US Army Corps
of Engineers
MISSISSIPPI VALLEY DIVISION

BIOLOGICAL ASSESSMENT

INTERIOR POPULATION OF THE LEAST TERN, *Sterna antillarum*
REGULATING WORKS PROJECT, UPPER MISSISSIPPI RIVER (RIVER MILES 0-195) AND MISSISSIPPI RIVER AND TRIBUTARIES PROJECT, CHANNEL IMPROVEMENT FEATURE, LOWER MISSISSIPPI RIVER (RIVER MILES 0-954.5, AHP)

U. S. Army Corps of Engineers
Mississippi Valley Division/
Mississippi River Commission
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Preface

This Biological Assessment is based on extensive habitat and least tern population data collected along the Mississippi River over the past 15 years as part of the Lower Mississippi River Environmental Program being conducted by the Mississippi River Commission/Mississippi Valley Division (MVD) of the U.S. Army Corps of Engineers and the Memphis, New Orleans, St. Louis and Vicksburg Engineer Districts. The work was sponsored by the Engineering Division, MVD, under the Channel Improvement feature of the Mississippi River and Tributaries Project and was carried out under the direction of the President Designee of the Mississippi River Commission, MG Phillip R. Anderson.

Stephen P. Cobb, Environmental Analysis Division, MVD, prepared the report. Nancy Towne and Paul Clouse, DynTel Corp., assisted with habitat mapping and the spatial analysis of habitat and least tern data. Dr. Tom Pullen (LMVD) prepared portions of the literature review and conducted agency coordination, and Dr. David Biedenharn, U.S. Army Engineer Waterways Experiment Station (WES) provided input concerning long term river trends. John Rumancik, Memphis District, conducted the annual field censuses of least terns on the Middle and Lower Mississippi River. Dr. Francisco Vilella, Cooperative Fish and Wildlife Research Unit, Mississippi State University, performed portions of the statistical and population analyses of the least tern census data. Dr. Rose Kress, WES, and Texas A&M University, Department of Forestry developed the sandbar vegetation maps.

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PART I: INTRODUCTION

Background

The least tern, *Sterna antillarum*, is a colonial, migratory shore bird that breeds and nests on bare to sparsely vegetated riverine sandbars, sand pits, shorelines and similar habitats in the Mississippi River and Rio Grande River Basins of the mid-continental United States. The largest interior population of the least tern in the U. S. is found along the Lower Mississippi River (LMR).

On June 27, 1985 the interior population of the least tern was listed as endangered (50 Federal Register 21, 784-21, 792), but no critical habitat has been designated. This action was taken because of apparent declining population numbers and loss or degradation of riverine sandbar habitat. The habitat decline was attributed to construction of navigation and flood control projects and other development. At the time of listing, the interior population was estimated at 5,000 birds (Sidle and Harrison, 1990).

The Recovery Plan for the least tern (Sidle and Harrison, 1990) contains strategies for recovery of the species. The recovery criteria outlined were designed to ensure the protection, restoration and enhancement of essential habitat, establishment of management plans, and increase of population numbers throughout the range to 7,000 birds. For the Lower Mississippi River the Recovery Plan goal was for current numbers (2,200-2,500) to remain stable for 10 years. No target population levels were stipulated for the Middle Mississippi River (MMR).

Purpose and Scope

This Biological Assessment (BA) is being prepared pursuant to Section 7 of the Endangered Species Act, as amended. The purpose of the BA is to evaluate effects on the interior population and habitats of the least tern of the Regulating Works Feature of the Mississippi River Between the Ohio and Missouri Rivers Project, and the Channel Improvement Feature of the Mississippi River and Tributary Project. These two civil works projects encompass approximately 1,150 miles of the Mississippi River within the jurisdiction of the U. S. Army Engineer Division, Mississippi Valley (MVD) and the St. Louis, Memphis, Vicksburg, and New Orleans Engineer Districts. These two projects are managed by MVD as a unit and together constitute one of the world's largest river engineering projects.

This BA also includes results of the Mississippi Valley Division's efforts to accomplish parts of the population and habitat monitoring steps outlined in the Recovery Plan.

A system-wide or landscape approach was taken in the analyses of project effects on the least tern. The least tern range includes over 600 miles of the Mississippi River within the project area. Therefore, customary yearly evaluations of effects of project construction at scattered sites along the river, without consideration of cumulative or system-wide effects, do not adequately address potential impacts to the least tern.

The Fluvial System

The Mississippi River is one of the world's largest alluvial river systems, having a drainage basin of 1,245,000 square miles, one-eight of North America, encompassing 41 percent of the contiguous United States and parts of two Canadian provinces. Worldwide, the Mississippi River ranks fourth in drainage area, seventh in length, and sixth in average discharge. The main stem of the river courses 2,348 miles from Lake Itasca in northern Minnesota to the Gulf of Mexico.

The floodplain and river channel environments of the MMR and LMR are a mosaic of fluvial landforms and channel bedforms created by geomorphic processes involving the transport of water and sediment by the river. The floodplain riverward of the main line levees contains a diverse bottomland hardwood forest interspersed with a variety of fluvial lakes, agricultural lands, and urban areas. Portions of the floodplain are inundated in most years by river waters.

Middle Mississippi River (MMR)

The MMR originates at the confluence of the Mississippi and Missouri Rivers and extends 195 miles southward to the junction of the Mississippi and Ohio Rivers. About 40 percent of discharge (Q) is received from the Missouri River Basin and 60 percent from the Mississippi River Basin, while the opposite occurs for sediment load. Average discharge is about 195,000 cfs at St. Louis for the period 1944-1994. April has the highest average monthly Q and December has the lowest average monthly Q. The northern 150 miles has relatively low sinuosity and is contained in a 3-4 mile wide, deeply incised valley bounded by steep rock bluffs. The southern 45 miles of the river, located within the alluvial Mississippi Embayment, has a wide floodplain and more tortuous course. Top bank width averages about 3,200 feet.

Lower Mississippi River (LMR)

The LMR begins at the confluence of the Mississippi and Ohio Rivers in southern Illinois and flows southward 955 miles to Head-of-Passes, La., where the channel subdivides into several distributaries that convey discharge to the Gulf of Mexico. The channel pattern is generally meandering. Mean top bank width is 5,450 ft, while mean width of the low-water (3 percentile Q) channel is 2,960 ft (Tuttle and Pinner, 1982). At Vicksburg, Miss. (river mile 437) mean Q is 617,000 ft^3 sec^{-1} for the 1944-1994 period and means average suspended sediment load (Q_s) is 198 x 10^6 tons yr^{-1} (Moody and Meade, 1992). River slope ranges from 0.3 to 0.5 ft mi^{-1} north of Old River, La. (RM 315) and is 0.2 ft mi^{-1} or less from Old River to Head-Of-Passes.

The LMR hydrograph is variable, with yearly stage fluctuations of 20-40 ft (mean=22 ft) (Fig. 2). April has the highest average monthly Q (947,457 ft^3 sec^{-1}), and October has the lowest average monthly Q (260,844 ft^3 sec^{-1}) (Tuttle and Pinner, 1982). The timing, duration, and frequency of annual low-discharge and high-discharge events, however, vary widely among years.

The channel environment of the LMR is comprised of the main and secondary channels, sandbars, and steep banks. Each of these geomorphic zones may be modified by the presence of stone dike and bank stabilization structures. There are about 482,418 acres of aquatic habitat within the top banks of the river, assuming a bank-full stage.

The LMR floodplain lying riverward of the levees is comprised of about 2.25 million acres and varies in width from 1 to 15 miles. The land cover in 1992 consisted of about 1,313,090 acres of forests, 371,569 acres of agricultural lands, and 127,408 acres of lakes, streams, and man-made water bodies. These lands function as the main overflow system of the river and contain a diversity of terrestrial habitats and bottomland hardwood forests. Sugarberry/American elm/green ash, sycamore/Sweetgum/ American elm, black willow and cottonwood/willow forest types make up 70 percent of the wooded bottomlands.

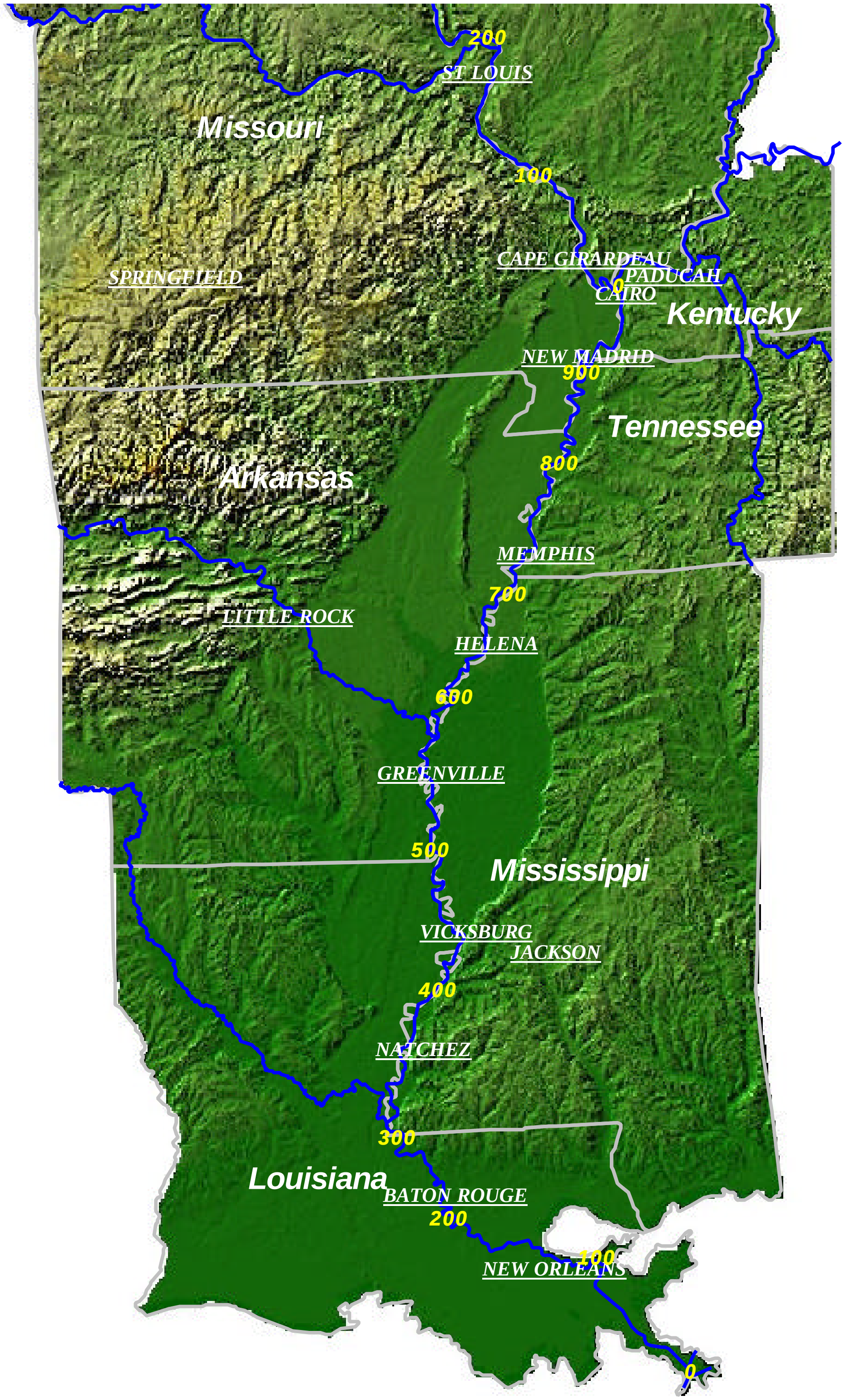


Figure 1. Mississippi River Reach for the least tern Biological Assessment. Study area shown in blue.

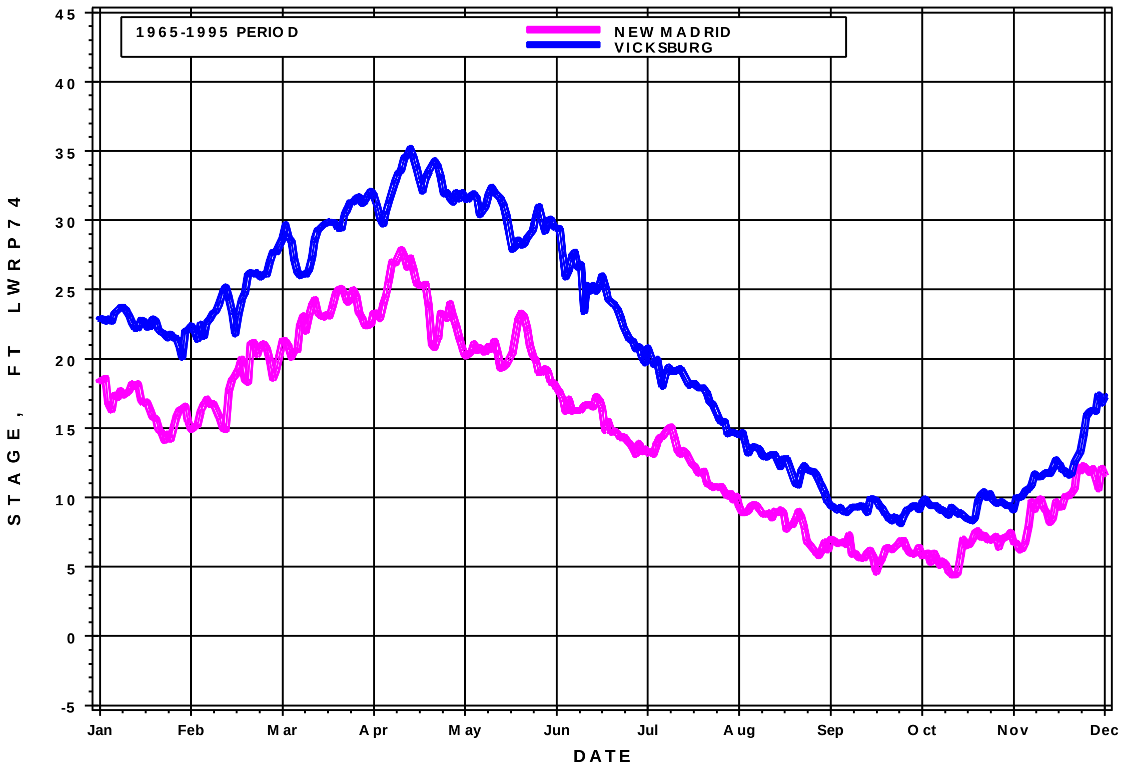


Figure 2. Lower Mississippi River hydrographs based on mean daily stages, 1965-1995 for the New Madrid, Mo. (RM 890) and Vicksburg, Miss. (RM 437) gages.

Project Description

The Mississippi River Between the Ohio and Missouri Rivers Project was authorized by the River and Harbor Act of 21 January 1927, Rivers and Harbors Commission Document No. 9, 60th Congress, and the 3 July 1930 Rivers and Harbors Commission Document No. 12, 70th Congress. The project provides for obtaining and maintaining a minimum navigation channel depth of not less than nine feet and a minimum width of not less than 300 feet at low water, with additional width in bends from the mouth of the Ohio River to the northern boundary of the City of St. Louis, Mo., and a minimum width of not less than 200 feet, with additional width in bends from the City of St. Louis to the mouth of the Missouri River. The regulating works portion of the project consists of stone dikes, bendway weirs, and revetments. Approximately, 587,720 linear ft. of stone dikes, 84,060 linear ft of bendway weirs, and 169.2 miles of stone revetment have been constructed. The regulating works are approximately 66 percent complete and are scheduled to be finished in 2014.

The Mississippi River and Tributaries Project was authorized by the Flood Control Act of 1928, which has been modified numerous times to provide the present project authority. The MR&T Project includes several features for flood protection and navigation in the Lower Mississippi Valley. The Channel Improvement feature of the project provides for a low-water navigation channel nine feet deep and 300 feet wide from Baton Rouge, La to Cairo, Ill and for stabilization of river banks to protect the flood control levees from Head-of-Passes, La. to Cairo, Ill. and on the lower 9 miles of the Ohio River.

The Channel Improvement feature of the MR&T Project consists of the construction of stone dikes, foreshore protection dikes, and articulated concrete mattress (ACM) and trench fill revetments in the main stem of the Mississippi River. Construction dredging has also been used in a few instances. As of September 30, 1996 there were approximately 288 miles of stone dikes, 129 miles of foreshore dikes, and 1,023 miles of operative revetment on the LMR. Stone dike work is about 85 percent physically complete, with 51 miles of dikes remaining to be constructed. ACM revetment work is approximately 94 percent physically complete, with 62 miles to be built in the future. The project is scheduled to be finished in 2020.

River Engineering Structures

Three main types of river engineering structures are used in the MMR and LMR: revetments, dikes, and bendway weirs. Systems of these structures work in concert in a river reach to achieve both flood control and navigation objectives. The effects of these structures on least tern habitat are discussed in Part III.

Revetments

Revetments are placed on riverbanks to arrest bank caving and protect levees and other structures, and to maintain an efficient channel alignment. Caving banks of the LMR are typically stabilized with articulated concrete mattress (ACM) (Fig. 3).

ACM is made up of concrete blocks 46.5 inches long, 17.75 inches wide, and three inches thick spaced one inch apart and tied together with corrosion-resistant wire to form a continuous mattress. ACM is laid on the graded bank slope from just above the low-water elevation to the channel bottom. The upper bank area is graded to a maximum slope of 1 vertical to 3 horizontal and paved with riprap stone; asphalt was used prior to the early 1960's. ACM is flexible, strong, and durable and insures complete coverage of the bank. About eight percent of the ACM surface is comprised of spaces between the individual blocks.

Trench fill revetment is also occasionally used in the LMR for major channel realignment. A trench is excavated on the land or island along the design channel alignment and filled with quarry stone. When the river migrates laterally into the filled trench, the stone launches and stabilizes the bank.

In the MMR, stonefill revetment is used. It consists of quarry-run stone placed on the ungraded bank, with extra stone at the toe of the bank for launching. Off-bank revetment is used at some locations for environmental enhancement.

Dikes

Stone dikes are constructed in the river channel to develop a self-maintaining (minimal maintenance dredging), low-water navigation channel with authorized project dimensions and alignment (Fig. 4). Bank protection is also an ancillary purpose in some instances. Dike systems function, in conjunction with revetments, to modify and stabilize channel alignment, reduce discharge through secondary channels, and decrease width and increase depth of the low-water (navigation) channel, mainly in channel crossings (Fenwick 1969; Cobb and Magoun 1985). Systems of stone dikes are placed across secondary channels associated with point bars, islands, and mid-channel bars, and on alternate bars in straighter reaches (Figs. 5).

Design of stone dike systems is variable and depends on purpose, site conditions, and economics (Wilkinson, 1972; Pokrefke, 1990). Spacing of dikes is based on experience and local factors, but is typically one to two times the length of the next upstream dike. Dikes comprising a system may be stepped-up, i.e., dike crown elevations increase downriver, or stepped-down, i.e., dike elevations decrease downriver. Stepped-down dike systems tend to increase deposition between dikes during high discharges which successively overtop each dike as stages rise, while stepped-up systems tend to promote scour between successive dikes (Franco, 1967; Fenwick, 1969). However, studies of dike systems on the LMR have shown that sedimentation was higher in level and stepped-up systems than in stepped-down systems. This may be due to the large channel width and wide spacing of dikes.

Transverse stone dikes are linear structures that range in length from 1,000 to 12,000 feet (mean = 2,000 ft.) and are built of large quarry-run stone. They extend from the bank into the channel and are oriented normal to flow or are angled as much as 30 degrees downstream or upstream, depending on local conditions and objectives. Stone dikes are trapezoidal in cross-section, generally with a crown width of 5-14 ft and a longitudinal profile that slopes from the riverbank towards the channel. A sloped dike profile enables the structure to affect channel alignment over a range of low to mid-bank stages. Dike length is based on total channel width and the design width or trace of the navigation channel, i.e., the required amount of channel contraction and conveyance. Crown elevations are based on the degree of channel control required, existing bed elevations, and costs. For example, a dike that traverses a deep secondary channel may have a relatively low crown elevation because construction cost increases exponentially as a function of dike height. A trail or L-head section may be constructed at a right angle and extend downstream from the channelward tip of a transverse dike to increase channel control at reduced cost or to simulate bank alignment. In addition, weir sections, aligned with the axis of the secondary channel, are placed in dikes for habitat conservation purposes.

Bendway Weirs

Bendway weirs are linear stone structures, similar to transverse stone dikes, except for where they are placed in the channel. These structures are placed from the concave bank across the main or navigation channel. A series of weirs are constructed in a bend to form a functional system. These structures typically have elevations 20 feet or more below the LWRP, thereby allowing passage of navigation traffic, and are variously angled upstream depending on site conditions. Bendway weir systems are designed to increase uniformity of flow, to lower velocities, and to reduce shoaling in a bend. These effects are accomplished by widening the low-water channel and making it shallower, resulting in a more rectangular, as opposed to a triangular, channel cross-section.

The number, length, elevation, angle, and spacing of bendway weirs are based on site conditions and physical model tests. Bendway weirs were developed by the St. Louis District, and are used extensively on the MMR. Only one bendway weir system, at Victoria Bend (RM 595), has been installed on the LMR.

Figure 3a. Articulated concrete mattress revetment, Lower Mississippi River.

Figure 3b. Environmental weirs, Bondurant Towhead Dike System, RM 394, Lower Mississippi River.

Figure 4. Transverse stone dike, Lower Mississippi River.

Figure 5. Island 86 dike system, RM 520, Lower Mississippi River, showing sandbar, wooded sandbar, and diked secondary channel habitat.

PART II: LEAST TERN LIFE HISTORY AND ECOLOGY

Distribution

The least tern (Fig. 6) is a colonial, migratory waterbird. Interior populations in the United States are found in spring and summer along the Mississippi, Red, Arkansas, Ohio, Missouri, Platte and Rio Grande rivers and tributaries. Currently, interior populations of the least tern reproduce throughout their historic range. Wintering areas for interior populations have not been precisely defined; however, least terns of unknown populations are found along the Central American coast and the northern coast of South America from Venezuela to northeastern Brazil (Whitman, 1988; Sidle and Harrison, 1990).

On the Mississippi River, least terns are most abundant from Cape Girardeau, Mo. southward to Vicksburg, Miss. Small numbers of the species occasionally occur between Cape Girardeau and St. Louis, Mo. and between Vicksburg, Miss and Old River, La.

Reproduction

Least terns arrive on the Mississippi River from late April to mid-May. Reproduction takes place from May through August, and the birds migrate to the wintering grounds in late August or early September.

Soon after arrival in the breeding area, least terns form colonies of less than a dozen to several hundred birds. Nest building and egg laying follow courtship and breeding. Nests, shallow scraps in the sandy substrate (Fig. 7), are usually aggregated in colonies on bare or sparely vegetated sandbars or similar habitats, such as sand and gravel pits. In addition, least terns are known to nest in sand mining pits, parking lots, plowed fields, and similar areas when optimum habitat is unavailable. Nests are generally well elevated above the water surface and may be a few yards apart or widely scattered. Colony members actively defend nesting territories.

Reproductive site fidelity of coastal least tern populations is high (Thompson, 1982), but there is limited data on site fidelity for Mississippi River least terns. Given the highly dynamic bed and planform of the historic river, ability to return to previously used colony sites is not likely a critical life history requirement.

Least terns can reproduce in about 50 days, if not interrupted by rises in river stages or other perturbations. Egg laying begins in late May and clutch size is two to three (Fig. 7). Eggs are incubated from 17 to 28 days by both sexes (Sidle and Harrison, 1990). If initial nesting efforts are not successful, re-nesting may take place. Re-nesting in California least terns coincides with first time nesting by two-year-olds and may produce two peaks in courtship behavior, egg laying, hatching, and fledging (Massey and Atwood 1981). Re-nesting has not been well documented in LMR colonies. Chicks hatch within one day of each other and are brooded for about one week, and fledging occurs after three weeks. Fledglings usually remain near the nest site, gradually wandering farther as they mature. While fledglings are given attention by the parents, they may move to other colonies, confounding survival estimates (Thompson, 1982).

Population Biology

The life span of the least tern is 15 to 25 years, although mortality during the first five years may be high. Estimated adult survival rate ranges from 81 to 88 percent (Massey *et al.*, 1981; Thompson, 1982; Kirsch, 1996), and were reported to be 85 percent on the LMR (Renken and Smith, 1995).

Annual nesting success and egg, chick, and fledgling survival rates vary widely with location and time. On the Mississippi

Figure 6. Least tern and nest with eggs, Lower Mississippi River.

River bordering the State of Missouri clutch size, nesting success rate, and fledgling survival rate per breeding pair averaged 2.28, 62 percent, and 0.7 for 1986-1989 (Smith and Renken, 1993; Renken and Smith, 1995). At four major colony sites on the LMR within the State of Mississippi the mean number of nests per colony was 338 and nesting success averaged 87 percent in 1995. Mean number of nests per colony was 270 and nesting success was 38 percent in 1996. Fledgling survival per breeding pair for 1995-1996 ranged from 0.51 to 1.86 and averaged 1.33 for 1995 and 0.68 for 1996 (Woodrey and Szell, 1997). Along the Missouri River fledgling survival rates ranged from 0.2 to 0.93 per breeding pair (Mayer and Dryer, 1988; Schwalbach, 1988, and Boyd 1987). On the lower Platte River, Nebraska, least tern clutch size, nesting success, and fledgling survival rate averaged 2.4, 54 percent, and 0.48 per breeding pair for 1987-1990 (Kirsch, 1996). A fledgling survival rate of 0.5 per breeding pair is generally considered the level of recruitment necessary to maintain a stable population of least terns (Thompson, 1982; Hill, 1985).

The timing and frequency of high river stages, heavy rains, predation, disease, and other factors affect the reproductive success of interior least tern populations. Flooding can cause massive egg and chick mortality, and heavy rains can drown large numbers of chicks in the nest (Boyd 1987). On the LMR within the State of Missouri, sandbar flooding destroyed about 40 percent of nests in 1986 and 1989, exceeding mortality from predation (Smith and Renken 1993). On the lower Platte River flooding was the greatest cause of least tern egg and chick mortality (Kirsch, 1996). Inundation of nests from 26-31 July 1996 destroyed many nests at four sites on the LMR just before the peak hatching period, resulting in low nesting success for that year as compared to 1995 (Woodredy and Szell, 1997).

Predation by coyotes, raccoons, barred owls and other predacious birds can also be significant. Woodrey and Szell (1997) noted severe predation of eggs, chicks and fledglings by barred owls (*Strix varia*), raccoons (*Procyon lotor*), and coyotes (*Canis latrans*) on the LMR. Barred owls captured many adults and most of the chicks at Kangaroo Point and depredated many fledglings at Porter Lake bar in 1996. In 1995, coyotes and domestic dogs destroyed many young after river stages dropped and the bars became accessible. All terrain vehicle traffic was found to result in nest, egg, and chick disturbance and fatalities in 1988 (Smith and Renken, 1993). This effect was probably exaggerated in 1988 by record low river stages that made sandbars unusually accessible. Isolation of sandbars from the riverbank may reduce predation and disturbance by mammals, although raccoons and coyotes are able swimmers (Woodrey and Szell, 1997), but isolation does not deter avian predators.

Diet and Feeding Habits

Least terns are almost exclusively piscivorus (Anderson 1983), preying on small fish, primarily minnows (Cyprinidae). Prey size appears to be a more important factor determining dietary composition than preference for a particular species or group of fishes (Moseley, 1976; Whitman, 1988).

Fishing occurs close to the nesting colonies and may occur in both shallow and deep water, in main stem river habitats or backwater lakes or overflow areas. Radio-telemetry studies have shown that terns will travel up to 2.5 miles to fish (Sidle and Harrison, 1990). Along the Mississippi River, individuals are commonly observed hovering and diving for fish over current divergences (boils) in the main channel, in areas of turbulence and eddies along natural and revetted banks, and at “run outs” from floodplain lakes where forage fish may be concentrated.

Habitat

Sparsely vegetated portions of sandbars and islands are typical nesting sites for least terns along the LMR. Nests are often at higher elevations and well removed from the water’s edge, a reflection of the fact that nesting starts when river stages are relatively high. Most nests on LMR sandbars are within about 10 inches of a stick or other debris (Smith and Renken, 1991). Many sandbars are very large in size (hundreds of acres) and provide ample space for wide dispersal of nests, except in high water years. Smith and Renken (1991) have demonstrated that colony size is often inversely proportional to sandbar size in LMR habitats, with large colonies forming in years when high water restricts the amount of emergent sandbar. The most highly utilized bars are those with <10 percent vegetation cover, fine to coarse sand sediments, and that were estimated to be emergent continuously for at least 100 days from 15 May to 31 August (Smith and Renken 1991).

Little is known regarding habitat characteristics of preferred feeding areas for interior least terns. A variety of both main stem river and adjacent backwater or overflow habitats that may provide fish are readily available to the birds. Studies have demonstrated that fish populations are abundant in lower Mississippi river habitats. Tibbs (1995) reported larger concentrations of forage fish along the borders of LMR sandbars than in open channel areas. Various studies have demonstrated the abundance and diversity of forage fishes in the LMR in sandbar, natural and revetted bank, and diked secondary channels of the LMR (Baker *et al.*, 1988). Fish standing stock measurements in diked secondary channels at slackwater show that forage-sized individuals are abundant and numerically dominate the fish assemblage (S.P. Cobb, unpublished data).

Figure 7. Least tern nest with eggs and chick, Lower Mississippi River.

PART III: LEAST TERN HABITAT

General

Sandbars are the primary habitat used by least terns for breeding, nesting, rearing, loafing, and roosting along the MMR and LMR (Figs. 6, 7), although during floods the species has been known to nest in agricultural fields, parking lots, and other bare areas.

Sandbars are fluvial landforms and channel bedforms that range in size from small, newly-formed spits of sand to expansive bars and mature islands several miles long, > 2,000 acres in area, and forested at higher elevations (Fig. 8). Sandbars vary widely in mode of formation, age, topography, slope, shape, juxtaposition to the riverbank, amount of woody vegetation, and sediment grain size.

In alluvial rivers, sandbars are dynamic channel bedforms. Their longevity may be measured by a flood event, an annual hydrograph, years, or decades. Individual sandbars typically wax and wane over time as fluvial processes adjust channel geometry to varying sediment load and discharge and the construction of river engineering works, and other influences.

On the Mississippi River, sandbar sediments consist of fine, medium, and coarse sand and gravel mixtures, and unconsolidated silt-clay lenses. The latter are accreted during periods of low and decreasing discharge, but are often scoured away or buried beneath deposits of sand or gravel during subsequent spates. Extensive gravel and cobble deposits are found on the upstream end of some large sandbars and islands and may stabilize them against erosion.

