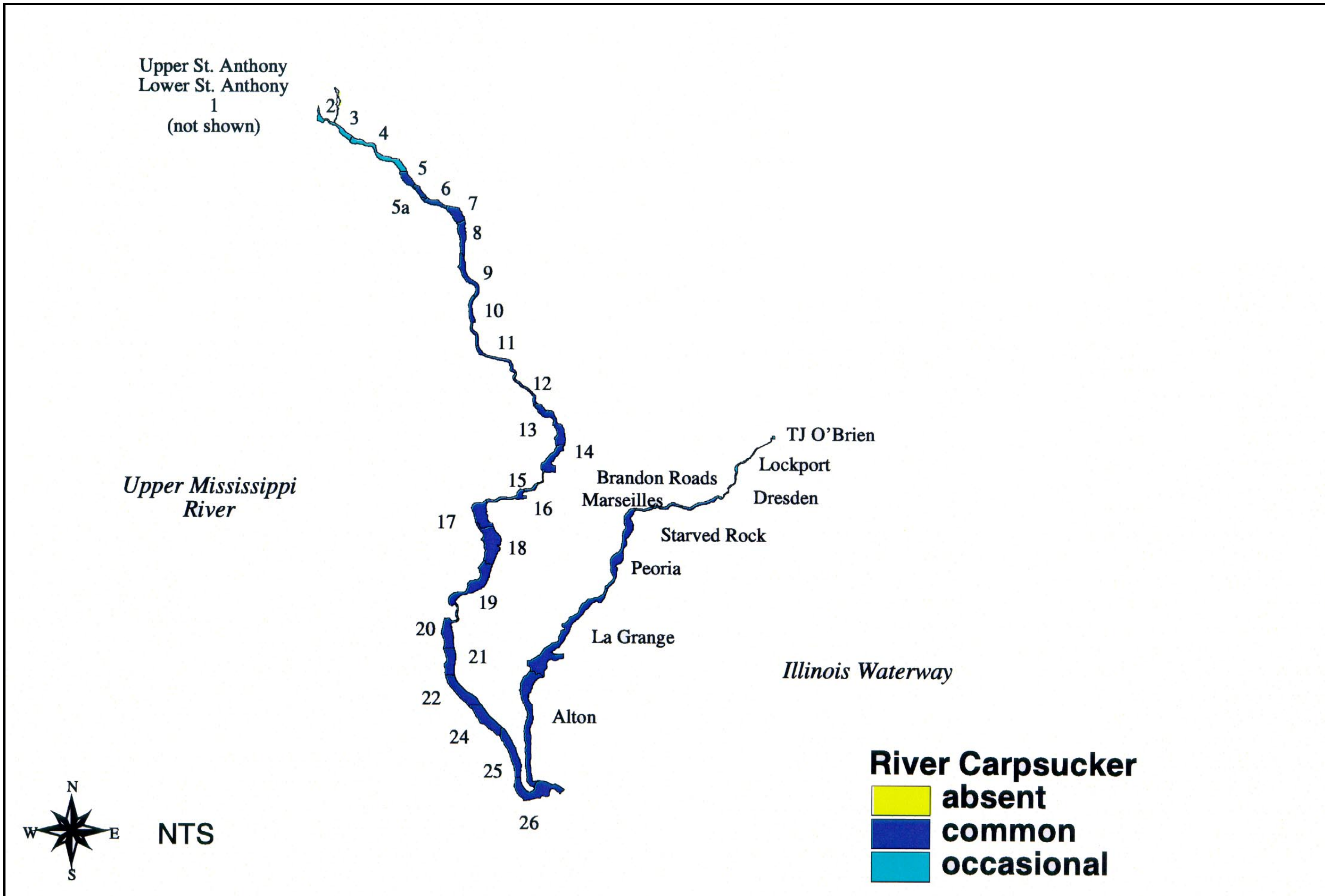


Figure 17. Distribution and abundance of river carpsucker in the Upper Mississippi River and the Illinois Waterway

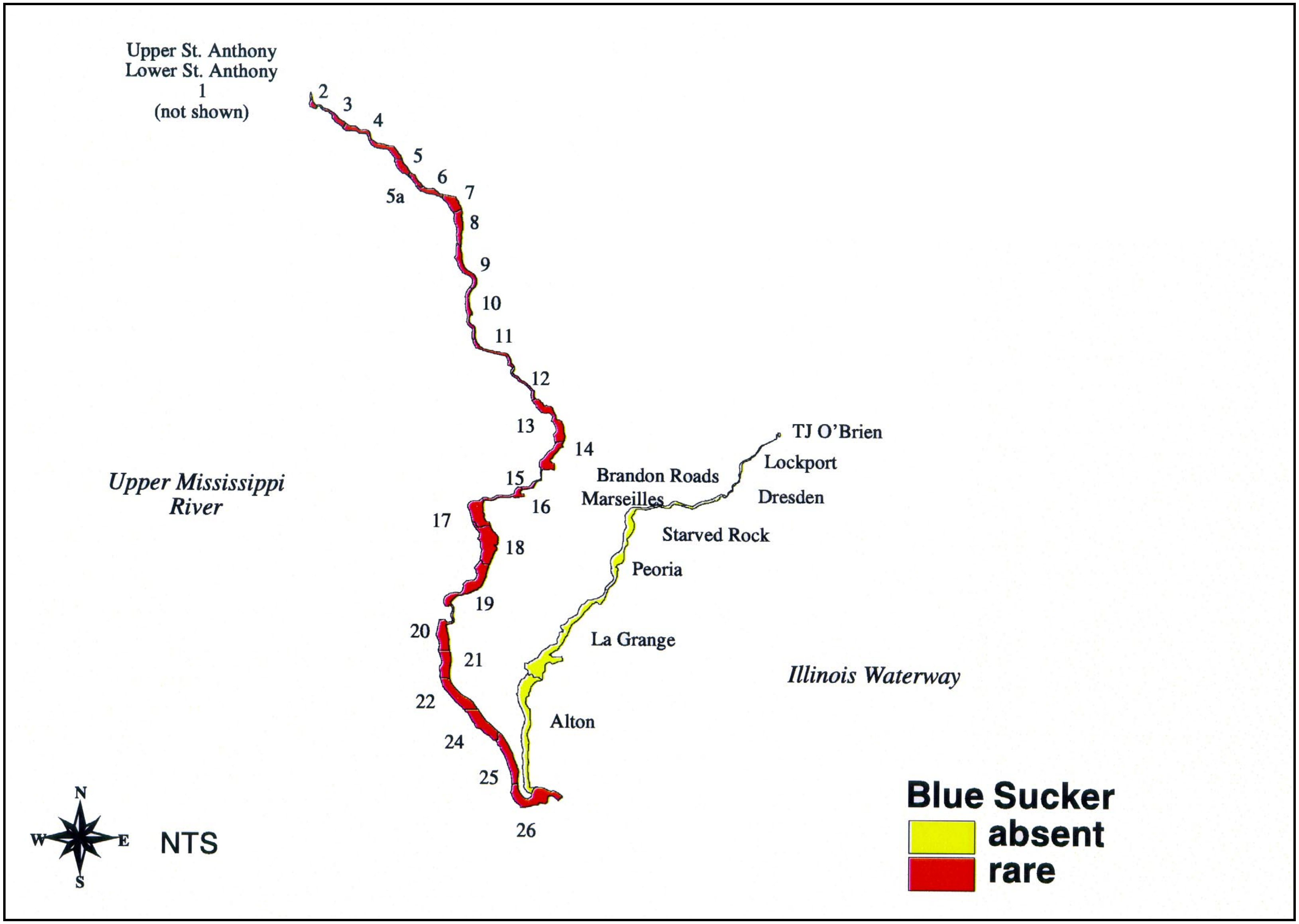


Figure 18. Distribution and abundance of blue sucker in the Upper Mississippi River and the Illinois Waterway

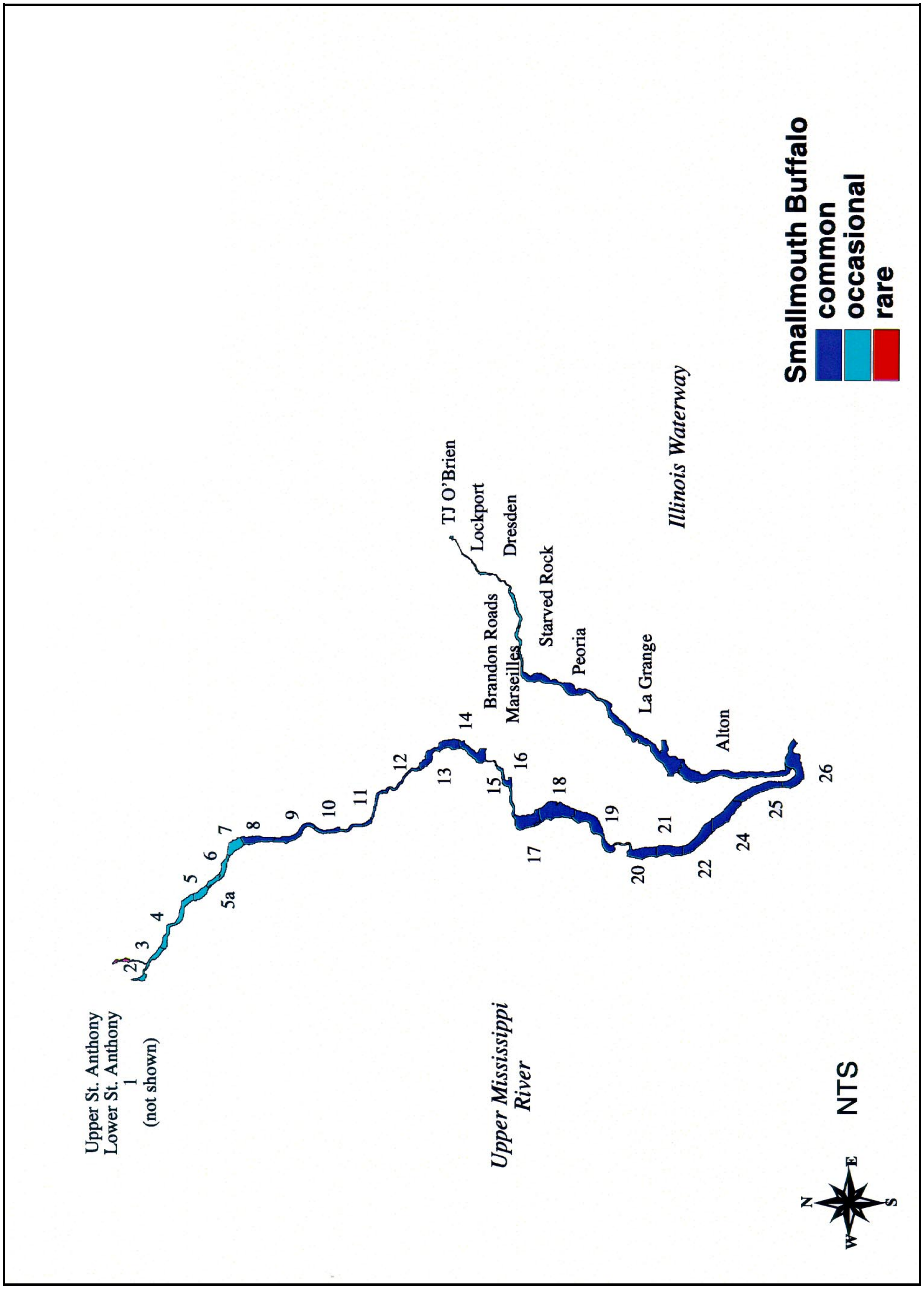


Figure 19. Distribution and abundance of smallmouth buffalo in the Upper Mississippi River and the Illinois Waterway

flooded meadows (Becker 1983; Littlejohn et al. 1985; Holland-Bartels et al. 1990b; Etnier and Starnes 1993). Larvae are common in backwater habitats of the UMR and occur consistently in the main channel drift with peak densities in late May (Holland-Bartels et al. 1990b; Gutreuter, Dettmers, and Wahl 1998) (Figure 2).

Bigmouth buffalo inhabit pools of large streams, lowland lakes, and impoundments, but they occasionally enter small creeks to spawn (Holland-Bartels et al. 1990b). This species is more tolerant of turbidity than other species of *Ictiobus* and inhabits deep, slow, sluggish, or still waters of large rivers and reservoirs such as those found in the UMR (Holland-Bartels et al. 1990b). Bigmouth buffalo often congregate in schools at midwater or near the bottom (Pflieger 1997); they commonly occur in the majority of the UMR-IWW System (Figure 20). Bigmouth buffalo migrate to small streams to spawn on riprap in quiet backwaters, shallow water, over sand or gravel bottoms, or on aquatic vegetation, and spawn from April to May (Holland-Bartels et al. 1990b). Larvae occur in backwater habitats of the UMR and are often in the main channel drift (Figure 2), with peak densities occurring in late May (Holland-Bartels et al. 1990b; Gutreuter, Dettmers, and Wahl 1998).

Spotted suckers prefer clear, warm waters with no noticeable current, abundant aquatic vegetation, and a soft substrate with large amounts of organic debris (Holland-Bartels et al. 1990b; Etnier and Starnes 1993). They are intolerant of turbid water and industrial pollution (Carlander 1969). In the UMR, they are commonly to occasionally found in the upper pools and are rarely found in the lower pools; in addition, they rarely occur in the IWW (Figure 21). Spotted suckers spawn in riffle areas over rubble bottoms, habitat often found in main channel border areas, during April and May (Carlander 1969; Littlejohn et al. 1985; Pflieger 1997).

Shorthead redhorse occur in pools with no noticeable current as well as in moderately large rivers having gravel or rocky bottoms and a permanent, strong flow (Scott and Crossman 1973; Holland-Bartels et al. 1990b; Etnier and Starnes 1993); their general habitat is listed as main channel in Littlejohn et al. (1985) (Figure 4). This species is common in all pools of the UMR and occurs occasionally in pools of the IWW (Figure 22). Shorthead redhorse spawn in April and May in small rivers or streams in shallow riffles or over gravel, sand, stones, or rubble, habitats commonly found in main channel border areas (Burr and Morris 1977; Becker 1983; Littlejohn et al. 1985; Pflieger 1997). Larvae of shorthead redhorse are usually associated with vegetation in backwater areas of the UMR (Holland-Bartels et al. 1990b).

