Habitat Use and Movements of Largemouth Bass Associated with Changes in Dissolved Oxygen and Hydrology in Kissimmee River, Florida

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Abstract: Habitat use and movements associated with changes in dissolved oxygen (DO) levels and hydrology for 20 radio-tagged largemouth bass (*Micropterus salmoides*) were studied in the Kissimmee River, Florida, in 1992 and 1993. River channel littoral vegetation, smartweed (*Polygonum hydropiperoides*) and spatterdock (*Nuphar luteum*), were habitat types bass most commonly used. Bass maintained home areas in remnant channels and the C-38 canal that had DO >2 ppm throughout the year. During summer when DO dropped slowly over several weeks, bass were frequently located in waters with DO between 1 and 2 ppm. Daily movements, which averaged <100 m in more than half of the location samples, were greatest when previous location DOs were <1 ppm during summer and <2 ppm during fall. Daily movements >1 km from June through October were coincidental to acute decreases in DO <2 ppm at previous location sites. Although bass were occasionally located in waters with DO <1 ppm during summer, they usually died or moved out of these low DO areas. Northern remnant river channels and northern sections of the C-38 canal in impounded river pools consistently maintained higher DO levels (>2 ppm) than southern areas. Bass were tracked to these northern areas during periods of stressful DO. During periods of increased flow and high water, bass moved into smartweed, spatterdock, and submerged willow (*Salix* spp.) along channel margins, and inundated floodplain with terrestrial grasses, where flow averaged <6 cm/sec. Bass returned to previously established home areas after DO increased above lethal concentrations or as flood plain waters receded. Improvements in DO availability and reestablishment of complex floodplain habitat, which are dependent on reintroduction of historic flow regimes and amelioration of river channel habitat, are keys for restoration of the Kissimmee River's fisheries.

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Prior to channelization, the Kissimmee River was composed of a meandering, braided channel that flowed 166 km between Lake Kissimmee and Lake Okeechobee, Florida (U.S. Army Corps Eng. 1985). The river was a highly productive riverine/wetland system considered optimal riverine habitat for largemouth bass and other fish species. It was augmented by a 1.5–3.0 km wide floodplain containing extensive marshes, numerous shallow backwater areas, and oxbow lakes that became linked with the river during periods of high discharge. River hydrology reflected a typical subtropical wet/dry cycle (annual water level fluctuation of 1–2 m) with consistent seasonal wetting and drying occurring only in peripheral areas (Toth 1993).

As a part of a larger flood control project for central and southern Florida, the Kissimmee River was channelized into an 80-km box-cut canal (C-38) by the U.S. Army Corps of Engineers in the 1960s. Channelization and spoil deposition resulted in loss of 13,000 ha of wetlands in the lower Kissimmee River basin (Pruitt and Gatewood 1976). Over 55 km of river channel and 2,800 ha of oxbow and backwater habitats were destroyed (U.S. Corps Eng. 1985). Remaining river channels and backwater habitats rapidly degraded as lack of water flow caused accumulation of organic sediments and encroachment of dense vegetative growth (Pruitt and Gatewood 1976, Toth 1993). Lack of historical flow regimes and stabilization of water levels throughout the year not only diminished beneficial effects of flood pulses (Junk et al. 1989, Bayley 1991), but also resulted in prolonged DO lags (<2 ppm) during summer and fall (Perrin et al. 1982). These factors shifted fish populations from desirable river-floodplain species, including centrarchids and cyprinodontids, to more undesirable species, such as poecilids, Florida gar (*Lepisosteus platyrhincus*), and bowfin (*Amia calva*) that are more tolerant of poor environmental conditions, such as low DO (Bull et al. 1991).

In an effort to return the river to a more natural condition, in 1992 the U.S. Congress passed the Water Resources Development Act which authorized Kissimmee River restoration. The proposed restoration project, which will begin construction in 1998, includes backfilling 35 km of the C-38 canal, reestablishing 14 km of river channel, removing 2 water control structures, and leveling berms along the canal. The plan will, in theory, restore flow regimes to historic river channels and seasonal water fluctuations onto the floodplain. Critical restoration elements will be floodplain habitat availability during the wet season, a fluctuating hydrograph with seasonal draining of wetland marshes, and enhanced flow to maintain satisfactory DO throughout the year (Toth 1993, Dahm et al. 1995).