Basic Fluvial Processes

In order to completely define the effects of dike and revetment construction on LMR sandbar habitat for least terns, it would be necessary to fully understand the fluvial processes that mold channel morphology, as well as long term trends in the river's response to system alterations. Obviously, this is not only impractical within the context of this report, but is beyond the current knowledge of river processes. To provide some insight, however, into how the complex fluvial processes of the Mississippi River affect sandbar habitat, some basic concepts of fluvial geomorphology are presented.

Theoretically, an alluvial river is continuously adjusting its hydraulic geometry and slope to transport the ambient discharge and sediment load with the minimal amount of energy. This is the concept of a graded stream (Mackin, 1948) and may be described by the relationship proposed by Lane (1955):

$$\gamma QS \approx Q_s D_{50}$$

where γ is water density, Q is water discharge, S is channel slope, Q_s is bed material load, and D_{50} is median grain size of the bed sediments. A significant change in one of these system variables will elicit an adjustment in one or more of the others to regain quasi-equilibrium. A river may react to a change in discharge or bed material load by adjusting channel width (*w*), depth (*d*), shape (width-depth ratio *(F*), meander wave length (*L*), or sinuosity (*P*) as illustrated by the qualitative models of channel adjustment (Schumm, 1977). Two of these models are:

(A) Increase in discharge alone

$$Q^+ \sim w^+ d^+ F^+ L^+ S^-$$

(B) Increase in bed material load alone

$$Q_s^+ \sim w^+ d^- F^+ L^+ S^+ P^-$$

For example, although basin slope has a major effect on sediment load of a river, other variables affect this process, including water temperature (effect on density and stream power), channel roughness, sediment grain size, type of channel bottom (sand, clay, clay lenses), duration and magnitude of *Q*, and river engineering structures.

Natural influences on LMR channel morphology include valley geology (e.g., depth to non-erodable tertiary deposits, bluffs, and fault zones), alluvial deposits such as gravel beds and highly cohesive abandoned channel deposits that prevent lateral and vertical channel movements, variable hydrology (stage and discharge), and high bed material load (Tuttle and Pinner, 1982; Saucier, 1994)). Geologic controls affect valley slope and channel morphology, and account, in part, for the great variability among reaches and frequent non-conformity with standard geomorphic relationships (Schumm *et al.*, 1994).

One important natural factor that affects channel morphology is the magnitude and duration of *Q*. Long duration flood events will result in the movement of large amounts of bed material and suspended load through the river system, with sandbar morphology being effected by movement and storage of the additional quantities of sand. Conversely, if low peak discharges are the norm, then the amount of sediment that is passed through the system will have minimal effect on sandbar morphology. Therefore, during prolonged wet periods Mississippi River channel and sandbar morphology may be altered significantly as compared to low discharge years. Timing of high-discharges are also important since water temperature (density) is a major determinant of stream power. A flood that occurs in winter is more efficient in moving sediment and would have a different affect on sandbar morphology than a warm season flood.

Man-made influences include effects on stages from confinement of flows by levees, effects of cutoffs on slope, channel stabilization by revetments, and contraction and realignment of the low-water channel with dike systems (Tuttle and Pinner, 1982).

The bendway cutoff program from 1933 to 1942 has had the greatest influence of any natural or man-made event on the recent morphology of the LMR (Tuttle and Pinner, 1982). One natural and 14 man-made cutoffs between RM 343 and 678 shorted the river's length by approximately 142.3 miles in nine years. These actions caused an immediate flow line lowering of 16 feet at Arkansas City and 12 feet at Vicksburg for *Q* = 1,200,000 cfs (Madden, 1974). Although the river's attempts to increase sinuosity and lower slopes made steeper by the cutoffs were limited by bank stabilization, significant increases in channel width and cross-sectional area occurred between 1948-51 and 1975, especially in straighter reaches.

Sandbar Fluvial Processes and Types

Sandbars of various types and modes of formation are characteristic of alluvial rivers (Kellerhall, 1976), but not all bar types are found in a single alluvial stream. Those found in the MMR and LMR are point bars, alternate or channel side bars, mid-channel bars, and islands.

Point bars are developed on the convex side of bends by lateral accretion of sand and gravel bed sediments eroded from upstream banks and the bed and transported downriver by convergent, helical flow (Fisk 1944; Saucier 1974; Ritter 1984). Thus, as the river moves laterally during meandering, the concave bank in a bend erodes and the point bar builds on the opposite bank.

Point bar cutoffs, the most common type on the LMR (Tuttle and Pinner, 1982), often result in the formation of large mid-channel bars and islands. This type of cutoff is created as flow assumes a shorter, more efficient route across an elongated, short-radius bend during repeated high-discharge events. Over time the evolving channel across the point bar enlarges and becomes the main channel. The original main channel becomes a secondary channel, and the severed apex of the point bar is transformed into a large sandbar or island.

Alternate or channel side bars accrete adjacent to the channel bank in straight to moderately sinuous reaches as a result of meandering processes. Fluvial processes similar to those that create point bars produce them. They are formed when the low-water channel is much narrower in width than the high-water channel.

Mid-channel sandbars form in channel crossings (generally analogous to riffles in small streams) or straight reaches where widening of the channel occurs as the thalweg crosses to the opposite bank downstream. The widened channel results in decreased velocity and divergent flow, reducing sediment transport capacity and prompting initial sediment deposition and bar formation (Ritter, 1984). The enlarged channel cross-sectional area and bifurcation of flow promotes continued bar growth, since sediment transport capacity is a power function of Q.

Sandbars tend to grow in height on the upstream portions where coarse-grained material is deposited. Finer bed material particles are deposited on the lateral margins and downstream ends of sandbars due to dispersion of flow and increased depth. Thus sandbars enlarge laterally and downriver.

Sandbars that are persistent, stable, typically forested, and have elevations approaching that of the top bank of the river are classed as islands (Kellerhall, 1976). Large islands are characteristic fluvial landforms of the Mississippi River.

Lower Water Reference Planes

The low water reference plane (LWRP) for the Mississippi River is a computed water surface elevation profile based on low discharge statistics for a long period of daily gage records (Fig. 9). Reference planes are used in the design of river engineering structures, to compare river stages among gages, contour hydrographic and topographic data, and for habitat mapping. Since water surface and bed elevation slope downriver, national geodetic vertical datum (NGVD) elevations cannot be used to compare topographic relief or the height of features along the river with respect to the water surface elevations. River engineering structures designed using an LWRP are more uniform in size and the effects they have on river channel morphology.

The standard method now in use for deriving an LWRP for the LMR involves computation of the three percentile (97 percent exceedence) discharge for a 20-year period of daily records at all stage-discharge gagging stations. The three percentile discharge is used because it most closely represents the discharge used to compute historic reference planes. Gage rating curves (plots of discharge vs. stage) are then used to determine the NGVD water surface elevation of the three percentile discharge. To complete the reference plane, these elevations are extrapolated between gages using a recently measured low water surface profile of the river. NGVD elevations of the LWRP are assigned a value of 0, and elevations are referenced as feet above or below this base. For example, an elevation 25 feet above the LWRP would be designated as LWRP+25 ft, and an elevation 10 feet below the LWRP would be referred to as LWRP-10 ft.

To account for river channel adjustments, four LWRPs were used during the time period for this report: 1946 mean low water plane; 1962 average low water plane; 1974 low water reference plane; and the 1993 low water reference plane. For simplicity, these are referred to as LWRP46, LWRP62, LWRP74, and LWRP93.

The standard method described was used to develop the 1974 LWRP and the 1993 LWRP for the LMR. The reference planes developed in 1946 and 1962 were based on very similar methods that involved averaging either low-flow stages or discharges, but differed somewhat among Corps of Engineer districts, depending on project needs.

Habitat Classification and Mapping

Habitat Classes

A geomorphic-based classification (Cobb, 1999) was used to map aquatic habitats, including sandbars. Fluvial landforms and bedforms, river bottom slopes and elevation, and presence of river engineering structures were used to class the channel environment into 22 habitat types.

Sandbar habitats are defined as flat-sloped (<= 1V:7H) portions of main and secondary channels with bed elevation >= LWRP-10 ft and bounded by deep channel habitat, steep bank habitat, or land (Fig. 10). Sandbars habitat maps are based on LWRP elevations to allow computation of habitat areas above or below water at specific river stages and comparisons of habitat areas among river reaches and over time.

There are six sandbar habitat classes defined by fluvial zones and presence or absence of river engineering structures: main channel, diked main channel, temporary and permanent secondary channel, and diked temporary and permanent secondary channel sandbars. Wooded portions of all sandbars were combined into a single wooded sandbar class (Table 1).

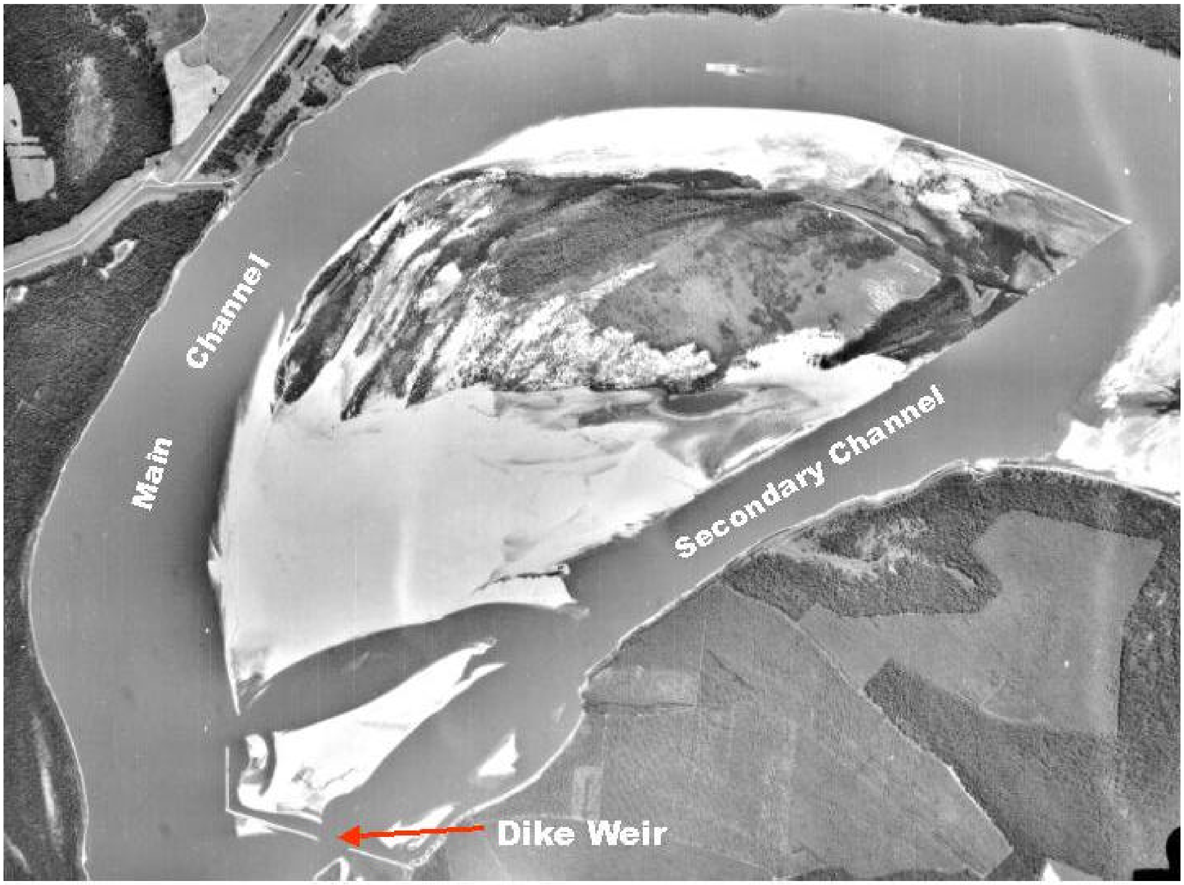


Figure 8. Choctaw Bend, Lower Mississippi River (RM 560), showing middle bar, sandbar, main channel, diked secondary channel habitats, and dike environmental weir.

Habitat Mapping

LMR geomorphic habitats (Fig. 10,11), including sandbars, were mapped using the previously described classification from comprehensive hydrographic surveys of the LMR for five nominal time periods: 1940's (1948-1950), 1960's (1963-1965), 1970's (1974-1975), 1980's (1987-1989), and 1990's (1994). In discussions of temporal trends in sandbar habitat involving several LWRPs, elevations are simply referred to as LWRP, it being implied that the LWRP is the one used for the respective comprehensive hydrographic survey. MMR habitats were mapped from a 1994 hydrographic survey and aerial photography.

Comprehensive hydrographic surveys consist of riverbed elevations measured along standard survey ranges oriented perpendicular to the axis of flow (bank to bank) and spaced at intervals of approximately 0.2 mi. These surveys were typically a composite of ranges surveyed over a period of 1-2 years, except in 1994 when GPS technology allowed the survey to be finished in about 2 months. Since only areas that were accessible by boat were surveyed, elevation data for areas above the waterline were obtained from stereographic analysis of aerial photography and topographic surveys. Wooded portions of bars and islands were delineated from 1:20,000 scale aerial photographs obtained for each comprehensive hydrographic survey.

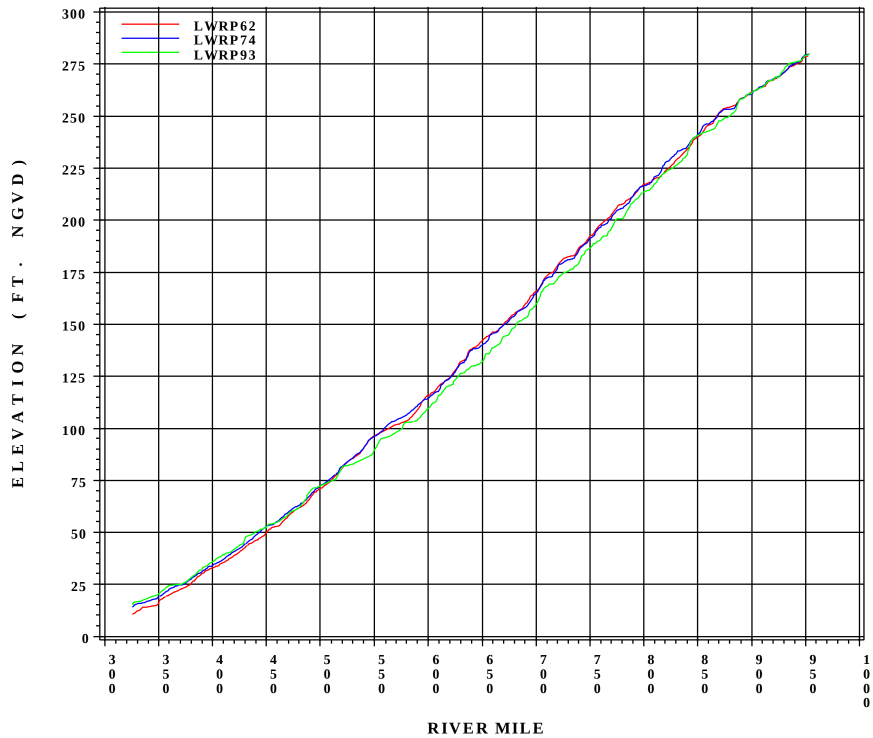


Figure 9. Lower Mississippi River low water reference planes.

Table 1. Mississippi River geomorphic habitat classes for the channel environment

Main Channel Classes	Temporary Secondary Channel Classes	Permanent Secondary Channel Classes
Deep Channel	Deep Channel	Deep Channel
Sandbar	Sandbar	Sandbar
Steep Bank	Steep Bank	Steep Bank
Diked Deep Channel	Diked Deep Channel	Diked Deep Channel
Diked Sandbar	Diked Sandbar	Diked Sandbar
Revetted Steep Bank	Revetted Steep Bank	Revetted Steep Bank
Diked Revetted Steep Bank	Diked Revetted Steep Bank	Diked Revetted Steep Bank

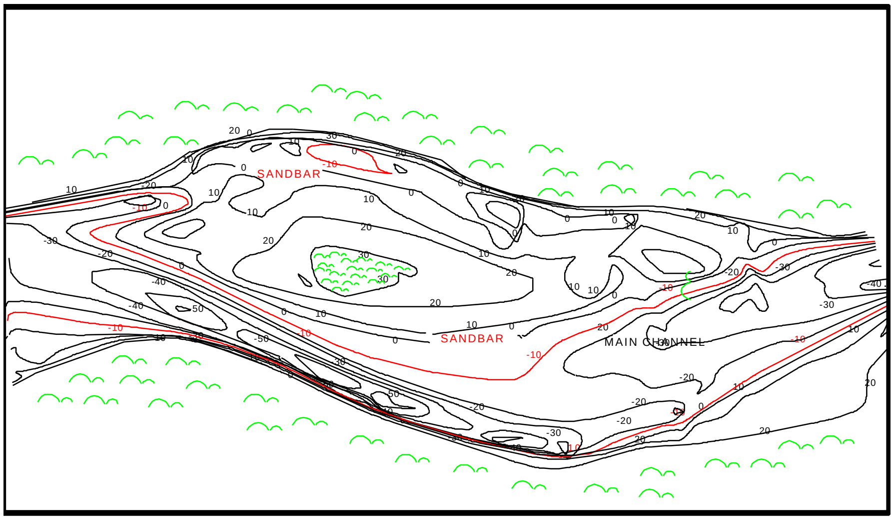


Figure 10. Schematic of sandbar habitat map. Areas with slopes flatter then 1V:7H (14%) and above the LWRP-10 ft contour shown in red are sandbar habitat types.

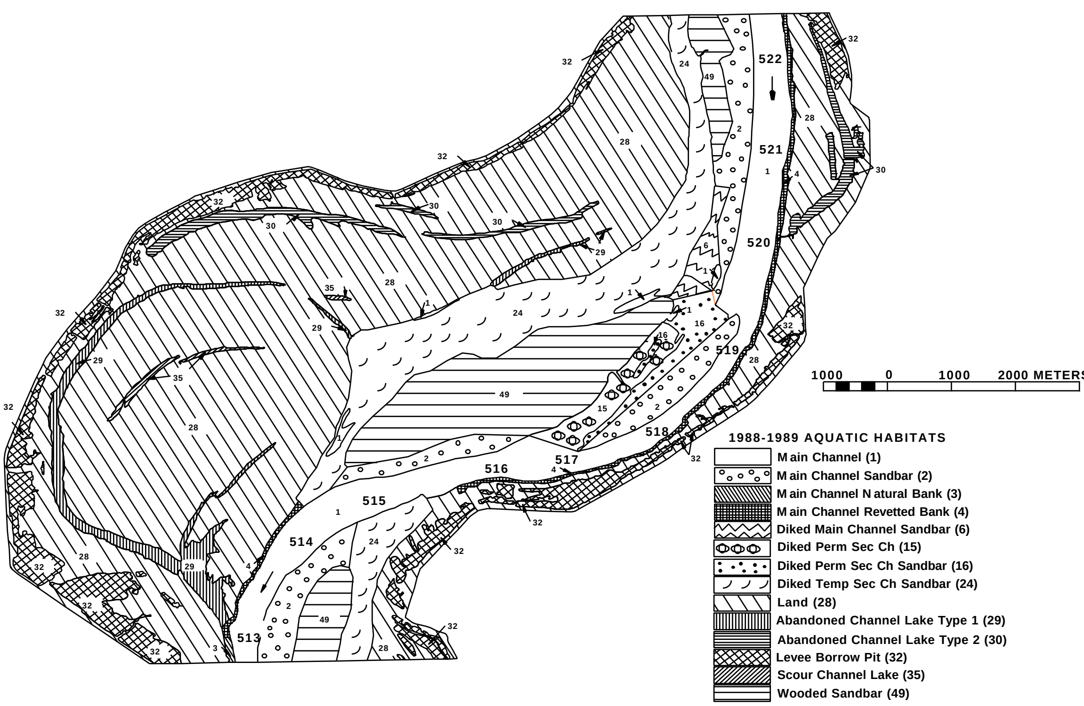


Figure 11. Geomorphic habitat classes, Lower Mississippi River.

The 1988-89 comprehensive hydrographic survey was contoured using the 1974 LWRP. Data from measured low water profiles of the LMR in 1988 and other years and stage-discharge data indicated, however, that substantial changes had occurred in the low water profile by 1988, and a new LWRP was developed for the LMR in 1993. Consequently, 1988-89 sandbar areas were adjusted to LWRP93 elevations to compensate for changes in the low water profile. The adjustments were made using river stage-sandbar area relationships for each 20-river mile reach. For example, if the LWRP had lowered five feet in a reach between 1974 and 1993, sandbar area were revised by subtracting five feet from the LWRP elevation and re-computing sandbar area from the stage-area relationship.

Three-dimensional digital elevation models (DEM) of the river channel were developed from the hydrographic and topographic elevations. NGVD elevations from the hydrographic and topographic surveys were converted to LWRP elevations prior to a developing a DEM. Triangulated irregular network (TIN) models (a type of DEM) of channel reaches were first developed, and a 50-m elevation grid model was derived from the TIN models. The elevation grid model was used for spatial habitat analyses.

Geomorphic habitat types were delineated on the comprehensive hydrographic survey base maps using the quantitative habitat definitions. These maps were digitized, line cleaned, edited, and processed into 50-m grid cell format using GRASS software. The grid cell maps were also converted to Modular GIS Environment (MGE) grid cell format and incorporated into the Regional Engineering and Environmental Geospatial Information System (REEGIS) for spatial computations.

Spatial Analyses

Simulation of river stage effects on the amount of sandbar habitat above the water during the least tern nesting season were accomplished by spatial analysis of the digital sandbar habitat and elevation map layers for each survey period. A cross-tabulation was done between the 1948-50, 1963-65, 1974-75, and 1988-89 channel elevation and corresponding geomorphic habitat grids using the GRASS 4.0 r.mapcalc function. Results of these analyses were tabulations of sandbar habitat area by 5-foot elevation intervals for 48 20-RM reaches encompassing the entire LMR. These data were entered into SAS datasets for statistical analyses, production of graphs and summary data tables, and development of river stage-emergent sandbar habitat regressions. The 1994 sandbar habitat data were not available in time to conduct a detailed spatial distribution analysis for this report.

All least tern site locations and counts were assigned geographic coordinates and processed into the REEGIS database as point features. These data were used to generate maps of least tern colony sites and to quantify the amount and spatial distribution of sandbar habitat used by terns.

Programs (GOAL scripts) were written in MGE Grid Analyst to generate new grid cell files representing total sandbar habitat above the LWRP and LWRP+10 ft elevations. These grid files were then converted to vector format. The digital vector maps of the 1980's sandbar habitats and least tern nesting sites for the 1986-1995 period were used to develop topological themes from which the proportion and distribution of sandbar habitat used by least terns and the amount of sandbar habitat connected to the main river bank at different river stages was computed. Intergraph's MGE Analyst software was used for these spatial analyses.

Sandbar Habitat Types and Spatial Distribution

Middle Mississippi River

In the MMR there are approximately 35,736 acres of non-vegetated sandbar habitat with elevation > LWRP74-10 ft., based on the 1994 geomorphic habitat map. Main channel, diked main channel, secondary channel, and diked secondary channel are the sandbar habitat types that are present. Main channel and diked main channel sandbar habitats predominate, comprising 49.5% and 32.3% of total sandbar area.

Spatial distribution of total sandbar habitat is relatively uniform in the reaches from RM 0 to 50 and RM 130 to 180, while sandbar quantities vary substantially among 10-river mile reaches between river miles 50 and 130 (Fig. 12a).

The 1994 hydrographic survey used to map aquatic habitats was made during relatively low river stages. Therefore, the digital elevation model (DEM) for this survey could not be used to develop a complete sandbar area-river stage relationship. It was possible, however, to compute the amount of sandbar potentially available as habitat for the least tern, i.e., the amount found above the LWRP. Results of these analyses showed there were 20,412 acres of non-vegetated sandbar habitat above the LWRP. About 4,975 acres (111 ac RM^{-1}) were located between the Mouth of the Ohio and Thebes Gap (RM 0-45) and 15,437 acres (103 ac RM^{-1}) between Thebes Gap and the Mouth of the Missouri River (RM 45-195). It is interesting that the amount of sandbar per unit length of river is similar between these two reaches. The river enters the Mississippi Alluvial Valley at Thebes Gap and is more sinuous from this point to the confluence with the Ohio River than in the upstream reach.

Lower Mississippi River

Sandbar habitats are a characteristic feature of the fluvial landscape of the LMR. A total of 146,288 acres of sandbar bar habitat above the LWRP elevation was present between RM 0 and 954, based on the 1988-89 geomorphic habitat map. Bare (non-vegetated) sandbars comprised 119,460 ac (81.7 percent) of the total, and the remaining sandbars are wooded. Most LMR sandbar habitat (97.9 percent) was found between Cairo, Ill. (RM 954) and Old River, La. (RM 315) (Fig. 12b, 13). The sharp decline in sandbar habitat area south of Old River (RM 315) coincides with a general decrease in low-water channel slope. A second decrease in sandbar habitat area occurs at Baton Rouge, La. (RM 230), where the river enters a distinct geomorphic segment, the Chenier plain geologic province (Saucier, 1994). Few sandbars are found from RM 115 to Head-of-Passes. River slope in this segment is nearly flat due to the close proximity to the Gulf of Mexico, and the channel is generally U-shaped. Cross-sectional area and mean depth are large and habitat diversity is low.

From Old River, La. (RM 315) to Cairo, Ill. (RM 954), the reach inhabited by the least tern, there was approximately 144,479 acres of sandbar habitat; about 116,936 ac (91.3%) was non-vegetated. Main channel was the dominant sandbar habitat type, with diked temporary and main channel habitats ranking second and third in abundance (Table 2). Fifty-two percent of sandbar habitat was associated with dike systems.

The quantity of sandbar habitat varied inversely with elevation above the LWRP (Table 3, Fig. 14, and Appendix B). There was 116,685 ac (182 ac/RM) of non-vegetated sandbar habitat above the LWRP elevation, 31,959 ac above LWRP+15 ft (50 ac/RM), and 17,109 ac above LWRP+20 ft (27 ac/RM). The indirect relationship between sandbar topography and area resulted from a combination of smaller areas and greater quantities of woody vegetation at higher elevations.

Sandbar distribution patterns along the LMR north of Old River may be categorized into three segments: Old River-Milliken's Bend (RM 315-455); Milliken's Bend-Commerce (RM 455-695); and Commerce-to-Cairo (RM 695-955). Differences among these segments are more pronounced for sandbar area above the LWRP (Fig. 14). The Old River-Milliken's Bend segment was characterized by high variation in sandbar area among 20-RM reaches, with one high-area reach, Waterproof to Bondurant Chute (RM-385), that contained four large mid-channel bars. The Milliken's Bend-to-Commerce reach was characterized by uniformly large sandbar areas above LWRP, a single high-area reach (RM-505), and large variation in area among reaches at upper elevations. Comparatively low variation in sandbar area among reaches, and comparatively small sandbar area at higher elevations are found in the Commerce-to-Cairo Reach.

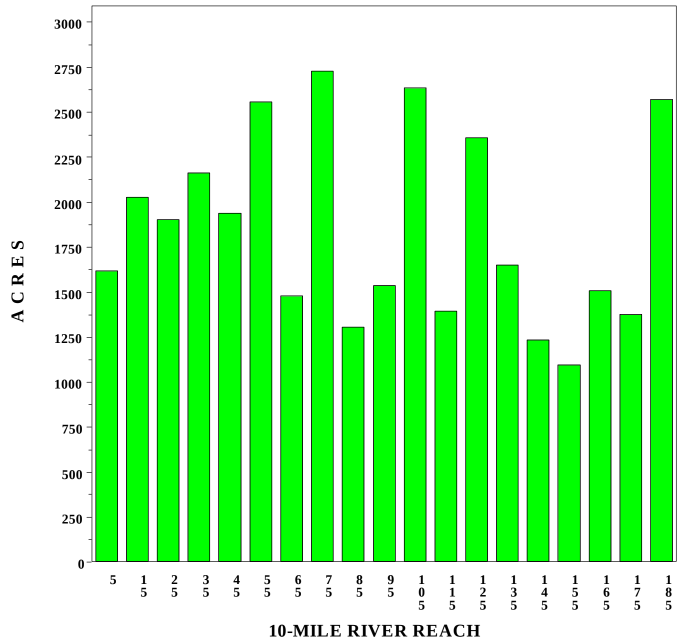


Figure 12a. Sandbar habitat, 1994, Middle Mississippi River, RM 0-195.

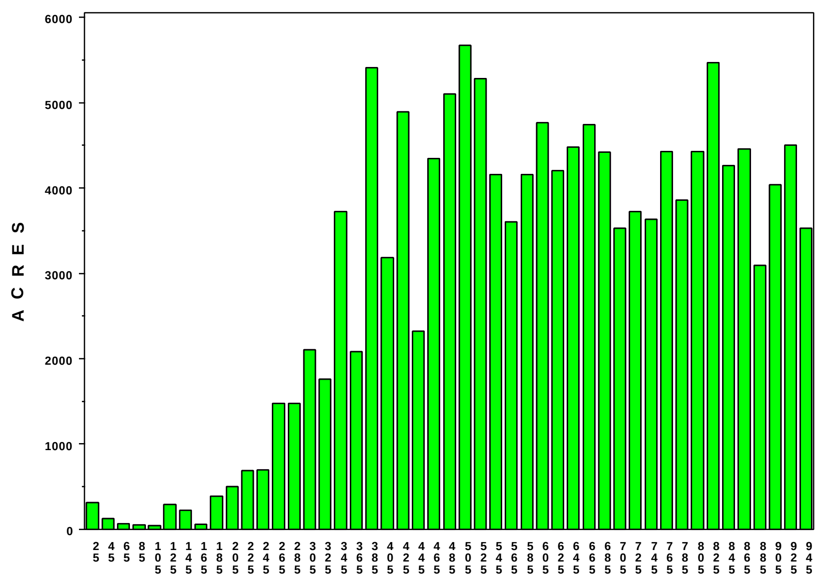


Figure 12b. Non-vegetated sandbar habitat above the 1974 low water reference plane, 1988-89, Lower Mississippi River.

