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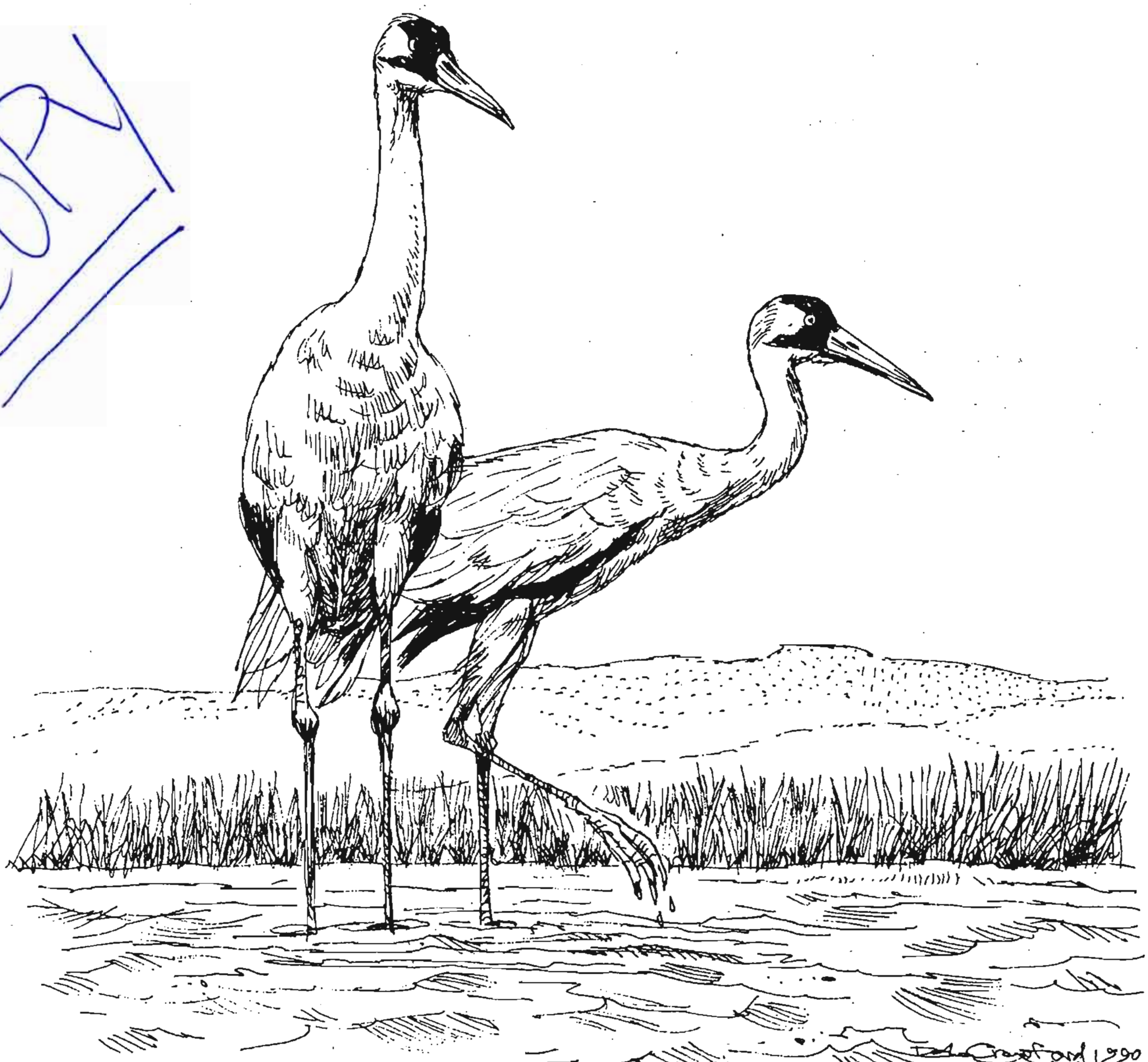

Fish and Wildlife Service
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ABSTRACT.—Information is drawn from the literature and the professional opinions of behaviorists and habitat use experts, and used to describe requirements of whooping cranes (*Grus americana*) during migration. Migration strategies of North American cranes are compared and inferences drawn. The requirements for usable food and cover are examined and described quantitatively for evaluations that focus on roosting habitat. When possible, information is presented in terms of both traditional and nontraditional stopover areas. Perceived problems with the data and their interpretation, are discussed, and issues requiring further study are identified. Relations presented do not represent selection, as defined by use and availability studies, but rather should be interpreted as a formalized synthesis of information directed by the opinions of recognized authorities in crane biology. Site-specific evaluation criteria address issues of visibility, water depth, wetland size, and disturbance; suitability relations are presented for each habitat component. Horizontal visibility is defined as a straight-line distance to the nearest obstruction greater than 1 m in height, and that distance must be greater than 20 m before a site can be considered as potential habitat. Optimum water depth is considered to be less than or equal to 30 cm. The minimum wetland size considered usable for roosting is 0.04 ha. Disturbances are treated as zones of influence around selected features with no zone having a minimum width of less than 100 m. Broad-scale evaluations can employ information readily available from inventories or surveys such as wetland system, class, water regime, and size, to rapidly screen potential habitat suitability over large geographic areas. Suggestions for application of evaluation criteria are presented.

Introduction

The whooping crane (*Grus americana*) is perhaps one of the most publicly visible representatives of the more than 300 species and subspecies on the United States endangered species list (Smith et al. 1986). As a species, the whooping crane can be traced back at least to the Upper Pliocene (Miller and Botkin 1974), but evidence collected since Europeans arrived in North America indicates that the species was probably never abundant (Allen 1952). Allen (1952) estimated a pre-1870 peak population of 1,300–1,400 whooping cranes, with numbers declining rapidly thereafter. The last surviving representative of a nonmigratory breeding population along the Louisiana coast was taken into captivity in 1950 (Smith et al. 1986), and by the winter of 1952–53, only 21 whooping cranes survived in the wild (Boyce 1987). As of March 1990, there were 157 whooping cranes in the wild and 55 in captivity (J. C. Lewis, U.S. Fish and Wildlife Service, Albuquerque, New Mexico, personal communication).

All wild whooping cranes occur in two migratory populations (Fig. 1). In the first population, nesting occurs within a 3,800-km^2 segment of Wood Buffalo National Park in northeastern Alberta and south-central Northwest Territories, Canada (Kuyt and Goossen 1987). This population (144 birds as of March 1990; J. C. Lewis, personal communication)

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Fig. 1. Migration corridors for the Grays Lake–Bosque del Apache and Wood Buffalo–Aransas populations of whooping cranes (modified from Smith et al. 1986).

winters along the coast of Texas on about 8,175 ha of salt flats and islands in and around Aransas National Wildlife Refuge (NWR; Stehn and Johnson 1987).