Because largemouth bass have been identified as a restoration-critical species for its ecological and economic importance in the river (Bull et al. 1991), a study was initiated in 1992 to determine how bass adapt to changes in DO and hydrology (flow and water level) in the channelized river system and predict how the restored system will affect bass and other fish species. Our objectives were to document habitat most frequently used by bass, determine the range of DO and flow rates with which bass associate, and evaluate movement patterns in relation to these parameters, especially during periods when DO is stressful (<2 ppm).

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Methods

The Kissimmee River drains a total watershed greater than 7,700 km^2 (U.S. Army Corps Eng. 1985). It is composed of the 9-m deep C-38 canal and 98 km of remnant channel. The system is divided into a series of 5 impoundments (pools A, B, C, D, and E), each controlled by a separate water control structure. Water in each pool, excluding Pool B, is held at a constant level, and average drop in elevation between pools is about 2 m (U.S. Army Corps Eng. 1985). Because flows are directed through the C-38 canal, most remnant river channels are stagnant. However, notched weirs in Pool B, installed in 3 sections of the C-38 canal during a restoration demonstration project in 1987, force water into adjacent remnant river channels and cause periodic floodplain inundation during high water discharges (Bull et al. 1991, Toth 1993).

The Kissimmee River is a low order stream with an average gradient of 0.07 m/km (Bass and Cox 1985). Although average daily discharge is about 62 m^3/sec, flows are sporadic and occur only in response to water level regulation schedules in the upper basin lakes (Obeysekera and Loftin 1990). The Kissimmee River is a warm-water stream (mean water temperature = 22.9 C) with circumneutral waters (mean pH = 6.9). River water chemistry is considered intermediate compared to other central and southern Florida rivers (Bass and Cox 1985).

Littoral vegetation is abundant in all pools. Dominant emergent species include spatterdock, smartweed, and maidencane (*Panicum hemitomon*). Submersed species include hydrilla (*Hydrilla verticillata*) and coontail (*Ceratophyllum demersum*). Primary overstory consists of wax myrtle (*Myrica cerifera*), willow, live oak (*Ouercus virginiana*), and bald cypress (*Taxodium distichum*) (Milleson et al. 1980, Bull et al. 1991).

A radio-telemetry study of largemouth bass was conducted in pools B and C (Fig. 1) from 28 January 1992 through 29 November 1993. Largemouth bass were captured by electrofishing. Only bass >1 kg were implanted with transmitters to insure transmitter weight did not exceed 2% of the fish's weight. Fish were weighed to the nearest 14.2 g, measured to the nearest mm (TL), and examined upon incision to determine sex.

Radio transmitters (ATS Model 5 implantables) were implanted surgically following procedures described by Bruno et al. (1990) and Mesing and Wicker (1986). Each largemouth bass was also tagged with a Floy FD-68BC anchor tag to allow for external identification of individual fish. All fish were released at the capture site. Each bass was located twice weekly with an Advanced Telemetry Systems (ATS) receiver, an ATS loop antenna, and a 15-cm coaxial cable antenna. When a bass was found, a Loran-C receiver (Tigershark LCL #TS25-NA) was used to obtain latitude-longitude coordinates, which were cross referenced with U.S. Geological Survey (USGS) 7.5-minute topographical map coordinates. Location sites for each large-