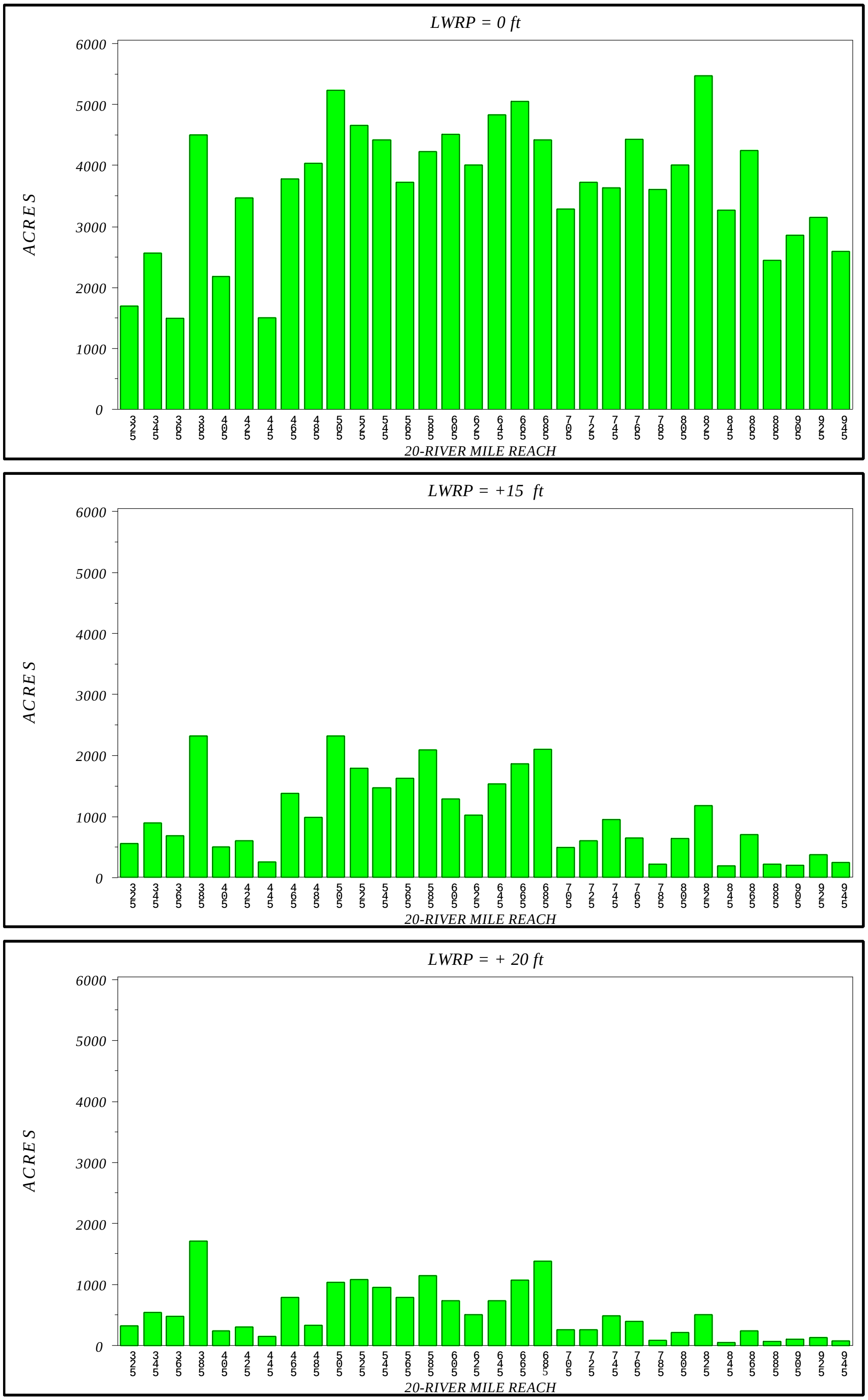


Figure 13. Spatial distribution of 1988-89 bare sandbar habitat above the LWRP93, LWRP93+15 ft, and LWRP93+20 ft elevations, Lower Mississippi River, RM 0-954. Passes.

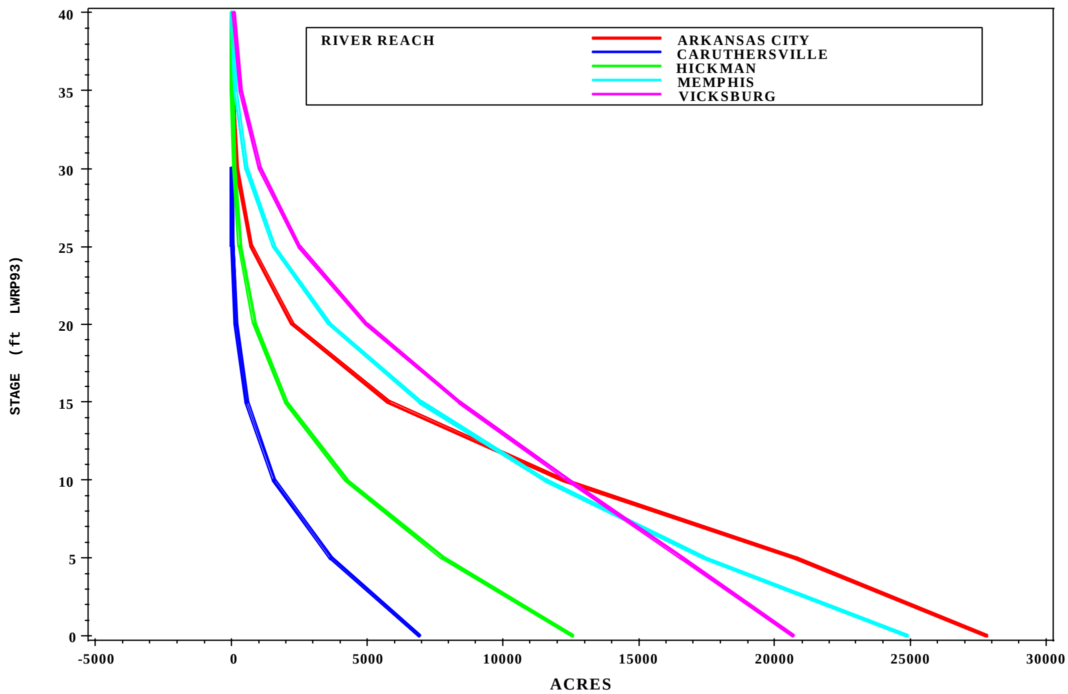


Figure 14. River stage-sandbar area relationships, Lower Mississippi River, RM 315-954.

Temporal Sandbar Habitat Trends

System-wide

Along the LMR there was a decrease in non-vegetated sandbar habitat of about one-third between the late-1940's and the mid-1960's. This precipitous decline in sandbar area was largely caused by the river's response to the series of bendway cutoffs made between 1933 and 1945. The river's immediate response to the cutoffs was an increase in slope, an increase in stream power, and a widening and deepening of the channel. These effects eroded many mid-channel and alternate sandbars and decreased sandbar area. In addition, some channel training structures, mainly wooden pile dikes, were constructed during this period, but they were generally ineffective.

After adjustment to the cutoffs, the amount of sandbar habitat has been fairly stable. There was a small increase in sandbar habitat from the mid-1960's to the late 1980's. The quantity of sandbar habitat decreased moderately between the late-1980s and the mid-1990s between elevation LWRP+0 ft. and LWRP+15 ft. and increased significantly at higher elevations. The magnitude of these changes increased directly with sandbar elevation (Table 4).

There was a net increase in bare sandbar habitat on the LMR, upstream of Old River, from the mid-1960's through the mid-1970's to the late-1980's (Table 3, Fig. 15, and Appendix A). The magnitude of increase varied directly with elevation above the LWRP from 7.4 to 76.2 percent (Table 4). There was a small net increase (6.3 percent) in total bare sandbar habitat above the LWRP from the 1960's to the 1970's, and between the 1970's and the 1980's. Sandbar above the LWRP+15 ft elevation increased about 10 percent for the 1960s-1970s, 1970s-1980s and 1980s-1990s intervals. For sandbar above the LWRP+20 and LWRP+25 ft elevations, a large increase in area was measured in the 1960s-1970s (27 and 81 percent) and 1980s-1990s (33 and 77 percent) intervals. A much smaller net gain (8 percent) occurred in the 1970s-1980s period for sandbar above LWRP+20 ft., and a slight decrease (-3 percent) was found for the sandbar above LWRP+25 ft. The sharp increase in total bare sandbar area at higher elevations between the 1960s and the 1970s was mainly a result of bar accretion in dike systems, while the smaller rate of increase in bare sandbars in the 1970s-1980s interval was, at least partially, caused by colonization of sandbars by woody vegetation. The decline in low-elevation and the increase in high-elevation sandbar area in the 1980s-1990s interval appears to be a result of growth in bar height and possibly lateral erosion during the 1993 flood.

In the 1960s-1970s interval, bare sandbar habitat above the LWRP increased in 23 of the 20-river miles upstream of Old River, mostly between RM 375 and 775 (Fig. 16 and Appendix A). Sandbar area above LWRP+15 ft. increased in 17 reaches, mainly between RM 775-795 and 835-895. Growth in size of sandbars by vertical and lateral accretion where dike systems were constructed appears to be the main factor responsible for most sandbar increases, while erosion of point bar and mid-channel bars within the design channel trace was the primary factor resulting in decreases in sandbar habitat during this period, especially between RM 775 and 895. Encroachment of woody vegetation also reduced bare sandbar area above LWRP+15 ft. in some locations. Differences in elevation of the LWRP from 1962 and 1974 were relatively small (< 2 feet) and probably did not contribute significantly to sandbar changes during this period. The flood of 1973 probably also affected sandbar morphology during the 1960s-1970s period by eroding some bars, including vegetation stands, and causing deposition on others, but this effect could not be documented.

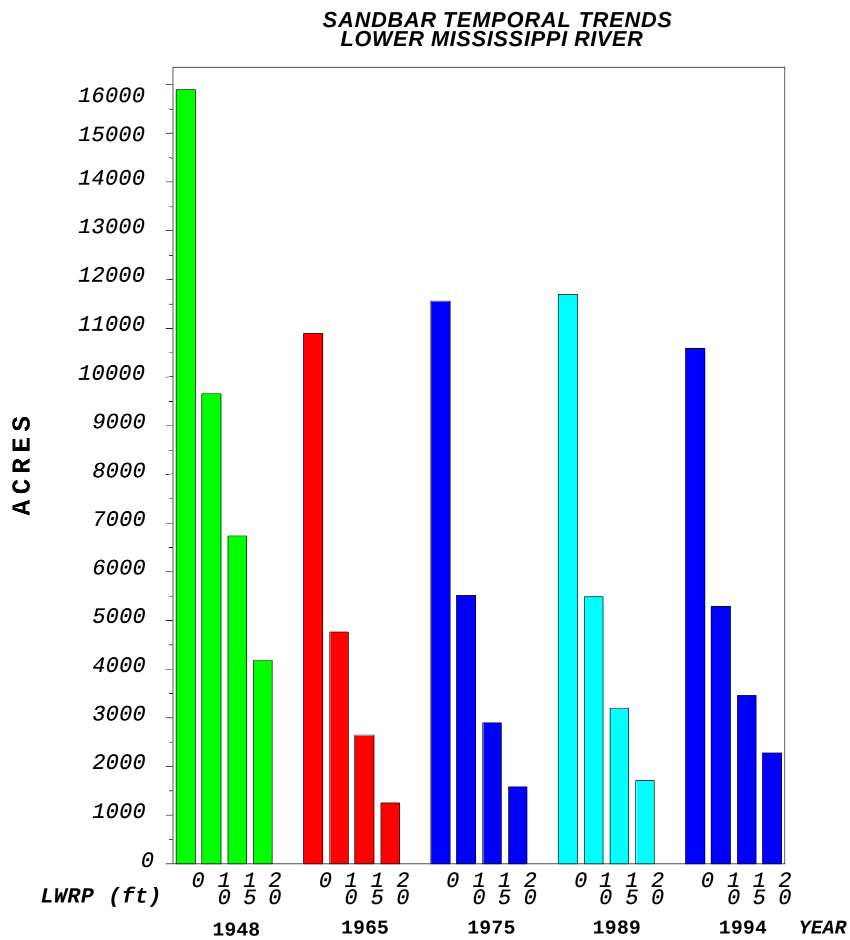


Figure 15. Temporal trends in spatial distribution of non-vegetated sandbar habitat above LWRP elevations, Lower Mississippi River, RM 315-954.

Table 2. Distribution of bare sandbar habitat, 1988 -89 habitat map, Lower Mississippi River, RM 315-954. LWRP values are feet above the 1993 low water reference plane.

	SANDBAR HABITAT CLASS													
FEET	MC		DMC		PSC		DTSC		DPSC		TSC		TOTAL	
LWRP	ACRES	%	ACRES	%	ACRES	%	ACRES	%	ACRES	%	ACRES	%	ACRES	%
+30	1,141	34.7	445	13.5	9	0.3	1,383	42.0	191	5.8	122	3.7	3,290	100.0
+25	2,974	36.6	976	12.0	36	0.4	3,289	40.5	440	5.4	404	5.0	8,119	100.0
+20	6,053	35.4	2,217	13.0	118	0.7	7,127	41.7	898	5.2	697	4.1	17,109	100.0
+15	11,409	35.7	4,615	14.4	390	1.2	12,537	39.2	1,875	5.9	1,133	3.5	31,959	100.0
+10	19,826	36.2	8,577	15.7	1,120	2.0	19,748	36.0	3,593	6.6	1,935	3.5	54,799	100.0
+5	32,000	37.4	13,482	15.8	2,123	2.5	27,357	32.0	7,332	8.6	3,296	3.9	85,590	100.0
0	47,221	40.5	18,110	15.5	3,278	2.8	32,466	27.8	11,355	9.7	4,255	3.6	116,685	100.0

NOTE: MC = main channel sandbar; DMC = diked main channel sandbar; TSC = temporary secondary channel sandbar; DTSC = diked temporary secondary channel sandbar; PSC = permanent secondary channel sandbar; DPSC = diked permanent secondary channel sandbar

Table 3. Bare and wooded sandbar habitat distribution by elevation above the low water reference plane, Lower Mississippi River, RM 315-954. Low water reference planes used for each year are: LWRP46 for 1940s; LWRP62 for 1960s; LWRP74 for 1970s; and LWRP93 for 1980s and 1990s.

		BARE		WOODED		TOTAL	
PERIOD	LWRP	ACRES	%	ACRES	%	ACRES	%
1948	+30	10,404	72.9	3,871	27.1	14,275	100.0
	+25	22,400	75.7	7,206	24.3	29,606	100.0
	+20	41,862	77.6	12,053	22.4	53,915	100.0
	+15	67,267	80.5	16,277	19.5	83,544	100.0
	+10	96,515	83.8	18,627	16.2	115,142	100.0
	0	158,074	88.0	21,482	12.0	179,556	100.0
1963	+30	894	20.6	3,446	79.4	4,340	100.0
	+25	4,608	30.7	10,394	69.3	15,002	100.0
	+20	12,444	40.8	18,071	59.2	30,515	100.0
	+15	26,458	52.0	24,377	48.0	50,835	100.0
	+10	47,475	63.1	27,729	36.9	75,204	100.0
	0	108,660	80.6	26,176	19.4	134,836	100.0
1975	+30	3,408	31.2	7,512	68.8	10,920	100.0
	+25	8,351	35.9	14,888	64.1	23,239	100.0
	+20	15,841	45.0	19,339	55.0	35,180	100.0
	+15	28,990	57.1	21,783	42.9	50,773	100.0
	+10	55,136	70.0	23,625	30.0	78,761	100.0
	0	115,501	85.2	20,104	14.8	135,605	100.0
1988	+30	3,290	31.3	7,227	68.7	10,517	100.0
	+25	8,119	34.5	15,432	s65.5	23,551	100.0
	+20	17,109	45.3	20,687	54.7	37,796	100.0
	+15	31,959	57.2	23,886	42.8	55,845	100.0
	+10	54,799	67.5	26,420	32.5	81,219	100.0
	0	116,685	80.8	27,794	19.2	144,479	100.0
1994	+30	--------	----	--------	----	--------	----
	+25	14,419	34.5	--------	----	--------	----
	+20	22,701	45.3	--------	----	--------	----
	+15	34,595	57.2	--------	----	--------	----
	+10	52,926	67.5	--------	----	--------	----
	0	105,797	80.8	--------	----	--------	----

Table 4. System-wide changes in total bare sandbar habitat by elevation above the low water reference plane, Lower Mississippi River, RM 315-954.

ELEVATION ABOVE THE LWRP	PERCENT CHANGE, 1940s TO 1960s	PERCENT CHANGE, 1960s TO 1970s	PERCENT CHANGE, 1970s TO 1980s	PERCENT CHANGE, 1980s TO 1990s
0	-31.3	6.3	1.1	-9.3
+10	-50.8	16.1	-0.6	-0.9
+15	-60.7	9.6	10.2	8.2
+20	-70.3	27.3	8.1	32.7
+25	-79.4	81.2	-2.8	77.6

Bare sandbar habitat area above the LWRP elevation generally declined downstream of RM 595 in the 1970s to 1980s period, and increased upriver of RM 595 (Fig. 17 and Appendix A). Spatial changes during this period for sandbar area above LWRP+15 ft. and LWRP+20 ft. showed a general upward trend from RM 495 to 955, and a declining trend from RM 495 to Old River. Between RM 495 and 595, the significant decreases in sandbar area above the LWRP where offset by increases in bar area above LWRP+15 ft. This effect was largely a result of increases in bar heights due to deposition of sediments between the LWRP and LWRP+15 ft. elevations, with little lateral expansion of the bars (Fig. 18).

Trends in Selected Reaches

A detailed description of temporal changes in sandbar area for three 20-river mile reaches is presented to illustrate the different trends in sandbar habitat. In the first reach, sandbar habitat area declined over time; an increase in sandbar habitat occurred with time in the second reach; and in the third reach, sandbar area fluctuated. The chronology of dike and revetment construction is also presented.

Reach RM 535-555

This reach extends from north of the Greenville, MS Bridge upriver to Huntington Point, MS. The reach is relatively straight with low sinuosity. Extensive river engineering works have been constructed to increase the depth and improve the alignment of the navigation channel, reduce maintenance dredging, and establish a safer approach to the Greenville Bridge for southbound towboats.

Initially, stone dikes where built on the left descending bank in 1963 to reduce discharge through the Miller Bend secondary channel and correct divided-flow conditions. Over 50,000 linear ft. of dikes were constructed along both banks from 1965 to 1971 (mostly from RM 543-549) to further reduce secondary channel flows. No additional dike work was done until 1982. Over the ensuing four years nearly 11,000 linear ft. of stone dikes were constructed, primarily on the right descending bank at Tarpley Island and Leland Bar, to improve the approach to the Greenville Harbor entrance and the general alignment of the downstream navigation channel. ACM revetment was constructed along most of the left descending bank between RM 535-545 in the 1950's and early 1960's to protect the mainline levees and stabilize channel alignment.

Total non-vegetated sandbar area above the LWRP and LWRP+10 ft. elevations varied little between 1963 and 1975 but declined 12 percent and 6 percent between 1975 and 1988 (Fig. 19 and Appendix A). A 25% decrease in sandbar above LWRP+15 ft. occurred in the 1963-1975 interval, but sandbar area increased over 70 percent in the 1975-1988 period. From 1963 to 1975 willows colonized higher portions of Island 82 (RM 544R) and Tarpley Island (RM 540R) sandbars, but these decreases were offset by accretion at the Miller Bend (RM 548L), Leland Neck (RM 540L), and Leland Bar (RM 537R) sandbars. Between 1975 and 1988 bare sandbar area at elevations <LWRP+15 ft. decreased, while areas above LWRP+15 ft increased significantly, primarily as a result of bar accretion. Although woody vegetation expanded on Miller Bend, Leland Neck, and Tarpley Island bars, this loss of bare sandbar was more than offset by vertical and lateral bar grow and effects of lowering of the LWRP an average of six feet between 1974 and 1993.

Reach RM 675-695

This reach begins at Harbert Point, MS near the confluence of the St. Francis River and extends upstream to Commerce, MS. The reach is sinuous, encompassing Walnut, Mhoon, and Peters Bends.

Stone dikes were first constructed in 1968 when two structures were built on the point bar at Commerce to increase the depth and decrease the width of the low-water navigation channel and stabilize the associated channel crossing. By 1974, 17,040 linear ft. of stone dikes had been constructed. These consisted of the Below Walnut Bend dike system (RM 676R) built in 1971 to reduce secondary channel flow, and the Bordeaux Point dike system (RM 681L) initially constructed in 1972 to stabilize the channel crossing in Mhoon Bend. In 1986 Peters dike system (RM694R) was installed to stabilize channel conditions between Commerce revetment and Peters revetment.

Total dike length was 27,980 linear ft. by 1988 as a result of extending and raising Commerce dikes in 1987 and 1989.

A large gain in total non-vegetated sandbar habitat was observed between 1963 and 1975, but sandbar area underwent a small decline between 1975 and 1989 (Fig. 20 and Appendix A). Sandbar above the LWRP increased 71% (1,863 ac) from 1963 to 1975; twofold and fivefold increases occurred in sandbar area above the LWRP+10 ft. and LWRP+20 ft. elevations. These increases were evidently a result of significant accretion, downstream expansion and woody vegetation losses at the Commerce point bar (RM 693) following dike construction, accretion of a large sandbar in the Below Walnut Bend dike system (RM 676), and formation of an alternate bar on the concave side of Walnut Bend (RM 681), apparently a result of erosion of the right bank. Non-vegetated area on the Ashley Point sandbar (RM 687) enlarged as a result of erosion of willow stands on the bar apex, but this increase was offset by degradation of the downstream margin of the bar. The relatively greater increases in sandbar area at the two higher elevations resulted from vertical accretion and absence of woody vegetation. Between 1975 and 1989, sandbar area above the LWRP declined slightly, while sandbar area at higher elevations increased significantly from a combination of bar accretion and a five-foot decrease in the LWRP between 1974 and 1993 (Fig. 18).

Reach RM 835-855

This reach is moderately sinuous. It extends from Island No. 18 near Heloise, Tenn. upriver to Fritz Landing, Tenn., about nine river miles north of Caruthersville, Mo. Linwood Bend in the downstream portion of the reach has a moderate radius of curvature, while Little Prairie Bend at the upstream end of the reach has a sharp radius and pronounced point bar. Blaker Towhead, a large island and associated secondary channel, is located in the straight segment between the two bends.

Nine stone dike systems have been constructed in the reach. Initially, Hathaway dike system (4,713 linear ft) was constructed in 1963 on the left bank at the upstream entrance to Little Prairie Bend (RM 854) to scour a large mid-channel bar that was hindering navigation and to enhance channel stability. By 1975 five additional dike systems, (36,057 linear ft), had been constructed. Robinson Bayou dikes 1 and 2 (RM 853R) were built across the channel from Hathaway to reduce low-water channel width and eliminate the mid-channel bar. Island 15 (RM 851L) and Sandy Hook dike systems (RM 850R) were constructed to reduce flow in the left bank secondary channel and improve the right bank channel for navigation at Little Prairie Bend. In addition, the expansive Caruthersville-Linwood dike system on Linwood Bend point bar (RM 840-845R) and Tennemo dikes on the opposite bank were completed to constrict the low-water channel and shift the alignment towards the left bank. By the end of 1988, 83,713 linear ft. of stone dikes had been installed, including two new dike systems: Tennemo (RM 842L) to maintain the left-bank channel alignment and Island 18 (RM 837L) to constrict the navigation channel and diminish divided flow conditions.

Bare sandbar area diminished greatly from 1963 to 1975, but regained size between 1975 and 1989 (Fig. 21 and Appendix A). Sandbars remained relatively low in elevation, limiting vegetation colonization. The 1963-1975 decrease of 62.1% and 78.4% for sandbar habitat above LWRP and LWRP+10 ft was caused by significant erosion of the large sandbars at Hathaway (RM 854L) Little Prairie Bend (RM 851R), Linwood Bend (RM 841L), and at the head of Island 18. Sandbars were accreted in association with Dikes 1 and 2 on the Island 15 point bar (RM 850L). From 1975 to 1989, sandbar habitat above the LWRP and LWRP+10 ft increased 98.7% and 38.8%. This increase was mainly a result of formation of a large sandbar (RM 843-845R) in the Caruthersville-Linwood dike system in association with the crossing into Linwood Bend and lateral growth of the Island 18 middle bar (RM 836R). A relatively small amount of sandbar above LWRP+20 ft occurred throughout the period. These changes were mainly attributable to the river's initial response to dike construction,

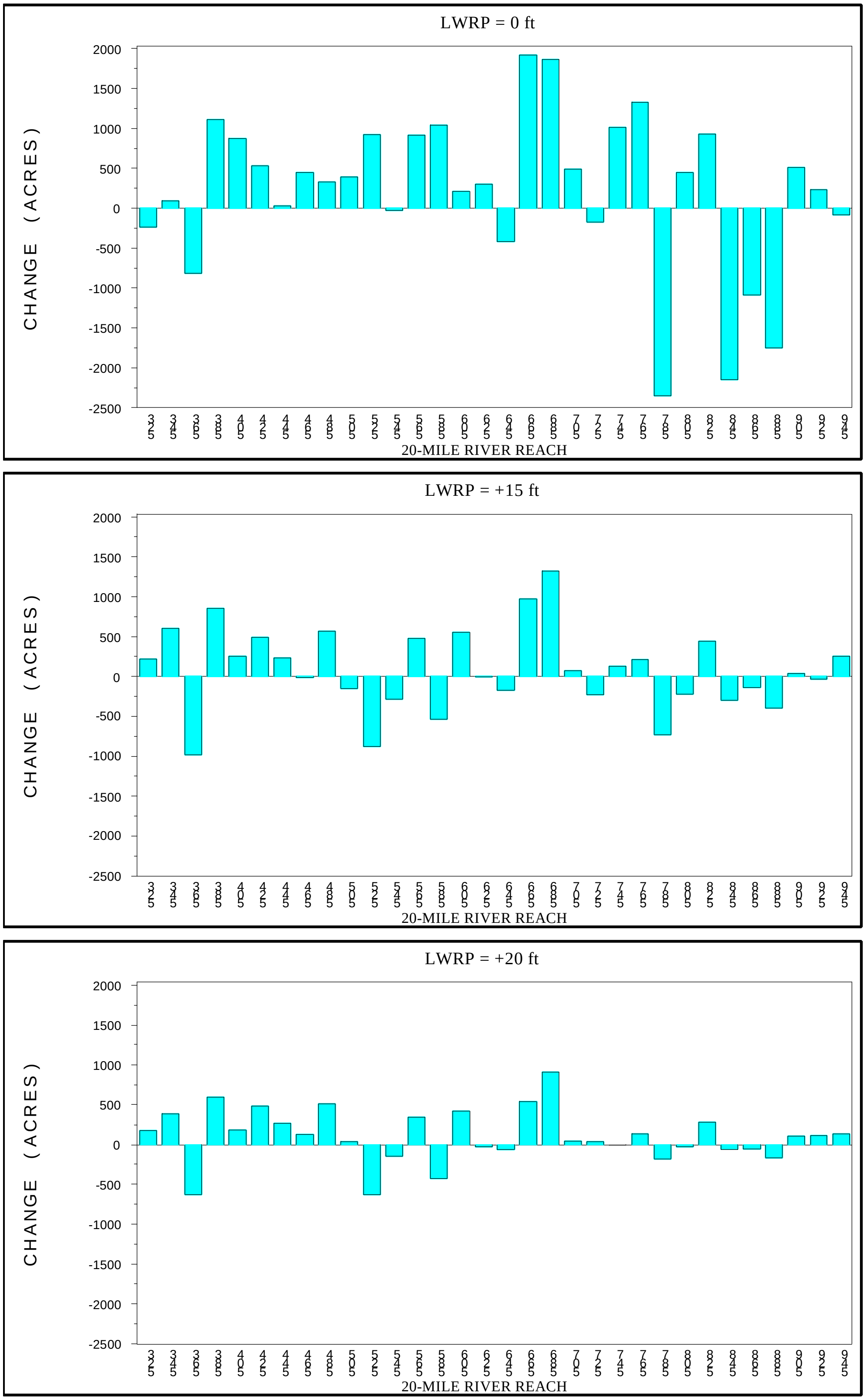


Figure 16. Changes in total bare sandbar habitat area from the 1960's to the 1970's by 20 - river mile reach, Lower Mississippi River.

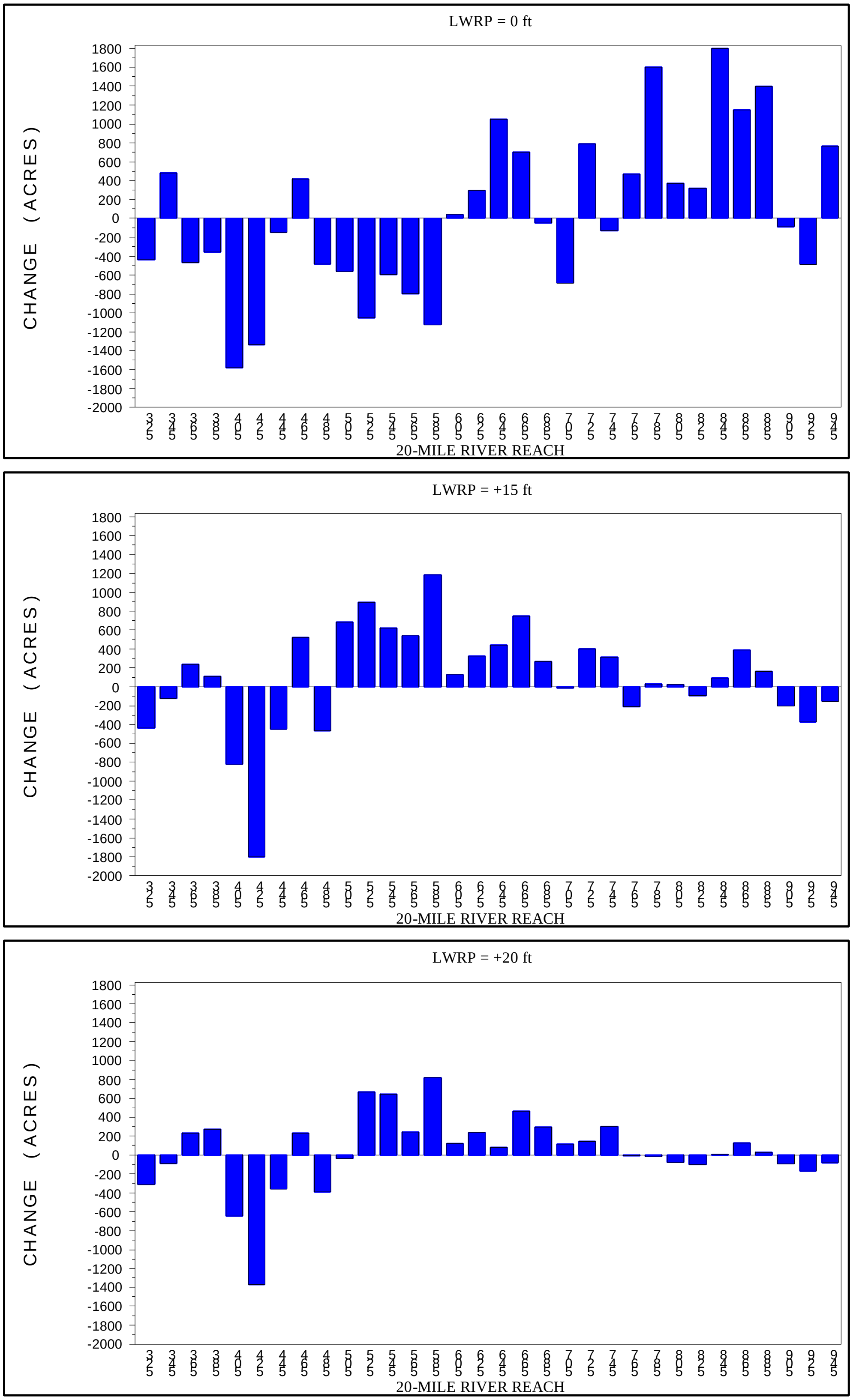


Figure 17. Changes in total bare sandbar habitat ar ea from the 1970's to the 1980's by 20-river mile reach, Lower Mississippi River.