### Catfishes

The catfish family Ictaluridae consists of 39 species, all restricted to North America (Pflieger 1997). Catfishes spawn in natural cavities, in excavated nests, or in hollow objects; one or both parents (usually the male) remain with the eggs until they hatch and guard the fry until they leave the nest (Holland-Bartels et al. 1990b). After the young have completely absorbed the yolk sac, they are

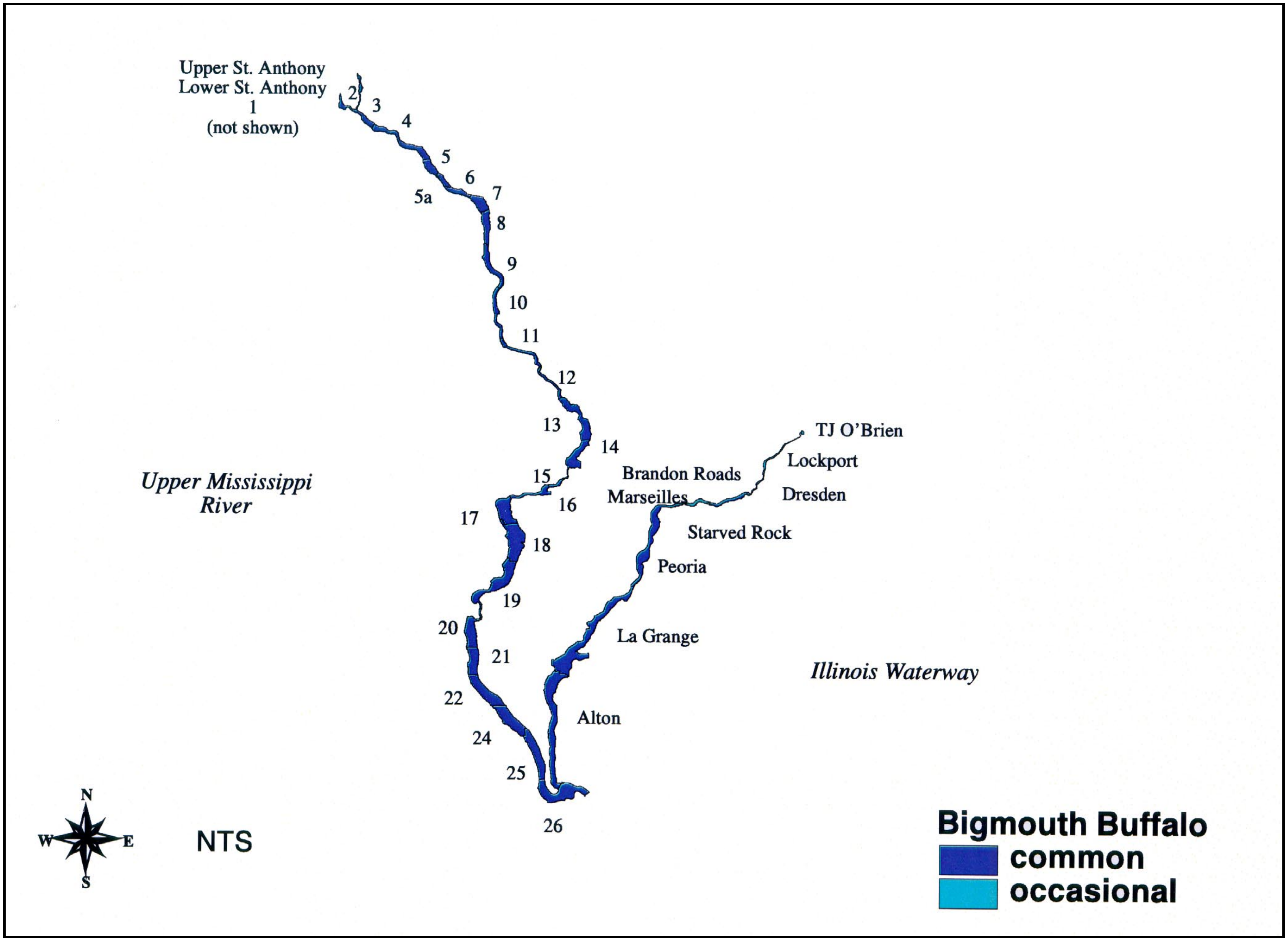


Figure 20. Distribution and abundance of bigmouth buffalo in the Upper Mississippi River and the Illinois Waterway

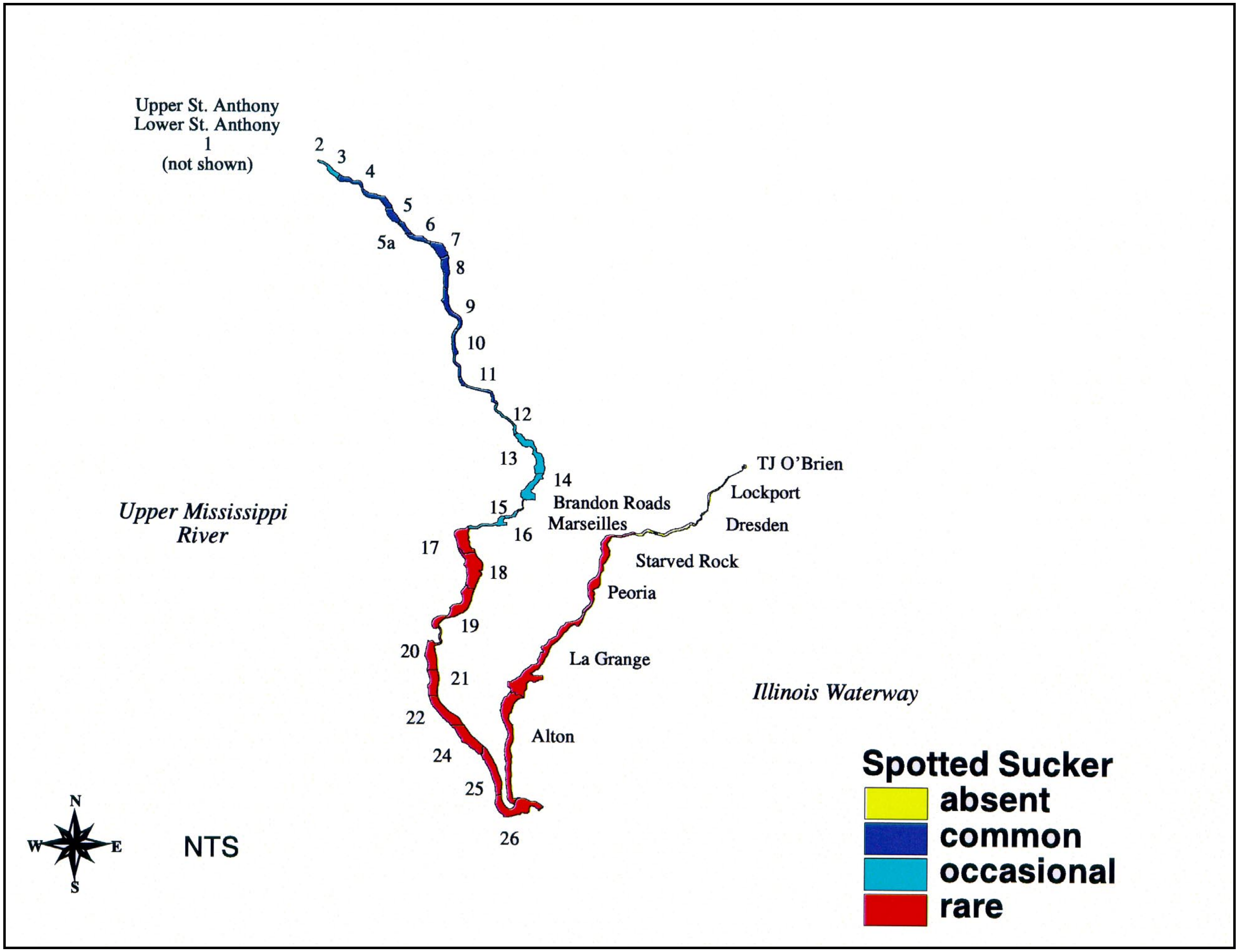


Figure 21. Distribution and abundance of spotted sucker in the Upper Mississippi River and the Illinois Waterway

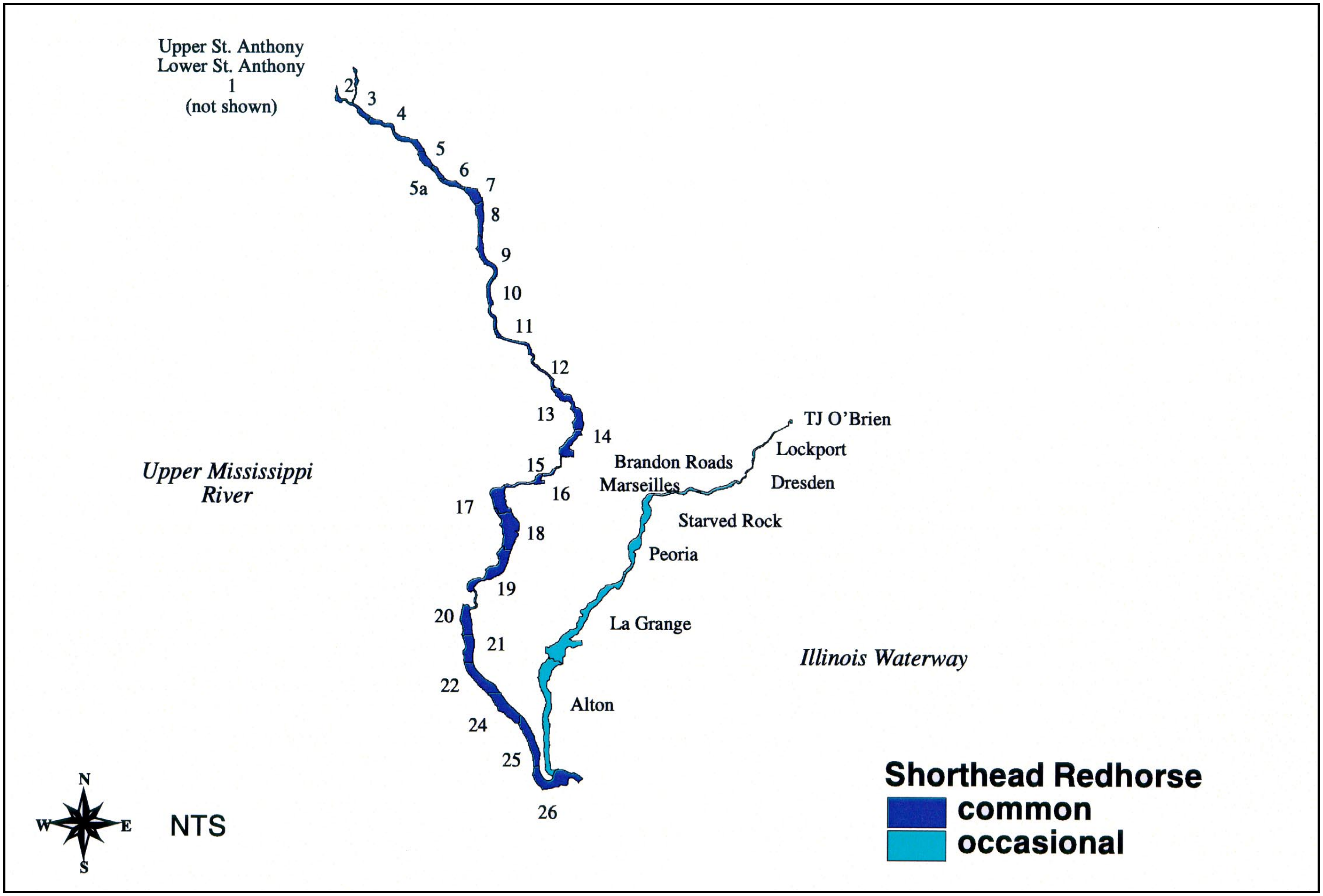


Figure 22. Distribution and abundance of shorthead redhorse in the Upper Mississippi River and the Illinois Waterway

considered to be juveniles and are sometimes called alevins (Holland-Bartels et al. 1990b). Catfishes are most active at night and are secretive during the day (Pflieger 1997). Channel catfish, blue catfish, and flathead catfish were selected for this ecological risk assessment.

Channel catfish are omnivores and are commonly found throughout the UMR-IWW System (Figure 23). Littlejohn et al. (1985) list their general habitat as the main channel (Figure 4). They frequent channels of large rivers in areas with currents that vary from none to swift (Miller 1966). In the UMR-IWW System, they seek cover during the day on or near the bottom in cool, deep waters and are most active in shallow sloughs and along river shores at dusk and dawn (Farabee 1979). Channel catfish nests are made on the bottom in mud or under rock ledges in protected or weedy areas; they spawn from May to July (Holland-Bartels et al. 1990b; Etnier and Starnes 1993; Pflieger 1997). Yolk-sac larvae are rarely collected in main channel drift samples; however, alevins are abundant in the main channel trawl catches and are most commonly collected at night (Holland-Bartels et al. 1990b).

Blue catfish are absent in the upper pools of the UMR and the IWW but are commonly to occasionally found in the lower pools of the UMR (Figure 24). This catfish has nearly disappeared from the Mississippi drainage upstream from the mouth of the Missouri River (Pflieger 1997). The blue catfish is a big river fish; it seldom achieves the high population densities of the channel catfish and is less abundant at most localities than the flathead catfish (Pflieger 1997). The life history of the blue catfish is similar to that of the channel catfish. Blue catfish are found in main channels, along banks and sandbars, and in pools and sloughs; they are uncommon in oxbow and floodplain areas (Baker et al. 1991; Rohde et al. 1994). They are omnivores and prefer deep water, firm substrates, and considerable current (Etnier and Starnes 1993; Rohde et al. 1994). Blue catfish spawn from May through June and nest under logs or undercut river banks (Etnier and Starnes 1993; Rohde et al. 1994).

Flathead catfish are piscivorous and inhabit a variety of streams but avoid those with high gradients or intermittent flows (Littlejohn et al. 1985; Holland-Bartels et al. 1990b). The flathead catfish is a solitary species; adults occur in pools near logs, piles of drift, or other cover, and the young live among rocks in riffle areas and are most active at night (Pflieger 1997). Flathead catfish are common throughout most of the UMR-IWW System (Figure 25). Flathead catfish spawn in June and July, building nests or shallow depressions near submerged objects, in secluded shelters, or in dark areas; males guard the nest and young (Holland-Bartels et al. 1990b).