Efforts to establish a second population of whooping cranes were initiated in 1975 at Grays Lake NWR in southeastern Idaho, using greater sandhill cranes (*Grus canadensis tabida*) of the Rocky Mountain population (Drewien and Bizeau 1974) as foster parents for eggs taken from the Wood Buffalo population (Drewien and Kuyt 1979). The Grays Lake whooping cranes, now numbering 13 (J. C. Lewis, personal communication), have not nested, but migrate annually and winter in and around Bosque del Apache NWR in south-central New Mexico (Drewien and Bizeau 1978). The Patuxent Wildlife Research Center maintains a captive flock of whooping cranes (32 birds as of March 1990; J. C. Lewis, personal communication) near Laurel, Maryland (Derrickson and Carpenter 1981). A second captive flock of 22 birds was recently established at the International Crane Foundation in Baraboo, Wisconsin (J. C. Lewis, personal communication). Another whooping crane is in a zoo.

Published information describing the habitat requirements of whooping cranes during migration is limited. At a recent workshop, authorities familiar with the types of habitats used by whooping cranes during migration discussed the concept of habitat suitability for this species. The results of those discussions and a discussion of documented migration strategies used by sandhill cranes (*Grus canadensis*) are presented here. Sandhill crane migration strategies differ from those of whooping cranes, but a discussion should assist the reader unfamiliar with migration terminology in better understanding how we assume whooping cranes use habitat resources. Many of the relations presented are assumptions. Small sample sizes and questions concerning sites that are used and what sites are available preclude exact determinations of preferences and requirements. Therefore, the information in this report is a synthesis from observations of used sites. My purpose is to present this information in the form of testable hypotheses that can be the focus of future research.

Migration Strategies

To understand what habitats are used by migrating whooping cranes, a discussion of migration strategies of North American cranes is warranted. Melvin and Temple (1981) described three categories of migration habitat for sandhill cranes: staging areas, traditional stopover areas, and nontraditional stopover areas. Staging areas are sites where cranes gather during the first segment of their fall migration. These sites are relatively close to the breeding grounds (within the first 20% of the migration route's length) and are typically used every year. Use of these sites may be traditional, but may vary annually depending on weather, food availability, water levels, human activity, and probably other factors as well. Two of these other factors might be (1) the opportunity or need to ready themselves physiologically by replenishing or adding to their energy reserves for the next stage of migration; and (2) social interactions, such as flocking, which will later facilitate learning of the migration route for young cranes, and aid in finding unevenly distributed resources (Melvin and Temple 1981). The length of time spent at staging areas varies from a few days to several weeks. Sandhill cranes do not seem to stage for their spring migration north to the breeding grounds.

Traditional stopover areas farther along the migration route (between 25 and 75% of the distance between the breeding and wintering grounds) may be used for extended periods during spring or fall migrations, and are used every year. Melvin and Temple (1981) believed that traditional stopover areas were actively sought by individual cranes year after year, and that individuals used only one traditional stopover area per migration. At least in spring, traditional stopover sites seem to be used to accumulate lipid reserves (Krapu et al. 1984, 1985). A majority of migrating sandhill cranes probably spend at least a month at traditional stopover sites (Melvin and Temple 1981).

Nontraditional stopover areas offer suitable habitat for sandhill cranes seeking a place to spend the night (Melvin and Temple 1981). These sites are used opportunistically and usually for short periods, such as overnight or for several days if inclement weather is encountered. Habitat characteristics vary but usually include shallow water, gently sloping shoreline, and a site free from human activity.

Our understanding of whooping crane migration strategies is limited. Whooping cranes migrate alone, in pairs, in family groups, and in small flocks, but never in the large flocks characteristic of sandhill cranes (Johnson 1981). The largest confirmed sighting of whooping cranes between 1940 and spring 1984 was of 19 individuals at Salt Plains NWR, Oklahoma, on 2 November 1979 (Smith et al. 1986). The next largest sightings involved two incidents of 12 birds each. These incidents are unusual because the most frequent sightings (73%) involve one to three cranes (Fig. 2). The general pattern of sightings involves either overnight stopovers, or stopovers of longer duration (Johnson and Temple 1980).

The Patuxent Wildlife Research Center recently completed a cooperative study of migrating whooping cranes using radio-tagged individuals of the Wood Buffalo–Aransas population (Howe 1987, 1989). These studies reveal that monitored whooping cranes spent 68.4% of crane-use days in Saskatchewan during four fall migrations (a crane-use day is one crane using a roosting site for one night; Howe 1989). Saskatchewan accounts for about one-third of the straight-line distance between Wood Buffalo National Park (breeding grounds) and Aransas NWR (wintering grounds). Whooping cranes spend several weeks in the central Saskatchewan prairies, feeding primarily on grain. This pattern of localized use for extended periods suggests that areas in cen-

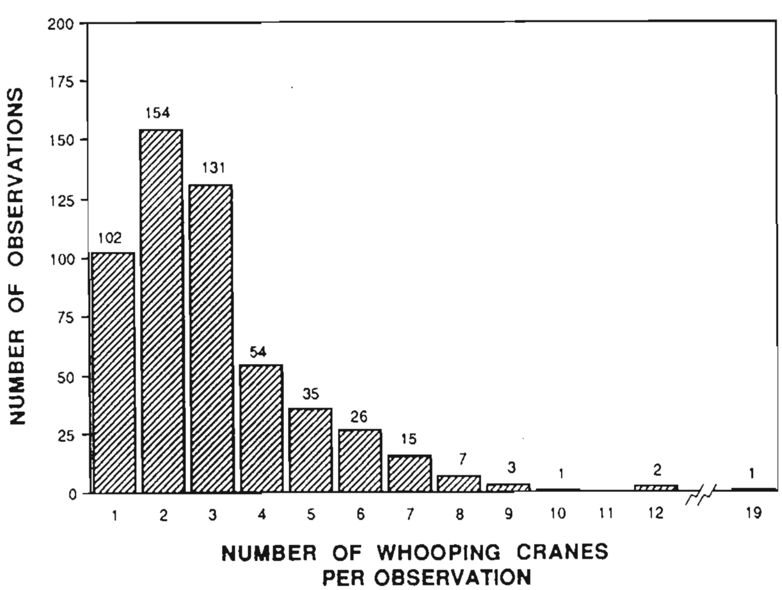

Fig. 2. A comparison of the frequency at which various groupings of whooping cranes have been sighted (data from Smith et al. 1986).

tral Saskatchewan serve as fall staging sites for migrating whooping cranes (Howe 1989). The remaining crane-use information for radio-tagged migrants of the Wood Buffalo–Aransas population indicates that roost sites were used for 1 or 2 days in Montana, North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, and Texas (Howe 1989). Exceptions occurred in Kansas and Nebraska, where one crane spent 4–5 days at a roost in Kansas (spring 1984), and two subadults spent 3 weeks in Nebraska (spring 1984). Howe's (1989) data showed no functionally analogous use of staging areas during spring migration by the Wood Buffalo–Aransas population of whooping cranes.