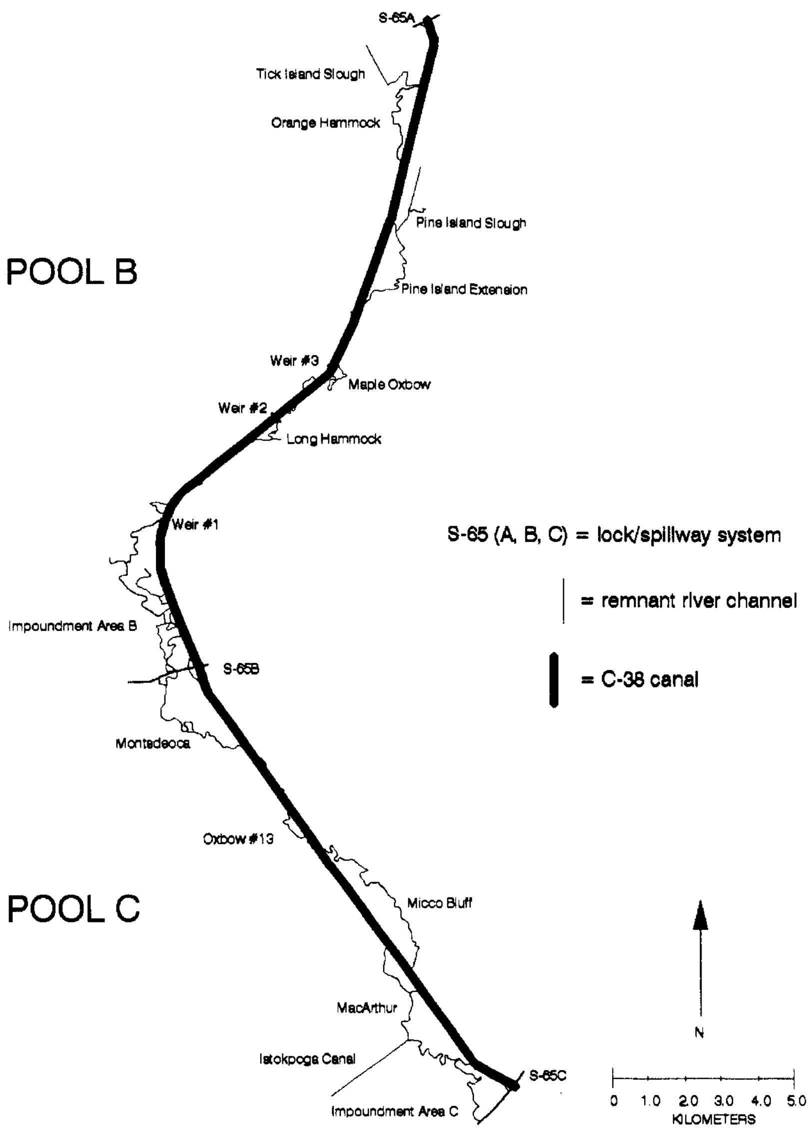

Figure 1. Map of pools B and C, Kissimmee River, Florida.

mouth bass were transposed to Kissimmee River maps copied from the USGS maps. These maps were used to display bass movements in the Kissimmee River and to indicate those periods over which largemouth bass movement was greatest. Date, time of day, geographical coordinates, habitat type, substrate type, and water depth were recorded at each location site. Current velocity, DO, and water temperature profiles also were measured at 0.5-m intervals at present and previous location sites.

We determined primary habitat use by counting the number of occurrences in each habitat type. Primary habitat was defined as the most abundant habitat feature at each bass location site. Examples of primary habitat included vegetation species, open water, or submerged log. Area habitat was defined as remnant river channel or C-38 canal.

Daily movement of individual bass was calculated as the straight-line distance between latitude-longitude coordinates at the present and previous locations divided by the number of days between locations. Maximum extent of movement for each bass was calculated from the longest distance moved between consecutive locations by use of the respective latitude-longitude coordinates. These distances, though not true measures of home range size, serve as indicators of bass movement and area of primary activity, especially for those utilizing the relatively straight C-38 canal. Home area was subjectively designated as the area in which the fish's movements consistently occurred. A home area was considered abandoned when at least 4 consecutive locations (in ≥2 weeks) were >1 km from the nearest home area location.

Largemouth bass movements were assessed in relation to changes in DO during winter (Jan–Mar), spring (Apr–Jun), summer (Jul–Sep), and fall (Oct–Dec). We used the habitat suitability index (HSI) scale developed by Stuber et al. (1982) to set our parameter value ranges that define the ecological value of each location at which bass were found (e.g., DO <2.0 ppm, HSI = 0.1; DO ≥2.0 ppm and DO <5.0 ppm, HSI = 0.4; DO ≥5.0, HSI ≥0.8). The HSI value scale, which ranges from 0 (unsuitable) to 1 (optimal habitat), was viewed as a best available relative indicator of habitat life-support potential. We further defined DO between 1.0 and 2.0 ppm as stressful and DO <1.0 ppm as lethal based on observations of Whitmore et al. (1960), Moss and Scott (1961), and Petit (1973). To evaluate movement associated with changes in DO, within-season daily movement distances between DO ranges at previous locations (previous location DO) were compared with 1-way analysis of variance and Tukey's post hoc multiple-range test. Data were analyzed with the SYSTAT® statistical package (Wilkinson 1990). Significance of all statistical tests was established at $\alpha \leq 0.05$.

