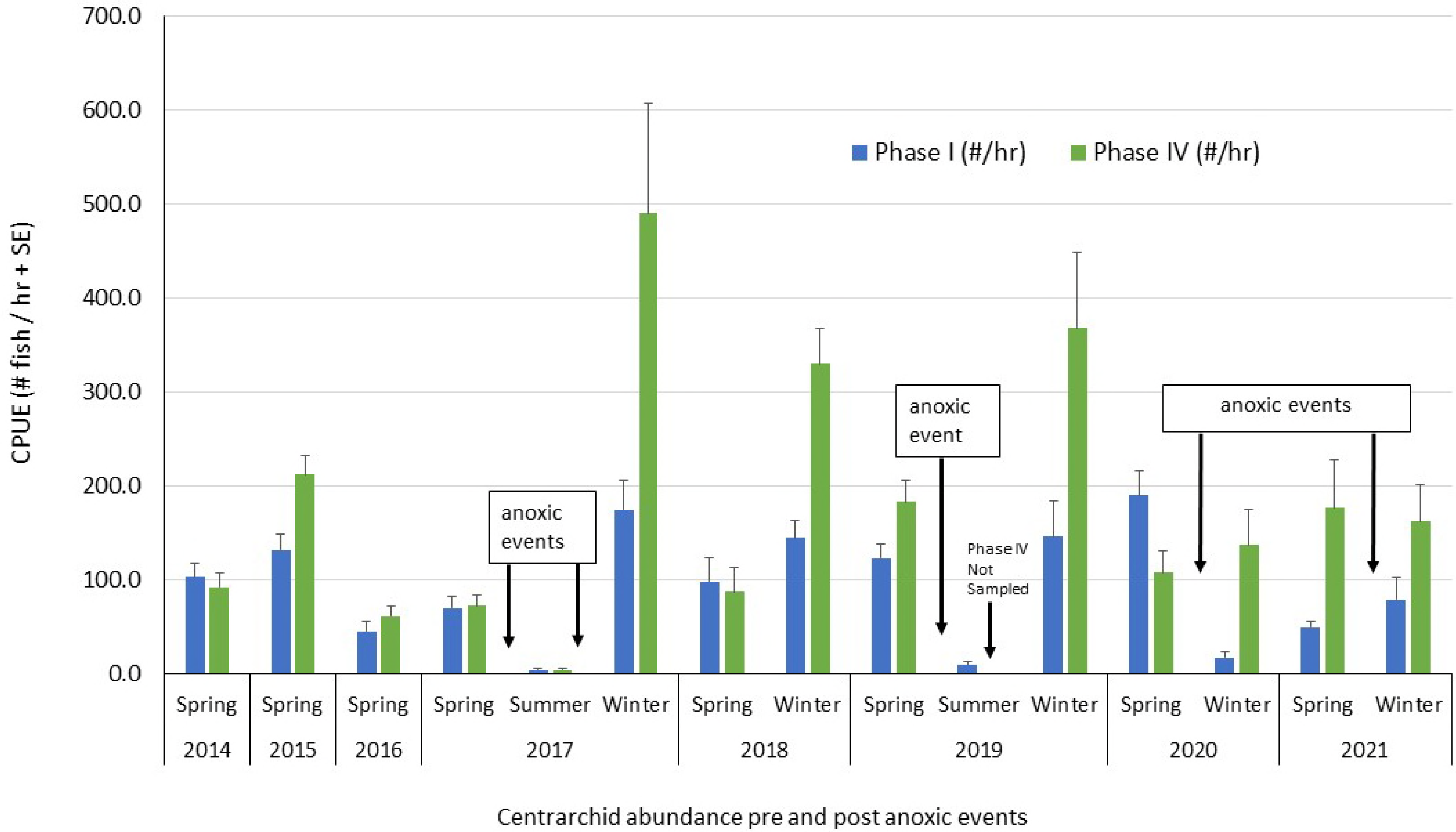


Figure 9-33. Mean CPUE (abundance) in number per hour (#/hr) of all centrarchid species collected in Phase I (blue bars) and Phase IV (green bars) during spring 2014–winter 2021. The 2021 winter sampling occurred in January 2022 (PW2022). Anoxic events exceeding 30 days total occurred during summers 2015, 2016, 2017, 2019, 2020, and 2021.

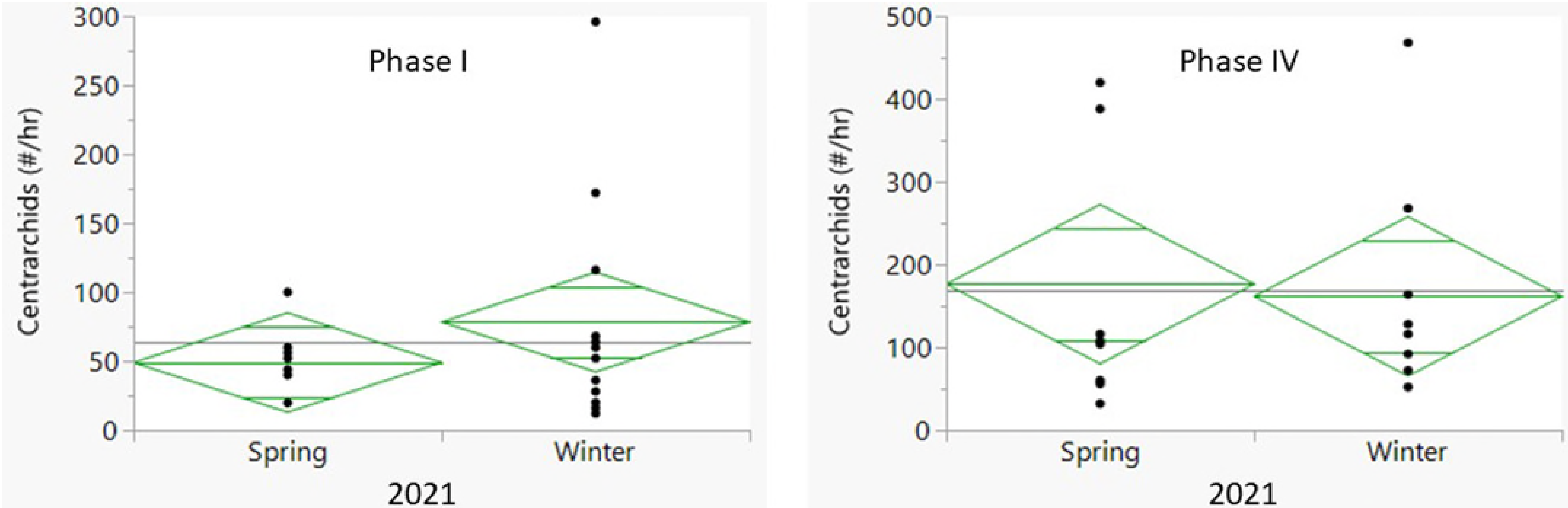


Figure 9-34. Mean number of centrarchids (mid-horizontal line inside triangle) collected in Phase I (left panel) and Phase IV (right panel) during spring and winter seasons 2021. Vertical points indicate CPUE values from individual sampling locations.

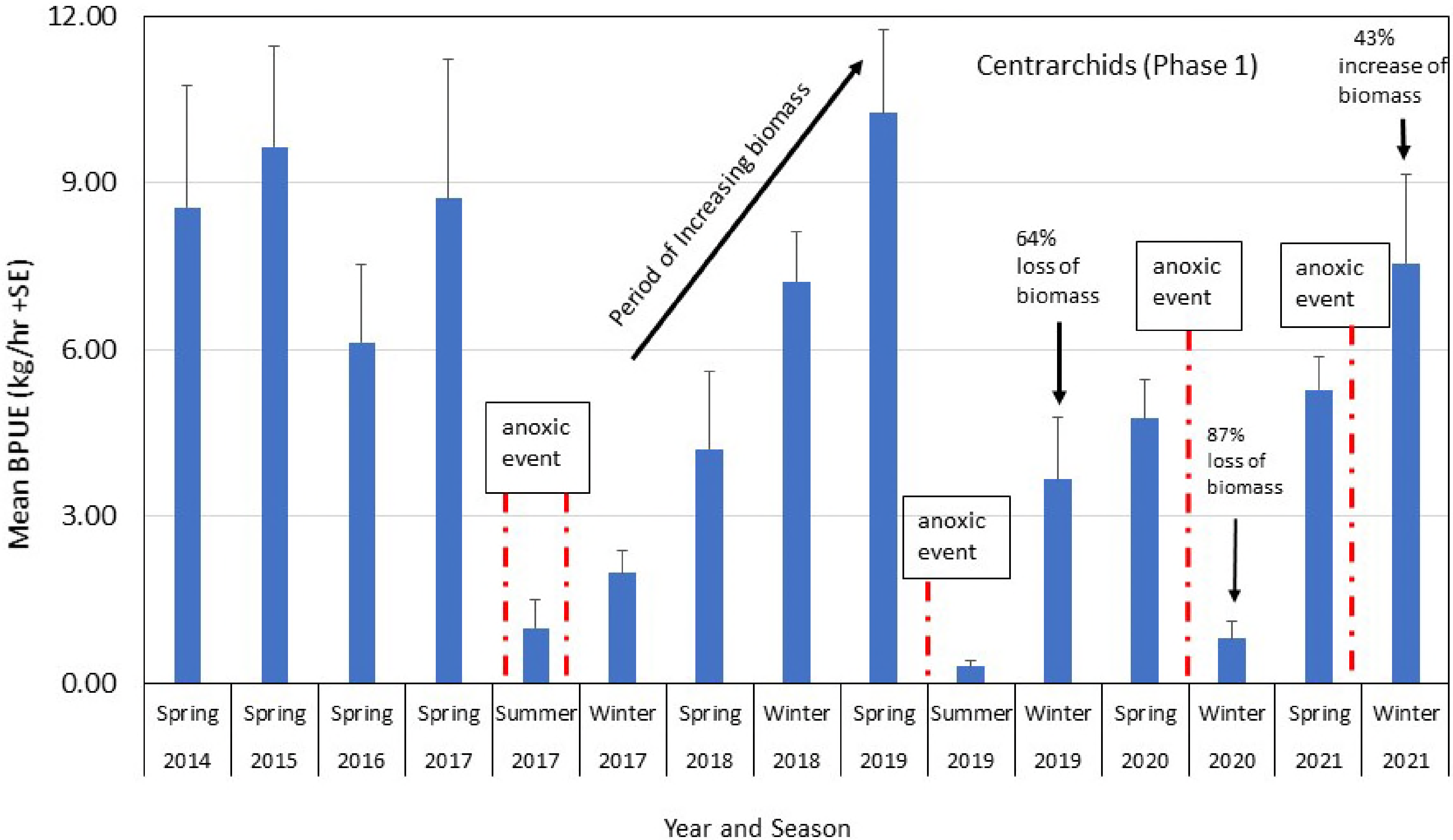


Figure 9-35. Mean biomass of all centrarchid species (kg/hour ± SE) collected prior to and after anoxic events (DO crash) that occurred during summers 2017, 2019, 2020, and 2021. The vertical red lines indicate the occurrence of anoxic events. Data were collected from 12 monitoring sites in the Phase I area of the Kissimmee River Restoration Project.

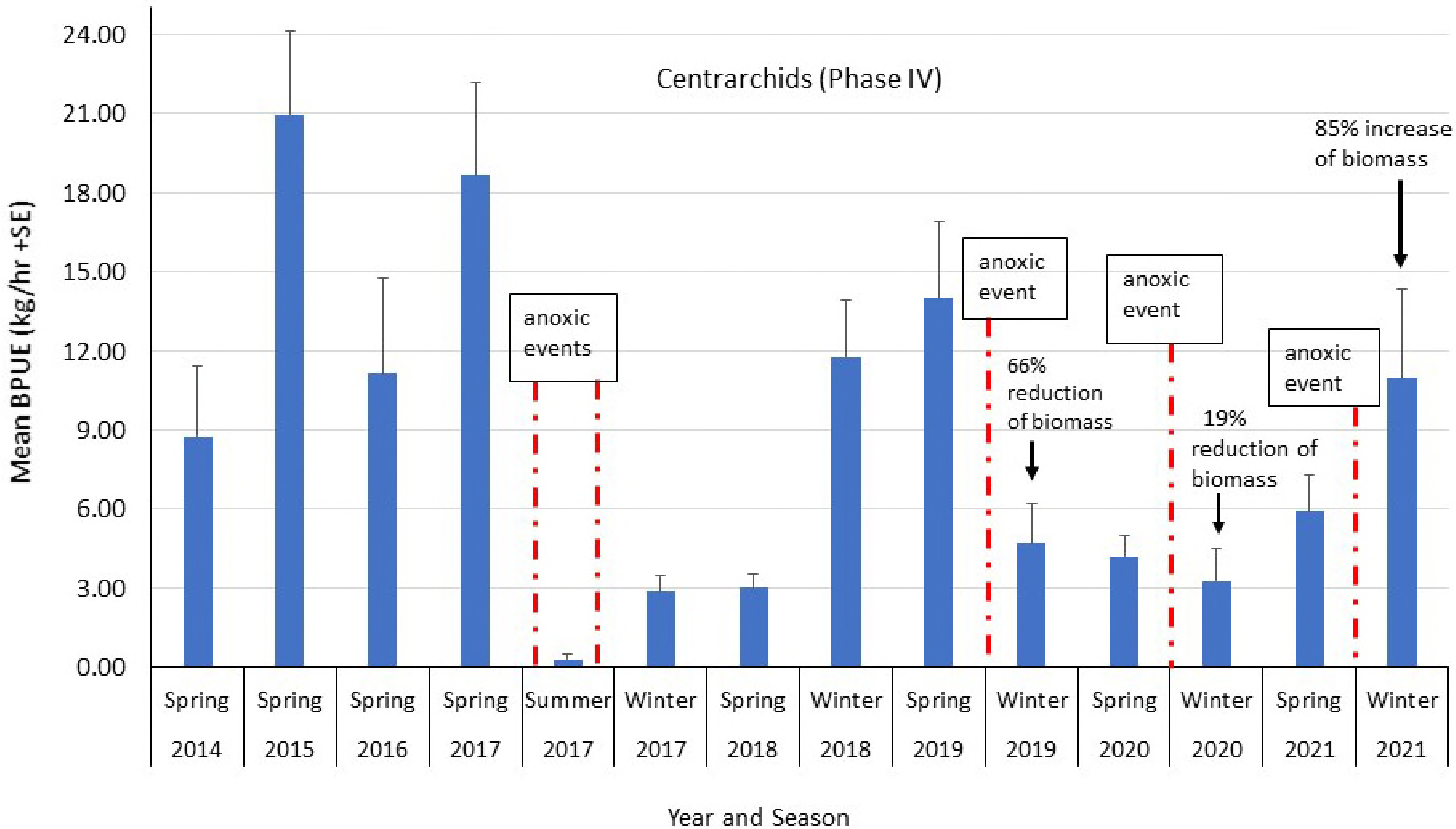


Figure 9-36. Mean biomass of all centrarchid species (kg/hour ± SE) collected prior to and after anoxic events (DO crash) that occurred during summers 2017, 2019, 2020, and 2021. The vertical red lines indicate the occurrence of anoxic events. Data were collected from 10 monitoring sites in the Phase IV area of the Kissimmee River Restoration Project.

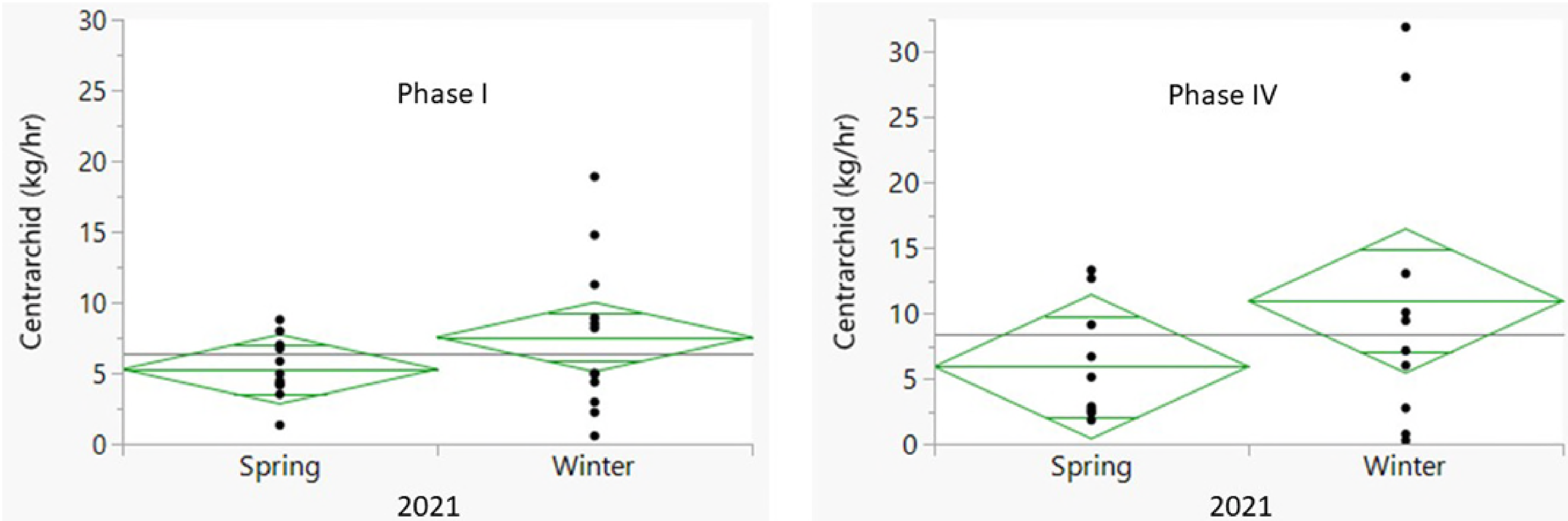


Figure 9-37. Mean centrarchid biomass (kg/hr) (center line inside each triangle) by season in Phase I (left panel) and Phase IV (right panel). Vertical points show biomass values for individual sampling locations.