Johnson and Temple (1980) found no indication from historic sighting records that whooping cranes of the Wood Buffalo–Aransas population used traditional stopover areas in the United States. Rather, these authors argued that the several locations with numerous historic sightings generally have prominent physical features that may attract cranes from long distances, especially in dry years. For the Wood Buffalo–Aransas population, several of these locations with prominent features encountered during migration have been designated as critical habitat: Salt Plains NWR, in Alfalfa County, Oklahoma; Quivira NWR and Cheyenne Bottoms Waterfowl Management Area, in Reno, Stafford, and Barton counties, Kansas; and portions of the Platte River from Lexington to Shelton, Nebraska (Smith et al. 1986). A cursory examination of Appendix C in Smith et al. (1986) reveals other areas with several confirmed sightings of the Wood Buffalo–Aransas population, including Washita NWR in Oklahoma; Kirwin NWR in Kansas; the Rainwater Basin and Niobrara River in Nebraska; Long Lake NWR and Audubon NWR in North Dakota; and Medicine Lake NWR in Montana.

The pattern of migration differs for the Grays Lake–Bosque del Apache whooping crane population. These cranes seem to use the same areas in the same manner as their foster parent sandhill cranes. Greater sandhill cranes of the Rocky Mountain population gather at fall staging areas in southeastern Idaho, western Wyoming along the Bear River, and in adjacent areas of Utah, with the largest concentrations at Grays Lake and Teton Basin, Idaho (Drewien and Bizeau 1974). Cranes remain at staging areas for 2–7 weeks, feeding on barley (*Hordeum vulgare*) adjacent to roost sites until migration begins. Two areas in the San Luis Valley of southern Colorado that are heavily used during migration have been designated critical habitat: Monte Vista NWR and Alamosa NWR (Smith et al. 1986). Both sandhill cranes and whooping cranes use this valley from late August to late November, and from mid-February to early May each year (Kauffeld 1981).

Kauffeld (1981:119) provided the following description of crane habitat use in the San Luis Valley:

> Habitat used by sandhill and whooping cranes on the refuges is similar. Roosting locations are ponds and sloughs where the birds use water up to 0.3 m deep. Loafing areas are wet meadows of baltic rush (*Juncus balticus*), sedges (*Carex* spp.), spikerush (*Eleocharis* spp.), greasewood (*Sarcobatus vermiculatus*), and a variety of grass species. These meadows do not have to be very wet to attract cranes; 2 to 4 cm of water is satisfactory. Cranes will sometimes use dry meadows as long as a ditch with water or a stream is nearby. Although some feeding activity occurs in meadows, they are primarily used for resting, preening, and other social activities. The other major habitat used is grain fields during morning and evening. Barley is the primary crop so cranes use it most frequently, but will also utilize wheat, field peas, and potato fields. Primary feeding activity in potato fields is searching for insects and grubs. Cranes seem to prefer wheat over barley, and waste grain from wheat fields will be cleaned out rapidly.

Food

Most studies of diet during migration have been reconstructions of what potential food items may have been present at the time of crane use (Johnson and Temple 1980). By necessity, these studies focus on site descriptions. Based on available information, whooping cranes seem to be opportunistic in their feeding habits during migration; readily exploiting most potential animal and plant food sources, including cultivated grains such as barley, corn (*Zea mays*), sorghum (*Sorghum vulgare*), and wheat (*Triticum aestivum*; Johnson and Temple 1980; Howe 1987). Johnson and Temple (1980) evaluated 100 upland feeding observations of whooping cranes, and only 8 occurred in tame pastures and subirrigated meadows. The remaining observations occurred in croplands, including summer fallow and disked fields. Whooping cranes will probably attempt to consume any suitable plant or animal food item they encounter (Johnson and Temple 1980).

Johnson and Temple (1980) also evaluated wetlands reportedly used in 19 observations of feeding whooping cranes; only two wetlands, an ephemeral pond (Table 3; Shaw and Fredine 1956, two observations) and an irrigation-tailwater pit (one observation), involved spring sightings. The remaining eight wetland categories accounted for one to three fall observations each, except man-made reservoirs, which accounted for five sightings. Potential food items at these wetland feeding sites included *Sagittaria* tubers, frogs, crayfish, small fish, insects, salamanders, and tadpoles.

Radio-tagged whooping cranes exhibited similar feeding patterns during spring and fall migrations, with 42% of all feeding sites occurring in croplands (Howe 1987). Family groups (juveniles accompanied by adults) used wetlands for feeding in 67% of recorded feeding sites, whereas 70% of the feeding sites used by nonfamilies were cropland. Palustrine wetlands were used as feeding sites by family groups more often than nonfamilies (Howe 1987).

Upland and wetland feeding sites seem to have several characteristics in common (Johnson and Temple 1980). Overhead and horizontal visibilities are usually excellent at both types of feeding sites and are believed to provide security from predators and potential human disturbance. Horizontal visibility is the unobstructed view, at crane eye level (1.4 m above the substrate), measured as the horizontal distance to the nearest obstruction (Shenk and Armbruster 1986). Visual obstructions can be any feature, such as vegetation >1.4 m in height, buildings, or abrupt changes in topography (e.g., high banks or steep slopes). The mean slope at upland feeding sites is generally <10 degrees (Johnson and Temple 1980; Howe 1987). The mean water depth at 39 wetland feeding sites was 20.2 cm (Howe 1987).

All cranes may use vegetation as a cue to visibility. Upland feeding sites generally lack nearby trees and shrubs, but may support short vegetation at the use site (Johnson and Temple 1980). Wetland feeding sites are characterized by very sparse or very short emergent vegetation. Lovvorn and Kirkpatrick (1981) noted that sandhill cranes seldom land in dense herbaceous vegetation >18 cm in height.

Howe (1987) reported that 56% of paired feeding and roosting sites were separated by <1 km, and that whooping cranes often walked from the roost site to feed in an adjacent field. Optimum habitat for sandhill and whooping cranes in the San Luis Valley has roosting, loafing, and feeding areas within 1–2 km of one another (Kauffeld 1981). Cranes did not use feeding areas >10 km from roost sites. Sandhill cranes (predominantly *G. c. canadensis* and *G. c. rowani*) using the Platte River in central Nebraska as a traditional spring stopover do not travel long distances to feed (U.S. Fish and Wildlife Service 1981). Ninety percent of the Platte River observations were within 4.5 km of the river, and no sandhill cranes were observed >8.3 km from the river.

Kauffeld (1981:119) described the daily feeding patterns of cranes during their extended stopover in the San Luis Valley of Colorado:

> Each habitat type is usually used in the course of cranes' daily activities. Cranes leave the roost at or shortly after sunrise and fly to grain fields to feed. Feeding continues until 0930 to 1000 hours and then cranes fly to loafing areas. At about 1530 to 1600 hours they fly to grain fields to feed again. About sunset they return to the roost. Weather extremes can cause changes in activity patterns. On extremely cold days cranes will often spend nearly all day feeding in the grainfields. On warm days the amount of time spent feeding will often be 1 to 2 hours less than normal and more time will be spent at loafing sites.