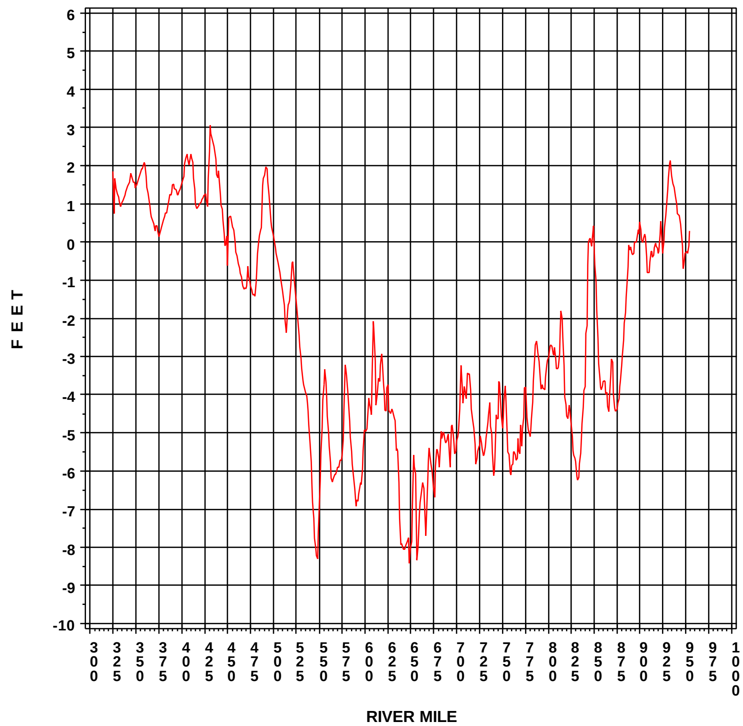


Figure 18. Differences in 1974 and 1993 low water reference planes, Lower Mississippi River.

resulting in erosion of point/middle bars, constriction and deepening of main channel crossings, and subsequent deposition of sediments and lateral bar building over time in dike systems. A 1.7 ft. average decrease in the LWRP also contributed to observed increase in sandbar area in 1989 (Fig. 18).

Comparison With Historic Studies

Nunnally and Beverly (1986) discussed temporal changes in water surface area of generalized aquatic habitat types on the LMR from Old River to Cairo. Comparisons were made of habitat areas measured from controlled aerial photography flown in 1962 and 1976 by the Corps of Engineers. While the study focused on changes in water surface area, amounts of isolated sandbars and islands visible above the water were also quantified. Based on these analyses, a 35 percent reduction in the total area of sandbars and islands from 1962 to 1976 was reported. These data were part of the information used to justify listing of the least tern as endangered (Sidle and Harrison, 1990) and were cited by Smith and Stucky (1988) as a basis for recommending sandbar habitat management needs for the LMR.

The aerial photography used by Nunnally and Beverly (1986) was the same imagery used to develop planimetric and topographic information for the 1960's and 1970's comprehensive hydrographic surveys from which the sandbar habitats for this report were mapped. While Nunnally and Beverly (1986) reported a large decline in sandbar and island habitat for the 1960s-1970s interval, the sandbar habitat data presented herein shows a small increase in sandbar habitat in the same river reach for this time interval and larger amounts of emergent sandbars.

Total sandbar and island area reported by Nunnally and Beverly (1986) is much smaller than areas reported herein (Appendices A,B) because these authors apparently mapped only mid-channel sandbars and islands that were surrounded by water on the aerial photographs. In contrast, all sandbars and islands, including those that were connected to the riverbank and not surrounded by water, were mapped for this report. Since large amounts of alternate bars and point bars abut the riverbank, omission of these would cause total sandbar area to be under estimated.

Because river stages were not the same for the 1962 and 1976 aerial photography, Nunnally and Beverly made a gross adjustment to measured habitat areas to account for the generally lower stages in 1976 and for the fact that the LWRP74 was lower than the LWRP62. The net result of these adjustments was to decrease measured sandbar and island habitat area for 1976 by 11.1 percent. An analysis for this report revealed, however, that river while stages averaged 4.5 ft lower in the Memphis District Reach (RM 600-954) for the dates of the aerial photography, they averaged 1.3 ft higher in the Vicksburg District Reach (RM 320-600) in 1976 than in 1962. Some discrepancies between stages for flight line dates in Corps of Engineer records and those reported by Nunnally and Beverly (1986) were also found.

The most serious flaw in the habitat data presented by Nunnally and Beverly (1986) was the failure of these authors to account for differences in river stages within mapping years. An analysis of Corps of Engineers records of aerial photography dates, corresponding river stages and the river miles encompassed by each flight line (Tables 5a, 5b) was made for this report to quantify these differences. River stages between Cairo and Old River, La. for the 1962 photography were found to range from 1.8 to 11.0 feet above LWRP62, and river stages for the 1976 photography were found to range from -0.9 to 15.6 feet above LWRP74. Nunnally and Beverly made no correction to measured habitat areas for these significant within-year stage variations for either mapping year. Obviously, measured habitat area from either set of photography cannot be combined to obtain yearly totals nor used to assess spatial changes between 1962 and 1976.

River stage-sandbar area relationships developed for 20-river mile reaches for this report (Fig. 14) for 1963-65 and 1975-1976 show that, due to the flat slope, sandbar area decreases from 5 to 15 percent with each one-foot increase in elevation between 0 and 15 feet above the LWRP. Thus a ten-foot difference in ambient river stage between two reaches covered by different flight lines could result in a 50 to 150 percent difference in sandbar area between reaches due solely to river stage effects.

Lastly, Nunnally and Beverly (1986) adjusted the 1976 habitat areas for differences in elevation between the LWRP62 and LWRP74, further affecting their results. Such adjustments are inappropriate for quantifying the amount of habitat either above or below water at a specific river stage. The purpose of using an LWRP is to have a common base elevation for computing habitat areas along the entire stream for a given year. Therefore, adjusting measured habitat areas to a reference plane from the preceding decade prior to making temporal comparisons between two time periods is inappropriate for spatial analysis.

In summary, the conclusion of Nunnally and Beverly (1986) that a 35 percent decline in LMR sandbar and island area took place from 1962 to 1976 between LMR RM 320 and 954 is erroneous because: 1) effects of within year variations in river stage on habitat area measured from aerial photographs were not taken into account; 2) inappropriate adjustments for differences between the LWRP62 and LWRP74 were made to 1976 habitat areas; and 3) incorrect river stages were used for adjusting habitat areas for portions of the 1976 aerial photography because some erroneous flight line dates were used.

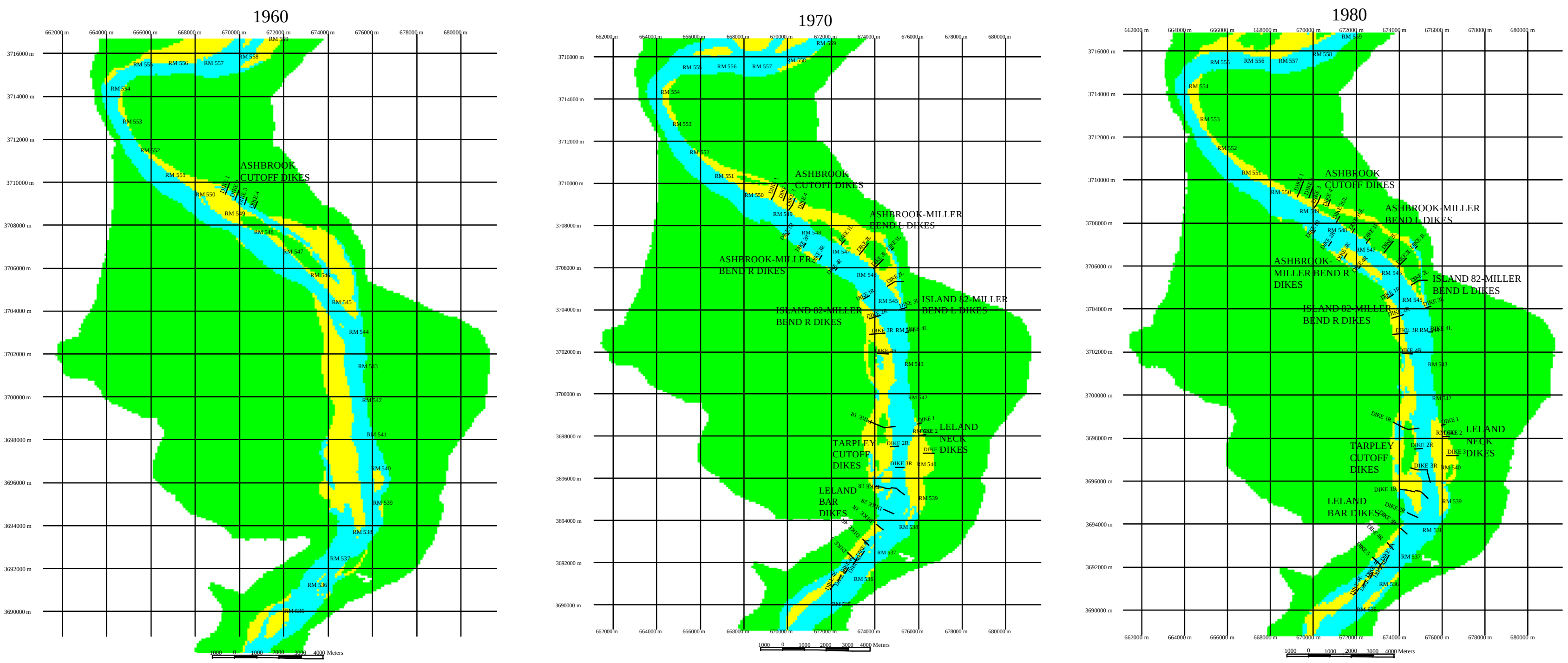


Figure 19. Sandbar habitat maps for 1960's, 1970's, and 1980's, RM 535-555, Lower Mississippi River (yellow = sandbar, blue = water, green = woods).

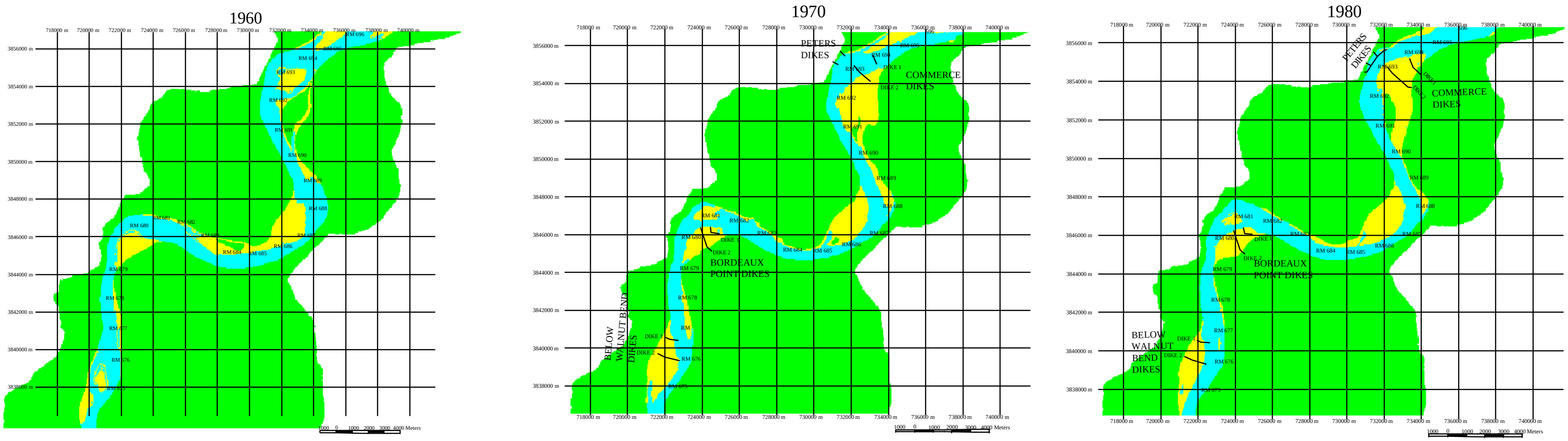


Figure 20. Sandbar habitat maps for 1960's, 1970's, and 1980's, RM 675-695, Lower Mississippi River (yellow = sandbar, blue = water, green = woods).

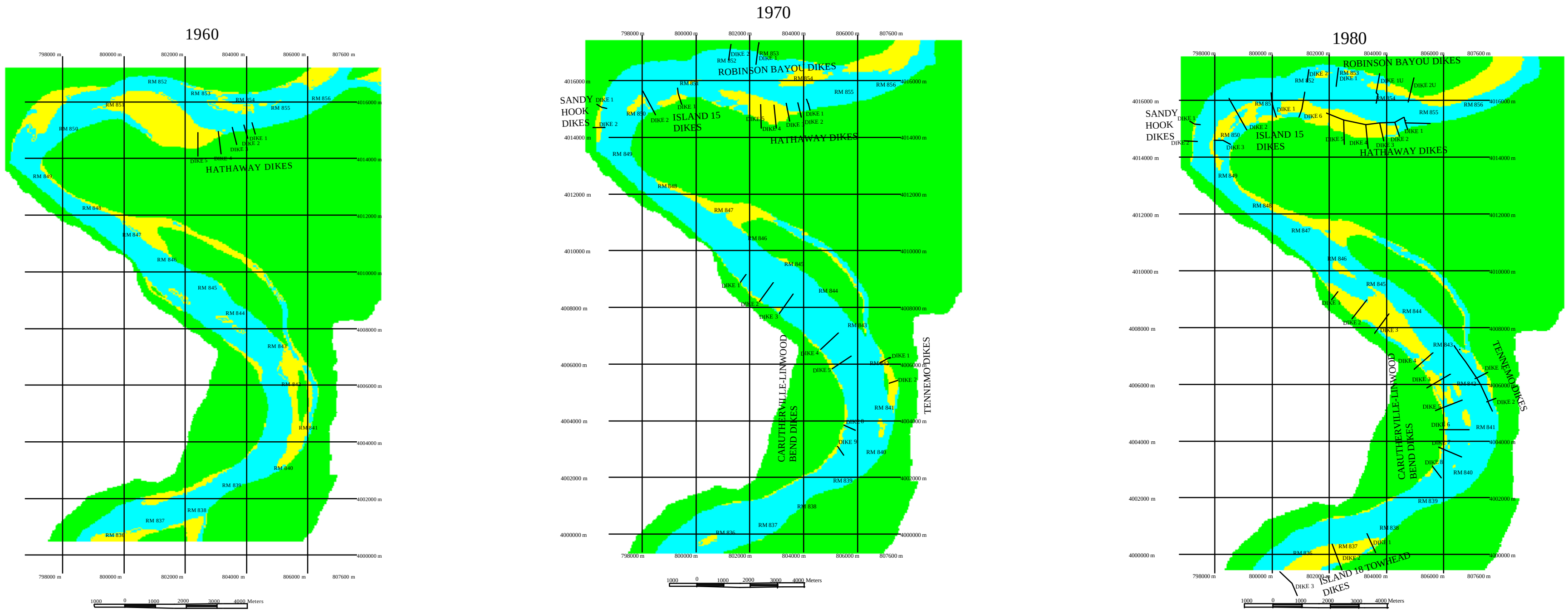


Figure 21. Sandbar habitat maps for 1960's, 1970's, and 1980's, RM 835-855, Lower Mississippi River (yellow = sandbar, blue = water, green = woods).

Table 5a. Dates and river stages as feet LWRP62 for Lower Mississippi River reaches covered by the 1962 aerial photography fligh t lines used by Nunnally and Beverly (1986).

Flight Lines – 1962 Photos	Miles	Date	Gage	LWRP62 Stage
RM 930 to 955	25	28Aug62	Cairo	3.9
RM 895 to 930	40	7Sep62	Columbus	6.3
			Hickman	7.5
			New Madrid	5.8
RM 870 to 895	19	20Aug62	New Madrid	3.7
RM 865 to 870	15	7Sep62	New Madrid	5.8
RM 860 to 865	15	20Aug62	New Madrid	3.7
RM 855 to 860	15	7Sep62	New Madrid	5.8
			Cottonwood	7.7
RM 850 to 855	5	28Sep62	Cottonwood	6.2
RM 835 to 850	15	7Sep62	Cottonwood	7.7
RM 825 to 835	10	28Sep62	Cottonwood	6.2
RM 820 to 825	5	7Sep62	Cottonwood	7.7
RM 770 to 820	50	28Sep62	Cottonwood	6.2
			Fulton	1.8
RM 695 to 770	75	17Aug62	Fulton	2.2
			Memphis	4.4
			Mhoon Ldg	4.9
RM 630 to 695	65	18Aug62	Mhoon Ldg	4.3
			Helena	4.8
RM 600 to 630	30	27Aug62	Fair Ldg	2.4
RM 452 to 600	148	07Aug62	Rosedale	10
			Ark. City	8.8
			Greenville	9.6
RM 390 to 452	62	11Aug62	Vicksburg	10.4
RM 350 to 390	40	19Aug62	St. Joseph	7
RM 320 to 350	30	12Aug6	Natchez	11

Table 5b. Dates and river stages as feet LWRP74 for Lower Mississippi River reaches covered by the 1976 aerial photography flight lines used by Nunnally and Beverly (1986).

Reach - 1976 photos	Miles	Date	Gage	LWRP74 Stage
RM 920 to 955	35	22Sep76	Cairo	-0.9
			Columbus	0
			Hickman	1.1
RM 840 to 920	80	01Oct76	Hickman	5.2
			New Madrid	4.4
RM 760 to 840	80	02Oct76	Cottonwood	2.7
			Fulton	0.6
RM 665 to 760	95	03Oct76	Memphis	2.4
			Mhoon Ldg	2.8
			Helena	1
RM 645 to 665	20	14Oct76	Helena	-0.2
RM 600 to 645	45	01Nov76	Fair Landing	5.4
RM 507 to 600	93	29Jan76	Rosedale	15.6
			Ark. City	13.9
			Greenville	12.9
RM 320 to 507	187	20Oct75	Vicksburg	11.6
			St. Joseph	11.8
			Natchez	11.7

Sandbar Habitat Availability

The availability of sandbar habitat to least terns for breeding, nesting, and rearing of chicks from 15 May to 31 August is a key variable in the population ecology of this water bird. Only portions of sandbars that are not densely covered by woody vegetation and that are emergent during the 15 May to 31 August period are potentially available to least terns. The two major determinants of sandbar habitat availability for least terns are: 1) density and amount of woody vegetation; and 2) river stage frequency and duration.

Sandbar Vegetation

Reproduction and Colonization

As sandbars grow in size and height, some portions will attain elevations that are above water long enough to become colonized by woody vegetation (Fig. 22). Two species of early successional or pioneer species of bottom land hardwood trees are the first to become established: Black willow, *Salix nigra Marshall*, and sandbar willow, *S. interior.* Black willow is a large species, attaining heights of up to 150 ft with an average life span of about 55 years, although sound trees >75 years old have been found (Pitcher and McKnight, 1990). Sandbar willow is more shrub-like, reaching an average height of about 30 ft and an average age of 35 years.

Black willow is the most ubiquitous pioneer species on LMR and MMR sandbars, while sandbar willow is much less abundant. Black willow comprised 50 percent of sandbar and island woody vegetation on 1992 land cover maps. The spatial dominance of black willow may be partly attributable to this species greater tolerance for poorly drained, silty-sand or silt-clay soils. Finer-grained sediments required for willow establishment (Appendix C, Fig. C1) may occur along the lateral margins and at the downstream end of sandbars. Sandbar willow is restricted to drier and sandier soil conditions. Mixed stands of the two willow species are common, but the short-lived sandbar willow dies, leaving monospecific mature black willow stands.

The reproductive strategy and physiology of black and sandbar willow are adapted to the hydrologic and geomorphic processes of alluvial river systems. Flowering of willows takes place in early spring at about the time of leaf emergence. The abundant (2-5 million per pound) small seeds ripen in about 45 days and, aided by a covering of cottony fibers, are dispersed great distances by wind and water (Pitcher and McKnight, 1990). Upon settling on bare sand or silty-sand substrates, seeds germinate within 8-24 hours, if soil moisture is sufficient to prevent desiccation (Ottenbriet and Staniforth 1992; Barnes 1985; Noble 1979).

The narrow combination of river stage, soil moisture, and seed availability required for the germination and survival of willow seedlings on a sandbar occurs infrequently. On the MMR and LMR, it is probably only necessary for river stage to remain below a newly seeded area for a 2-3 week period prior to inundation for colonization to be successful. Black willow seedlings may tolerate 32 days of continuous inundation (Hosner 1958), but prolonged flooding of small seedlings may cause mortality. A stable river stage for 13-22 days was found to be necessary for successful establishment of sandbar willows along the Minnesota River (Noble 1979). The approximate elevation of this relatively steady river stage marked the lower boundary of a tier or age zone.

Such sporadic reproductive success results in multiply tiers of even-aged willow stands on older, taller point bars and mid-channel and alternate bars. Sandbars with up to 5 or 6 tiers of sandbar willow are common along the MMR and LMR (Appendix C, Fig. C1).

Succession

Monospecific willow stands are characteristic of sandbars, since willows need bare soil for establishment, are highly shade-intolerant, and do not normally succeed themselves. Stem density is very high in young willow stands, but decreases with time due to mortality and competition. Taller individuals have the lowest mortality rates. Cloning of sandbar willow can increase spatial coverage, and stems damaged by scour or inundation commonly sprout (Krinard, 1985).

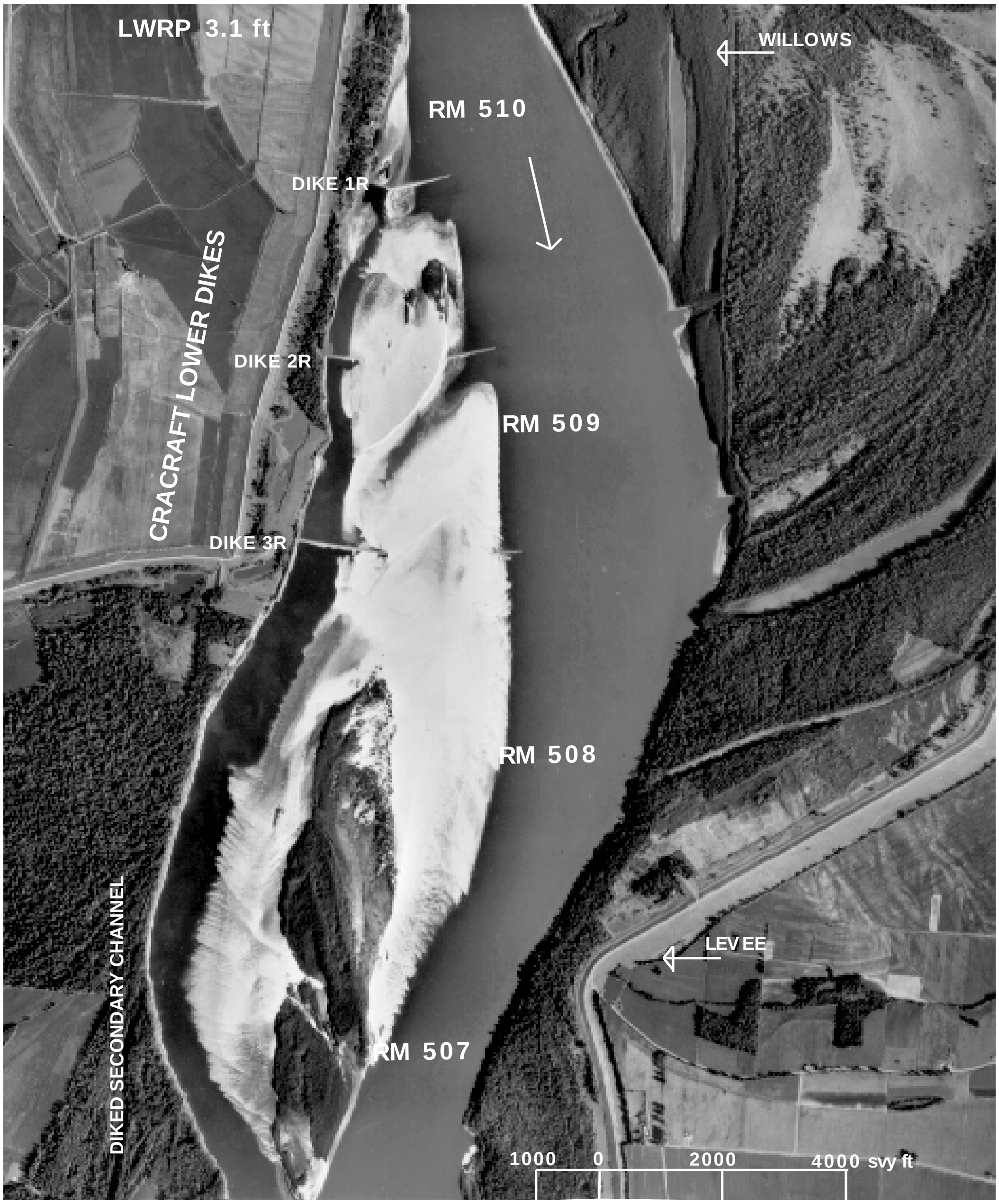


Figure 22. Sandbar habitat, 1994, Cracraft-Carolina Reach, Lower Mississippi River.

Once established, willow trees create conditions that promote continued sandbar enlargement and expansion of woody vegetation coverage. Stems and boles slow velocities during high-discharge events, increasing sediment deposition and vertical and lateral sandbar accretion. New willow stands are established on fresh alluvium around the periphery of sandbars. Existing trees generate lateral roots and continue vertical growth through the deposited sediment. Black willows may have trunks buried as much as 20 ft in the substrate (Krinard, 1985).

Mature willow stands on sandbars may be succeeded by more shade-tolerant Cottonwood (*Populas deltoides*).

Cottonwood stands made up 16 percent of woody vegetation on Mississippi River sandbars in 1992. The shade-tolerant, fast-growing Sugarberry-American Elm-Green Ash association, or the riverfront Sycamore/Sweetgum/American Elm association, depending on soil drainage and flooding frequency, replaces Cottonwood stands. These late-successional bottom land hardwood forest types materialize only on sandbars that are sufficiently stable to attain an age of at least 50 years.

Establishment and maturation of willow and cottonwood stands may stabilize and promote sandbar enlargement, but the fluvial processes of lateral and vertical accretion and floods can cause whole or partial sandbar destruction and reset the successional sequence, as was observed at Commerce (Fig. 20). Lateral migration of the river channel and scouring forces during floods may erode sandbars, even those with older stands of willows and cottonwoods. In some instances, new area is formed on the secondary channel side of a mid-channel sandbar, while large portions of the main channel side of the sandbar are eroded (Figs. 33, 34). In more extreme cases, entire sandbars are scoured away. Conversely, new sandbars are formed and the process of succession is repeated.

<u>Temporal Trends</u>

Temporal trends in woody vegetation (black and sandbar willow and cottonwood) dynamics on LMR sandbars varied among river reaches and sandbars and time scales (Appendix D). In general it was found that as sandbars increased in size and height over time, woody vegetation typically became established on the higher portions of the bar. This process may take several years to occur. Once established, willow and cottonwood stands adjusts in size to vertical and lateral sandbar growth and tends to stabilize as sandbar growth diminishes. A few sandbars, however, did not become vegetated because they never attained sufficient heights.

Woody vegetation stands are persistent on stable sandbars, but may be wholly or partially destroyed by mass erosion or flood events on other sandbars. Hydrologic effects, mainly scour during high discharges, were found to limit the colonization and spatial distribution of vegetation on point bars in short-radius bends. Shifts in river channel alignment or formation of a point bar cutoff may were found to destroy vegetation stands with a new cycle of vegetation colonization commencing on newly formed portions of the sandbar, depending on topography.

The temporal scale for which sandbar vegetation dynamics are viewed was also found to be important. Pronounced temporal cycles in sandbar woody vegetation were observed in river reaches where the period of record was on the order of 50 years. These were mainly the result of sandbars with woody vegetation accreting to the riverbank to become fast land, followed by a new sequence of mid-channel sandbar formation and vegetation establishment. Sandbars with periods of record of 25 to 30 years showed a trend of increasing vegetation coverage with time until sandbar size and height became stable or did not become vegetated.

Hydrologic cycles were found to be a significant factor in sandbar woody vegetation dynamics. The extreme and prolonged low-discharges of 1988 (Figure 24) allowed the establishment of woody vegetation on several sandbars that had remained without vegetation for several years previous to this event.

<u>Effects of Floods</u>

Flood events are a mechanism for large-scale destruction of willows and other vegetation on sandbars, thereby resetting the vegetation succession sequence. Extended inundation may cause stunting (Noble 1979; Shull 1944) of larger trees. Older, taller willow stands may endure much longer periods of flooding (Krinard 1985). Black and sandbar willow, however, are susceptible to drought due to their shallow root systems.

On the LMR, river stages were abnormally high throughout the summer during the flood of 1993, with an unusually prolonged high-discharge event from July through September 1993. Stages in 1993 were continuously >LWRP74+20 ft on the New Madrid gage, except for about two weeks in late May-early June, and were >LWRP+25 ft on the Vicksburg, MS gage from May-August.

To determine gross effects of the 1993 flood on sandbar vegetation, 1992 and 1994 forest and land cover maps derived from late September/early October aerial photography were compared for 21 sandbar complexes between RM 459 and 947.