Results

A total of 883 locations were recorded for the 20 radio-tagged largemouth bass. Bass lengths ranged from 424 to 576 mm and their weights from 1,035 to 2,835 g. Mean daily movement for the bass was 196.9 m (SD = 328.0). Daily movements averaged <100 m for more than half of all location samples (Fig. 2). Daily movements >1 km were most common in summer (13 locations) and spring (9 locations) (Fig. 2).

Largemouth bass utilized various habitats in proportion to the habitat's frequency of occurrence in the river. Bass occupied home area in remnant river runs and the C-38 canal, but only 25% utilized both areas with regularity (>30% of locations in both areas). Bass located in the C-38 canal were most commonly associated with smartweed while those in remnant river runs were equally divided between smartweed, spatterdock, and aquatic grasses (Table 1). Bass living in remnant river runs

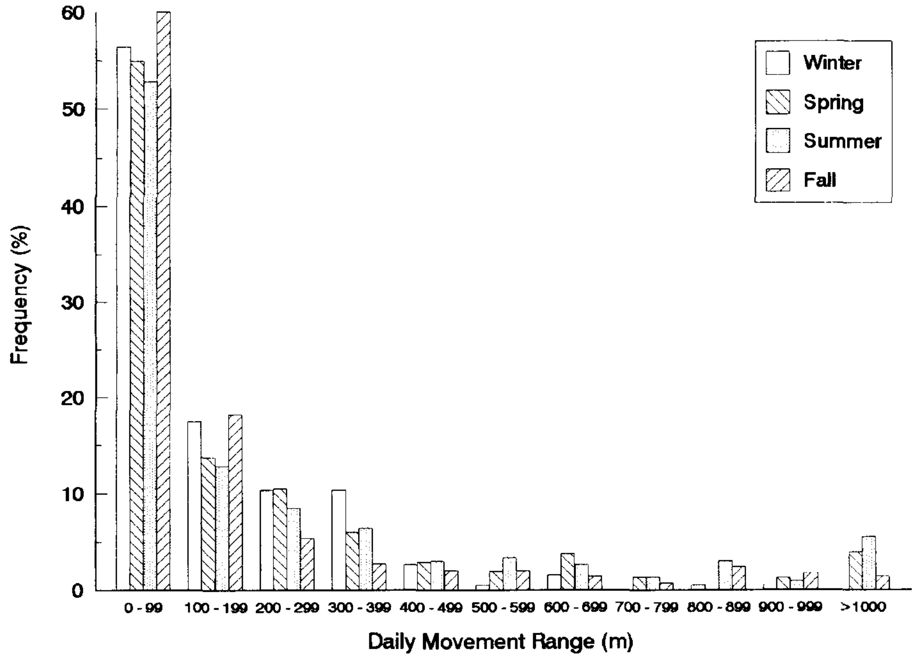

Figure 2. Largemouth bass straight line daily movement in 100-m increments by season, pools B and C, Kissimmee River, Florida, 28 January 1992–29 November 1993.

were located frequently around overhanging and submerged willow, wax myrtle, or oak trees.

Water quality parameters measured at largemouth bass location sites were indicative of moderate to good largemouth bass habitat during most months. Mean DO ranged from 3.89 ppm (SD = 2.24) in summer to 6.36 ppm (SD = 1.23) in winter. Location sites with DO >5 ppm (HSI ≥0.8; Stuber et al. 1982) were most frequent in winter and spring (Fig. 3). In summer and fall, DO at bass location sites was most often between 2 and 5 ppm (HSI = 0.4; Stuber et al. 1982) (Fig. 3). Almost a fourth of summer location sites had DO <2 ppm (HSI = 0.1; Stuber et al. 1982) (Fig. 3). Eleven of 13 observations in which bass survived DO generally considered lethal to largemouth bass (<1 ppm; Moss and Scott 1961, Petit 1973) were recorded during summer. Mean water temperature ranged from 18.7 C (SD = 2.2) in winter to 27.9 C (SD = 3.2) in summer. Current velocities were negligible (≤6.0 cm/sec) at a minimum of 92.2% of bass locations in any season. Zero flow was recorded at 82.6% of locations. Bass were found in current velocities >20 cm/sec (HSI = 0; Stuber et al. 1982) only 4 times (0.4%).

Increases in daily movement distances during summer and fall months may have been associated with DO lags to stressful and lethal levels. During summer, significantly greater distances were moved when previous location DOs were <1.0 ppm compared to distances moved when previous location DOs were ≥1.0 ppm (Fig.