These patterns are similar to those observed for cranes using nontraditional stopovers (Johnson and Temple 1980). On days when whooping cranes resume their migration, they feed until midmorning and then may leave from the feeding site, or they may return to the roost for water before departing.

Cover

Cover is synonymous with roost sites for migrating whooping cranes. Cranes generally use wetlands for roost sites; all 64 records of crane roosts investigated by Johnson and Temple (1980) were in wetlands, but Drewien and Bizeau (1981) and Ward and Anderson (1987) each reported one upland-roost site used by radio-tagged whooping cranes. The most commonly cited criterion used to describe crane roosting habitat, however, is the presence of some type of wetland. There are numerous wetland definitions, but for the purposes of this discussion:

> WETLANDS are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water . . . wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes; (2) the substrate is predominantly undrained hydric soil; and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of the year (Cowardin et al. 1979:3).

The Cowardin et al. (1979) classification system treats wetlands in a hierarchical structure, begin-

Table 1. *Continued.*

Shaw and Fredine (1956)	Cowardin et al. (1979)		
Wetland type[a]	Wetland class	Water regime	Water regime definitions
6. Shrub Swamps	Scrub–Shrub Wetland	All water regimes defined here except permanently flooded	
7. Wooded Swamps	Forested Wetland	All water regimes defined here except permanently flooded	
8. Bogs	Scrub–Shrub Wetland Forested Wetland Moss–Lichen Wetland	Saturated	(As defined above)

[a]Crane use has been reported only from wetland types 1–8; therefore, types 9–20 are not addressed.

Table 2. *Comparison of the wetland classes of Stewart and Kantrud (1971) with the water regime modifiers of Cowardin et al. (1979).*

Stewart and Kantrud (1971)	Cowardin et al. (1979)	
Wetland class	Water regime	Water regime definitions
I. Ephemeral ponds	None, not considered a wetland	
II. Temporary ponds	Temporarily flooded	Surface water present for brief periods during growing season, but water table usually lies well below soil surface for most of season
III. Seasonal ponds and lakes	Seasonally flooded	Surface water present for extended periods, especially early in growing season, but absent by end of season in most years
IV. Semipermanent ponds and lakes	Semipermanently flooded	Surface water persists throughout growing season in most years
None[a]	Intermittently exposed	Surface water present throughout the year except in years of extreme drought
V. Permanent ponds and lakes	Permanently flooded	Water covers land surface throughout year in all years
VI. Alkali ponds and lakes	Intermittently flooded (with saline or hypersaline water)	Substrate usually exposed, but surface water is present for variable periods without detectable seasonal periodicity
VII. Fen (alkaline bog) ponds	Saturated	Substrate saturated to surface for extended periods during growing season, but surface water seldom present

[a]No corresponding wetland class exists for the intermittently exposed water regime.

1986). Howe (1987), however, reported that radio-tagged whooping cranes in family groups used a variety of wetland types for roosting, but concentrated their activity in shallow water. Ponds and lakes were more heavily used by nonfamilies. Differences in season use were noted; intermittently exposed wetlands were used more for roosting in fall and temporary wetlands were used most commonly in spring, but this may reflect a scarcity of the more ephemeral wetlands in fall (Howe 1987). When evaluated by water regime modifier, no significant ($P = 0.08$) differences were detected in wetland use between roosting family groups and nonfamilies. Johnson and Temple (1980) found a similar seasonal pattern when evaluating past sightings; shallow Type 1 and Type 3 wetlands (Table 3) were used more frequently than other types in spring, whereas manmade reservoirs, Type 5 wetlands, and shallow rivers were used more frequently in fall.

Table 3. *Wetlands used by roosting whooping cranes as described by Johnson and Temple (1980).*

Wetland	Number used[a]	
	Spring	Fall
Type 1	4	1
Type 3	5	4
Type 4	1	2
Type 5 (fresh water)	1	4
Type 5 (brackish or alkaline)	0	4
Type 1/3[b]	0	3
Type 3/4[b]	1	0
Type 4/5[b]	0	5
Playa lake	0	1
Inland salt marsh	0	3
Manmade reservoir	1	13
Stock pond	2	1
Shallow river	1	7

[a] Johnson and Temple (1980) did not explain how these 64 observations were selected from the hundreds available.
[b] These wetlands exhibited characteristics of both types listed.

Sandhill cranes (Lovvorn and Kirkpatrick 1981) and whooping cranes (Johnson and Temple 1980) generally do not roost in water deep enough to cover the tibiotarsus–tarsometatarsus joint. For whooping cranes, this height is about 28.1 cm for females and 28.6 cm for males (Walkinshaw 1973). Mean water depth at 80 roost sites was 18.1 cm (Howe 1987). At one wetland, where water depths gradually increased from 0 to 51.6 cm, cranes roosted in 18 cm of water (Ward and Anderson 1987). Johnson and Temple (1980) evaluated 57 sites with historic whooping crane use and concluded that optimum water depth for roosting ranges from 7.6 to 20.3 cm. Although the conditions at the time of roosting are unknown, these conclusions are based on depth measurements ranging from 5 to 40.6 cm at 40 of the sites, and on numerous photos of cranes standing in water. Two sandbar roost sites in the Platte River in Nebraska were submerged at depths of 10–13 cm (Lingle et al. 1984) and 20–28 cm (Lingle et al. 1986).

Whooping cranes and sandhill cranes generally roost away from shore or dense emergent vegetation. Johnson and Temple (1980) suggested that wetlands should be shallow enough to permit whooping cranes to roost at least 6.1–9.1 m from the shoreline or dense emergent vegetation. Two subadults radio-tracked through four roost sites in the United States roosted an average of 18.6 m from the shore (Ward and Anderson 1987). At one site, where wetland size and water depth permitted whooping cranes a choice of locations, they roosted 15–20 m from shore in 18 cm of water. A study by Lovvorn and Kirkpatrick (1981) illustrates the importance of water to greater sandhill cranes. The cranes they studied did not use a historical roost site until it was flooded with shallow water in falls 1978 and 1979. The roost was dry before flooding, but secure from public access. Cranes began roosting at the site the first night following flooding. Greater sandhill cranes preferred to roost in water <25 cm (below the tibiotarsus–tarsometatarsus joint), and promptly waded to shallower water if they landed in deep water (Lovvorn and Kirkpatrick 1981).