A small (9 percent) decrease between 1992 and 1994 occurred in average black willow stand size, while mean stand size of cottonwood/black willow increased 55 percent and cottonwood declined 67 percent. Mean stand size of the riverfront association (sycamore/Sweetgum/American elm), and Hackberry associations was significantly smaller in 1994 (Table 6).

Effects of the 1993 flood were not catastrophic on the LMR and a major setback of vegetation succession did not happen. Large-scale spatial changes were observed at only four of the 21 sandbar complexes. Black willow stands were greatly reduced in size (48-82 percent) and riverfront and Hackberry associations were mostly destroyed (converted to bare sand or water) at Island No. 70 (RM 608), Corona Bar (RM 753), and Kentucky Point (RM 884). At Prairie Point Towhead (RM 665), riverfront hardwoods and black willow/cottonwood stands changed little in size from 1992 to 1994, while sugarberry/American elm/green ash stands were eliminated. Stands of black willow, cottonwood/willow, and scrub/shrub (probably seedling willows or willow saplings destroyed by flood water) increased moderately in size at several sites.

<u>Elevation Controls</u>

In the LMR and MMR, new willow stands are established typically on the low-elevation margins of older, vegetated sandbars and the higher portions of younger, non-vegetated sandbars. Multiple tiers or zones of even-aged black willow are common on sandbars (Appendix C, Fig. C1).

Willows do not become established on portions of MMR and LMR sandbars that are submerged for a sufficient duration in the late spring-early summer. This precludes settlement and germination of seeds or survival of young seedlings. Thus, there is a limiting elevation below which willows will not become established on sandbars.

To provide an estimate of the controlling elevation for willow tree establishment, the elevation of the down-slope boundary of the youngest tier of willows was surveyed at 167 LMR sites between RM 376 and 946. Sites were located on the upstream, downstream and lateral margins of the sandbars.

The elevation of the down-slope boundary of willow stands followed the general topographic trends of the sandbars, decreasing from upriver to downriver along the sandbar axis normal to river flow (Appendix C Figs. C1, C8). Mean stand boundary elevation was LWRP93+22.5 ft, while the median was 20.7 ft and the mode was 18 ft above the LWRP93 (Fig. 23).

The minimum elevation of woody vegetation was LWRP+11 ft, indicating that willow and cottonwood do not persist below this elevation on LMR sandbars. Sandbar areas <=LWRP+10 ft in elevation are submerged 240 to 300 days annually, depending on location along the river (Table 7). There are about 60,000 acres of non-vegetated LMR sandbar lying between the LWRP93 and LWRP93+10 ft. elevations. This sandbar habitat can be expected to remain free of willow trees and available to least terns, depending on river stage. There is an additional 37,000 acres of sandbar located between the LWRP93+10 and the LWRP+20 ft elevation (the median limiting elevation). Portions of this habitat also can be expected to remain bare (Table 3 and Appendix A).

The maximum observed down-slope elevation of a willow tree stand was LWRP+40 ft. on the head of a large island. Highest elevations, coarsest sediments, and greatest hydraulic forces are found on the upstream end of sandbars. Willow and cottonwood trees found here were probably established when this portion of the sandbar was at a lower elevation, and grew commensurate with sediment deposition (see <u>Succession</u>).

The vegetation elevation data indicate that portions of sandbars lying below an elevation of LWRP93+11 ft will not become permanently vegetated, while on the average, areas lying below LWRP93 +22 ft will remain bare. Areas on the head of sandbars will remain wholly or partially vegetation free at elevations up to LWRP93+40 ft. Bare sand will persist on the high-elevation heads of many sandbars because of scour during floods and the presence of sediments too coarse and dry for germination and survival of black and sandbar willow seeds. At Cracraft Bar (RM 505) there were over 200 acres of bare sand on the upstream end of the bar above elevation LWRP+20 ft (Fig. 22, and Appendix C, Fig. C3). Similar conditions occur at Choctaw Bar and Hotchkiss Bend (Appendix C, Fig. C8). Such areas should serve as important least tern reproduction areas in high-discharge years.

Effects of River Stage and Discharge

The proportion of sandbar habitat that is potentially available to least terns lies above the elevation of the LWRP. Portions of sandbar lying below the LWRP elevation are submerged >97.0 percent of the time on the average. The amount and length of time sandbar habitat is above water, however, is a function of river stage.

The quantity of emergent sandbar habitat varies inversely with river stage (Fig. 14). During extremely low discharges, entire sandbar habitats may be above the water, while at mid-bank to bank-full stages, sandbars are mostly or entirely submerged. These extremes are exemplified by the record low-flow conditions of 1988 and the prolonged high river stages of summer 1993 (Fig. 24).

Daily changes in river stage result in a continually varying amount of emergent sandbar area (Figs. 24-25). Within-year variation in the timing and frequency of low- and high-discharge episodes are exemplified by the occurrence of multiple high-discharge events in late-spring/summer of 1986 and 1992.

The relationship between sandbar area and elevation or river stage is curvilinear (Fig. -26). Effects of river stage fluctuations on the quantity of emergent sandbar habitat are exaggerated by their low relief (typical slopes < 14%). For example, a sandbar two miles in length with a perimeter of 15,000 ft and a uniform slope of 1V:15H would have a 75 ft wide zone with an area of 26 acres inundated by a five-foot rise in river stage. Quantitative relationships between river stage and non- vegetated sandbar area for LMR reaches are shown in (Table 8, Fig. 14, and Appendix A).

Table 6. Sandbar vegetation changes, 1992 -1994, Lower Mississippi River, RM 315-954.

FOREST TYPE/ASSOCIATION	1992 AC	1994 AC	% Dif
Black Willow	147.6	133.8	-9.3
Cottonwood/Black Willow	74.4	115.1	54.6
Cottonwood	80.9	26.9	-66.8
Sycamore/Sweetgum/Amer. Elm	151.4	100.3	-33.8
Hackberry/Amer. Elm/Green Ash	85.8	2.6	-97.0
Hackberry	7.8	0.0	-100.0
Scrub/Shrub	41.5	54.5	31.1
Cropland	578.3	577.4	-0.2
Pasture/Old Field	128.2	15.3	-88.1

Table 7. Variation in percent of time and number of days that river stages are greater than the minimum (LWRP+10 ft), maximum (LWRP+40 ft), and mean (LWRP+22 ft) willow stand down slope boundary elevations on LMR sandbars, RM 376 -946.

GAGING STATION	PERCENT TIME LWRP93+10 FT EXCEEDED	DAYS RIVER STAGE >LWRP 93+ 10 FT	PERCENT TIME LWRP93+22 FT EXCEEDED	DAYS RIVER STAGE >LWRP 93+ 22 FT	PERCENT TIME LWRP93+40 FT EXCEEDED	DAYS RIVER STAGE >LWRP 93+ 40 FT
NEW MADRID	66.6	243.0	17.2	63.0	0.00	0.0
MEMPHIS	67.6	247.0	19.4	71.0	0.02	7.0
ARK. CITY	74.1	270.0	27.4	100.0	0.02	7.0
VICKSBURG	85.2	299.0	40.5	148.0	0.08	29.0

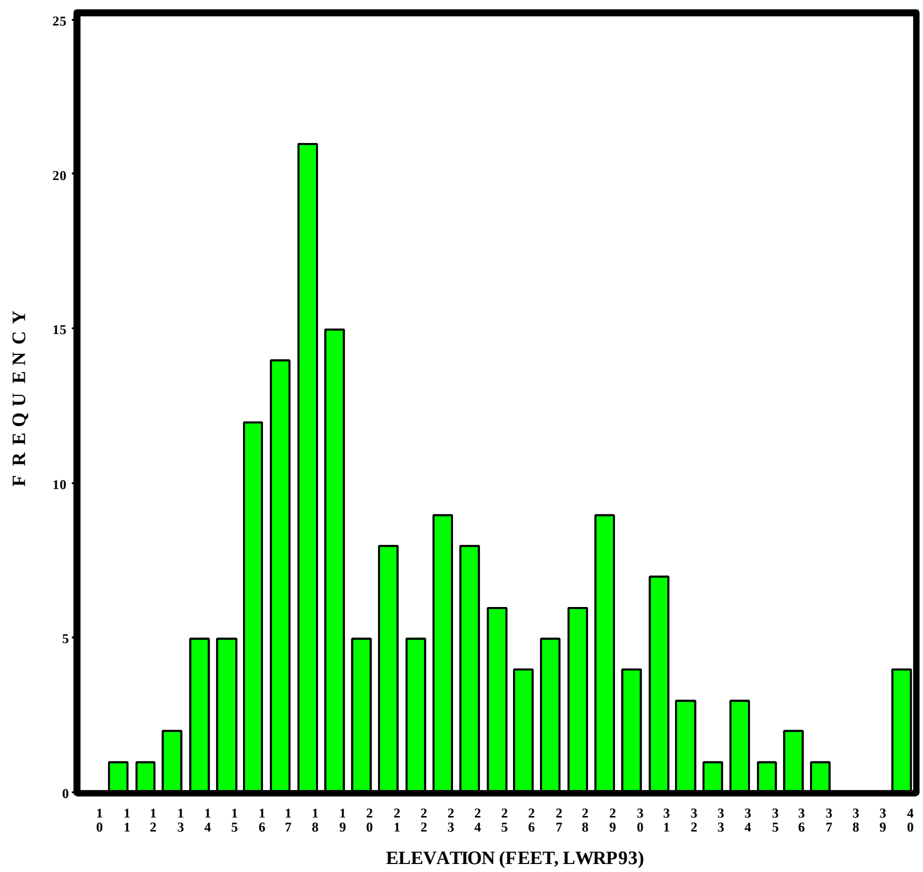


Figure 23. Frequency distribution of down -slope elevations of sandbar and black willow stands, Lower Mississippi River sandbars, RM 376-946.

Periods when sandbars are continually emergent are important to the reproductive success of the least tern. Lack of habitat due to inundation when least terns are arriving in the Lower Mississippi River Valley and sporadic increases in river stage after egg laying and hatching, may increase mortality and reduce recruitment. A small, untimely increase in river stage can inundate large expanses of sandbar and destroy least tern nests, eggs, and chicks.

(Smith and Renken, 1991) hypothesized that sandbar sites continuously above the water 100 days from 15 May-31 August are important to least terns on the Mississippi River bordering the State of Missouri, although the species can reproduce (nesting to fledging) in a minimum of 50 days. They found that sandbars continuously above the water for at least 100 days during the least tern season were most frequently inhabited by the species. However, no quantitative information on the frequency and duration that sandbars were above the river level or quantitative relationships between river stage and sandbar topography were presented.

A hydrologic analysis was performed for this study to evaluate the frequency and duration of emergent sandbar events, i.e., events when portions of sandbars are above water. The start date, end date, and number of days river stage was continuously less than six LWRP elevations, from 15 May through 31 August, were computed from daily stage records. These analyses were based on data from six LMR gages for a 31-year period of record (1965-1995), and for three LMR gages for a 34-year period of record (1965-1998). The target elevations used were LWRP, LWRP+10, LWRP+15, LWRP+20, LWRP+25 ft and LWRP+30 ft. River gage readings were converted to LWRP equivalent elevations using the LWRP that was in use at the time. Computed durations equate to periods of time when river stage was continually less than the target LWRP elevation, i.e., sandbar areas above these elevations would be continually above water.

Since the critical part of the least tern season (15 May-31 August) is 109 days in length, only the highest portions of sandbars are continuously emergent for 100 days (91.7% of the time) during this period. The hydrologic analysis revealed that 100-day emergent events occurred infrequently (10–22 percent of the years) for sandbar areas <LWRP+20 ft in elevation (Tables 9-11; Figs. 26-29). The small amount of non-vegetated sandbar that is found at elevations >= LWRP+20 ft (8,119 ac; 13 ac/RM) and the low frequency of 100-day duration events for lower elevations during the least tern season suggests that 100 days of continuous sandbar emergence is not critical to least tern reproductive success.

Table 8. River stage-area relationships for 1988-89 non-vegetated sandbar habitat, LMR RM 315-955. Percent of time that river stage exceeds LWRP74 elevations, 15 May to 31 August, 1965-1995. Stages combined for New Madrid, Memphis, Helena, Arkansas City, Vicksburg, Greenville, and Natchez gage stations.

ELEVATION FT, LWRP74	ACRES ABOVE LWRP74 ELEVATION	PERCENT OF TIME EXCEEDED	EMERGENT DAYS	SUBMERGENT DAYS
+20	17,117	37.3	68	41
+15	31,959	52.7	52	57
+10	54,868	70.5	32	77
+5	85,905	86.5	15	94
0	116,936	97.2	3	106

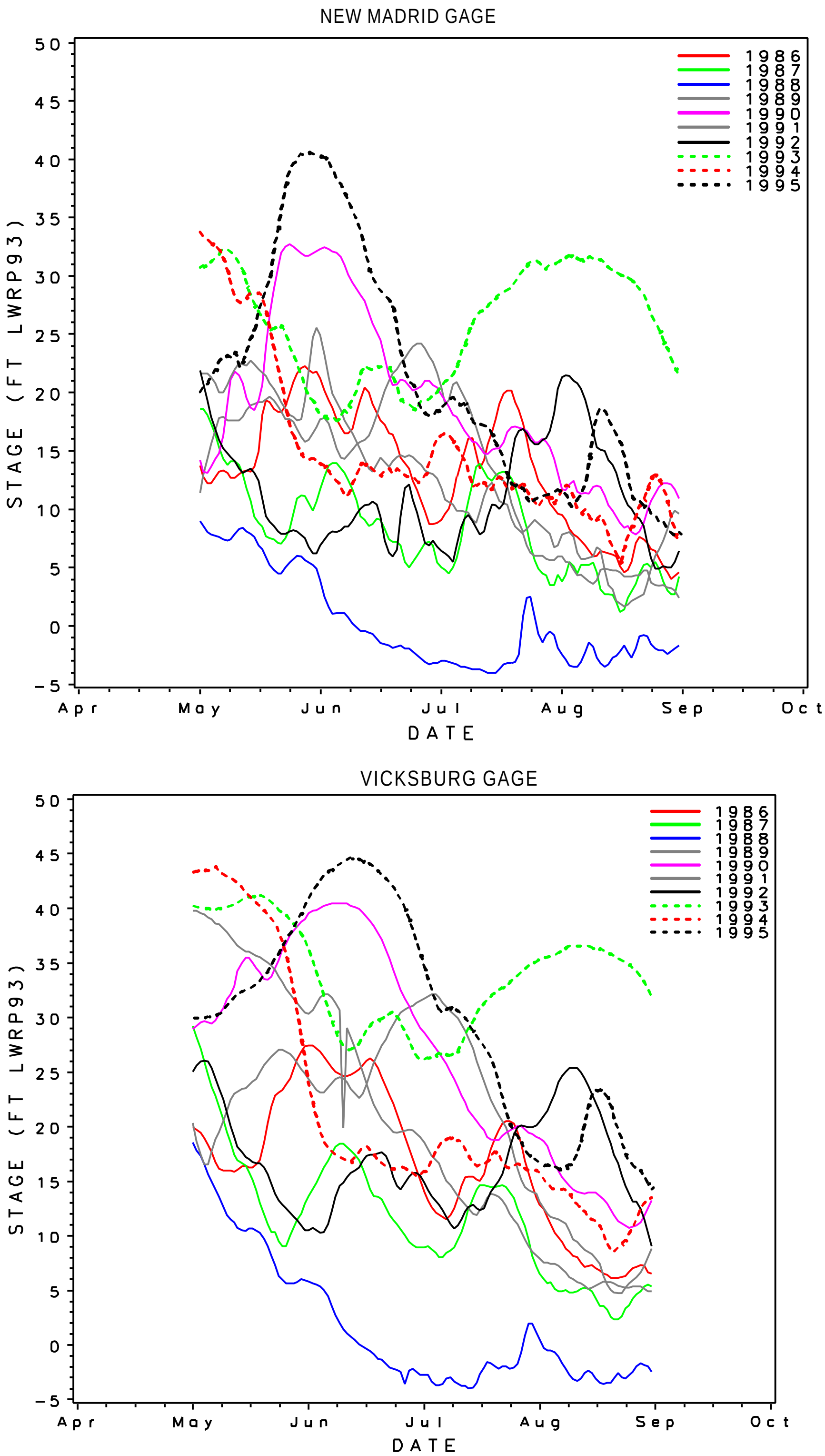


Figure 24. Annual river stage hydrographs for least tern season, 1986 -1995, Lower Mississippi River, New Madrid, Missouri and Vicksburg, Mississippi gages.

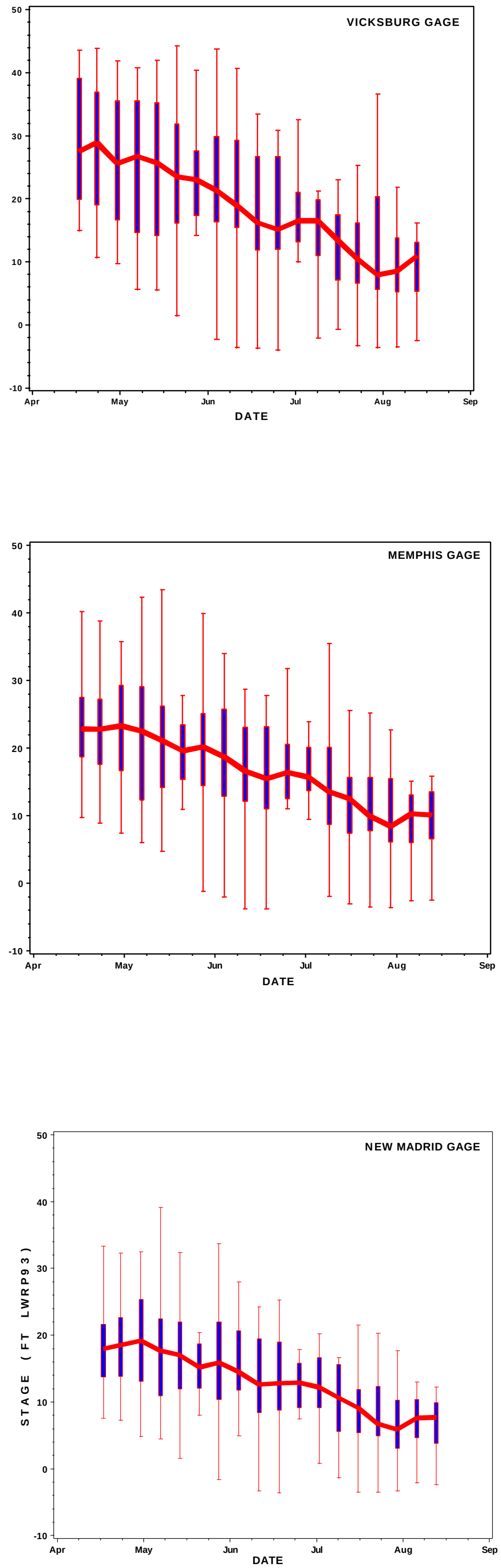


Figure 25. Weekly river stage statistics during the least tern season, 1960 -1995, at Lower Mississippi River gages. Red line is the median, blue bar is the 25th to 75th percentile, and vertical red lines connect the maximum and minimum.

Emergent sandbar events >= 50 continuous days in duration, the minimum time required to complete least tern reproduction, occurred frequently during the 31-year period of record for the LWRP+15 ft (29 –50 percent of the years) and LWRP+20 ft (59-74 percent of the years) elevations for the Greenville, Miss. (RM 530) and upriver gages, and for the LWRP+20 ft (41-44 percent of the years) and LWRP+25 ft (59-65 percent of the years) elevations at the Vicksburg and Natchez gages. Duration of continuously emergent events averaged 75 days for the LWRP+15 ft elevation and 85 days for the LWRP+20 ft elevation for all gages combined. The frequency of continuously emergent events was low (6-12 percent) for the LWRP+10 ft elevation at all gages (Tables 10-12; Figs. 26-29). River stage during the least tern season is <LWRP+15 ft approximately 33 percent of the time for the Vicksburg and Natchez gages, 60 percent of the time for the Greenville gage, and 70 percent of the time for the Caruthersville gage. This downstream trend is also evident in the cumulative stage frequency plots for these gages (Fig. 30), which show the Vicksburg and Natchez gages have distinctly lower intercepts that the upstream gages. The declining downriver trend in the frequency of emergent events >=50 continuous days in duration is partly a backwater effect resulting from decreased channel slope downstream of Old River, La.

The frequency of 75-day duration events of continuous sandbar emergence was great enough to be significant to least tern reproductive success (Table 11). These events occurred 4-5 years out of 10 for sandbars above LWRP+20 north of Greenville and sandbars above LWRP+25 down river. These events may not be as significant as 50-day duration events due to the smaller areas (Table 3).

Results of the hydrologic analysis suggest that northward of about Greenville, Miss. (RM 530), non-vegetated sandbar above elevation LWRP93+15 ft is most important for least tern reproduction while downstream of Greenville, bare sandbar above LWRP+20 ft is most important on the LMR. There was 19,662 ac (47 ac/RM) of bare sandbar habitat upriver of Greenville (RM535) and 6,956 ac (32 ac/RM) of bare sandbar habitat above elevation LWRP93+20 ft between Greenville and Old River.

Least terns are found in greatest concentrations (45 major colonies) along the LMR upriver of Greenville, Miss. (RM 530), with fewer major colonies occurring southward to about RM 430, and little or no utilization of the plentiful sandbar habitat farther downstream. In late April and early May, when terns are arriving and river stage is high, significantly more sandbar may be submerged south of RM 530. This condition might cause the birds to travel further north, where larger quantities of sandbar habitat may be above water, to initiate breeding and nesting.

Effects of Changes in River Flow lines

A detailed study of stage and slope adjustments in the pre- and post-cutoff channel of the LMR indicated that the present river could be divided into six segments with regard to channel stability (Biedenharn, 1995) (Table 13a). It was found that the LMR between Natchez and Cairo is responding to the series of cutoffs in the same manner a stream reacts to a single cutoff (Lane, 1955), and that slopes and stream power are greater today than in the pre-cutoff period. Since bed material size (D_{50}) has not changed significantly on the LMR since 1932, and may be finer (Nordin and Queen 1992), it can be inferred from Lane's relationship that an increase in stream power with no change in D_{50} would be offset by an increase in bed material load (Q_s) to satisfy equilibrium. LMR channel response to the steeper slopes is driven by head cutting and channel degradation mechanisms in upstream reaches resulting in the delivery of an excess sediment supply to downstream reaches (Biedenharn, 1995).

Changes in low water channel morphology and flow lines may have an important effect on sandbars. Along the LMR, the low-water channel has exhibited a spatial pattern of degradation and aggradation, similar to that estimated from changes in high-discharge channel slopes. A comparison of the 1974 and 1993 LWRPs shows that the low-water profile lowered up to 8.5 feet between RM

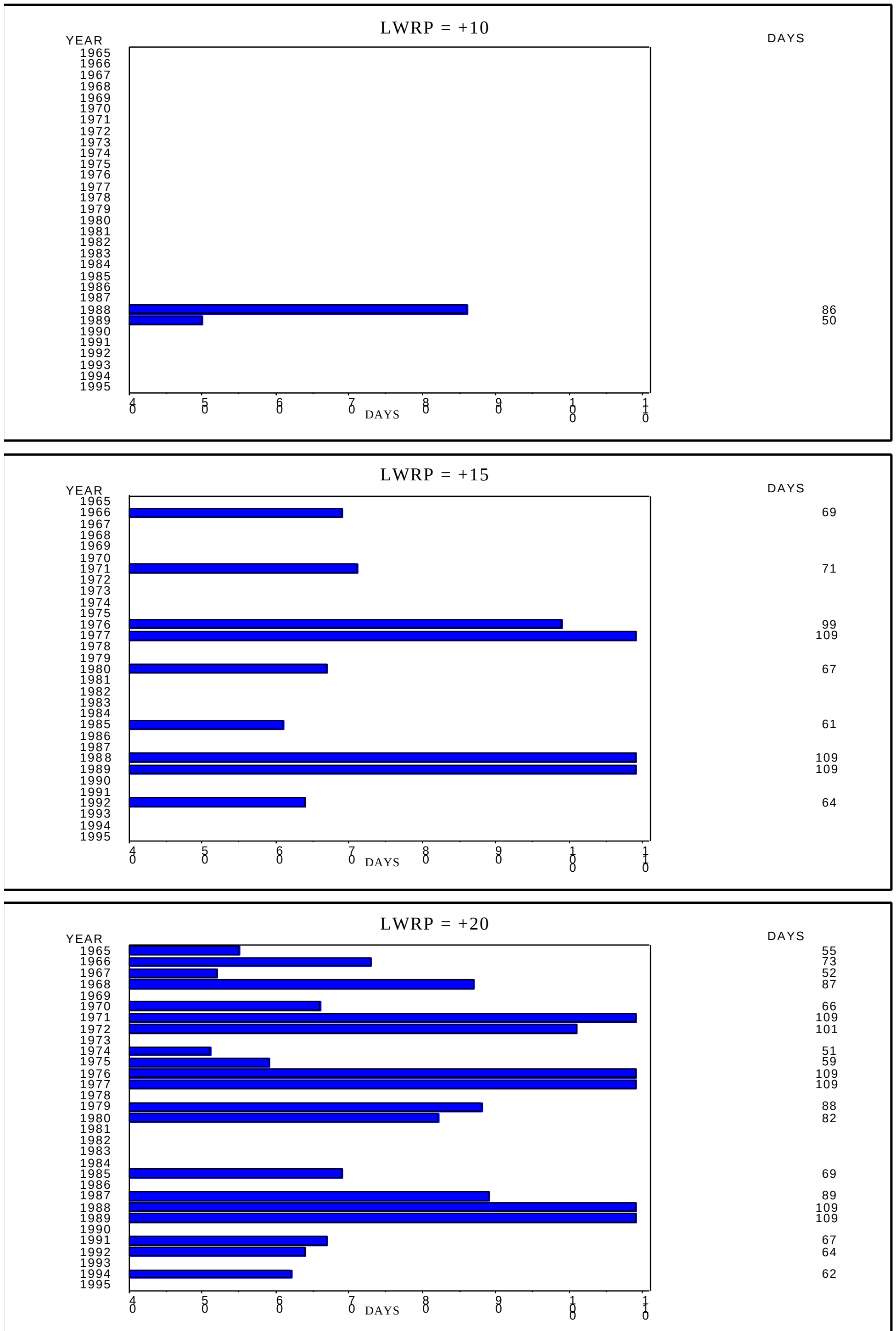


Figure 26. River stage events >= 50 continuous days, 15 May -31 August, Thebes, Mo. gage, 1965-1995.

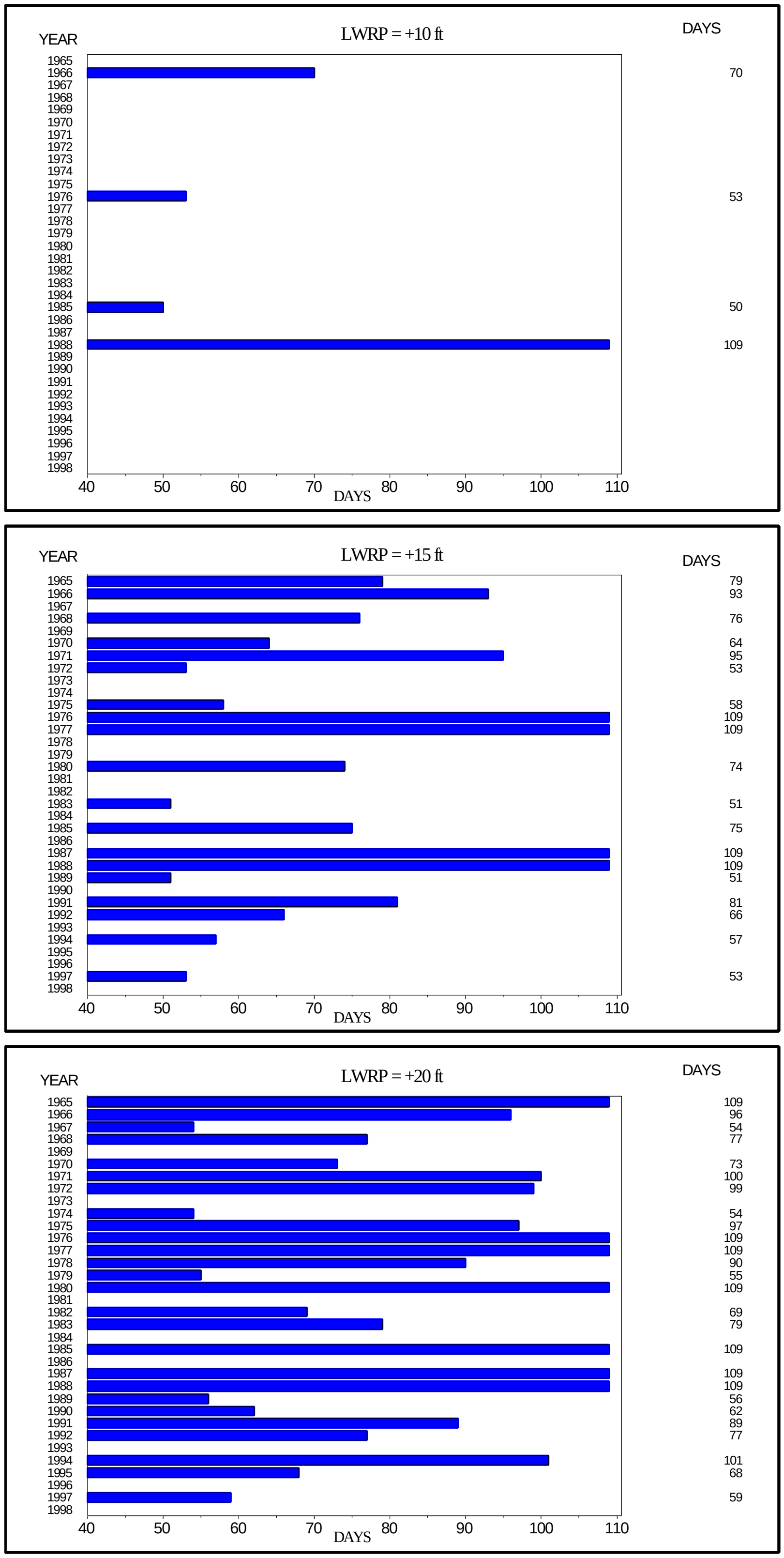


Figure 27. River stage events >= 50 continuous days, 15 May -31 August, New Madrid, Mo. gage, 1965-1995.