Table 1. Primary habitat types at location sites for 20 largemouth bass in pools B and C, Kissimmee River, Florida, 28 January 1992–29 November 1993.

Habitat type		*N* occurrences			% occurrences		
Scientific name	Common name	Total	C-38 Canal	Remnant river runs	Total	C-38 Canal	Remnant river runs
Polygonum hydropiperoides	smartweed	291	201	89	32.9	44.9	20.6
Nuphar luteum	spatterdock	185	97	88	21.0	21.6	20.4
Panicum spp./*Sacciolepis striata*	aquatic grasses	103	17	86	11.7	3.8	20.0
Salix spp.	willow	81	17	64	9.2	3.9	14.8
Typha spp.	cat-tail	60	56	5	6.9	12.4	1.1
	open water	39	27	12	4.5	6.0	2.9
Myrica cerifera	wax myrtle	36	12	24	4.1	2.8	5.5
	submerged tree	19	0	19	2.2	0.0	4.4
Ceratophyllum demersum	coontail	12	7	5	1.3	1.5	1.1
Quercus spp.	oak	11	1	10	1.2	0.2	2.2
Ludwigia octovalis	yellow primrose	9	0	9	1.0	0.0	2.0
Hydrocotyle umbellata	water pennywort	8	1	7	0.9	0.2	1.5
Hydrilla verticillata	hydrilla	7	6	1	0.8	1.3	0.2
Pistia stratiotes	water lettuce	7	1	6	0.8	0.2	1.3
Eichhornia crassipes	water hyacinth	3	1	2	0.3	0.2	0.5
Pontederia lancifolia/P. cordata	pickerelweed	3	0	3	0.3	0.0	0.7
Scirpus californicus/S. validus	bulrush	2	2	0	0.2	0.4	0.0
Alternanthera philoxeroides	alligatorweed	1	0	1	0.1	0.0	0.2
Cladium jamaicense	sawgrass	1	0	1	0.1	0.0	0.2
Utricularia spp.	bladderwort	1	0	1	0.1	0.0	0.2
	sandbar	1	0	1	0.1	0.0	0.2
Myriophyllum aquaticum	parrot's feather	1	1	0	0.1	0.2	0.0
Nymphea mexicana	yellow water-lily	1	1	0	0.1	0.2	0.0
Najas guadalupensis	southern naiad	1	1	0	0.1	0.2	0.0
Total		883	449	434	100.0	100.0	100.0

