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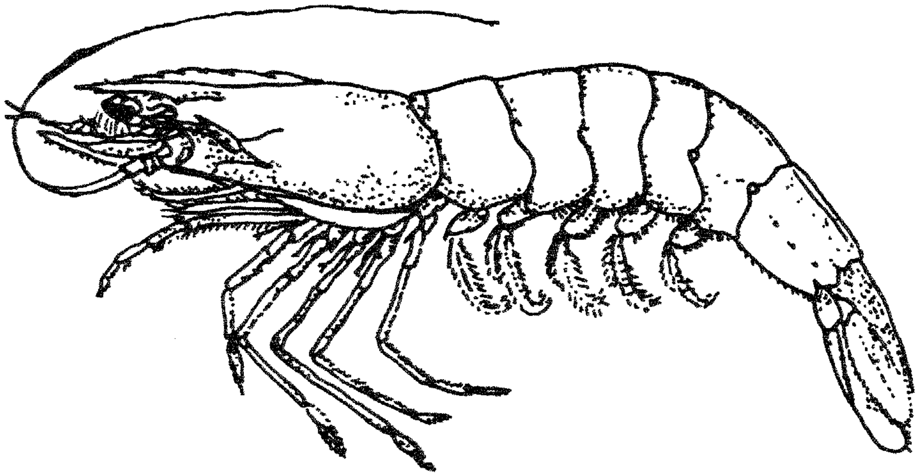
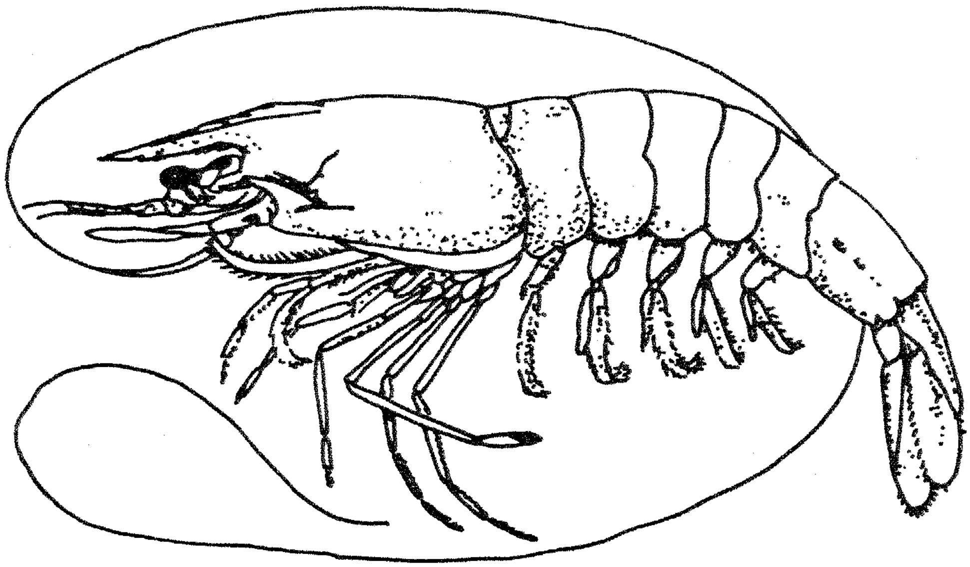
HABITAT SUITABILITY INDEX MODELS: NORTHERN GULF OF MEXICO BROWN SHRIMP AND WHITE SHRIMP





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HABITAT SUITABILITY INDEX MODELS: NORTHERN GULF OF MEXICO BROWN SHRIMP AND WHITE SHRIMP

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PREFACE

The habitat use information and habitat suitability index (HSI) models in this report on northern Gulf of Mexico brown shrimp and white shrimp are intended for use in impact assessment and habitat management. The models were developed from a review and synthesis of existing information and are scaled to produce an index of habitat suitability between 0 (unsuitable habitat) and 1 (optimally suitable habitat). Assumptions used to transform habitat use information into the HSI model and guidelines for model applications, including methods for measuring model variables, are described.

These models are hypotheses of species-habitat relationships, not a statement of proven cause and effect relationships. The models have not been field-tested, but have been applied to four hypothetical data sets which are presented and discussed. For this reason, the U.S. Fish and Wildlife Service encourages model users to convey comments and suggestions that may help increase the utility and effectiveness of this habitat-based approach to fish and wildlife management. Please send any comments and suggestions you may have on the brown shrimp and white shrimp HSI models to:

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CONTENTS

ACKNOWLEDGMENTS

Development of the habitat suitability index models and the narrative for brown and white penaeid shrimp were constructively reviewed by Drs. N. Benson and C. Cordes of the National Coastal Ecosystems Team, U.S. Fish and Wildlife Service, Dr. R. E. Condrey of the Center for Wetland Resources, Louisiana State University, and several anonymous reviewers. Thorough evaluations of model structure and functional relationships were provided by personnel of the U.S. Fish and Wildlife Service's National Coastal Ecosystems Team and Western Energy and Land Use Team. Model and supportive narrative reviews were also provided by representatives of the National Marine Fisheries Service and by Regional personnel of the U.S. Fish and Wildlife Service. Finally, funding for model development and publication was provided by the U.S. Fish and Wildlife Service.

BROWN SHRIMP (Penaeus aztecus)

and

WHITE SHRIMP (Penaeus setiferus)

HABITAT USE INFORMATION

Introduction

Shrimp are the most valuable commercial fishery in the United States and an important sport fishery (Burkenroad 1934; Garcia and LeReste 1981; National Marine Fisheries Service 1981). Brown shrimp and white shrimp are found along much of the Atlantic and Gulf of Mexico coasts. The geographic range of the brown shrimp extends from Martha's Vineyard, Massachusetts, through the Gulf of Mexico to the Yucatan Peninsula, Mexico (Lassuy 1983). Maximum densities of brown shrimp occur along the Texas-Louisiana coast (Lassuy 1983).

Perez-Farfante (1969) listed white shrimp as occurring along the Atlantic coast from Fire Island, New York, to St. Lucie Inlet, Florida. White shrimp are distributed along the Gulf of Mexico coast from Ochlockonee River of Apalachee Bay, Florida, west and southward around the gulf to Ciudad Campeche, Mexico. Highest densities of white shrimp occur off the Louisiana coast in waters less than 9.1 m (30 ft) deep (Klima et al. 1982, cited by Muncy 1983).