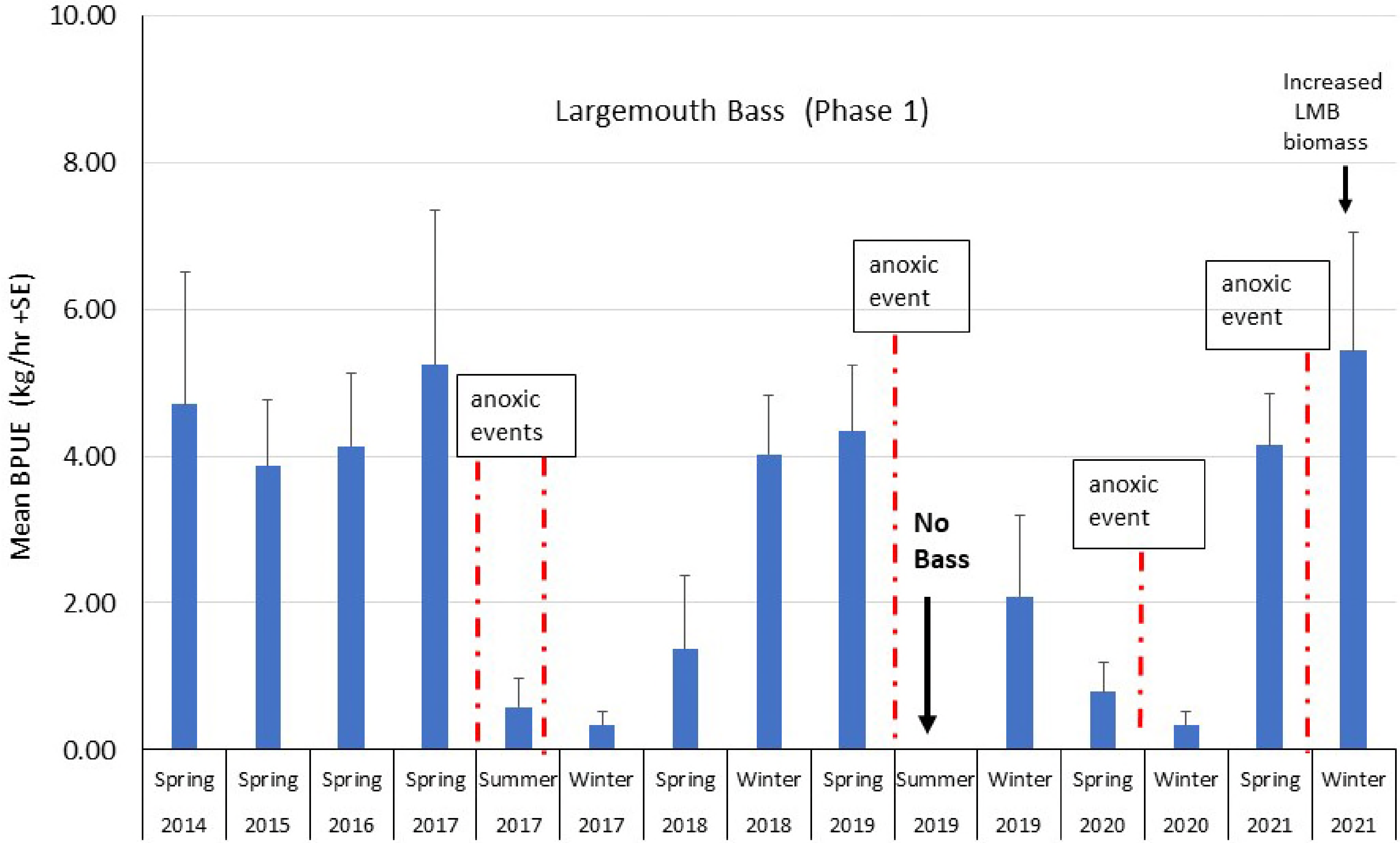


Figure 9-38. Largemouth bass (LMB) biomass (kg/hr ± SE) in Phase I by season and year.

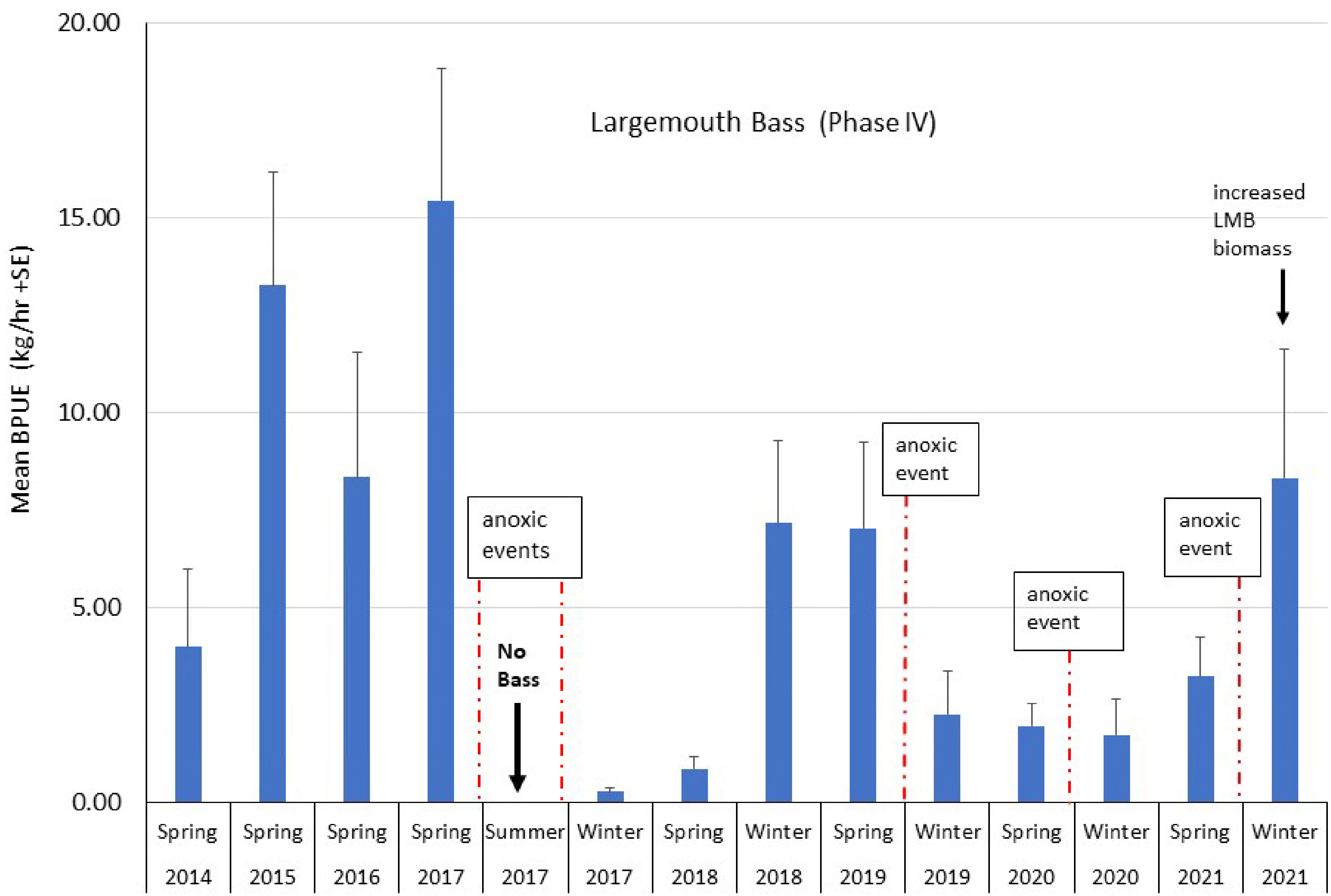


Figure 9-39. Largemouth (LMB) biomass (kg/hr ± S.E.) in Phase IV by season and year.

In addition to DO requirements, many fish species found in the Kissimmee River use floodplain habitat for both reproduction and feeding. Bass and bluegill depend on shallow floodplain areas for spawning because they prefer to build their nests in relatively shallow, open areas with sandy substrate. Water operations that limit or prevent access to floodplain habitat during spawning season is likely another factor impacting the river's centrarchid community. LMB in the region commonly spawn during the dry season (December–April) when water temperature is between 15 and 25 degrees Celsius (ºC) (Rogers and Allen 2009). Although the river typically has adequate DO for spawning in dry season (estimated at > 5 mg/L by Lee et al. 1980), the floodplain has been inundated during bass spawning season only three of the past eight years (**Figure 3-40**). Bluegill sunfish can spawn during both the dry (spring) and wet (summer) seasons when the floodplain is inundated. This extended spawning season may help them recover from the impacts of anoxic events more rapidly than LMB.

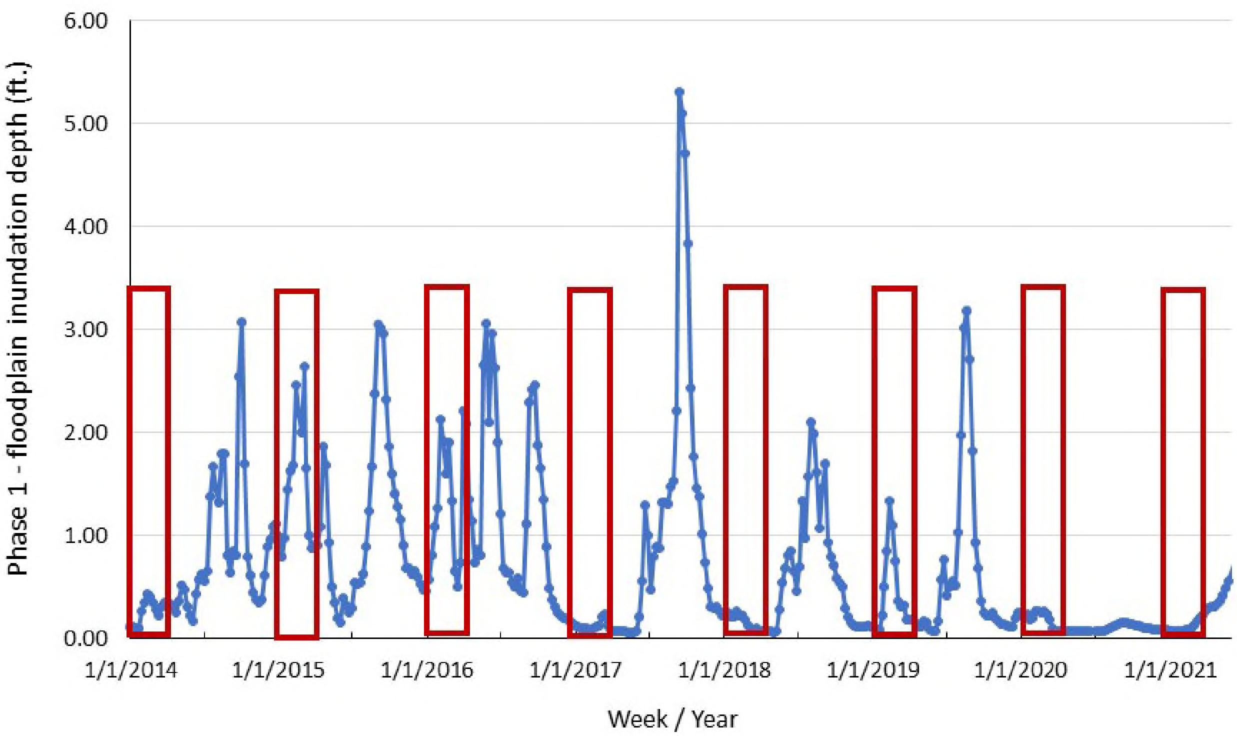


Figure 9-40. Hydrograph (blue line) showing the weekly average inundation depth of the Phase I floodplain (2014–2021). Red boxes represent the approximate spawning season (January–April) of largemouth bass. The floodplain was adequately inundated only during the 2015 and 2016 bass spawning season and for part of the 2019 season.

Telemetry Study – Monitoring Largemouth Bass Movement in the Kissimmee River

Due to the extreme loss in fish abundance and biomass that occurred in previous summer anoxic events, it is probable that some of the increases in centrarchid biomass observed during winter sampling the same year were due to fish migrating into Phase I and Phase IV from other regions. To evaluate the presence of LMB migration into and out of the restored region of the river, a multi-year telemetry tracking study was initiated in 2020 and continued through 2021. One hundred LMB were fitted with radio transmitters and unique external tags, 50 in January/February 2020 and an additional 50 in February 2021. Each year, 10 of the fish were collected and released in Lake Kissimmee, 10 in Pool A, and 30 in the restored section of the

Kissimmee River. Tagged fish ranged in size from 367 to 632 mm TL, were in good physical condition, and weighed 900 grams or more.

Passive and active tracking methods were used to monitor LMB movements in the river for a two-year period. Four stationary receivers were installed as passive tracking gates to detect emigration to the restored area from upstream or out of the restored area in either direction. These receivers were placed at monitoring stations S65, S65-A, and P33 in early 2020 and a fourth receiver was placed at Riverwoods Field Laboratory in spring 2021. The movement of tagged fish was actively monitored weekly or bi-weekly by boat. When a fish was located, time, depth, GPS location, water temperature, DO, habitat type, water velocity, and any other observations were noted, and behavior was categorized as stationary or moving.

During low flow conditions all LMB were found in the main river channel. During higher flow conditions, fish gained access into side channels and floodplain habitat and used these areas heavily, which are ideal for spawning and foraging. An example of seasonal habitat use, as influenced by flow, is evident in **Figure 9-41**, as the fish moved from river channel to floodplain when the latter was inundated.

Figure 9-41. Representative movements of fish Lotek 97 in upper Phase IV. The green and yellow points indicate fish location, and the numbers indicates the month it was located. This fish was present in the open channel and oxbows much of the time but during mid-summer 2021 when flows at S65-A were > 1,000 cfs this fish made regular use of the slough and floodplain habitat.

Across both years there were 1,427 detections of live LMB between S65-A and the Istokpoga Canal. Individual fish behavior varied with some fish regularly moving ~~multiple kilometers~~ up and down the river while others remain in the same general area for months. In 2020, all tagged fish remained alive through the end of April. As water temperature increased, DO decreased from an average greater than 6 mg/L in April and May, to less than 2 mg/L in June and less than 1 mg/L during the months of July and August. Only 4 LMB of the 30 originally released in the restored section of the river are believed to have survived the prolonged period of stressful low DO conditions during summer 2020. Two of the surviving fish remained in the canal or the upper part of Phase IV and may have survived low DO events by remaining in these areas for the duration of the summer.

At the start of the 2021 wet season (June), there were 30 live tagged LMB in the restored sections of the river. Twenty-six of the bass were tagged in February 2021 and the other four bass were tagged in 2020. The anoxic conditions during summer 2021 were apparently less severe than the previous summer. Only six of the 26 fish (23%) tagged in 2021 died during the low-oxygen period in August and all four fish surviving from 2020 lived through 2021. By September 2021, most of the fish were residing upstream of station KRBN. The DO had recovered to favorable levels by November 2021 in all areas of the river and by December 2021 the surviving fish were distributed between Istokpoga Canal and the lower C-38 Canal just upstream from Phase IV.

There was some exchange of fish between water bodies separated by control structures and between Pools C and D in both years. Five of the 20 fish tagged in Pool A moved into Lake Kissimmee. Three of the 20 fish tagged in Lake Kissimmee moved downstream into Pool A. Exchanges through structures were primarily during low flows during the dry season and migrations south out of the restoration area were during high flow/low DO conditions during the wet season. Movement of study fish upstream was just as common as fish moving downstream. The return of fish that had migrated south into, or perhaps beyond, Pool D indicates that movement of fish from downstream (south) into the restoration area is likely to be as or more important than fish moving downstream from the north.

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. In 2020, the river was anoxic for 64 days. Conditions improved somewhat in 2021 but the river remained anoxic for 35 days and hypoxic for another 29 days. The District continues to work to reduce the severity and duration of Kissimmee River hypoxic/anoxic events to the extent possible.

WADING BIRDS AND WATERFOWL

Birds are integral to the Kissimmee River 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, Florida Game and Fresh Water Fish Commission 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 2021-2022 dry season within PW2022 and compare recent data to the KRREP avian restoration expectations. Statistical significance was evaluated at $\alpha = 0.05$.

Wading Bird Abundance

Expectation 24

[a] Mean annual dry season density of long-legged wading birds (excluding cattle egrets) on the restored floodplain will be ≥ 30.6 birds per square kilometer or birds/km^2 (3-year running average) and

[b] at least 85% of the monthly surveys will have ≥ 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 2002–2021 = 39.0 ± 3.0 birds/km^2; (**Figures 9-42** and **9-43**). The long-term annual three-year running mean (2002–2022) is 41.4 ± 3.2 birds/km^2, significantly greater than the restoration expectation of 30.6 birds/km^2 (t-test, $p < 0.002$, Williams and Melvin 2005b). Annual three-year running means have been significantly greater than the restoration expectation of 30.6 birds/km^2 in only 5 of the past 19 years of the survey period 2002-2022. These were 2002-2004, 2003-2005, 2004-2006, 2005-2007, and 2018-2020.

Mean monthly wading bird abundance within the restored portions of the river during the 2021–2022 dry season was 25.1 ± 7.9 birds/km^2), bringing the three-year (2019–2022) running average to 25.3 ± 5.1 birds/km^2, not significantly greater than the restoration expectation of 30.6 birds/km^2 (t-test, $p = 0.16$, **Figure 9-43**). Only two of the seven surveys (29%) in the 2021-2022 dry season recorded ≥ 30.6 birds/km^2, well below the restoration expectation of at least 85%.

Rainfall during the 2021-2022 dry season was near average in the Upper Kissimmee Basin (102% of average) and below average in the Lower Kissimmee Basin (67% of average), while the preceding wet season rainfall was near average in both basins (91 and 101% of average, respectively). Well above average numbers of wading birds were observed during the first two flights of the season (November and December), following a rapid recession of water levels on the floodplain in November that led to optimal foraging conditions. Water levels continued to decline up to the January 4 survey date, by which wading bird numbers had declined by approximately 60% and floodplain water depths averaged approximately 0.21 ft (**Figure 9-44)**. Bird numbers remained below average for the remainder of the dry season as water levels fluctuated widely (~0.95 ft) from mid-January through the end of May, causing at least two ecologically significant reversals (water level increases) of > 0.25 ft on the floodplain in February and April (**Figure 9-44**). Such reversals during the dry season typically decrease prey availability for wading birds by dispersing prey items over a larger surface area of the floodplain and greater depth.

