BIOLOGICAL REPORT 82(10.154)
SEPTEMBER 1987

HABITAT SUITABILITY INDEX MODELS: OSPREY

n and Wildlife Service

. Department of the Interior

Biological Report 82(10.154)
September 1987

HABITAT SUITABILITY INDEX MODELS: OSPREY

by

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Suggested citation:

Vana-Miller, S.L. 1987. Habitat suitability index models: osprey. U.S. Fish Wildl. Serv. Biol. Rep. 82(10.154). 46 pp.

PREFACE

This document is part of the Habitat Suitability Index (HSI) model series [Biological Report 82(10)], which provides habitat information useful for impact assessment and habitat management. Several types of habitat information are provided. The Habitat Use Information section is largely constrained to those data that can be used to derive quantitative relationships between key environmental variables and habitat suitability. This information provides the foundation for the HSI model and may be useful in the development of other models more appropriate to specific assessment or evaluation needs.

The HSI Model section documents the habitat model and includes information pertinent to its application. The model synthesizes the habitat use information into a framework appropriate for field application and is scaled to produce an index value between 0.0 (unsuitable habitat) and 1.0 (optimum habitat). The HSI Model section includes information about the geographic range and seasonal application of the model, its current verification status, and a list of the model variables with recommended measurement techniques for each variable.

The model is a formalized synthesis of biological and habitat information published in the scientific literature and may include unpublished information reflecting the opinions of identified experts. Habitat information about wildlife species frequently is represented by scattered data sets collected during different seasons and years and from different sites throughout the range of a species. The model presents this broad data base in a formal, logical, and simplified manner. The assumptions necessary for organizing and synthesizing the species-habitat information into the model are discussed. The model should be regarded as a hypothesis of species-habitat relationships and not as a statement of proven cause and effect relationships. The model may have merit in planning wildlife habitat research studies about a species, as well as in providing an estimate of the relative suitability of habitat for that species. User feedback concerning model improvements and other suggestions that may increase the utility and effectiveness of this habitat-based approach to fish and wildlife planning are encouraged. Please send suggestions to:

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ACKNOWLEDGMENTS

I gratefully acknowledge the assistance and support of Patrick J. Sousa, National Ecology Research Center, throughout the development of this model, from securing funding to editorial advice. In addition, Mr. Sousa's commitment to the publication of this model is greatly appreciated.

I would like to thank the following individuals for their review of this model:

Dr. Charles J. Henny, U.S. Fish and Wildlife Service, Patuxent Wildlife Research Center, Corvallis, OR

Dr. Donald R. Johnson, University of Idaho, Moscow

Dr. Sergej Postupalsky, University of Wisconsin, Madison

Dr. Robert S. Cook, Colorado State University, Fort Collins

Dr. Ronald A. Ryder, Colorado State University, Fort Collins

Dr. Richard D. Laven, Colorado State University, Fort Collins

The cover of this document was illustrated by Jennifer Shoemaker. Word processing was provided by Dora Ibarra, and figures were prepared by Brenda Heidebrecht. Kay Lindgren assisted with literature search and acquisition.

Partial funding for the completion of this model was provided by the National Ecology Research Center, Fort Collins, CO.

OSPREY (*Pandion haliaetus*)

HABITAT USE INFORMATION

General

The osprey (*Pandion haliaetus*) "is widely distributed throughout the world and has been divided into five subspecies" (Bent 1937:352); more recently, Prevost (1983) recognized four subspecies. Only one subspecies, *P. h. carolinensis*, occurs in the United States and Canada although *P. h. ridgwayi* occurs in the Bahamas, the Yucatan Peninsula, and Belize (Prevost 1983). This cosmopolitan subspecies "breeds in North America from northwestern Alaska, northern Yukon, western and southern MacKenzie, northern Saskatchewan, northern Manitoba, northern Ontario, central Quebec, central Labrador and Newfoundland south locally to Baja California (both coasts), the Tres Marias Islands (off Nayarit), Sinaloa, central Arizona, southwestern and central New Mexico, southern Texas, the Gulf coast, and southern Florida..." (American Ornithologists' Union 1983:101). It "winters in the Americas from central California, southern Texas, the Gulf coast, Florida and Bermuda south through middle America...the West Indies and South America (also the Galapagos Islands) to southern Chile, northern Argentina and Uruguay" (American Ornithologists' Union 1983:101). North American ospreys are migratory throughout most of their range (Henny and Van Velzen 1972; Kennedy 1973; Melquist et al. 1979) "...except for the population[s] of South Florida, Baja California, and the Pacific coast of Mexico which are resident ..." (Prevost 1983:160).

Ospreys occur "primarily along rivers, lakes, and sea coasts" (American Ornithologists' Union 1983:100), estuaries, "...sometimes [at] small streams and ponds" (Brown and Amadon 1968:196), or any body of water where fish, their principal food, are available (Bailey and Niedrach 1965). Five major breeding concentrations currently exist in the United States, totaling around 8,000 nesting pairs (Henny 1983). The populations are (in order of abundance): Atlantic coast, Florida and the Gulf coast, Pacific Northwest, western Interior, and Great Lakes.

Food

Fish that frequent shallow waters or occur near the surface of deeper waters are most often taken by ospreys (Bent 1937; Swenson 1978). Ample areas of clear, unobstructed (above and below the water surface), shallow water appear important to efficient foraging, where prey species are more visible and thus vulnerable to osprey attack (Dunstan 1967; Postupalsky and Stackpole 1974; Prevost 1977). Waters choked with extensive emergent and submergent vegetation reduce prey visibility and fishing success (Postupalsky and Stackpole 1974; Prevost 1977). Dense overhanging vegetation along the shorelines of rivers and lakes can be a problem to foraging ospreys by reducing their view of the water surface (Hynes 1970). Visibility also is reduced when waters are heavily shaded or turbid (Flook and Forbes 1983).

Ospreys have been observed using two methods of hunting (Dunstan 1967). Ospreys often perch in an overhanging tree or other prominent structure, such as a rock along the shoreline of a lake or river (Brown and Amadon 1968; Prevost 1977), and then swoop to the water surface with only their feet and legs entering the water (Dunstan 1967). When hunting over open water away from the shore, ospreys fly approximately 10 to 35 m above the water, searching the surface for fish (Grosvenor and Wetmore 1934; D.S. MacCarter 1972). When prey is sighted, the osprey hovers briefly in flight, with rapidly beating wings, then plunges downward into the water, sometimes diving as far as 1 m below the surface (Poole and Spitzer 1983).

Reservoirs often provide improved foraging conditions over rivers and oligotrophic lakes because of a larger percentage of still, shallow, open water with an abundant fish population and reduced turbidity; the latter results in increased water clarity and higher visibility of fish (Roberts 1969; Van Daele et al. 1980; Swenson 1981b; Flook and Forbes 1983; Henny 1983). A comparison of foraging times and nesting densities between free-flowing river habitat and three river impoundments on the upper Missouri River, Montana, indicated a more readily available food source and higher nesting densities at the impoundments (Grover 1983). The increased prey availability may have resulted from decreased water turbidity and an increase in still, shallow areas (Swenson 1981b). A rippled water surface appears to reduce prey visibility (Grubb 1977). In a 3-year study of an osprey breeding population at Cascade Reservoir, Idaho, osprey productivity was highest during the year of the lowest water levels, suggesting that prey were more available in the low water years (Van Daele and Van Daele 1982). However, Postupalsky (Department of Wildlife Ecology, University of Wisconsin, Madison, WI; pers. comm.) observed just the opposite during low-water years in Michigan. Many shallow areas became exposed or choked with aquatic vegetation. The extent of the most profitable foraging sites was thus greatly reduced and resulted in lower osprey productivity in dry, low-water years.

Benthic or bottom-feeding fishes are particularly vulnerable prey because they are slow and least wary of attack from above (Swenson 1979b; Alt 1980). Haywood and Ohmart (1986) found that stream characteristics were related directly to prey vulnerability and availability; shallows and riffles adjacent to pools provided forage for benthic-feeding fish and subsequently drew the fish nearer to the water surface, increasing their vulnerability. Benthic-feeders were major prey species for osprey populations in Idaho (Schroeder 1972; Van Daele and Van Daele 1982), Wyoming (Alt 1980), Montana (D.S. MacCarter 1972; Grover 1983), and California (Garber 1972; French and Koplin 1977).

The particular species of fish is apparently not critical, as ospreys are known to consume a variety of species (Bent 1937) (Table 1). Rather, the abundance or availability of a particular fish species determines what is taken (Melquist 1974; Prevost 1977; Flook and Forbes 1983), as well as where osprey foraging activities are concentrated (Bent 1937; Newton 1979). Ospreys

Table 1. Freshwater fish species consumed by ospreys by reference and location.

Reference	Location	Prey species[a]
D.S. MacCarter (1972)	Flathead Lake, Montana	largescale sucker*, mountain whitefish*, lake whitefish*, yellow perch (*Perca flavescens*), peamouth, cutthroat trout, black bullhead, pumpkinseed
Grover (1983)	Missouri River, Montana	white sucker* (*Catostomus commersoni*), longnose sucker* (*C. catostomus*), common carp, rainbow trout, brown trout (*S. trutta*), mountain whitefish, yellow perch
Alt (1980)	Grand Teton - Yellowstone National Parks	Utah sucker*, Utah chub (*Gila atraria*), cutthroat trout
Swenson (1975)	Yellowstone National Park	cutthroat trout*, longnose sucker
Lind (1976)	Deschutes National Forest, Oregon	tui chub*, rainbow trout*, brook trout*, kokanee (*Oncorhynchus nerka*), coho salmon, mountain whitefish
Hughes (1983)	Fern Ridge Reservoir, Oregon	common carp*, black crappie

(Continued)

Table 1. (Concluded)

Reference	Location	Prey species[a]
Van Daele and Van Daele (1982)	Long Valley, Idaho	brown bullhead*, northern squawfish*, yellow perch, rainbow trout, coho salmon, kokanee, mountain whitefish, largescale sucker
Schroeder (1972)	Northern Idaho	northern squawfish*, peamouth*, kokanee, trout (*Salmo* sp.), char (*Salvelinus* sp.), brown bullhead, black crappie, bluegill, largescale sucker
Garber (1972)	Northeastern California	tui chub*, rainbow trout*, brown bullhead, brown trout, coho salmon, Tahoe sucker
Dunstan (1967, 1974)	Chippewa National Forest, Minnesota	black crappie*, white crappie, (*Pomoxis annularis*), bluegill*, yellow perch, largemouth bass (*Micropterus salmoides*), pumpkinseed
Postupalsky (pers. comm.)	Fletcher Pond, Michigan	bullhead* (*Ictalurus* sp.), bluegill*, crappie* (*Pomoxis* sp.), northern pike (*Esox lucius*), yellow perch, rock bass (*Ambloplites rupestris*)
Flook and Forbes (1983)	Creston, British Columbia	black bullhead*, pumpkinseed, yellow perch, largemouth bass, northern squawfish

[a]Common and scientific names follow Robins et al. (1980). Major prey species are denoted by an asterisk (*). Scientific names are included for species not mentioned in text.

actually use a relatively small proportion of the fish fauna present, usually two or three species, as observed at Flathead Lake, Montana (D.S. MacCarter 1972). There, largescale suckers (Catostomus macrocheilus) and whitefish (Prosopium williamsoni and Coregonus clupeaformis) composed 59.4% and 26.1% of 241 observed prey items over 2 years. In Grand Teton National Park, Wyoming, catostomids, primarily Utah sucker (C. ardens), accounted for 73.7% of all fish bones collected from osprey nest sites (Alt 1980); cyprinids and salmonids composed 17.0% and 10.3%. The diet of ospreys in western Oregon consisted of 67% common carp (Cyprinus carpio) and 33% black crappie (Pomoxis nigromaculatus) (Hughes 1983). Fifty-two percent of fish taken by ospreys in northern Idaho were northern squawfish (Ptychocheilus oregonensis) or peamouth chub (Mylocheilus caurinus), while salmonids accounted for 18% and ictalurids 13% of the diet (Schroeder 1972). Tui chub (Gila bicolor) composed 48% of fish found in northeastern California osprey nests; 34% were rainbow trout (Salmo gairdneri) and 18% were Tahoe suckers (C. tahoensis) (Garber 1972). In north-central Minnesota, bluegills (Lepomis macrochirus) and black crappie composed 35.2% and 31.0% of osprey prey remains collected (Dunstan 1974). The major prey item for ospreys in southeast British Columbia was black bullhead (Ictalurus melas) (83%), followed by pumpkinseed (Lepomis gibbosus) (10%) (Flook and Forbes 1983).

Size is very important in determining selection for a particular fish species over more abundant species of less desirable length (Lind 1976; Swenson 1978; Van Daele and Van Daele 1982). Although ospreys usually select benthic-feeding fishes over other equally available fishes because they are relatively easy to capture (Swenson 1979b), "any medium-sized (15-35 cm) fish feeding near the surface is predisposed to osprey attack" (Hughes 1983:272). Along the southern half of Yellowstone Lake, Wyoming, cutthroat trout (Salmo clarki) 25 to 35 cm in length composed 83% of the diet (Swenson 1978). There, ospreys foraged mainly over deep water; immature trout in Yellowstone Lake are found near the surface of deeper water, with mature trout frequenting the shallow waters (Benson 1961; Dean and Varley 1973). Ospreys captured 43% tui chub and 57% salmonids at Crane Prairie Reservoir, Oregon (Lind 1976); however, >80% of gill-netted fish at the reservoir, over a 10-year period, were tui chub (Campbell and Locke 1961-1970). This species was probably not used in proportion to its apparent numbers because of its size; the majority of tui chub in the reservoir were ≤15 cm in length, whereas rainbow and brook trout (Salvelinus fontinalis) averaged 27 and 23 cm (Campbell and Locke 1966-1970; Lind 1976).