These species occur in both marine and estuarine habitats and have similar life histories. Adult shrimp spawn offshore in marine waters; the fertilized eggs become free-swimming larvae. After several molts they enter estuarine waters as postlarvae. Both species depend heavily on estuaries and coastal wetlands (Kutkuhn 1966; Turner 1977). Wetlands within the estuary offer both a concentrated food source and a refuge from predators. After growing into juveniles the shrimp leave the estuary to move offshore where they become adults. The timing of immigration and emigration, spatial use of a food-rich habitat, and physiological and evolutionary adaptations to tides, temperature, and salinity differ between the two species.

The critical habitat factors affecting brown and white shrimp have been inferred from examination of data from commercial landings. The sustainable annual commercial yield of penaeid shrimp is unusual in the fishing industry. Very few individuals live more than a year, and the majority harvested are less than 6 months old in areas where there is an extensive inshore fishery. There is no demonstrable stock-recruitment relation. Fishing that would influence recruitment, given present technology, is essentially impossible: it is not presently economically or technically feasible to take so many shrimp that too few survive to provide an adequate supply for the following year (Van Lopik et al. 1979; Dr. R.E. Condrey, Center for Wetland Resources, Louisiana

State University, Baton Rouge; pers. comm.). Because of these characteristics, fishing mortality and yield in any one year have not been shown to affect yield in the following year.

Reproduction and Life History

Brown and white shrimp are sexually dimorphic (Cook and Lindner 1970; Lindner and Cook 1970). Mature females tend to be larger than males of the same age (Williams 1955). Female and male white shrimp attain sexual maturity at sizes of 135 mm (5.3 inches) and 155 mm (6.1 inches), respectively (Perez-Farfante 1969). Brown shrimp mature sexually when they are at least 140 mm (5.5 inches) (Renfro and Brusher 1964). Males deposit spermatophores on females during copulation, and eggs are fertilized externally (King 1948). Individual white shrimp may release one million eggs per spawn (Anderson et al. 1949, 1965). It is unclear whether multiple or single spawning occurs, although the latter is probable (King 1948; Lindner and Anderson 1956; Perez-Farfante 1969).

Brown shrimp spawn in offshore marine water deeper than 18 m (59 ft), usually in water 46 to 109 m (151 to 358 ft) deep (Renfro and Brusher 1963). Most brown shrimp spawn in the spring and early summer; some also spawn in the fall (Pearson 1939; Renfro and Brusher 1963).

White shrimp spawn in offshore waters 7 to 31 m (23 to 102 ft) deep, from spring to fall (Lindner and Anderson 1956; Renfro and Brusher 1963; Bryan and Cody 1975). Spawning activity is probably correlated with a rapid change in bottom temperature (Lindner and Anderson 1956; Perez-Farfante 1969).

Recruitment of postlarvae to estuaries. Movement of postlarval brown shrimp into estuaries has been observed from January through June in Louisiana with various peaks from February to April (George 1962; Gaidry and White 1973; White and Boudreaux 1977). A peak migration from March to April has been observed in Galveston Bay (Baxter 1966; Baxter and Renfro 1967). Lower levels of recruitment of brown shrimp postlarvae have also been observed from February to December (St. Amant et al. 1966a).

Recruitment of postlarval white shrimp into estuaries occurs from late spring to fall when temperatures are above 25°C (77°F) (Baxter and Renfro 1967). Postlarval white shrimp are most abundant in the estuary from June through September in Louisiana (Gaidry and White 1973). Recruitment in Texas and Mississippi lasts from May through October (Christmas et al. 1966; Baxter and Renfro 1967). Gaidry and White (1973) suggested that some young white shrimp migrate from estuaries to nearshore marine waters during late fall to overwinter and move back to estuaries in early spring. Some white shrimp, probably less than 10% of the population, overwinter in Texas coastal bays and estuaries (Donald A. Meinke, U.S. Fish and Wildlife Service, Corpus Christi, Texas; pers. comm.).

Postlarvae and juveniles in estuaries. Four to six weeks after entering the estuarine nurseries, brown shrimp postlarvae transform into juveniles. Young brown shrimp remain in shallow estuarine areas near the marsh-water or mangrove-water interface or in seagrass beds which provide both feeding habitat and protection from predators (Figure 1). As they reach 60 to 70 mm (2.4 to 2.8 inches) total length (TL), they move away from these interface areas

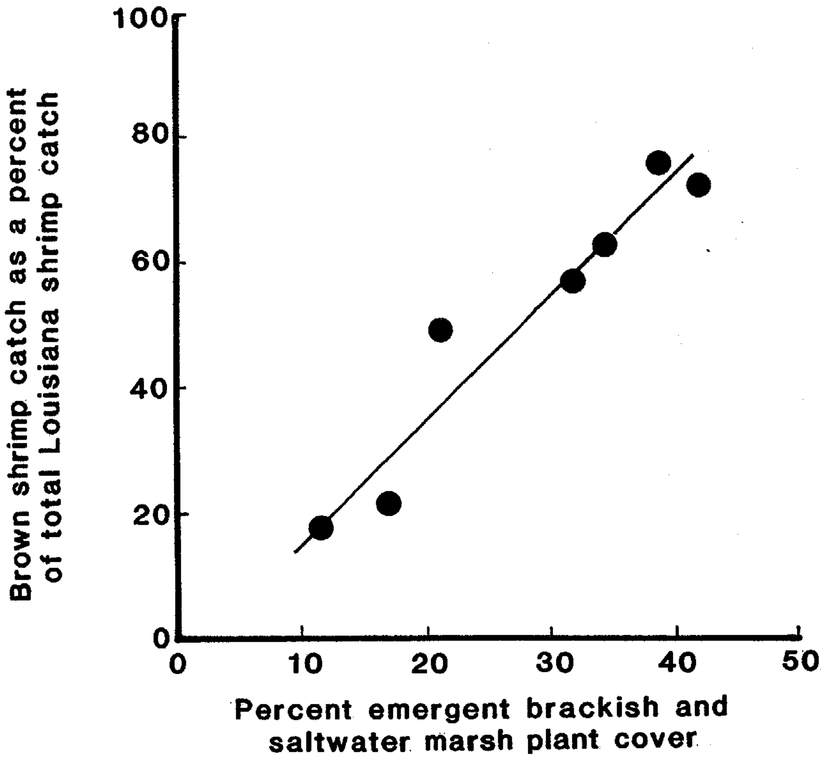


Figure 1. The percentage of brown shrimp caught within hydrological units of inshore Gulf of Mexico as a function of saline vegetation. The white shrimp catch is a function of freshwater vegetation.

into deeper, open water; and at 90 to 110 mm (3.5 to 4.3 inches) TL, brown shrimp begin their gulfward migration (Gaidry and White 1973; Van Lopik et al. 1979).