As in previous years, white ibis (*Eudocimus albus*) dominated the surveys numerically (2,193, 50.1%), followed in order of abundance by small white herons (snowy egrets [*Egretta thula*] and juvenile little blue heron [*Egretta caerulea*]; 702, 16.0%), great egret (*Ardea alba*; 513, 11.7%), great blue heron (*A. herodias*; 280, 6.4%), roseate spoonbill (*Platalea ajaja*; 244, 5.6%), glossy ibis (*Plegadis falcinellus*; 183, 4.2%), small dark herons (tri-colored herons [*Egretta tricolor*] and adult little blue heron; 74, 1.6%), wood stork (*Mycteria americana*; 36, 0.8%), and black-crowned and yellow-crowned night herons (*Nycticorax nycticorax* and *Nyctanassa violacea*, 148, 3.7%).

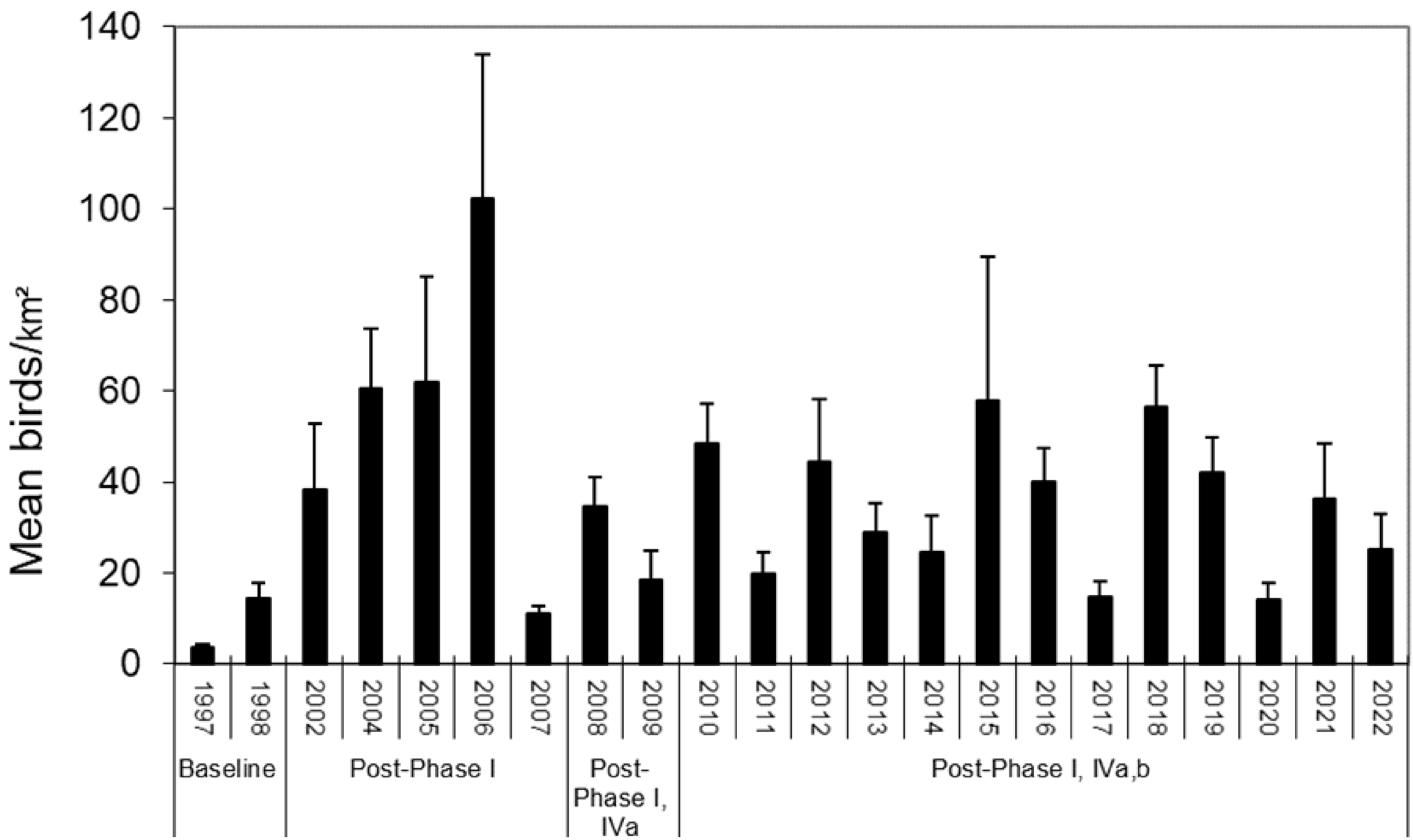


Figure 9-42. Baseline and post-Phases I, IVA, and IVB mean abundance ± SE of long-legged wading birds/km^2, excluding cattle egrets, during the dry season (December–May) within the 100-year flood line of the Kissimmee River.

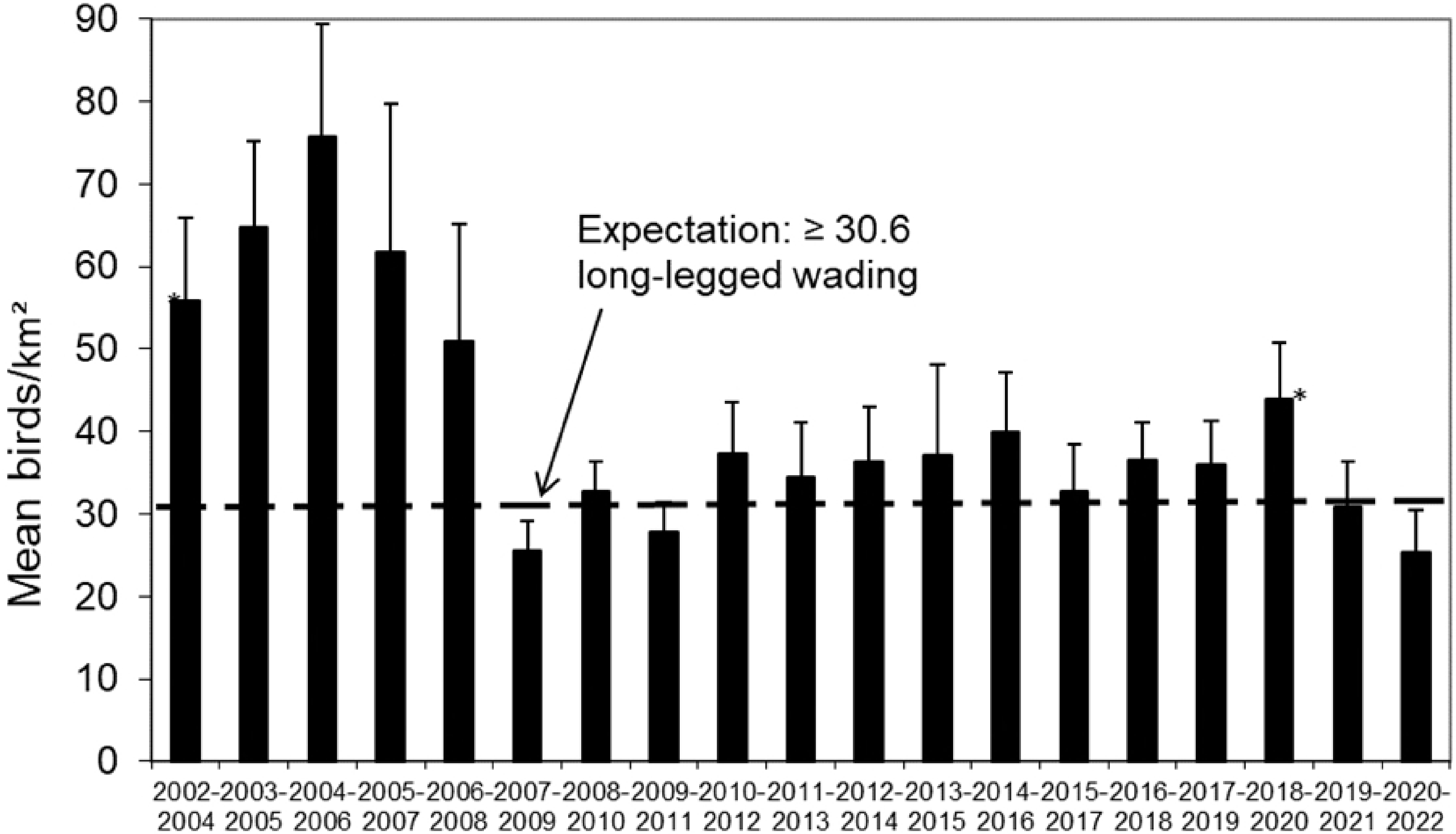


Figure 9-43. Post-restoration abundance as three-year running averages ± SE of long-legged wading birds/km^2, excluding cattle egrets, during the dry season (December–May) within the Phase I, IVA, and IVB restoration areas of the Kissimmee River. An * indicates significantly greater than the restoration expectation of 30.6 birds/km² (t-test, p-value < 0.05).

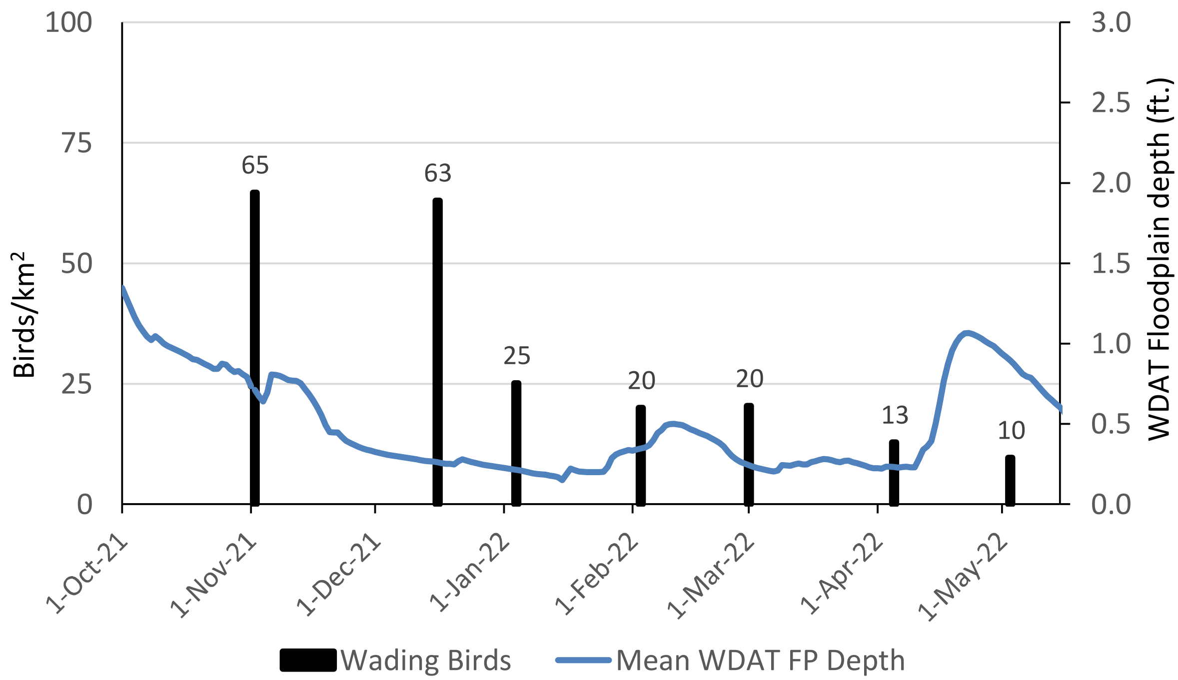


Figure 9-44. Wading bird abundance versus mean floodplain (FP) depth in the KRRA (Phases I, IVA, and IVB) during the 2021-2022 dry season (November–May). Floodplain depth is obtained from the South Florida Water Depth Assessment Tool (WDAT; Godin 2012).

Waterfowl Abundance and Species Richness

Expectation 25

[a] Winter (November–March abundance of waterfowl within the restored area of the floodplain will be ≥ 3.9 ducks per square kilometer or ducks/km^2 (3-year running average) in at least 80% of the monthly surveys, and

[b] waterfowl species richness will be ≥ 11 (3-year species total).

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 3-year running average (2002–2022) of waterfowl abundance is 12.2 ± 1.4 birds/km^2, significantly greater than the restoration expectation of 3.9 birds/km^2 (t-test, $p < 0.001$) (**Figure 9-45**). Annual 3-year running means were significantly greater than the restoration expectation of 3.9 birds/km^2 in 13 of the past 19 years of the survey period 2002–2022 (t-test, p-values < 0.05). Periods that were not significantly greater than the target value were 2004-2006, 2005-2007, 2006-2009, 2007-2010, 2019-2021, and 2020-2022 (**Figure 9-46**).

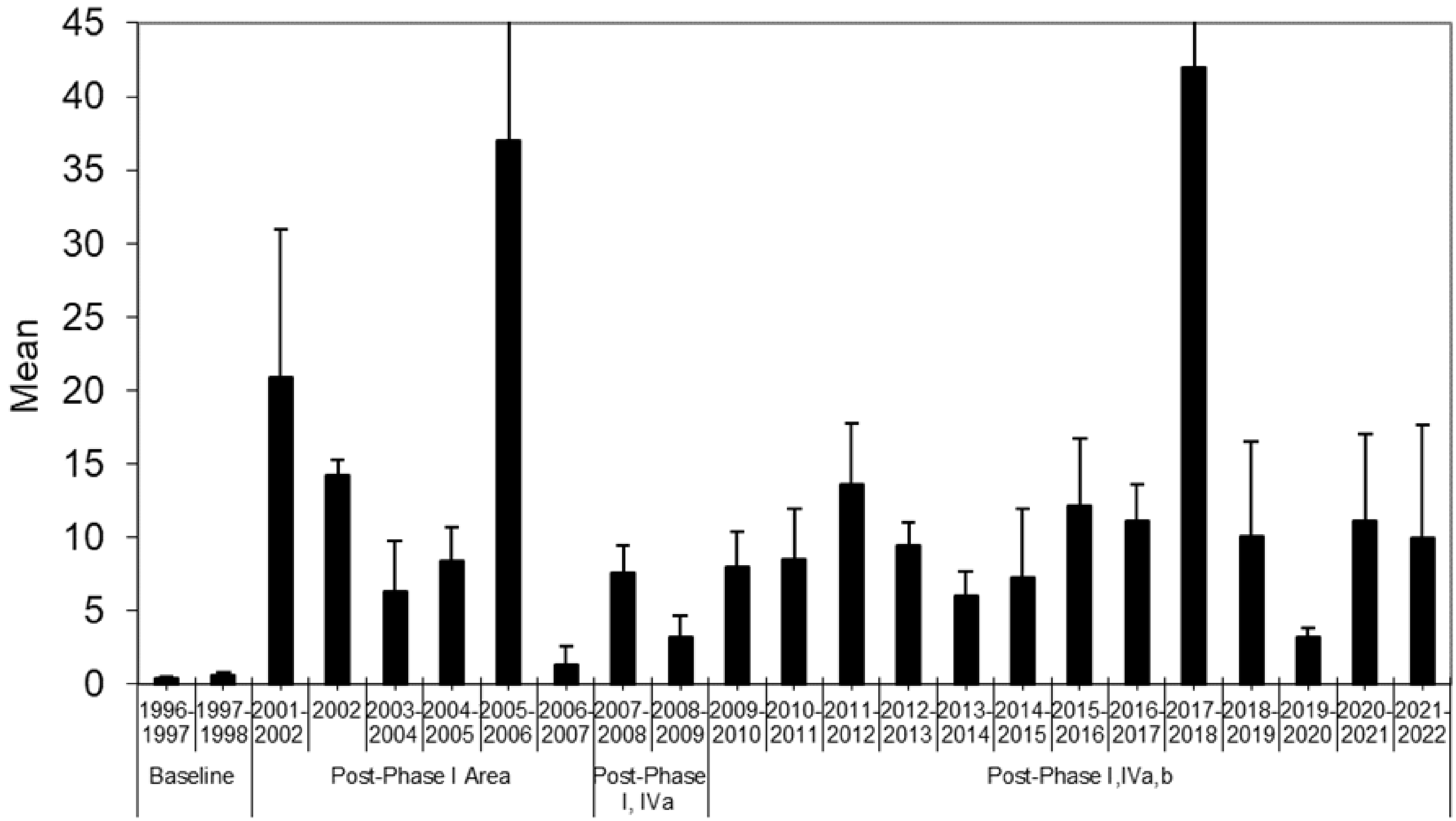


Figure 9-45. Baseline and post-Phases I, IVA, and IVB mean abundance ± SE of waterfowl during winter (November–March) within the 100-year flood line of the Kissimmee River. Baseline abundance was measured in the Phase I area prior to restoration. Measurement of post restoration abundance began approximately nine months following completion of Phase I.