Wetlands with extensive vegetation are generally not used for roosting by whooping cranes (Howe 1987). Johnson and Temple (1980) found only one site where whooping cranes may have roosted in emergent vegetation. Wetlands with either a perimeter of vegetation or no vegetation at all were used more often ($P = 0.06$) for roosting than feeding by radio-tagged cranes. Family groups of whooping cranes roosted in wetlands with clumped vegetation more often than nonfamily groups, and nonfamilies roosted more commonly at sites with peripheral vegetation. Johnson and Temple (1980) suggested that whooping cranes will roost closer to low or scattered emergent vegetation than they will to tall and dense vegetation such as cattails (*Typha* spp.) and bulrushes (*Scirpus* spp.). Greater sandhill cranes at Jasper–Pulaski Fish and Wildlife Area in northwestern Indiana either landed directly in the water at roost sites, or in sparse vegetation, but seldom landed in dense herbaceous vegetation >18 cm tall (Lovvorn and Kirkpatrick 1981).

Horizontal visibility, believed to be related to security (Shenk and Armbruster 1986), seems to be a characteristic of crane roost sites, but quantitative information is limited. Greater sandhill cranes avoid disturbance by maximizing either distance or visual isolation from human activities. Visibility at a traditional sandhill crane stopover site was 140 m for roosts surrounded by woody vegetation and 380 m for roosts visible from a road (Lovvorn and Kirkpatrick 1981). Information for whooping crane roosts is more circumstantial. Although Johnson and Temple (1980) suggested that no visual obstructions occur within 15–91 m of a whooping crane roost, they also said that the distance between roosts and roads or other human developments should be 274–366 m. Howe (1987) reported that visibility around a roost site was generally <3 km and often <1 km. Measured distances at five roosts used by two radio-tagged subadult whooping cranes provided the following information: mean visibility of 599 m, with a range from 100 to 1,000 m; mean distance to an actively used road of 1,170 m, with a range from 250 to 2,800 m; and mean distance to an occupied house of 1,450 m, with a range of 250 to 2,800 m (Ward and Anderson 1987).

Riverine roost sites are sometimes found in the widest unobstructed channel widths available (Lingle et al. 1986), which vary with the river system. For example, Johnson and Temple (1980) reported channel widths ranging from 55 to >366 m in the seven riverine sightings they evaluated. Unobstructed channel widths for two recent roost sites on the Platte River were 350 and 311 m (Lingle et al. 1984, 1986), and B. Johns (Canadian Wildlife Service, Saskatoon, unpublished data) provided channel width data for eight riverine roost sites in Saskatchewan, all of which were >375 m.

The size of wetlands used for roosting is an issue that has received a great deal of attention (Shenk and Armbruster 1986). Howe (1987) reported that half (24 of 48 sites) of the roost sites evaluated between 1981 and 1984 were <1 ha. This information was seemingly collected from the specific wetland the radio-tagged whooping crane used, without regard for surrounding habitat. For example, Howe's Table 1 (1987) listed two wetlands <1 ha used by whooping cranes in Oklahoma. Smith et al. (1986) list two color-marked and radio-tagged cranes in Oklahoma between 13 and 22 October 1983, at Salt Plains NWR. Four roost sites are depicted by Ward and Anderson (1987) near Salt Plains NWR in fall 1983. Although no data on roost size are presented, two roosts are described as occurring in a Lacustrine System (i.e., >8 ha). Presumably, the same two color-marked and radio-tagged whooping cranes provided the opportunity for three different groups of investigators to report their findings in a variety of ways. In addition, from 15 to 21 October 1983, three other whooping cranes (one adult was color-marked) were on the refuge, and on 4 November 1983, 10 whooping cranes were sighted on the refuge (Smith et al. 1986). The radio-tracking data reveal nothing about the size of wetlands used by the 10–13 other whooping cranes in their stopover at this large wetland complex; some clarification on the use of wetlands by the two radio-tagged birds seems warranted. It seems that the size of wetlands used by cranes is an issue requiring further evaluation and research.

Description of Habitat Use

Whooping cranes have been the subject of numerous habitat studies since the establishment of Aransas NWR in 1937 and the 1954 discovery of the breeding grounds for the Wood Buffalo–Aransas population (Smith et al. 1986). As marking and tracking techniques improve, more studies are focusing on the requirements of migrating whooping cranes (Drewien and Bizeau 1981; Howe 1987, 1989; Ward and Anderson 1987). In this report I focus on habitat used by migrating whooping cranes and attempts to formulate the existing information into suitability criteria that can be used to compare habitat conditions for localized, on-site evaluations, as well as assessment studies at a broad geographic scale. The criteria attempt to describe the suitability of roosting habitat provided by nonriverine wetlands. Criteria associated with riverine habitat requirements are the focus of other, ongoing efforts (Carlson 1987; Ziewitz 1987).

Suitability criteria take the form of indices ranging in value from 0 to 1. This approach works well in a variety of comparisons, including habitat selection studies. Note, however, that selection, as defined by use and availability studies, has not been evaluated for habitat used by migrating whooping cranes. The suitability criteria should be interpreted as a formalized synthesis of information from the literature cited, and the opinions of recognized authorities on crane biology. The criteria can be viewed as hypotheses of whooping crane migration–habitat relations but are not statements of proven cause and effect. Actual use of a site by cranes is dependent on many factors and may not correspond to predicted suitability levels at a single point in time. Since the performance measure used in this exercise is habitat use, any site receiving use by whooping cranes has, in effect, contributed an aggregate suitability value of 1 to this exercise. The objective of this section is to describe the perceived importance of each identified suitability criterion in a manner that preserves its potential for maintaining that aggregate value, or reducing it. This approach obviously requires interpretations that are subject to change as more information becomes available, or as existing information is reevaluated.

Earlier efforts directed at developing suitability criteria for whooping crane use of sites along the Platte River attempted to focus attention on data pertinent only to the Wood Buffalo–Aransas population (Shenk and Armbruster 1986). Participants at the Fort Collins workshop described in this report decided to evaluate all information available to them, and then decide on its validity as specific questions arose. For example, the Grays Lake–Bosque del Apache population would probably provide more examples of extremes in habitat use; this may reflect the behavior of the sandhill crane foster parents, or the fact that more extremes in habitats are available to this population.

The criteria developed at the workshop and presented here focus on roosting habitat. In situations where differences were perceived in the use of traditional and nontraditional stopover sites, two relations (curves) are presented for the same criterion. Traditional stopover areas should be treated as staging areas until more information becomes available. The relation between food and habitat suitability is unclear. For example, whooping cranes tend to feed more in wetlands than do sandhill cranes. Juvenile feeding rates are about twice those of adults in fall (workshop participants, personal communication), and family groups of whooping cranes feed more in wetlands in fall than do birds without young (Howe 1987). These differences are difficult to translate into suitability criteria, and in the following discussions food is treated as a distance relation between the potential roost site and grain fields. Physiological requirements for water and behavioral requirements for loafing sites are assumed to be addressed for criteria used to evaluate roosting habitat.