In nursery grounds, juvenile white shrimp move further up water courses than brown shrimp juveniles: up to 160 km (99 mi) in Louisiana and 210 km (130 mi) in northeast Florida (Perez-Farfante 1969). Upon reaching 120 to 140 mm (4.7 to 5.5 inches) TL, white shrimp leave Gulf of Mexico embayments as waters cool from September to December (St. Amant et al. 1966b), although in winter smaller white shrimp may emigrate and return to estuaries when water temperatures rise (Etzold and Christmas 1977).

The migration of shrimp from shallow estuaries to deeper marine waters is influenced by tides, lunar cycles, maturation state, and estuarine temperature changes (Gaidry and White 1973; Blackmon 1974). Field studies in North Carolina have shown that white and brown shrimp will leave estuarine nursery areas prematurely if large freshwater inflows occur (Hunt et al. 1980; Jones and Sholar 1981; Laney and Copeland 1981).

Growth and Food

After fertilization, the demersal brown and white shrimp eggs become planktonic larvae and pass through five naupliar, three protozoeal, and three mysis stages (Pearson 1939; Anderson et al. 1949; Perez-Farfante 1969) over a period of 10-25 days (Johnson and Fielding 1956; Cook and Murphy 1969). Growth rates vary widely and are dependent on temperature, season, size, and sex (Lindner and Anderson 1956; Costello and Allen 1968; Perez-Farfante 1969; Fontaine and Neal 1971; Chavez 1973). Winter growth is generally considered slow. St. Amant et al. (1966a) observed that daily growth of brown shrimp was negligible below 16°C (61°F), less than 1 mm (0.04 inches) between 16°C (61°F) and 20°C (68°F), and less than 1.5 mm (0.06 inches) around 25°C (77°F). For brown shrimp, growth is slow (0.5 mm or 0.02 inches/day) in January and February, increases in March, and reaches a maximum (0.5-3.3 mm or 0.02-0.13 inches) from April to June (Loesch 1965; Ringo 1965; St. Amant et al. 1966a; Broom 1968; Ford and St. Amant 1971; Swingle 1971). This increase in growth rate has been associated with the warming of estuaries in the spring (St. Amant et al. 1962; Ford and St. Amant 1971).

Parrack (1978) estimated growth rate of brown shrimp from mark and recapture experiments conducted in the northern Gulf of Mexico by Clark et al. (1974). He concluded that females grow more rapidly and attain a larger final length and weight than males.

Growth rates of estuarine white shrimp estimated from trawl samples ranged from 0.6 to 2.2 mm/day (0.02 to 0.09 inches/day) in summer (Gunter 1955; Williams 1955; Loesch 1965). Mark and recapture experiments on white shrimp have indicated that small shrimp grow faster than large shrimp at the same temperature, and growth is highest for all sizes in the warmer months (Lindner and Anderson 1956; Klima 1964, 1974).

All actively feeding stages of the brown shrimp are omnivorous. Larvae feed in the water column on both phyto- and zooplankton (Van Lopik et al. 1979). After moving into estuarine nursery areas, postlarvae become demersal and feed at the vegetation-water interface. Jones (1973) reported that postlarvae from 25 to 44 mm (1 to 1.7 inches) indiscriminately ingested the top layer of sediment, which contained primarily marsh plant detritus, algae, and microorganisms, and termed them "omnivorous encounter feeders." Additionally, he found that 45- to 65-mm (1.8- to 2.6-inches) juveniles selected the organic fraction of the sediment and termed them "opportunistic omnivores." Individuals over 65 mm began to disperse to deeper waters and became more predaceous, but occasionally ingested both detritus and algae and were termed "omnivorous predators." Prey included polychaetes, amphipods, nematodes, chironomid larvae, and ostracods.

Both juvenile and adult white shrimp are omnivorous, and the primary differences in food selection are the nature and location of materials selected. Three studies on gut contents, summarized by Etzold and Christmas (1977), indicated major food items were detritus, chitin, parts of annelids and gastropods, fish parts, bryozoans, sponges, corals, algal filaments, and stems and roots of vascular plants.

Specific Habitat Requirements

Estuarine vegetation. From a long-term perspective, the total yields of adult brown and white shrimp are directly limited by the quantity and quality of marshes and submerged vegetation available to postlarvae and juveniles. Estuarine marshes and seagrass beds provide food and protection to shrimp. Laboratory and field experiments with a variety of aquatic organisms have documented the usefulness of restrictive spaces in protecting prey from larger predators (Charnov et al. 1976; Vince et al. 1976). Laboratory studies of predation on juvenile brown shrimp by pinfish (Lagodon rhomboides) and croaker (Micropogonius undulatus) indicated that lower predation rates occur in salt marsh vegetation (Minello and Zimmerman 1982).

Within each hydrological unit from Florida to Louisiana where shrimp are fished, the harvest is directly proportional to the area of estuarine vegetation (Figure 2). When marshes are separated from the estuary with levees or bulkheads, food resources are unavailable to shrimp and densities of postlarvae and juveniles in the estuary are lower (Mock 1967; Lindall et al. 1973,