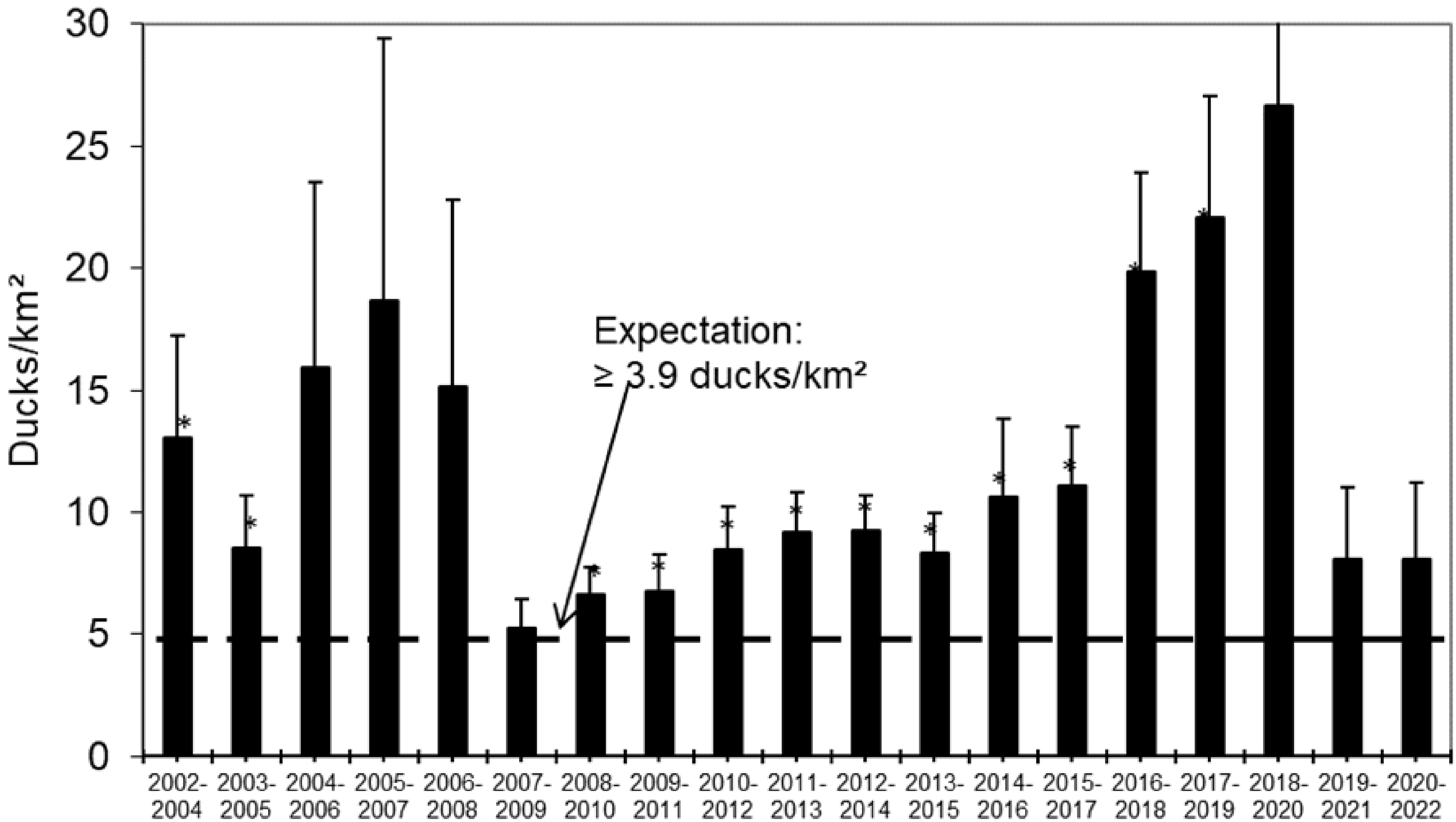


Figure 9-46. Post-restoration abundance as 3-year running averages ± SE of waterfowl (ducks/km^2) during the winter (November–March) within the Phase I, IVA, and IVB restoration areas of the Kissimmee River. An * indicates the average is significantly greater than the restoration expectation of 3.9 ducks/km² [t-test, p-value < 0.05].

Waterfowl abundance during the 2021-2022 dry season was 10.0 ± 7.7 ducks/km², bringing the 3-year (2020-2022) running average to 8.1 ± 3.1 ducks/km², not significantly greater than the restoration target of 3.9 ducks/km² (t-test, p-value = 0.10) (**Figures 9-45** and **9-46**). Since 2001, annual duck abundance has ranged from 42.0 ± 11.2 ducks/km^2 to 1.3 ± 1.3 ducks/km^2 (mean for 2002–2022 = 13.6 ± 1.8 birds/km^2). Two of the five monthly surveys (November and January) during winter 2021-2022 were above the restoration target of 3.9 ducks/km^2, but this was not enough to bring the seasonal average above the restoration target (**Figure 9-47**). This dry season also did not meet the secondary restoration expectations that at least 80% of the monthly surveys will record ≥ 3.9 ducks/km^2 and species richness will be ≥ 11 (3-year species total).

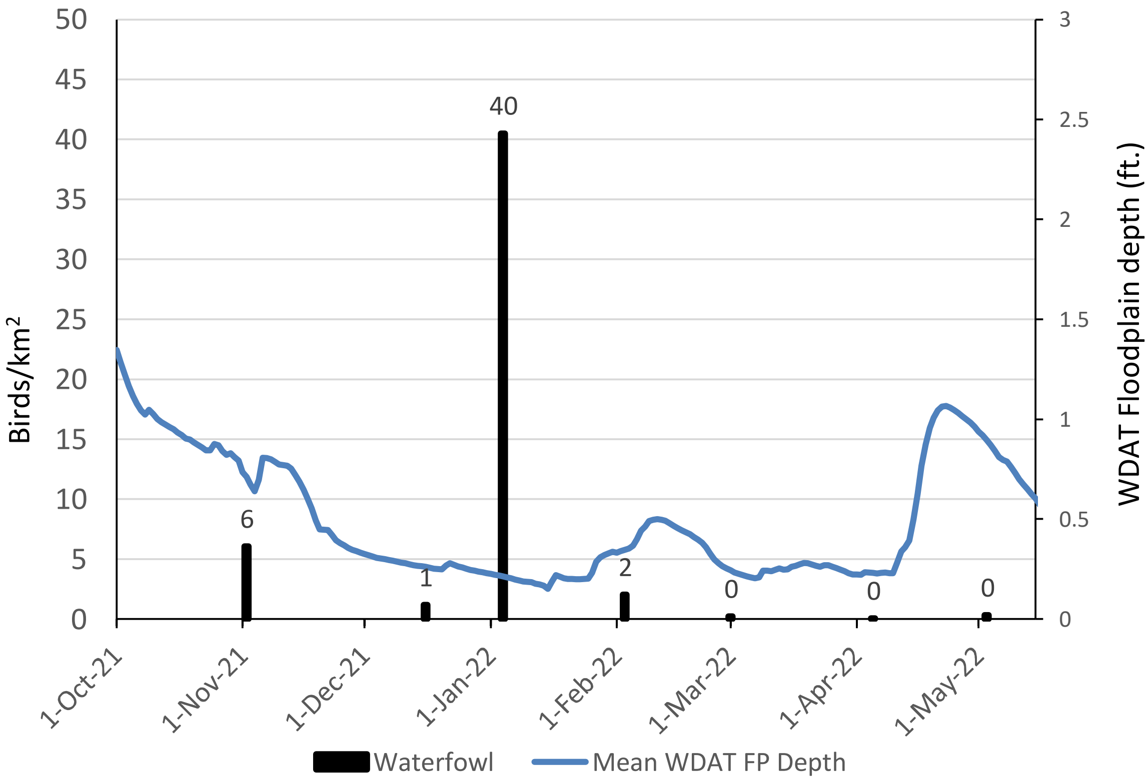


Figure 9-47 Waterfowl abundance versus mean floodplain depth in the KRRP area (Phases I, IVA, and IVB) during the 2021-2022 dry season (November 2021–May 2022). Source of floodplain depth data is the South Florida Water Depth Assessment Tool (WDAT; Godin 2012).

Interestingly this year, the northern pintail (*Anas acuta*), a species of duck not regularly observed on the floodplain, dominated numerically (631, 61.3%), followed by significantly lower numbers of mottled duck (160, 15.5%), teal (*Anas* sp.; 134, 13.0%), black-bellied whistling duck (*Dendrocygna autumnalis*; 99, 1.6%), hooded merganser (3, 0.3%), and fulvous whistling duck (*Dendrocygna bicolor*; 3, 0.3%). All of the northern pintails were observed in 3 large flocks along the same transect during the January survey. No other duck species were observed this year on the floodplain. The 3-year species total for 2020–2022 was 7 species, below the restoration target for waterfowl species richness of ≥ 11 species (3-year species total).

Although the American wigeon (*Mareca americana*), northern pintail, northern shoveler (*Spatula clypeata*), ring-necked duck (*Aythya collaris*), and black-bellied whistling duck were not detected during the baseline surveys, they have been present following restoration construction. However, these species are not regularly observed; therefore, the restoration target for waterfowl species richness (≥ 11 species) has yet to be reached on an annual or cumulative basis. Blue-winged teal and mottled duck remain the two most commonly observed species.

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.

UPPER KISSIMMEE BASIN

The Kissimmee Chain of Lakes (KCOL) and Upper Kissimmee Basin (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 portion of UKB 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 a variety 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.

MONITORING HEADWATERS REVITALIZATION AND THE UPPER KISSIMMEE BASIN

As the final component of KRRP, the HRS was designed to increase storage in the Headwater Lakes to provide appropriate flow patterns to the restored Kissimmee River and floodplain. KRRP construction was completed in 2021 and agencies are currently evaluating conditions paving the way to adoption of HRS. The increased storage that results due to higher maximum regulatory stages is also expected to improve the quantity and quality of littoral habitat in the Headwater Lakes. The HRS will increase regulatory stages and change the operating schedule for the S-65 structure, which controls discharge from and stage in 3 major waterbodies in the KCOL, including Lakes Cypress, Hatchineha, and Kissimmee (USACE 1996), together known as the Headwaters Lakes (**Figure 9-2**).

Vegetation Monitoring

Monitoring vegetation within the existing littoral zones and up to future lake regulation elevations is necessary to estimate the effects of HRS (USACE 1996) on the quantity and quality of littoral habitat in the Headwater Lakes (USACE 1996). The need for vegetation monitoring was also identified in the KUB 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 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 to address these needs. The first is a District project and involves tracking changes in specific plant community types over time and documenting whether distributional shifts up or down slope occur. The second is an FWC project and involves quantifying specific littoral communities via aerial imagery on a 3 to 5 year rotation in the major KCOL water bodies. The FWC is currently evaluating new methods for this project including the use of satellite imagery, therefore there are no new aerial imagery results to discuss for WY2022.

Permanent District Monitoring Stations

Long-term, permanent monitoring stations were established on three of the major water bodies in the KCOL (East Tohopekaliga, Tohopekaliga, and Lake Kissimmee) in early 2015, and sampled annually in August from 2015 to 2021 (WY2016–WY2022), excluding 2019 and 2020. Lake Kissimmee is the only lake of the three that will have a different regulation schedule under the HRS, with Lakes Tohopekaliga and East Tohopekaliga serving as control lakes for comparison. The permanent monitoring stations include belt transects set perpendicular to shore in the upper reaches of the littoral zone. The work presented here is preliminary and exploratory; for this reason, statistical significance and sample statistics were not evaluated for this report.

Methods

Three interrupted belt transects (Baker et al. 1987) have been established perpendicular to shore between the low and high water elevations of the current regulation schedules, and on Lake Kissimmee they extend upslope to what will be the high water elevation under the HRS (**Figure 9-48**). Perpendicular to each transect, two rectangular, 1 x 2-m quadrats were sampled 1 m from the transect at each half-foot elevation break (e.g., Frahn et al. 2014), totaling 7 sampling locations (two sub-samples each) on each transect for Lake Tohopekaliga and East Lake Tohopekaliga, and 11 for Lake Kissimmee. Lake Kissimmee transects include four additional sampling locations that extend from the current high pool elevation (52.5 ft NGVD29) to the future high pool elevation under HRS once it is fully implemented (54 ft NGVD29). Under the future schedule, water levels are expected to occur at these higher elevations more often and increased hydroperiods are expected to support more wetland species in these areas. For additional information about transect methodology see Koebel et al. 2019.

Plant species abundance is visually estimated using modified Daubenmire (1959) cover classes (Bousquin and Colee 2014) in the late summer/fall of each year. All transects were placed along grazed or mowed shorelines (plots at higher elevations extend into areas where vegetation is kept short by mowing or grazing). The number of species were plotted by elevation for each year on each lake and cubic spline smoother line (lambda 0.05 [JMP 2021]) was fit to the data to show general trends along shoreline gradients. Previously, cluster analysis using Sorenson distance measure and flexible Beta of -0.25 was used to identify four plant communities occurring along the transects: upland, and short-, medium-, and long-term hydroperiod communities. Species representative of each cluster were identified via indicator species analysis (Tichý and Chytrý' 2006, Koebel et al. 2019). Based on the indicator species analysis results, indicator species were separated into plant communities, and total abundance of each plant community was reported for each elevation, including the sampling locations on Lake Kissimmee that extend to the future high pool elevation (54 ft NGVD29).

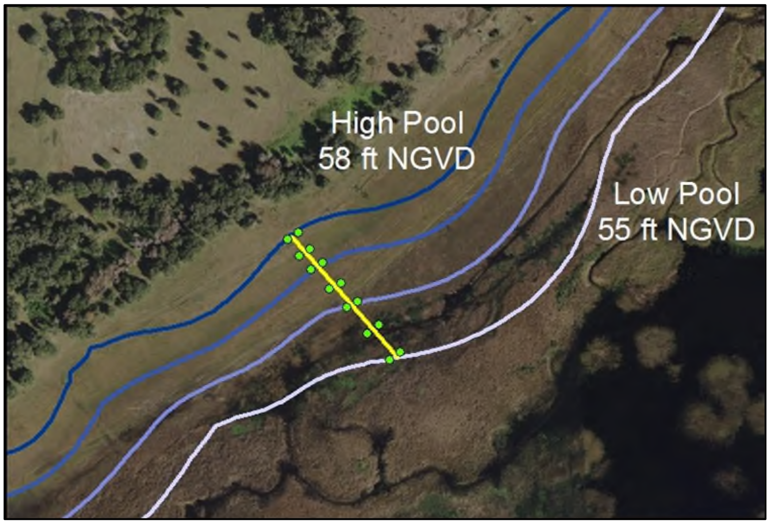


Figure 9-48. Example of line transects (yellow) and subsamples (green circles) are shown to demonstrate approximate locations spanning 58-55-ft elevation contours (ft NGVD29) on East Lake Tohopekaliga, or the maximum and minimum of the annual regulation schedule

Results

We recorded more species in the previous sampling effort (2018 or WY2019) along transects on Lakes Kissimmee and Tohopekaliga compared to previous years, which was a result of more Facultative Wet species (**Figure 9-49**). There were also more Obligate species recorded that year on Lake Kissimmee along most of the elevation gradient. In the most recent sample (2021 or WY2022), again more Facultative and Facultative Wet species were observed on both lakes. There was little variation in species richness observed on East Lake Tohopekaliga.

Grouping species into hydroperiod communities, we observed an increase in percent cover of Long and/or Medium Hydroperiod communities in all three lakes from 2017 to 2018, corresponding with a rather wet period that began in spring 2016 and culminated with Hurricane Irma in September 2017 (**Figure 9-50**). Although this period was wetter overall, water levels on Lake Kissimmee fell very low during a regional drought in late spring 2017, which coincided with Upland community species being observed at lower elevations in 2017. Following a year of continuous high water, a higher percent cover of the Long Hydroperiod community was observed on Lake Kissimmee in 2021 than in 2018, as well as more observations of these species at higher elevations suggesting expansion upslope. There was a managed drawdown on East Lake Tohopekaliga, followed by a wet 2020-2021 period, after which more upland species were observed at high elevations, a higher cover of Medium hydroperiod communities were observed at lower elevations, and there was a decrease in observed cover of Long Hydroperiod communities. This is typical of what is expected after a substantial decrease in water levels.

Discussion

The three lakes above differ in size, shape, and location in the watershed, resulting in different water level patterns in each. Multiple storms and highwater events affected areas of the KCOL throughout the sampling period, most notably Hurricane Irma in September 2017, which kept higher elevations inundated for multiple weeks in all three lakes (**Figure 9-51**). The following year, there were apparent declines in short hydroperiod communities in all three systems.

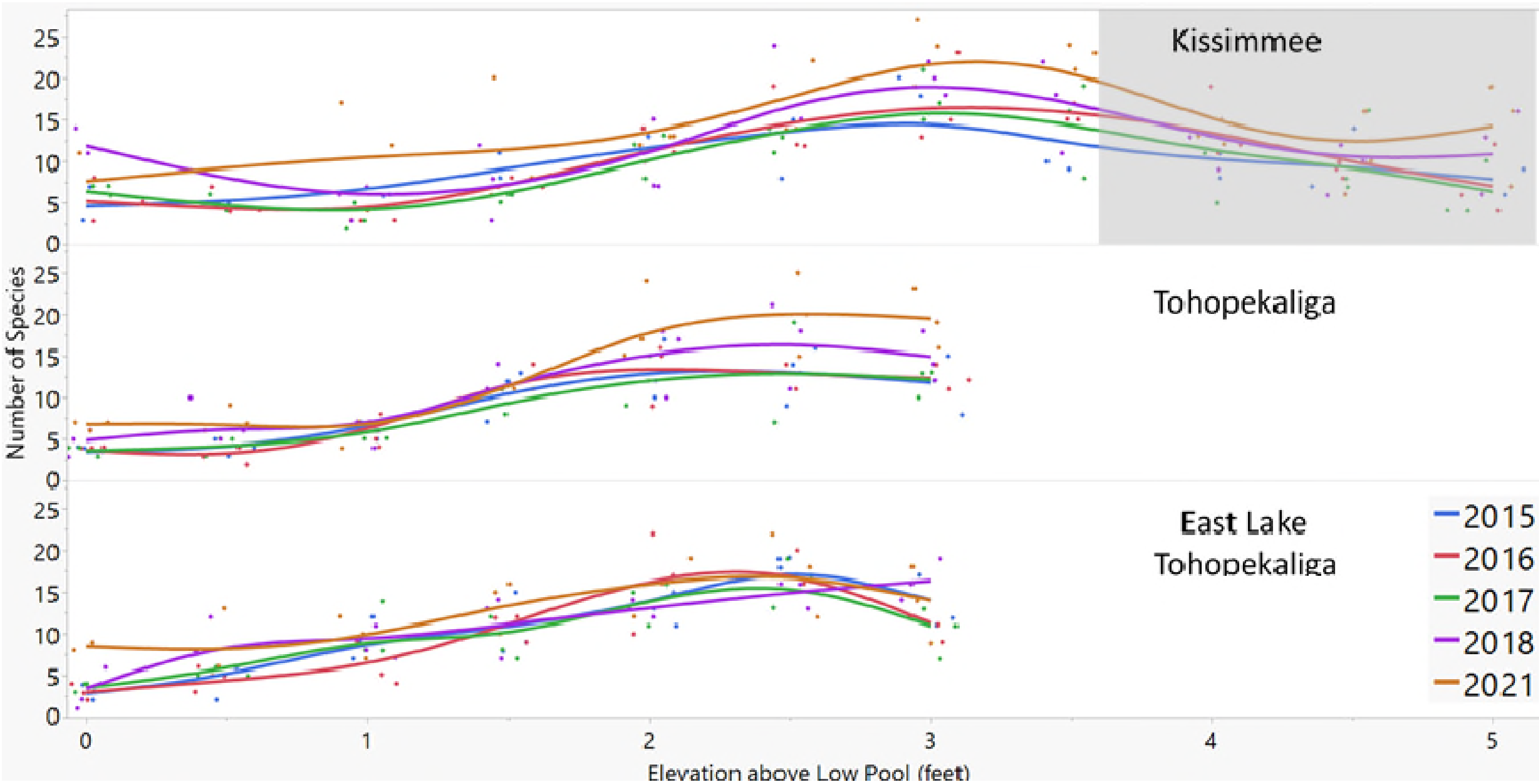


Figure 9-49. Number of species by elevation on transects in each of the study lakes during samples from 2015 to 2021. The gray box represents the future regulation expansion on Lake Kissimmee upon adoption of the HRS. Regulation schedules vary seasonally from 55 to 58 ft NGVD29 on East Lake Tohopekaliga, 52 to 55 ft NGVD29 on Lake Tohopekaliga, and 49.0 to 52.5 ft NGVD29 on Lake Kissimmee. Smoother lines with lambda 0.05 are shown fit through the data points.