### Temperate basses

The temperate basses are primarily marine in distribution, but a few species occur in fresh water (Pflieger 1997). White bass is the representative of this family (Moronidae) selected for the ecological risk assessment. They prefer open waters of lakes and reservoirs or rivers with moderate current (Becker 1983) and are often found in the main channel of the Mississippi River (Littlejohn et al.

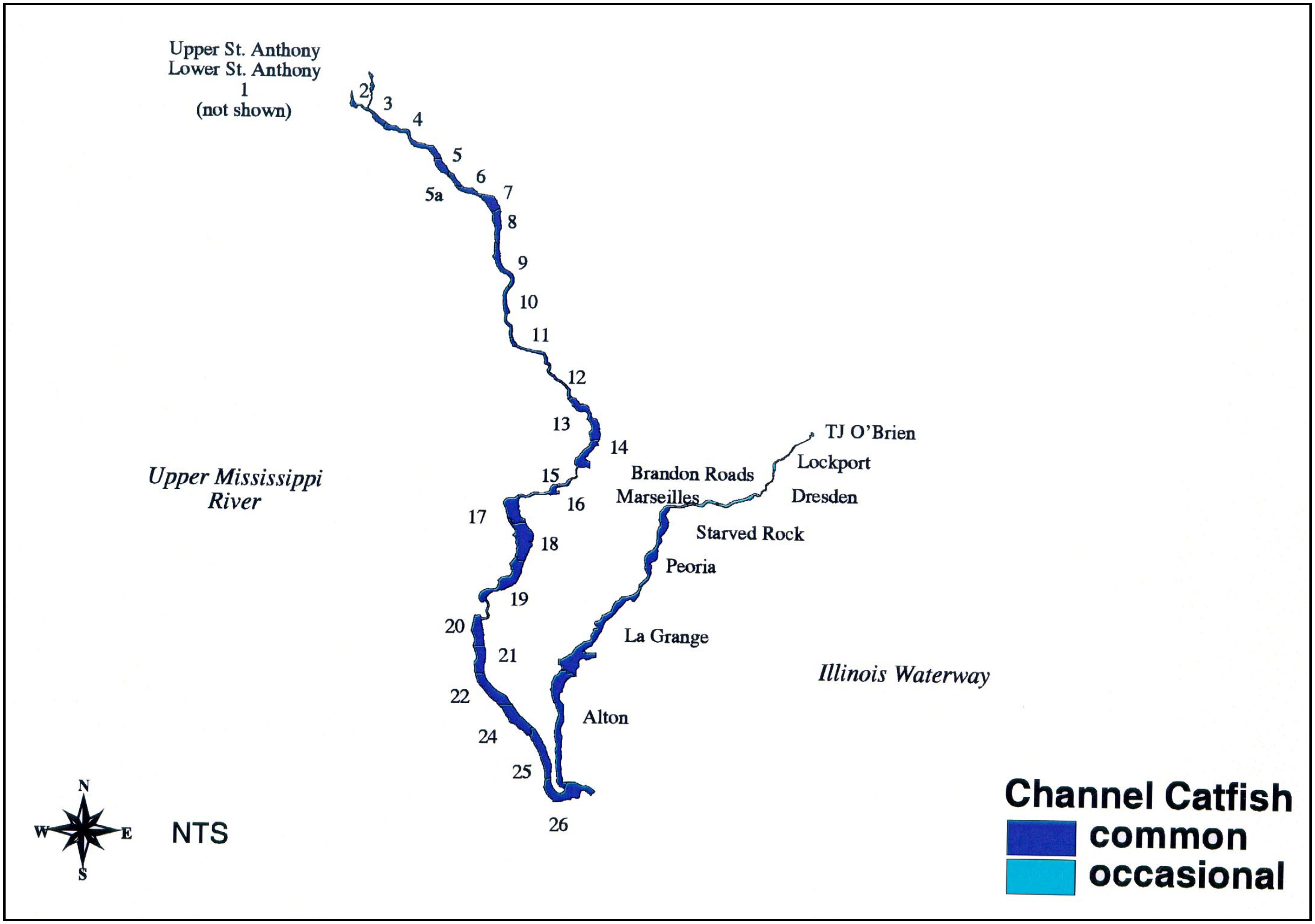


Figure 23. Distribution and abundance of channel catfish in the Upper Mississippi River and the Illinois Waterway

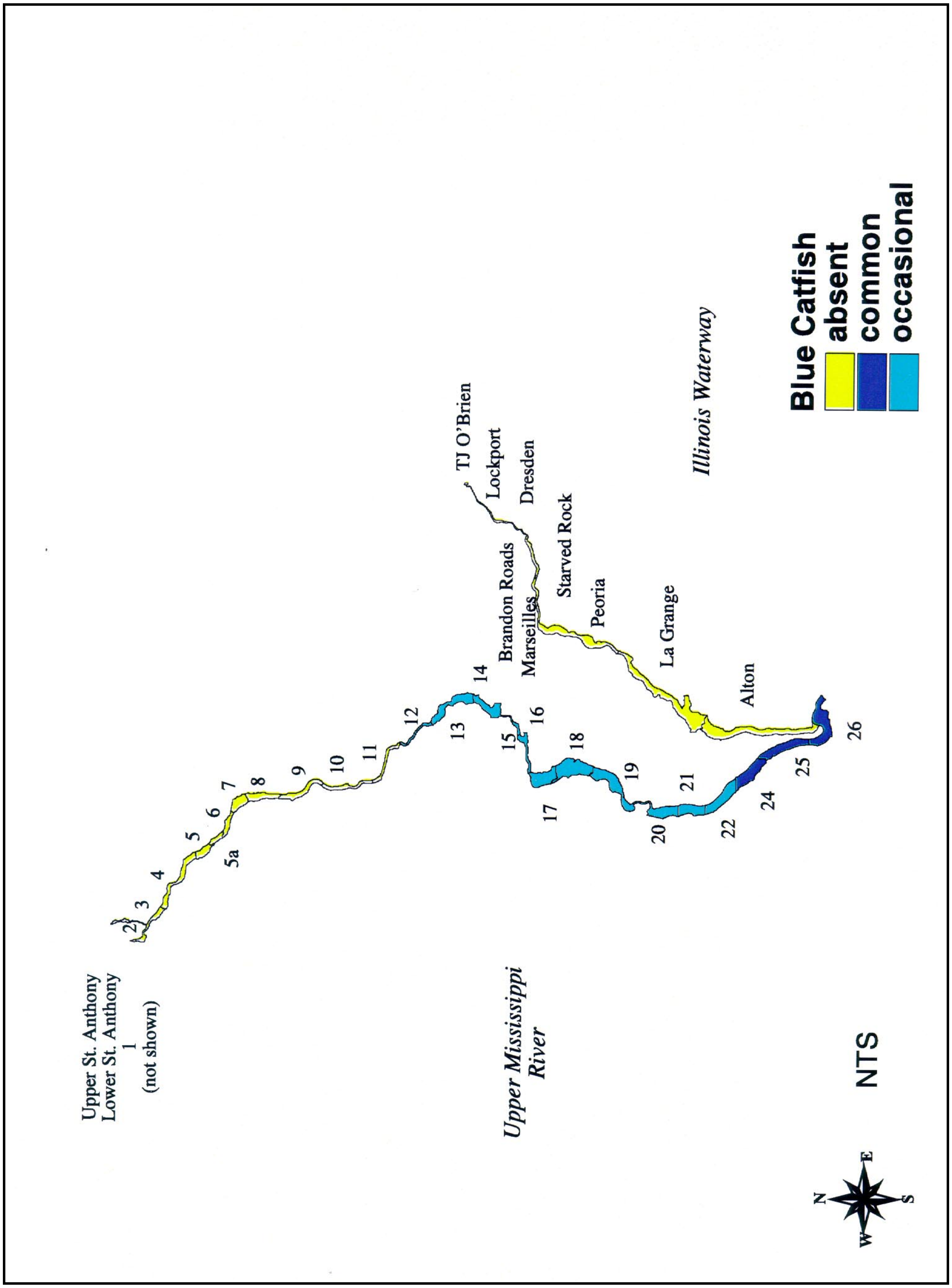


Figure 24. Distribution and abundance of blue catfish in the Upper Mississippi River and the Illinois Waterway

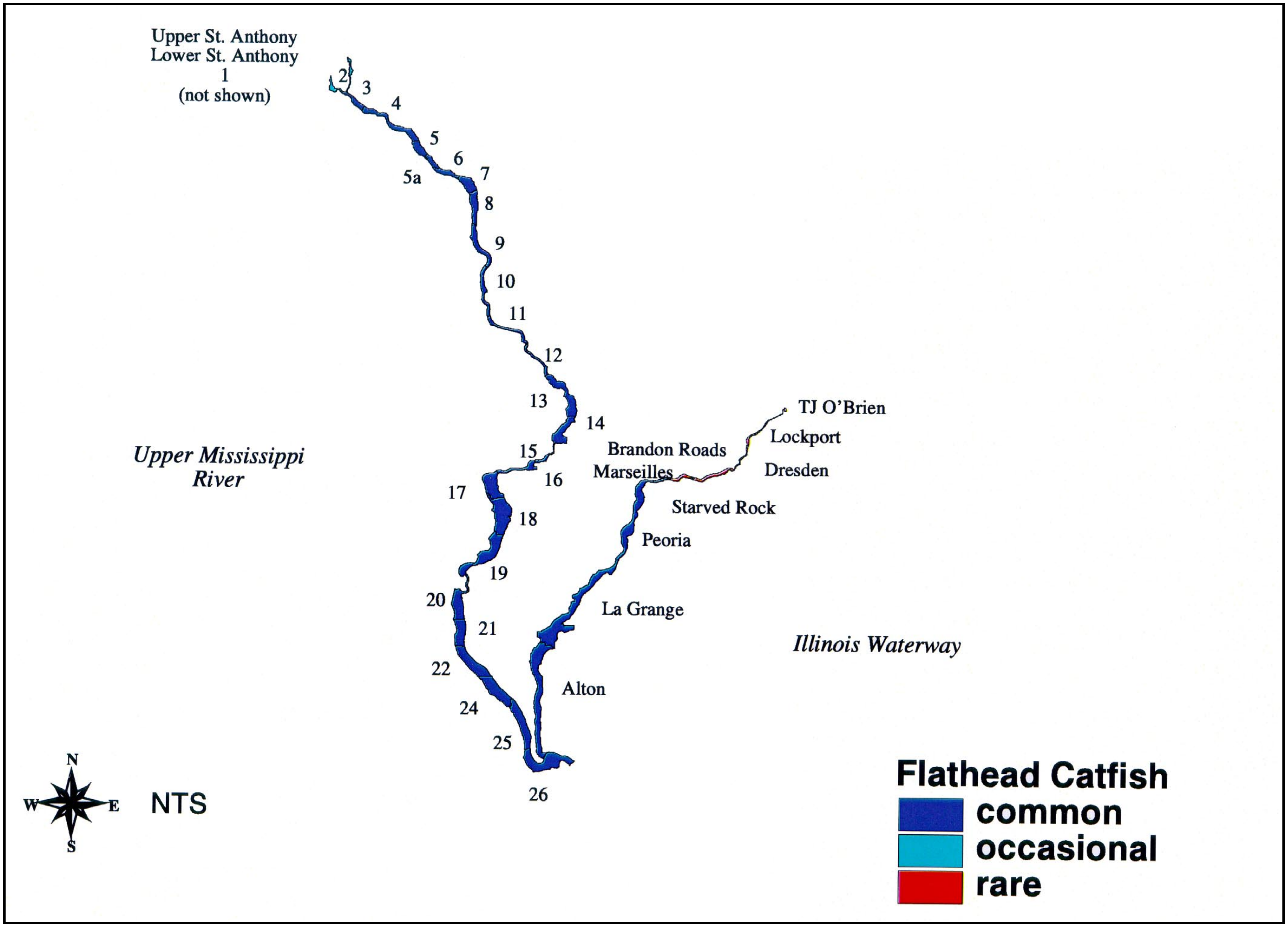


Figure 25. Distribution and abundance of flathead catfish in the Upper Mississippi River and the Illinois Waterway

1985; Holland-Bartels et al. 1990b). White bass are omnivores, travel in large schools, and feed at the surface (Scott and Crossman 1973). They are common throughout most of the UMR-IWW System (Figure 26).

White bass spawn from late April to early June in flowing waters of tributary streams or shallow, shoreward areas with some current; they require a firm bottom of gravel, sand, or rubble (Holland-Bartels et al. 1990b). Due to the abundance of adult white bass and the scarcity of yellow bass (*Morone mississippiensis*), most small *Morone* collected are assumed to be white bass; *Morone* spp. are sometimes predominant in the main channel drift in late May and are often abundant in areas that receive flow from flooded woodlands (Holland-Bartels et al. 1990b; Gutreuter, Dettmers, and Wahl 1998). Juveniles inhabit main channel areas almost exclusively and move into main channel border areas at night, presumably from open water (Scott and Crossman 1973; Smith 1979; Becker 1983; Holland-Bartels et al. 1990b) (Figure 3).

### Sunfishes

The sunfish family (Centrarchidae) is a North American family containing 29 species that are sometimes divided into three groups: sunfishes, crappies, and black basses (Etnier and Starnes 1993; Pflieger 1997). One sunfish, two crappies, and two black basses, which have known distributions in the UMR-IWW System, were selected for this risk assessment: bluegill, white crappie, black crappie, smallmouth bass, and largemouth bass. All five species are important to the recreational fishery. Most centrarchids are sedentary fish, remaining much of the time near submerged cover or hovering quietly in the shade of a tree or other object hanging over the water; all species construct a nest (Pflieger 1997). Identification of larvae has been primarily to genus because of difficulty in consistent identification to species without extensive effort, particularly in *Lepomis* and *Pomoxis* spp. (Holland-Bartels et al. 1990b). All genera are much more abundant in backwater areas or border areas than in the main channel; however, centrarchid larvae regularly make up a small part (4 percent) of the main channel drift (Holland et al. 1984; Holland-Bartels et al. 1990b; Gutreuter, Dettmers, and Wahl 1998).