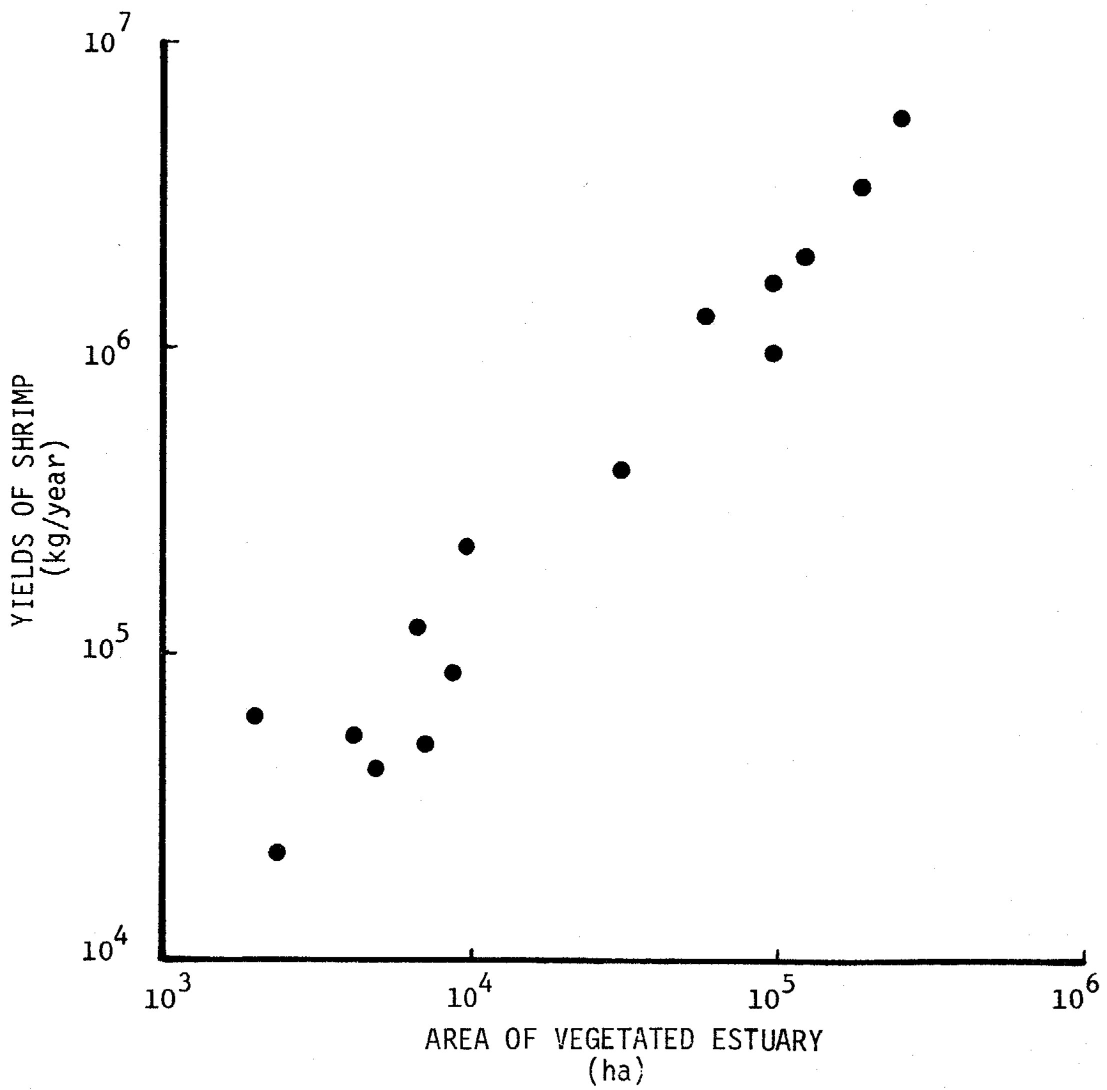


Figure 2. The inshore shrimp yields and the area of vegetated estuary for the National Marine Fisheries Service statistical reporting areas of the northern Gulf of Mexico. Data are described in Turner (1977).

1975; Trent et al. 1976). The same pattern holds true for developed penaeid shrimp industries throughout the world: where intertidal wetland area is high, yields are high (Doi et al. 1973; Turner 1977). In addition to intertidal wetland area, density of the wetland vegetation is important. More shrimp are found when wetland vegetation occurs in higher densities (Zimmerman et al. 1982).

Substrate. Brown shrimp and white shrimp both prefer soft bottom substrates. Soft substrates are rich in food materials which make up the bulk of the shrimp's diet (Williams 1955, 1959; Mock 1967; Van Lopik et al. 1979). Postlarval brown shrimp numbers are greatest in soft bottom, shallow areas of estuaries in or near marshes or seagrass beds (Christmas et al. 1966); settling postlarvae's significant preference for soft, muddy substrates with decaying vegetation has been demonstrated experimentally (Williams 1958). When exposed to experimental substrates, white shrimp selected muddy substrates of loose peat and sandy mud. Juvenile white and brown shrimp avoided coarse substrate and sought food, rather than cover, in soft bottoms (Williams 1958).

Salinity. Copeland and Bechtel (1974) documented the distribution of brown and white shrimp within different estuarine temperature and salinity zones for the northern Gulf of Mexico. White shrimp are generally found in lower salinity waters than brown shrimp. Postlarval brown shrimp and white shrimp exhibit similar differences under laboratory conditions (Keiser and Aldrich 1976). Brown shrimp have been reared in the laboratory in water with 1.0 part per thousand (ppt) salinity (Venkataramaiah 1971), but the general interpretation is that they prefer salinities of 10 to 20 ppt (Gunter et al. 1964). Optimal salinities for brown shrimp postlarvae appear to be higher than they are for white shrimp (Rose et al. 1975). Lethal limits for postlarvae are as low as 38 ppt at 28°C (82°F) and may decrease with higher temperature (Wilson et al. 1979).

Temperature. Brown shrimp and white shrimp prefer temperatures above 15°C (59°F) in the estuary and laboratory (Venkataramaiah 1971). Further, Zein-Eldin and Aldrich (1965) reported a peak growth rate for brown shrimp at 25°C (77°F). Brown shrimp have been collected in waters with temperatures as low as 2°C (36°F), but few have been taken in waters with temperatures below 10°C (50°F), with highest catches taken in waters above 20°C (68°F) (Swingle 1971; Christmas et al. 1976). Temperatures of 4.4°C (40°F) or less may cause mass narcosis and mortality (Gunter and Hildebrand 1951). Temperatures above 32.2°C (90°F) can cause severe stresses (Kutkuhn 1966).

Temperature-salinity interaction. A wide range of temperature and salinity combinations can be tolerated by shrimp. But during periods of extreme temperatures, it is difficult for shrimp to adapt to extreme salinities, and vice versa (Zein-Eldin and Aldrich 1965; St. Amant et al. 1966a; Venkataramaiah et al. 1974).

Year-to-year variations in shrimp harvest are frequently as high as 100% and are most often a result of extremes in salinity and temperature during the period when postlarvae are in the estuary. The annual success of the brown shrimp harvest in Louisiana is directly correlated with the temperature of both the estuarine water in mid-April and the acreage of marsh found in areas with salinities above 10 ppt (Barrett and Gillespie 1973, 1975; Barrett and

Ralph 1976). In Louisiana, good brown shrimp production is expected if the spring is dry and warm. A similar phenomenon along the northern Texas coast has been observed (Condrey, pers. comm.).