In west-central Idaho, the diet of ospreys consisted primarily of brown bullheads (Ictalurus nebulosus) (37.7%), followed by salmonid species (20.8%) and northern squawfish (19.3%) (Van Daele and Van Daele 1982); 42.1% and 46.7% of all fish taken were 11 to 20 cm and 21 to 30 cm in length. The diet of these ospreys in Idaho changed among and within years, probably as a result of changes in prey availability. Although brown bullheads composed only 7.6% of gill net captures, their availability increased because they rested near the surface of the water on warm days, whereas most suckers caught in gill nets were too large to be easily captured by ospreys (Van Daele and Van Daele 1982). The mean lengths for the two major prey species of ospreys in Minnesota were 12.8 cm for bluegill and 17.2 cm for black crappie (Dunstan 1974). Fish caught by ospreys in southwestern Montana averaged 22.0 cm in length (Grover

1983). The average length of fish delivered to osprey nests at Eagle Lake, California, was 31 cm (Garber 1972). Fish preyed on by ospreys nesting along major northwestern California streams ranged from 22.9 to 40.6 cm (French 1972).

Although ospreys feed almost entirely on live fish (Bent 1937; Brown and Amadon 1968), ospreys have been observed carrying a variety of nonfish prey including aquatic and terrestrial birds, small mammals, reptiles, amphibians, and invertebrates (Bent 1937; Wiley and Lohrer 1973; Melquist 1974; Swenson 1975). Remains of these nonfish prey items often are observed in the nest and often are brought to the nest as building or lining material, rather than as prey (Postupalsky, pers. comm.).

Water

Dietary water is assumed to be adequately available to ospreys during foraging and in food digestion. Water requirements of nestlings are satisfied by water contained in their food, whereas adults may occasionally drink, especially on hot days (Postupalsky, pers. comm.).

Cover

The literature does not indicate a need for cover during the breeding season other than the presence of at least one suitable perch in the vicinity of the nest (Schroeder 1972). The perch can be any elevated structure (Garber 1972) for sunning and feeding as long as it is within sight of the nest (Zarn 1974). It often is a sturdy branch protruding to the side or above the nest, or a nearby tree of a height similar to the nest tree (Lind 1976; Van Daele et al. 1980; Mullen 1985). Other cover needs, such as protection from extreme weather conditions, are assumed to be accounted for in the reproductive habitat requirements.

Reproduction

Tall dead snags surrounded by water provide ideal nesting sites for inland-breeding ospreys (Berger and Mueller 1969; Roberts 1969; Henny et al. 1978a). Ospreys also commonly nest in live trees, some with dead or missing crowns (French 1972; D.L. MacCarter 1972; Postupalsky 1977b); on utility poles (Prevost 1977; Sindelar 1977; Odom and Guthrie 1980); on rock pinnacles and cliffs (Bailey and Niedrach 1965; Swenson 1981a); on duck blinds, buoys, and channel markers (Reese 1970; Wiemeyer 1971); on pilings (Melquist 1974; Schroeder and Johnson 1977); and on artificial nesting platforms (Rhodes 1972; Postupalsky and Stackpole 1974; Schaadt and Rymon 1983; Scott and Houston 1983).

The particular species of nest tree, the height of the nest tree or structure, and the surrounding tree density are highly variable and do not appear critical to osprey nest site selection (Bent 1937; Swenson 1975; Richardson 1980). Rather, ospreys seem to choose stable nesting structures with maximum visibility from the nest, which is generally afforded by a tree or structure with a basket-shaped or flat top and a height similar to or taller than surrounding structures (Garber 1972; Postupalsky and Stackpole 1974; Swenson 1975; Lind 1976; Richardson 1980; Grover 1983). Tree species chosen as nest sites include a variety of deciduous and coniferous species.

In west-central Idaho, all osprey nests had a relatively unobstructed view of their surroundings and at least one nearby perch (Van Daele and Van Daele 1982); 82% of the nests were >20 m in height and 66% of the nests were located on snags. The majority of nests in northern Idaho and northeastern Washington were located on black cottonwoods (Populus trichocarpa), pilings, conifers, and utility poles (Melquist 1974; Schroeder and Johnson 1977). Piling nests, some only 3 m above the water surface, had high reproductive success (Schroeder 1972). An osprey population in western Montana nested predominantly at the apex of snags 14 to 20 m in height; selection was apparently related to snag availability rather than osprey preference for a particular species of nest tree or snag, and all nest trees had at least one perch on or near the nest tree (Mullen 1985). Nest tree heights elsewhere in Montana were highly varied; trees at Flathead Lake ranged from 7.6 to 39.6 m in height (D.L. MacCarter 1972), whereas tree heights on the upper Missouri River ranged from 4.8 to 27.2 m (Grover 1983). Even with this high variability, all upper Missouri River nest trees were as tall as, or taller than, surrounding trees. Tree density at the river nest sites ranged from 4.4 to 453.0 trees/ha, suggesting its minor importance in nest site selection. In most areas where artificial structures and power/telephone poles were used, there were no trees within 100 m of the nest structure (Grover 1983). Ponderosa pines (Pinus ponderosa) with somewhat flattened, basket-shaped tops were used exclusively by ospreys nesting over land near Crane Prairie Reservoir, Oregon, even in areas where flat-topped trees were relatively scarce (Lind 1976). Fifty-six percent of the pine trees with nests were snags, whereas all nests over the water were on snags. Land and lake nests in the area averaged 36.6 and 9.0 m in height.

In northern Minnesota, nests were primarily on the tops of dead or partially dead conifers and usually on the tallest tree in an open area (Dunstan 1967; Mathisen 1977); the heights of 77 nests ranged from 9 to 27 m (Dunstan 1973). Osprey nest heights at Yellowstone National Park ranged from 6 to 33 m (Swenson 1975; 1981a); most nests were in dead trees with broken tops, which were taller than the surrounding trees. Nest locations ranged from dense forests to open burned areas; tree density at the nest sites ranged from 3 to 1,429 trees/ha. A similar wide range of tree densities also was noted by Richardson (1980). In addition to the tree nests, 10 occupied nests were located on rock pinnacles in the Grand Canyon of the Yellowstone River (Swenson 1981a). Northeastern California ospreys nested on dead snags and live trees with equal frequency; nest heights ranged from 2 to 49 m (Garber 1972). In New Hampshire, ospreys nested primarily in large, dead, white pine (Pinus strobus) trees with broken tops (Smith and Ricardi 1983). The nest trees were significantly taller than the surrounding vegetation and ranged from 15.7 to 30.3 m in height. Nest heights in the Great Whale Region of Quebec were 2 to 3 m, 6 to 8 m, and 30 m for nests on boulders, black spruce (Picea mariana) trees, and a rock pillar (Bider and Bird 1983).

Osprey breeding density in some regions is limited by the shortage of nest sites (Andrewartha and Birch 1954); this is suggested by immediate increases in breeding densities following the erection of nesting platforms (Rhodes 1972; Garber et al. 1973; Newton 1980). Ospreys readily adapt to artificial nesting structures as is evident by their now widespread use, particularly in the Great Lakes and western interior (Garber et al. 1973; Postupalsky and Stackpole 1974; Henny 1977b, 1983). Some ospreys appear to prefer the artificial structures, selecting them over nearby natural nesting sites. In Long Valley, Idaho, ospreys frequently nested on power poles, although natural sites were available (Melquist 1974; Van Daele 1980). Artificial platforms were installed on several of these poles to guard against the danger of electrocution.

Artificial nesting structures often enable breeding ospreys to use habitat lacking adequate nest sites but with suitable food resources and minimal human activity (Henny 1977b; Newton 1980). Fletcher Pond, a storage reservoir, is the site of Michigan's largest osprey colony (Postupalsky and Stackpole 1974). The installation of artificial nesting platforms reversed a downward trend in the population; from 1966 to 1972 the number of nesting pairs increased from 11 to 18. Overall productivity on artificial platforms was better than that on natural nests in Michigan; nestling mortality decreased from 28% to 7% by elimination of nest blowdowns (Postupalsky and Stackpole 1974). Fledglings were placed at artificial nesting platforms using the hacking technique to restore osprey populations to areas of their former breeding range in the Tennessee Valley (Hammer and Hatcher 1983) and the Pocono Mountains of northeastern Pennsylvania (Schaadt and Rymon 1983). The young ospreys translocated to Tennessee supplemented two active nests that had been relocated from natural to more secure artificial nest sites; this resulted in the first successful fledging there in 20 years (Hammer and Hatcher 1983).

Artificial nesting platforms are typically installed on appropriate live trees with dead or missing crowns, sturdy snags, or on artificial supports (Roberts 1969; Garber et al. 1973; Postupalsky 1978; Eckstein et al. 1979). Artificial nest structures in Idaho consisted of 1-m^2 platforms placed atop posts 8 m in height, some with a 1-m perching arm (Van Daele et al. 1980). A tripod-type platform has proven successful for nesting ospreys in northern Michigan; the 0.9-m diameter platform is mounted on three steel pipe legs and sits 3.5 to 5.0 m above the water (Postupalsky and Stackpole 1974; Postupalsky, pers. comm.). Nesting platforms in north-central Colorado were plywood disks approximately 1 m in diameter with 15-cm-long dowels placed around the perimeter to keep nesting material in place (Postupalsky 1978; G.R. Craig, Colorado Division of Wildlife, Fort Collins, CO; pers. comm.). Live trees of the proper height relative to surrounding trees were topped for platform placement either at new locations or near existing deteriorating nest sites (Craig, pers. comm.).

Ospreys usually maintain one or more alternate or "frustration" nests in addition to their main nest (D.L. MacCarter 1972; Swenson 1975; Mullen 1985). These nests may be on adjacent trees or snags, or up to 2 km away if suitable nearby supports are absent. The term "frustration nest" describes a specific type of alternate nest; a nesting pair may build a new nest later in the nesting season after experiencing nesting failure at their original nest site (Postupalsky 1977a).

Interspersion

Ospreys are less territorial than other fish-eating birds, such as the bald eagle (*Haliaeetus leucocephalus*) (Swenson 1975) and the belted kingfisher (*Megaceryle alcyon*) (Prose 1985). Breeding ospreys usually defend only the nest currently in use or under construction, the immediate surroundings, and accessory perches (Swenson 1975; Postupalsky 1977a).

For several raptors, including the osprey, breeding density is broadly related to food supply (Lack 1954; Newton 1976). Nesting density varies between regions even in suitable habitat where ospreys are not restricted by lack of nest sites or harassment from humans. Differences in density are most likely related to food availability (Wynne-Edwards 1962; Newton 1980; Eriksson 1986). Osprey densities are greater and increasing in areas where food resources are concentrated, as demonstrated by the increase in inland osprey populations at or near new reservoirs in the western United States (Henny 1977b, 1983).

Reservoir construction appears to have improved habitat of the upper Missouri River, Montana, for ospreys; nesting densities at three reservoirs were higher compared to densities along the free-flowing river (Grover 1983). In Oregon, osprey nests were found on or adjacent to 11 reservoirs (Roberts and Lind 1977). A large concentration of approximately 50 osprey pairs is known to nest at Cascade Reservoir, Idaho; this area contained <12 nests in the late 1940's (Larrison et al. 1967; Van Daele and Van Daele 1982). This population has increased since the formation of the reservoir in 1948 and subsequent habitat improvement. More recently, 49% of inland breeding ospreys in northern California nested along reservoirs, habitat that was not available 75 years ago (Henny et al. 1978b).

Ospreys are known to breed colonially as well as solitarily (Ames and Mersereau 1964; Dunstan 1967; Garber 1972). Whether the reported nesting colonies are actually colonies is debatable (Postupalsky, pers. comm.). Colonial breeding is generally regarded as an adaptation to improve foraging success or reduce losses from predation (Lack 1968). Although not proven, colonial breeding in ospreys might be adaptive through information exchange when fish abundance is unpredictable or fish are present in dense concentrations (Eriksson 1986), such as in shallow areas and at dam sites, or when potential nesting sites are concentrated in relation to potential feeding areas (Ward and Zahavi 1973). In these instances, osprey nesting territories are grouped near a waterbody where foraging is largely centered in a common area (Swenson 1975; Newton 1976; MacCarter and MacCarter 1979).

Colonial nesting ospreys are more prevalent near coastal waters (Ames and Mersereau 1964; Reese 1977; Spitzer and Poole 1980), although nesting concentrations are not uncommon at inland lakes and reservoirs (Garber 1972; D.S. MacCarter 1972; Swenson 1975; Lind 1976; Postupalsky 1977b; Van Daele and

Van Daele 1982). Generally, nesting territories close to these larger waterbodies are smaller and overlapping, with nests as close as 55 to 65 m (Brown and Amadon 1968), because of the proximity to abundant fish (Swenson 1975, 1978; Newton 1976; Alt 1980). Flathead Lake, Montana, supported two large nesting concentrations at the northern end and the south-central part of the lake, with additional nest sites scattered between; four to seven osprey pairs were observed nesting on about 2 ha of land (D.L. MacCarter 1972). In 1980, 20 to 22 osprey pairs were recorded nesting at Lake Almanor, California; 25 of the 39 nest sites existing in the area were within 400 m of the shore, with the remaining sites measured at distances up to 3.9 km away (Airola and Shubert 1981). Osprey nesting populations in Idaho (Van Daele et al. 1980) and Wyoming (Swenson 1975) were concentrated on or around the primary foraging sites, Cascade Reservoir and Yellowstone Lake, respectively.

Power line pylons were the preferred locations for colonial nesting in northeastern Nova Scotia, as only 4 of 26 nests were within 3 km of a large waterbody (Prevost 1977). Along a 3-km segment of power line, four osprey nests were within 800 m. At Lake Umbagog, in northeastern New Hampshire, nest sites ranged from 66 to 458 m from the water (Smith and Ricardi 1983). The largest concentration of osprey nests in Oregon is centered at Crane Prairie Reservoir and the surrounding 4.6 km of forest (Roberts and Lind 1977). From 1970 to 1971, there were active "lake" nests as close as 80 m (Lind 1976); however, during the 1969 nesting season, two osprey pairs nested successfully within 46 m of each other (Roberts 1970). An osprey population of 50 to 59 pairs inhabits Lake Ellis Simon, a 600-ha freshwater lake in North Carolina; distances between nest sites ranged from 100 to 450 m (Hagan 1986). In the Chippewa National Forest, Minnesota, ospreys usually nest as isolated pairs, although semicolonial nesting occurs in some areas, all closely associated with water (Dunstan 1973; Mathisen 1977). Nine nests were found within 1.6 km of one another (Mathisen 1977). Any advantage to colonial nesting ospreys from these large foraging waterbodies may be offset by increased intraspecific competition for fish because of the higher nesting densities (Eriksson 1986).