Site-specific Evaluations

Existing data for confirmed site use by whooping cranes contain some habitat information (Smith et al. 1986). This information is difficult to interpret, however, because of questions concerning how location and number of crane observers influence the probability of a sighting and of the statistical parameters of the resulting sample data (Shenk and Armbruster 1986). Radio-tracking data collected by the Patuxent Wildlife Research Center between 1981 and 1984 provide a systematic documentation of habitat use by a small selected subset of the Wood Buffalo–Aransas population, but without accompanying estimates of habitat availability do not provide insight into preferred habitat characteristics (Howe 1987). The relation between this sample and the habitat requirements of the entire population is unknown. Given these constraints, the performance measure for this model is habitat use, but criteria should not be interpreted as representing selection.

The issues of staging area versus traditional stopover areas versus nontraditional stopover areas are also important in understanding habitat use by migrating whooping cranes. Tradition may play a role in the use of staging and traditional stopover areas, but workshop participants also discussed differences in resources supplied by these areas as opposed to nontraditional stopover sites. Although the initial attractant to any site is probably the presence of water, staging areas and, presumably, traditional stopover sites become multiple-day crane-use sites not only because of wetland characteristics but also because of the type and abundance of food. In contrast, the primary attractant to a nontraditional stopover site is the presence of water, and food may be of limited importance.

Workshop participants also discussed seasonal differences in habitat use. During fall migration, grain food is abundant throughout both migration corridors and probably is not limiting; however, less water may be available for roosting in fall, especially during drought years. Human activity (hunting, grain harvest) that may disturb roosting cranes probably is more prevalent in fall. In spring, water is usually abundant, but grain food is less available than in fall, and spring storms may cause problems for migrating whooping cranes. Although roost sites used during both spring and fall migrations were discussed at the workshop, only one set of criteria is presented in this report. The primary emphasis is on wetlands; therefore, application will probably yield the most conservative values for fall habitat conditions.

Visibility Component

Although crane use of nesting and wintering territories is very site-specific (Kuyt and Goossen 1987; Stehn and Johnson 1987), use of wetlands during migration differs. In migration, cranes may initially be attracted to a wetland because it seems to offer security from predators or potential human disturbance. One cue to security may be provided by an unobstructed view, both vertically and horizontally, at crane eye level. Cranes respond to obstructions that obscure visibility through avoidance of the area around the obstruction.

Although almost any physical feature can obstruct visibility, the most common obstructions are tall, dense vegetation, buildings, and changes in topography, such as high banks or steep slopes. Obstructions can occur within, at the edge of, or outside the wetland basin. Attempts to explain this perceived crane response to horizontal visibility can take the form of some distance relation between the potential roost site and a defined obstruction ≥ 1 m tall (Shenk and Armbruster 1986). Horizontal visibility is defined here as a straight-line distance to the nearest obstruction ≥ 1 m in height.

Cranes may respond differently to visual obstructions, depending on whether the potential roost site is used as a traditional stopover or a nontraditional stopover. Workshop participants assumed that familiarity with a site plays a role in such responses. On traditional stopovers, for example, cranes may tolerate visual obstructions closer to the roost than on nontraditional stopovers (workshop participants, personal communication). Cranes ma ... use sites with dense vegetation close to the ... site, but 20-m over-water distance seems to re ... at the approximate tolerance limit for nontrad ... al sites. If no emergent vegetation is present, or ... ly partly surrounds the wetland, then horiz ... visibility would be measured to the nearest obj ... tside the wetland basin that obscures several (... egrees of visibility. The relation between horiz ... visibility and suitability for both traditional s ... er areas and nontraditional sites is represent ... the suitability index for horizontal visibility (... V) and is presented in Fig. 3.

Water Depth Component

Workshop participants assumed tha ... er is preferred for roosting, although cranes oc ... ally use sandbars or mudflats above the surfa ... ter line; however, water must be present to ir ... attract birds to such sites. Exceptions do oc ... Drewien and Bizeau (1981), Ward and Anders ... 87), and Howe (1989) each reported a single ... ence of whooping cranes roosting on dry la ... e mean water depth measured by Howe (198 ... etlands used for roosting was 14.1 cm (N = ... Only 4% of the recorded depths exceeded 30 c ... orkshop participants, personal communicatio ...

Water depth information can be inc ... ated into considerations of wetland suitabili ... several ways. A histogram of depth frequ ... can be compared to suitability, or, if availab ... ths are known, some estimate of selection can ... eloped. Such approaches tend to emphasiz ... hnique, however, and may not provide much ... ht into crane use of a wetland in terms of water depth. At one site where wetland size and water depth permitted whooping cranes a choice of locations, the cranes roosted 15 to 20 m from shore in 18 cm of water (Ward and Anderson 1987). Whooping cranes may prefer to roost closer to shore in large wetlands if water depth permits, and they may avoid the interior of large wetlands (workshop participants, personal communication). These concerns can be treated with a simple binary variable to derive a suitability index value for water depth (SIWD):

if water depth $\leqslant$30 cm then SIWD = 1,
if water depth >30 cm then SIWD = 0.

Wetland Size Component

The size of wetlands used for roosting by whooping cranes has received a great deal of attention, but much of the information relating wetland size to crane use seems inconclusive (Shenk and Armbruster 1986). Whether this lack of definition is a reflection of how the data were collected or evaluated is unknown. For this discussion, I assumed that wetlands $\geqslant$0.04 ha have some potential value as a nontraditional stopover site, with optimum conditions for wetland size beginning at 1.0 ha (Fig. 4, suitability index for wetland size, or SIWS). The minimum area was selected to coincide with the minimum size of wetlands recorded on maps produced by the U.S. Fish and Wildlife Service's National Wetland Inventory Program. The selection of 1.0 ha as a threshold for optimum conditions is an arbitrary choice that coincides with data presentation categories from Howe (1987, 1989). Although 36 of 69 roost sites used by radio-tagged whooping cranes were $\leqslant$1 ha in size (Howe 1989), these data do not distinguish

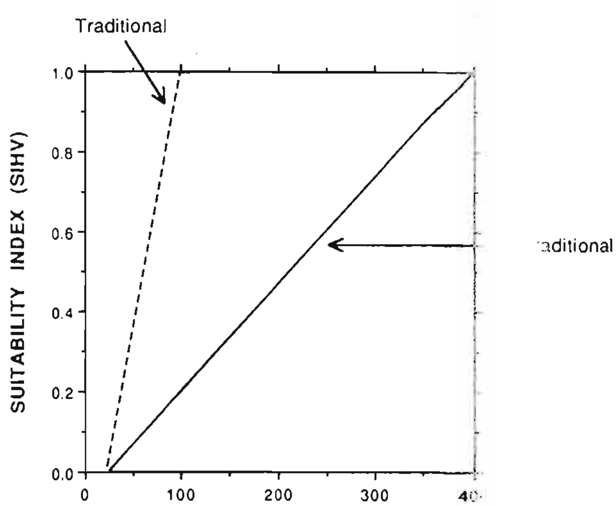

Fig. 3. The assumed relation between hori ... visibility and suitability for traditional stopover a ... and nontraditional sites.