HABITAT SUITABILITY INDEX (HSI) MODELS

Model Applicability

Brown and white shrimp occupy a wide range of habitats of varying quality. In their short 1-year life span they adapt to seawater, then shallow brackish or freshwater habitats, and then seawater again. Our knowledge of these species is incomplete. Consequently, generalized statements about habitat requirements cannot be applied equally to all populations. Each variable in the models should be evaluated and modified as necessary for best results in a local situation.

Large fluctuations exist in the water quality factors included in the models. For this reason, long-term existing data sets should be used or field measurements of these variables should be made over a period of weeks or months. Unpublished sampling records available from county, parish, State, and Federal agencies should be consulted for a perspective on the regional long-term conditions. Often data from a long-term general monitoring program are preferable to those from a few site-specific measurements.

Geographic area. The models are applicable to the estuaries and bays of the northern Gulf of Mexico, from Tampa Bay, Florida, to Corpus Christi Bay, Texas.

Life history stages. Only postlarval and juvenile life stages in estuarine habitats are included in the models. For the intended use of this model, marine habitats are not considered as vulnerable to structural project impacts as estuarine nursery areas.

Season. Habitat should be evaluated between January and May for brown shrimp and between May and October for white shrimp.

Minimum habitat areas. The minimum habitat area is that area of contiguous suitable habitat required for brown and white shrimp to develop and reproduce successfully. No minimum size requirements for brown and white shrimp have been identified in the literature.

Cover types. Because brown and white shrimp live in waters which alternately flood and recede, salt and brackish marshes and submerged seagrass beds are to be evaluated with these HSI models. These cover types correspond to the estuarine intertidal emergent and estuarine subtidal aquatic bed habitats of Cowardin et al. (1979). The characteristics of each cover type are closely related. For example, food resources in the water are directly dependent on the availability of vegetated areas, and water temperature and salinity in vegetated areas are usually influenced by the salt and heat balance of open waters.

Verification. The output from the shrimp HSI models is an index between 0.0 and 1.0 which reflects total shrimp production or carrying capacity for an area. Hypothetical data sets were used to verify that model outputs were reasonable. These data sets are presented later. Dr. Richard Condrey, Center for Wetland Resources, Louisiana State University, Baton Rouge, reviewed and evaluated the brown shrimp and white shrimp HSI models throughout their development. His ideas and suggestions from these experts were incorporated into the model-building effort.

Model Descriptions

Overview. Although definitive agreement between field and laboratory studies has not been consistently obtained for brown shrimp and white shrimp, similar patterns between field and laboratory results with regard to habitat requirements and environmental driving forces have been observed. However, the importance of site-to-site variations in habitat quality and quantity is generally unknown except on the level of local hydrologic units. For example, it is presently possible to estimate the potential commercial fishing success for shrimp in an entire estuary if estuarine river flow and regional temperatures during the period that larvae and juveniles are in estuarine areas are known (Barrett and Ralph 1976; Turner 1977); but the impact on shrimp of a hot, salty brine discharge into a 12-ha (30-acre) wetland is not as well known. The HSI models were designed to estimate site-to-site variations.

Chemical toxicants are not included in the models because their impact on habitat is presently very difficult to assess. There are few reliable field studies available to address the multitude of known toxic compounds.

Figure 3 illustrates the relationship of habitat variables to life requisite components and life stages of brown shrimp and white shrimp in estuarine habitats.

Food and cover component. The percentage of marshes and/or submerged grassbeds in or near a bay or estuary (V_1) is the most important variable in the shrimp HSI models. The vegetated area, in or near a bay estuary is directly proportional to the habitat's long-term carrying capacities for either brown or white shrimp. A 100% coverage of marshes and/or submerged grasses in a bay, estuary, or hydrologic unit was assumed to be the optimum condition, in terms of the vegetation variable. Although important, density of vegetation was not included in the model. Currently, there are not enough data to show the relationship between density and habitat suitability. In addition, there are difficulties measuring a variable of this type.

Substrate composition (V_2; brown shrimp, V_{2b}; white shrimp, V_{2w}) contributes to the food and cover component and is important in determining shrimp distribution. This variable was assumed to be related to a habitat's carrying capacity for brown shrimp and white shrimp. A separate suitability graph is presented for each species because they differ in their use of substrate types. Mud and silt bottoms were assigned the highest suitability index, while areas with substrates composed of fine sand or coarse sand, shell and/or gravel were arbitrarily assigned lower values. Furthermore, because brown shrimp are stronger burrowers than white shrimp, sandy substrates were assigned higher values for brown than for white shrimp. The value of shell and gravel substrate for feeding or refuge from predation is not specifically known for shrimp, but this substrate type was assumed to be of some importance to the overall survival of shrimp and was arbitrarily rated at a suitability index of 0.2.