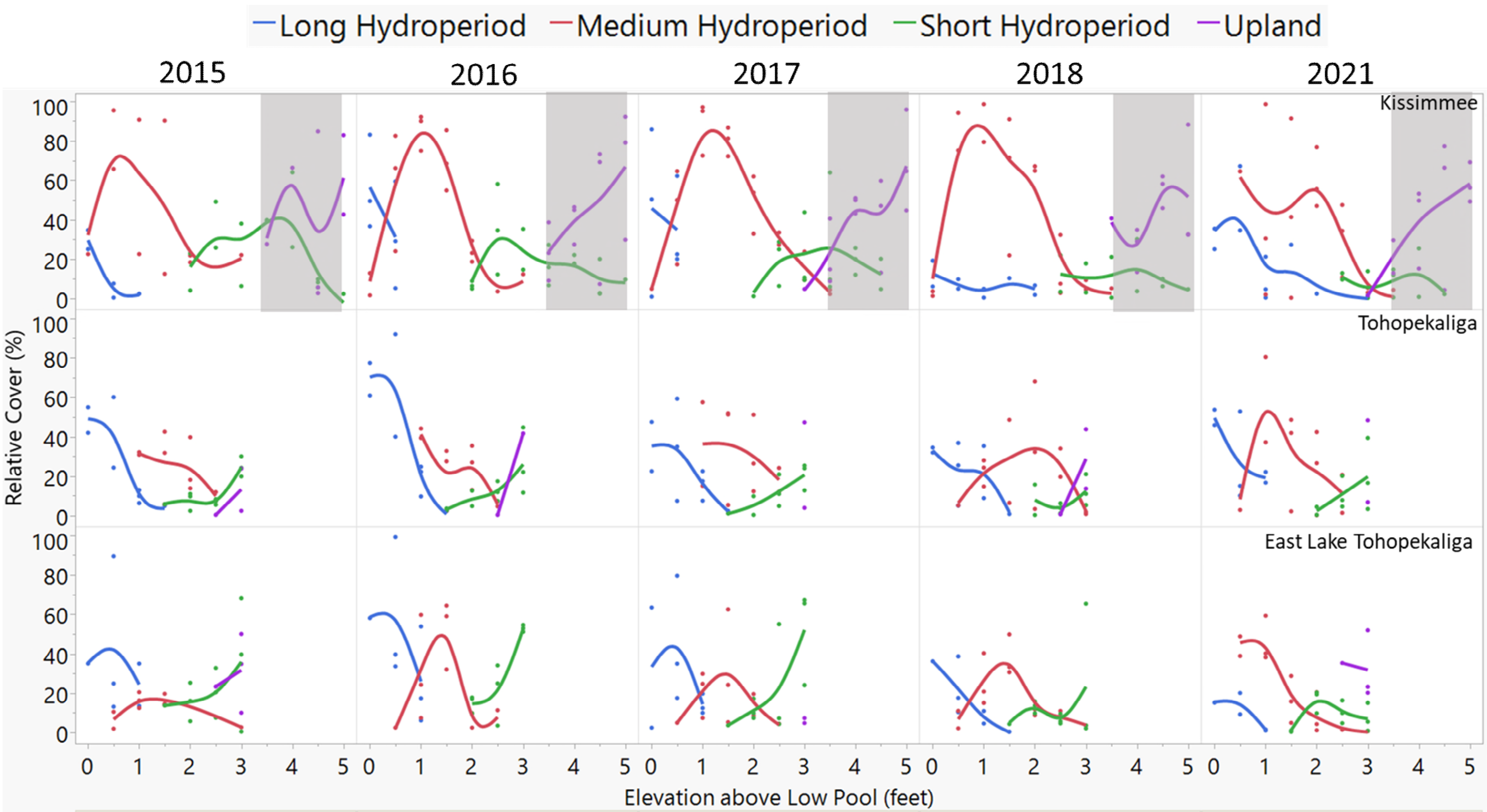


Figure 9-50. Abundance of indicator species grouped by plant community along elevation gradients on each lake during annual samples from 2015 to 2021. Gray boxes represent the elevations of the future HRS.

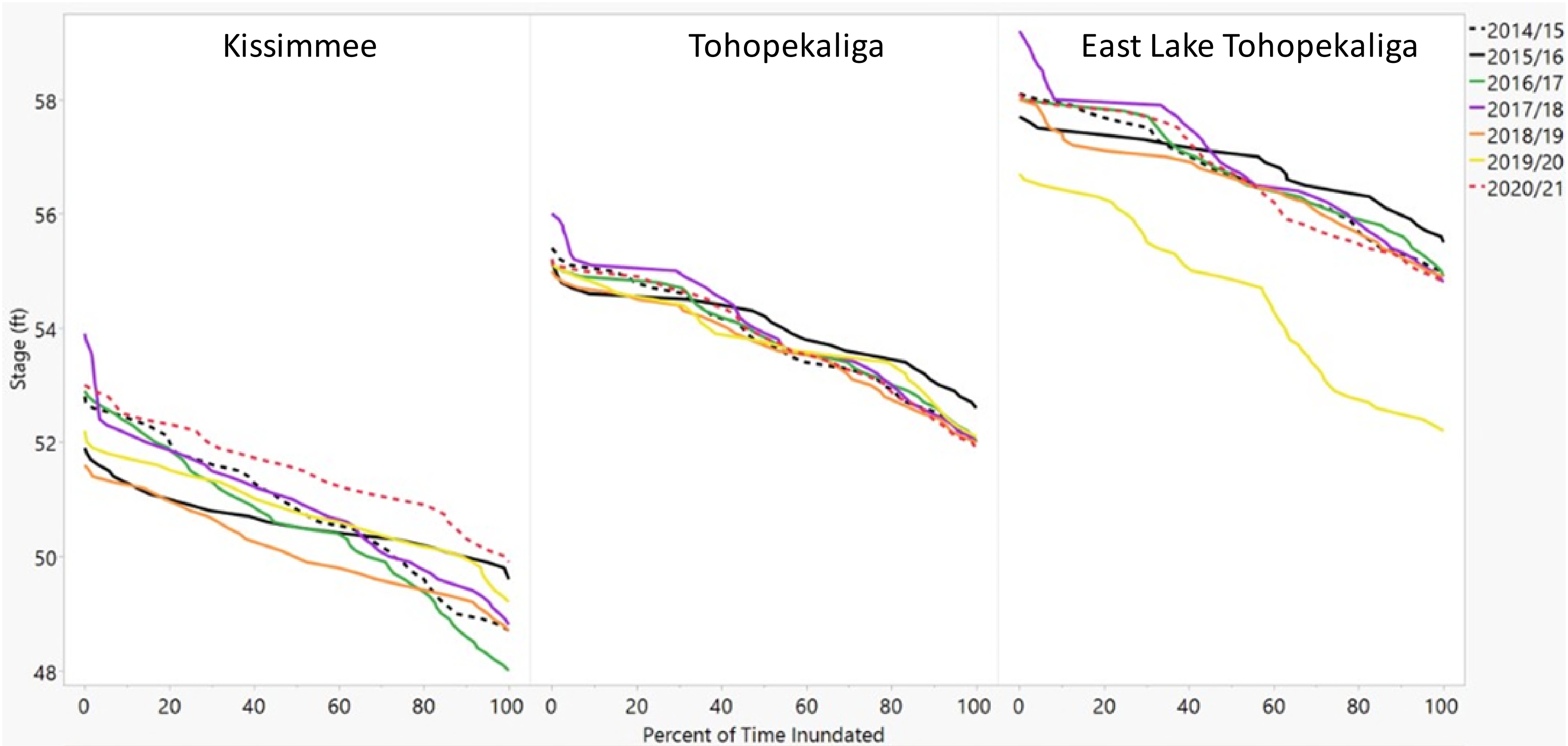


Figure 9-51. Stage duration curves for Lake Kissimmee, Lake Tohopekaliga, and East Lake Tohopekaliga for 2014-2015 through 2020-2021. Note the wide range in hydroperiod at the higher elevations with broad divergence between years on East Lake Tohopekaliga and Lake Kissimmee.

Although hydrology in 2020 and 2021 varied among the lakes, water levels were especially high on Lake Kissimmee from late May 2020 through July 2021 and moderately high on Lake Tohopekaliga but were far lower than average on East Lake Tohopekaliga due to a drawdown conducted by FWC for habitat enhancement. Subsequently, there was a decrease in Long Hydroperiod communities on East Tohopekaliga and a shift downslope in Medium Hydroperiod communities, whereas both Lakes Kissimmee and Tohopekaliga showed apparent increases in Long Hydroperiod communities during that time. Similarly, there were upslope shifts in Medium Hydroperiod communities on Lakes Kissimmee and Tohopekaliga in that time as well. When water levels inundate higher elevations more frequently, the ecotone overlapping the short hydroperiod and upland plant communities can expand, which is also the area where we find highest species richness; the majority belonging to Facultative (e.g., *Axonopus furcatus*) and Facultative Wet (e.g., *Rhynchospora fascicularis*) functional groups. Species richness at most elevations was highest on Lakes Kissimmee and Tohopekaliga in 2021 and 2018 (the first sampling period following Hurricane Irma); 2018 and 2021 also had the highest peak richness on both lakes (**Figure 9-49**).

Similar to trends shown here, potential effects from HRS implementation will be assessed through shifts in peak abundance or peak diversity of plant communities along the shoreline elevation gradient. Thus far, results indicate similarities between the lakes' littoral zone vegetation. On every lake, hydroperiod communities are represented by the same indicator species or groups of species. Peaks in diversity or abundances occur at similar elevations (relative to low pool or approximate annual minimum water levels) although these peaks vary in width between lakes (perhaps due to differences in seasonal water level fluctuation, other fine-scale hydrological variations, or bathymetric gradients). These and other analyses specific to community or species abundance will be important in assessing how operations for the restored Kissimmee River affect habitats upstream of the project and will help guide future water management decisions.

FISHERIES

The KCOL fishery is monitored by FWC via electrofishing and creel (angler) surveys. On the two lakes most important to anglers, Lakes Kissimmee and Tohopekaliga, annual sampling includes electrofishing surveys in the fall (fish community) and spring (LMB), and creel (angler) surveys conducted from January through May. Fall surveys provide community data with number of fish per functional group, which are black crappie (*Pomoxis nigromaculatus*), catfish, exotic species, small forage fish, LMB, rough fish, and sunfish. Spring surveys provide an assessment of the size distribution and relative abundance of LMB populations. Creel surveys have been conducted at Lake Kissimmee since 2011 and Lake Tohopekaliga since 2018. In addition, smaller lakes are also periodically sampled in the spring. This report includes results from fall and spring 2021 on Lakes Kissimmee and Tohopekaliga, and spring 2020 on Lakes Cypress and Hatchineha.

Electrofishing Sampling

Electrofishing surveys use a standardized sampling protocol first implemented in 2006 where random transects near shorelines are sampled for 15 minutes each. A total of 25 transects each were sampled on Lakes Kissimmee and Tohopekaliga and 21 transects each on Lake Cypress and Hatchineha.

Lakes Kissimmee and Tohopekaliga

On both lakes, the fish community has always been numerically dominated by sunfish (i.e., bream, *Lepomis* spp.) and forage fish (**Figure 9-52**). The forage fish category is comprised of a variety of fish families but is dominated by small-bodied fishes (e.g., minnows [Cyprinidae], live bearers [Poeciliidae], and shad [Cluepeidae]); as the name implies, this group is also an important component of lake food webs, sustaining predators and other fish.

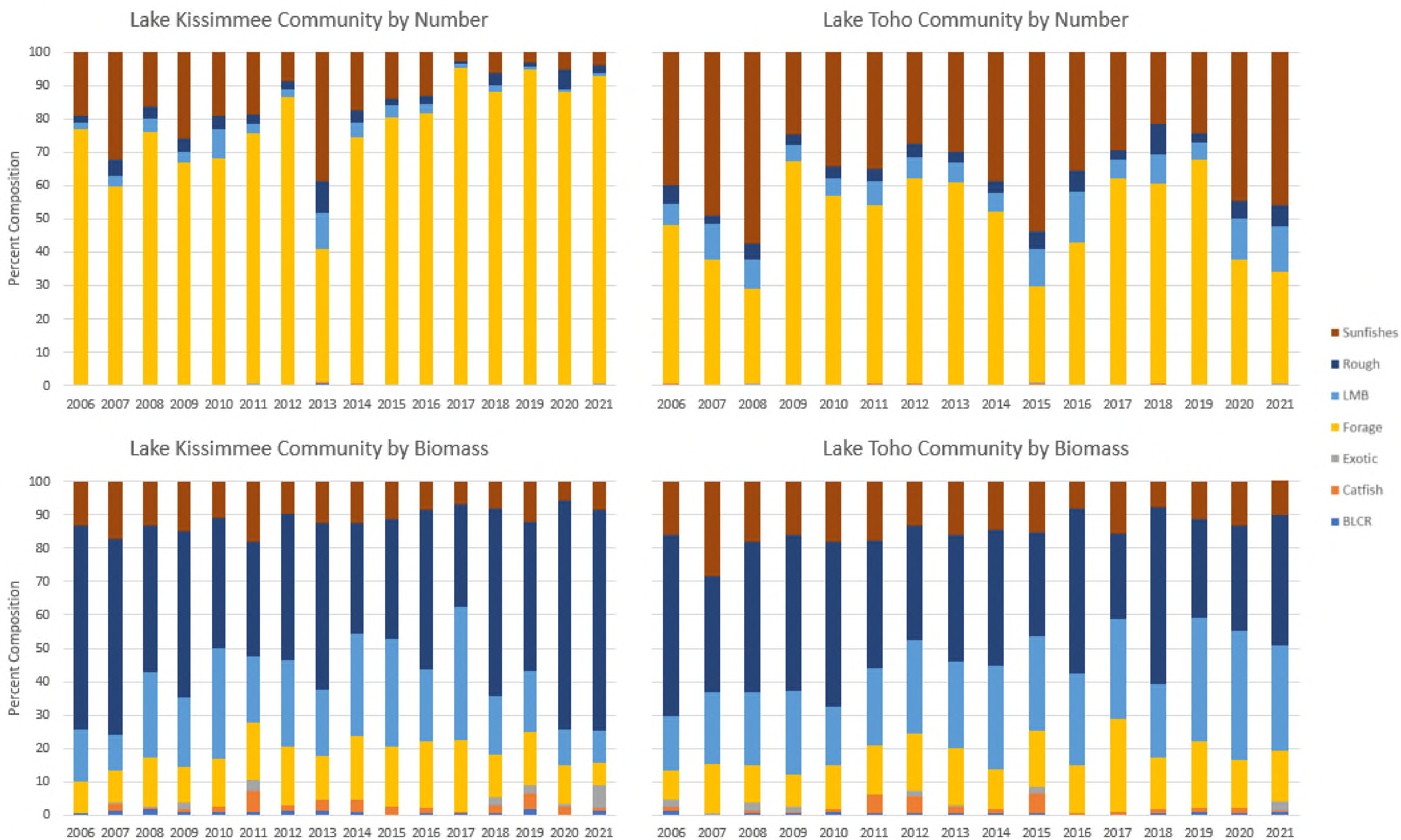


Figure 9-52. Fish community structure by number (total percent of all fish sampled annually; top) and biomass (total percent of all fish sampled annually by weight, bottom). LMB = largemouth bass and BLCR = black crappie.

The fish community biomass has always been dominated by rough fish, primarily Florida gar (*Lepisosteus platyrhincus*) and bowfin (*Amia calva*) (**Figure 9-52**). These data vary annually, yet appear typical to a complex, Central Florida lake system (Bachmann et al. 1996). Gamefish include the complex of sunfish, LMB, black crappie (*Pomoxis nigromaculatus*), and catfishes (channel catfish [*Ictalurus puntatus*] and bullheads [*Ameiurus* spp.]). Additionally, non-native fishes continue to make up small portions of the fish community both by number and biomass. Non-native fish include armored sailfin catfish species (*Pterygoplichtys* spp.), brown hoplo (*Hoplosternum littorale*), blue tilapia (*Oreochromis aureus*), and Mayan cichlid (*Mayaheros urophthalmus*).

On Lake Kissimmee, overall gamefish abundance (by number and biomass), are at or near historical low values, particularly sunfish and LMB populations (**Figure 9-52)**. Both sunfish and LMB show declines beginning in fall 2017. The LMB average composition (by number) during the 2006–2016 period was 4.47%, which fell to 1.05% during the 2017–2021 period. The sunfish average during the 2006–2016 period was 20.27%, which fell to 4.17% during the 2017–2021 period. In contrast, gamefish and non-gamefish communities on Lake Tohopekaliga appear balanced both in number and in biomass.