Bluegill are abundant in most of the UMR-IWW System (Figure 27). The bluegill is a schooling species found in lakes, ponds, reservoirs, and streams (Holland-Bartels et al. 1990b). It is common in all habitats, including deep and shallow waters, but it is most abundant in shallow, slow-moving waters (Rasmussen 1979; Farabee 1979). Bluegill are omnivores (Littlejohn et al. 1985). They build nests in the shallows of lentic habitats near shore on sand or gravel (Becker 1983). Spawning occurs in May to early July in the UMR (Carlander 1977; Becker 1983; Holland-Bartels et al. 1990b). Male bluegill clear the nest, defend the nest, and guard the young (Littlejohn et al. 1985). Larvae stay closely associated with the nest bottom until after yolk absorption, then remain in the littoral zone through at least the juvenile stage. Larvae of *Lepomis* (probably mostly bluegills) are abundant in backwater habitats and occur regularly in the main channel ichthyoplankton drift (Figure 2); densities in both backwater and main channel collections peak in late June (Holland-Bartels et al.

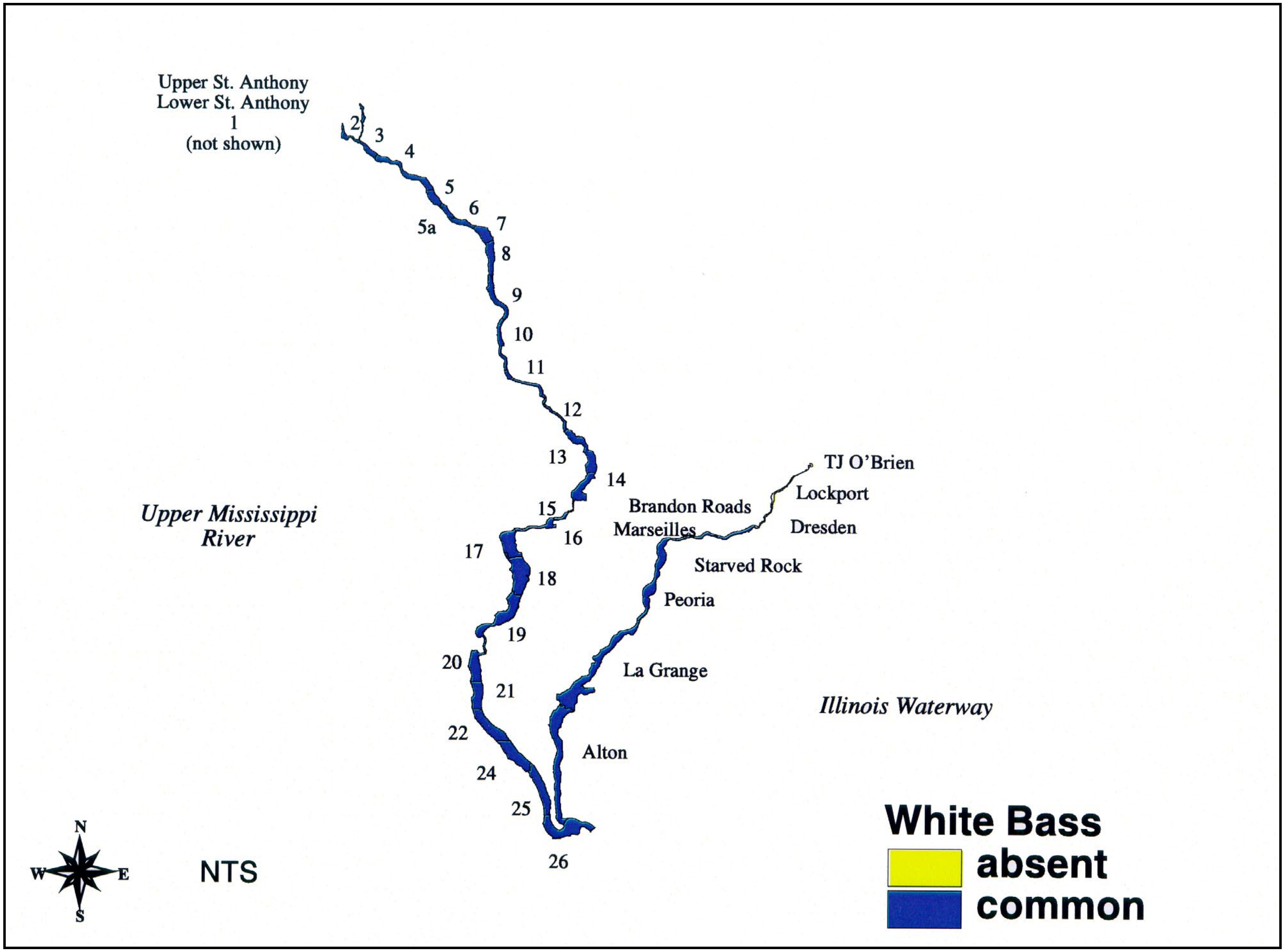


Figure 26. Distribution and abundance of white bass in the Upper Mississippi River and the Illinois Waterway

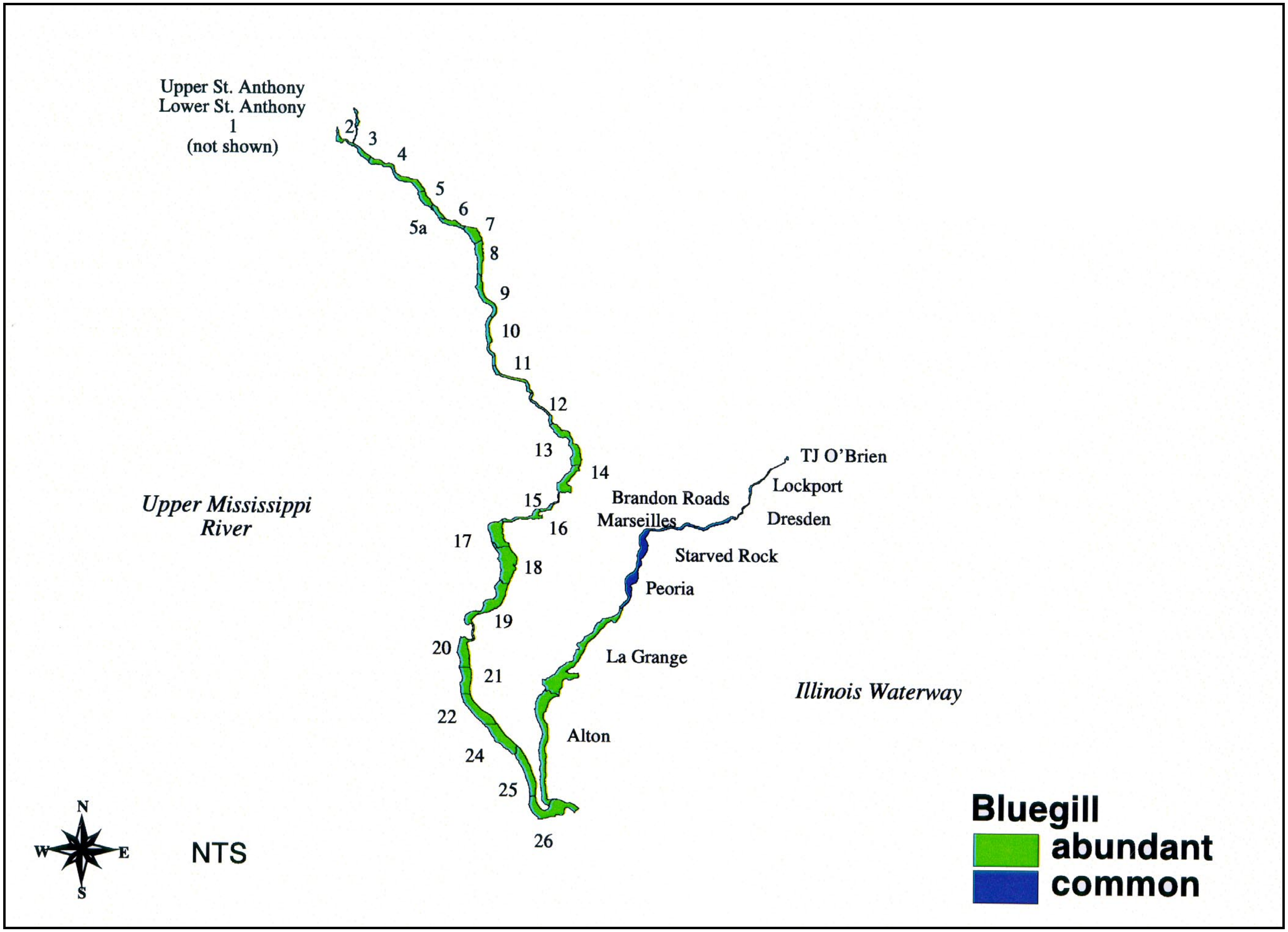


Figure 27. Distribution and abundance of bluegill in the Upper Mississippi River and the Illinois Waterway

1990b). Young of the year are closely associated with submergent vegetation in backwaters in the UMR (Holland and Huston 1985) (Figure 3).

White crappie are omnivores and occur in all habitat types of the UMR but prefer deep, quiet waters (Farabee 1979; Littlejohn et al. 1985). They are common in most pools of the UMR-IWW System (Figure 28). White crappie do not school but congregate in loose aggregations in suitable cover (Holland-Bartels et al. 1990b; Pflieger 1997). They are usually found in silted streams, slow-moving areas of rivers, and impoundments; they avoid areas of excessive turbidity and continuously cool water (Scott and Crossman 1973). White crappie spawn in May and June (Rasmussen 1979) in ponds, lakes, and reservoirs, in deeper water than other centrarchids, over clay, mud, sand, gravel, rocks, or on aquatic vegetation (Becker 1983; Holland-Bartels et al. 1990b). The male selects the spawning area and guards the young (Littlejohn et al. 1985). Larvae occur in ichthyoplankton drift collections in early to mid-May, are most abundant in backwaters, and demonstrate a significant drift into the main channel at dusk (Holland and Sylvester 1983) (Figure 2).

Black crappie are common throughout the majority of the UMR-IWW System (Figure 29). They are found less often than white crappie in turbid environments (Scott and Crossman 1973). Black crappie usually form moderately large schools in association with abundant growths of vegetation over sand to muck bottoms (Holland-Bartels et al. 1990b). They spawn in vegetated areas or in the protection of undercut banks; their nests are constructed in sand, gravel, or mud on bottoms that are softer and muddier than those used by other centrarchids (Scott and Crossman 1973; Eddy and Underhill 1974). Spawning occurs in May and June (Becker 1983; Holland-Bartels et al. 1990b). The male clears the nest, defends the nest, and guards the young (Littlejohn et al. 1985). Larvae occur in ichthyoplankton drift collections in the UMR in May (Holland-Bartels et al. 1990b); they are most abundant in backwaters but tend to drift into the main channel at dusk (Holland and Sylvester 1983) (Figure 2).

Smallmouth bass prefer habitats with rocks and submerged logs, such as areas near wing dams and riprap in the UMR-IWW System; they have less affinity for vegetation than the largemouth bass (Scott and Crossman 1973; Farabee 1979; Etnier and Starnes 1993). It exhibits little tolerance for siltation and turbidity (Pflieger 1997). In the UMR-IWW System, smallmouth bass are common in most pools (Figure 30). Smallmouth bass are piscivores (Littlejohn et al. 1985), and during the day may be observed almost motionless near submerged cover or cruising around their home territory (Pflieger 1997). Male smallmouth bass clear the nest, defend the nest, and guard the young (Littlejohn et al. 1985). Smallmouth bass spawn in sheltered areas with current over clean gravel and sand in May and June (Eddy and Underhill 1974; Farabee 1979; Smith 1979; Becker 1983). Fry leave the nest as a school 6 to 15 days after hatching and are guarded by the male for a few days (Farabee 1979). Larvae are rarely collected in the main channel or associated backwaters of the UMR (Holland-Bartels et al. 1990b).

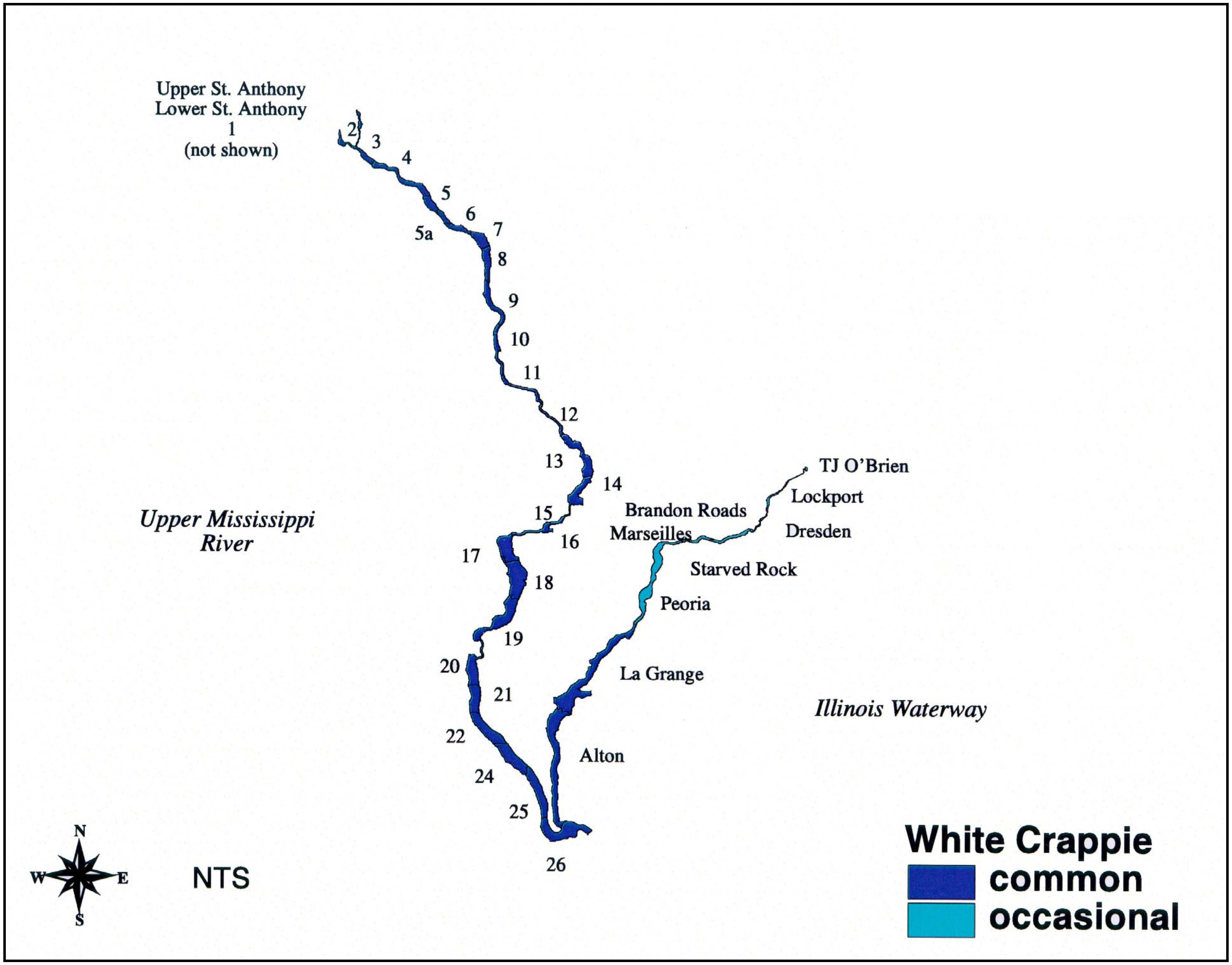


Figure 28. Distribution and abundance of white crappie in the Upper Mississippi River and the Illinois Waterway