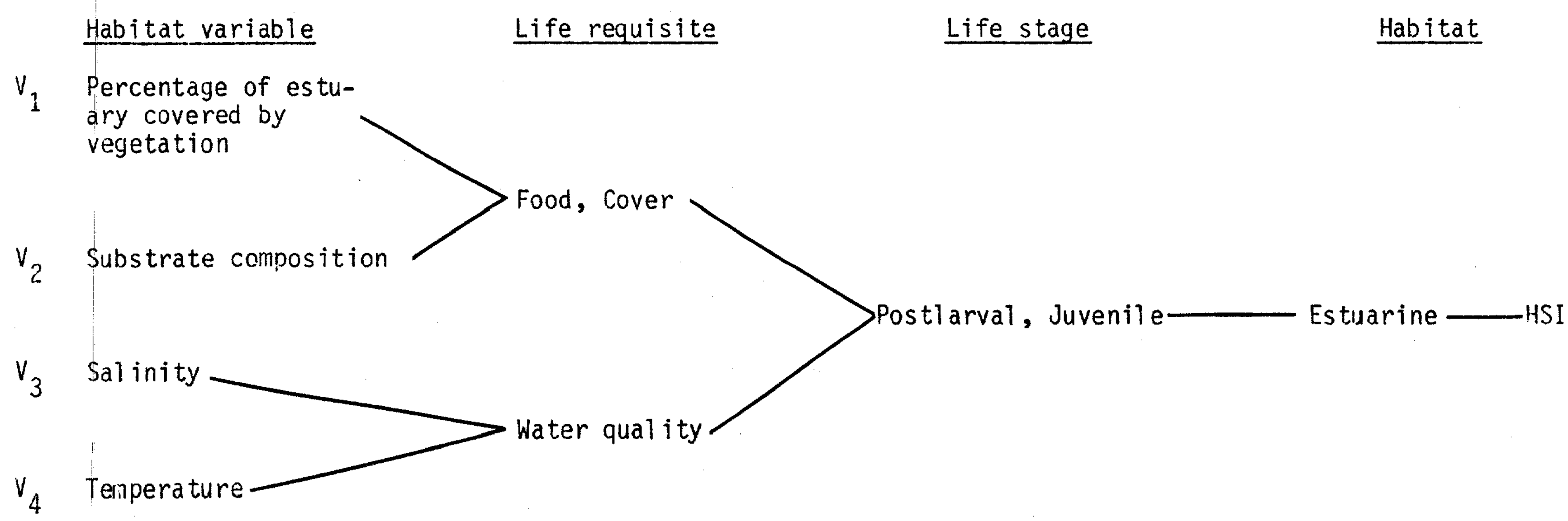


Figure 3. Relationship of habitat variables and life requisites to the habitat suitability index (HSI) for brown and white shrimp in estuarine habitats. Potentially modifying the HSI is the hydrological connection between the shrimp nursery areas and the offshore water (see text).

Water quality component. Salinities in bays and estuaries (V_3) are important to shrimp during the season when postlarvae and juveniles are in the nursery areas. Salinity preferences differ for brown shrimp (V_{3b}) and white shrimp (V_{3w}), and these differences are included in the models. Suitability index graphs developed for these variables are based on species preferences inferred from trawl studies, statistical analyses of commercial landings data, and laboratory studies. Salinities of 10-20 ppt and 1-15 ppt are assumed to be optimal for brown shrimp and white shrimp, respectively.

Temperature (V_4) is a localized habitat variable in the water quality component. Postlarvae and juveniles grow over a wide temperature range, but generally do best between 20° and 30°C (68° and 86°F) (Zein-Eldin and Aldrich 1965; Venkataramaiah 1971). Temperature values below or above this range were considered less than optimal, with 5°C (41°F) and 40°C (104°F) considered unsuitable for both shrimp species. The suitability of most habitats will be 1.0 except in those few instances where thermal effluents, perhaps from a powerplant, raise in situ temperatures significantly.

Suitability Index (SI) Graphs for Habitat Variables

The relationships between habitat variables and habitat suitability are shown graphically for estuarine (E) habitats. The suitability index (SI) values are read directly from the graph. Optimal suitability for a variable is 1.0.

Suitability index graphs for the habitat variables are based on the assumption that the suitability of a variable can be represented by a two-dimensional response surface and is independent of other variables in the model. This condition is not always met. For example, water temperatures and salinity combine to affect wetland macrophyte production, hence, plant cover. Data sources and assumptions associated with the documentation of the SI graphs appear in Table 1.

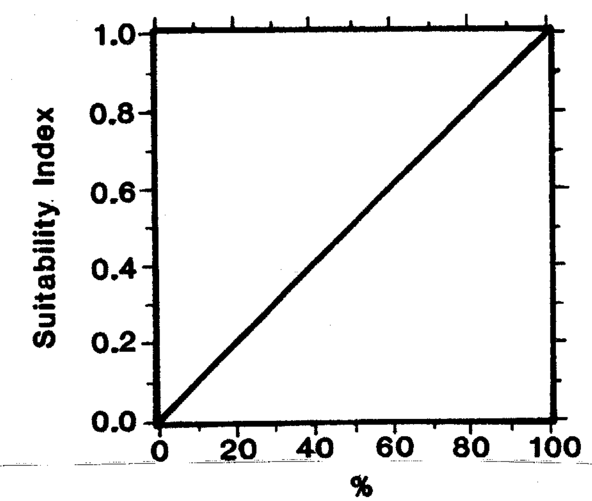
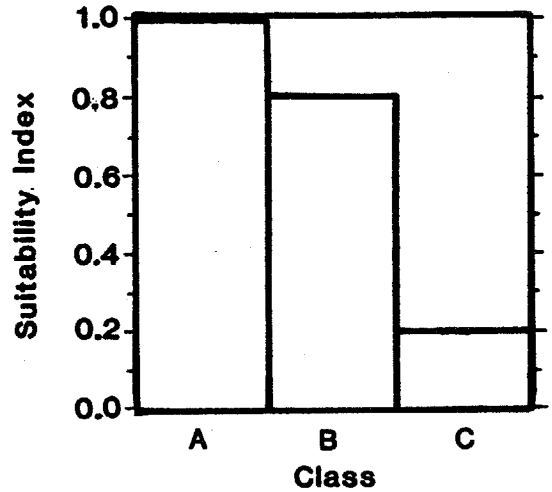
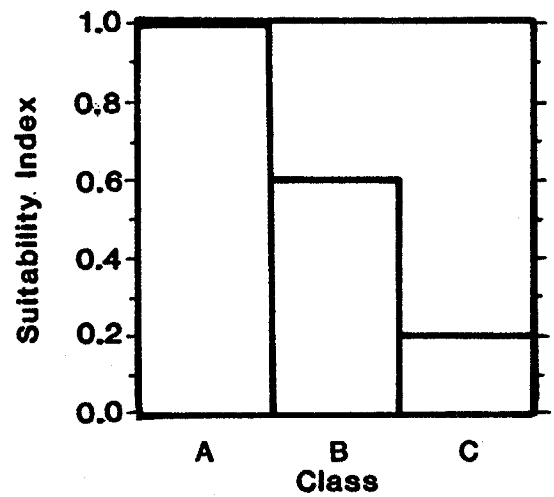
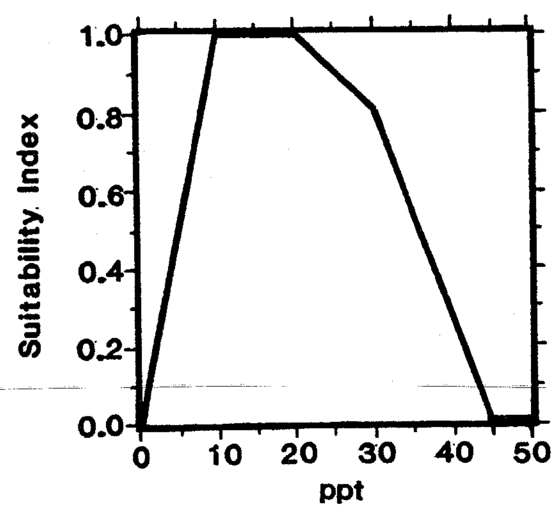
Habitat	Variable		Suitability Graph
E	V_1	Percentage of estuary covered by vegetation (marsh and seagrass).	