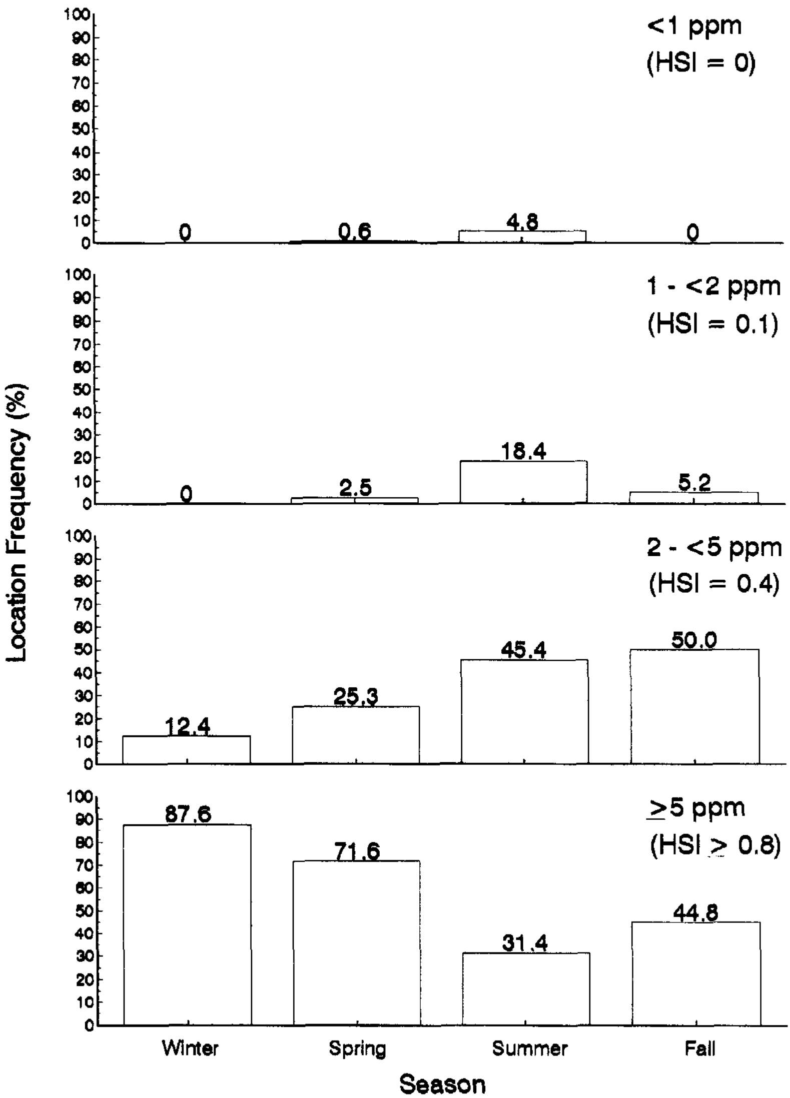

Figure 3. Dissolved oxygen ranges (ppm) at largemouth bass locations (percent frequency) by season, pools B and C, Kissimmee River, Florida, 28 January 1992–29 November 1993. All measurements were taken at 0.5 m depth.

4). During fall, bass moved significantly greater distances when previous location DOs were <2.0 ppm compared to distances moved when previous location DOs were ≥2.0 ppm (Fig. 4). Although previous location DOs were <2.0 ppm at 10 locations during spring, no differences in distances moved were detected between previous location DOs for spring or winter (Fig. 4).

Eleven bass tracked during summer and fall moved long distances (>1 km) after sudden, large decreases in DO. Bass emigrated from established home ranges during periods when previous location DO ranged from 0.10 to 0.80 ppm at 25–27 C. Four dead bass were located where DOs were <1.0 ppm. Bass moved to northern sections of the C-38 canal and Pine Island Extension in Pool B (Fig. 1) during periods of stressful DO in southern portions of the pool. Northern areas of the pool generally maintained sufficient DO (1.85–5.0 ppm) during summer and fall. Bass in Pool C migrated to the northern half of the C-38 canal (Fig. 1) when DO dropped below 2 ppm in established home areas. An exception to this pattern was a bass in Pool C, which moved south from its established home area in the middle of the pool. The fish migrated out of Pool C through the spillway or locks at S-65C and found refuge in the northernmost river channel and the upper C-38 canal of Pool D (next pool south of Pool C). In this area, DO at location sites ranged from 1.00 to 4.15 ppm. Bass that maintained home areas in the northern sections of each pool did not abandon these areas. Bass returned to previously established home areas after DO increased above stressful levels.

During high water flow periods in Pool B (≥6 cm/sec), bass were located in protected (flow ≤6 cm/sec, HSI = 1.0; Stuber et al. 1982) areas. These included heavily vegetated areas containing smartweed and spatterdock beds, overhanging willow and oak along channel margins, and inundated floodplain with terrestrial grasses. In January and April 1993, water levels were sufficiently high in Pool B to inundate historic floodplain along remnant river channels and areas not restricted by the spoil levee. Three of 4 bass, whose home ranges were adjacent to these areas, utilized flooded pasture during this high water period. The fourth bass remained in an area of the C-38 canal where the floodplain was inaccessible, but was found in flooded willow trees and other terrestrial vegetation along the C-38 canal banks. Bass returned to previous home areas as water levels receded.

Discussion

Numerous studies have documented the homing tendencies of black basses (*Micropterus* spp.), especially largemouth bass (Warden and Lorio 1975, Winter 1977, Doerzbacher and Bryan 1983, Savitz et al. 1983, Mesing and Wicker 1986), with occasional displacement outside established areas (Quinn et al. 1978, Mesing and Wicker 1986). Home range size and abandonment of home areas have been attributed to searching for spawning habitat (Mesing and Wicker 1986, Bruno et al. 1990), availability of forage and protective habitat (Savitz et al. 1983), fish size (Mesing and Wicker 1986), and changes in water quality (Doerzbacher and Bryan 1983, Gent et al. 1995). In this study, we found changes in DO, particularly declines below stressful