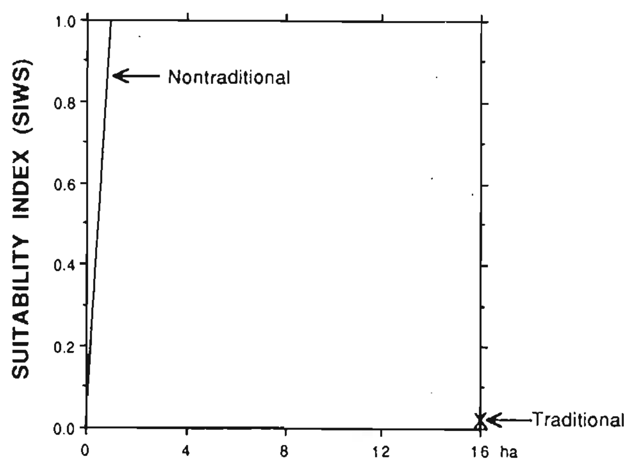

Fig. 4. The assumed relation between wetland size and roosting suitability for traditional and nontraditional sites.

between traditional and nontraditional site use, and thus, time spent at each site. Workshop participants believed that the probability of occurrence of a suitable roost site is higher for larger wetlands (≥1 ha). Less is known about wetland size and how it affects suitability of a wetland as a staging area or traditional stopover area; however, workshop participants assumed that wetlands used traditionally in Saskatchewan become suitable at about 16 ha, and reach optimum size at some greater but unknown size. Whooping cranes of the Grays Lake–Bosque del Apache population use many smaller (<16 ha) wetlands annually in the San Luis Valley in Colorado (R. C. Drewien, University of Idaho, Moscow, unpublished data). This may reflect the fact that few large (>16 ha) wetlands are available in this area. Wetland size is a subject that warrants further investigation.

Disturbance Component

Little quantitative information exists concerning the effects of human activities on habitat use by whooping cranes. Participants at the Fort Collins workshop suggested that the issue of human activity or disturbance and wetland suitability for roosting be treated in the same way that has been suggested for the perceived responses of sandhill cranes to human activity (Armbruster and Farmer 1981).

The approach used for sandhill cranes identifies a zone of influence around some permanent feature, such as a road. The width of the zone or buffer is assumed to represent the relative magnitude of human activity associated with the feature. Table 4 identifies the suggested widths of various zones of influence for sandhill cranes roosting in the Platte River in central Nebraska. Workshop participants believed these zone widths seemed reasonable for whooping cranes except that power lines should be treated as a potential mortality factor (Brown et al. 1987, Faanes 1987), and the minimum width for any feature should be no less than 100 m.

Food Component

Workshop participants assumed that suitability of a roost site would be enhanced by the proximity of food. Optimum conditions probably exist when food is available immediately adjacent to a roost site. Grain seems to be the key food during migration, with invertebrates taken opportunistically. Kauffeld (1981) estimated that greater sandhill cranes, and some whooping cranes, daily consume 113–151 g of grain. This amount should not pose a problem for small numbers of cranes using most areas overnight. Cranes spending longer periods at a site, however, or competing with waterfowl for limited grain food, could encounter food shortages, depending on local conditions. Kauffeld (1981) noted a depletion of food led to an early spring departure by cranes from traditional use sites. The situation is different along the Platte River in central Nebraska where an estimated 500,000 sandhill cranes spend several weeks each spring. Reinecke and Krapu (1986) predicted no food shortages for this many cranes, plus additional whooping cranes, waterfowl, and cattle, as long as current land-use practices continue. Because of the difficulty associated with measuring waste grain availability (Baldassarre et al. 1983; Frederick et al. 1984; Reinecke and Krapu 1986), the variable of interest is food location in relation to the roost site. For this model, however, workshop participants assumed that food must be present within 1.5 km of the roost site to provide optimum conditions, and the roost is unsuitable if food is absent within 8 km. Note, however, that whooping cranes of the Grays Lake–Bosque del Apache population annually use several sites that have no grain within 8 km (R. C. Drewien, unpublished data).

No quantitative information was available at the workshop to evaluate the relative importance (when compared to grain food) of cover types supplying invertebrate food items. Although family groups seem to feed more in wetlands (including wet meadows) than do birds without young (Howe 1987), this perceived differential use is not treated in the model.

Table 4. *Types of disturbances and size of affected area assumed to influence riverine roost sites of sandhill cranes in Nebraska (Armbruster and Farmer 1981).*

Type of disturbance	Width of affected area (m)[a]
Paved road	400
Gravel road	200
Private road	40[b]
Urban dwelling	800
Single dwelling	200
Railroad	400
Commercial development	800
Recreational area	200
Powerlines	40[b]
Bridges	400

[a] Width of a band on one side of a linear feature, or the radius around a point.
[b] Increase these widths to at least 100 m for whooping cranes.

Broad-scale Evaluations

The second objective of the workshop was to modify existing information into suitability criteria that can be applied over large geographic areas, using maps from the U.S. Fish and Wildlife Service's National Wetland Inventory Program or using other remotely sensed information. At this level of resolution, the concept of macrohabitat selection should be addressed. In macrohabitat selection, extrinsic or extra-habitat constraints, such as accessibility, are believed to be more important than intrinsic or within-habitat constraints, such as food (Hutto 1985). Based on this concept, workshop participants identified a set of criteria slightly different from those described for site-specific evaluations, but used the same habitat characteristics.

Wetland System Descriptor Component

The Cowardin et al. (1979) classification system treats wetlands in a hierarchical structure, beginning at the system level. For this discussion, the two systems of interest are Lacustrine and Palustrine (Riverine Systems were not addressed at the Fort Collins workshop).

Wetland Class Descriptor Component

Below the system level is the wetland class descriptor (Cowardin et al. 1979). Cranes generally avoid rocky substrates and heavily vegetated sites. For this exercise, Unconsolidated Bottom and Emergent Wetland (Nonpersistent)were the only wetland classes within the Lacustrine System assumed suitable for roosting cranes. Within the Palustrine System, workshop participants assumed that the following classes have potential suitability: Unconsolidated Bottom, Unconsolidated Shore, and Emergent Wetland (Persistent and Nonpersistent).

Water Regime Component

The final level of detail in this classification system is an attempt to describe the water regime of the wetland (Cowardin et al. 1979). Because workshop participants were interested in describing potential habitat in broad geographic terms, they focused on the more permanent water regimes that would supply habitat in most years. The more permanent water regime modifiers selected as having potential suitability include semipermanently flooded, intermittently exposed, permanently flooded, and artificially flooded (ponds, lakes, and reservoirs) wetlands. Cranes readily use less permanent wetlands if available. These water regimes include temporarily, intermittently, and seasonally flooded wetlands.