Catch rates for adult LMB (> 2 years old) on both lakes were within the historical averages since standardized sampling began in 2007 (**Figure 9-53**). However, on Lake Kissimmee catch rates for age-2+ LMB have been variable since 2017, ranging from 6 to 10 bass per sample, and catch rates for presumed age-1 bass have been consistently low since 2017. The low recruitment is likely a main cause of the variable catch rates of age-2+ bass. A probable cause of these low recruitment rates is lack of habitat. Coverage of submerged aquatic vegetation (SAV) decreased by half from 2015 to 2019 and has remained low since (**Figure 9-54**). Since 2017, SAV has decreased by approximately 10%.

Catch rates for age-1 and age-2+ LMB have been variable in Lake Tohopekaliga. SAV consistently covers > 50% of the lake (**Figure 9-55**). Although this level of vegetation can support a robust bass fishery, too much SAV for extended periods can cause problems with the bass fishery as well. The abundance of habitat promotes survival of juvenile bass, which in turn creates competition for the lake's resources. High levels of vegetation have been known to have impacts on overall growth of bass populations and can create a fishery with a high abundance of small bass, limiting the production of larger, quality bass.

Lakes Cypress and Hatchineha

Lake Cypress had moderate catch rates of LMB (12.8 ± 1.4 bass per sample; mean ± standard error). The Lake Cypress bass sample (n = 239) was dominated by presumed age-1 bass (< 230 mm) and low catches of good harvest-size fish (> 409 mm; **Figure 9-55**). Lake Cypress has abundant SAV, which likely promotes bass recruitment but may reduce growth to larger sizes, resulting in high abundance of small to medium sized bass (**Figure 9-56**).

Lake Hatchineha had low catch rates of bass (7.24 ± 0.99 bass per sample). The sample was dominated by 30- to 40-centimeter bass, with low catches of presumed age-1 (< 230 mm) bass and very few large fish (> 500 mm; **Figure 9-57**). Unlike Lakes Cypress and Tohopekaliga, Lake Hatchineha has a moderate level of SAV (21% coverage), but a large portion of the vegetation is limited to a single, dense area in the northeast part of the lake (**Figure 9-54**).

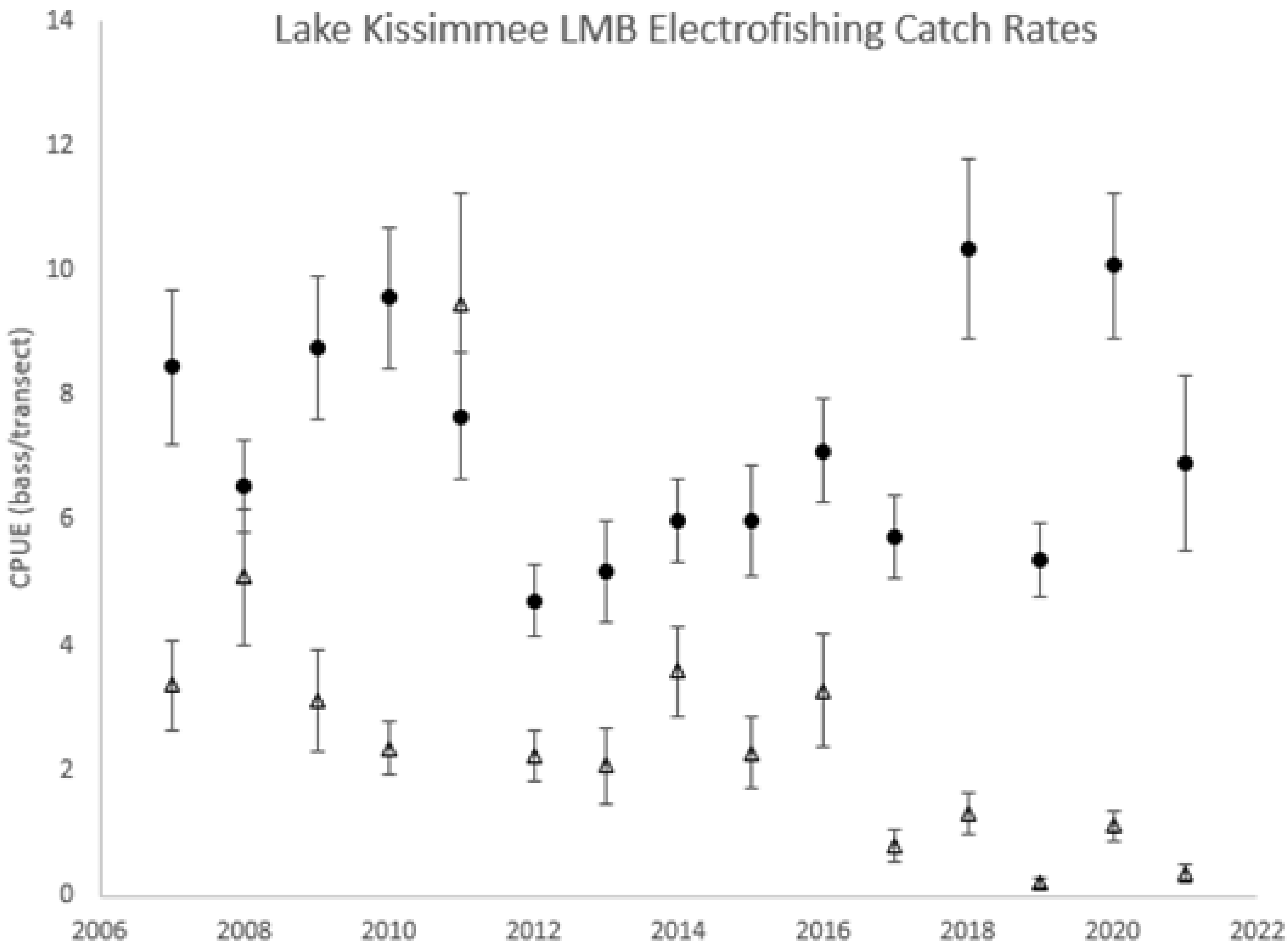


Figure 9-53. Electrofishing catch rates on Lake Kissimmee (2007–2021). Presumed age-1 bass (< 230 mm) are denoted by white triangles and presumed age-2 bass are denoted by black circles. Standard error is denoted by error bars for each year.

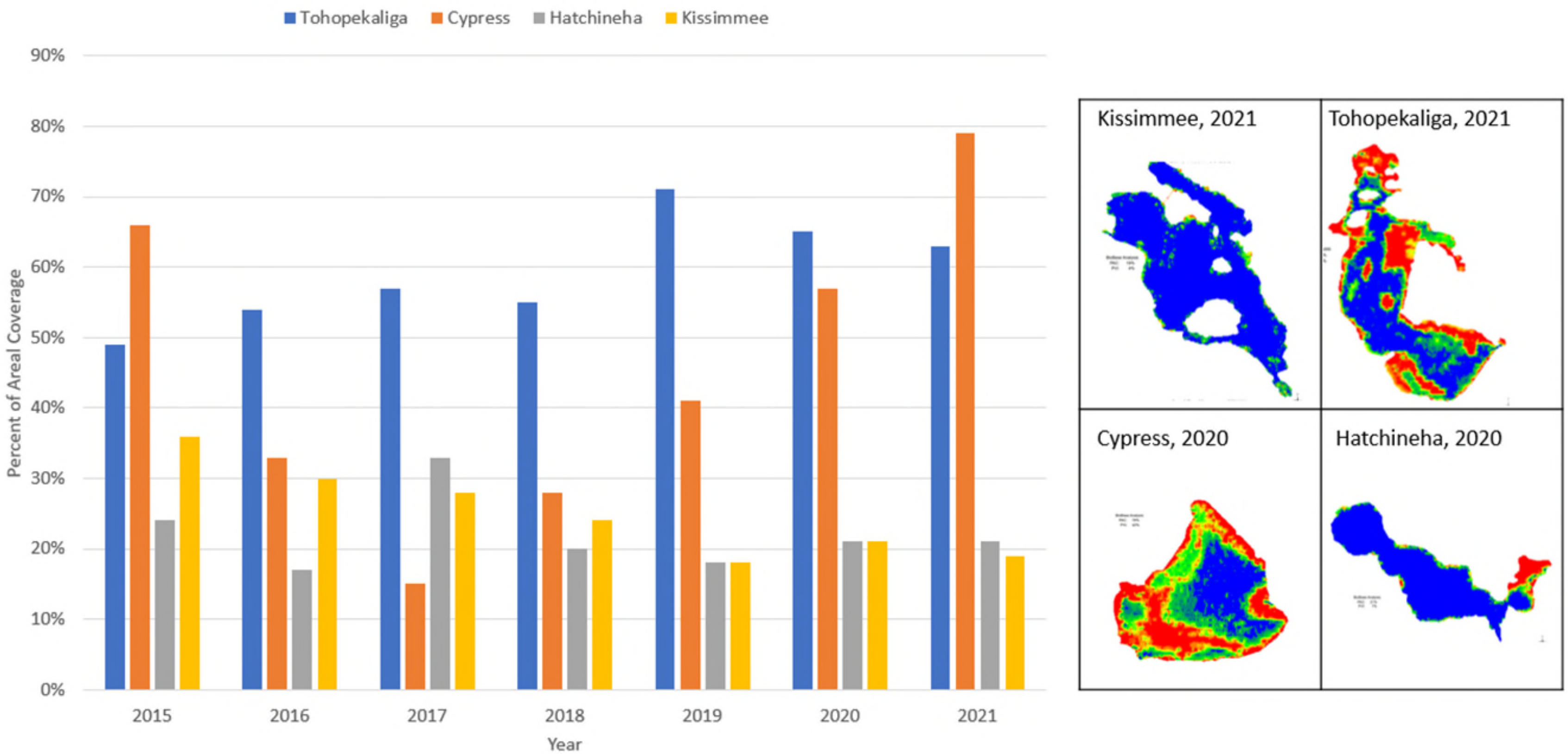


Figure 9-54. Percent areal coverage of SAV on Lakes Kissimmee, Tohopekaliga, Cypress, and Hatchineha from 2015 to 2021. Accompanying images show each lake with SAV in reds (high density) and greens (low density) and open water in blue. Lakes are not shown to scale.

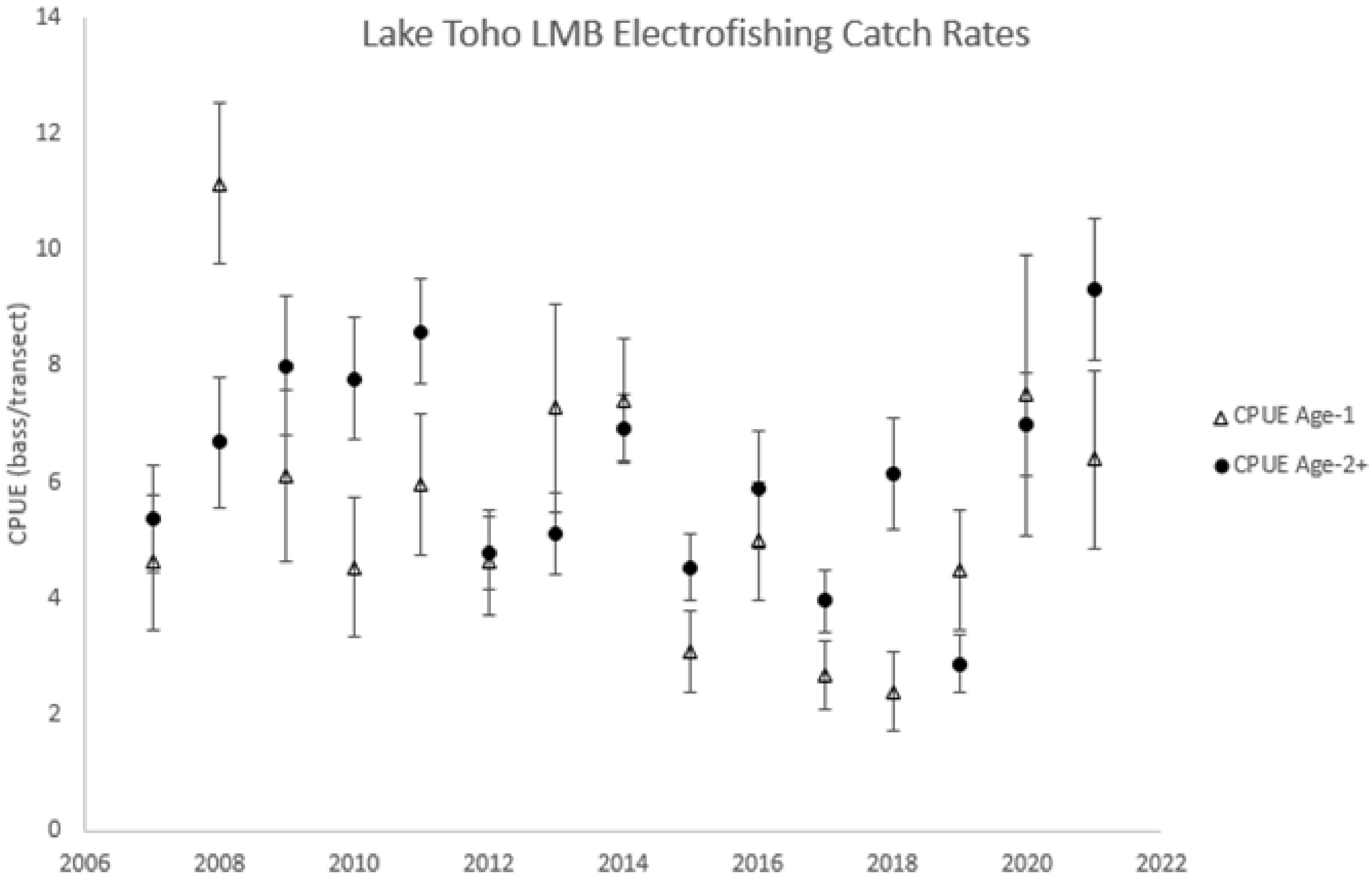


Figure 9-55. Electrofishing catch rates on Lake Tohopekaliga (2007–2021). Presumed age-1 bass (< 230 mm) are denoted by white triangles and presumed age-2 bass are denoted by black circles. Standard error is denoted by error bars for each year.

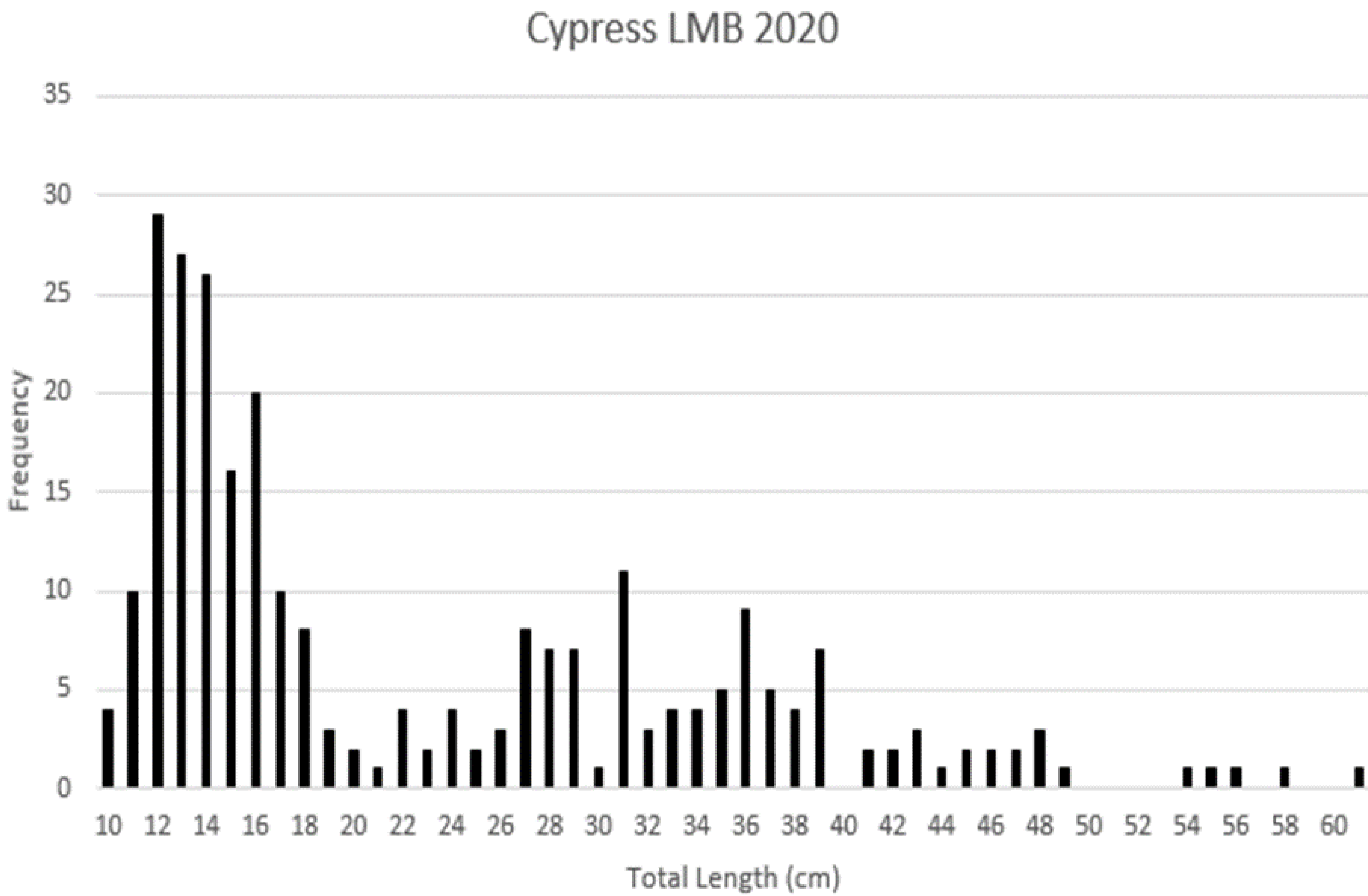


Figure 9-56. Distribution of length of LMB sampled at Lake Cypress in spring 2020.