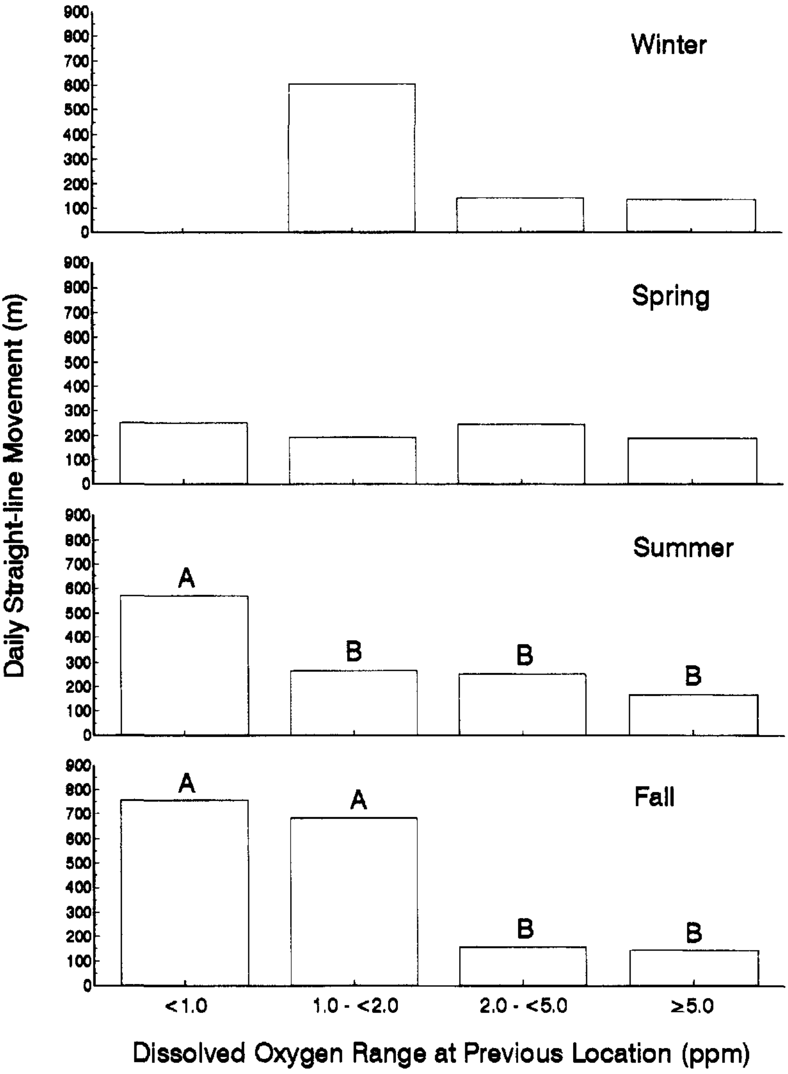

Figure 4. Mean daily movement (m) associated with dissolved oxygen ranges (ppm) at previous largemouth bass locations by season, pools B and C, Kissimmee River, Florida, 28 January 1992–29 November 1993. All measurements were taken at 0.5 m depth. Within each season, means with the same letter are not significantly different. Letters are omitted if none of the values are significantly different ($\alpha \leq 0.05$).

levels, and water levels that effected floodplain inundation to be primary influences in largemouth bass habitat use and movement patterns. Bass temporarily abandoned established home areas when DO dropped to stressful levels or when previously unavailable floodplain habitat was inundated by high water.

Largemouth bass associated most frequently with emergent and submerged shoreline vegetation. Based on observations of Kissimmee River habitat during the study, smartweed was one of the most common vegetation species in the C-38 canal. Spatterdock and smartweed were both abundant in remnant river runs. Submerged and overhanging trees, such as willow, wax myrtle, and oak, were also prevalent in old river sections. This type of cover is widely recognized as excellent largemouth bass habitat (Carlander 1977, Stuber et al. 1982). Bass also used the C-38 canal and remnant river runs in proportion to their respective surface areas of 715.0 (55%) and 594.3 (45%) ha (Milleson et al. 1980). Of those bass located primarily in the C-38 canal or remnant runs, 60% used the C-38 canal as their home area and 40% used river runs.