Where ospreys breed solitarily, as in river-nesting pairs, prey are rather evenly distributed over the available foraging areas (Eriksson 1986). These ospreys, particularly those with forest nests, appear to defend larger nest territories (French 1972; Lind 1976; Richardson 1980; Grover 1983); food resources are more evenly distributed but often less abundant and at greater distances from the nest sites (Newton 1976). Twenty-four osprey nests were located within 1.6 km of the Rogue River, Oregon; 13 of these were found along a 27.2 km portion of the river (Roberts and Lind 1977). The average distance between occupied osprey nests along the Snake River, Wyoming, was 8.1 km; nests at four lakes were noticeably closer together with a combined average of 2.9 km between lake nest sites (Richardson 1980). Successful forest nests at Crane Prairie Reservoir, Oregon, averaged 2.31 km apart, although two osprey pairs nested successfully 322 m from each other (Lind 1976). The distance between osprey nest sites along major forested streams in northwestern California averaged 8 km (French 1972); the range of 1.6 to 22.4 km between adjacent nesting territories suggested that intraspecific conflict occurs at some foraging sites during nest site selection, resulting in the exclusive use of one or more fishing areas by each nesting pair.

Apparently, abundant but distant food resources are often worthwhile to ospreys because many birds expend the extra energy required to fly farther for food when foraging areas and nesting habitat are optimally suitable (Newton 1976; Van Daele and Van Daele 1982). Ospreys occupied nests on 10 rhyolite pinnacles in the Grand Canyon of the Yellowstone River, Wyoming (Swenson 1981a); these nesting pairs traveled between 4.5 km and 6.5 km to forage on the Yellowstone River. Michigan ospreys have nested up to 6.4 km from the closest waterbody of any size (Postupalsky 1977b). The average distance covered in osprey flights between seven active nest sites and foraging areas was 2.6 km in the Chippewa National Forest, Minnesota (Dunstan 1974). Of 60 osprey nest sites located in northeastern California, 55% were within 1 km of a waterbody, whereas the remaining osprey pairs nested up to 10 km from a lake or reservoir (Garber 1972). Ospreys nesting on the south half of Flathead Lake, Montana, usually traveled 10 km or more to the lower Flathead River to forage (D.L. MacCarter 1972; Klaver et al. 1982). Seventy-nine osprey nests were found at the Creston Valley Wildlife Management Area in southeastern British Columbia at distances up to 3 km from all possible foraging waters (Flook and Forbes 1983). In 1969, nine pairs were found nesting up to 11.2 km from Crane Prairie Reservoir, Oregon (Roberts 1970). The following 2 years, three of four active nests farther than 4.5 km from the water were successful; there was no significant difference between 26 successful and 15 unsuccessful forest nesting attempts relative to the distance between each active nest and the nearest body of water (Lind 1976). In Long Valley, Idaho, no significant differences were noted either in osprey productivity relative to the distance of a nest to fishable water or another active nest; 65% of the nesting ospreys foraged regularly in Cascade Reservoir, some traveling as far as 10 km to do so (Van Daele and Van Daele 1982). In Nova Scotia, Canada, ospreys nesting at Gaspereau Lake shifted their hunting activity and flew up to 12 km to forage in coastal estuaries when fish abundance in the lake decreased (Prevost 1977).

Brood reduction is often associated with low food abundance as well as the distance from colony site to foraging areas because of the potential difficulty in getting adequate quantities of food to the young (Clum 1986; Hagan 1986). At Lake Ellis Simon, ospreys flew 13 to 14 km up to four times a day to primary coastal foraging sites, although freshwater fish were available in the lake itself (Hagan 1986). In the northeast, Spitzer (1978) suggested that reproductive success of an osprey population had been limited in recent years by food availability, and much more severely than in nearby nesting areas that had more diverse feeding habitat. This was supported by observations of ospreys flying 6 to 12 km to suitable foraging areas; at these distances, energetic limitations may have had an effect, explaining brood size reduction in the population (Spitzer 1978).

Ospreys exhibit strong nest-site fidelity, usually returning year after year to the same nesting area to breed (Greenwood 1980; Henny 1983; Poole and Spitzer 1983). Band recoveries from 3-year-old and older ospreys, obtained during the breeding season, indicated that at least 90% of the adult birds returned to the State in which they were hatched or to an adjacent State (Henny and Van Velzen 1972). Males arrive at the nesting areas shortly before females and "are more likely than females to return to their original nesting areas" (Poole and Spitzer 1983:52). Female birds usually disperse farther than males (Greenwood 1980); Spitzer and Poole (1983) found that 10.3% of female ospreys moved >200 km but males did not move beyond 37 km. In Sweden, banding data suggested that 76% of ospreys nested within 125 km of their hatching place; the remaining 24% nested between 300 and 600 km away (Osterlof 1951). Osterlof (1977) noted, however, that some ospreys establish their first breeding territories >1,000 km from their natal areas. A similar review of North American banding data showed that 69% were recovered within 30 km of their hatching place, 25% between 30 and 125 km, and only 6% between 125 and 350 km (Henny 1977b, 1983).

Ospreys usually do not extend their range into new suitable habitat beyond 100 to 125 km of existing nesting concentrations; this directly affects the ability of the species to pioneer new habitat and expand breeding range (Henny 1977b, 1983). Much of the dispersal data, however, pertains to the rather continuous population nesting along the Atlantic coast. The situation in the West is unknown and may be quite different as the population in general is not continuous (C.J. Henny, U.S. Fish and Wildlife Service, Patuxent Wildlife Research Center, Corvallis, OR; pers. comm.). In fact, small and individual osprey colonies have been established at numerous western reservoirs by long-distance dispersers (Henny 1983). Postupalsky (pers. comm.) found that dispersal movements of 100 km are not unusual; movements of up to 400 km have been documented.

Increased food resources provided by reservoirs encourages nesting at the periphery of the present breeding range, as demonstrated by the recent establishment of a small osprey breeding population of 11 pairs in southeastern Montana (Swenson 1981b; Henny 1983). The lack of historical observations of ospreys during the breeding season and the present absence of ospreys nesting along rivers strongly suggest that ospreys did not nest here before reservoirs were created (Swenson 1981b). Migrating ospreys originating in central Canada were probably drawn to the favorable conditions of the reservoirs.

Special Considerations

There has been much discussion as to whether or not human activity negatively affects nesting ospreys. Apparently, some ospreys are able to nest successfully in close proximity to human activity (Schmid 1966; Newton 1976; Poole 1981). Historically, ospreys were described as "equally at home near the shore of some remote wilderness lake, ...in open farming country, or even close to houses" (Bent 1937:352). Osprey nests were commonly found near houses on structures placed by landowners to encourage nesting ospreys, as well as on power poles, chimneys, and windmill towers. "Suburban" ospreys between New York City and Boston nested near highways, heavy boating traffic, and other potentially intense human activity (Poole 1981). Three years of reproductive success for these nesting pairs was not significantly different than that for ospreys nesting in more remote locations with little human activity. Osprey populations elsewhere along the Atlantic coast, including resident ospreys in Florida, nest in close association with humans and often constant, intense human activity (Reese 1970; Spitzer and Poole 1980; Poole 1981). In California, ospreys nested adjacent to roads, a highway offramp, and in a highway median strip and successfully fledged young (French 1972; French and Koplin 1977). Ospreys in western Montana also initiated nesting near roads, houses, and even near an approach corridor for aircraft (Mullen 1985). Continuous boating activities on Yellowstone Lake, Wyoming, appeared to have a minimal effect on osprey nesting success (Swenson 1975). Ospreys also nested successfully in areas frequently and heavily used by humans at Flathead Lake, Montana (D.L. MacCarter 1972), and in northern Idaho (Schroeder 1972). An osprey pair in an urban area of Connecticut nested successfully for 5 years on top of a light tower in a large parking lot adjacent to an amusement park/beach complex (Poole and Spitzer 1983). In the situations described above, ospreys were exposed to continuous human activity throughout the nesting cycle, starting with courtship and nest building (Swenson 1975; French and Koplin 1977).

Studies considering the effects of human activity on ospreys in California (French 1972; Garber 1972; Levenson and Koplin 1984), Idaho (Van Daele and Van Daele 1982), Wyoming (Swenson 1975, 1979a; Richardson 1980), Montana (D.L. MacCarter 1972; Mullen 1985), Minnesota (Dunstan 1973), Maryland (Reese 1977), and the northeast Atlantic seaboard (Poole 1981; Poole and Spitzer 1983) all indicated that tolerance of human activity was dependent on the timing and frequency of such activity and the degree of habituation to the activities. Ospreys initiating nesting in or near an area with human activity may be more tolerant of subsequent human activities than those nesting farther from humans or those that begin nesting with humans absent (Swenson 1975, 1979a; Van Daele and Van Daele 1982).

Sporadic human activity occurring abruptly at critical periods after initiation of osprey nesting appears to affect ospreys most severely (French 1972; Swenson 1975, 1979a; Richardson 1980; Koplin 1981). Ospreys seem most vulnerable to activity during the critical periods of incubation and early nestling stages; alarmed adults that are repeatedly flushed from their nests expose the eggs or nestlings to extreme heat or cold, predators, or even premature fledging of young, which ultimately can lead to embryonic death or increased fledgling mortality (Swenson 1979a; Poole 1981; Van Daele and Van Daele 1982; Levenson and Koplin 1984). In assessing disturbance from human activity, researchers often identified a "critical distance" from the nest beyond which ospreys appear undisturbed by human activity. This distance varied from 0.2 km (Postupalsky, pers. comm.) to 1.5 km (Garber et al. 1973; Swenson 1975; Lind 1976; Van Daele and Van Daele 1982; Levenson and Koplin 1984).

Logging activities, beginning after the onset of nesting and occurring on a temporary basis, were thought to adversely affect nesting success on private timber lands in California (French 1972; Ueoka 1974). Although regular boating at Yellowstone Lake, Wyoming, had a minimal effect on osprey nest success, abrupt recreational use of the lakeshore during the incubation period caused a pronounced decrease in osprey success at lake nests (Swenson 1975, 1979a). Several nests were abandoned in Minnesota during the incubation period; in one area, nest abandonment coincided with abrupt and heavy use of the shoreline beginning in mid-May and lasting through the summer (Dunstan 1973). Remote osprey nests in Connecticut repeatedly showed low hatchability of eggs compared to nests more exposed to human activities; it would seem improved nest success resulted when ospreys at exposed sites became habituated to frequent boating and fishing activities (Ames and Mersereau 1964). In Idaho, ospreys nesting in close proximity to humans usually stayed on their nests longer than those nesting at a greater distance, especially during the incubation period (Van Daele et al. 1980; Van Daele and Van Daele 1982).

HABITAT SUITABILITY INDEX (HSI) MODEL

Model Applicability

Geographic area. This model was developed for the breeding range of migratory ospreys that forage in freshwater habitats (lakes, rivers, and reservoirs) throughout the United States. Ospreys that are resident in southern portions of North America, including Baja California, Mexico, and southern Florida, are excluded. This model specifically addresses the habitat requirements of migratory ospreys breeding in the spring-summer seasons, particularly the effects of human activity experienced on arrival at the nesting area and throughout the nesting cycle.

Season. This model is intended to evaluate the breeding season habitat of migratory ospreys during the April-August nesting season.

Cover types. This model was developed for application in Lacustrine (L) and Riverine (R) cover types (U.S. Fish and Wildlife Service 1981). The 5-km portion of land that borders the open water or associated Palustrine [Forested Wetland (FW), Scrub/Shrub Wetland (SSW), and Herbaceous Wetland (HW)] cover type also is evaluated as additional reproductive habitat. This additional reproductive habitat includes uplands such as Forest (F), Tree Savanna (TS), Shrubland (S), and Shrub Savanna (SS) cover types.

Minimum habitat area. Minimum habitat area is defined as the minimum amount of contiguous suitable habitat that is required before an area will be occupied by a particular species. This information was not found in the literature for ospreys.

Verification level. This model was reviewed by the following individuals:

C.J. Henny, U.S. Fish and Wildlife Service, Patuxent Wildlife Research Center, Corvallis, OR

D.R. Johnson, Department of Biological Sciences, University of Idaho, Moscow, ID

S. Postupalsky, Department of Wildlife Ecology, University of Wisconsin, Madison, WI

R.A. Ryder, Department of Fishery and Wildlife Biology, Colorado State University, Fort Collins, CO

Their review comments and suggestions have been incorporated into the model. However, they do not necessarily endorse all aspects of the model. The model has not been field tested as a predictor of osprey nesting success or other measurable responses of osprey populations or individual ospreys.

Model Description

Overview. The breeding season HSI model for the osprey considers food and reproduction as the primary components of breeding habitat. The model is based on variables that are relatively rapid, easy, and cost-effective to estimate with minimal field sampling. The final HSI value considers the abundance and accessibility of prey and the quality and availability of nesting habitat. Food is evaluated with different variables for lacustrine and riverine cover types. The model assumes that the presence of suitable nesting structures, minimal disturbance from human activity, and access to a waterbody with high fish production provides optimal conditions for nesting ospreys.

The following sections describe the logic and assumptions used to translate habitat information for the osprey into the variables and equations used in the model. The suitability levels of variables and the relationships between variables are also described.

Food component. Osprey breeding habitat suitability is primarily dependent on easy access to an abundant fish population. Specifically, fish standing crop, water surface obstruction, and water clarity in the evaluation area are assumed to be the major factors determining the amount of fish available to a population of nesting ospreys. Because ospreys eat fish almost exclusively, food suitability, and thus habitat suitability, is assumed to increase as the number of available fish increases. However, water clarity generally decreases with increasing waterbody productivity. Thus, highly productive waterbodies may not provide the greatest number of available fish because low water clarity prevents ospreys from seeing their prey or because obstructions prevent them from efficiently attacking prey.