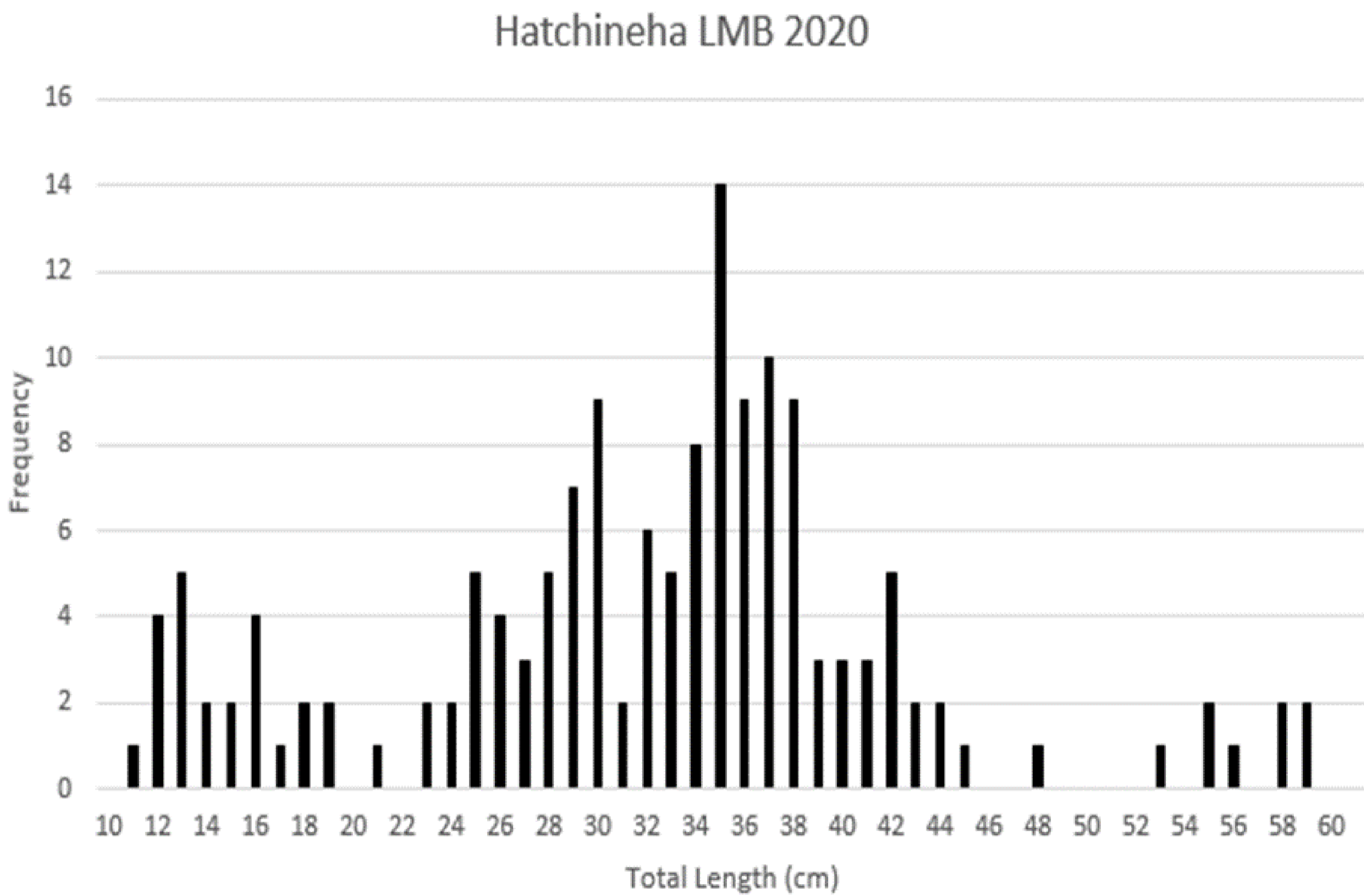


Figure 9-57. Distribution of length of LMB sampled at Lake Hatchineha in spring 2020.

Creel Surveys on Lakes Kissimmee and Tohopekaliga

Creel surveys have been conducted on Lake Kissimmee since 2011 and Lake Tohopekaliga since 2018. The goal is to estimate angler effort (number of hours spent fishing and for each fish species) and angler catch rates (how many fish caught or harvested per hour or fish/hr). The survey is designed to coincide with the majority of black crappie and LMB spawning seasons, when angler use tends to be highest. Since 2018, total angler effort has been around 100,000 hours on Lake Kissimmee, a marked decrease from 2011–2016 (150,000 hours) and from the 2010 high of > 207,000 hours (**Figure 9-58**). Total angler effort on Lake Tohopekaliga has stayed relatively stable, ranging from 50,000 to 68,000 hours in the past 4 years.

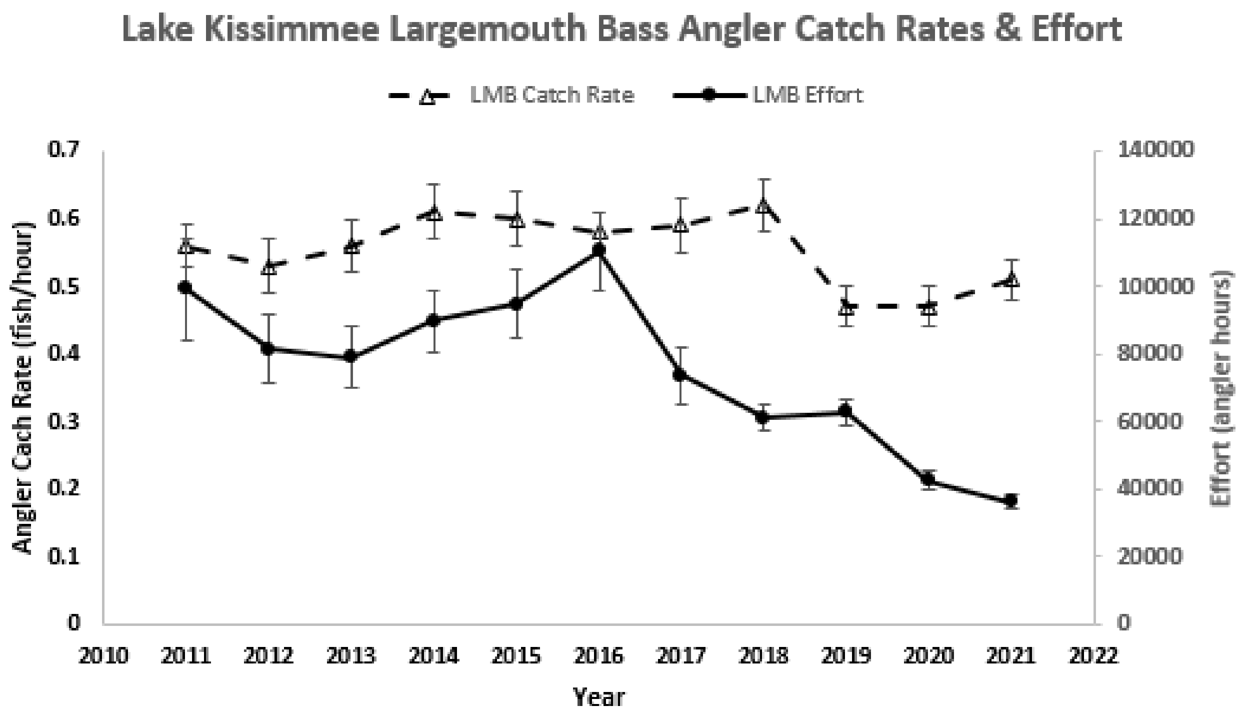
LMB effort on Lake Kissimmee has steadily declined since 2016 yet angler catch rates did not decline until 2019 (**Figure 9-58**). Since then, catch rates have remained stable at ~0.5 fish/hr. It is unknown why angler effort is decreasing but is likely due to multiple factors including the decrease in catch rates and loss of angler preferred vegetation (SAV beds). Black crappie effort has remained relatively stable since 2012 except for 2018 when effort dropped for a single year. Crappie harvest rate has also remained constant throughout time, except for 2016 when lower harvest rates were seen.

On Lake Tohopekaliga, LMB catch rates have remained high (> 0.8 fish/hr) since 2019 and peaked at 1.04 fish/hr, which represents an above average bass fishery (**Figure 9-59**). Black crappie effort, meanwhile, is usually low compared to other popular crappie fisheries. Total angler hours for crappie are generally below 3,000 hours but peaked in 2021 with 4,365 hours. Black crappie harvest rates can be high but are also variable ranging from 1.8 to 3.1 fish/hr.

Many of the declines in the Lake Kissimmee fishery occurred after Hurricane Irma, which impacted much of Central Florida in September 2017. The direct and indirect effects have been documented in FWC's long-term monitoring of the lake, and in this chapter last year; plant community losses on Lake Kissimmee, namely decreases in deep-water grasses, floating leaf, and BLM communities (Koebel et al. 2022). Hurricane Irma, and perhaps other unmeasured factors, appear to be having long-term impacts on Lake Kissimmee (see also Chapter 8B of this report for similar effects on Lake Okeechobee). While cause for concern, there are signs that conditions are at least not declining further. Vegetation coverage, bass recruitment, and bass catch rates all declined sharply after the hurricane but have since stabilized. Current rates of LMB recruitment (**Figure 9-53**) suggest that catch rates (both electrofishing and angler) for adult LMB will likely decline over the next few years if improvements in do not occur.

Once recognized nationally as a premier bass fishery, the current state of Lake Kissimmee no longer supports the robust fishery that existed. FWC is engaging with SFWMD and USACE to seek opportunities for habitat improvement (SAV and deep-water grasses) for bass, specifically through large-scale management actions (i.e., drawdown). Increases in habitat will promote recruitment, which should translate to increased fishing effort, which has waned in recent years.

Lake Tohopekaliga, on the other hand, has consistently high coverage of SAV (**Figure 9-54**) that supports LMB recruitment (**Figure 9-55**). These high levels of vegetation may be affecting growth and the number of large, quality and trophy size fish in the population. Angler catch rates for LMB in Lake Tohopekaliga are well above average (**Figure 9-59**), yet bass angling effort has not increased; though effort is affected by many conditions independent of the fishery (economy, travel, COVID, etc.). Other fisheries, like black crappie (and anecdotally bream sunfish) may also benefit from decreased SAV and a better balance of the vegetation community. Overall, the Lake Tohopekaliga fish community composition is well-balanced, with an abundance of forage for sportfish and low levels of non-native fish.



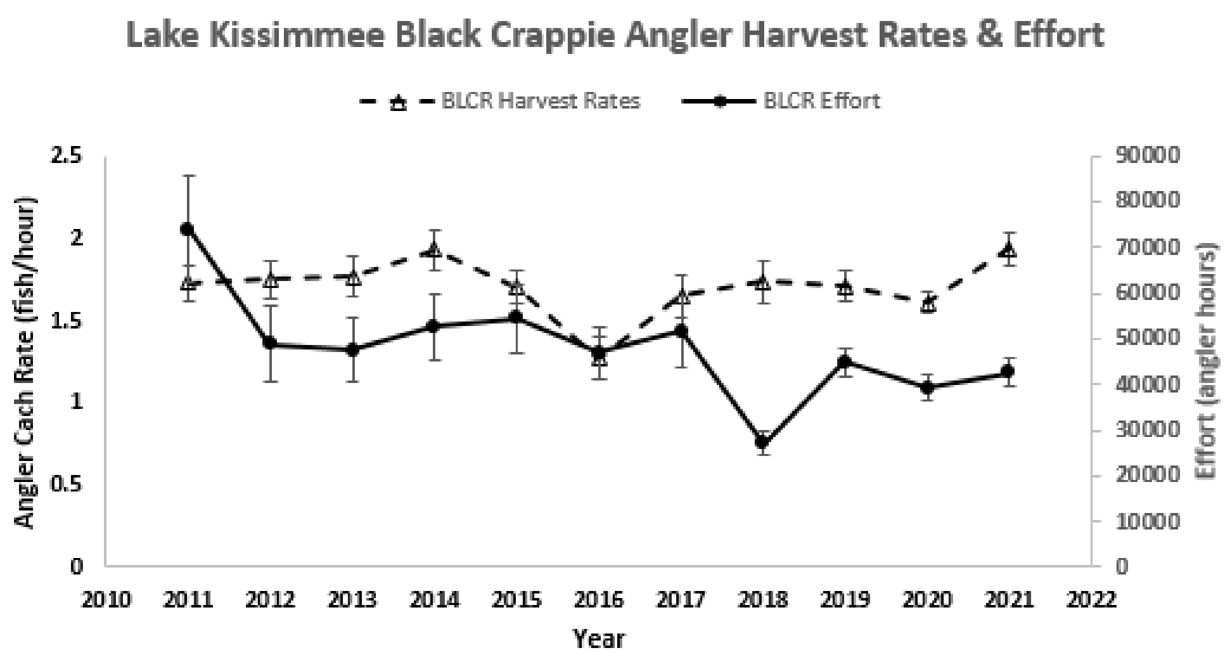
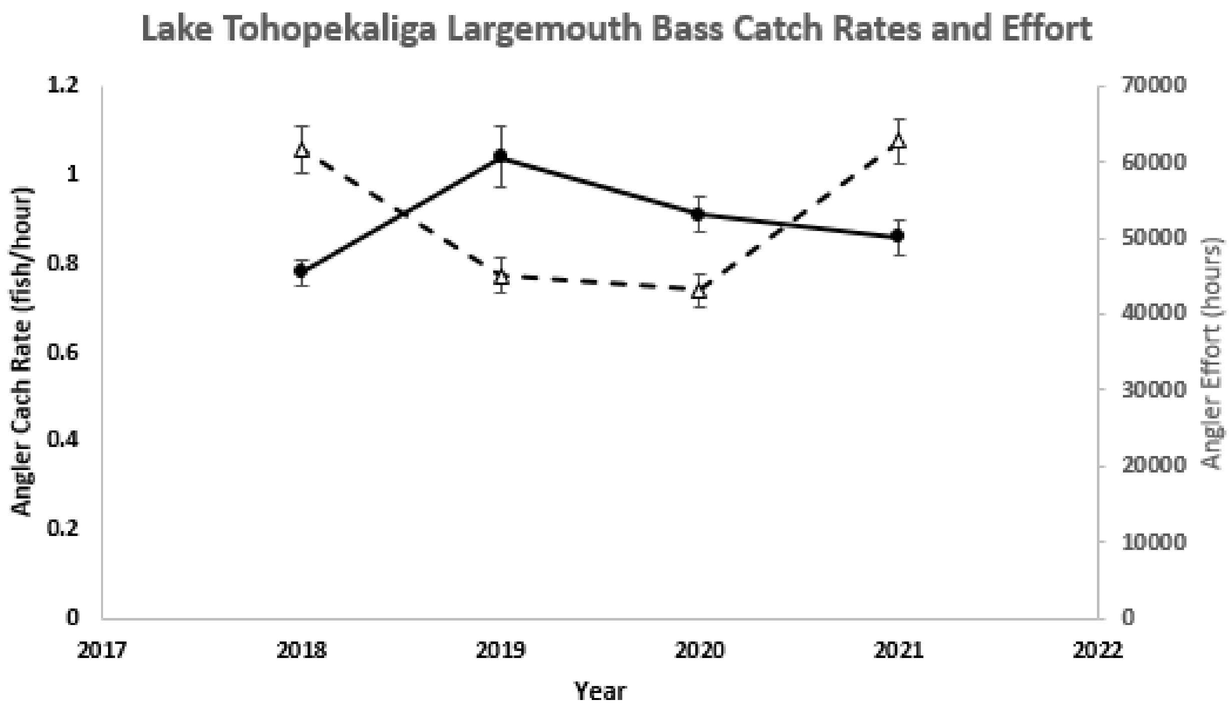


Figure 9-58. LMB catch rates (fish caught per hour) and effort (hours spent fishing) for Lake Kissimmee.



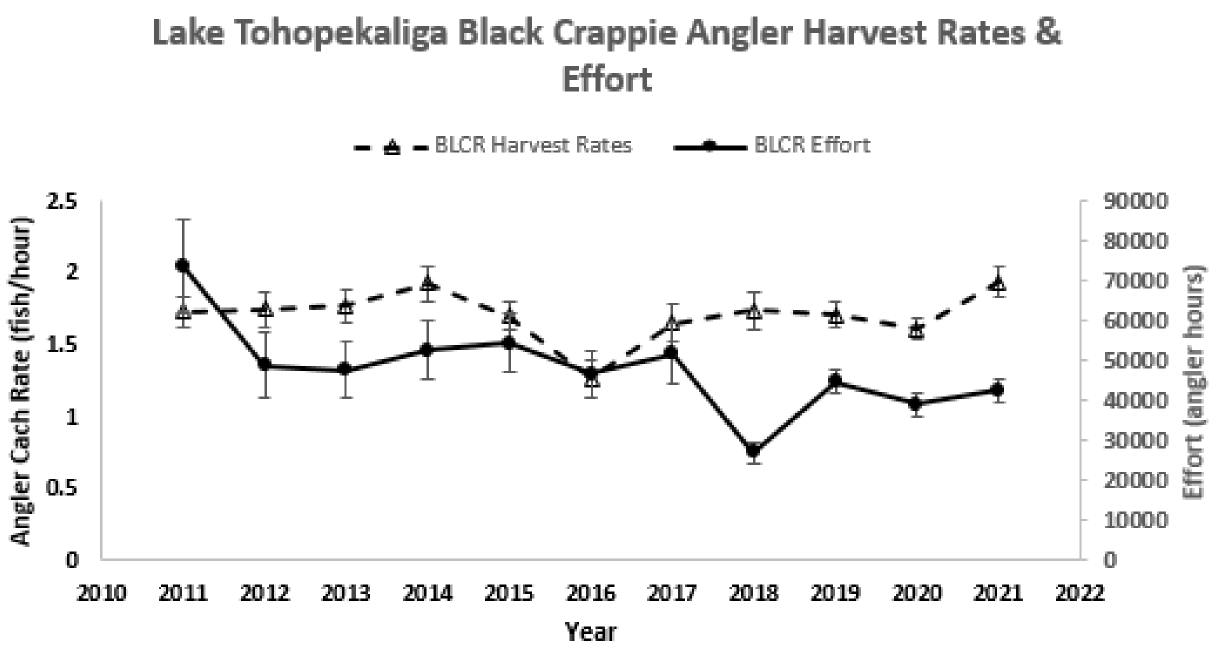


Figure 9-59. LMB and black crappie catch rates (fish caught per hour) and effort (hours spent fishing) for Lake Tohopekaliga.