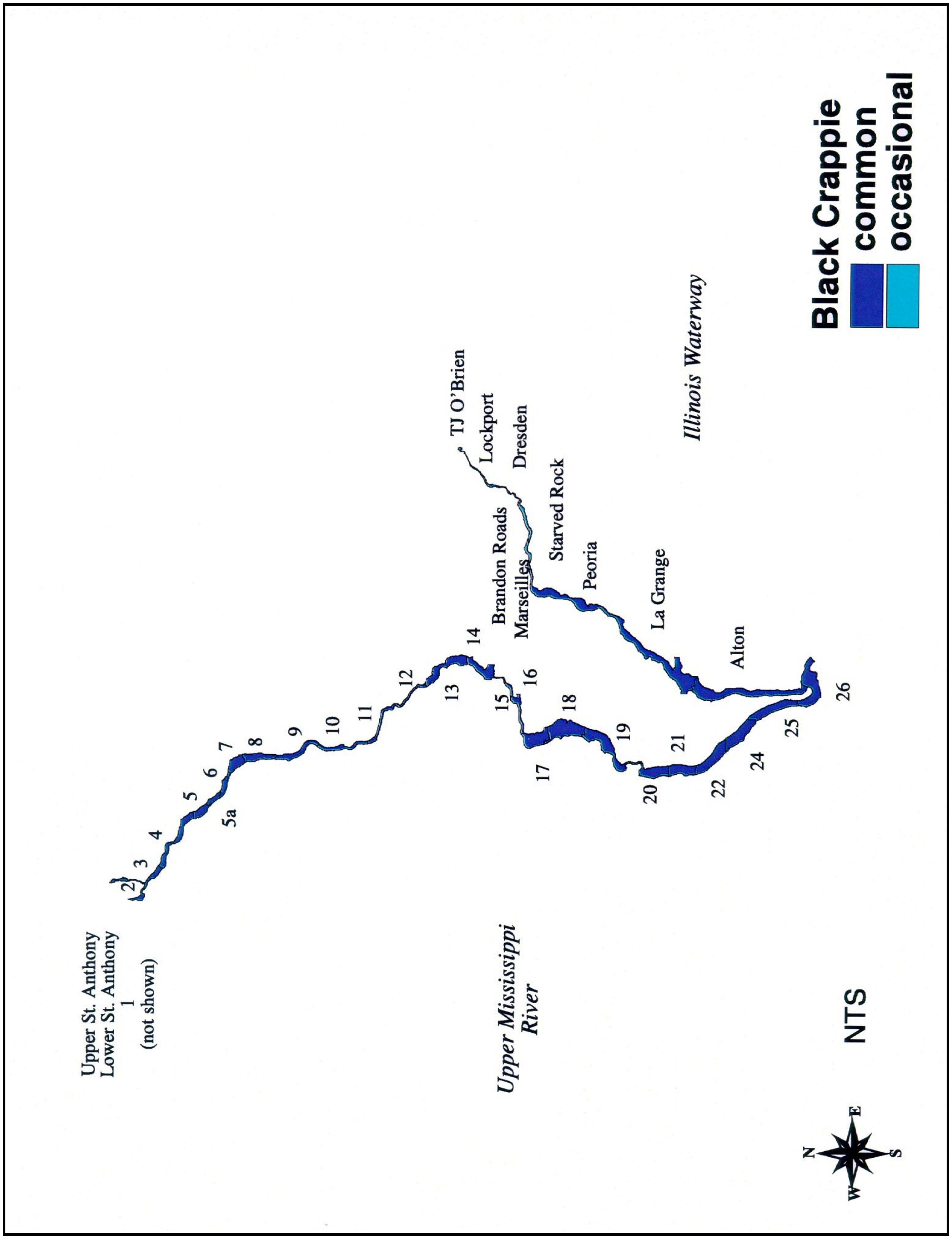


Figure 29. Distribution and abundance of black crappie in the Upper Mississippi River and the Illinois Waterway

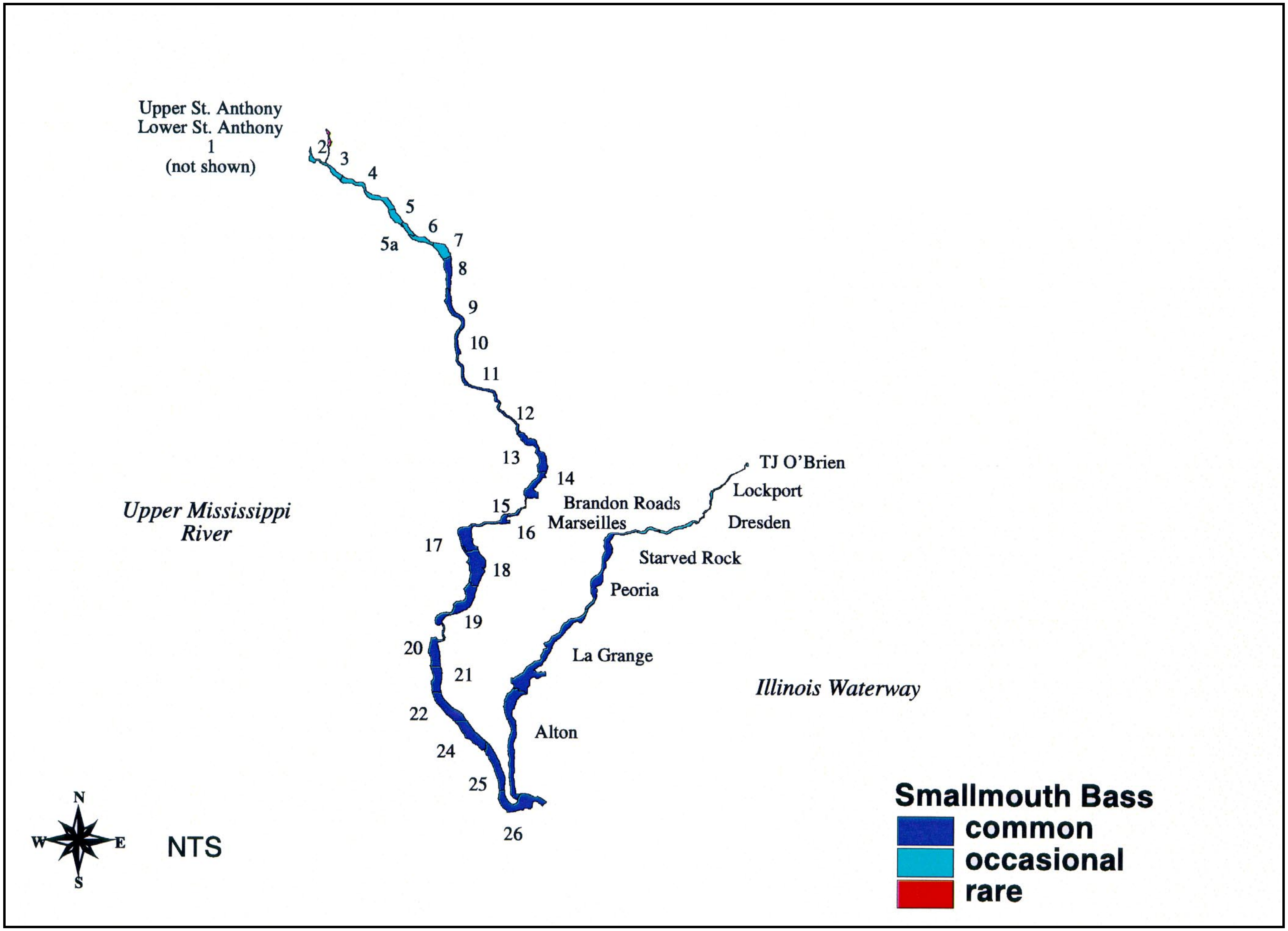


Figure 30. Distribution and abundance of smallmouth bass in the Upper Mississippi River and the Illinois Waterway

Largemouth bass are piscivores (Littlejohn et al. 1985). They are characteristic of natural lowland lakes, man-made impoundments, permanent pools of small streams with low or intermittent flow, and quiet backwaters of large rivers (Carlander 1977; Holland-Bartels et al. 1990b). Largemouth bass are intolerant of excessive turbidity and siltation and thrive in warm, moderately clear water with no noticeable current; they are replaced by one of the other black basses in streams with continuous strong flow (Pflieger 1997). They are frequently associated with soft bottoms, stumps, and extensive growths of emergent and submergent vegetation but can be found in most UMR-IWW System habitat types (Scott and Crossman 1973; Farabee 1979). Largemouth bass are common throughout most of the UMR-IWW System (Figure 31). Male largemouth bass clear the nest, defend the nest, and guard the young (Littlejohn et al. 1985); the male largemouth is a more attentive parent than any of the other sunfishes (Pflieger 1997). Largemouth bass build nests in shallow, quiet water in emergent vegetation on sand, gravel, or marl; they spawn from April through July (Becker 1983; Holland-Bartels et al. 1990b). Larvae remain in the nest until the yolk is absorbed and then form a school that is guarded by the male. In many areas of the UMR, larvae and juveniles are specifically associated with dense beds of submerged vegetation (Holland-Bartels et al. 1990b).

### Perches

The perch family (Family Percidae) is one of the largest groups of North American freshwater fishes, including more than 150 named species (Pflieger 1997). Eighteen species of perches are found in the UMR-IWW System. Two piscivorous species that are important to the recreational fishery were selected for this risk assessment: sauger and walleye.

Sauger are common throughout the majority of the UMR-IWW System (Figure 32). Sauger prefer large, turbid, slow-flowing rivers or shallow, turbid lakes. In the UMR, they live in the shallow, more turbid, littoral zones (i.e., main channel borders) (Scott and Crossman 1973; Holland-Bartels et al. 1990b) (Figure 4). They are the most numerous game fish collected from wing dam habitats and are also common in tailwaters (Pitlo 1981). The sauger grows more slowly and does not grow as large as the walleye (Pflieger 1997). Sauger spawn in April or May over shallow shoals or bars in main channel border areas or mussel beds or over rock or gravel substrates (Scott and Crossman 1973; Holland-Bartels et al. 1990b). The photophobic larvae spend much of the time scattered among bottom materials and are rarely collected with standard tow nets (Holland-Bartels et al. 1990b). Young sauger represent a minor component of the total ichthyoplankton drift in the UMR and never exceed 3 percent of the catch, even during their peak densities in early May (Holland 1985; Gutreuter, Dettmers, and Wahl 1998). Juvenile sauger have occasionally been collected on shallow mud flat areas (Farabee 1979).

Walleye commonly occur in upper pools of the UMR, occasionally occur in the lower pools of the UMR, and rarely occur in most of the IWW (Figure 33). Walleye inhabit areas in lakes and large rivers with gravel, bedrock, and firm substrates where the turbidity is low (Scott and Crossman 1973). It is nocturnal,

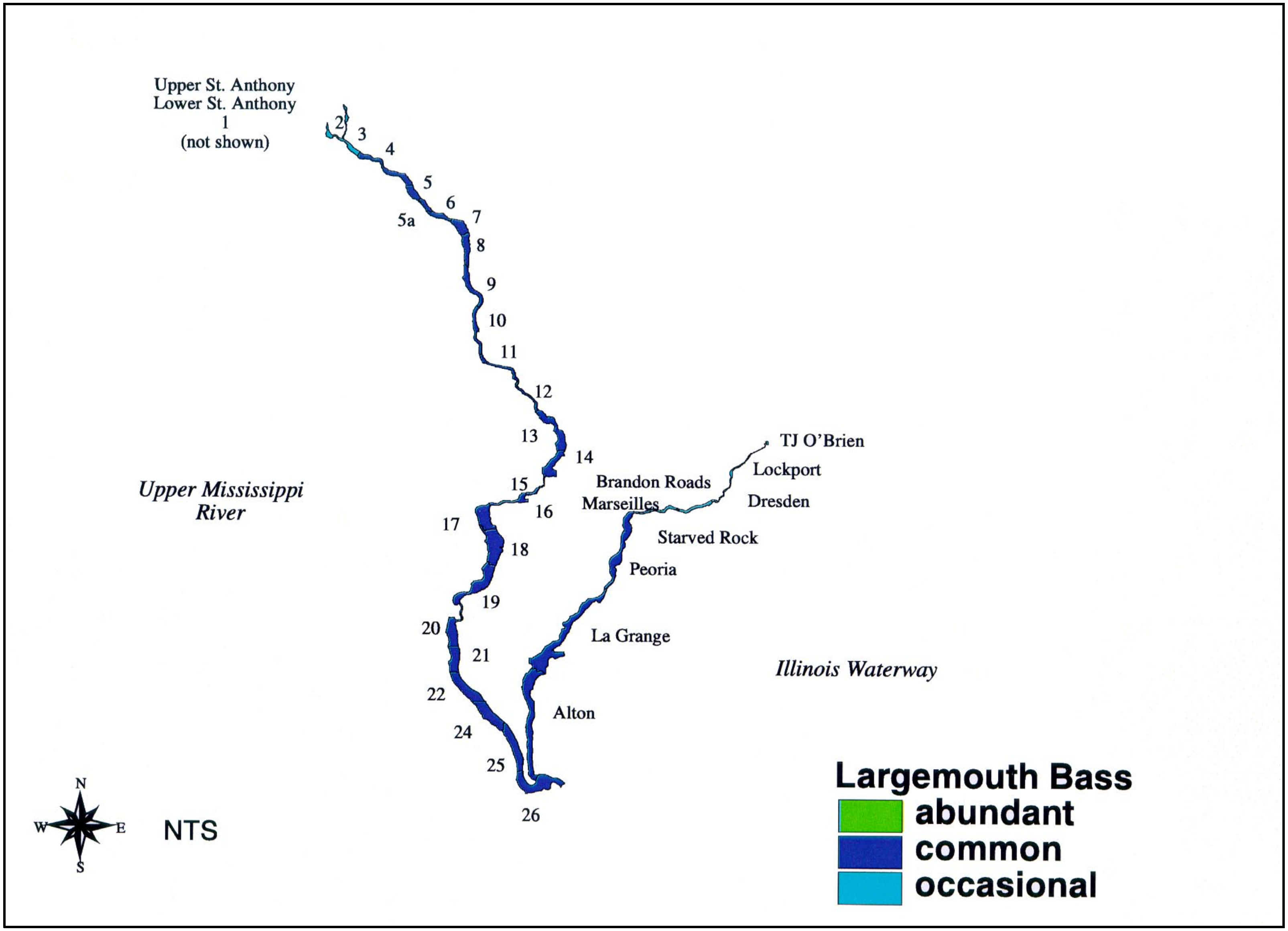


Figure 31. Distribution and abundance of largemouth bass in the Upper Mississippi River and the Illinois Waterway