Fish production is difficult to estimate; however, fish standing crop is often measured by State game and fish agencies. With a higher fish standing crop, more potential food would presumably be available to ospreys. Fish standing crop is highly variable between waterbodies. Ploskey et al. (1986) reported a range in mean fish standing crops from 14.08 to 1,775 kg/ha in 327 U.S. reservoirs with surface areas of 202 ha or more. The upper quartile standing crop (value equaled or exceeded by 25% of the reservoirs) of 314 kg/ha from Ploskey et al. (1986) was arbitrarily selected as the standard of comparison for fish standing crop in this model. All lakes and reservoirs with fish standing crops equal to or greater than 314 kg/ha are given a suitability index of 1.0; all lower values are rated proportionately on a 0 to 1 scale (Figure 1). If actual mean standing crop data are not available, reservoir standing crop can be estimated using the equations presented in Ploskey et al. (1986), or other similar sources (e.g., Jenkins 1967, 1970). These equations do not require field sampling; rather, data obtainable from

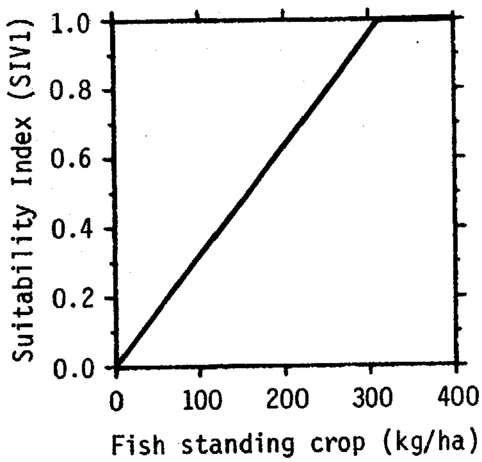


Figure 1. The relationship between fish standing crop in lakes or reservoirs and suitability indices for the osprey.

the U.S. Army Corps of Engineers, the U.S. Geological Survey, and the U.S. Environmental Protection Agency can be used. If standing crop data are not available and the reservoir equations are not appropriate (e.g., northern lakes and reservoirs or small reservoirs and ponds), the Morphoedaphic Index (MEI) (Ryder 1965) may be used to estimate potential fish yield or fish standing crop and, subsequently, food suitability for ospreys.

The MEI (Ryder 1965, 1978, 1982) is often expressed as the ratio:

$$MEI = \frac{TDS}{\bar{Z}}$$

where TDS = total dissolved solids (mg/liter)

$\bar{Z}$ = mean depth (m)

MEI is used to predict fish yield in north-temperate lakes as follows (Ryder et al. 1974): fish yield (kg/ha/yr) = $0.966\sqrt{MEI}$.

A modified form of the MEI substitutes either conductivity or total alkalinity for TDS (Ryder 1964). Peterson (1986) used the MEI to estimate bald eagle food suitability, whereas others have suggested correlations between the MEI and bald eagle nesting densities (Gerrard et al. 1983; Detrich 1986). Studies have shown that the MEI also is significantly related to standing crop of several fish species. Sport fishes compose a higher proportion of the total standing crop as waters become less fertile (lower MEI values) (Jenkins and Morais 1971; Jenkins 1982). At MEI values >20, increases in total standing crop of fish are largely due to higher biomasses of bottom feeders such as common carp (Jenkins 1982), a major prey species of ospreys.

The relationship of MEI to biomass is not constant for all ranges of MEI. Maximum fish yield and biomass generally occur at MEI values of 40 to 100 (Ryder et al. 1974) (Figure 2). At MEI values >100, reservoir fish standing crops gradually decrease (Jenkins 1967), although newer data (Jenkins 1982) show less of a decline than previously described. Lakes or reservoirs with an

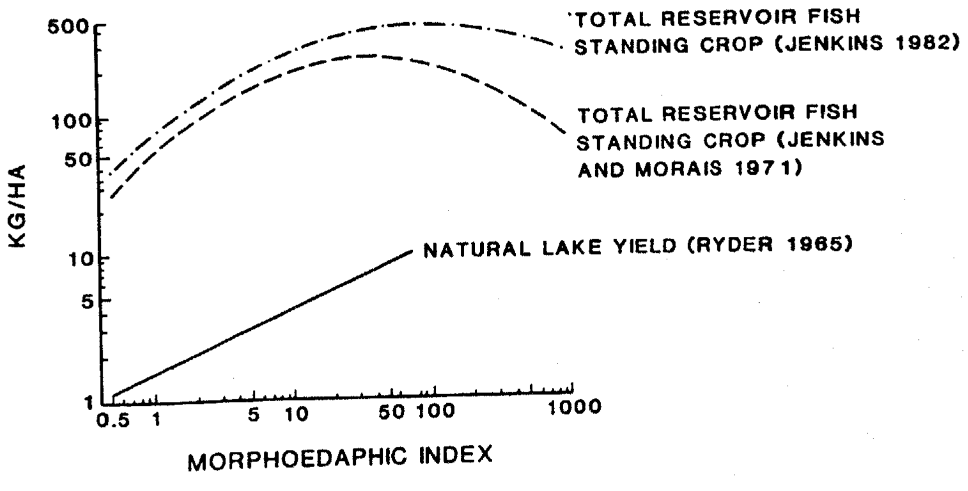


Figure 2. The relationship between the Morphoedaphic Index and fish yield for north-temperate lakes of North America and fish standing crop in south-temperate reservoirs of the U.S.

MEI ≥100 usually have TDS of ≥200 mg/liter (Ryder et al. 1974). Freshwater fish species may begin to undergo osmotic or ionic stress at these levels, resulting in lower rates of production. Fish biomass in reservoirs may be estimated from the MEI using Figure 2. Figure 1 is then used to transform this estimated biomass to a suitability index. Because the lines describing fish yield in north-temperate lakes and fish standing crop in reservoirs are essentially parallel for MEI ≤50, SIV1 for natural lakes is determined by using the reservoir standing crop line in Figure 2 to estimate the standing crop in the lake, and then converting the estimated standing crop to SIV1 using Figure 1. Equations 1 and 2 describe the standing crop curves provided by Jenkins (1982) and Jenkins and Morais (1971), respectively (Figure 2).

$$TC = 10^{(1.862 + 0.796 \log_{10}MEI - 0.204 \log_{10}MEI^2)} \quad (1)$$

$$TC = 10^{(1.7415 + 0.8619 \log_{10}MEI - 0.2830 \log_{10}MEI^2)} \quad (2)$$

where TC = total fish standing crop in kg/ha

MEI = Morphoedaphic Index

There are several other conditions limiting productivity that must be considered when applying the MEI. North-temperate lakes with mean depths <5 m are subject to reduced fish populations through winterkill, whereas lakes approaching a mean depth of 25 m produce low fish yields even when TDS is optimum (Ryder et al. 1974; Oglesby 1977). Differences in the length of the growing season and, therefore, fish production for a specific MEI value, will result from changes in latitude and elevation (Ryder et al. 1974). Fish yield (and thus fish production) at any MEI value is said to increase exponentially from the Arctic to the tropics (Henderson et al. 1973) and decrease with increased altitude in mountainous areas (Schlesinger and Regier 1982). Therefore, osprey habitat comparisons based on MEI or fish standing crop estimates should be limited to habitats of similar latitude and altitude.

In certain situations, fish standing crop (or MEI) may not accurately reflect food availability, as is the case with trout in deep waters (D.R. Johnson, Department of Biological Sciences, University of Idaho, Moscow, ID; pers. comm.). Due to seasonal changes, large bodies of water stratify and trout descend to cooler depths. Where trout are the primary prey, high standing crops of trout may indicate abundant food while their actual availability to ospreys is much lower (Johnson, pers. comm.).

The River Continuum Concept (Vannote et al. 1980) is a general theoretical framework that considers running water systems as continuous gradients of physical conditions from the headwaters to the mouth. The stream order system (Strahler 1957; Leopold et al. 1964; Hynes 1970) physically classifies elements of a drainage system and can be broadly characterized into three groupings (Cummins 1975; Vannote et al. 1980): orders 1-3, headwaters; orders 4-6, medium-sized streams; and orders 7-12, large rivers. Fish populations along the river gradient shift from a low diversity of coolwater species to more diverse warmwater communities; midsized rivers are characterized by piscivorous and invertivorous species, whereas some planktivorous species are found in large rivers (Vannote et al. 1980).

The River Continuum Concept describes the structure and function of communities along a river system. It is useful in identifying riverine cover types most appropriate for osprey nesting habitat or, specifically, potential riverine habitats providing physical features for optimum foraging efficiency. Streams of orders 1-3 are strongly influenced by riparian vegetation and are likely to be heavily shaded and contain large amounts of allochthonous detritus. Potential riverine habitats of this size are assumed to be unsuitable for ospreys, as the vegetative canopy would obscure visibility of the water surface. The transition zone from headwater streams to medium-sized rivers is primarily dependent on the degree of shading (Minshall 1978). The transition is about at order 3 for deciduous and some coniferous forests; at higher elevations and latitudes and in xeric conditions where riparian vegetation is restricted, the transition may be at order 1, and thus, such streams may provide suitable riverine habitat for ospreys. For riverine cover types, it is assumed that food suitability and, hence, habitat suitability, can be optimum only when potential riverine habitat is of a stream order >3 as defined by Vannote et al. (1980). Therefore, streams of order ≤3 should not be evaluated with this model.

Osprey access to fish is the second aspect of importance in determining food suitability. Osprey foraging efficiency, and thus habitat suitability, generally improves with the amount of clear and unobstructed water. Obstructions at or below the water surface, such as emergent and submergent vegetation, reduce prey visibility and thus osprey fishing success. Obstacles above the water surface, such as dense overhanging vegetation along water margins, obscure prey visibility as ospreys hover overhead and dive for prey. It is assumed that the proportion and distribution of the water surface obstruction relative to the area of the waterbody are important criteria in determining accessibility to fish. Food suitability in regard to water surface obstruction is generally assumed to decrease as water surface obstruction increases; 100% water surface obstruction is assumed to be unsuitable. The categories described below classify the proportion and distribution of potential water surface obstruction important to food suitability and thus habitat suitability. The categories were designed to emphasize the importance of the littoral zone for foraging. In situations where the littoral zone provides adequate foraging opportunities (assumed to exist when ≤75% of the littoral zone is obstructed), it is assumed that the open water (nonlittoral) zone will not influence foraging suitability. In situations where >75% of the littoral zone is obstructed and, therefore, unavailable for foraging, then foraging suitability will be determined by the amount of unobstructed open water outside of the littoral zone. The user should select the category that most closely describes the waterbody under evaluation. Suitability levels for water surface obstruction (SIV2) are presented in Figure 3. Obstacles on or just below the water surface and overhanging vegetation above the water surface are assumed to be obstructive.

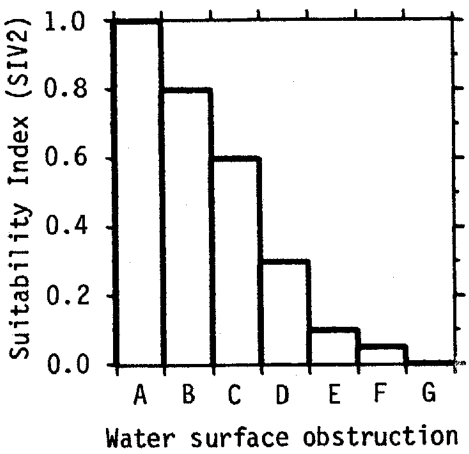


Figure 3. The relationship between categories of water surface obstruction and suitability indices for the osprey (see text for definition of categories).

Category A: ≤25% of the water surface along the littoral zone is obstructed. Littoral zone is defined as extending from the shoreward boundary of the waterbody to a depth of 2 m below low water, a modification of the definition of Cowardin et al. (1979).

Category B: 26% to 50% of the water surface in the littoral zone is obstructed.

Category C: 51% to 75% of the water surface in the littoral zone is obstructed.

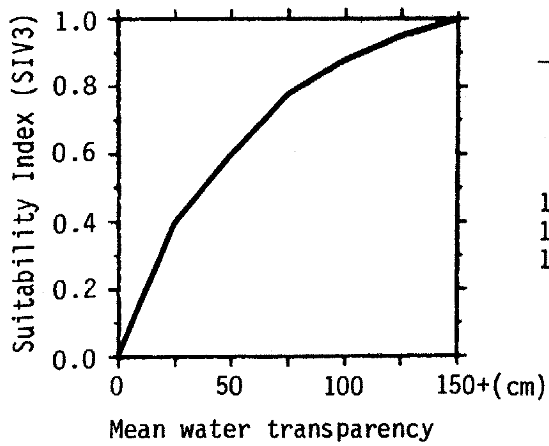
Category D: 76% to 100% obstruction of the water surface in the littoral zone and ≤25% obstruction of the surface in open water.

Category E: 76% to 100% obstruction of the water surface in the littoral zone and 26% to 50% obstruction of the surface in open water.

Category F: 76% to 100% obstruction of the water surface in the littoral zone and 51% to 75% obstruction of the surface in open water.

Category G: 76% to 100% of the surface of the littoral zone and the open water are obstructed.

Ospreys prefer clear water for foraging; as water clarity increases, visibility, and thus osprey foraging efficiency, increases. Water clarity is influenced by the light absorption characteristics of water and the presence of particulate and dissolved matter (Wetzel 1975). Ospreys dive as deep as 1 m for their prey. It is assumed that the depth to which fish are visible is equal to the Secchi disk depth. It is also assumed that optimum conditions for water clarity exist when fish are visible at a depth of ≥1.5 m (Figure 4). This depth was arbitrarily chosen; it is based on the belief that visibility greater than the osprey's diving depth will enhance the detectability of potential prey (Eriksson 1985). As the depth at which fish are visible increases, the number of available prey is assumed to initially increase rapidly and then increase at a declining rate. Increases in water clarity beyond normal diving depths are assumed to result in much smaller increases in prey availability because most of the fish at water depths less than or equal to diving depth (1 m) would already be visible.



x	y
0	0
25	0.4
50	0.6
75	0.78
100	0.88
125	0.95
150	1.0

Figure 4. The relationship between mean water transparency and suitability indices for the osprey.

The suitability of the food component (SIF) in lacustrine cover types is a function of the suitability indices for estimated fish biomass (SIV1), surface obstruction (SIV2), and water clarity (SIV3). Equation 3 is used to determine the food suitability index for lacustrine cover types.

$$SIF_L = SIV1 \times SIV2 \times SIV3 \qquad (3)$$

SIF_L is defined as the product of the three variables because obstructions make a portion of the waterbody unavailable for foraging regardless of water clarity, whereas turbid water reduces foraging efficiency in the remaining unobstructed areas. Thus, SIV2 and SIV3 both independently reduce, but not increase, the basic food supply determined by fish biomass.