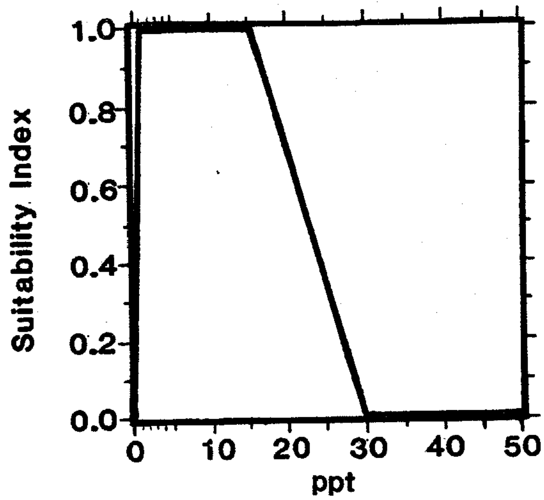
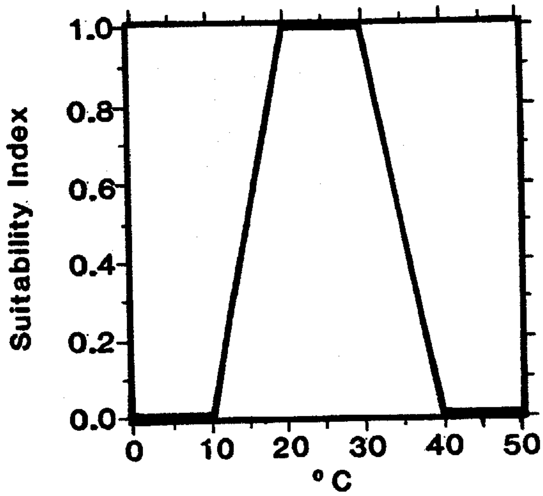
Table 1. Data sources and assumptions for gulf coast brown shrimp and white shrimp suitability indices.

Variable	and source	Assumption
V_1	Mock 1967; Doi et al. 1973; Lindall et al. 1973, 1975; Turner 1977; Zimmerman et al. 1982	Marsh vegetation and seagrass provide food for growth and protection from predators. If at least 100% of the estuary is covered by marsh and seagrass, the suitability is considered to be optimum for this variable.
V_{2b}	Williams 1955; Garcia and LeReste 1981	Soft bottoms with decaying vegetation provide food for brown shrimp.
V_{2w}	Williams 1955; Garcia and LeReste 1981	Soft bottoms with decaying vegetation provide food for white shrimp.
V_{3b}	McFarland and Lee 1963; Zein-Eldin and Griffith 1970; Copeland and Bechtel 1974; Keiser and Aldrick 1976; Turner 1977	Salinity levels affect growth of brown shrimp.
V_{3w}	McFarland and Lee 1963; Zein-Eldin and Griffith 1970; Copeland and Bechtel 1974; Keiser and Aldrich 1976; Turner 1977	Salinity levels affect growth of white shrimp.
V_4	Loesch 1965; Ringo 1965; St. Amant et al. 1966a; Broom 1968; Zein-Eldin and Griffith 1970; Ford and St. Amant 1971; Swingle 1971; Copeland and Bechtel 1974; Rose et al. 1975	Optimal temperatures are those that support rapid growth.

Habitat	Variable		Suitability Graph
E	V_{2b}	Substrate composition -- brown shrimp: 1) Soft bottom -- peaty silts, organic muds with decaying vegetation and organic material. 2) Muddy sands, fine sands. 3) Coarse or hard bottom -- sands, shell, gravel with little or no organic material.	

Habitat	Variable		Suitability Graph
E	V_{2w}	Substrate composition -- white shrimp: 1) Soft bottom -- peaty silts, organic muds with decaying vegetation and organic material. 2) Muddy sands, sands. 3) Coarse or hard bottom -- sands, shell, gravel with little or no organic material.	

Habitat	Variable		Suitability Graph
E	V_{3b}	Mean salinity during spring -- brown shrimp.	

Habitat	Variable		Suitability Graph
E	V_{3w}	Mean salinity during summer -- white shrimp.	
E	V_4	Mean water temperature (spring for brown shrimp and summer for white shrimp).	

Component Index (CI) Equations and HSI Determination

To obtain an HSI for brown shrimp or white shrimp in estuarine habitats, the SI values for each habitat variable or life requisite must be combined. The suggested equation is as follows:

Component	Equation
Food, Cover (FC)	$(SI^2_{V_1} \times SI_{V_{2b}})^{1/3}$ for brown shrimp
	$(SI^2_{V_1} \times SI_{V_{2w}})^{1/3}$ for white shrimp
Water quality (WQ)	$(SI_{V_{3b}} \times SI_{V_4})^{1/2}$ for brown shrimp
	$(SI_{V_{3w}} \times SI_{V_4})^{1/2}$ for white shrimp

HSI = FC or WQ, whichever value is lowest.

Squaring SI_{V_1} allows this variable to contribute more to the composite index value than any of the other three. This heavier weighting of V_1 is related to its effect on the long-term carrying capacity of the habitat and to its provision of both food and cover for shrimp.

Modifier. Certain structures including weirs, levees, and cattle walkways can close off the hydrological connection between estuarine shrimp habitat and the offshore habitat, and have negative impacts on shrimp (Figure 4). The connection can be estimated from a linear measurement of the confining borders of the study area (levees, roads, spoil banks) as a percentage of the unconfined outline of the natural hydrologic unit. When this hydrologic connection falls to 10% or less, the HSI for the estuarine habitat is 0. A completely impounded marsh would have no coupling to the open water and thus an HSI equal to 0.

Four sample data sets from which suitability indices were determined and an HSI calculated are in Table 2. The data sets represent a range of conditions and reflect the carrying capacity trends which the authors believe are appropriate for the kinds of hypothetical water bodies listed in Table 2.

Field Use of the Model

The level of detail used in addressing a particular field problem will depend on time and effort constraints. Field studies in northern Gulf of Mexico estuaries have been conducted over many years and in numerous locations. Many government agencies, some universities, and some industrial interests have probably collected data of interest for the region under study. In general, the regional natural resource agencies will be of most help in locating data which have some statistically useful sampling protocol. The data used in application of this model should be accompanied by appropriate documentation to insure that decisionmakers understand the quality of the data. Enough field measurements should be made to ensure reliability. Table 3 provides information on collecting data for the model.