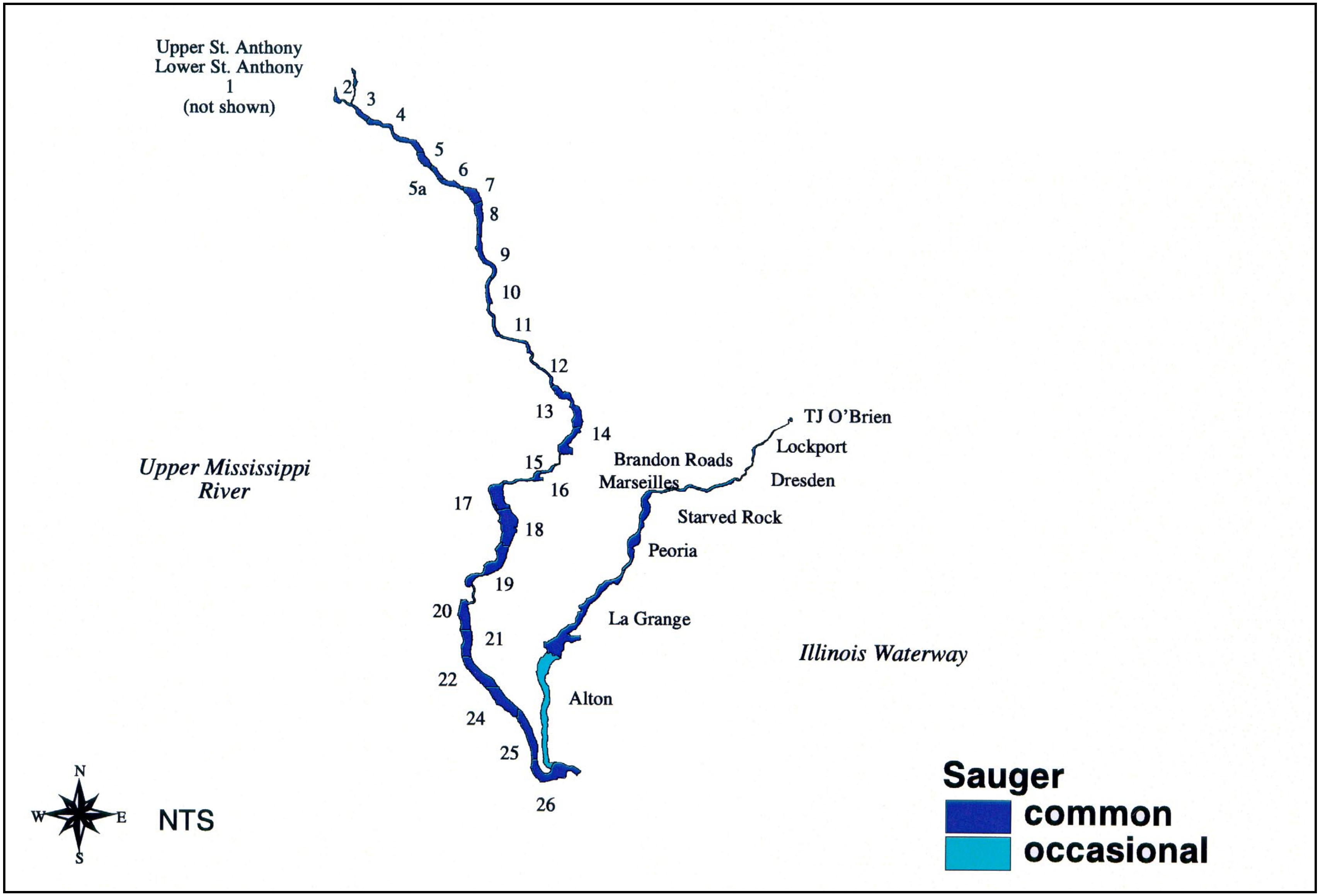


Figure 32. Distribution and abundance of sauger in the Upper Mississippi River and the Illinois Waterway

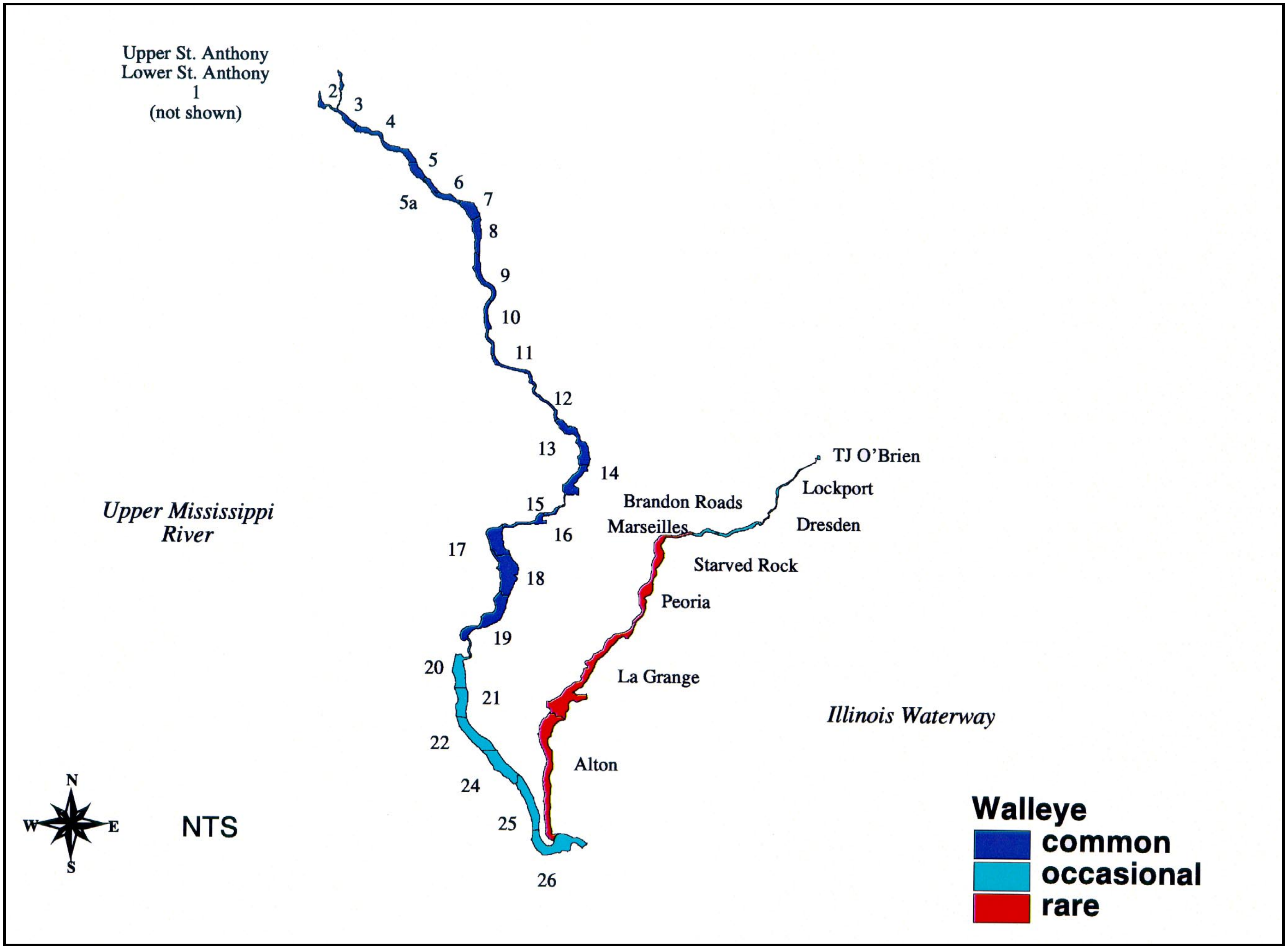


Figure 33. Distribution and abundance of walleye in the Upper Mississippi River and the Illinois Waterway

moving to shoals to feed in late evening and returning to deeper water before daybreak (Pflieger 1997). Both adults and juveniles have been collected in the main channel, main channel border, deep sloughs, and backwater areas of the UMR (Rasmussen 1979), but their general habitat is considered to be the main channel border (Littlejohn et al. 1985) (Figure 4). During high water, walleye may move into stands of flooded timber; during low water, they congregate around wing and closing dams (Holland-Bartels et al. 1990b). Walleye spawn in mid-April to early May over rocky areas below falls and dams, in riprap areas of dam tailwaters and coarse gravel shoals of lakes, or over vegetation (Scott and Crossman 1973; Holland-Bartels et al. 1990b; Etnier and Starnes 1993). In the UMR, spawning sites have been verified in areas of flooded emergent vegetation and in outer bends of the main channel (Holland-Bartels et al. 1990b). Larval walleye are a minor component of ichthyoplankton drift samples; the density of larval walleye in the drift peaks in early May (Holland-Bartels et al. 1990b; Gutreuter, Dettmers, and Wahl 1998).

### Drums

The drum family (Sciaenidae) are widely distributed throughout most temperate and tropical continental shelf habitats; of the 160 species described, only 1 completes its life cycle in freshwater in North America: the freshwater drum. The omnivorous freshwater drum lives near the bottom in large rivers, lakes, and impoundments; its general habitat in the UMR is considered to be the main channel (Littlejohn et al. 1985; Pflieger 1997) (Figure 4). In the UMR-IWW System, this fish is abundant in all pools (Figure 34). Adults move into shallow water in the spring and back into deep main channel waters in the late fall (Farabee 1979).

Freshwater drum spawn in open water near the surface from mid-May to mid-July (Holland-Bartels et al. 1990b). Eggs and larvae of the freshwater drum make up a large percentage of the main channel ichthyoplankton drift (Gutreuter, Dettmers, and Wahl 1998). Concentrations of eggs and larvae are greatest in surface waters just upstream of locks and dams; eggs are sometimes five times more abundant here than in other areas of the pools (Holland-Bartels et al. 1990b). Eggs and larvae are also abundant just below the locks and dams, suggesting that a large percentage of eggs and larvae go through or over dams (Holland-Bartels et al. 1990b). Larvae are found in the main channel bottom waters and tend to migrate to the surface at night (Holland-Bartels et al. 1990b).

## Model Descriptions

The four models used to assess the impacts of commercial navigation on fish entrainment are described in the following paragraphs.

### The Conditional Entrainment Mortality model

The CEM model (e.g., Boreman et al. 1981) has been adapted to estimate the mortality suffered by larvae, young of the year, and adult fishes as a function of