For riverine cover types of stream order >3, it is assumed that SIF_R is best represented by the product of SIV2 (surface obstruction) and SIV3 (water clarity). Stream order is important to food suitability because it identifies riverine habitats of appropriate size and community structure for osprey foraging habitat. The product of SIV2 and SIV3 is used because these two variables are assumed to affect food availability in the same manner described above for lakes. Equation 4 is used to determine the food suitability index for riverine cover types of stream order >3.

$$SIF_R = SIV2 \times SIV3 \qquad (4)$$

Reproduction component. Nest site quality and availability, minimal disturbance from human activity, and proximity to foraging waters are major aspects of osprey nesting habitat. Specifically, the potential for suitable nesting structures and the degree of impact from human activity are important in determining the reproductive suitability of habitat for ospreys.

It was noted earlier that osprey nesting requirements are not specific. A wide range of conditions, including both nest structures and their spatial distribution, could be suitable. Consequently, it is assumed that reproductive suitability for ospreys will be optimum only if there is an adequate number of nest sites (i.e., trees or potential nesting structures) within an area containing the waterbody under evaluation.

A potential nesting area is defined in this model by the presence of trees or structures suitable for nest sites located over water or within 5 km of the waterbody under evaluation. These potential nest sites may be on islands within a river or lake. To qualify as potential nest sites, trees or structures must be at least 2.0 m high, and as tall or taller than the nearest tree or structure, while not touching the surrounding vegetation. Trees may be alive or dead but must have an open canopy allowing easy access to the nest and maximum visibility from the nest. Trees must also provide good support for a nest, either as a broken top of a trunk or sturdy branches at or near the tree top. Artificial nesting structures should have a sturdy nest base with a minimum diameter of 16.0 cm at the top and a nesting platform of a minimum 0.9-m diameter and 2.5-cm thickness. Each potential nest site should have at least one elevated structure nearby for use as a perch. Potential nest sites should be at least 100 m from other potential nest sites within the nesting area under evaluation. Two suitable trees or nesting structures are needed for each potential nest site in a nesting area.

Ideally, evaluation of potential nesting structures would involve inventory of structures and comparison of the inventory to an estimate of the need for nesting structures. In order to estimate the need for nesting structures, an estimate of potential nesting pairs is necessary. In order to estimate the number of pairs, the fish standing crop must be evaluated, then related to the number of ospreys that could be supported by the available standing crop (all other factors assumed to be optimal). However, data directly relating osprey numbers specifically to fish standing crop are not available in the literature, presumably because of the numerous other factors involved in determining the actual number of nesting ospreys. Because of the lack of definitive information that would help determine the size of potential nesting populations, it is left to the discretion of the model user to determine if "adequate" potential nest structures are available (see <u>Application of the Model</u> for an alternative approach to evaluating potential nesting structures). "Adequate" is qualitatively defined here to mean that nest structures will be no more limiting than the available food resources. In most cases, it will be relatively easy to determine if potential nest structures are adequate. Waterbodies with an abundance of forested cover types within 5 km will generally provide an abundance of potential nest structures in excess of the maximum population that could be supported based on the food resource. In situations where this is not the case, artificial nesting structures can be installed. In either case, a lack of nesting structures will not limit habitat suitability for ospreys. Only in those instances where natural nesting structures are "inadequate" and where there are no plans to install artificial nesting structures will potential nesting structures influence habitat suitability. In such instances, users are advised to document the lack of potential nesting structures and assign the waterbody a suitability based on a subjective evaluation of suitability of nesting structures.

The second important aspect in determining reproductive suitability for nesting ospreys is disturbance resulting from human activity. Osprey nesting success is often negatively affected by the nature of certain human activities, as well as by the timing and frequency of the activities. As noted earlier, several studies indicated that some human activities cause the incubating bird to spend long periods of time off the nest, exposing the eggs or young to extreme weather and temperature conditions, and ultimately resulting in egg loss or increased fledgling mortality. Contrary to these findings, other researchers contend that human activity has little or no effect, citing examples of osprey pairs with high nesting success while exposed to high levels of human activity. The majority opinion, however, is that the timing and frequency of human activity and the degree that ospreys become habituated to such activity early in the nesting season are the criteria important to determining the effect of human activity on ospreys. Beyond a critical distance of 0.2 to 1.0 km from nesting sites, ospreys do not appear to respond to human activity. It is assumed in this model that activities affecting ≥50% of the potential nesting area decrease overall suitability of an area as potential nesting habitat, and thus such an area should receive a lower suitability value. The presence of activity reduces the ratio of available habitat without potential disturbance to available habitat with potential disturbance. Human activities affecting <50% of the potential nesting area are assumed to be not as limiting as above because the majority of the evaluation area with a higher suitability (i.e., without human activity) is available as potential nesting habitat. A more precise evaluation of human activity would quantify the effects of human activities on potential nesting structures rather than on an area basis. This approach is considered to be impractical for most applications of this model.

The categories described below are assumed to adequately classify the types and levels of human activity most important for reproductive suitability. Suitability levels for human activity (SIV4) are presented in Figure 5.

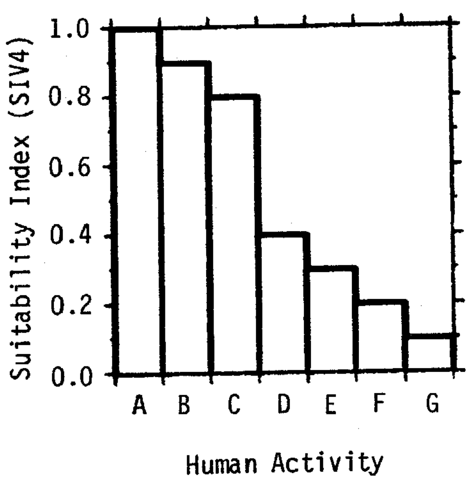


Figure 5. The relationship between categories of human activity at osprey nesting areas and suitability indices for the osprey (see text for definitions of categories).

Category A: no human activity is present on the waterbody and within 0.5 km of the waterbody's shoreline. [This category describes an ideal situation, which will be unattainable in most situations].

Category B: human activity is present in the potential nesting area and occurs predominantly on a relatively constant or year-round basis, which allows ospreys to become habituated to the activities. The timing of the activity is such that it is present before or at the start of the April-August breeding season, often continuing throughout the season. The activity affects <50% of the evaluation area. The following are examples of this category of activity: well-traveled roads and trails; logging; and year-round use of waterways, shorelines, riverbanks, buildings, and private and nonrecreational lands.

Category C: activity present is same as Category B, but affects ≥50% of the area under evaluation.

Category D: activity is present in the evaluation area and occurs predominantly on an irregular or seasonal basis, or begins abruptly during the critical portion of the breeding season (April-June). The activity is often from recreational activities that occur during the incubation period such that the birds are not able to become habituated to the activity prior to incubation. The activity affects <50% of the area under evaluation. The following are examples of this category of activity: infrequent and seasonal use of roads and trails; seasonal use of waterways, shorelines, riverbanks, beaches, buildings, boat launches, camping and picnic sites; and spring logging activities.

Category E: disturbance present is same as Category D, but with the majority of activity concentrated at or affecting the waterbody, particularly along the shoreline.

Category F: activity present is same as Category D, but affects ≥50% of the area under evaluation.

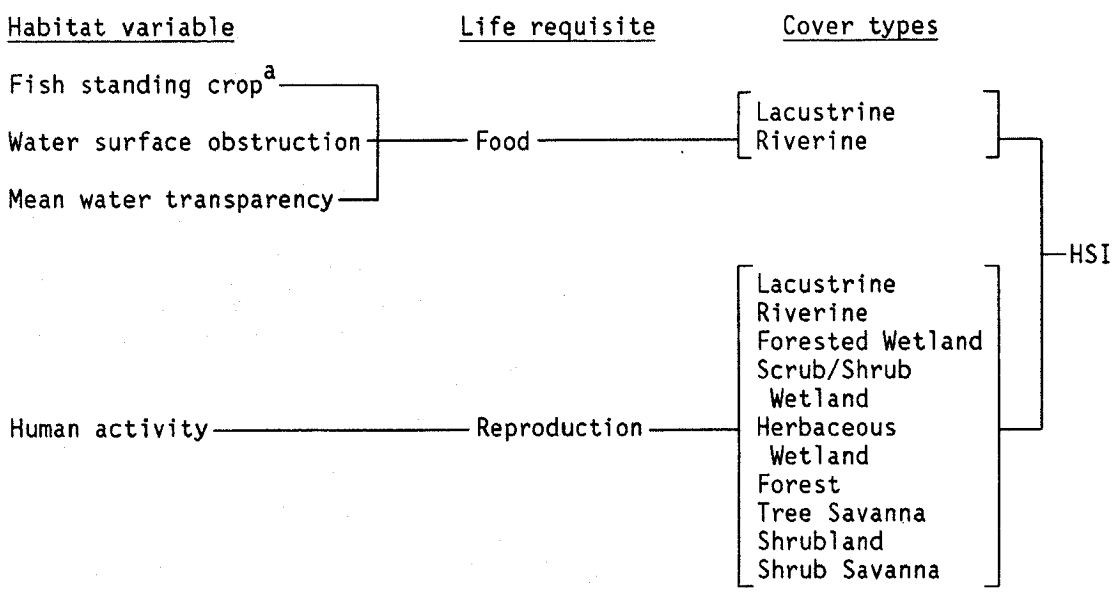
Category G: activity present is same as Category D and affects ≥50% of the area under evaluation, but with the majority of activity concentrated at or affecting the waterbody, particularly along the shoreline.

The suitability index for reproduction (SIR) is equal to the suitability index of the category of human activity (SIV4), presuming that the user has concluded that "adequate" nesting structures are available.

<u>HSI determination.</u> The HSI for breeding habitat of migratory ospreys inhabiting freshwater and the surrounding 5 km of land is equal to the lowest life requisite suitability index for either food (SIF) or reproduction (SIR).

Application of the Model

Summary of model variables. This model uses three habitat variables to evaluate the food life requisite and one habitat variable to evaluate the reproduction life requisite. The relationships among habitat variables, life requisites, cover types, and the HSI for osprey are shown in Figure 6. Definitions of variables and suggested measurement techniques are presented in Figure 7.



[a]Applies only to the lacustrine cover type.

Figure 6. The relationship of habitat variables, life requisites, cover types, and the HSI for osprey breeding habitat.

Variable (definition)	Cover types	Suggested techniques
Fish standing crop [the combined weight of fish present in a given area at a given point in time].	L	Published data (e.g., State fish and game agencies).
Morphoedaphic Index (MEI) [a ratio of total dissolved solids solids (TDS) to the mean depth ($\bar{Z}$) of a waterbody; measures productivity of a waterbody using the following formula: $MEI = \frac{TDS}{\bar{Z}}$ where TDS is measured in milligrams per liter and $\bar{Z}$ is measured in meters].	L	TDS meter, conductivity meter, soundings, laboratory analysis, publish-data (Seyb and Randolph 1977; Bloomfield 1978a,b, 1980; Omernik and Kinney 1983; Johnson et al. 1985; Hamilton and Bergerson, n.d.).
Water surface obstruction [the proportion of the water surface and up to 1.5 m below that is shaded or obstructed during the spring and summer by submergent, emergent, and floating vegetation, leaves, logs, or overhanging shore vegetation, and the distribution of the obstructions on the waterbody; described by seven categories].	L,R	On-site inspection, line intercept (Hays et al. 1981).

Figure 7. Definitions of habitat variables and suggested measurement techniques.

Variable (definition)	Cover types	Suggested techniques
Mean water transparency [the average of the depth at which a weighted white disk, 20 cm (8 inches) in diameter, disappears from view, and the depth where it reappears upon raising it after it has been lowered beyond visibility, when measured at midday in the spring and summer].	L,R	Secchi disk (Orth 1983; Hamilton and Bergerson, n.d.).
Human activity [an evaluation of the type, frequency, and timing of an activity as it relates to the habitat and osprey nesting cycle; described by seven categories of human activity].	R,L,HW,SW,FW,F, TS,S,SS	On-site inspection, aerial photographs, topographic maps, land status and land use records, opening of fishing seasons and campsites.

Figure 7. (Concluded)

Use of the model. The recommended approach for applying this model is as follows:

1. Select a lacustrine or riverine (sensu Cowardin et al. 1979) cover type for evaluation as potential osprey breeding habitat.

2. Is the waterbody in an area where ospreys are known to have nested historically? If not, is the waterbody within 125 km of an existing osprey breeding area? Is the waterbody used by migrating ospreys or along known migratory routes? If the answer is no to each of these three questions, then the waterbody will probably not provide useable habitat for ospreys.

3. If the waterbody is a river or portion thereof, the river must have a stream order >3, to be considered as potentially suitable habitat for the osprey. If the user is certain there are few fish present in the size class 15-35 cm, the river should not be evaluated with this model. Stream order can be determined from aerial photographs and topographic maps according to the method of Strahler (1957).

4. Include the 5 km of land surrounding the waterbody in the area to be evaluated. Does the waterbody or the surrounding 5 km of land possess adequate structures appropriate for nest placement (determined subjectively by the user)? If not, is the user planning to install and maintain artificial nest structures? If the answer to both questions is no, the waterbody and surrounding area will probably not provide suitable nesting habitat for the osprey.

Upon satisfaction of the appropriate criteria, the user can proceed to estimate the suitability of the lake or river as breeding habitat for the osprey by using the variables, curves, and equations provided in the model. When determining the HSI for osprey breeding habitat, the user may wish to divide a large evaluation area (waterbody and the surrounding 5 km of land) into two or more smaller areas; the same variables are then used to evaluate each subset area. This will result in two or more HSI values with potentially increased sensitivity, as several of the habitat variables, particularly MEI and human activity, might vary from one portion of a waterbody to another (e.g., a shallow basin of a large lake may have high fish productivity but intense, seasonal human activity, whereas a deeper basin may be less productive but surrounded by privately owned land with minimal human activity). The user should visit the evaluation area to confirm information obtained from aerial photographs and maps. Measurement of water transparency and surface obstruction should be taken both in the spring and summer during typical water conditions, e.g., not after heavy rains which may cause unusually high but temporary turbidity.