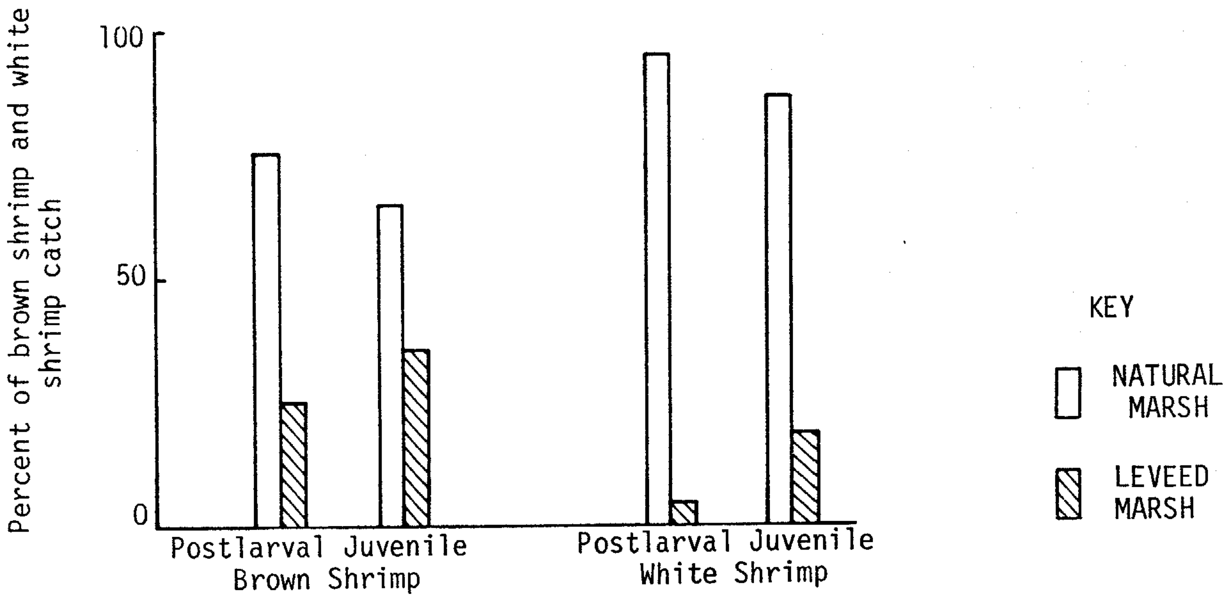


Figure 4. Brown shrimp and white shrimp catch at adjacent marshes, one natural and one with a levee reducing access. Most of the postlarval and juvenile shrimp were caught near the natural marsh (Mock 1967).

Table 2. Calculations of the habitat suitability indices for brown shrimp and white shrimp (HSI_b and HSI_w) for four data sets using habitat variables (V), suitability indices (SI), and model equations.

Model component	Data set I		Data set II		Data set III		Data set IV	
	Data	SI	Data	SI	Data	SI	Data	SI
V_1	100	1.0	50	0.5	20	0.2	10	0.1
V_{2b}	Mud	1.0	Shell	0.2	Mud	1.0	Fine sand	0.8
V_{2w}	Mud	1.0	Shell	0.2	Mud	1.0	Fine sand	0.6
V_{3b}	30	0.8	10	1.0	20	1.0	5	0.5
V_{3w}	30	0.0	10	1.0	20	0.67	10	1.0
V_4	25	1.0	25	1.0	30	1.0	20	1.0
HSI_b	0.89		0.37		0.34		0.20	
HSI_w	0.0		0.37		0.34		0.18	

Table 3. Description of variables for brown and white shrimp HSI models and suggested techniques for measuring the variables for estuarine open water and wetland habitats.

Variable	Variable description	Suggested technique
V_1	Percentage of estuary covered by vegetation	Planimeter 7½ minute U.S. Geological Survey (USGS) quadrangle maps of area or inspect aerial photographs; include submerged grassbeds. Take field measurements.
V_2	Substrate characteristics	Visually inspect the study site; use bottom grab sampler.
V_3	Salinity	Contact State and local natural resource agencies and universities. Measure with refractometer.
V_4	Temperature	Contact State and local natural resource agencies and universities. Measure with thermometer.

These models are primarily to be applied only to areas that are vegetated, and not to open-bay bottom areas. Bay bottom habitats are not thought to be critically limiting to shrimp populations. Application of this model to open-bay bottoms should only be considered if a project could affect potential growth of wetland vegetation.

These models do not apply to projects whose major effects would be to significantly lower the dissolved oxygen (DO) level. Typically, for fish and some invertebrates, levels below 15% saturation can cause significant mortality (Waterman 1960; Doudoroff and Shumay 1970; Hoss and Peters 1976; Trent et al. 1976). Such projects would include sewage waste dumping which would greatly increase the biological oxygen demand and warm-water effluent of powerplants. These models would need to be modified to evaluate impacts of lowered DO concentrations.

Interpreting Model Outputs

HSI scores are useful primarily as a means of comparison. If two areas have different scores, then the one with the higher value should be the better habitat.

When the impact of projects on shrimp habitat are being evaluated, it may be necessary to consider the entire hydrologic unit in which the study area is located. Project impacts may not be limited to the study area.

ADDITIONAL HABITAT MODELS

Two types of habitat models already exist. One, by Turner (1977), includes only wetland area and quality and was primarily designed to test the hypothesis that wetlands limit commercial yields of shrimp. Other models by Gunter and Edwards (1969), Barrett and Gillespie (1975), Barrett and Ralph (1976), Van Lopik et al. (1979), and Hunt et al. (1980) include water temperature and salinity as environmental driving forces and are designed to evaluate these parameters' effects on annual variations in commercial yields of shrimp.

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16. Abstract (Limit: 200 words)

A review and synthesis of existing information were used to develop estuarine habitat models for brown shrimp (*Penaeus aztecus*) and white shrimp (*Penaeus setiferus*). The models are scaled to produce an index of habitat suitability between 0 (unsuitable habitat) and 1 (optimally suitable habitat) for estuarine areas of the northern Gulf of Mexico. Habitat suitability indexes are designed for use with habitat evaluation procedures previously developed by the U. S. Fish and Wildlife Service.

17. Document Analysis a. Descriptors

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