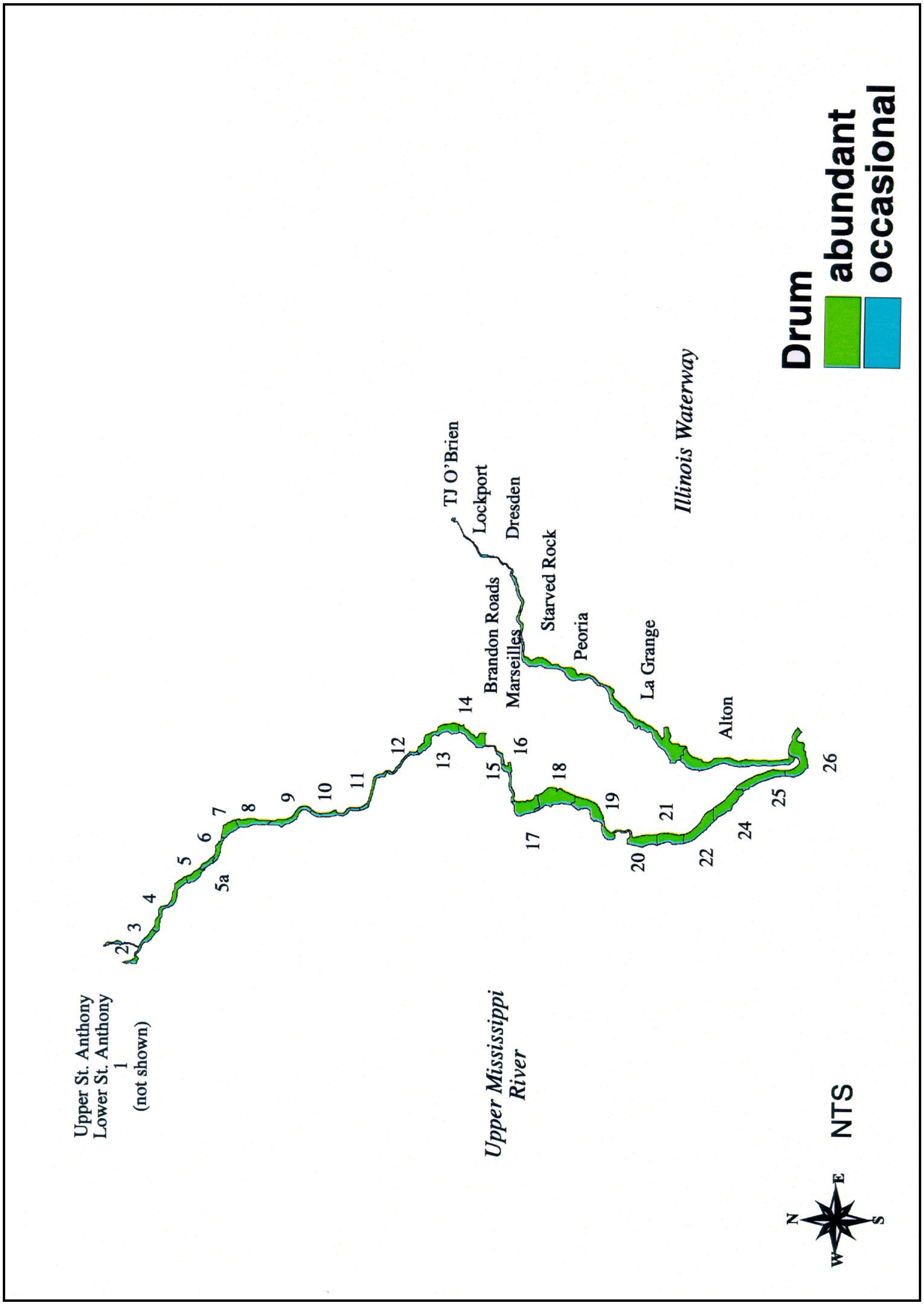


Figure 34. Distribution and abundance of drum in the Upper Mississippi River and the Illinois Waterway

increased commercial traffic on the UMR-IWW System. This model has also been referred to as the Empirical Transport model or the Proportional Mortality model. The CEM has been used mainly to estimate fish mortality associated with entrainment by the cooling systems of electric power generating facilities (e.g., Boreman and Goodyear 1988; Boreman et al. 1981). Adapting this model for the assessment of fish entrainment by commercial traffic required quantification of the volumes of water entrained through the propellers of different commercial vessels and barge configurations that operate on the UMR-IWW System.

Fish mortality due to entrainment in the propeller zone of a passing vessel can be expressed as the fraction of the initial population (or life stage) that would die assuming no other sources of mortality. For a group of fish vulnerable to entrainment, the conditional entrainment mortality rate, $m_t$, can be defined as (Boreman et al. 1981):

$$m_T = 1 - \sum_{s=1}^{S} R_s \prod_{j=0}^{J} \prod_{l=1}^{L} \sum_{k=1}^{K} D_{l,k} \exp\left(-E_{s+j,l,k}\, C_{j,l} t_j\right) \quad (4)$$

where

- $R_s$ = the proportion of total eggs spawned over the entire spawning season $S$
- $j$ = the age group of individuals for J-age groups within each life stage
- $l$ = life stage of $L$ total life stages addressed by the model application
- $k$ = one of $K$ total regions within the water body subjected to entrainment
- $D_{l,k}$ = the proportion of age-$j$ organisms initially occurring in region $k$
- $E_{s+j,l,k}$ = the instantaneous entrainment mortality rate constant (time$^{-1}$) of life stage-$l$ organisms in region $k$ during time-step $s + j$
- $C_{j,l}$ = the fraction of age-$j$ organisms in life stage $l$
- $t_j$ = the duration of age-$j$

Several simplifying assumptions were made that reduced the complexity of implementing Equation 4 for this assessment. All organisms within each life stage were assumed to be of equal age, $j = 1$. The entrainment calculations focused on the navigation channel as the single region within each UMR-IWW System pool; therefore, $k$ was also 1 and $D_{lk}$ dropped out of the model. Finally, all age-$j$ organisms were assumed to be in the same life stage: $C_{j,l} = 1.0$. Entrainment was calculated each month of the spawning season for each of the selected fish species. Therefore, $R_s$ defined the fraction of total spawning that occurred in month $s$, and $t_j$ was defined correspondingly as the number of days in each month of the spawning season for each species (Boreman et al. 1981). The resulting reduced form of Equation 4 used in the calculations was:

$$m_t = 1 - \sum_{s=1}^{S} R_s \exp\left(-E_{s+j}, t_j\right) \quad (5)$$

In this assessment, $E_{s+j}$ defined the instantaneous entrainment mortality rate constant for each life stage and specified time interval (e.g., month). The instantaneous constant $E$ is a function of the amount of water entrained by the propellers per unit time in relation to the volume of river (i.e., hydraulic classification pool volume), the susceptibility of the fish (life stage) to entrainment, and mortality subsequent to entrainment, in general form:

$$E = Qp\, w\, f \;/\; V \qquad (6)$$

where

$Q_p$ = volumetric flow rate through the propeller(s)

$w$ = ratio of the average concentration of the life stage in the entrained water to the average concentration in the river volume

$f$ = fraction of entrained organisms killed as a result

$V$ = volume of the river pool being modeled

In the adaptation used to assess navigation impacts on fish life stages, Equation 5 was reformulated as:

$$E_i = n\, R\, w_i\, f_i\, t_i \qquad (7)$$

where $R = Q_p/V$, $n$ specifies the number of tows passing through the pool per day, and $t_i$ is the duration of life stage $i$ in days. The parameter $w_i$ estimates the relative concentration of life stage $i$ individuals in the zone of entrainment (i.e., $Q_p$) compared with the concentration of individuals in the remainder of the main channel. The $f_i$ value defines the fraction of individuals entrained that are killed for life stage $i$. In this assessment, $i = 1$ for the larval stage, 2 for young of the year, and 3 for adult fish.

Using the model to assess each species of interest, each vessel type, and each pool requires developing estimates for the parameters in Equation 7. The traffic projections, based on economics, produce estimates of $n$ (e.g., vessels/day). The $f_i$ values for larval and young-of-the-year fish derive from the experimental work performed by Killgore et al. (in preparation). The percent mortality (initial and delayed) using the highest propeller velocities from the experiments of Killgore et al. was used. For sturgeon, paddlefish, and blue sucker, $f_i$ values for larval fish were matched up by species; for the remaining species, the highest value of 0.87 was used (Appendix A). Because experiments were performed on only one species of juvenile fish (common carp) (Killgore et al., in preparation), young-of-the-year $f_i$ values were the same for all species (0.225, the mean percent mortality of two experiments on juvenile carp). For the adult life stage of all species, it was assumed that the initial and delayed mortality associated with passing through the propeller was 1.0 (Appendix A). The flow rates through propellers derive from the work of Maynord (1999) and Holley (in preparation). Pool volumes depended on the hydraulic classification and discharge or stage height (e.g., low, medium, high) derived from analysis of historical discharge data.[1]

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[1] Kevin Landwehr, personal communication, U.S. Army Engineer District, Rock Island.

A $w_i$ value was estimated for each life stage of each species for each month of the year. The $w_i$ values were derived from the life history information for each species discussed during workshops or obtained from the literature (Appendix A). The $w_i$ value is 0 if the life stage for that particular species does not occur in the main channel in that particular month; 0.25 if the ratio of the average concentration of the life stage of that particular species in the main channel to the average concentration in the main channel river volume for that month is very small, such as the concentration occurring for some bottom-dwelling species or species that spend a majority of time in the backwaters; 0.50 if the average concentration of the life stage of that particular species in the main channel to the average concentration in the main channel river volume for that month is fairly low (this value also applied to some species closely associated with the river bottom); and 1.0 if the concentration of that particular life stage for a species in a given month is evenly distributed across the main channel.

The yearly sum of $w_i$ values for each life stage of the 30 fish species selected for modeling is presented in Table 7; the $w_i$ values were summarized in anticipation of making conservative entrainment calculations. Although the $w_i$ value does not calculate risk, it does provide guidance of the susceptibility of a fish species to entrainment by a commercial tow. The higher the sum of $w_i$ values, the higher the potential risk of the species being affected by increased commercial navigation traffic. The ranking of a fish species provided by the $w_i$ can also be used in the selection of species for analysis. Since the larval stage is the stage most vulnerable to entrainment, the $w_i$ values calculated for this stage are probably the most useful when comparing species susceptibility. In addition, since many adult fish move to avoid passing commercial tows, $w_i$ values estimated for the adult stage may be overestimates. It has been shown that some fishes avoid large vessels in the marine environment (Neproshin 1978; Misund and Aglen 1992; Soria et al. 1996). Todd et al. (1989) observed radio-tagged channel catfish moving in response to oncoming towboats in the IWW. In addition, Lowery et al. (1987) used hydroacoustic sensing to monitor the response of fishes to tow passages in the Cumberland River and found that some fishes moved away from passing tows. However, the strength of the avoidance reaction varied with direction of tow travel and whether or not the barges were loaded, and some fish may not avoid entrainment.

The CEM model can estimate the proportional mortality for three life stages of each species assessed: larvae, young of the year, and adult fishes. However, this assessment addressed only larval mortality for each species and traffic scenario. Larval entrainment data for selected power plants on the UMR-IWW System will be used to provide some context for evaluating the results of the CEM calculations for commercial vessels. The cooling water intakes of power plants located on the UMR-IWW System are additional sources of larval entrainment mortality (Figure 35). Fish larvae are killed because they are entrained in or impinged on the power plant water intake structures. The increase in larval mortality that results from increased commercial traffic will be compared on a pool-by-pool basis with that for larvae entrained by power plants (Appendix C).

**Table 7**
**Sums (Over a Year) and Total Sum of the Monthly Estimated $w_i$ Values for Each Life Stage of the 30 Fish Species Selected for Modeling**

| Species | Sum of Monthly $w_i$ Value | | | |
|---|---|---|---|---|
| | Larval Stage | Young-of-the-year Fish | Adult Fish | Total for All Life Stages |
| Emerald shiner | 4.0 | 6.0 | 9.0 | 19.0 |
| Gizzard shad | 4.0 | 2.5 | 4.5 | 11.0 |
| Freshwater drum | 4.0 | 2.0 | 4.5 | 10.5 |
| Shorthead redhorse | 3.0 | 3.0 | 4.5 | 10.5 |
| Bigmouth buffalo | 3.0 | 2.5 | 4.5 | 10.0 |
| Smallmouth buffalo | 3.0 | 2.5 | 4.5 | 10.0 |
| White bass | 4.0 | 3.0 | 2.25 | 9.25 |
| Spotted sucker | 3.0 | 3.0 | 2.25 | 8.25 |
| River carpsucker | 4.0 | 1.5 | 2.25 | 7.75 |
| Goldeye | 4.0 | 3.0 | 0 | 7.0 |
| Walleye | 1.5 | 3.0 | 2.25 | 6.75 |
| Sauger | 1.5 | 3.0 | 2.25 | 6.75 |
| Channel catfish | 3.0 | 3.0 | 0 | 6.0 |
| Blue catfish | 3.0 | 3.0 | 0 | 6.0 |
| Common carp | 6.0 | 0 | 0 | 6.0 |
| Mooneye | 3.0 | 2.5 | 0 | 5.5 |
| Shovelnose sturgeon | 1.0 | 1.25 | 2.25 | 4.5 |
| Lake sturgeon | 1.0 | 1.25 | 2.25 | 4.5 |
| Pallid sturgeon | 1.0 | 1.25 | 2.25 | 4.5 |
| Paddlefish | 0.75 | 1.5 | 2.25 | 4.5 |
| Bluegill | 4.0 | 0 | 0 | 4.0 |
| Shortnose gar | 1.0 | 1.5 | 0 | 2.5 |
| Blue sucker | 0.75 | 1.5 | 0 | 2.25 |
| Flathead catfish | 0.75 | 1.25 | 0 | 2.0 |
| Black crappie | 2.0 | 0 | 0 | 2.0 |
| White crappie | 2.0 | 0 | 0 | 2.0 |
| Northern pike | 0.75 | 0 | 0 | 0.75 |
| Largemouth bass | 0.75 | 0 | 0 | 0.75 |
| Smallmouth bass | 0.75 | 0 | 0 | 0.75 |
| Bowfin | 0.75 | 0 | 0 | 0.75 |

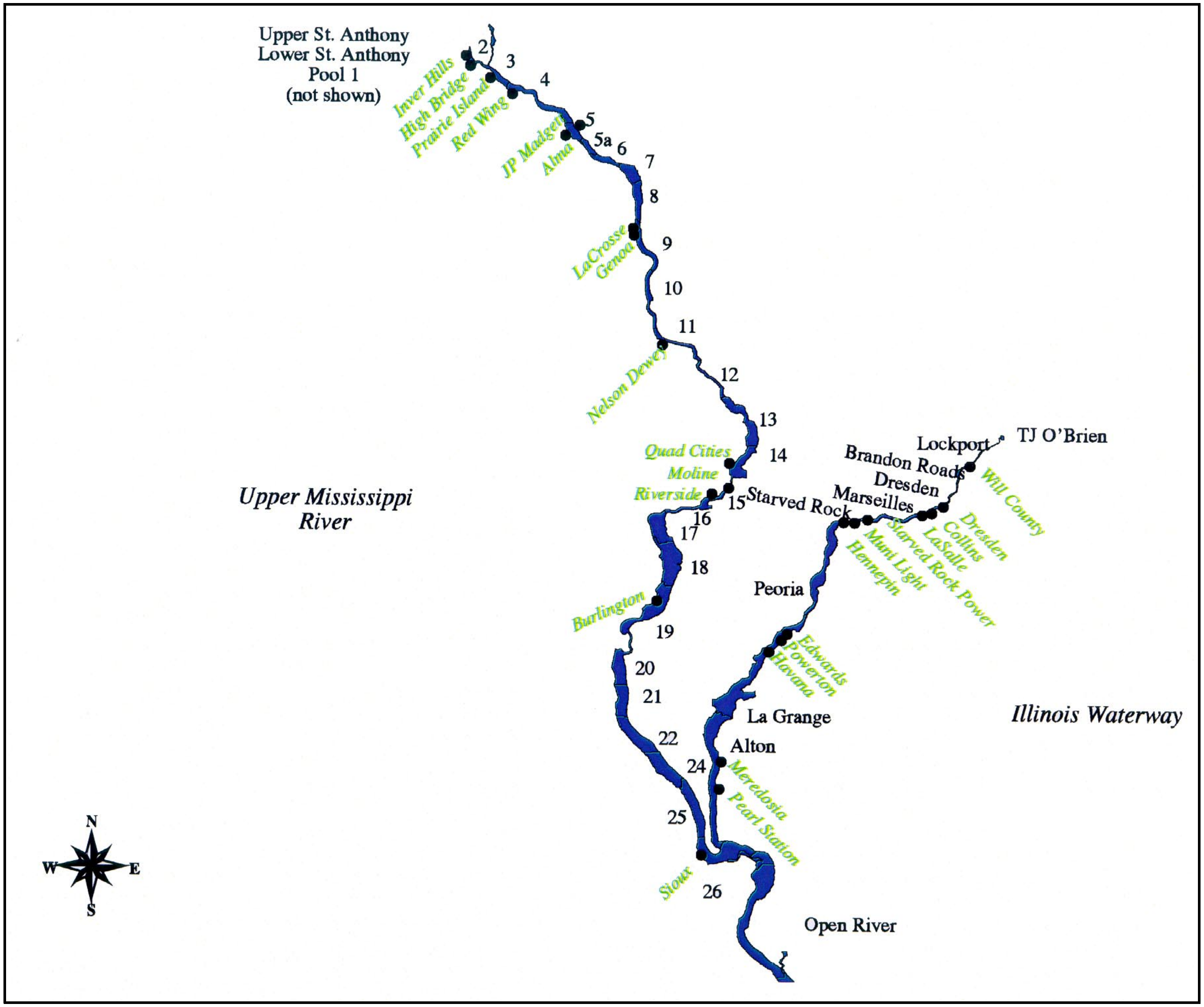


Figure 35. The location of power plants with water intakes on the Upper Mississippi River-Illinois Waterway