Similar to Lake Tohopekaliga, the high amount of SAV (**Figure 9-54**) on Lake Cypress appears to promote high LMB recruitment (**Figure 9-56**). Lake Hatchineha generally lacks vegetation (**Figure 9-54**), which probably limits LMB recruitment (**Figure 9-57**). There are no angler surveys at Lake Cypress and Hatchineha, so all catch information is anecdotal from local biologists. Lake Cypress can produce good numbers and size of bass, but often the lake receives little fishing pressure of any kind. Lake Hatchineha receives very low effort, probably the lowest per acre than any other Kissimmee Chain lake.

In conclusion, Lakes Hatchineha and Kissimmee have low catch rates of LMB, which is likely related to low amounts of SAV. Results of recent fish, angler, and SAV monitoring indicate that Lake Kissimmee has experienced declines since Hurricane Irma in September 2017. In contrast, Lakes Tohopekaliga and Cypress have high levels of SAV and stable fisheries.

SNAIL KITES

Statewide snail kite nesting effort, distribution, and population size are systematically monitored by the University of Florida on an annual basis (see Fletcher et al. 2022 for details). This monitoring effort covers most wetlands, statewide, in which snail kite breeding activity has been observed within the last two decades or more, including the UKB, which is mainly summarized here (**Figure 9-60** and see Koebel et al. 2021).

In 2021, 585 active nests (i.e., containing eggs or nestlings) were found throughout the snail kite's Florida range. This represents a year of good nesting effort after two poor years in 2020 (184 active nests) and 2019 (275 active nests). Nesting in the KCOL made up only 15% of the statewide snail kite nesting effort in 2021, its lowest contribution since at least 2006. This low contribution of nesting effort in the KCOL is mostly attributed to high nesting effort in Lake Okeechobee and Everglades Stormwater Treatment Areas (STAs).

Within the KCOL, there were 11 nests located at East Lake Tohopekaliga (< 1% of the statewide nesting effort), 53 nests located on Lake Tohopekaliga (8% of the statewide nesting effort), and 25 nests (5% of the statewide nesting effort) on Lake Kissimmee in 2021. FWC implemented a planned drawdown and habitat enhancement project on East Lake Tohopekaliga and therefore did not have any snail kite nesting in 2020 due to low water levels. Of the 89 nests in the KCOL, 30 nests (34%) were observed to be successful.

In summary, snail kite nesting was higher in southern habitats in 2021, mostly in newly impounded STAs and Lake Okeechobee, and moderate in the KCOL and other areas. Nesting effort was slightly below average in the KCOL but the contribution to statewide nesting was the lowest percentage in recent record. This may be due more to optimal conditions elsewhere than suboptimal conditions in the KCOL, since snail kites frequently traverse most of the southern peninsula in search of habitat (Fletcher et al. 2022). The consistency of nesting in the KCOL for more than two decades supports its importance to the overall kite population in Florida. There is also an increase in use of non-traditional nesting areas since the proliferation of exotic apple snails, which play a significant role in statewide snail kite nesting distribution; particularly in 2021 with nearly half of all nests occurring in impounded wetlands (Fletcher et al. 2022).

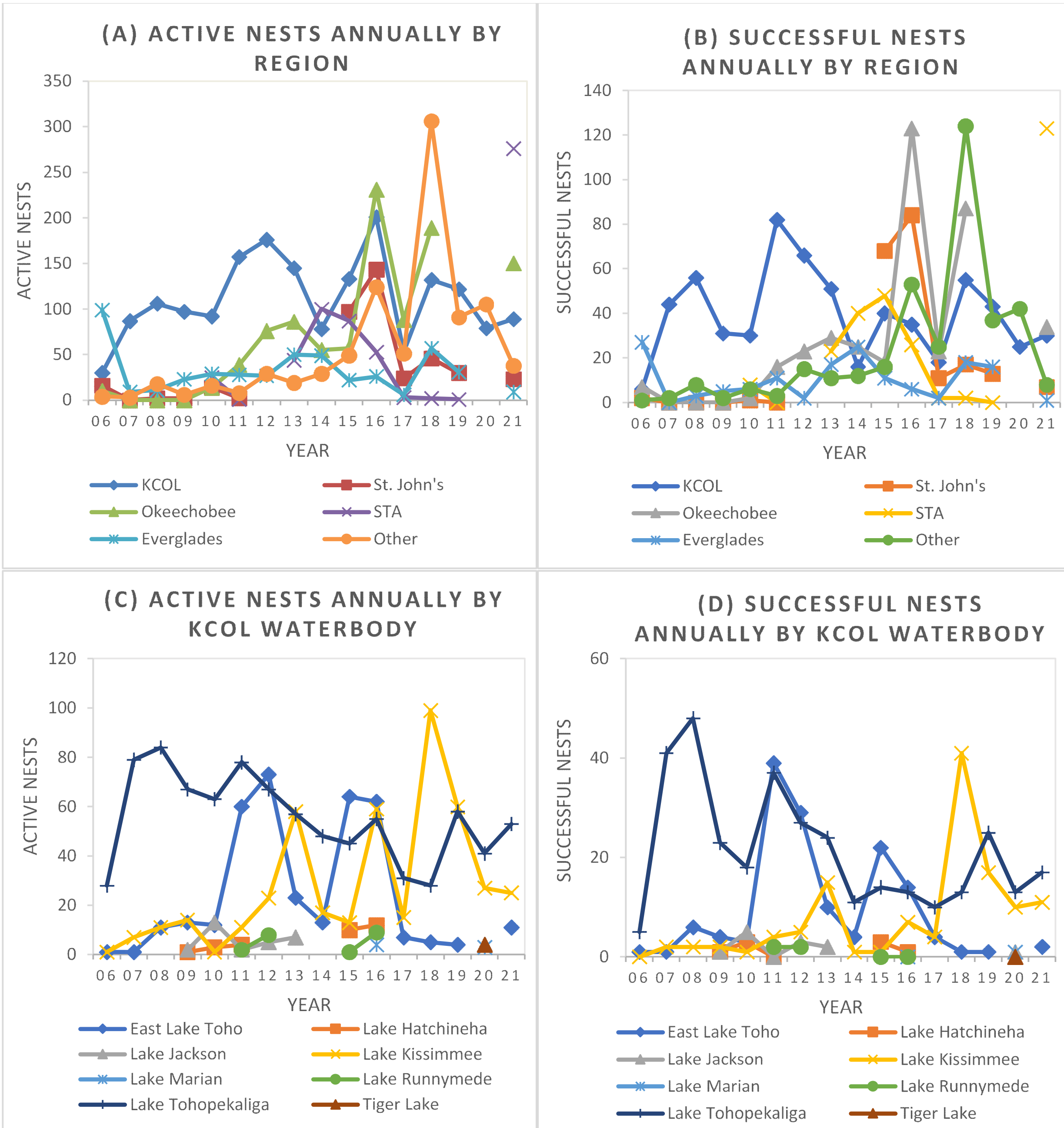


Figure 9-60. (A) Active snail kite nests for each region from 2006 to 2021 and (B) the total number successful. (C) Active snail kite nests for each major water body in the KCOL, and (D) the total number successful from 2006 to 2021.

ALLIGATORS

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). See Koebel et al. (2021) for details on methods and analyses.

Lake Kissimmee

Total alligator population estimates on Lake Kissimmee have continued to stay strong in recent years. The 2021 estimated population was 13,514 alligators, an increase of approximately 177% since population monitoring began in 1991 (**Figure 9-61a**). The estimated number of juvenile (1–4 ft) alligators was 7,204 individuals, a 303% increase over the 1991 estimated population. The adult (6 ft and larger) portion of the alligator population also increased and was estimated at 3,200 individuals, a 31% increase since 1991.

Lake Tohopekaliga

Alligator population estimates on Lake Tohopekaliga have continued to stay strong as well. The 2021 estimated population was 8,247, an increase of 251% since population monitoring began in 1994 (**Figure 9-61b**). The estimated number of juvenile (1–4 ft) alligators was 4,789 individuals, a 298% increase over the 1994 estimated population. The adult (6 ft and larger) portion of the alligator population also increased and was estimated at 1,980 individuals, a 183% increase over the 1994 estimated population.

East Lake Tohopekaliga

Total alligator population estimates on East Lake Tohopekaliga have remained relatively stable. The 2021 estimated population was 106 alligators, similar to estimates (decrease of 6%) when population monitoring began in 2003. The estimated number of juvenile (1–4 ft) alligators was 28 individuals, a 33% decline from the 2003 estimated population. The adult (6 ft and larger) portion of the alligator population was 38 individuals, a 36% decrease from the 2003 estimated population.

Lake Hatchineha

Total alligator population estimates on Lake Hatchineha have remained strong. The 2021 estimated population was 3,364 alligators, a 169% increase since population monitoring began in 1988 (**Figure 9-61c**). The estimated number of juvenile (1–4 ft) alligators was 1,639 individuals, a 143% increase since 1988. The adult (6 ft and larger) portion of the alligator population also increased and was estimated at 1,182 individuals, a 176% increase over the 1988 estimated population.

Cypress Lake

The 2021 estimated population on Cypress Lake was 594 alligators, a 50% decrease since population monitoring began in 2000. The estimated number of juvenile (1–4 ft) alligators was 161 individuals, while the estimated number of adult alligators was 334 individuals. Those estimates represent a 52 and 33% decrease, respectively, from the 2000 estimated population.

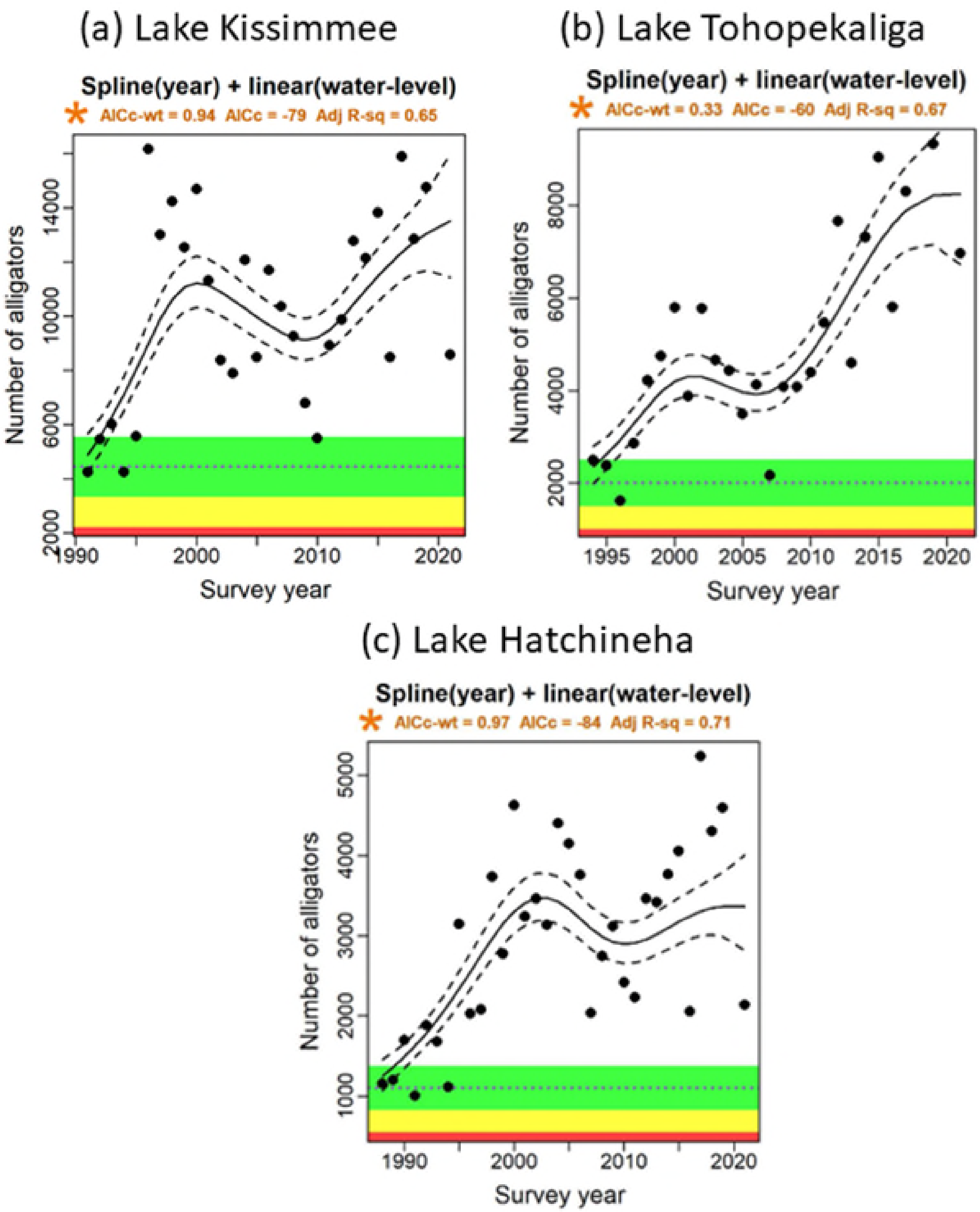


Figure 9-61. Alligator population trends on (a) Lake Kissimmee, (b) Lake Tohopekaliga, and (c) Lake Hatchineha, based on night light surveys conducted between 1988 and 2021. Green-shaded area represents ± 25% of the population management target; yellow-shaded area represents 25–50% of the target; and 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.

KCOL Alligator Populations 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 have been 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 subsequent high recruitment of younger alligators into adult size classes.

Trend analyses for East Lake Tohopekaliga and Cypress Lake indicate declines for juveniles, adults, and total populations. However, all size classes on the lakes remain within the acceptable range of population estimates. The decline of adults might reflect harvesting from recreational and nuisance trappers, while declines in juveniles may suggest a decrease in available habitat for smaller alligators. The removal of dense emergent vegetation and hydrilla 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 us to assess 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.

Bachmann, R.W., B.L. Jones, D.D. Fox, M.V. Hoyer, L.A. Bull, and D.E. Canfield. 1996. Relations between trophic state indicators and fish in Florida (U.S.A.) lakes. *Canadian Journal of Fisheries and Aquatic Sciences* 53:842-855.

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.

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.

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.

Cheek, M.D., D.H. Anderson, D.J. Colangelo, S.G. Bousquin, B.L. Jones, L. Spencer, R.T. James, J. Zhang, and C. Carlson. 2015. Chapter 9: Kissimmee River Restoration and Basin Initiatives. In: *2015 South Florida Environmental Report – Volume I*. South Florida Water Management District, West Palm Beach, Florida.

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.

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.

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.

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

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.

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.

Enloe, S.F., K.H. Quincy, M.D. Netherland, and D. K. Lauer. 2020. Evaluation of fluazifop-P-butyl for para grass and torpedograss control in aquatic and wetland sites. Journal of Aquatic Plant Management 58: 36-40.

FLEPPC. 2019. *2019 FLEPPC's List of Invasive Plant Species*. Florida Exotic Pest Plant Council. Available online at https://floridainvasivespecies.org/plantlist2019.cfm.

Fletcher, R., C. Poli, B. Jeffery, M. Beatty, and A. Gonzalez. 2022. *2022 Annual Report on the 2021 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. Appendix B: Waterfowl Ecological Studies. In: *Recommended Program for Kissimmee River Basin*, Florida Game and Fresh Water Fish Commission, Tallahassee, FL.

Florida Game and Fresh Water Fish Commission. 1991. *Lake Okeechobee-Kissimmee River-Everglades Resource Evaluation Project*. Federal Wallop-Breaux Completion Report F-52-5, Tallahassee, Florida.

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.

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.

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

Hill, N.M., P.A. Keddy, and I.C. Wisheu. 1998. A hydrological model for predicting the effects of dams on the shoreline vegetation of lakes and reservoirs. *Environmental Management* 22:723-736.

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.

JMP Version 15. 2021. SAS Institute Inc., Cary, NC.

Keddy, P.A., and L.H. Fraser. 2000. Four general principles for the management and conservation of wetlands in large lakes: The role of water levels, nutrients, competitive hierarchies and centrifugal organization. *Lakes & Reservoirs: Research and Management* 5:177-185.

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.

Koebel, J.W., S.G. Bousquin, D.H. Anderson, M.D. Cheek, C. Carroll, H. Chen, C. Hanlon, L. Spencer, B.C. Anderson, T. Beck, and A. Brunell. 2021. Chapter 9: Kissimmee River Restoration and Other Kissimmee Basin Initiatives. In: *2021 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, D. Marois, R. Botta, C. Hanlon, B.C. Anderson, T. Beck, and A. Brunell. 2022. Chapter 9: Kissimmee River Restoration and Other

Kissimmee Basin Initiatives. In: *2022 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.

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.

Perrin, L.S., M.J. Allen, L.A. Rowse, F. Montalbano, K.J. Foote, and M.W. Olinde. 1982. *A Report on Fish and Wildlife Studies in the Kissimmee River Basin and Recommendations for Restoration*. Florida Game and Fresh Water Fish Commission, Okeechobee, FL.

Quincy, K., and S. Enloe. 2020. Evaluation of fluazifop-P-butyl and sethoxydim for *Hymenachne amplexicaulis* control in mixed and monotypic emergent plant communities. *Journal of Aquatic Plant Management* 58:105-111.

Rogers, M.W., and M.S. Allen. 2009. Exploring the generality of recruitment hypotheses for largemouth bass along a latitudinal gradient of Florida lakes. *Transactions of the American Fisheries Society* 138:23-37.

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.

Sellers, B., R. Diaz, W.A. Overholt, K.A. Langeland, and J. Gray. 2008. Control of West Indian marsh grass with Glyphosate and Imazapyr. *Journal of Aquatic Plant Management* 46:189-192.

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.

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.

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.

USFWS. 1994. Annex D: Fish and Wildlife Coordination Act Report, Kissimmee River Headwaters Revitalization Project by the United States Fish and Wildlife Service. In: United States Army Corps of Engineers, 1996, *Integrated Project Modification Report and Supplement to the Final Environmental Impact Statement*, *Central and Southern Florida Project*, *Kissimmee River Headwaters Revitalization Project*, Jacksonville, FL.

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.