Several studies have described responses of largemouth bass to low DO. Moss and Scott (1961) reported largemouth bass withstood sudden drops in DO to 0.92–1.40 ppm for 24 hours at water temperatures between 25 and 35 C. Whitmore et al. (1960) observed, at water temperatures between 17 and 22.5 C, largemouth bass showed no avoidance to DO of 6 ppm, some avoidance to 3.0–4.5 ppm, and strong avoidance to 1.5 ppm. Petit (1973) reported that largemouth bass stopped feeding at DO of 2 ppm, and at 1 ppm (25.2–25.5 C) all died within 11 hours. Davis (1975), upon review of numerous studies on oxygen requirements of fishes and other aquatic organisms, concluded a minimal level of 2.5 ppm at 25 C was needed to maintain a healthy freshwater fish community. Cech et al. (1979) recommended DO of 2.60 ppm at 25 C and 2.85 ppm at 30 C. In one of the few field studies examining largemouth bass response to changing water quality, Doerzbacher and Bryan (1983) observed higher incidence of movement to locations with higher DO and a temperature preference of 28 C; however, no DO preference was detected. Gent et al. (1995) observed movement of largemouth bass out of backwater areas of the Mississippi River as DO fell below 6 ppm; however, certain bass remained in areas with DO down to 3 ppm. Largemouth bass movements during our study did not appear to be affected by moderate changes in DO as long as DO remained >2 ppm. Kissimmee River largemouth bass were located in water with DO >2 ppm throughout the year and DO between 1 and 2 ppm in summer, but were rarely found alive at concentrations <1 ppm.

We observed home area abandonment by largemouth bass during acute changes in DO below 2 ppm. These periods occurred from June through October. Increased movements associated with these decreases in DO may have been the result of bass searching for areas with higher DO. Remnant river channels in southern sections of the impounded pools were characterized by stagnant water, muck-covered bottoms, and shallow channels heavily vegetated with smartweed and floating tussocks. DO was depressed in these areas much of the summer. Bass tracked in Pools B and C used the C-38 canal to move from these areas to remnant river channels and areas of the C-38 canal in the northern region of the pools. Although bass reoccupied previously established home areas as DO increased above stressful levels, these summer DO lags reduced suitable river habitat to only a fraction of what was usable during winter and spring.

Use of littoral areas and inundated floodplain by bass when flow rates exceeded optimal levels were important findings in regard to future evaluation of Kissimmee River restoration. Carline and Klosiewski (1985) found that rapid flow increases, which were confined to the channel in high banked streams, were mitigated in a river that had a floodplain adjacent to the channelized sections and unaltered areas. As flows increased, current velocities in the main channel moderated as water spread out onto the floodplain. Life histories of many fish species are dependent on movement between channel and floodplain habitat during high flow or high water periods. Fish movement into these areas allowed utilization of important resources (Welcomme 1979, Junk et al. 1989). The floodplain functions as forage, breeding, and nursery habitat for fishes, water-birds and other wildlife and as a natural water-cleansing mechanism (Welcomme 1979, Junk et al. 1989). Normal water discharge (40–57 m^3/sec) in the pre-channelized river resulted in overbank water flow and mean water velocities <60 cm/sec (Toth 1993). As historical discharge rates and 10,730 ha. of riverine floodplain are reestablished, littoral zone and floodplain utilization by important fish species, such as largemouth bass, will serve as an important key to river restoration.

Management Implications

This study demonstrated minimum DO tolerance of largemouth bass under natural conditions and suggested bass use refuge areas during periods of low DO. Refuge areas were located in northern sections of the C-38 canal in pools B and C and the Pine Island Extension in Pool B. During the construction phase of Kissimmee River restoration, passageways to these refuge areas in northern sections of each pool need to be maintained.

Use of floodplain habitat by largemouth bass was also documented during periods of increased current velocities and high water levels. With over 100 km^2 of ecosystem expected to be restored (Toth 1993), floodplain use and the associated increases in productivity by largemouth bass and other fish species will be important criteria which can be used to judge restoration success.

Existence of a functioning floodplain dependent on naturally occurring flow regimes is essential for restoration of all components of any riverine floodplain ecosystem, including channel littoral areas and broadleaf marsh, wet prairie, and wetland shrub communities. Interactions between the channel and floodplain, reestablishment of complex floodplain habitat, enhanced densities of forage fish and aquatic invertebrates, and improved DO availability are the essential factors to enhancing favorable ecological response. The absence of minimum flow throughout the year and a more natural hydrologic scheme that results in productive flood pulses throughout the river floodplain are the greatest hinderances to the establishment of healthy fish and wildlife populations. Aquatic communities will likely not change in the Kissimmee River until hydrologic conditions and the entire ecosystem approach historical conditions.

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