Alternative evaluation of nesting structures. The model requires a subjective determination of whether adequate nesting structures are available in the potential nesting area. If nesting structures are adequate (qualitatively defined as being no more limiting than the available food resources), then the area is evaluated with the model to determine reproductive suitability for the osprey. If no nesting structures are available, the area is unsuitable. Otherwise, guidelines are not provided for rating habitat based on nest site availability. A quantitative description of "adequate" is not provided in the model, but such a description could be developed using the following procedure.

An estimate of maximum nesting density (nesting pairs per unit area of waterbody) is difficult to determine because osprey populations throughout the United States appear to be in the middle of a dynamic situation, possibly exhibiting characteristics of irruptive populations (Henny, pers. comm.). Henny suggested, however, that the nesting population at Crane Prairie Reservoir, Oregon, could serve as a rough measure of maximum nesting densities likely to occur around eutrophic waterbodies. The standing crop of fish in Crane Prairie Reservoir is estimated to be 280 kg/ha, estimated by first determining the Morphoedaphic Index, and then using the curves from Jenkins (1982) as presented in Figure 2. Presently, the Crane Prairie population is a fair representative of a generally stable, freshwater-foraging osprey population in the United States. At the reservoir, an average of 40 nesting pairs were observed using the 1,686-ha waterbody, or 1 pair per 42 ha of foraging area. This estimate should not be misinterpreted to mean that waterbodies <42 ha in size will not support nesting ospreys; it is simply an estimate (admittedly rough) of maximum nesting density of ospreys.

The number of nesting pairs that could potentially be supported by the fish standing crop of a given waterbody can be estimated by assuming that the information from Crane Paririe Reservoir is an appropriate standard of comparison. Conditions at a waterbody under evaluation can simply be compared to the Crane Prairie conditions to estimate the potential nesting density (and then the number of nesting pairs). For example, if the standing crop of fish is 140 kg/ha (compared to 280 kg/ha at Crane Prairie), then it can be reasonably assumed that the maximum nesting density would be one-half the density observed at Crane Prairie, or 1 pair per 84 ha. This approach assumes that other factors affecting habitat suitability for the osprey (e.g., water clarity, surface obstruction, and human activity) are at optimum levels. The following process should be used to estimate the expected number of pairs based on available food resources:

1. Determine the size of the waterbody under consideration.

2. Determine the fish standing crop of the waterbody.

3. Use Equation 5 to calculate the potential number of osprey pairs that could be supported by the fish standing crop.

$$NP_E = (SC_E/SC_{CP}) \times D_{CP} \times A_E \quad (5)$$

where NP_E = the estimated number of osprey pairs that can potentially be supported by the food resources of the waterbody being evaluated

SC_E = estimated standing crop of fish (kg/ha) in the waterbody

SC_{CP} = estimated standing crop of fish (kg/ha) in Crane Prairie Reservoir (estimated to be 280 kg/ha)

D_{CP} = estimated nesting density at Crane Prairie Reservoir (equal to 1 pair/42 ha of foraging area)

A_E = the size of the waterbody being evaluated (ha)

The estimate resulting from Equation 5 is the number of osprey pairs that the evaluation area can potentially support with its fish standing crop, using Crane Prairie Reservoir as the standard of comparison. The potential nesting density calculated with Equation 5 for the area under evaluation will be greater than observed at Crane Prairie Reservoir if the fish standing crop is >280 kg/ha. Any other density estimate can be used as a standard of comparison as long as the user believes it to be a reasonable estimate of maximum nesting density.

The estimate of potential nesting pairs determined above can be used to derive a suitability index for nesting structures. It is recommended that there be two potential nesting structures for each potential nest site (see p. 22 for definitions of potential nest structures). Therefore, optimum conditions for nesting structures will exist when there are at least twice as many potential nesting structures as the number of pairs that can be supported by the fish standing crop (Figure 8). When numbers of nesting structures are less than required to support all potential pairs, the suitability is assumed to be directly proportional to the proportion of the optimum number of nesting structures that are present. For example, if it is estimated that 100 nesting structures are needed to support the potential population, but only 60 such structures are present, the suitability of nesting structures is assumed to be 0.6. Once the suitability index for nesting structures (SIV5) has been estimated (by entering the observed value on the area being evaluated into the curve presented in Figure 8), it can be used along with the suitability index for human activity (SIV4) to determine an overall nesting suitability index (Equation 6).

$$SIR = SIV4 \times SIV5 \qquad (6)$$

where SIR = the suitability index for reproduction

SIV4 = the suitability index for human activity

SIV5 = the suitability index for the number of nesting structures

The overall HSI in lacustrine cover types can then be determined based on the lowest of the indices for reproduction (SIR) and food (SIF_L).

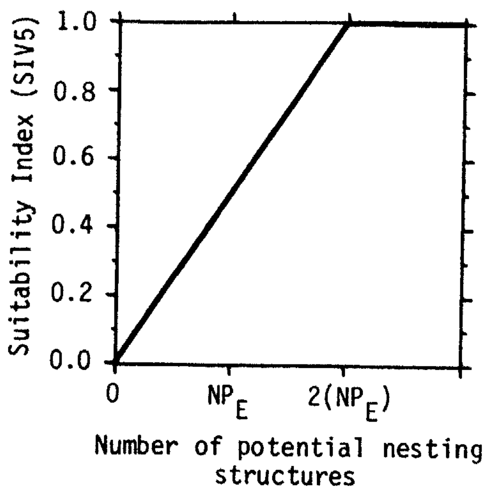


Figure 8. The relationship between the number of potential nesting structures and suitability indices for the osprey (NP_E is the estimated number of pairs that can be supported based on the fish standing crop).

The approach outlined above refers to lacustrine waterbodies; the approach can be adapted for use in riverine systems by using a standard of comparison that places density on a length basis (e.g., numbers per km of river). The primary advantage of this alternative approach is that it provides a means by which to evaluate the number of nesting structures in terms of how many osprey pairs could be supported by the available food resources. The primary disadvantage is that it is difficult to determine a nesting density that serves as a reasonable standard of comparison. Existing data are based on site-specific conditions and are rarely evaluated in terms of optimum nesting density. In order to determine such an estimate based on fish standing crop, a number of important variables must be ignored, such as levels of human activity, pesticide loads, historical use of sites by ospreys, and availability of other foraging areas.

In most cases, there will be little need to enumerate potential nesting structures. Nesting structures will usually be adequate in forested areas; in areas that are not forested, artificial nesting structures can be installed. In the latter instance, the approach described here can be used to determine the number of structures that should be installed. As a result, nesting suitability will be a function of human activity alone, as it is in the current model.

Model assumptions. The following assumptions were made in the development of the HSI model for the osprey.

1. This model assumes there is no minimum amount of contiguous habitat required for ospreys. Instead, a maximum amount of contiguous habitat is given for an evaluation area, i.e., a waterbody and the surrounding 5 km of land. It is assumed that optimum nesting habitat for ospreys would be located within 5 km of a waterbody. The model does not establish a minimum size waterbody for evaluation other than that required for classification as lacustrine and riverine cover types (Cowardin et al. 1979).

2. Several studies (Swenson 1979a, 1983; Wetmore and Gillespie 1976; Clum 1986; Swenson et al. 1986) have suggested that the timing of ice-out on lakes and rivers affects nest success of ospreys and bald eagles because of the limited availability of aquatic prey. This is especially true at higher elevations and more northern latitudes (Johnson and Melquist 1973; Gerrard et al. 1975; Swenson 1975; Henny 1977a). Ice-out is defined as "the earliest date on which the water was reported to be completely free of all floating ice and remained so until the following freeze-up" (Allen and Cudbird 1971:vi). In parts of Labrador and Quebec, Canada, a significant correlation was observed between osprey productivity and the date of ice-out at waterbodies in the spring (Wetmore and Gillespie 1976). Limited egg-laying or poor hatching success resulted in reduced numbers of young per occupied nest and was more pronounced in years of later ice-out. During a 6-year period, osprey nest success and productivity on Yellowstone Lake, Wyoming, was lowest the year ice-out occurred a week later than normal (Swenson 1979a). This model does not include a habitat variable for ice-out because it potentially affects only a specific portion of the breeding range. However, the user should be aware of this potentially limiting factor when selecting a waterbody for evaluation. As suggested in the literature (Dunstan 1967; Swenson 1975; Wetmore and Gillespie 1976; Henny 1977a; Prevost 1977; Richardson 1980), ice-out that does not occur by May 31 appears to limit prey availability during the preincubation period.

3. Because an index of productivity, such as the MEI, is not available for riverine cover types, this model assumes that the river continuum concept (Vannote et al. 1980) provides an adequate framework for estimating osprey habitat suitability. Based on this concept, streams of a stream order ≤3 probably have vegetative canopies that

are too closed and lack fish populations of adequate number and size (11 to 35 cm) for ospreys. However, under conditions of moderate or severe human-induced perturbations (e.g., water pollution, channelization), even streams of higher order may not provide suitable habitat.

4. The osprey nests on a variety of structures, including artificial nest-platforms, snags, and trees. The need for a nest site is assumed to be essentially a point resource. The model describes desirable characteristics of potential nesting structures as suggested in the literature. Tree species, density, and absolute height of the nest structure are assumed to be insignificant factors in nest site selection. Limb structure suitable for nest placement and support, nest height relative to surrounding vegetation, and maximum visibility from the nest during the breeding season are assumed to be important criteria for determining nest site selection.

5. Human impacts on nesting ospreys are highly variable. The model assumes that a categorical description of human activities known to disturb ospreys, as suggested in the literature, most appropriately classifies the nature, timing, and intensity of human activities that affect ospreys. The model assumes that human impacts can be classified further by identifying the proportion of the evaluation area that is most affected by human activity. The values <50% and ≥50% were chosen to focus on the potential availability of suitable nest sites relative to activities affecting the evaluation area (e.g., if activities affect a minor portion of the evaluation area, suitable nest sites may still be potentially concentrated on the major, unaffected portion of the evaluation area). The assignment of a percentage of the evaluation area affected by human activity is used only to further identify the severity of activity in a single evaluation area and thus its overall suitability as potential nesting habitat. Percentages are not intended for quantitative comparisons, e.g., comparing two or more nesting areas, unless they are of similar acreage and habitat suitability. Human activity is assumed to be not limiting to ospreys at specific foraging sites away from nest sites or in transit between nesting and foraging areas. The user, however, may need to consider intense human activity at particularly important foraging areas.

Environmental contaminants, such as DDT and its metabolites, have not been included as a habitat variable. Contaminants are presently more of a concern on the wintering grounds in Central and South America than on breeding habitat in the United States, where pesticide use has decreased and osprey production has improved since the DDT ban in 1972 (Johnson and Melquist 1973; Airola and Shubert 1981; Henny 1983). Organochlorine pesticide residues (primarily DDE) and decreased eggshell thickness have been documented in several raptor species that have experienced severe population declines due to reproductive failure (Hickey and Anderson 1968; Peakall 1970; Ratcliffe 1970; Henny 1977b, 1983). Evidence of pesticide residues exists predominantly for osprey populations along the northern Atlantic coast (Henny 1983). Michigan, Wisconsin, and the northern Atlantic coast from Boston to Cape May, New Jersey, reported extremely low rates of reproduction compared to the more southern portion of the Atlantic seaboard and the West. Although reproduction in osprey populations continues to improve (Henny 1983), possible environmental contamination may still be having an adverse impact on some pairs.

Acid rain, through its effect on fish, could also potentially threaten osprey prey availability and thus osprey productivity over several portions of its breeding range [for an excellent summary of acid rain see Cowling (1982a,b)]. As lake pH decreases, the number of fish species present usually decreases (Beamish and Harvey 1972; Schofield 1976). The tolerance level of fish to acid is different for each species (Harvey 1980). Important food sources such as brown bullhead, white sucker, largemouth bass, and yellow perch are among the fish species tolerant or moderately tolerant to acidification (Malley 1985). The lake trout is one of the most sensitive species and is known to be eaten by ospreys (D.S. MacCarter 1972; Melquist 1974), along with several other salmonid species.

Even if acid rain is brought under control over the next decade, many acid-sensitive fish species may be lost, and some osprey populations will suffer, especially if more tolerant fish species are unavailable. Areas within the nesting range now considered to be at risk from acid rain include southeastern Ontario, southern Quebec, and parts of Maine, New Hampshire, northeastern New York, Minnesota, Wisconsin, and Michigan (Henny 1983; Malley 1985; Clum 1986). Ospreys presently nesting in these areas will potentially be threatened by effects of lake and stream acidification. The extent to which metals mobilized by acid rain and accumulated by fish will affect osprey productivity is currently unknown, but the potential impact should not be overlooked.

SOURCES OF OTHER MODELS

An HSI model for ospreys is currently being developed for use in Michigan (J. Haufler, Department of Fishery and Wildlife, Michigan State University, Lansing, MI; pers. comm.).

REFERENCES

Airola, D.A., and N. Shubert. 1981. Reproductive success, nest site selection, and management of ospreys at Lake Almanor, California, 1969-1980. California-Nevada Section, The Wildlife Society. 1981 Transactions:79-85.

Allen, W.T.R., and B.S.V. Cudbird. 1971. Freeze-up and break-up dates of waterbodies in Canada. Canadian Meteorological Service, Toronto. 144 pp.

Alt, K.L. 1980. Ecology of the breeding bald eagle and osprey in the Grand Teton-Yellowstone Parks Complex. M.S. Thesis. Montana State University, Bozeman. 95 pp.

American Ornithologists' Union. 1983. Check-list of North American birds, 6th ed. American Ornithologists' Union, Washington, DC. 877 pp.

Ames, P.L., and G.S. Mersereau. 1964. Some factors in the decline of the osprey in Connecticut. Auk 81(2):173-185.

Andrewartha, H.G., and L.C. Birch. 1954. The distribution and abundance of animals. University of Chicago Press. 782 pp.

Bailey, A.M., and R.J. Niedrach. 1965. Birds of Colorado. Vol. I. Denver Museum of Natural History. 454 pp.

Beamish, R.J., and H.H. Harvey. 1972. Acidification of the LaCloche Mountain Lakes, Ontario, and resulting fish mortalities. J. Fish. Res. Board Can. 29:1131-1143.