The calculated values of proportional mortality define an ecological effect of concern in assessing risks. Functions relating traffic intensity (i.e., vessels/day) to estimates of proportional mortality can be constructed using the model for specific traffic scenarios. More consistent with a probabilistic framework for risk, the uncertainties associated with the parameter values can be quantified and propagated through the calculations to estimate the likelihood that proportional mortality will exceed a specified value (e.g., 0.10). However, probabilistic risk assessments will be deferred to future traffic projections that will be provided by economic models of alternative plans for modifying the navigation infrastructure (e.g., guide walls, mooring cells, lock expansions).

The CEM model has proven useful in assessing the potential impacts of fish entrainment by power plant water intakes (Boreman and Goodyear 1988). Validation of this model as applied to navigation impacts on the UMR-IWW System is constrained by the resources available for field sampling and collection of injured and dead fish following tow passage. The results of trawling activities conducted during the 1996 and 1997 field seasons will be used to evaluate model predictions of entrainment mortality for the adult stages of selected species in the UMR-IWW System (Gutreuter, Dettmers, and Wahl 1998).

The utility of the CEM model for assessing potential navigation impacts on UMR-IWW System fishes is determined in part by the assumptions fundamental to the model. The main assumptions underlying the CEM model include the following: (a) the data describing the spatial-temporal location of the organisms are accurate; (b) the entrainment impacts do not alter the distribution of organisms within the water body; (c) natural mortality is uniform throughout a given life stage; and (d) density-dependent responses are not important (Boreman and Goodyear 1988).

In addition to a direct examination of the CEM estimates for different species, pools, and traffic scenarios, the results of the CEM model also serve as inputs to the EAL model. The EAL model extrapolates entrainment mortalities to estimates of the numbers of future individual adult fish that will be lost from the population as a result of a commercial vessel passage through a pool. Correspondingly, one method of integrating the effects of multiple vessels and pools lies in simply adding the number of future lost adults for each species and traffic scenario.

### The Equivalent Adults Lost model

Estimating the impacts of incremental mortality of early life stages in terms of losses in future adults is an important component of this ecological risk assessment. These losses were calculated using the EAL model (Horst 1975; Goodyear 1978). The EAL model translates the proportional mortalities estimated by the CEM model to numbers of lost future fish as the result of entrainment mortality suffered by larvae. The number of future adults lost due to larval entrainment mortalities was estimated using the equation:

$$EAL = L \bullet \left\{ \exp\left( -\sum_{i=1}^{3} Z_i \; t_i \right) - \exp\left[ -\sum_{i=1}^{3} \left( Z_i + T_i \right) t_i \right] \right\} \tag{8}$$

where

$L$ = number of entrained and killed larvae

$i$ = 1 (larvae), 2 (young of the year), or 3 (adult)

$Z_i$ = non-tow (natural) mortality rate of life stage $i$

$t_i$ = duration of life stage $i$, days

$T_i = n \cdot R_i w_i f_i$ = tow-induced mortality rate of life stage $i$ (see description of the CEM model, Equations 4-7).

Calculation of EAL requires estimates for the same parameters used in the CEM model (Boreman et al. 1981), together with estimates for the non-tow mortality rates for preadult life stages. That is, the tow-induced mortalities will be estimated using the CEM model. Natural mortality rates have been estimated for larvae, young of the year, and adults for 30 species of fishes selected for this risk assessment. These mortality rates were obtained primarily through searching the technical literature, or where data were not available, professional judgment.[1] The sources of the natural mortality rates are listed in the tables in Appendix A. In many cases, species-specific data from other locations or data from similar species were used. Where necessary, daily mortality rates were estimated from reported annual mortality rates.

The nature of the model projections (i.e., future fish lost) makes it difficult to evaluate the performance and reliability of the EAL model. Its validity is influenced not only by the assumptions and limitations specific to this model, but also by the accuracy and precision of the estimates of conditional entrainment mortality that serve as a primary input to the EAL model. It must again be emphasized that the main utility of the EAL model is to put any suspected increase in mortality rate into more concrete terms (i.e., numbers of fish) that can then be used to assess significance, as well as to develop mitigation alternatives. Calculations (future fish lost) resulting from the EAL model for species considered important to the commercial fishery can also be compared to commercial catch data compiled by the UMRCC to evaluate the reasonableness of the larval entrainment estimates and to assess the possible significance of lost future adults (Appendix D).

The calculated values of EAL can be used as ecological effects of concern in assessing risks. Functions relating traffic intensity (i.e., vessels/day) to estimates of EAL can be constructed using the model for specific traffic scenarios. More consistent with a probabilistic framework for risk, the uncertainties associated with the parameter values can be quantified and propagated through the calculations to estimate the likelihood that EAL will exceed a specified value

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[1] Steve Gutreuter, personal communication, U.S. Geological Survey, Upper Mississippi Science Center.

(e.g., 100 fish). Probabilistic estimation of risk is one objective of future refinement and expansion of this risk assessment of commercial navigation.

The key assumption underlying the EAL model is that the fish population of interest is essentially in a steady state, with individuals only replacing themselves throughout their life span. Limitations in the EAL model projections parallel those of the CEM model, given the structural and functional interrelations between the two models. In addition, direct extrapolation of the entrainment mortality model results, using the EAL model calculations, assumes that all other conditions that potentially influence fish population dynamics remain unchanged during the period of extrapolation. It should be recognized that the EAL model provides a first approximation to the severity of potential losses; the model does not necessarily give insights concerning the longer term viability of the impacted population.

### The Recruitment Forgone model

Jensen (1990) derived a model for estimating the effect of fish larvae entrainment on the number of individual fish recruited into the fishery. The model is based on a description of the change in the size of a cohort subject to exponential mortality:

$$RF = L\,R_0/Q \tag{9}$$

where
$RF$ = estimate of the number of lost recruits
$L$ = estimated number of larvae killed by entrainment
$R_0$ = net reproductive rate (assumed = 1.0)

The $Q$ term (not to be confused with entrainment rate, $Q_p$) adjusts for natural mortality, growth, and fecundity from the time of egg hatching, through the larval, young-of-the-year, and juvenile life stages to the age of maturity (= assumed age of recruitment) according to the following (Jensen 1990):

$$Q = H\,W_{INF}\;P_1\,P_2 \sum_{i=0}^{3} \frac{U_i \exp\left[-iK\left(x_M - x_0\right)\right]}{Z + iK} \left\{1 - \exp\left[-\left(Z + iK\right)\left(x_V - x_M\right)\right]\right\} \tag{10}$$

where
$H$ = number of eggs produced per gram of female biomass
$W_{INF}$ = the asymptotic weight, $g$
$P_1$ = fraction of eggs that hatch
$P_2$ = fraction of females in the population
$U_i$ = 1, -3, 3, and -1 for $i$ = 0, 1, 2, and 3, respectively
$i$ = life stage

$K$ = annual growth coefficient, 1/year
$x_M$ = age at maturity, years
$x_0$ = theoretical age when length equals zero
$Z$ = instantaneous mortality rate for adults, 1/year
$x_v$ = the oldest age attainable, years

In addition to estimates of the number of entrained larvae, the RF model parameters need only to be estimated for the recruited members of the population (Jensen 1990). This is the main advantage offered by the RF model. It is not necessary to estimate the abundance of fish in different life stages. Data describing fish abundance are largely not available for fish populations on the UMR-IWW System. The RF model simply estimates the number of fishes that will not enter the fishery as a function of the number of fish larvae killed by entrainment.

Jensen (1990) used the RF model to estimate recruitment forgone for a population of yellow perch in the western basin of Lake Erie. These fish were subject to entrainment by the Monroe Power Plant water intake, Monroe, Michigan. However, the projections of RF were not evaluated in relation to any field measurements. As with the EAL model, validation of future projections from the RF model is possible for the UMR-IWW System assessment. This would necessarily involve a substantial investment in monitoring of recruitment classes of the species and pools of interest.

In addition to uncertainties introduced through the process of parameter estimation, an additional and important assumption underlying the RF model is that the fish population of interest is at equilibrium (i.e., net reproductive rate $R_0$ = 1.0). As indicated by Equation 9, the relation between RF and $R_0$ is linear with a slope of *L/Q*. Thus, one limitation of this model is that for populations that are rapidly increasing, the assumption of $R_0 = 1$ can lead to underestimation of recruitment forgone in relation to larval entrainment mortality (Jensen 1990).

### The Production Forgone model

The Production Forgone (PF) model was proposed by Rago (1984) as an alternative method for assessing the consequences of fish entrainment and impingement losses at water intakes for power plants. The future fish biomass (i.e., metric tons) that would have been produced by the larvae killed by entrainment is estimated by the PF model. Rago (1984) described mortality and growth using simple exponential equations that Ricker (1975) used in the original formulation of production. Jensen et al. (1988) developed a PF model based on the growth and mortality equations of the Beverton and Holt (1957) model wherein the life span of a fish was divided into four stages: larvae, young of the year (age 0), juvenile, and adult.

The PF model of Jensen et al. (1988) is equated as:

$$PF = \sum_{i=1}^{3} \frac{G_i N_i W_i}{G_i - Z_i} \left[ e^{(G_i - Z_i)t_i} - 1 \right] \tag{11}$$

where

$i$ = 1 (larvae), 2 (young of year), 3 (adults)

$G_i$ = growth rate of life stage $i$

$N_i = N_{i\text{-}1} \exp(-Z_{i\text{-}1}t_{i\text{-}1})$ = number of life stage $i$ individuals that are killed ($i$ = 2,3)

$W_i = W_{i\text{-}1} \exp(G_{i\text{-}1}t_{i\text{-}1})$ = average weight of life stage $i$ individuals ($i$ = 2,3)

$Z_i$ = mortality rate of life stage $i$

$t_i$ = time duration of life stage $i$

As with the other models, necessary parameters were derived from existing data and information summarized in the technical literature. Growth rates required by the PF model can also be estimated using regressions of weight-length data (e.g., the von Bertalanffy growth equation) combined with estimates of fish length for each age class. The PF model parameters were estimated for the 30 fish species included in this risk assessment (Appendix A). Particular emphasis was placed on the species identified by the initial CEM model results as being potentially at greater risk.

The PF as a result of entrained fish larval mortality was estimated in relation to alternative traffic scenarios on the UMR-IWW System. These results may be particularly useful for assessing the ecological and economic significance of losses to forage fish species that are not of direct value to the commercial or sport fishery. Lost future biomass calculated using the PF model for species considered important to the commercial fishery will be compared to commercial catch data compiled by the UMRCC (Appendix D).

Jensen et al. (1988) applied the PF model to a population of gizzard shad subject to entrainment by a power plant water intake in western Lake Erie. Extensive sensitivity analysis of the model by Jensen et al. (1988) demonstrated that the estimated survival rate of first-year fishes was a critical model parameter. The key assumption of this modeling approach is that the future growth of the population will be similar to its recent history. In other words, mortality and growth schedules inferred from current population structure will likely apply over future time periods similar to the life span of the species of concern.

## Parameter Estimation

Parameter values for the fish entrainment models were developed for each of the 30 species using data and information published in the open scientific literature, books, technical reports, and professional judgment, where necessary. Model parameters for each of the 30 species are presented in Appendix A.

Where particular interpretations or simplifying assumptions were necessary in using available data to estimate model parameter values, attempts were made to bias parameter values toward overestimating potential impacts and risk.

Estimates of larval density (number of larvae/$m^3$) were central to this assessment of entrainment mortality by commercial navigation. Existing larval density data were collated for as many of the 30 species as possible from technical reports, the open literature, power plant water intake fish entrainment and impingement studies or monitoring reports, and a recent field study on the UMR-IWW System (Gutreuter, Dettmers, and Wahl 1998) (Appendix B). Whenever possible, larval density estimates were matched up on a pool-by-pool basis or within a range of pools when the data sets were developed. If more than one value was available for a particular month, the highest value was selected in developing the data set. However, the lowest larval density estimate was used for blue sucker because it is a rare species. Many of the larval density data have not been classified to the species level. Where necessary, larval density estimates were derived using data from the closest related family or genus. Density data for young-of-the-year and adult fish were not available for the 30 species in the UMR-IWW System. However, for a particular UMR-IWW System pool in which the species was known to occur, representative values were estimated using the distributions maps of each species according to the following assumption: rare = 0.10, occasional = 0.25, common= 0.50, and abundant = 0.99 (number/$m^3$). Therefore, this assessment addresses larval mortality only.