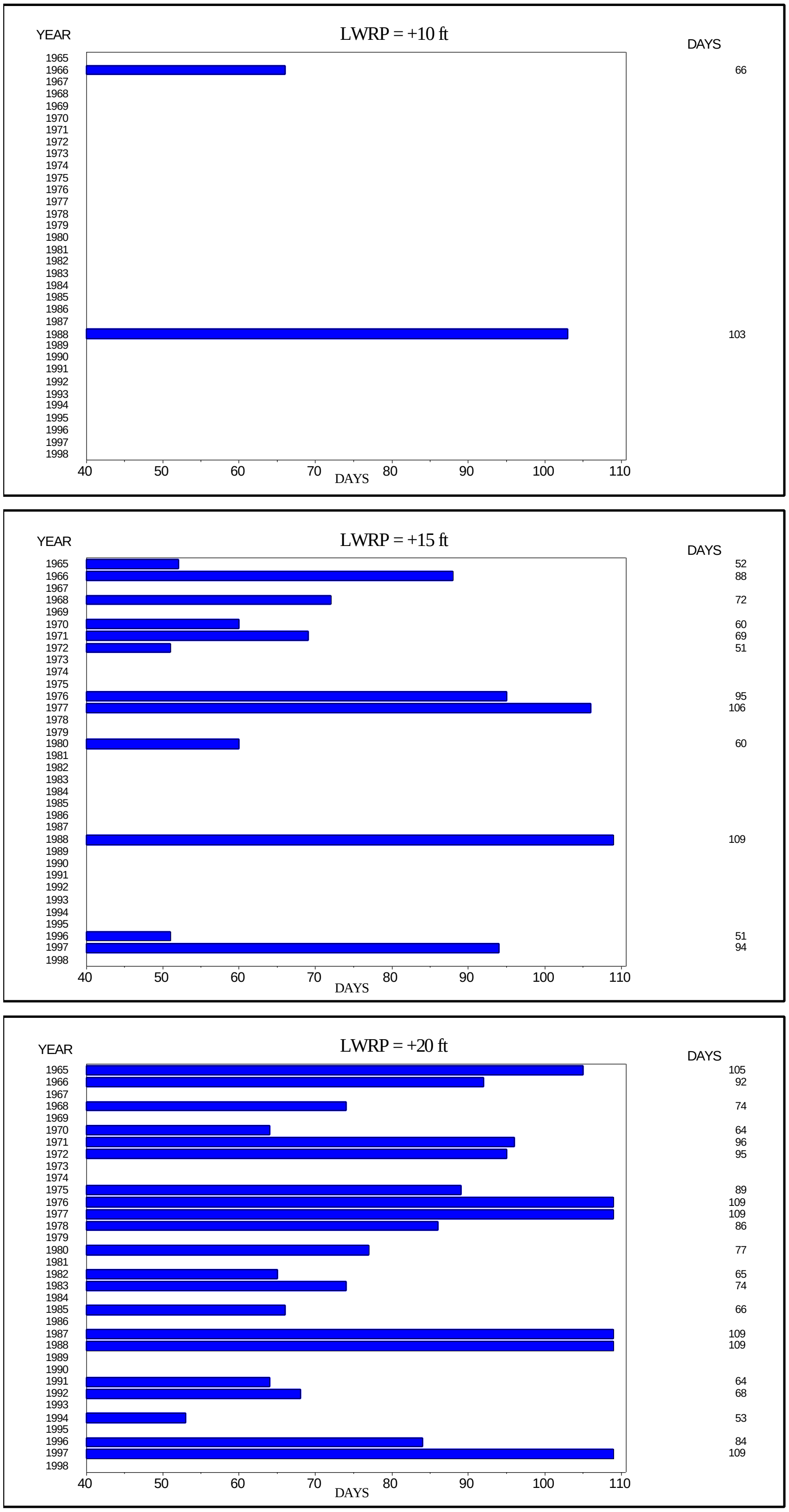


Figure 28. River stage events >= 50 continuous days, 15 May -31 August, Helena, Ark. gage (RM 663), 1965-1995.

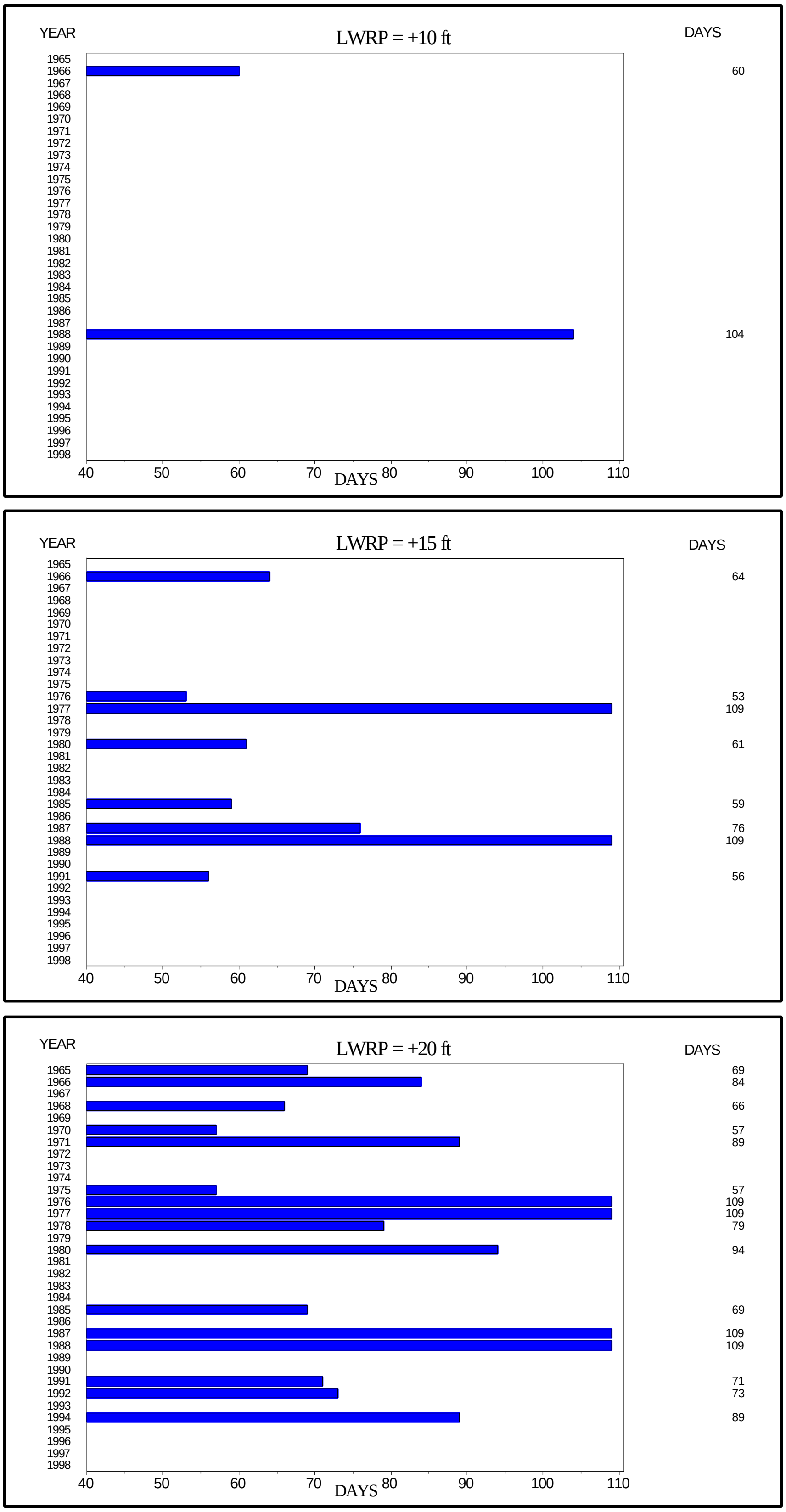


Figure 29. River stage events >= 50 continuous days, 15 May -31 August, Vicksburg, Miss. gage (RM 437), 1965-1995.

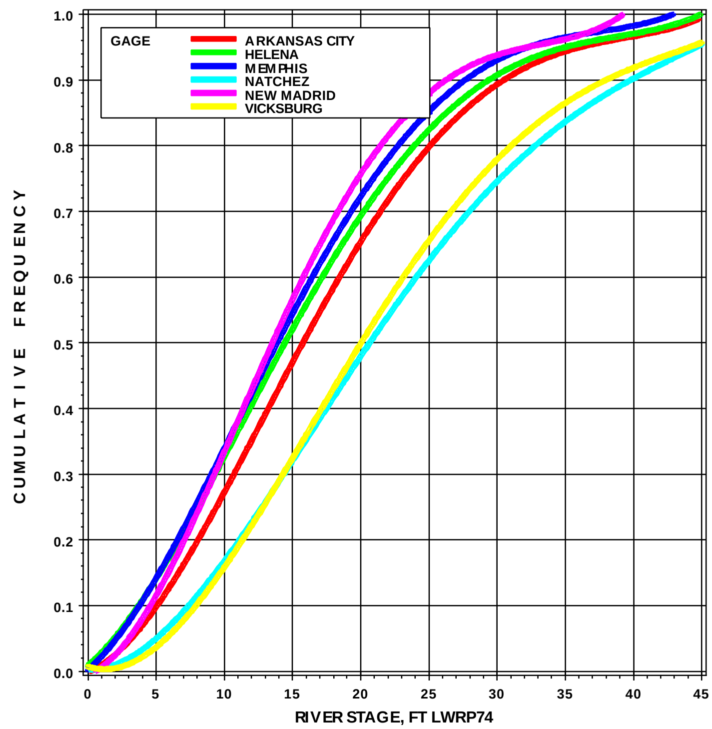


Figure 30. Cumulative stage frequency, 1960-1995, Lower Mississippi River gage stations.

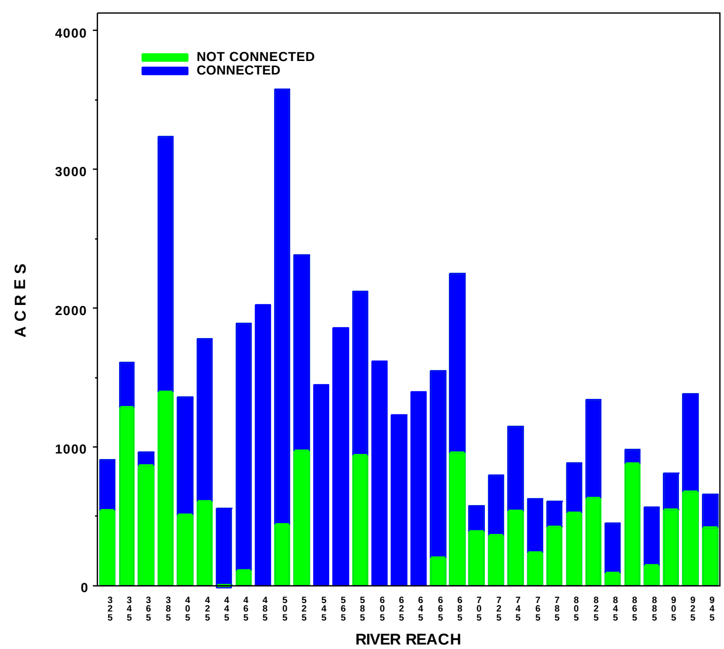


Figure 31. Spatial distribution of bare sandbar connected and not connected to the river bank at river stages, LWRP93+10 ft, Lower Mississippi River. Based on 1988-1989 habitat map data.

Table 9. Duration of events >= 50 continuous days when river stage is less than the specified LWRP elevation during the least tern season (15 May through 31 August), 1965 -1995, at Lower Mississippi River gage stations. LWRP elevations used are LWRP62 (1965 -1973), LWRP74 (1974-1985), and LWRP93 (1986-1995).

	GAGE											
	HELENA FEET LWRP				NEW MADRID FEET LWRP				VICKSBURG FEET LWRP			
YEAR	10	15	20	30	10	15	20	30	10	15	20	30
1965	0	52	105	109	0	79	109	109	0	0	69	107
1966	66	88	92	107	70	93	96	109	60	64	84	90
1967	0	0	0	91	0	0	54	99	0	0	0	86
1968	0	71	73	77	0	5	76	81	0	0	65	70
1969	0	0	0	109	0	0	0	109	0	0	0	0
1970	0	60	64	104	0	64	73	109	0	0	57	90
1971	0	69	96	109	0	95	100	109	0	0	89	109
1972	0	50	94	104	0	52	98	109	0	0	0	94
1973	0	0	0	73	0	0	0	79	0	0	0	54
1974	0	0	0	70	0	0	53	78	0	0	0	52
1975	0	0	89	103	0	52	96	108	0	0	0	87
1976	0	109	109	109	51	99	109	109	0	0	109	109
1977	0	106	109	109	0	108	109	109	0	102	109	109
1978	0	0	87	96	0	0	90	101	0	0	75	85
1979	0	0	0	104	0	0	53	109	0	0	0	75
1980	0	62	78	109	0	63	80	109	0	0	63	109
1981	0	0	0	109	0	0	0	109	0	0	0	65
1982	0	0	65	109	0	0	68	109	0	0	0	63
1983	0	0	74	79	0	0	79	85	0	0	0	69
1984	0	0	0	87	0	0	0	94	0	0	0	76
1985	60	68	109	109	52	76	109	109	0	56	63	108
1986	0	0	0	109	0	0	0	109	0	0	0	109
1987	0	0	109	109	0	109	109	109	0	76	109	109
1988	102	109	109	109	109	109	109	109	103	109	109	109
1989	0	0	0	59	0	51	56	109	0	0	0	53
1990	0	0	0	72	0	0	62	84	0	0	0	64
1991	0	0	64	87	0	81	89	109	0	56	71	83
1992	0	0	69	109	0	67	78	109	0	0	74	109
1993	0	0	0	0	0	0	0	67	0	0	0	0
1994	0	0	53	100	0	57	101	109	0	0	89	94
1995	0	0	0	67	0	0	68	79	0	0	0	51

Table 10a. Duration of events >= 100 continuous days when river stage is less than the specified LWRP elevation during the least tern season (15 May through 31 August), 1965 -1995, at Lower Mississippi River gage stations. LWRP elevations used are LWRP62 (1965-1973), LWRP74 (1974-1985), and LWRP93 (1986-1995).

	GAGE								
	HELENA			NEW MADRID			VICKSBURG		
	FEET LWRP74			FEET LWRP74			FEET LWRP74		
YEAR	10	15	20	10	15	20	10	15	20
1965	0	0	105	0	0	109	0	0	0
1966	0	0	0	0	0	0	0	0	0
1967	0	0	0	0	0	0	0	0	0
1968	0	0	0	0	0	0	0	0	0
1969	0	0	0	0	0	0	0	0	0
1970	0	0	0	0	0	0	0	0	0
1971	0	0	0	0	0	100	0	0	0
1972	0	0	0	0	0	100	0	0	0
1973	0	0	0	0	0	0	0	0	0
1974	0	0	0	0	0	0	0	0	0
1975	0	0	0	0	0	0	0	0	0
1976	0	109	109	0	0	109	0	0	109
1977	0	106	109	0	108	109	0	102	109
1978	0	0	0	0	0	0	0	0	0
1979	0	0	0	0	0	0	0	0	0
1980	0	0	0	0	0	0	0	0	0
1981	0	0	0	0	0	0	0	0	0
1982	0	0	0	0	0	0	0	0	0
1983	0	0	0	0	0	0	0	0	0
1984	0	0	0	0	0	0	0	0	0
1985	0	0	109	0	0	109	0	0	0
1986	0	0	0	0	0	0	0	0	0
1987	0	0	109	0	109	109	0	0	109
1988	102	109	109	109	109	109	103	109	109
1989	0	0	0	0	0	0	0	0	0
1990	0	0	0	0	0	0	0	0	0
1991	0	0	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	101	0	0	0
1995	0	0	0	0	0	0	0	0	0

Table 10b. Duration of events >= 75 continuous days when river stage is less than the specified LWRP elevation during the least tern season (15 May through 31 August), 1965 -1995, at Lower Mississippi River gage stations. LWRP elevati ons used are LWRP62 (1965-1973), LWRP74 (1974-1985), and LWRP93 (1986-1995).

	GAGE								
	HELENA			NEW MADRID			VICKSBURG		
	FEET LWRP74			FEET LWRP74			FEET LWRP74		
YEAR	10	15	20	10	15	20	10	15	20
1965	0	0	105	0	79	109	0	0	0
1966	0	88	92	0	93	96	0	0	84
1967	0	0	0	0	0	0	0	0	0
1968	0	0	0	0	75	76	0	0	0
1969	0	0	0	0	0	0	0	0	0
1970	0	0	0	0	0	0	0	0	0
1971	0	0	96	0	95	100	0	0	89
1972	0	0	94	0	0	98	0	0	0
1973	0	0	0	0	0	0	0	0	0
1974	0	0	0	0	0	0	0	0	0
1975	0	0	89	0	0	96	0	0	0
1976	0	109	109	0	99	109	0	0	109
1977	0	106	109	0	108	109	0	102	109
1978	0	0	87	0	0	90	0	0	75
1979	0	0	0	0	0	0	0	0	0
1980	0	0	78	0	0	80	0	0	0
1981	0	0	0	0	0	0	0	0	0
1982	0	0	0	0	0	0	0	0	0
1983	0	0	0	0	0	79	0	0	0
1984	0	0	0	0	0	0	0	0	0
1985	0	0	109	0	76	109	0	0	0
1986	0	0	0	0	0	0	0	0	0
1987	0	0	109	0	109	109	0	76	109
1988	102	109	109	109	109	109	103	109	109
1989	0	0	0	0	0	0	0	0	0
1990	0	0	0	0	0	0	0	0	0
1991	0	0	0	0	81	89	0	0	0
1992	0	0	0	0	0	78	0	0	0
1993	0	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	101	0	0	89
1995	0	0	0	0	0	0	0	0	0

Table 11. Frequency of emergent sandbar events during the least tern season, 15 May through 31 August, 1965 -1995, at Lower Mississippi River gages.

	RIVER STAGE (FEET LWRP)														
	10			15			20			25			30		
DAYS	50	75	100	50	75	100	50	75	100	50	75	100	50	75	100
NEW MADRID (RM 889)	4	1	1	17	10	3	25	17	8	30	25	16	31	30	22
MEMPHIS	3	1	1	12	6	2	22	15	7	30	22	12	30	28	22
HELENA (RM 663)	3	1	1	11	4	3	19	12	6	28	20	8	30	25	19
ARKANSAS CITY	2	1	1	10	3	2	20	13	6	30	20	9	30	26	17
GREENVILLE (RM 530)	2	1	1	14	5	3	20	13	6	30	20	10	31	25	17
VICKSBURG (RM 437)	2	1	1	6	3	2	15	8	4	22	14	7	29	20	10
NATCHEZ (RM 365)	2	1	1	5	2	2	14	5	3	20	12	4	26	18	9

Table 12. Summary statistics for events when river stage was less than LWRP elevations for >= 50 continuous days for the least tern season, 15 May through 31 August, 1965 -1995, at Lower Mississippi River gage stations.

	LWRP ELEVATION																			
	<+10 FT				<+15 FEET				<+20 FEET				<+25 FEET				<+30 FEET			
GAGE	N	MEAN	MIN	MAX	N	MEAN	MIN	MAX	N	MEAN	MIN	MAX	N	MEAN	MIN	MAX	N	MEAN	MIN	MAX
NEW MADRID	4	71	51	109	17	78	51	109	25	85	53	109	30	95	59	109	31	101	67	109
MEMPHIS	3	79	61	107	12	80	51	109	22	86	51	109	30	90	54	109	30	101	71	109
HELENA	3	76	60	102	11	77	50	109	19	87	53	109	28	87	50	109	30	97	59	109
ARK. CITY	2	84	64	104	10	75	58	109	20	85	51	109	30	86	50	109	30	98	64	109
GR'NVILLE	2	84	64	104	14	76	51	109	20	86	53	109	30	87	51	109	31	96	51	109
VICKSBURG	2	82	60	103	6	77	56	109	15	82	57	109	22	84	55	109	29	86	51	109
NATCHEZ	2	80	58	102	5	75	50	109	14	74	50	109	20	82	57	109	26	87	51	109

435 and 885 (Vicksburg to New Madrid), but generally increased between RM 325 and 435 (Vicksburg to Natchez), and was relatively stable from RM 885 to 954 (New Madrid to Cairo). Comparison of measured low-water profiles for the 1962 and 1988 extreme low-discharge events also indicated a generally lower profile in 1988 upstream of RM 430 and a generally higher profile from Vicksburg to Old River (Elliott, Rentschler, and Brooks, 1991).

Changes in the LWRP can affect sandbar morphology and availability to least terns. Conceptually, if sandbar morphology remained more or less static, lowering of the LWRP would increase the duration and amount of sandbar above the water at a given river stage, while increases in the LWRP would have the opposite effect. Analysis of variance showed that the mean percent change in bare sandbar area above LWRP+10, LWRP+15, and LWRP+20 ft (47.5, 67.2, 74.4) between the 1970s and 1980s was significantly greater (P>0.01) for reaches where the LWRP lowered, as opposed to aggradational reaches (-27.6, -27.7, -35.8). No significant difference in change was found for bare sandbar area above the LWRP+0 ft.

Sandbar and River Bank Contiguity

The frequency and duration that sandbars are connected to the riverbank are important to habitat quality for least terns on the Mississippi River. Sandbars may be physically contiguous with the bank or connected to the bank by stone dike structures. Sandbars that are connected to the bank over a range of river stages during the nesting season may be more accessible to coyotes, raccoons, and other land predators of tern eggs and chicks and to disturbances by humans, especially ATV vehicles. Significant predation of least terns by avian species such as the barred owl, has been observed along the LMR (Woodrey and Szell, 1997). These predators, however, are not influenced by bank contiguity. Hence, the importance of sandbar isolation from the riverbank for protecting eggs and chicks from predation may have been exaggerated.

Results of GIS spatial analyses of sandbar bank contiguity in the LMR indicated that about one-third of the sandbar area is physically connected to the river bank at a river stage of LWRP93+10 ft and about two-thirds of the sandbar area are isolated from the river bank at this river stage. The portion of contiguous sandbars varied widely (0-90%) among the 20-river mile reaches (Fig. 31).

Effects of Dike and Revetment Structures

General

Dike and revetment systems may affect the quantity, morphology, and topography of sandbar habitat in the Mississippi River. But clearly distinguishing these effects from the many complex fluvial and hydrologic processes operating in the river (refer to Basic Fluvial Processes section) is very difficult. While dike and revetment systems may alter individual sandbars and the local morphology of the low water channel, these effects are superimposed on influences of other, often more long term, fluvial and hydrologic processes as well as fundamental geologic controls. Furthermore, the interaction of these complex variables may be synergistic or offsetting, depending on reach conditions. For example, dike and revetment systems may be contributing to LWRP lowering in a reach, but this effect may be ameliorated by concurrent channel aggradation caused by the cutoffs.

Dike Systems

Dike systems may cause localized flattening of channel slope, increased channel roughness, vertical accretion of bars, increases in main channel volume, and stage reductions at low-discharges (Tuttle and Pinner, 1982; Elliott, Rentschler, and Brooks, 1991). The degree of these effects depends on the geomorphic location, initial channel top bank width, degree of divided flow conditions and braiding, and channel depth.

Dike construction has generally contributed to the overall increase in LMR sandbar habitat in the past 35 years (refer to Habitat Temporal Trends section). Where dike systems are used to reduce secondary channel discharge, lateral and vertical sandbar accretion, secondary channel aggradation, and deepening and narrowing of the main channel are the typical responses. As a result of dike construction in straight or low-sinuosity reaches, alternate bars typically increase in size and height due to sediment deposition, while sandbars within the design channel trace are reduced in size or eliminated by erosion. Woody vegetation colonization on sandbars is influenced by dikes to the degree that these structures increase bar height above the LWRP+20 ft elevation.

Dikes can contribute to lowering of the LWRP by concentrating discharge in the main channel, resulting in degradation of the bed and increased volume of the low water channel. Studies by MVD show that channel volume below the LWRP elevation increased by 20 to 450 percent following dike construction in 16 of 20 LMR reaches. Eighteen secondary channels partially filled with sediment after dike construction, but thereafter tended to fluctuate about a dynamic equilibrium (Shields 1995). Sedimentation and bar accretion was greatest in dike systems located on point bars and the outside of bends and least in dike systems located in straight reaches and channel crossings. This response appeared unrelated to most dike system design parameters, although systems with level or stepped-down crown profiles and more closely spaced dikes experienced the least sedimentation.

The relationship between total length of dikes present and bare sandbar area above the LWRP elevation for 1965, 1976, and 1989 varied widely among the 37 20-RM reaches (Appendix C; Table 13b). While the efficacy of correlation analyses with N=3 is small, the analysis revealed significant positive or negative associations between total dike length and sandbar acres in many reaches. A positive correlation suggests that as amount of dike construction and control of the low-water channel increased, sandbars associated with dikes grew in height or size, woody vegetation was eroded, or new bars were formed in response to channel realignment.

Expected effects of a dike system on sandbar habitat may be negated, in some cases, by basic fluvial processes operating in the reach. For example, at Catfish Point (RM 570), a point bar cutoff was developing across the sharp, short-radius bend. Following construction of a closure dike with a crown elevation of LWRP+18 ft, however, the secondary channel significantly filled. The sandbar, however, did not grow vertically and become colonized by dense stands of woody vegetation. Instead, topography of the large point bar has remained relatively low and flat and mostly devoid of woody vegetation because of intensive scouring during high-discharges by water diverting across the short-radius bend. This is an example of channel planform geometry offsetting the typical aggradational response of a sandbar to dike construction.

Table 13a. Relationships between post-cutoff stability, and slope for six reaches of the Lower Mississippi River (from Biedenharn, 1995).

REACH		CHANNEL STABILITY REGIME, 1972-1992	% CHANGE IN MEAN SLOPE, PRE-CUTOFF vs. 1972-92
Fulton-New Madrid	RM 780-890	Transitional-dynamic equilibrium	5.7
Sunflower-Fulton	RM 630-780	Degradational	26.9
Rosedale-Sunflower	RM 590-630	Transitional	36.1
L. Prov.-Rosedale	RM 485-590	Dynamic Equilibrium	28.5
Vicksburg-L. Prov.	RM 435-485	Transitional	12.5
Natchez-Vicksburg	RM 360-435	Aggradational	7.8

Dike systems contribute to habitat diversity because they are comprised of a mosaic of steep bank, sandbar, and deep channel habitat types, a variety of microhabitats, and the stone structures. Deep plunge pools and scour pockets are created on the downstream side of many dikes and the stone provides cover and substrate for fish and invertebrates. A variety of bed sediment types are typically present, resulting in a diverse benthic invertebrate assemblage. Large quantities of epibenthic invertebrates, mainly caddisfly and midge larvae, are produced on the stone dikes. Important slackwater to low-velocity habitat conditions are also present in diked secondary channels during low- to medium-discharge periods. These areas function as nursery, feeding, and refuge areas for river fishes and water birds (Baker *et al.,* 1988). Fish standing crop in LMR dike systems at slackwater averaged 894 lbs/ac and 19,322 fish/ac. Forage fish, particularly threadfin and gizzard shad, were numerically dominant (S. P. Cobb, unpublished data).

Bendway Weirs

Effects of bendway weirs on sandbar habitat are relatively small. Channel widening caused by the weirs may erode the adjacent point bar or alternate bar. Loss of sandbar habitat on MMR and LMR to this process has been negligible. These submerged structures provide food and cover for river fishes and invertebrates in the open channel where these features are naturally lacking. Model studies to further evaluate the impact of bendway weirs on sandbars are being conducted by the St. Louis District.

Revetments

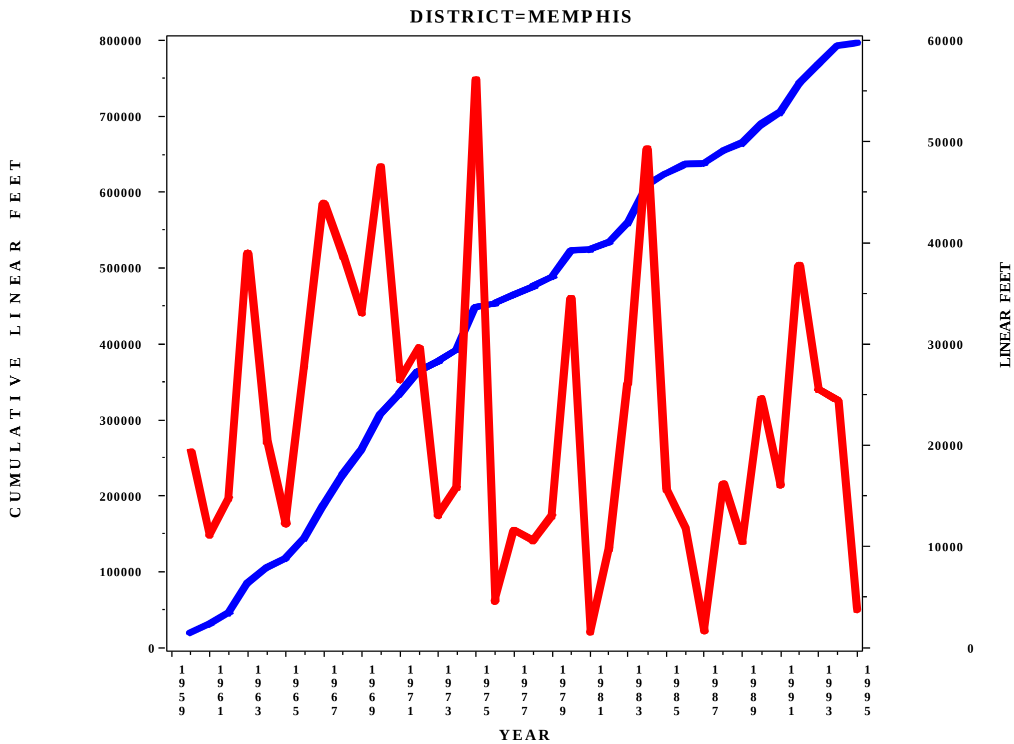
ACM revetments have little effect on sandbar habitat, since they are placed on steep caving banks. These structures often develop a deeper and narrower channel cross-section in bends at low flow. This effect tends to increase conveyance and flatten the low-water channel slope (Elliott, Rentschler, and Brooks, 1991) and may increase the size of the adjacent point bar. Revetments also stabilize channel alignment, thereby allowing dike systems to effectively operate to contract and deepen the low-water channel and remove or degrade mid-channel bars.

Habitat Stability

Today's MMR and LMR are dynamic, adjusting slope and morphology in response to changes in discharge, sediment load, and engineering works, and experiencing significant reworking during major floods, e.g., 1973, 1993, and 1997. Although the historic river of actively meandering bends and shifting bars has been largely controlled by river engineering works, channel morphology has not become static.