Size Component

Wetland size was the last criterion selected for broad-scale evaluations. Whooping cranes will use a wide variety of wetland classes, water regimes, and sizes. Size of wetland and how it relates to habitat suitability are poorly understood, but for this model, size is defined at 3.14 ha for a suitable wetland. This value was obtained by assuming that a wetland with a minimum radius of 100 m would permit cranes to roost in the center, at least 100 m from any onshore disturbance. The minimum width of any zone of influence around a potential disturbance feature was set at 100 m for site-specific evaluations.

Application of Suitability Criteria

Site-specific Evaluations

The suggested mechanism for application of the suitability criteria for site-specific evaluations involves an elimination process. The criteria can be applied in any order to achieve the same estimate of wetland suitability, but the order presented here may avoid unnecessary application of some criteria to what would be a totally unsuitable wetland for roosting whooping cranes.

First, some determination of the proximity of existing human activity centers (treated as types of disturbances in Table 4) should occur. If the entire wetland is within the zone of influence (100–800 m) of an activity center, the site is assumed unsuitable and no further evaluation is necessary. Only that portion of the wetland outside the appropriate zone of influence should receive further evaluation.

If the remaining wetland is >0.04 ha, the following steps should be taken (wetlands <0.04 ha are assumed to have no roosting value). All areas of exposed mudflats and tall (>1 m) emergent vegetation should be identified on a map of the wetland. Next, an isopleth should be added to the map to identify the location of water >30 cm in depth. Areas on the map with water depths >30 cm are assumed to have no roosting value (SIWD). A band 20 m in width should be added adjacent to mudflats and emergent vegetation >1 m, and surface water within that band should also be eliminated from further evaluation (SIHV).

At this point, the size criterion should be applied to the remaining usable wetland area. Wetlands with a usable area >1 ha receive a suitability index value of 1.0 (Fig. 4). Usable areas >0.04 ha but <1 ha receive a value as indicated in Fig. 4 (SIWS).

Within the remaining wetland area, a straight line, which identifies the maximum distance between the nearest visual obstruction outside the basin and the potential roosting area, should be drawn on the evaluation map (Fig. 5). This distance should be compared to SIHV, and the appropriate suitability index for roosting should be determined. This value

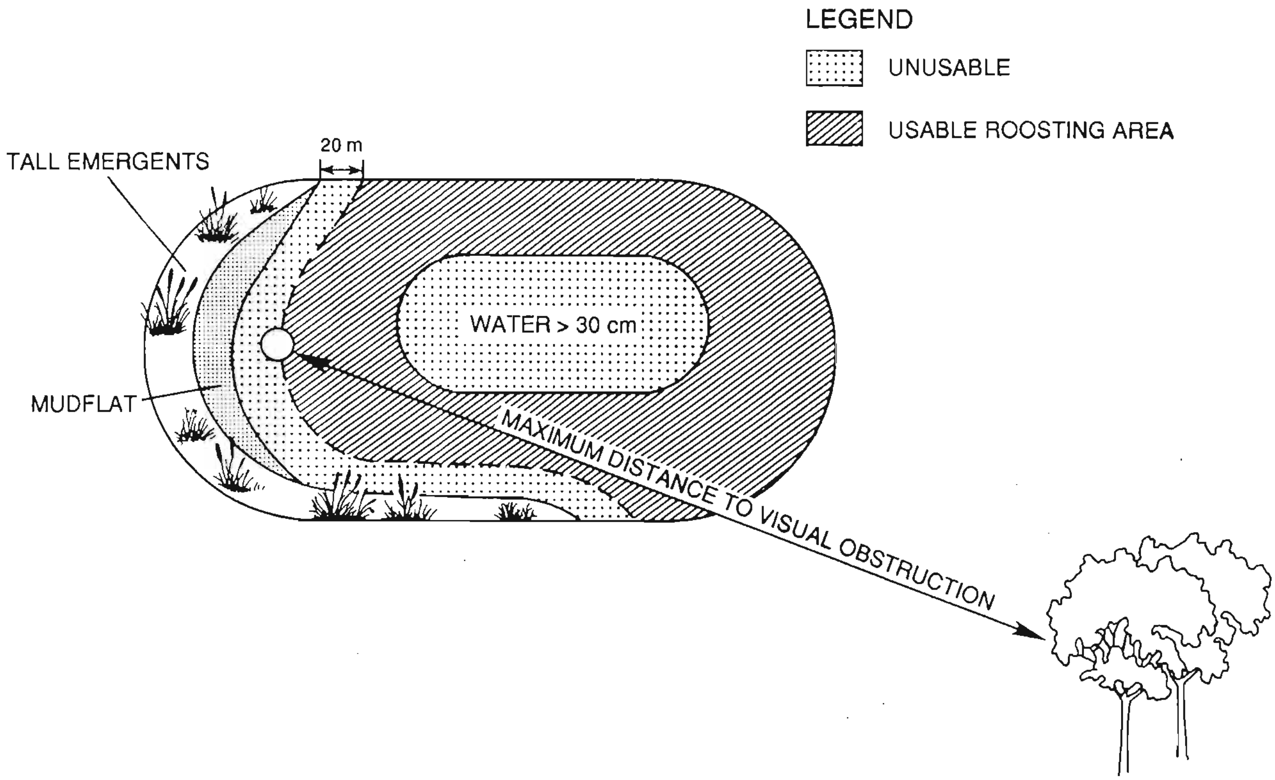

Fig. 5. An example application of the maximum distance between usable roosting areas and a visual obstruction outside the wetland basin.

is then multiplied by the suitability index determined for size in the previous step, to obtain a single suitability value for the wetland. Different wetlands can be compared by multiplying their final suitability value by their respective usable area. This composite estimate of quantity and quality can then be compared.

The approach described above does not deal with food. As previously mentioned, the relation between food availability and roost-site suitability is unclear. Food may enhance a nontraditional stopover site, but may not be necessary for its selection and use as a roost site for short periods. I assumed that sites used for longer periods or used traditionally supply food for whooping cranes. Individual users of this model must determine the value of this criterion and either apply the relation described here or develop an appropriate analysis technique for food availability.

Broad-scale Evaluations

The discussion of broad-scale evaluations defines optimum conditions with four binary suitability criteria. In this approach, a wetland is either suitable (1) or unsuitable (0). Suitable wetlands are large (at least 3.14 ha) and must be classified as Lacustrine (Unconsolidated Bottom and Nonpersistent Emergent Wetland) or Palustrine (Unconsolidated Bottom, Unconsolidated Shore, and Nonpersistent and Persistent Emergent Wetlands), with either semipermanently flooded, intermittently exposed, permanently flooded, or artificially flooded water regimes. These regimes favor more permanent wetlands and therefore provide a conservative estimate of roost-site availability. Participants decided to apply these criteria on a township basis throughout both migration corridors. This suitable wetland per unit area constraint can be adjusted as users become familiar with the behavior of the criteria.

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