Benson, N.G. 1961. Limnology of Yellowstone Lake in relation to the cutthroat trout. U.S. Fish Wildl. Serv. Res. Rep. 56. 33 pp.

Bent, A.C. 1937. Life histories of North American birds of prey, Part I. U.S. Natl. Mus. Publ. 167. Washington, DC. 409 pp.

Berger, D.D., and H.C. Mueller. 1969. Ospreys in northern Wisconsin. Pages 340-341 in J.J. Hickey, ed. Peregrine falcon populations: their biology and decline. University of Wisconsin Press, Madison, Milwaukee, and London.

Bider, J.R., and D.M. Bird. 1983. Distribution and densities of osprey populations in the Great Whale Region of Quebec. Pages 223-230 in D.M. Bird, ed. Biology and management of bald eagles and ospreys. Harpell Press, Ste. Anne de Bellevue, Quebec.

Bloomfield, J.A., ed. 1978a,b, and 1980. Lakes of New York State. 3 volumes. Academic Press, New York.

Brown, L., and D. Amadon. 1968. Eagles, hawks, and falcons of the world. Vol. 1. McGraw Hill, New York. 414 pp.

Campbell, C.J., and F.E. Locke, eds. 1961. Annual Report: Fishery Division. Oregon State Game Commission, Portland. 356 pp.

Campbell, C.J., and F.E. Locke, eds. 1962. Annual Report: Fishery Division. Oregon State Game Commission, Portland. 409 pp.

Campbell, C.J., and F.E. Locke, eds. 1963. Annual Report: Fishery Division. Oregon State Game Commission, Portland. 415 pp.

Campbell, C.J., and F.E. Locke, eds. 1964. Annual Report: Fishery Division. Oregon State Game Commission, Portland. 315 pp.

Campbell, C.J., and F.E. Locke, eds. 1965. Annual Report: Fishery Division. Oregon State Game Commission, Portland. 133 pp.

Campbell, C.J., and F.E. Locke, eds. 1966. Annual Report: Fishery Division. Oregon State Game Commission, Portland. 137 pp.

Campbell, C.J., and F.E. Locke, eds. 1967. Annual Report: Fishery Division. Oregon State Game Commission, Portland. 156 pp.

Campbell, C.J., and F.E. Locke, eds. 1968. Annual Report: Fishery Division. Oregon State Game Commission, Portland. 154 pp.

Campbell, C.J., and F.E. Locke, eds. 1969. Annual Report: Fishery Division. Oregon State Game Commission, Portland. 149 pp.

Campbell, C.J., and F.E. Locke, eds. 1970. Annual Report: Fishery Division. Oregon State Game Commission, Portland. 146 pp.

Clum, N.J. 1986. The effects of prey quantity on reproductive success of ospreys (Pandion haliaetus) in the Adirondack Mountains. M.S. Thesis. Cornell University, Ithaca. 149 pp.

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Fish Wildl. Serv. FWS/OBS-79/31. 103 pp.

Cowling, E.B. 1982a. Acid precipitation in historical perspective. Environ. Sci. Technol. 16:110A-123A.

Cowling, E.B. 1982b. An historical resume of progress in scientific and public understanding of acid precipitation and its biological consequences. Pages 43-83 in F.M. D'Itri, ed. Acid precipitation: effects on ecological systems. Ann Arbor Science Publishers, Ann Arbor, MI.

Cummins, K.W. 1975. The ecology of running waters; theory and practice. Proc. Pages 277-293 in Proc. Sandusky River Basin Symposium, May 2-3 1975. Tiffin, Ohio.

Dean, J.L., and J.D. Varley. [1973]. Annual project report, fishery management program, Yellowstone National Park, calendar year 1972. U.S. Bur. Sport Fish. Wildl. 84 pp. Unpub. ms.

Detrich, P.J. 1986. The status and distribution of the bald eagle in California. M.S. Thesis. California State University, Chico. 101 pp.

Dunstan, T.C. 1967. A study of osprey in Itasca County, Minnesota. M.A. Thesis. University of South Dakota, Vermillion. 66 pp.

Dunstan, T.C. 1973. The biology of ospreys in Minnesota. The Loon 45(4):108-113.

Dunstan, T.C. 1974. Feeding activities of osprey in Minnesota. Wilson Bull. 86(1):74-76.

Eckstein, R.G., P.V. Vanderschaegen, and F.L. Johnson. 1979. Osprey nesting platforms in north central Wisconsin. Passenger Pigeon 41(4):145-148.

Eriksson, M.O.G. 1985. Prey detectability for fish-eating birds in relation to fish density and water transparency. Ornis Scand. 16:1-7.

Eriksson, M.O.G. 1986. Fish delivery, production of young, and nest density of osprey (Pandion haliaetus) in southwest Sweden. Can. J. Zool. 64(9):1961-1965.

Flook, D.R., and L.S. Forbes. 1983. Ospreys and water management at Creston, British Columbia. Pages 281-286 in D.M. Bird, ed. Biology and management of bald eagles and ospreys. Harpell Press, Ste. Anne de Bellevue, Quebec.

French, J.M. 1972. Distribution, abundance, and breeding status of ospreys in northwestern California. M.S. Thesis. California State University (Humboldt), Arcata. 58 pp.

French, J.M., and J.R. Koplin. 1977. Distribution, abundance and breeding status of ospreys in northwestern California. Pages 223-240 in J.C. Ogden, ed. Trans. N. Amer. Osprey Res. Conf. U.S. Natl. Park Serv. Proc. Ser. No. 2. Washington, DC.

Garber, D.P. 1972. Osprey nesting ecology in Lassen and Plumas Counties, California. M.S. Thesis. California State University (Humboldt), Arcata. 59 pp.

Garber, D.P., J.R., Koplin, and J.R. Kahl. 1973. Osprey management on the Lassen National Forest, California. Pages 119-122 in F. Hamerstrom et al., ed. Management of raptors. Proc. Conf. Raptor Conserv. Tech., 22-24 March 1973. Ft. Collins, CO.

Gerrard, J.M., P.N. Gerrard, G.R. Bortolotti, and D.W.A. Whitfield. 1983. A 14-year study of bald eagle reproduction on Besnard Lake, Saskatchewan. Pages 47-58 in D.M. Bird, ed. Biology and management of bald eagles and ospreys. Harpell Press, Ste. Anne de Bellevue, Quebec.

Gerrard, G.M., P. Gerrard, W.J. Maher, and D.W.A. Whitfield. 1975. Factors influencing nest site selection of bald eagles in northern Saskatchewan and Manitoba. Blue Jay 33:169-176.

Greenwood, P.J. 1980. Mating systems, philopatry, and dispersal in birds and mammals. Anim. Behav. 28(4):1140-1162.

Grosvenor, G., and A. Wetmore. 1934. Book of birds. Nat. Geogr. Soc., Washington, DC. Vol. 1:168.

Grover, K.E. 1983. Ecology of the osprey on the upper Missouri River, Montana. M.S. Thesis. Montana State University, Bozeman. 58 pp.

Grubb, T.G. 1977. Weather-dependent foraging in ospreys. Auk 94(1):146-149.

Hagan, J.M. 1986. Temporal patterns in pre-fledgling survival and brood reduction in an osprey colony. Condor 88(2):200-205.

Hamilton, K., and E.P. Bergersen. No date. Methods to estimate aquatic habitat variables. Colorado Coop. Fishery Res. Unit, Ft. Collins, CO.

Hammer, D.A., and R.M. Hatcher. 1983. Restoring osprey populations by hacking preflighted young. Pages 293-297 in D.M. Bird, ed. Biology and management of bald eagles and ospreys. Harpell Press, Ste. Anne de Bellevue, Quebec.

Harvey, H.H. 1980. Widespread and diverse changes in the biota of North American lakes and rivers coincident with acidification. Pages 93-98 in D. Drablos and A. Tollan, eds. Ecological impact of acid precipitation. Proc. Int. Conf. Ecol. Impact Acid Precipt. Norway 1980, SNSF project.

Hays, R.L., C. Summers, and W. Seitz. 1981. Estimating wildlife habitat variables. U.S. Fish Wildl. Serv. FWS/OBS-81/47. 111 pp.

Haywood, D.D., and R.D. Ohmart. 1986. Utilization of benthic-feeding fish by inland breeding bald eagles. Condor 88(1):35-42.

Henderson, H.F., R.A. Ryder, and A.W. Kudhongania. 1973. Assessing fishery potential of lakes and reservoirs. J. Fish. Res. Board Can. 30:2000-2009.

Henny, C.J. 1977a. California ospreys begin incubation at a frozen mountain lake. Bird-Banding 48(3):274.

Henny, C.J. 1977b. Research, management, and status of the osprey in North America. Pages 199-221 in Proc. World Conf. on Birds of Prey (Vienna 1975). Internat. Counc. for Bird Preservation.

Henny, C.J. 1983. Distribution and abundance of nesting ospreys in the United States. Pages 176-186 in D.M. Bird, ed. Biology and management of bald eagles and ospreys. Harpell Press, Ste. Anne de Bellevue, Quebec.

Henny, C.J., and W.T. Van Velzen. 1972. Migration patterns and wintering localities of American ospreys. J. Wildl. Manage. 36(4):1133-1141.

Henny, C.J., J.A. Collins, and W.J. Deibert. 1978a. Osprey distribution, abundance, and status in western North America: II. The Oregon population. Murrelet 59(1):14-25.

Henny, C.J., D.J. Dunaway, R.D. Mallette, and J.R. Koplin. 1978b. Osprey distribution, abundance, and status in western North America: I. The northern California population. Northwest Sci. 52(1):261-271.

Hickey, J.J., and D.W. Anderson. 1968. Chlorinated hydrocarbons and eggshell changes in raptorial and fish-eating birds. Science 162(3850):271-273.

Hughes, J. 1983. On osprey habitat and productivity: a tale of two habitats. Pages 269-273 in D.M. Bird, ed. Biology and management of bald eagles and ospreys. Harpell Press, Ste. Anne de Bellevue, Quebec.

Hynes, H.B.N. 1970. The ecology of running waters. University of Toronto Press, Toronto. 555 pp.

Jenkins, R.M. 1967. The influence of some environmental factors on standing crop and harvest of fishes in U.S. reservoirs. Pages 298-321 in Reservoir fisheries resources symposium. Southern Division, Am. Fish. Soc., Bethesda, MD.

Jenkins, R.M. 1970. The influence of engineering design and operation and other environmental factors on reservoir fishery resources. J. Am. Water Res. Assoc. 16:110-119.

Jenkins, R.M. 1982. The morphoedaphic index and reservoir fish production. Trans. Am. Fish. Soc. 111(2):133-140.

Jenkins, R.M., and D.I. Morais. 1971. Reservoir sport fishing effort and harvest in relation to environmental variables. Am. Fish. Soc. Spec. Publ. 8:371-384.

Johnson, D.M., R.R. Peterson, D.R. Lycan, J.W. Sweet, M.E. Newhaus, and A.L. Schaedel. 1985. Atlas of Oregon lakes. Oregon State University Press, Corvallis. 317 pp.

Johnson, D.R., and W.E. Melquist. 1973. Unique, rare, and endangered raptorial birds of northern Idaho: nesting success and management recommendations. University of Idaho and USDA/Forest Service Publication No. R1-73-021. 42 pp.

Kennedy, R.S. 1973. Notes on the migration of juvenile ospreys from Maryland and Virginia. Bird-Banding 44(3):180-186.

Klaver, R.W., J.M. Smith, J.J. Claar, B.L. Betts, and L.C. Peterson. 1982. Osprey surveys in the Flathead Valley, Montana, 1977-1980. Murrelet 63(1):40-45.

Koplin, J.R. 1981. Reproductive performance of ospreys (*Pandion haliaetus*) in northwestern California. Nat. Geog. Soc. Res. Rep. 13:337-344.

Lack, D. 1954. The natural regulation of animal numbers. University Press, Oxford. 343 pp.

Lack, D. 1968. Ecological adaptations for breeding in birds. Methuen and Company, Ltd., London. 409 pp.

Larrison, E.J., J.L. Tucker, and M.T. Jollie. 1967. Guide to Idaho birds. J. Idaho Acad. Sci. 5:1-220.

Leopold, L.B., M.G. Gordon, and J.P. Miller. 1964. Fluvial processes in geomorphology. W.H. Freeman and Co., San Francisco. 522 pp.

Levenson, H., and J.R. Koplin. 1984. Effects of human activity on productivity of nesting ospreys. J. Wildl. Manage. 48(4):1374-1377.

Lind, G.S. 1976. Production, nest site selection, and food habits of ospreys on Deschutes National Forest, Oregon. M.S. Thesis. Oregon State University, Corvallis. 53 pp.

MacCarter, D.L. 1972. Reproductive performance and population trends of ospreys at Flathead Lake, Montana. M.S. Thesis. California State University (Humdoldt), Arcata. 80 pp.

MacCarter, D.S. 1972. Food habits of ospreys at Flathead Lake, Montana. M.S. Thesis. California State University (Humboldt), Arcata. 80 pp.

MacCarter, D.L., and D.S. MacCarter. 1979. Ten-year nesting status of ospreys at Flathead Lake, Montana. Murrelet 60(1):42-49.

Malley, D.F. 1985. Acid rain and its relationship to fish biology and bald eagles. Pages 114-138 in J.M. Gerrard and T.N. Ingram, eds. The bald eagle in Canada - Proceedings of Bald Eagle Days, 1983. White Horse Plains Publ., Headingley, Manitoba.

Mathisen, J. 1977. The status of ospreys in the Chippewa National Forest. Pages 175-179 in J.C. Ogden, ed. Trans. N. Amer. Osprey Res. Conf. U.S. Natl. Park Serv. Proc. Ser. No. 2. Washington, DC.

Melquist, W.E. 1974. Nesting success and chemical contamination in northern Idaho and northeastern Washington ospreys. M.S. Thesis. University of Idaho, Moscow. 105 pp.

Melquist, W.E., D.R. Johnson, and W.D. Carrier. 1978. Migration patterns of northern Idaho and eastern Washington ospreys. Bird-Banding 49(3):234-236.

Minshall, G.W. 1978. Autotrophy in stream ecosystems. BioScience 28(12):767-771.