The LMR has retained its dynamic nature because river engineering works do not completely control the fluvial processes that form the river channel, and the hydrologic regime is very similar to that of the historic river (Tuttle and Pinner, 1982). Dike systems are designed to control the low-water to mid-bank-full channel, not the total channel, and many of the river's banks have not been revetted, allowing for lateral channel movement, especially in straight reaches (Tuttle and Pinner, 1982). LMR top bank width north of Old River ranges from 5,000-17,000 ft, while low-water channel width is 1,000-2,500 ft. In the intervening areas of the channel, sandbars and islands are periodically reconfigured by the transport and subsequent storage of massive quantities of sediments over the annual hydrograph, particularly during major floods. An example of channel dynamics is Middle Ground Island (RM 410), where the right bank is caving in the secondary channel and a large section of new sandbar is being accreted along the margin of the island (Fig. 33). The annual hydrograph is largely controlled by rainfall events and patterns in the drainage basin.

Annual high-discharge events that are characteristic of the LMR are important to the maintenance of high-elevation areas of bare sandbar. These areas are emergent for long durations during the least tern nesting season and are important to reproductive success, particularly in high-discharge years. Stands of woody vegetation on sandbars and islands are often reduced in size or destroyed by scouring, sedimentation, and massive erosion (Fig. 34) during floods. Also, the



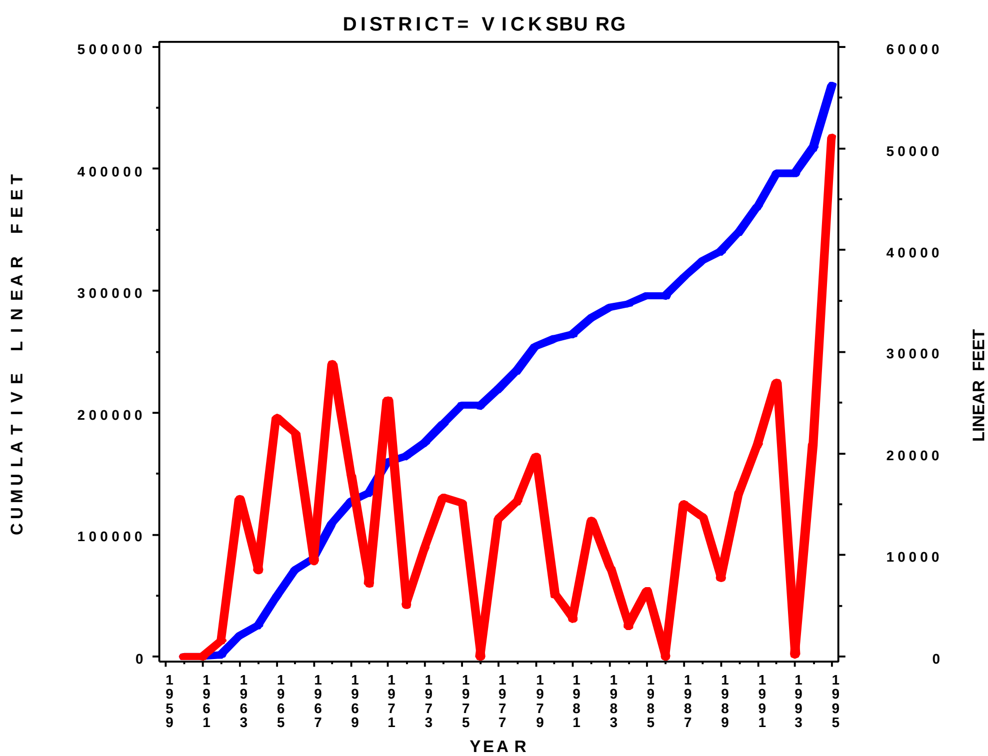


Figure 32. Stone dike construction history, Lower Mississippi River.

Table 13b. Relationship between linear feet of stone dikes and bare sandbar habitat area in 20-river mile reaches of the Lower Mississippi River for 1965, 1976, and 1989. R -values are correlation coefficients.

RIVER MILE	R-VALUE	RIVER MILE	R-VALUE	RIVER MILE	R-VALUE
325	-0.922	525	-0.367	765	+0.731
345	+0.995	545	-0.679	785	-0.758
365	-0.921	565	+0.212	805	+0.626
385	+0.586	585	-0.092	825	+0.160
405	-0.248	605	-0.929	845	-0.490
425	-0.581	665	+0.948	865	-0.968
445	-0.669	685	+0.513	885	+0.164
465	+0.820	705	-0.590	905	+0.553
485	-0.053	725	-0.850	925	-0.592
505	-0.100	745	+0.512	945	+0.415

heads of many bars and islands remain free of dense woody vegetation because coarser sand and gravel sediments, unsuitable for germination and survival of black willow seeds, are deposited there during high-discharges.

Summary

The system-wide net effect of dike and revetment construction and related long term channel responses on total bare sandbar habitat appears to have been comparatively small in the LMR. The amount of non-vegetated sandbar above the LWRP elevation increased 6 percent from the mid-1960's to mid-1970's, remained essentially unchanged through the late-1980's, and increased slightly in the mdi-1990's. Corresponding increases of 10 percent occurred in bare sandbar area above the LWRP+15 and LWRP+20 ft elevations. During this period, 240 miles of stone dikes were constructed and 100 miles of bank were stabilized with ACM revetment (Fig. 32 and Appendix D).

Significant quantities of bare sandbar habitat are still present in the LMR and MMR. While sandbars have been very dynamic in many reaches, with degradation of some bars, growth in size and elevation of other bars, and formation of new bars, there has been little net change in total habitat area. The general trend has been erosion of mid-channel bars within the design channel trace, vertical and lateral enlargement of alternate, other mid-channel, and point bars, and colonization of portions of sandbars at elevations >10 to 25 feet above the LWRP by black and sandbar willows and cottonwoods.

The large quantity and increasing amounts of Mississippi River sandbar habitat, and the under utilization of this habitat by the least tern, do not corroborate the findings and recommendations of Smith and Stucky (1988) and Smith and Renken (1991,1993) that sandbar habitat on the LMR is declining and that habitat restoration measures are needed. While decreases in sandbar habitat have taken place in some reaches, these losses have been offset by increases in other reaches. In addition, the findings of Nunnally and Beverly (1986) that a 35 percent decrease in LMR sandbar habitat took place between 1962 and 1976, and that sparked concern that least tern habitat was decreasing on the LMR, were found to be erroneous. Instead, sandbar area increased during this period.

Dike systems typically increase the size and height of sandbars upon which they are constructed and erode sandbars within the main channel locally and in the immediate downriver reach by altering channel alignment. Revetment effects are less pronounced, involving minor enlargements of point bars. Both types of structures may increase the availability of sandbar habitat to least terns by lowering the low water channel profile. Increases in bar elevation can also contribute to the magnitude and extent of woody vegetation colonization of sandbars.

It is not possible to clearly separate effects of river engineering structures on sandbars from the influences of other fluvial processes such as long-term channel degradation and aggradation. Effects of dike and revetment construction on sandbar size and topography may be overridden by dominant fluvial processes, planform geometry and long-term channel responses in some reaches, or these influences may be synergistic.

A high degree of bedform and sandbar habitat stability is not likely to be realized on the Mississippi River, despite the construction of extensive dike and revetment systems. These river engineering works, while providing an efficient navigation and flood control channel, have not completely arrested the river's ability to make vertical and lateral channel adjustments. Consequently, sandbars valuable to least terns will continue to be formed and re-distributed. Second, the discharge regime of the LMR, a major determinant of channel morphology and dynamics, is not expected to change appreciably in the future (Tuttle and Pinner, 1982). Third, the degree of physical control of the channel with river engineering works will not significantly increase, since the project is over 90 percent complete on the LMR and 66 percent complete on the MMR. Fourth, bed sediments transported and stored over annual hydrographs will continue to modify sandbar and island bedforms, especially during major flood events, and set back plant succession. Lastly, channel and bedform morphology in many reaches will continue to adjust over time in response to long term channel degradational and aggradational trends and cycles of low and high precipitation in the basin.

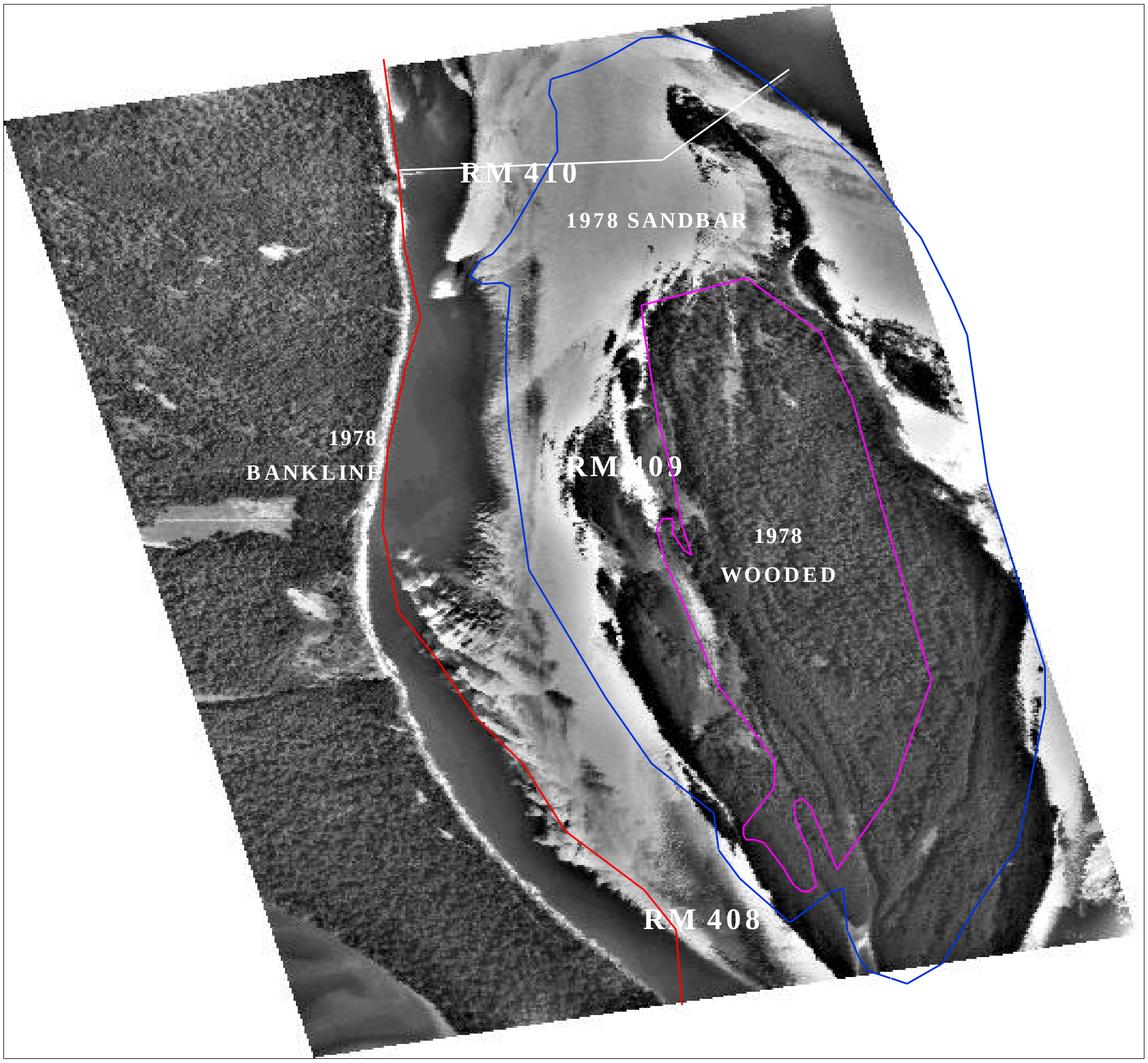


Figure 33. River dynamics at Middle Ground Island, RM 410, Lower Mississippi River. Note bank recession, sandbar growth, and expansion of woody vegetation between 1978 and 1994.

Figure 34. Actively eroding sandbar, Lower Mississippi River.

PART IV: LEAST TERN DISTRIBUTION AND POPULATION TRENDS

Introduction

The Army Corps of Engineers has conducted an annual census of least terns along the MMR and LMR since 1984. The Memphis District primarily carries out these surveys, with assistance from the St. Louis and Vicksburg Districts. A census is made each year from about Cape Girardeau, Mo. (UMMR RM 50) downriver to the vicinity of Vicksburg, Miss. (RM 430), a distance of about 725 river miles. Due to personnel constraints or other considerations, however, the census only extended downstream to Greenville, MS (RM 535) in some years, while field counts were made downriver to RM 430 in one year. Periodic aerial surveys are also conducted along the LMR from Baton Rouge, La. (RM 235) to Old River (RM 320) by staff of the New Orleans Engineer District.

Three field census methods were used: 1) aerial surveys from an airplane or, in recent years, a helicopter; 2) small boat survey; and 3) towboat survey. The aerial surveys typically required 2-3 days to complete, and the small boat survey required 10-11 days to complete. The aerial census is conducted first and the results are used to plan the small boat survey. During small boat surveys, field observers walk each sandbar where least terns are located and take general notes about colony activity, signs of predation, chick mortality, and habitat features (Rumancik, 1984 to 1997). Towboat surveys were conducted from aboard the MV/Mississippi during a routine river inspection trip and cover the river from St. Louis, Mo. to Old River, La.

The least tern census data have been collected in a consistent manner over the years. Surveys were began each year as river stages receded and sandbars became exposed above the water, typically when the stage was about LWRP93+20 ft on the Memphis, Tenn. gage. Two individuals have been members of the 2-4-person field team every year.

A statistical analysis of the census data indicated that least tern counts from the towboat survey where not correlated with the small boat and aerial census results. Consequently, this method was discontinued after 1995 and the data are not presented in this report. Observations from the M/V Mississippi were made while the boat was underway in the navigation channel and reducing speed or stopping for census purposes was not possible. In addition, the distance to many bars was too great to make reliable birds counts, and terns that may have been present on the back side of islands and bars could not be observed.

Spatial Distribution and Habitat Utilization

The spatial distribution pattern of least terns along the Mississippi River is heterogeneous, not random or clumped. Small portions of the river have large colonies, small colonies, or a few individuals in flight over open water, while long reaches of the river with ample sandbar habitat have no least terns (Figs. 36,37, and Appendix D).

Primary colony sites are defined for this study as sandbars that were utilized four or more years from 1986-1995 and had a mean count > 25 from the small boat survey. Fifty-one sandbars interspersed over 558 miles of the Mississippi met these criteria and consistently supported moderate to large numbers of least terns over the period of record (Table 14). These bars were distributed from Racetrack Towhead (RM 431) to Island No. 1 Towhead (RM 948) on the LMR and at Bumgard Island (RM 30) on the MMR (Fig. 35). Only seven primary colony bars were located between Old River, La. and Greenville, Miss., a distance of 220 river miles. No least terns were found in any year between Baton Rouge, La. (RM 230) and Old River, La. (RM 215).

The amount of available sandbar habitat used by least terns on the LMR was estimated for the eleven-year period 1986-1995 from topological analysis of the 1988-89 habitat maps and least tern site locations contained in the REEGIS database. Sandbar habitat above the LWRP elevation was used, even though available area varied as a function of river stage both within and among years. This was done to simplify the spatial analysis and provide a constant aerial measurement. These analyses were performed with the small boat and aerial least tern census data. If a sandbar polygon contained a single least tern colony or individual, the entire sandbar was classed as utilized. Since many sandbars in the LMR are large (>1,000 ac) and least terns were present on only a portion of the available area, these utilization estimates are very liberal.

Results of the utilization analysis suggests that sandbar habitat along the LMR and MMR is under-utilized by the least tern. Estimates of annual utilization ranged from 35 to 59 percent of available sandbar from 1986 through 1995 (Table 15). While the number of colonies per year ranged from 28 to 71 (Table 16), only 52 sandbars supported large colonies of least terns in four or more years between 1986 and 1995 (Table 14). Least terns used primary colony sandbars four to nine years between 1986-1995, but no bar was used every year.

Maximum colony size varied from 50 at Choctaw Bar to 900 terns at Nebraska Point; mean colony size ranged from 27.3 at Rabbit Island to 304.3 individuals at Nebraska Point. Colony size was highly variable at most sites over the years, (Coefficient of Variation (CV) = 50 to 150 percent), but was relatively consistent at Racetrack Towhead and Steypell bars (CV = 28.5 and 19.3 percent). Turnover rates for least tern colony sites on the lower Platte River were found to range from 7 to 18 percent per year (Kirsch, 1996).

Although sandbar habitat is abundant, least terns seldom, if at all, were found between Natchez, Miss. and Baton Rouge, La. (RM 365 to 230). No least terns were found in aerial surveys of the LMR from Baton Rouge, La. to Old River, La. during 1985-1988, 1990 and 1995. Likewise, least terns were not found along the MMR from Commercial Point to the Missouri River (UMR RM 32-195). In a given year along the MMR, least terns inhabited only one to three of the 41 major sandbars (>50 ac) or not more that 15 percent of total available sandbar habitat (20,412 ac). Only one sandbar (Bumgard Island, RM 30) is a major colony site. Least terns did not occupy most of the apparently available habitat on the Platte River (Kirsch 1996).

All primary colony sandbars were large (677-5426 ac above LWRP93) and had significant amounts of non-vegetated area (271-4,019 ac) above LWRP93+15 ft. They were also isolated from the riverbank at stages >LWRP93+10 ft., except for Terrene, Below Cherokee, and Stewart Towhead. Terrene is a very wide point bar and the latter two had peninsulas 2-3 miles long where colonies were located far from land.

Statistical analyses of the least tern census data were performed in an attempt to model the observed population distribution (Appendix G). A mixture of Poisson distributions, one for river miles without terns, one for river miles with large tern numbers, and one for river miles with small tern numbers, was found to fit the data better than a Poisson (random) or negative binomial (clumped) distribution, and confirmed the observed heterogeneous distribution of least terns. These results indicate that site selection of least terns is not due to purely random factors, and that exogenous variables affect location and selection of sandbars for colony sites. Differential resource selection is one of the principal factors allowing coexistence of species (Rozenweig and Abromski 1985). It is often assumed that a species will select resources that are best able to satisfy its life history requirements, and that high quality resources will be selected more than low quality ones. Least terns also respond to variations in the quality of their environment and ambient physical conditions.

One possible explanation for the patchy distribution of least terns on the LMR is the relationship between frequency and duration of river stages and amount of emergent sandbar habitat when terns are arriving on the river. In most years, only higher parts, if any, of sandbars are emergent when terns arrive on the LMR in late April-early May (refer to <u>Effects of Stage and Discharge</u> section). This effect is exaggerated downriver of about Vicksburg, Miss. (RM 437). Therefore, river stages could cause a patchy spatial distribution of least tern colonies due to the influence on sandbar habitat availability, especially in high-discharge years. If least terns arrive when river stages are high and all sandbars are submerged, they may be attracted to the first nearby sandbars that become emergent as stages recede, where they remain for the season. Along the lower Platte River, interior least terns did not strongly select sites with distinct sets of habitat features (Kirsch, 1996).

Temporal Population Trends

Annual least tern numbers along the Mississippi River generally increased from 1986 through 1999 but underwent cyclic fluctuations with a period of 3-4 years (Fig. 37, Appendix E; Kirsch and Sidle, 1999). Total numbers were comparatively low (<2,500) from 1986-1989 but increased dramatically (2.5X) in 1990 and remained relatively high (>3,400) through 1999. Least tern numbers decreased in 1991 and 1992 then nearly doubled to a peak of over 6,700 birds in 1994 and 1995. No reliable population data were available for 1996, but by 1997 least tern numbers had declined to about one-half 1995 levels. The population increased annually to a peak of 6,159 birds in 1999, a rise of about 60 percent over the 1997 count. Least terns' numbers have also been increasing in other river basins (Kirsch and Sidle, 1999).

Statistical modeling of the least tern annual census data from the small boat surveys indicated that the upward trend in Mississippi River least tern numbers from 1986-1995 was statistically significant (Appendix G). The model was based on a mixed Poisson distribution, which was found to best fit the heterogeneous, but non-random, spatial distribution of least terns along the Mississippi River. (Kirsch and Sidle, 1999) also found a statistically significant positive trend in the least tern population at select sites along the LMR and in the Mississippi River Basin.

The observed increase in the Mississippi River least tern population in 1990 and subsequent years may be partially related to hydrologic events affecting the availability of sandbar habitat during the least tern season. During infrequent low-water years, vast expanses of bare sandbar are continuously emergent during the entire least tern season, fish prey are probably concentrated, and mortality by land-based predators could be reduced by the long travel distances to colony sites. In addition, nesting success and chick survival are not affected by inundation. Populations of species such as the least tern with high longevity can decrease over long periods and then quickly rebound during infrequent occurrences of favorable conditions for reproduction (Mertz, 1971; Caswell, 1982).

From 1978 to 1987, only two emergent sandbar events (1980,1985) when river stages were continuously <LWRP+15 ft for 50 or more days occurred upriver of Greenville (RM 535), and least tern numbers were comparatively low during this period. The large population increase in 1990 was preceded by continuously emergent sandbar habitat above LWRP+15 ft for the entire least tern seasons of 1987 and 1988, but 1989 was a relatively high-discharge year with only sandbar area above LWRP+20 ft. available >50 continuous days at some locations. Since an increase in population density should be observed the year after a high rate of reproductive success, it appears that a long duration of continuously emergent sandbar habitat may not be directly related to the major population increase in 1990. It is also unlikely that the 1990 population increase is a result of high recruitment of mature 2-3 year old terns produced in the 1987-88 low-water years. In 1989 and 1990, river stages were relatively high (a short emergent sandbar event occurred in 1989 for the New Madrid gage), and bird numbers declined from the 1990 peak through 1992. Long-duration events of emergent sandbar happened again in 1991 and 1992, preceding the sharp increase in least tern numbers in 1993 (Figs. 26-29). Least tern numbers in 1995, however, did not decline in response to the absence of significant emergent sandbar habitat and lack of reproductive success during the 1993 flood event. Linear regression analyses of total least tern counts, adjusted for length of river surveyed, and the average number of days stages were < LWRP+10, +15 and +20 ft. in the previous year revealed no significant relationships (R^2<0.02).

Other variables also affect the Mississippi River least tern population, including immigration from other river basins and the northern Gulf of Mexico coast, disease, effects of pesticides on reproduction, and perturbations on the wintering grounds in South and Central America. Kirsch and Sidle (1999) suggested that since the reproductive rate appears insufficient to account for the large increase in LMR least tern numbers in 1990, surges of immigration from the U.S. Gulf Coast are the most plausible source of the population growth. The Gulf population is reportedly large and growing (Thompson *et al.,* 1997). Lack of annual population data for the Mississippi River prior to 1985, greatly limits conclusions about long term least tern population patterns or the true population status at the time the species was listed as endangered.

Animal existence in patchy environments, e.g., alluvial river sandbars, requires consideration of the spatial scales at which an organism operates (Wiens 1976). Short-lived and early successional species are more influenced by short-term environmental fluctuations than are long-lived species. This relates to the concept of grain response (Hutchinson and MacArthur 1959). Fine-grained responses of a population occur in direct proportion to the distribution of resources in the environment, whereas coarse-grained responses are characterized by a heterogeneous use of resources and a generally patchy spatial distribution. Least terns are long-lived birds that exhibit a coarse-grained response to the dynamic fluvial landscape and hydrology of the Mississippi River.

Natural populations of most species of colonial birds characteristically undergo cycles related to large-scale physical variations in the environment. This appears to be true for least terns, which are affected by periodic floods, temporal and spatial variation of sandbar habitat by fluvial processes such as meandering, and even geologic events such as earthquakes and channel avulsions. The Mississippi River has occupied six river meander belts during the Holocene (Saucier, 1994).

The life history strategies of many colonial waterbirds have resulted from a combination of the patchy distribution of suitable colony sites with minimal predation and disturbance for nesting and rearing young, and the patchy distribution of forage areas (Buckley and Downer, 1992). A better understanding is needed of how least tern colonies on isolated distinct sandbars (patches) can yield overall stability to a species population that is highly variable at the level of the individual colony (Smith and Renken 1993). One hypothesis is that distribution of numerous colonies over a large geographic area, e.g., sandbars along 600-700 miles of the Mississippi River, increases the probability that reproduction will be successful at an individual site. This could be due to spatial differences in ecological factors such as predation, as well as to environmental factors such as untimely floods and heavy rains while chicks are in the nest.

Natural variability in colony productivity has been documented for least tern colonies in the Mississippi River (Smith and Renken 1993; Woodrey and Szell, 1997). Interior least terns along the Mississippi River could be viewed as consisting of one or more metapopulations, whose dynamics may be determined not only by within-colony birth and death processes, but also by movement of individuals among colonies (Spendelow and Nichols et al. 1995).

The probability of individual small colonies becoming locally extinct is generally higher than for larger colonies (Soule 1990). The ability of small nesting colonies to persist could be enhanced by surplus individuals regularly produced by large, productive colonies, as well as by the innate nature of the species to colonize ephemeral or unstable habitats (McNicholl 1975).

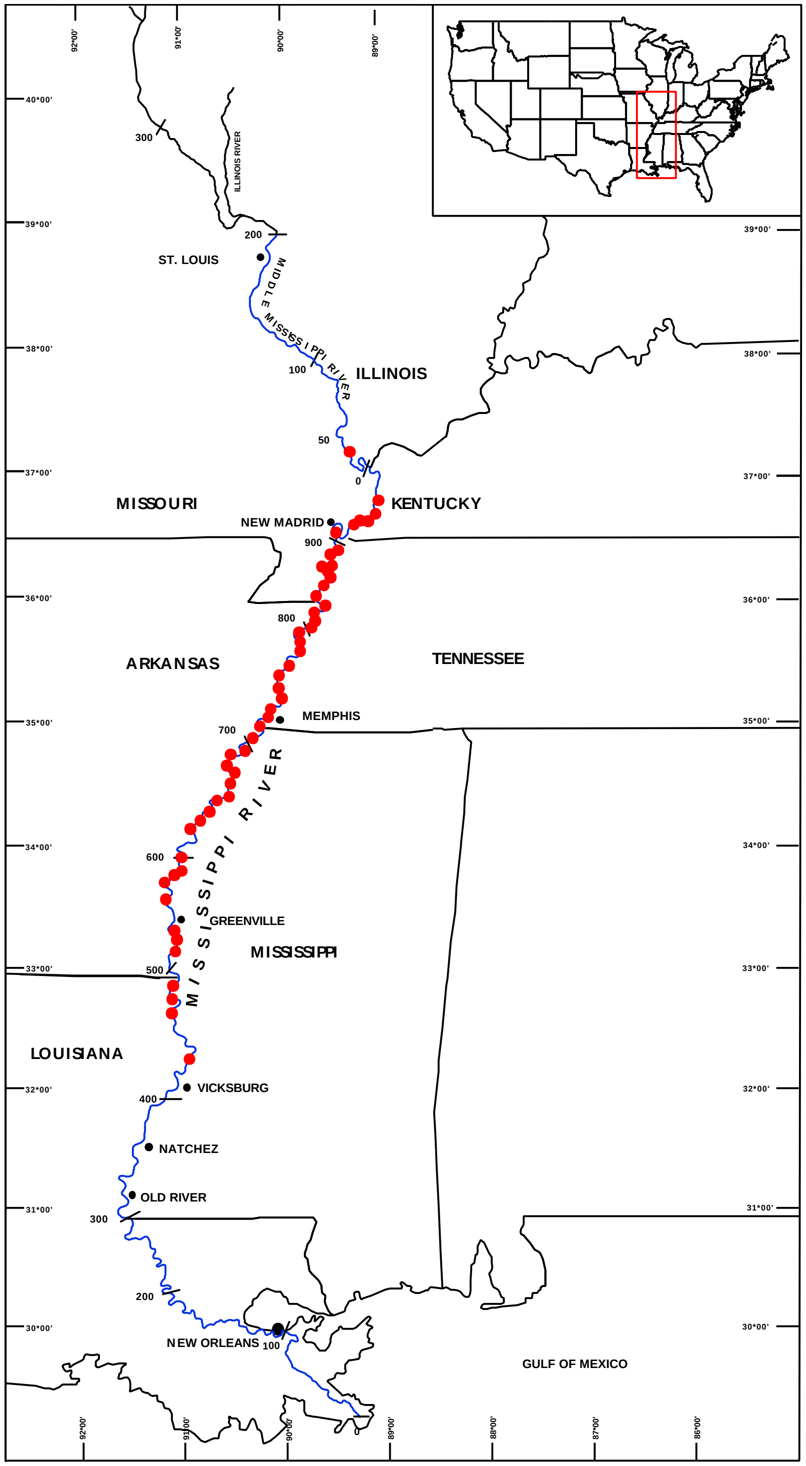
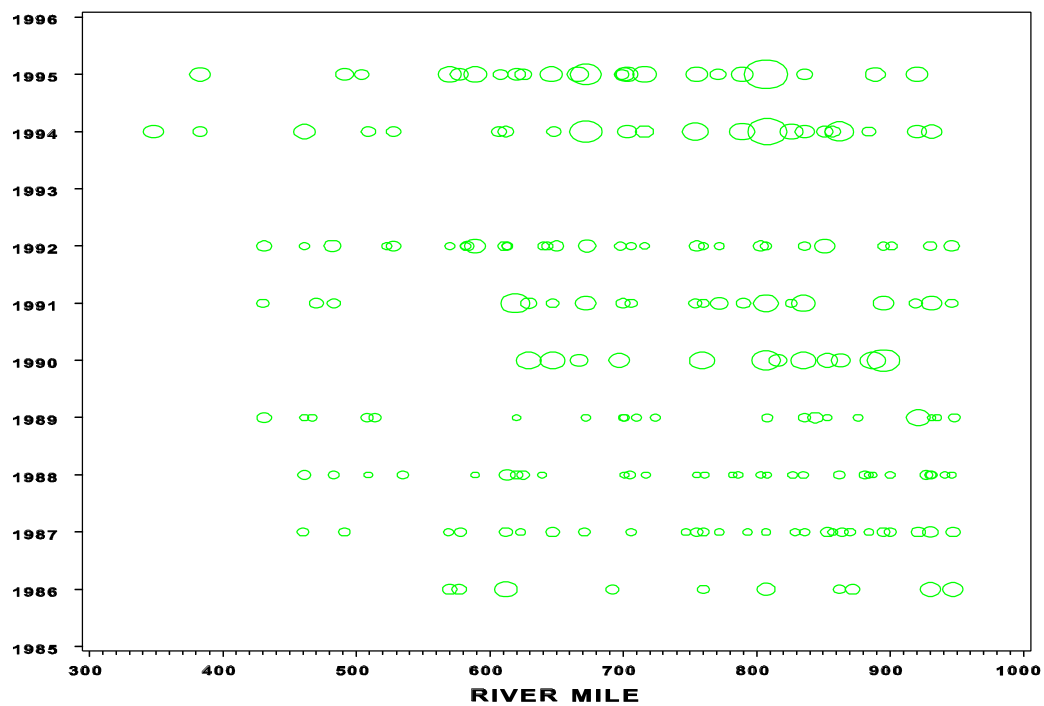


Figure 35. Spatial distribution of major least tern sites and colonies, middle and lower Mississippi Rivers.



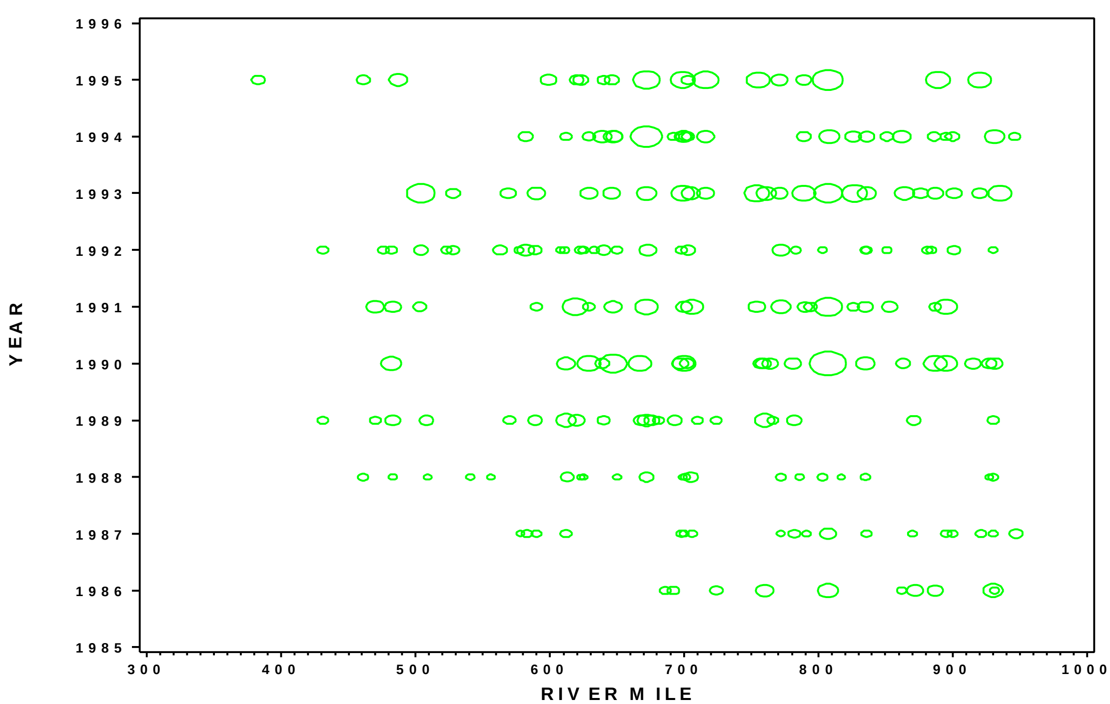


Figure 36. Distribution of least tern population counts greater than the annual mean count for the aerial and small boat censuses, 1986-1995, Lower Mississippi River. Circles are proportional to count size.

Table 14. Primary least tern colony sandbar locations, Lower and Middle Mississippi Rivers.

No.	SANDBAR	RIVER MILE	AC0	AC15	N	LEAST TERN COUNTS MEAN	MIN	MAX	CV
1	Nebraska Point Dikes	808	1713	751	9	304.3	37	900	105.8
2	Island No. 1 Towhead	948	1701	533	8	211.5	75	418	61.6
3	St. Francis Bend Dikes	673	1596	649	8	183.9	5	500	104.9
4	Densford Bar	755	1227	328	5	171.0	85	325	58.7
5	Island No.18 TH Dikes	837	.	.	5	144.4	24	300	91.5
6	Keys Point	792	.	.	6	139.3	9	333	107.9
7	Kentucky Point	890	5426	4019	9	135.8	12	300	88.2
8	Hotchkiss Bend Bar	895	1527	865	8	127.1	6	500	132.6
9	Hickman Bend Bar	921	.	.	8	119.9	25	270	76.2
10	Below Cherokee Dikes	865	.	.	8	108.5	7	400	119.2
11	Wolf Island Bar - Upper	931	677	427	6	98.5	9	200	84.3
12	Porter Lake Dikes	701	.	.	7	95.6	18	275	91.4
13	Racetrack Towhead Dikes	431	.	.	5	94.6	60	127	28.5
14	Below Knowlton Dikes	613	2318	849	8	90.0	25	193	61.4
15	Kangaroo Point Dikes	648	1312	594	8	89.1	14	300	107.8
16	Wolf Island Bar - Lower	930	1087	549	6	86.7	21	200	74.8
17	Terrene Dikes	590	2504	1440	9	86.3	23	250	96.0
18	Cow Island Bend	716	.	.	6	84.7	10	265	121.1
19	Willow Cutoff Dikes	461	1861	1157	8	84.6	15	220	71.7
20	Basket Bar Dikes	698	.	.	4	82.5	22	200	97.3
21	Cedar Point	761	.	.	9	76.0	10	300	114.0
22	Ajax Bar Dikes	483	1817	795	7	74.9	40	138	53.7
23	Lookout Bar Dikes	772	1052	271	8	73.8	3	152	88.4
24	Hathaway Dikes	853	.	.	5	69.6	4	200	114.7
25	Catfish Point Dikes	570	1898	888	9	69.1	12	250	106.0
26	Island No. 21	827	4410	2866	7	66.9	14	250	125.7
27	Below Prentis Dikes	578	2063	1242	8	65.4	10	150	69.8
28	Island No. 64 Dikes	629	1968	1121	9	64.6	6	300	147.9
29	Island No. 67 Dikes	620	1280	550	9	60.3	12	150	76.3
30	Steyppel Dikes	706	.	.	4	60.3	50	75	19.3
31	Island No. 86 Dikes	522	.	.	4	54.3	10	111	81.3
32	Cracraft Lower Dikes	510	2059	1110	7	52.3	21	100	56.7
33	Stewart Towhead Dikes	872	2450	603	7	50.9	14	100	55.4

(Continued)

(Table 14, Continued)

No.	SANDBAR	RIVER MILE	AC0	AC15	N	LEAST TERN COUNTS MEAN	MIN	MAX	CV
34	Below Island No. 9 Dikes	901	.	.	6	49.7	9	71	52.0
35	Island No. 25 Dikes	803	.	.	5	48.8	12	110	75.2
36	Ensley Bar	725	4236	1343	8	47.6	17	130	73.8
37	Tamm Bend	817	.	.	5	46.8	8	150	126.9
38	Chute of Island No. 14	858	.	.	7	46.3	8	123	80.9
39	Mouth of Arkansas River	583	2244	1020	8	43.8	5	138	101.4
40	Cottonwood Bar	470	2846	1778	6	42.5	23	100	70.2
41	Medley Bar	927	.	.	4	42.5	9	93	84.3
42	Island No. 62 Dikes	640	2873	1189	9	42.2	16	76	45.6
43	Below Ludlow Dikes	623	924	449	6	40.3	9	65	48.4
44	Prairie Point	668	3187	2430	5	39.4	2	150	159.2
45	Leota Dikes	514	.	.	6	39.0	8	71	74.8
46	Bumgard Island	30	.	.	8	38.3	14	70	49.2
47	Ashport/Golddust	795	.	.	7	32.4	6	69	69.1
48	Choctaw Bar	563	.	.	5	32.4	20	50	35.4
49	Plum Point Bar	786	.	.	5	32.0	8	80	91.9
50	Dean Island	757	1798	928	5	27.6	7	75	103.2
51	Rabbit Island	693	.	.	4	27.3	6	80	130.4

NOTE: AC0 and AC15 are acres of bare sandbar above LWRP74 and LWRP74+15 ft.
CV = Coefficient of Variation, N = Number years used from 1986-1995.
Mean is based on the number of years sandbar was used.

Major colony sandbars are those used four or more years from 1986-1995 and had a mean least tern count > 25.0.

Table 15. Lower Mississippi River Sandbar Utilization By Least Terns, RM 315 -954

Survey Method	Year	Acres Utilized	Acres Not Utilized	Percent Utilized
AERIAL1	1986	72965.34	26502.67	26.6444
AERIAL1	1987	66122.38	33345.64	33.5240
AERIAL1	1988	68559.45	30908.56	31.0739
AERIAL1	1989	54200.16	45267.85	45.5100
AERIAL1	1990	64132.56	35335.45	35.5244
AERIAL1	1991	55021.79	44446.23	44.6839
AERIAL1	1992	49539.13	49928.88	50.1959
AERIAL1	1993	54787.65	44680.36	44.9193
AERIAL1	1994	52767.57	46700.45	46.9502
AERIAL1	1995	63637.11	35830.90	36.0225
Small Boat	1986	70432.51	29035.50	29.1908
Small Boat	1987	65584.30	33883.71	34.0649
Small Boat	1988	60984.44	38483.57	38.6894
Small Boat	1989	53831.97	45636.04	45.8801
Small Boat	1990	69729.50	29738.51	29.8976
Small Boat	1991	56640.33	42827.69	43.0567
Small Boat	1992	49772.03	49695.98	49.9618
Small Boat	1994	49510.72	49957.29	50.2245
Small Boat	1995	62716.65	36751.37	36.9479

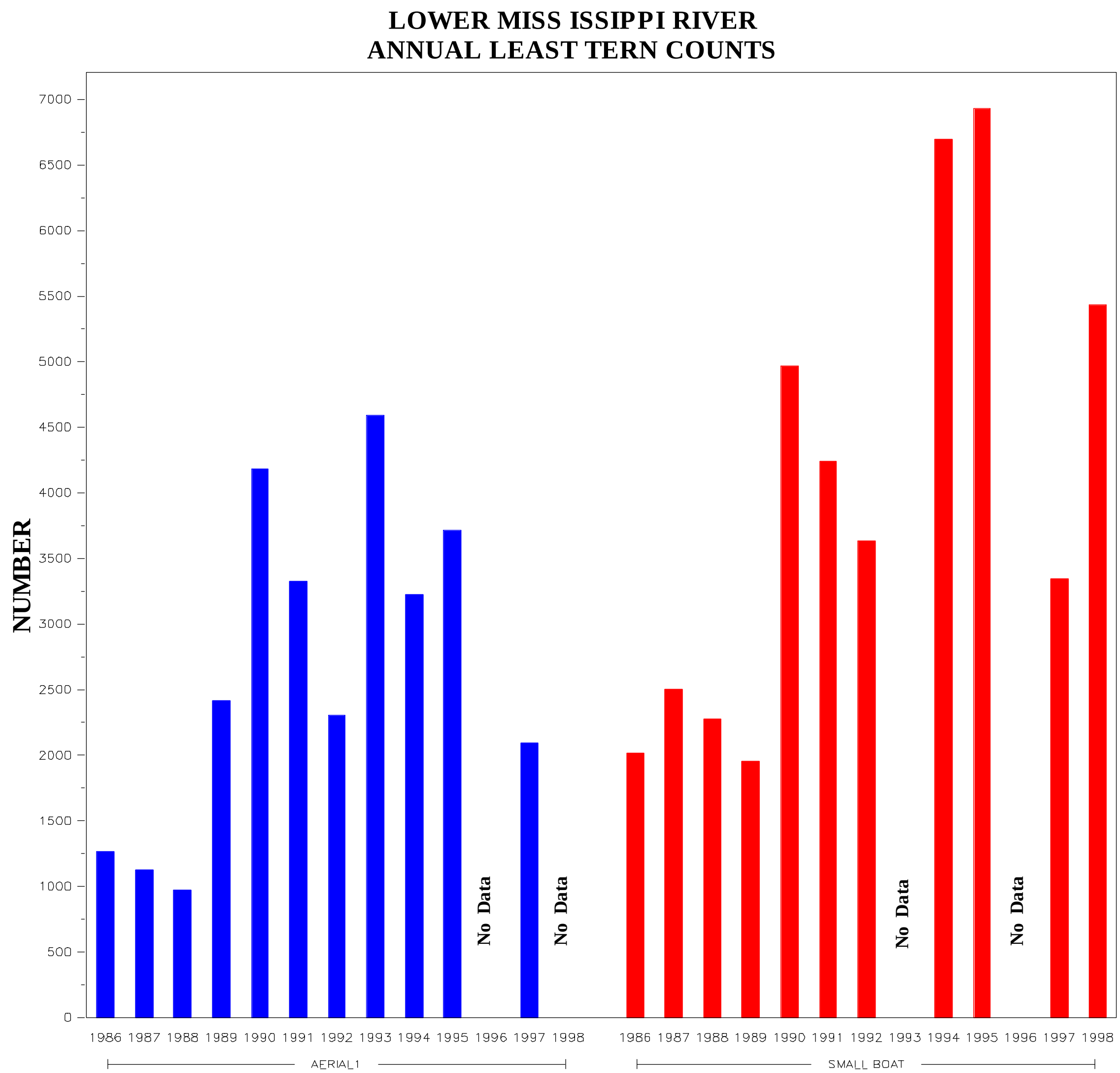


Figure 37. Temporal distribution of annual least tern population counts from the aerial and small boat censuses, Lower Mississippi River.

Table 16. Summary of least tern field census data, 1986 -1995, 1997-1999.

Aerial	18-20 Jun 86	10-11 Jun 87	7-8 Jun 88	6-7 Jun 89	10-18 Jun 90	18-19 Jun 91	8-10 Jun 92	7-8 Jun 93	23 Jul- 3 Aug 94	8-13 Jun 95	28-29 Jul 97	No data	No data
Count	1332	1125	1018	2503	4182	3358	2311	4589	3303	3713	2129	------	------
Sites	37	49	56	58	56	67	80	66	19	66	81	------	------
Colonies	16	24	31	46	36	56	61	46	40	41	23	------	------
Small Boat	23-26 Jun 86	15-19 Jun 87	16-28 Jun 88	13-20 Jun 89	17-21 Jun 90	22-27 Jun 91	17-21 Jun 92	No data	16-21 Jun 94	14-25 Jun 94	1-7 Aug 97	7-15 Aug 98	3-10 Jul 99
Count	2188	2206	2356	2005	5038	4297	3653	-----	6776	6932	3428	5538	6159
Sites	41	50	72	64	38	66	81	-----	78	71	79	91	134
Colonies	28	46	60	42	32	57	74	-----	69	64	57	39	60

PART V: SUMMARY AND CONCLUSIONS

Recovery Plan Objectives

The general steps stipulated in the Recovery Plan to accomplish the population recovery objectives for the interior least tern are:

1) Determine current distribution and population trends;
2) Determine current habitat requirements and status, including quantifying and evaluation of available breeding habitat and the previous extent of habitat and vegetation changes;
3) Preserve and enhance habitat;
4) Develop and implement educational programs about the least tern; and
5) Coordinate recovery efforts.

Habitat and Population Investigations

Recovery Plan objectives 1-2 have been generally satisfied by past and current study efforts. The Corps of Engineers and the States of Missouri and Mississippi have conducted extensive studies and investigations to fulfill the recovery plan objectives. Current least tern distribution and population trends on the Middle and Lower Mississippi Rivers have been monitored with annual population censuses by the Corps of Engineers. The Missouri Department of Conservation has conducted population counts along the river bordering the State of Missouri. Current population trends are well established by these data.

The States of Mississippi and Missouri are collecting field data on least tern reproductive success and other population demographics at numerous locations along the Lower Mississippi River.

Habitat mapping of the LMR for ten-year time intervals from the 1940's to the present by the Corps of Engineers has documented temporal and spatial trends in sandbar habitat. Current sandbar habitat quantities and distribution have been mapped for the MMR. In addition, studies of temporal trends in woody vegetation dynamics on sandbars, fishery populations in diked sandbar habitats, and effects of river hydrology on sandbar habitat availability have been carried out by the Corps of Engineers.

Environmental Engineering Features

Recovery Plan Objective 3 has been met for the Mississippi River by the incorporation of environmental considerations and features into the Corps of Engineers' river engineering projects. For the past 25 years on the MMR and for the last 10 years on the LMR, the Corps has been actively incorporating environmental features into dike system design, partly to improve sandbar habitat for least terns. Weirs or notches, low-sections in a dike that pass water at low stages, are the main environmental design feature in use. Dike weirs limit predator access to sandbars that are connected to the bank by dike structures. Weirs are effective over a range of river stages, depending on the invert elevation (LWRP to LWRP+5 ft.).

In the MMR, environmental notches have been constructed in over 65 dikes. The purpose of the dike notches on the MMR is to decrease sedimentation and increase aquatic habitat diversity. These measures have proved to be generally successful (Smith and Stucky, 1988). In addition, dike systems with stepped-up longitudinal profiles and other environmental designs have been developed and constructed for habitat improvement purposes. Studies are also being conducted by the St. Louis District to assess effects of bendway weirs on sandbar habitat and to create high-elevation sandbars.

In the LMR, weirs have been included in the design of all new dikes since 1990, and weirs are made for existing dikes as part of routine maintenance and repair work (Tables 17-18). The bottom width of stone dike weirs varies from about 100 to 300 feet and invert elevations range from LWRP to LWRP+5 feet (Fig. 3b). The purposes of the weirs are to reduce sedimentation rates and related aquatic habitat loss and to maintain flowing-water conditions at low stages in secondary channels and to isolate sandbars from access by least tern predators, such as coyotes. An extensive monitoring program is underway to determine the effects of dike weirs on habitat variables and fish populations and to improve weir design.

Epibenthic invertebrates are an important fish food in the LMR and increasing their production could result in a greater food supply for the piscivorus least tern. Roughening of the surface of concrete blocks to increase colonization and production of epibenthic invertebrate organisms, e.g., caddisfly and midge larvae, has been included as a standard design feature of all LMR ACM revetments since 1994. This environmental design feature, developed through extensive biological and engineering field tests, does not add to construction costs. Grooved revetment is being used exclusively for bank stabilization along the LMR.

Avoid and Minimize Measures

Dike and revetment construction schedules are routinely modified to avoid disturbing least terns utilizing sandbars where work is to be carried out. Corps construction contracts have clauses that allow the government to delay a contractor's work until least terns have migrated from the area. Also, ACM revetment construction and dredging by Corps of Engineers hired-labor forces and floating plant are rescheduled as necessary to avoid disturbing least tern colonies at work sites.

Conclusions

An extensive amount of information has been collected on the interior population and habitat of the least tern along the Mississippi River. A fundamental understanding of the species and its habitat requirements and status can be inferred from the available data, although specifics of population demographics and behavior are not fully understood. Based on detailed analysis and evaluation of the copious body of best available scientific and commercial data presented herein, it is concluded that the Channel Improvement Project on the Lower Mississippi River and the Regulating Works Project on the Middle Mississippi River are not likely to adversely effect the interior population of the least tern, *Sterna antillarum*. This conclusion is supported by the following summary information:

1) The population goal set forth in the Recovery Plan for the interior population of the least tern on the Lower Mississippi River is that “current number of adult birds (2,200-2,500) will remain stable for the next ten years. This goal has been met and far surpassed. Least tern counts from annual censuses of the river were at or near this population goal from 1986 through 1999, and exceeded it by a factor of two to three from 1990 through 1999. The estimated number of least terns was over 6,500 in 1994, 1995, and 1999, nearly the goal of 7,000 set in the Recovery Plan for the entire United States.

2) Current estimates of least tern reproductive success along the Lower Mississippi River appear sufficient to maintain a stable population at or above the Recovery Plan goal of 2,200 to 2,500. Fledgling survival rates for several years and locations on the LMR averaged 0.8 fledglings/pair (ranged = 0.2 to 1.5). A survival rate of 0.5 is generally considered adequate to support least tern population levels. The fledgling survival rate, however, does not appear large enough to account for the large population increase in 1990.

3) Estimated low population numbers for the least tern on the Mississippi River when the species was listed as endangered in 1985 were evidently not a result of habitat loss or degradation, since non-vegetated sandbar habitat along the LMR was increasing in area and elevation from the mid-1960s through the late-1980s. The least tern, like most other long-lived colonial water birds, is adapted to patchy, dynamic environments characteristic of large alluvial streams such as the Mississippi River. Wide, cyclic fluctuations in population numbers with the capacity to rebound under favorable conditions, is a documented trait of colonial water birds like the least tern. Information presented herein suggests that annual hydrologic events resulting in large amounts of continuously emergent sandbar in some years are not directly coupled to

subsequent large population increases. Many other variables, however, are likely to affect population fluctuations on the Mississippi River, such as floods, survival on the wintering grounds in Central and South America, pesticide effects on reproduction, predation, and disease.

4) Adequate quantities of suitable sandbar habitat are present along the Middle and Lower Mississippi Rivers to support a stable least tern population of at least 2,200 to 2,500 birds. About 20,000 ac (100 ac/mi) were present in 1994 in the MMR between Cairo, Ill. and St. Louis, Mo. In 1988-89, over 115,000 acres (180 ac/mi) of bare sandbar habitat above the low water reference plane and 32,000 acres (50 ac/mi) above the LWRP+15 ft elevation were available to least terns along the LMR between Old River, La. and Cairo, Ill.

5) While untimely river stage fluctuations can adversely affect least tern reproductive success for given year, hydrologic variations are probably not a significant long term limiting factor on the Mississippi River. A minimum of 50 days is required for the least tern to reproduce (nesting to fledging). Hydrologic analyses showed that sandbar habitat lying above the LWRP+15 ft elevation (32,000 ac.) would be continuously emergent for 50 days or longer (mean = 75 days) during the least tern season (15 May to 31 August) in four to five years out of ten. The 17,000 acres of bare sandbar above elevation LWRP+20 ft will be continuously above water for 50 or more days (mean=85 days) six to seven years out of ten.

6) System-wide, non-vegetated sandbar habitat has increased slightly over the past 35 years. This upward trend occurred although extensive engineering works were constructed in the Mississippi River during this period. The Channel Improvement Project on the LMR is over 90 percent physically complete and the Regulating Works Project on the MMR is over 65 percent complete. Construction of dike systems may accelerate growth in height and overall size of associated sandbars, while sandbars within the design channel trace may be eroded as a result of channel realignment and deepening.

7) Available sandbar habitat on the Mississippi River is not utilized to capacity by the least tern. Long river segments (50 to 150 river miles) containing large quantities of bare sandbar habitat were uninhabited by the least tern during the 15 years of record, and many sandbars (30 to 60%) in reaches frequented by the least tern were not utilized in a given year. While not all sandbar habitat is of equal quality for least terns, the vast sandbar resource appears in excess of that required by this species, and habitat does not appear to be limiting reproductive success or survival of the species.

8) The Middle and Lower Mississippi Rivers are not, and will not, become completely stabilized river systems. Existing sandbars will continue to change vertically and laterally or be eroded away and new ones formed, although not to the degree that was found in the historic river. The river channel at mid-bank to bank-full discharges remains moderately dynamic, i.e., it is not completely controlled by dikes and revetments. The river will continue to make vertical adjustments in slope and channel morphology in response to local and long term system changes and hydrologic cycles and undergo limited meandering in reaches where riverbanks have not been stabilized. Alternating movement and storage of the large bed material load coupled with a wide range in stages will modify sandbar habitat annually, as sediments are alternatively transported and stored over the hydrograph.

9) It is improbable that higher elevation areas of sandbars and islands will become completely overgrown with black willows and other woody vegetation to the point that bare sandbar habitat will become limiting to least terns. The variable hydrograph and periodic floods will maintain significant vegetation-free areas on the high upstream sections of most sandbar and islands. These areas will be available to least terns during high-discharge years. Furthermore, willows do not thrive on LMR sandbars at elevations less that 10 to 20 feet above the low water reference plane, leaving the large quantity (32,000-55,000 acres) of bare sandbar below these elevations available, depending on river stage.

10) The development, testing, and deployment of environmental design features for Mississippi River dike and

revetment systems and the scheduling of construction and navigation channel dredging to avoid disturbance of least tern colonies will be continued by the Army Corps of Engineers. Environmental design measures for dike weirs are being incorporated into the Master Plan for the Channel Improvement Project on the LMR. These measures will result in conservation of existing sandbars habitat for least terns as well as aquatic habitat important to fisheries.

11) Annual least tern population censuses and system-wide monitoring and assessment of sandbar and other riverine habitats in the Mississippi River will be continued by the Army Corps of Engineers. These data will detect temporal trends in least tern populations and habitat.

Recommendations

The least tern is a wide-ranging species, reproducing in the United States and wintering in South and Central America. More specific information on population dynamics and limiting factors is needed to fully understand the status of the least tern. It is recommended, therefore, that the Department of Interior:

A) Fund and initiate investigations of least tern population ecology on the wintering grounds in Central and South America to better define the winter range and determine if impacts to the species there are affecting observed population trends in the United States.

B) Fund and initiate studies of intra-basin movements of the interior least tern and interchanges of least terns between interior and coastal Gulf of Mexico populations within the United States.

C) Fund and carry out a program to gather reliable demographic data and to develop reliable population models for the least tern.

Table 17. Stone dikes with environmental weirs, Memphis District reach, Lower Mississippi River, RM 600-954.

DIKE SYSTEM	YEAR	DIKE RIVER MILE	DIKE NO.	NOTCH ELEV. LWRP	NOTCH ELEV. LWRP	B.W. FEET
ISLAND 1	91	949.0L	1U	12,5,0	0	50
WOLF ISLAND BAR*	94	935.0L	2	18,10,25	0,2	250
MOORE ISLAND	92	929.0R	2	18,15,5	0	200
MOORE ISLAND	92	928.0R	3	18,15	4	100
MOORE ISLAND	92	927.1R	4	18,15,10,15	1	200
BELOW WILLIAMS	96	926.0L	1U	22,17	5	100
BELOW WILLIAMS	92	925.5L	1	20,17,15	5	100
ISLAND 7-8	91	915.5R	5	VARIABLE	0	400
DONALDSON POINT	91	903.7R	4.5	15,10	0	50
DONALDSON POINT	91	901.5R	6	10	0	50
DONALDSON POINT	95	900.6L	7	10	0	200
DONALDSON POINT	95	899.8L	8	10,0	-10	550
HOTCHKISS BEND	92	895.4R	1	10	4	200
HOTCHKISS BEND	**	894.6R	2	15,10	5	600
HOTCHKISS BEND	92	894.2R	3	VARIABLE	0	50
HOTCHKISS BEND	92	893.6R	4	10,5	0	70
SLOUGH LANDING	92	895.8L	3	5	0	100
SLOUGH LANDING	92	894.2L	4	5	0	50
SLOUGH LANDING	92	893.5L	5	5	0	50
KENTUCKY POINT	93	887.2L	2	20	10	400
NEW MADRID BEND	93	887.0R	1	15,0	0	300
ISLAND 11	91	880.2R	4	15,10	5	800
ISLAND 20	94	829.5R	5	24,21,15	13	200
HEAD OF ISLAND 21	93	828.5L	4	15,5	5	50
HEAD OF ISLAND 21	93	828.0L	5	25,15,0	5	50
HEAD OF ISLAND 21	93	827.4L	6	25,20,15,-3	8	100
HEAD OF ISLAND 21	93	826.6L	7	20,15	7	50
FORKED DEER***	96	797.7L	4	15,0	0,-3	100,30
KEYES POINT	94	788.1L	4.5	25,15,3	13	100
LOOKOUT	91	770.8R	2.5	17,12,15,5	5	"V"
LOOKOUT	91	769.5R	4	15	5	380
AB LOOSAHATCHIE	92	743.8L	1	15	0	150
AB LOOSAHATCHIE	92	743.0L	2	15,10,5	0	230
ISLAND 40	95	742.0R	****	25	5	150
HOPEFIELD POINT	92	736.9R	2U	12,-3	5	50
HOPEFIELD POINT	92	736.5R	1U	10,5	0	50
SEYPPEL	96	704.9R	4	15	7	250
PICKETT	96	703.6L	3	24.3,18.6	7	200
WALNUT BEND	96	681.2R	1	20	8	100
WALNUT BEND	96	681.5R	2	20	10	100
BELOW KNOWLTON	92	612.0R	5	"20,15"	5	50

* Dike 2 has two notches, one at 1400 feet and one at 3000 feet – Both are the same elevation and width.
** Nature made notch
***100' width is at “0" LWRP with a 50’ notch in the center of the 100' at -3 LWRP .
****Stone fill revetment, but has a notch.

Table 18. Stone dikes with environmental weirs, Vicksburg District reach, Lower Mississippi River, RM 320-600.

DIKE RIVER MILE	DIKE SYSTEM	DIKE NO.
601.8-L	Island 70	2
578.6-L	Below Prentiss	2D
563.9-R	Chicot Ldg.	5
563.6-R	Chicot Ldg.	6
535.3-L	Warfield Pt.,	1
528.3-L	Refuge, dike	1
517.8-R	Island 86, dike	4
498.2-R	Wilson Pt, dike	3
493.9-L	Baleshed Ldg.	2
493.1-L	Baleshed Ldg.,	3
492.3-L	Baleshed Ldg.	4
490.1-L	Baleshed Ldg.	6
452.6-L	Forest Home	6U
452.0-L	Forest Home,	5U
451.4-L	Forest Home	4U
450.8-L	Forest Home	3U
450.2-L	Forest Home	2U
449.7-L	Forest Home	1U
449.2-L	Forest Home,	1
448.6-L	Forest Home	2
448.1-L	Forest Home	3
432.8-R	Racetrack Towhead	2U
432.3-R	Racetrack Towhead	1U
431.6-R	Racetrack Towhead	1
430.8-R	Racetrack Towhead	2
430.2-R	Racetrack Towhead	3
428.5-L	Below Racetrack	6
427.9-L	Below Racetrack	7
427.4-L	Below Racetrack	8
427.0-L	Below Racetrack	9
424.0-L	Diamond Cut-Off	3
423.3-L	Diamond Cut-Off	2
402.6-R	Coffee Pt., dike	4
401.8-R	Coffee Pt., dike	5
394.0-R	Bondurant T.H.	2
385.2-L	Spithead T.H.	3
384.4-L	Spithead T.H.	4
366.6-R	Fritz Island	3
350.5-L	Opposite Warnicott	3
349.6-L	Opposite Warnicott	4
347.8-L	Opposite Esperance Pt.	1
346.8-L	Opposite Esperance Pt.	3
347.6-R	Esperance Pt.	2
346.7-R	Esperance Pt.	3
346.0-R	Esperance Pt.	4
338.8-L	Buck Island	3
338.5-L	Buck Island	4

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