Mullen, P.D. 1985. Reproductive ecology of ospreys (Pandion haliaetus) in the Bitterroot Valley of western Montana. M.A. Thesis. University of Montana, Missoula. 59 pp.

Newton, I. 1976. Population limitation in diurnal raptors. Can. Field-Nat. 90(1):274-300.

Newton, I. 1979. Population ecology of raptors. Buteo Books, Vermillion, SD. 399 pp.

Newton, I. 1980. The role of food in limiting bird numbers. Ardea 68(1):11-30.

Odom, R.P., and J.W. Guthrie. 1980. Status of the osprey in Georgia. Oriole 45(2,3):25-33.

Oglesby, R.T. 1977. Relationships of fish yield to lake phytoplankton standing crop, production, and morphoedaphic factors. J. Fish. Res. Board Can. 34:2271-2279.

Omernik, J.M., and A.J. Kinney. 1983. An improved technique for estimating mean depth of lakes. Water Res. 17(11):1603-1607.

Orth, D.J. 1983. Aquatic habitat measurements. Pages 61-84 in L.A. Nielsen and D.L. Johnson, eds. Fisheries techniques. Am. Fish. Soc., Bethesda, MD.

Osterlof, S. 1951. Fiskgjusens, Pandion haliaetus (L.), flyttning. Var Fagelvarld. 10(1):1-15. [In Swedish, English summary.]

Osterlof, S. 1977. Migration, wintering areas and site tenacity of the European osprey (Pandion haliaetus haliaetus). Ornis Scand. 8:61-78.

Peakall, D.B. 1970. Pesticides and the reproduction of birds. Sci. Am. 222(4):72-78.

Peterson, A. 1986. Habitat suitability index models: bald eagle (breeding season). U.S. Fish Wildl. Serv. Biol. Rep. 82(10.126). 25 pp.

Ploskey, G.R., L.R. Aggus, W.M. Bivin, and R.M. Jenkins. 1986. Regression equations for predicting fish standing crop, angler use and sport fish yield for United States reservoirs. Administrative report No. 86-5. U.S. Fish and Wildlife Service, Great Lakes Fishery Laboratory, Ann Arbor, MI. 87 pp + figures.

Poole, A. 1981. The effects of human disturbance on osprey reproductive success. Colonial Waterbirds 4:20-27.

Poole, A.E., and P.R. Spitzer. 1983. An osprey revival. Oceanus 26(1):49-54.

Postupalsky, S. 1977a. A critical review of problems in calculating osprey reproductive success. Pages 1-11 in J.C. Ogden, ed. Trans. N. Amer. Osprey Res. Conf. U.S. Natl. Park. Serv. Proc. Ser. No. 2. Washington, DC.

Postupalsky, S. 1977b. Status of the osprey in Michigan. Pages 153-165 in J.C. Ogden, ed. Trans. N. Amer. Osprey Res. Conf. U.S. Natl. Park Serv. Proc. Ser. No. 2. Washington, DC.

Postupalsky, S. 1978. Artificial nesting platforms for ospreys and bald eagles. Pages 35-45 in S.A. Temple, ed. Endangered birds. University of Wisconsin Press, Madison.

Postupalsky, S., and S.M. Stackpole. 1974. Artificial nesting platforms for ospreys in Michigan. Pages 105-117 in F.N. Hamerstrom, Jr., B.E. Harrell, and R.R. Olendorff, eds. Management of raptors. Raptor Research Foundation, Raptor Research Rep. No. 2.

Prevost, Y.A. 1977. Feeding ecology of ospreys in Antigonish County, Nova Scotia. M.S. Thesis. Macdonald College of McGill University, Montreal, Quebec, Canada. 111 pp.

Prevost, Y.A. 1983. Osprey distribution and subspecies taxonomy. Pages 157-173 in D.M. Bird, ed. Biology and management of bald eagles and ospreys. Harpell Press, Ste. Anne de Bellevue, Quebec.

Prose, B.L. 1985. Habitat suitability index models: belted kingfisher. U.S. Fish Wildl. Serv. Biol. Rep. 82(10.87). 22 pp.

Ratcliffe, D.A. 1970. Changes attributable to pesticides in egg breakage frequency and eggshell thickness in some British birds. J. Appl. Ecol. 7(1):67-115.

Reese, J.G. 1970. Reproduction in a Chesapeake Bay osprey population. Auk 87(4):747-759.

Reese, J.G. 1975. Osprey nest success in Eastern Bay, Maryland. Chesapeake Sci. 16(1):56-61.

Reese, J.G. 1977. Reproductive success of ospreys in central Chesapeake Bay. Auk 94(2):202-221.

Regier, H.A., A.J. Cordonne, and R.A. Ryder. 1971. Total fish landings from freshwaters as a function of limnological variables of East-Central Africa. FAO Fish Stock Assess. Work. Pap. No. 3. 13 pp.

Rhodes, L.I. 1972. Success of osprey nest structures at Martin National Wildlife Refuge. J. Wildl. Manage. 36(4):1296-1299.

Richardson, L. 1980. Ospreys in the Bridger-Teton National Forest, Wyoming. Yale School of Forestry and Environmental Studies, New Haven, Connecticut. 60 pp.

Roberts, H.B. 1969. Management plan for the Crane Prairie Reservoir Osprey Management Area. Deschutes Natl. Forest, U.S. Forest Service, Bend, Oregon. 20 pp.

Roberts, H.B. 1970. Management of the American osprey on the Deschutes National Forest, Oregon. Raptor Res. News 4(6):168-177.

Roberts, H.B., and G.S. Lind. 1977. Status of the American osprey in Oregon. Pages 215-222 in J.C. Ogden, ed. Trans. N. Amer. Osprey Res. Conf. U.S. Natl. Park Serv. Proc. Ser. No. 2. Washington, DC.

Robins, C.R., R.M. Bailey, C.E. Bond, J.R. Brooker, E.A. Lachner, R.N. Lea, and W.B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada, 4th ed. Am. Fish. Soc. Spec. Pub. No. 12. Bethesda, MD. 174 pp.

Ryder, R.A. 1964. Chemical characteristics of Ontario lakes as related to glacial history. Trans. Am. Fish. Soc. 93:260-268.

Ryder, R.A. 1965. A method for estimating the potential fish production of north-temperate lakes. Trans. Am. Fish. Soc. 94:214-218.

Ryder, R.A. 1978. Fish yield assessment of large lakes and reservoirs - a prelude to management. Pages 403-423 in S.D. Gerking, ed. Ecology of freshwater fish production. Blackwell Science Publications, Oxford, U.K.

Ryder, R.A. 1982. The Morphoedaphic Index - use, abuse, and fundamental concepts. Trans. Am. Fish. Soc. 111(2):154-164.

Ryder, R.A., S.R. Kerr, K.H. Loftus, and H.A. Regier. 1974. The morphoedaphic index, a fish yield estimator - review and evaluation. J. Fish. Res. Board Can. 31:663-688.

Schaadt, C.P., and L.M. Rymon. 1983. The restoration of ospreys by hacking. Pages 299-305 in D.M. Bird, ed. Biology and management of bald eagles and ospreys. Harpell Press, Ste. Anne de Bellevue, Quebec.

Schlesinger, D.A., and H.A. Regier. 1982. Climatic and morphoedaphic indices of fish yields from natural lakes. Trans. Am. Fish. Soc. 111(2):142-150.

Schmid, F.C. 1966. The status of the osprey in Cape May County, New Jersey between 1939 and 1963. Chesapeake Sci. 7(4):220-223.

Schofield, C.L. 1976. Acid precipitation: effects on fish. Ambio. 5:228-230.

Schroeder, G.J. 1972. Results of a two-year investigation of the ospreys of northern Idaho. M.S. Thesis. University of Idaho, Moscow. 63 pp.

Schroeder, G.J., and D.R. Johnson. 1977. Productivity of northern Idaho osprey populations. Pages 199-203 in J.C. Ogden, ed. Trans. N. Amer. Osprey Res. Conf. U.S. Natl. Park Serv. Proc. Ser. No. 2. Washington, DC.

Scott, F., and C.S. Houston. 1983. Osprey nesting success in west-central Saskatchewan. Blue Jay 41(1):27-32.

Seyb, L., and K. Randolph, eds. 1977. North American project - A study of U.S. waterbodies. U.S. E.P.A., Ecol. Res. Series - EPA-600/3-77-086.

Sindelar, C., Jr. 1977. Reproduction in Wisconsin ospreys. Pages 167-173 in J.C. Ogden, ed. Trans. N. Amer. Osprey Res. Conf. U.S. Natl. Park Serv. Proc. Ser. No. 2. Washington, DC.

Smith, C.F., and C. Ricardi. 1983. Ospreys and bald eagles in New Hampshire: status, habitat, and nest site characteristics. Pages 149-155 in D.M. Bird, ed. Biology and management of bald eagles and ospreys. Harpell Press, Ste. Anne de Bellevue, Quebec.

Spitzer, P.R. 1978. Osprey egg and nestling transfers - their value as ecological experiments and as management procedures. Pages 171-182 in S.A. Temple, ed. Endangered birds. University of Wisconsin Press, Madison.

Spitzer, P.R., and A.F. Poole. 1980. Coastal ospreys between New York City and Boston: a decade of reproductive recovery 1969-1979. Amer. Birds 34(3):234-241.

Strahler, A.N. 1957. Quantitative analysis of watershed geomorphology. Trans. Am. Geophys. Union 38:913-920.

Swenson, J.E. 1975. Ecology of the bald eagle and osprey in Yellowstone National Park. M.S. Thesis. Montana State University, Bozeman. 146 pp.

Swenson, J.E. 1978. Prey and foraging behavior of ospreys on Yellowstone Lake, Wyoming. J. Wildl. Manage. 42(1):87-90.

Swenson, J.E. 1979a. Factors affecting status and reproduction of ospreys in Yellowstone National Park. J. Wildl. Manage. 43(3):595-601.

Swenson, J.E. 1979b. The relationship between prey species ecology and dive success in ospreys. Auk 96(2):408-412.

Swenson, J.E. 1981a. Osprey nest site characteristics in Yellowstone National Park. J. Field Ornithol. 52(1):67-69.

Swenson, J.E. 1981b. Status of the osprey in southeastern Montana before and after construction of reservoirs. West. Birds 12(1):47-51.

Swenson, J.E. 1983. Is the northern interior bald eagle population in North America increasing? Pages 23-34 in D.M. Bird, ed. Biology and management of bald eagles and ospreys. Harpell Press, Ste. Anne de Bellevue, Quebec.

Swenson, J.E., K.L. Alt, and R.L. Eng. 1986. Ecology of bald eagles in the Greater Yellowstone Ecosystem. Wildl. Monogr. 95:1-46.

Ueoka, M.L. 1974. Feeding behavior of ospreys at Humboldt Bay, California. M.S. Thesis. California State University (Humboldt), Arcata. 76 pp.

U.S. Fish and Wildlife Service. 1981. Standards for the development of Habitat Suitability Index models. 103 ESM. U.S. Fish Wildl. Serv., Div. Ecol. Serv., Washington, DC. n.p.

Van Daele, L.J. 1980. Ospreys and power poles in Idaho. Pages 104-112 in R.P. Howard, ed. A workshop on raptors and energy developments. U.S. Fish Wildl. Serv., Boise, Idaho.

Van Daele, L.J., and H.A. Van Daele. 1982. Factors affecting the productivity of ospreys nesting in west-central Idaho. Condor 84(1):292-299.

Van Daele, L.J., H.A. Van Daele, and D.R. Johnson. 1980. The status and management of ospreys nesting in Long Valley, Idaho. Final Proj. Rep., University of Idaho, Moscow. 49 pp.

Vannote, R.L., G.W. Minshall, K.W. Cummins, J.R. Sedell, and C.E. Cushing. 1980. The river continuum concept. Can. J. Fish. Aquat. Sci. 37(1):130-137.

Ward, P., and A. Zahavi. 1973. The importance of certain assemblages of birds as "information-centres" for food-finding. Ibis 115(4):517-534.

Wetmore, S.P., and D.I. Gillespie. 1976. Osprey and bald eagle populations in Labrador and northeastern Quebec, 1969-1973. Can. Field-Nat. 90(3):330-337.

Wetzel, R.G. 1975. Limnology. W.B. Saunders Co., Philadelphia. 743 pp.

Wiemeyer, S.N. 1971. Reproductive success of Potomac River Ospreys - 1970. Chesapeake Sci. 12(4):278-280.

Wiley, J.W., and F.E. Lohrer. 1973. Additional records of non-fish prey taken by ospreys. Wilson Bull. 85(4):468-470.

Wynne-Edwards, V.C. 1962. Animal dispersion in relation to social behavior. Hafner Pub. Co., New York. 653 pp.

Zarn, M. 1974. Osprey, *Pandion haliaetus carolinensis*. U.S. Bur. Land Manage. Habitat management series for unique or endangered species. No. 12. 41 pp.

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. Biological Report 82(10.154)	2.	3. Recipient's Accession No.
4. Title and Subtitle Habitat Suitability Index Models: Osprey			5. Report Date September 1987
			6.
7. Author(s) Sandra L. Vana-Miller			8. Performing Organization Rept. No.
9. Performing Organization Name and Address	Dept. of Fishery and Wildlife Biology Colorado State University Fort Collins, CO 80523		10. Project/Task/Work Unit No.
			11. Contract(C) or Grant(G) No. (C) (G)
12. Sponsoring Organization Name and Address	U.S. Department of the Interior Fish and Wildlife Service Research and Development Washington, DC 20240		13. Type of Report & Period Covered
			14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

A review and synthesis of existing information were used to develop a Habitat Suitability Index (HSI) model for the osprey (*Pandion haliaetus*). The model consolidates habitat use information into a framework appropriate for field application, and is scaled to produce an index between 0.0 (unsuitable habitat) and 1.0 (optimum habitat). HSI models are designed to be used with Habitat Evaluation Procedures previously developed by U.S. Fish and Wildlife Service.

17. Document Analysis a. Descriptors

Birds
Wildlife
Habitability
Mathematical models

b. Identifiers/Open-Ended Terms

Osprey
Pandion haliaetus
Habitat suitability

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Release unlimited	Unclassified	46
	20. Security Class (This Page) Unclassified	22. Price

(See ANSI-Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce