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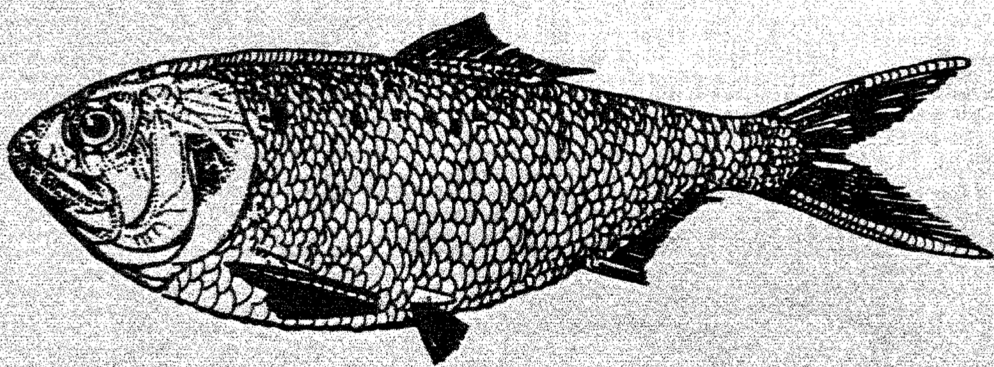
HABITAT SUITABILITY INDEX MODELS: GULF MENHADEN



Fish and Wildlife Service

U.S. Department of the Interior

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HABITAT SUITABILITY INDEX MODELS: GULF MENHADEN

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PREFACE

The habitat use information and habitat suitability index (HSI) models presented in this report on the gulf menhaden are intended for use in impact assessment and coastal habitat management. Two models were developed from a review and synthesis of existing information and are scaled to produce an index of habitat suitability between 0.0 (unsuitable habitat) and 1.0 (optimally suitable habitat). Assumptions used to transform habitat use information into the HSI models and guidelines for model applications are described.

The estuarine and marine HSI models presented herein are hypotheses of species-habitat relationships, not statements of proven cause and effect relationships. The models have not been field-tested, but they have been applied to sample data sets. 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 planning. Please send any comments or suggestions you may have on the gulf menhaden HSI models to:

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CONTENTS

ACKNOWLEDGMENTS

The habitat suitability index models for the gulf menhaden were evaluated during their development by Dr. Walter Nelson, National Marine Fisheries Service, and Mr. Bordon Wallace, Wallace Menhaden Products, Inc. Preparation of the final manuscript benefited from technical discussions between the authors and staff of the National Coastal Ecosystems Team. Constructive review comments and suggestions were also received from the staff of the Western Energy and Land Use Team, the National Coastal Ecosystems Team, and field biologists of the Fish and Wildlife Service and National Marine Fisheries Service. Funding for model construction and publication was provided by the Fish and Wildlife Service.

GULF MENHADEN (*Brevoortia patronus*)

HABITAT USE INFORMATION

The gulf menhaden is an estuarine-dependent marine species that inhabits northern Gulf of Mexico waters. The species is generally replaced at the southernmost extent of its range by the finescale menhaden (*Brevoortia gunteri*) in Texas and the yellowfin menhaden (*B. smithi*) in Florida. According to mark and recapture studies, there is little along-shore movement of gulf menhaden. Few gulf menhaden cross from one side of the Mississippi River Delta to the other (Kroger and Pristas 1979).

In the Gulf of Mexico, and for the United States as a whole, the gulf menhaden currently supports the largest commercial fishery by weight. In 1980, over 700,000 metric tons valued at $69 million dockside were landed in Mississippi and Louisiana alone (National Marine Fisheries Service 1981). Gulf menhaden are taken in purse seines from off Mobile Bay, Alabama, to Galveston Bay, Texas. The catch is taken primarily from estuarine waters of Mississippi and eastern Louisiana (Mississippi Sound and Chandeleur Sound) and nearshore marine waters of southwest Louisiana and Texas. A sizable catch is occasionally taken off Apalachicola Bay, Florida.

Age, Growth, and Food

Gulf menhaden spawn from fall to spring (mid-October through March) in marine waters. Planktonic larvae are transported via currents to estuarine nursery areas. Larvae enter estuaries when 3 to 5 weeks old. After the larvae grow and transform into juveniles in the shallow portions of the estuary, they move to open and deeper estuarine waters. Juvenile and adult gulf menhaden inhabit estuaries throughout the year (Perret et al. 1971; Swingle 1971; Christmas and Waller 1973). Most gulf menhaden, however, migrate from estuaries into offshore marine waters in late fall and winter. Precise information about offshore migration routes and environmental causes is not available. Sexual maturation is completed after two growing seasons (Christmas and Etzold 1977). Immature and spent adult menhaden migrate to estuarine waters from spring to fall (April to October). Mature gulf menhaden are sexually inactive in the estuary, but gonads mature for spawning in marine waters (Lewis and Roithmayr 1981). The gulf menhaden is a pelagic, schooling species throughout its life.

Larval menhaden feed on pelagic zooplankton in marine and estuarine waters. Although not much is known about the food habits of the gulf menhaden, Atlantic menhaden (*Brevoortia tyrannus*) larvae feed on copepods and copepod nauplii (June and Carlson 1971). Within the estuary, the mouthparts of the larvae transform, and juvenile and adult gulf menhaden become filter-feeding omnivores that primarily consume phytoplankton (Reintjes and June 1961; Reintjes and Pacheco 1966), but also ingest zooplankton, detritus, and bacteria (Darnell 1958).

Reproduction

Gulf menhaden spawn in marine waters of the Gulf of Mexico (Combs 1969). They generally spawn in open gulf waters from 2 to 140 m (7 to 459 ft) deep (Roithmayr and Waller 1963; Etzold and Christmas 1979; Lewis and Roithmayr 1981), and as far as 97 km (60 mi) offshore (Reintjes 1970; Chapoton 1974). Most gulf menhaden spawn in waters less than 18 m (60 ft) deep (Christmas and Waller 1975).

Gulf menhaden are intermittent spawners. Spawning has been reported from October through March (Turner 1969; Fore 1970), but is suspected to occur in some years from September through May (Etzold and Christmas 1979). Separate spawning peaks have been reported in late October and March (Baldauf 1954; Tagatz and Wilkens 1973) and in January and February (Combs 1969). Four or five spawning peaks may occur in one season at different locations throughout the Gulf of Mexico. The spawning season generally coincides with a period of relatively cool gulf waters that decline in surface temperature from an average of about 25°C (77°F) in October to a minimum of about 18°C (64°F) by March.

Specific Habitat Requirements

As an inhabitant of estuaries and marine waters, gulf menhaden must endure a wide range of water temperatures and salinities. This environmental variability leads to less clearly defined optima for all life stages. The known habitat requirements for each life stage (adult, egg, larval, and juvenile) are briefly described in the following sections.

Adult. Adults primarily inhabit the open waters of the Gulf of Mexico. They concentrate nearshore (less than 18 m or 60 ft) during spring and summer, and move offshore during fall and winter (Roithmayr and Waller 1963; Fore 1970; Chapoton 1974). In offshore marine waters, adults live in salinities as high or higher than 30 parts per thousand (ppt). The adults and second-year juveniles return to estuaries and nearshore marine waters in March and April (Christmas and Etzold 1977; Lewis and Roithmayr 1981). In the summer, adult gulf menhaden usually inhabit estuaries with salinities ranging from 5 to 10 ppt, and in deeper bays, to 15 ppt or more. Most gulf menhaden mature and first spawn in their second year of life. Immature and mature gulf menhaden live in, tolerate, and are affected by a wide range of water temperatures and salinities.

Egg. Fertilized eggs are buoyant (Hettler 1968; Reintjes 1969) and probably hatch within 48 hr (Christmas and Etzold 1977). Christmas and Waller (1975) collected fertilized eggs in surface plankton tows throughout the northern Gulf of Mexico during the spawning season. Although laboratory research is lacking, evidence suggests that high salinity marine waters are necessary for proper egg development. Gulf menhaden eggs and larvae have been collected in waters with salinities ranging from 6 to 36 ppt (Fore 1970; Christmas and Waller 1975); 88% of the eggs was collected from waters over 25 ppt. All eggs collected in low salinity waters were in advanced stages of development, indicating shoreward transport after spawning.

Eggs and larvae of gulf menhaden have been collected in water temperatures from 10° to 26°C or 50° to 79°F (Turner 1969; Fore 1970; Christmas and Waller 1975). Over 88% of the samples that contained eggs or larvae was collected from waters above 15°C (59°F), with an average temperature of 19°C (66°F).

Larvae. Menhaden larvae (9 to 25 mm standard length) are passively transported by currents from marine to estuarine waters, where they transform into juveniles (Reintjes 1970; Etzold and Christmas 1979). The larvae enter low salinity estuaries from September to April (Christmas and Etzold 1977) or May (Fore and Baxter 1972). Low salinities are thought to be necessary for larval Atlantic menhaden transformation (June and Chamberlin 1959). This may not apply in all situations as Reintjes and Pacheco (1966) reported that Atlantic menhaden completed transformation in the laboratory at salinities up to 40 ppt, and Simmons (1957) reported that menhaden are common in salinities up to 50 ppt in the vicinity of the Laguna Madre, Texas.

The dependence of menhaden on estuarine habitats is apparent, but not completely understood. There are no documented physiological requirements for estuarine dependence, but metamorphosing larvae are rarely taken in the ocean, indicating food and shelter provided by estuaries are essential (Nelson et al. 1977). Since gonadogenesis of young gulf menhaden is completed only in estuarine habitats (Combs 1969), exposure to brackish water is assumed necessary for early life development.

Juvenile. In estuaries, transformation to the juvenile stage occurs when gulf menhaden are 30 to 33 mm long (Tagatz and Wilkens 1973). First-year juveniles usually inhabit shallow parts of estuaries, but as they grow they migrate to the deeper, more saline waters of open bays, sounds, and nearshore marine waters. Some first-year juveniles may overwinter in estuaries.

All gulf menhaden life stages are most abundant in salinities ranging from 5 to 10 ppt. Large numbers of larvae and juveniles sometimes are found in salinities exceeding 10 ppt (Perret et al. 1971; Swingle 1971). Juvenile menhaden are tolerant of salinity changes and have been found in waters ranging from 9 to 67 ppt (Christmas and Etzold 1977). Menhaden numbers are greatly restricted in waters over 60 ppt, and mass mortalities have been reported at salinities of 80 ppt or higher (Simmons 1957).

Juveniles tolerate water temperatures from 5° to 34°C or 41° to 93°F (Christmas and Etzold 1977). Atlantic menhaden kills have been reported at water temperatures of about 3°C (37°F) or after rapid chilling to below 5°C or 41°F (Reintjes and Pacheco 1966). High water temperatures (39°C or 102°F) near a hot water discharge canal apparently caused a menhaden kill in Galveston Bay, Texas (Gallaway and Strawn 1974).

In open marine waters, juvenile menhaden are not threatened by low dissolved oxygen (DO) concentrations, as long as waters of higher DO concentrations are accessible. In restricted estuarine areas (e.g., dead end canals, enclosed harbor basins), plankton blooms may reduce DO to 3 ppm or less and cause fish kills.

Special Considerations

Larval menhaden enter estuaries when they are 3 to 5 weeks old (Reintjes 1970) and spread into shallow bayous of marshes where they feed and are afforded some protection from predation. The importance or effect of tidal marsh as a cover life requisite for gulf menhaden is difficult to quantify. The overall productivity of gulf coast estuaries and their importance as habitat for menhaden is dependent, in part, on the contribution of tidal marshes. Small (less than 50 acres) marsh areas generally do not support large concentrations of menhaden unless they are part of a larger estuarine complex.

HABITAT SUITABILITY INDEX (HSI) MODELS

Model Applicability

The great abundance of gulf menhaden and their wide distribution and use of estuarine and marine waters indicate that they can tolerate extremes of many environmental factors and are likely to be critically affected only by near catastrophic conditions.

Because of changing habitat requirements and seasonal movements of gulf menhaden during their life history, HSI models were developed for both estuarine and nearshore marine waters. The estuarine model should be applied where freshwater inflow is sufficient to dilute sea water throughout most of the year, i.e., bays, sounds, and aquatic habitats near the mouths of rivers that directly enter the northern Gulf of Mexico. The nearshore marine model should be applied to the open waters of the Continental Shelf out to the 70-m (230-ft) depth contour.

Each model was developed to evaluate independently the suitability of a specific habitat type. Therefore, when the estuarine model is used, it is necessary to assume that environmental conditions in nearshore marine habitats are sufficient to allow gulf menhaden to complete their life cycle and vice versa.

Geographic area. The models are designed to evaluate estuarine and nearshore marine habitats of the northern Gulf of Mexico from Texas to Florida. The models and their component habitat variables are generalized to reflect the life cycle and habitat requirements of the gulf menhaden and account for minor deviations in requirements of the species throughout its range.

Season. The two HSI models combined are designed for year-round applications. For applications involving only portions of the life cycle, the HSI values will apply only to seasons in which the life stage(s) occurs. Some of the habitat variables in the models pertain to environmental conditions that only happen during a particular season. It is assumed that as long as those life requisites for one season are fulfilled, habitat suitability in other seasons is not limiting.

Minimum habitat area. The minimum habitat area is the contiguous suitable habitat that is required for gulf menhaden to live and reproduce. No minimum spatial requirements for this species have been reported.

Life stages. The habitat requisites for each life stage (adult, egg, larval, and juvenile) are included in the models. If a life stage occurs in both marine and estuarine habitats, it is included in both HSI models.

Verification level. The acceptable model output is an index value between 0.0 and 1.0. The values are believed to have a positive relationship with carrying capacity for gulf menhaden. A four-step process was undertaken to verify that HSI's determined with the gulf menhaden models met a desired level of acceptance. The final models described in this report were refined after sample data analysis and review. To show how the models work, HSI values were calculated by the authors from scientific data for both estuarine and marine conditions. These data sets are presented in a later section. Dr. Walter Nelson (National Marine Fisheries Service, Pascagoula, Mississippi) and Mr. Borden Wallace (Wallace Menhaden Products, Inc., Metairie, Louisiana) reviewed the gulf menhaden models and agree that the HSI values for the selected test areas are generally realistic and quantify several important habitat variables.

Model Description

The rationale and general biological assumptions governing formulation of the gulf menhaden HSI models are given in this section. The estuarine and marine HSI models are based on five habitat variables (water temperature, salinity, water color, substrate composition, and marsh area) aggregated into three life requisites (water quality, food, and cover) for the four life stages (adult, egg, larval, and juvenile; see Figures 1 and 2).

The following sections identify and briefly describe the habitat variables used in each of the three life requisites of the models.

Water quality life requisite. Water quality is determined in the estuarine model by temperature (V_8 and V_{13}), salinity (V_9 and V_{14}), and dissolved oxygen (V_{10}) and in the nearshore marine model by temperature (V_1, V_6, and V_{13}) and salinity (V_2, V_7 and V_{14}). It is assumed that low DO concentrations are localized and temporary in the nearshore marine environment and that gulf menhaden would be able to avoid oxygen deficiencies there. Waters supersaturated with DO were not considered in either model since this condition only occurs for very short periods of time within the range of the gulf menhaden.

Planktonic menhaden larvae require favorable currents to make their way into the estuary. Ekman current transport studies in the northern Gulf of Mexico have shown net northerly movement of surface waters (Walter Nelson, personal communication, August 1981) that is assumed to be favorable throughout the range of the gulf menhaden; therefore, a current variable is not included in the models. Favorable tidal currents for gulf menhaden larvae were also assumed to occur. In either case, periods of optimum conditions may vary from year to year.

Food life requisite. It is assumed that food availability in both estuarine and marine habitats is primarily a function of the nutrient concentration

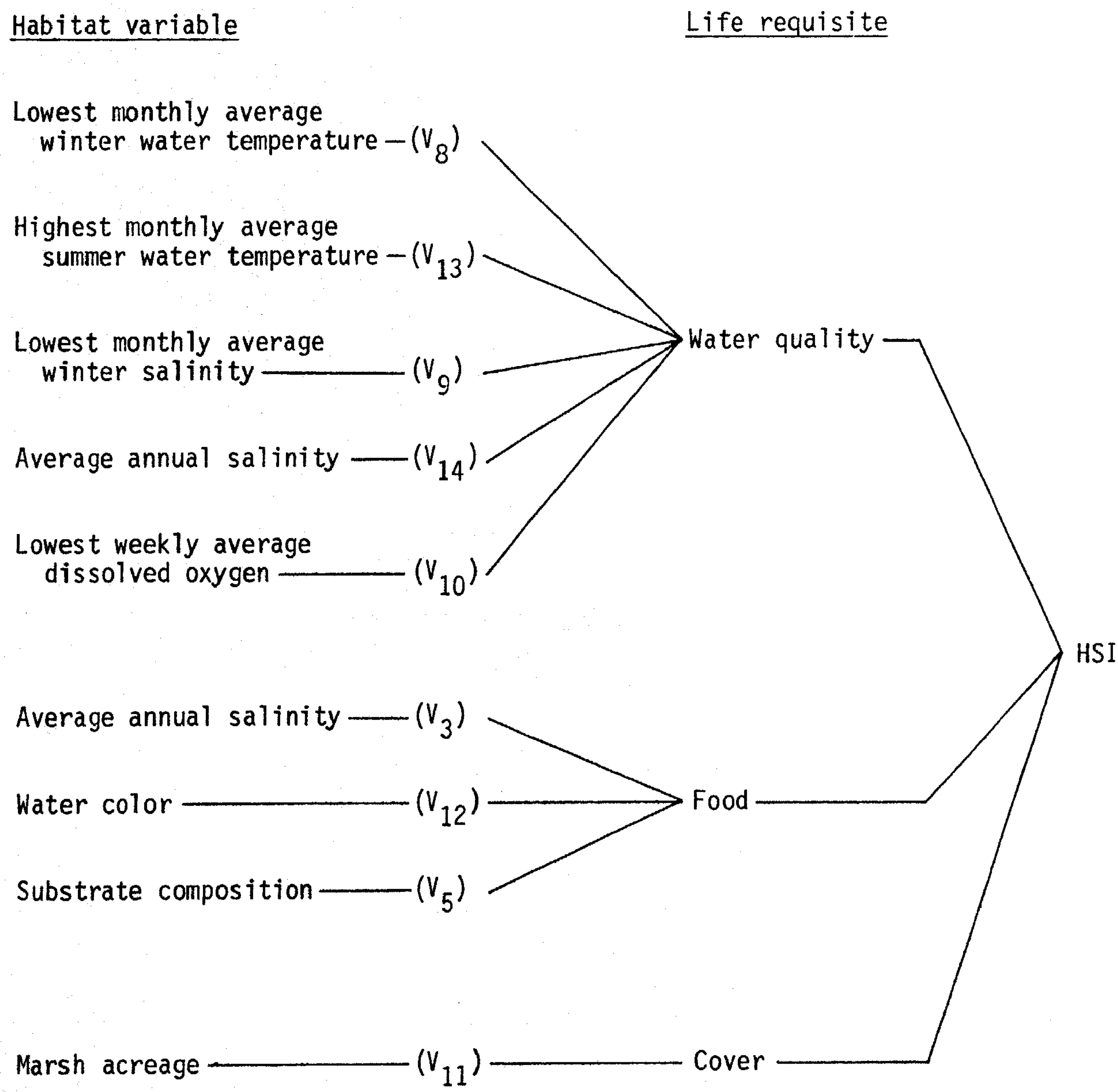


Figure 1. Relationship of habitat variables and life requisites to the habitat suitability index (HSI) for the gulf menhaden in estuarine habitats.

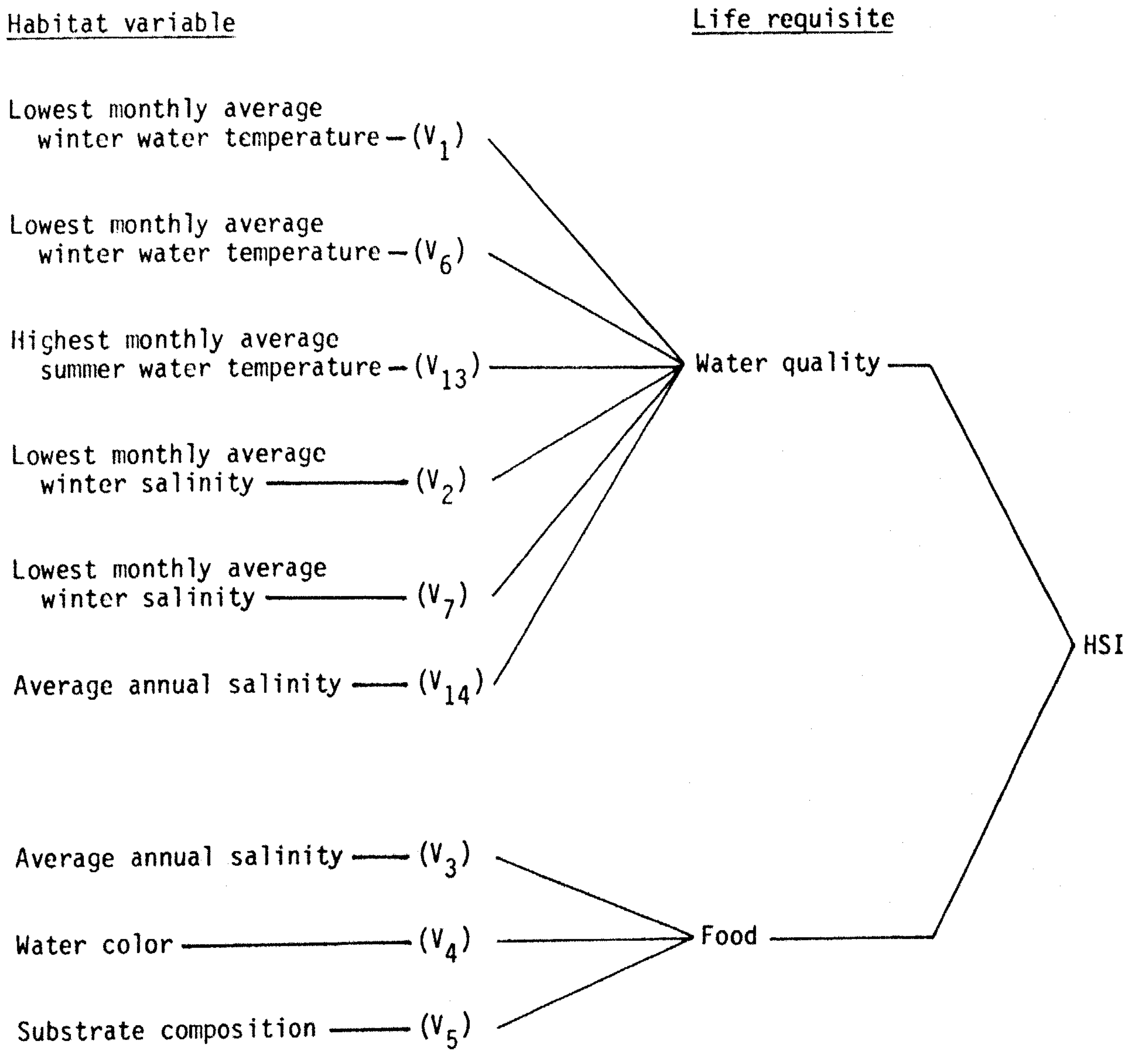


Figure 2. Relationship of habitat variables and life requisites to the habitat suitability index (HSI) for the gulf menhaden in marine habitats.

of freshwater entering coastal waters. Average annual salinity (V_3) is assumed to reflect the amount of freshwater entering coastal waters. Turbidity (as defined by water color, V_4 or V_{12}) is assumed to be a good index of the amount of nutrients and organic detritus in areas influenced by incoming freshwater. Given the general unavailability of definitive, long-term primary productivity information for the northern Gulf of Mexico, water color was arbitrarily agreed upon by the authors as an acceptable, alternate way to estimate turbidity due to nutrients in the water column. Dissolved coloring agents such as tannin and lignin should not appreciably affect water color caused by turbidity in estuarine and marine habitats.

Substrate composition (V_5) is included in the estimation of the food life requisites of gulf menhaden because estuarine and nearshore marine habitats are relatively shallow. It is assumed that currents and wave action will resuspend nutrients and organic detritus in, or deposited upon, bottom sediments. It is also assumed that muddy substrates are more suitable menhaden feeding areas than sandy substrates because of their generally dense benthic populations and richer organic content.

The availability of food was considered the most important life requisite for determining the habitat suitability for gulf menhaden. This importance is reflected by the weighting of the food suitability index (SI) value in both the estuarine and marine HSI models, and of the average annual salinity (V_3) and water color (V_4 or V_{12}) variables in the component life requisite equations.

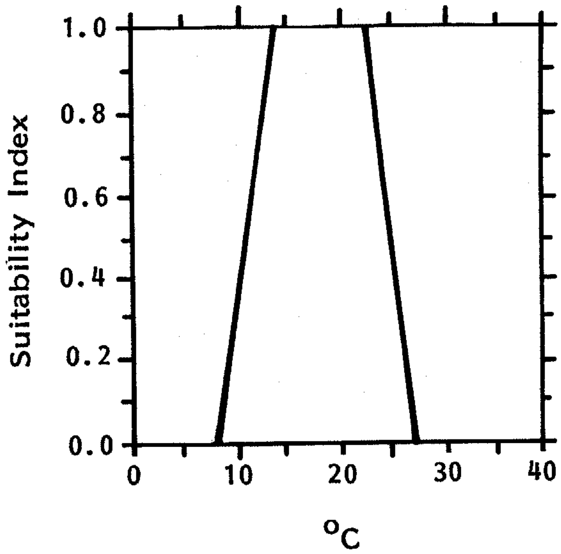
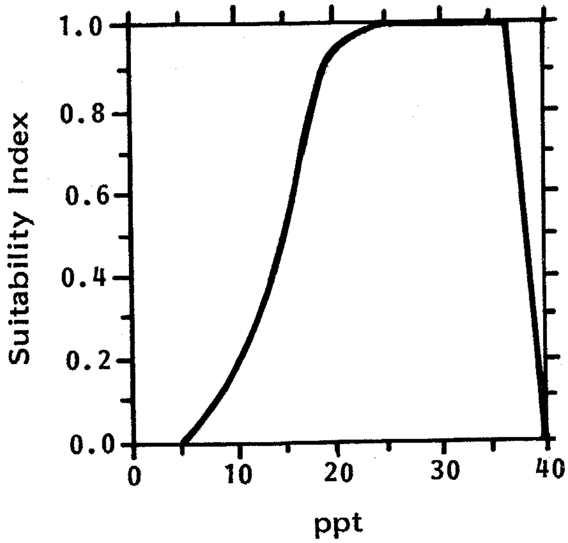
Cover life requisite. Cover is a necessary habitat variable in the estuarine model. Unobstructed bayous, tidal creeks, and drainage channels provide protection for early life history stages of gulf menhaden, particularly the larval stage. It is assumed that the number and extent of bayous and other natural drainage channels are directly proportional to the amount of available marsh (V_{11}).

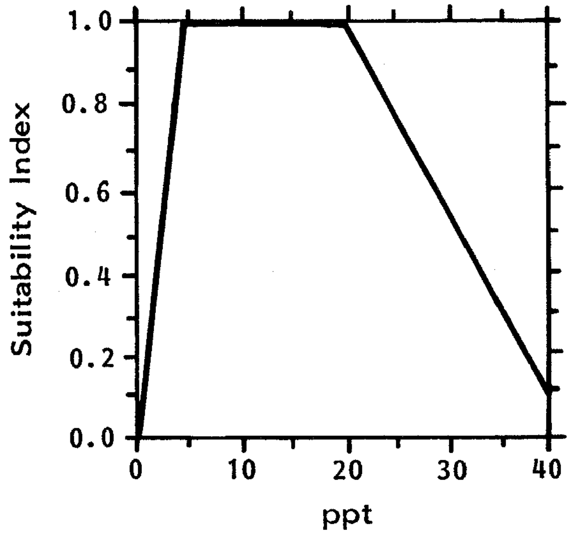
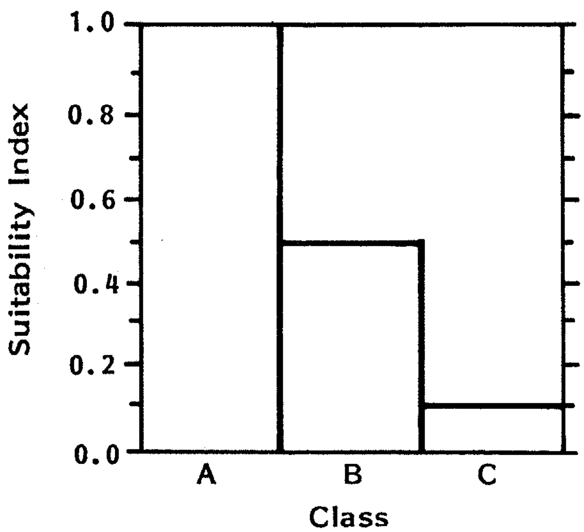
The geographic area to be considered in calculating the amount of marsh should not necessarily be limited to the proposed project site. Tidal marshes are major contributors to the quality of any estuarine ecosystem for gulf menhaden; consequently, the marsh habitat variable (V_{11}) enhances the overall HSI value. As a general rule of thumb, the amount of marsh should include unobstructed tidal marsh in the local drainage basin of the estuary where the project will be located.

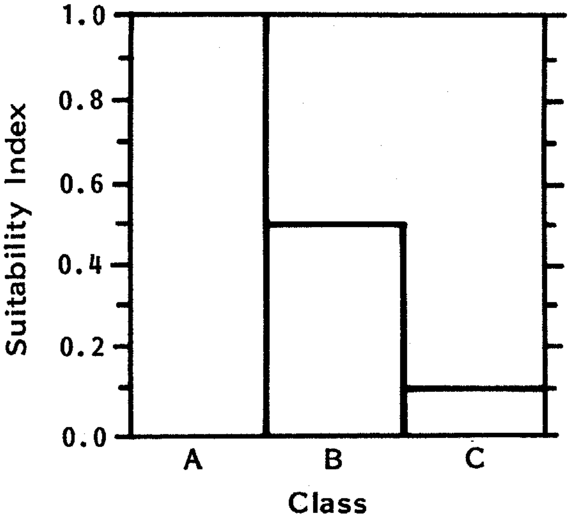
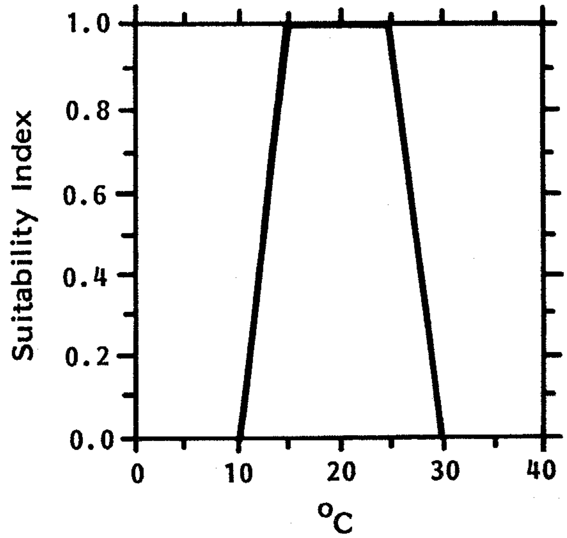
Suitability Index (SI) Graphs for Habitat Variables

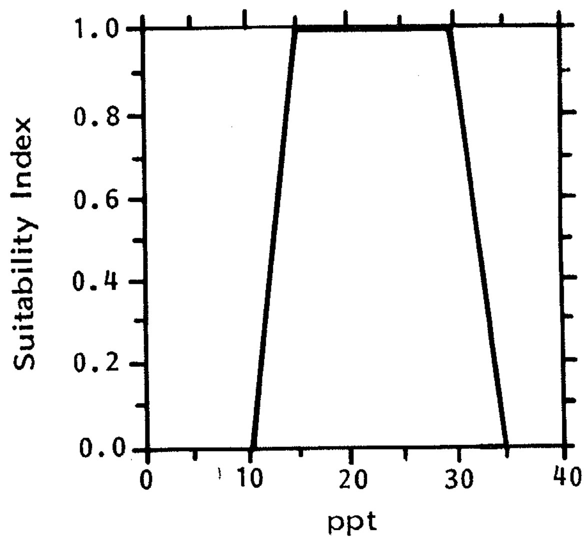
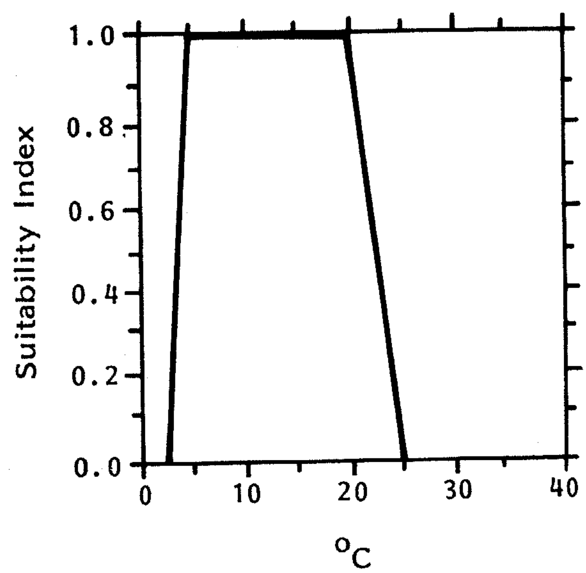
This section briefly describes the 14 habitat variables and depicts the relationships between variable values and the suitability of estuarine and marine habitats for gulf menhaden. Each variable is numerically identified and ascribed to the appropriate habitat category (M = marine, E = estuarine).

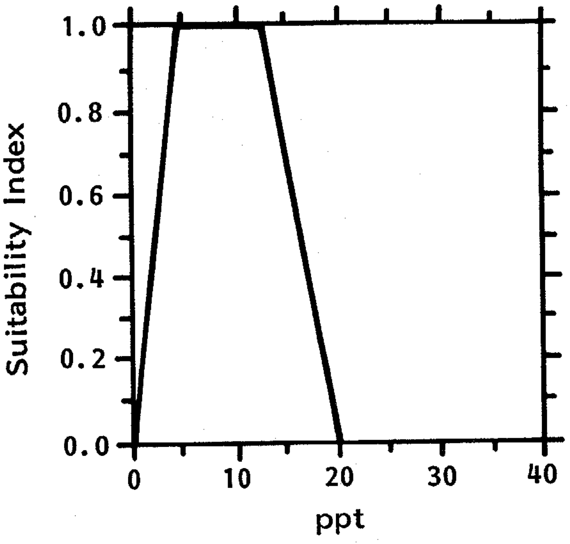
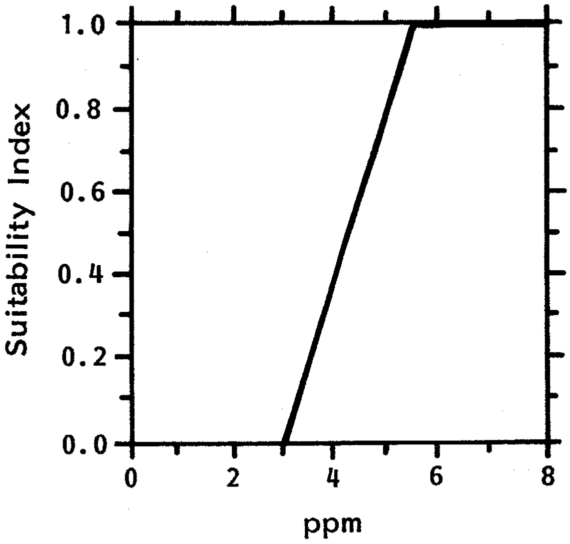
The HSI values are derived by transforming habitat data into suitability index (SI) values by the use of suitability graphs. The SI graphs are based on the assumption that the suitability of a particular habitat variable can be represented by a two-dimensional response surface and is independent of other variables that contribute to habitat suitability. The SI values are numerically combined to produce a composite HSI value.

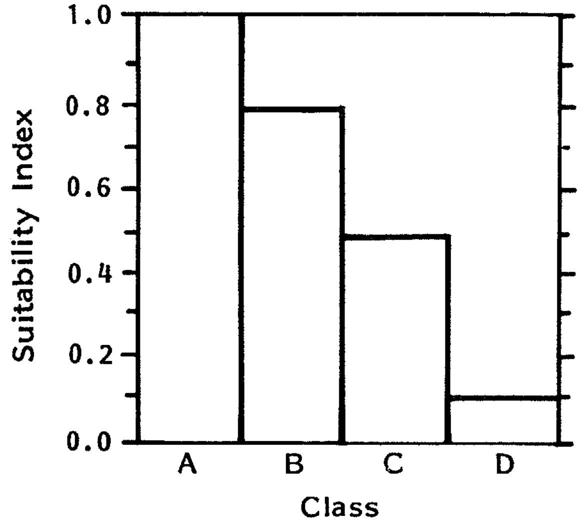
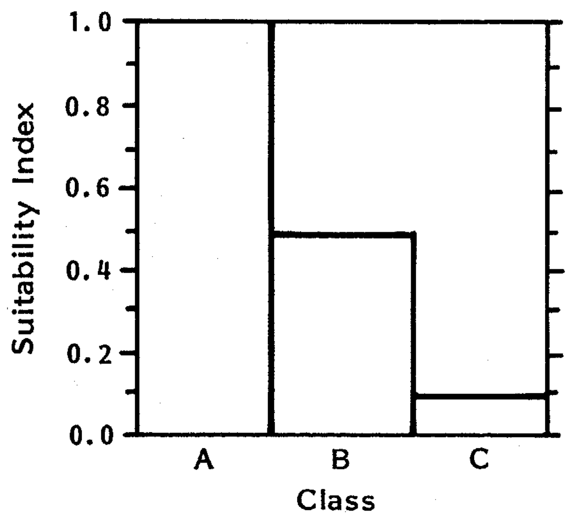
Habitat	Variable	Description	Suitability Graph
M	V_1	Lowest monthly average winter water temperature. It is assumed that winter (December through February) water temperature is one factor governing the suitable water quality conditions for spawning gulf menhaden and their eggs. The SI graph is based on habitat information from Turner (1969), Fore (1970), and Christmas and Waller (1975).	
M	V_2	Lowest monthly average winter salinity. It is assumed that winter salinity is the second factor governing suitable water quality conditions for spawning gulf menhaden and their eggs. The SI graph is based on habitat information from Fore (1970) and Christmas and Waller (1975).	

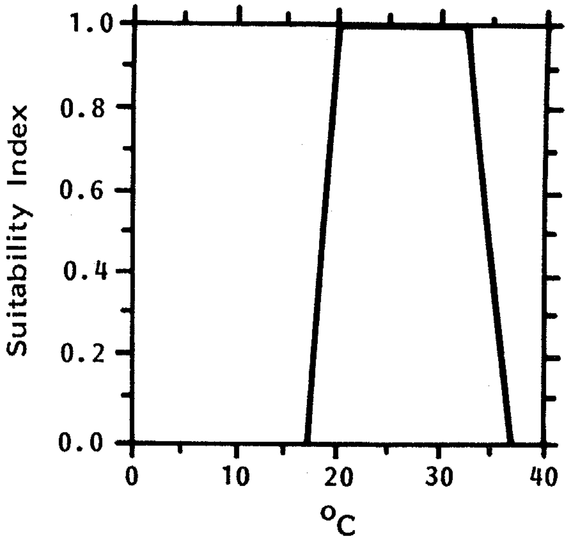
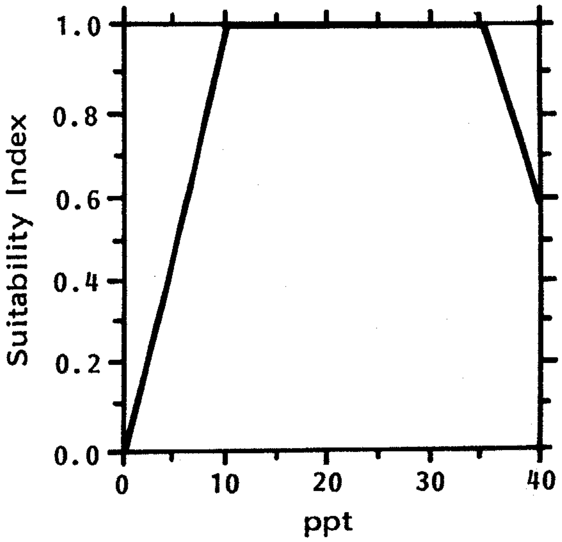
Habitat	Variable	Description	Suitability Graph
E,M	V_3	Average annual salinity. It is assumed that salinity is one factor governing food availability for all gulf menhaden life stages. The SI graph is based on the estimation of suitable habitat requirements of menhaden food organisms by the authors of this report.	
M	V_4	Marine water color. It is assumed that the assessment of long-term, historical water color is a second factor reflecting the presence of nutrients that promote the growth of food for gulf menhaden life stages inhabiting nearshore marine waters. The SI graph is based on the estimation of suitable food requirements by the authors. Water color variable V_{12} is substituted in food life requisite computations in the estuarine model. A) Brown or green B) Turquoise C) Blue or clear	

Habitat	Variable	Description	Suitability Graph
E,M	V_5	Substrate composition. It is assumed that the organic content of bottom sediments potentially available to be resuspended in the water column is a third factor governing food requisites for all gulf menhaden life stages. The SI graph is based on the estimation of suitable gulf menhaden food requirements by the authors. A) Mud B) Sandy mud C) Sand and shell	
M	V_6	Lowest monthly average winter water temperature. It is assumed that marine larvae have slightly higher water temperature requisites than spawning adult gulf menhaden and their eggs. The SI relationship is identical to and based upon habitat information used for V_1. Since larvae are being transported toward shallow, warmer waters, the SI relationship has been increased 2°C over that for V_1.	

Habitat	Variable	Description	Suitability Graph
M	V_7	Lowest monthly average winter salinity. It is assumed that marine larvae have lower and narrower salinity requisites than spawning adult gulf menhaden and their eggs. The SI relationship is based upon habitat information used for V_2.	
E	V_8	Lowest monthly average winter water temperature. It is assumed that estuarine larvae and juveniles have lower and slightly broader water temperature requisites than the adult, egg and marine larval life stages. The SI graph is based on estimation of suitable gulf menhaden water quality requirements by the authors and habitat information of Reintjes and Pacheco (1966) and Christmas and Etzold (1977).	

Habitat	Variable	Description	Suitability Graph
E	V_9	Lowest monthly average winter salinity. It is assumed that estuarine larvae and juveniles have lower and narrower salinity requisites than adult, egg, and marine larval life stages. The SI graph is based on estimation of suitable estuarine water quality requisites for gulf menhaden by the authors and habitat information from Perret et al. (1971) and Swingle (1971)	
E	V_{10}	Lowest weekly average dissolved oxygen concentration. It is assumed that short-term dissolved oxygen depletions do not diminish overall habitat suitability for gulf menhaden in estuaries. The SI graph is based on estimation of suitable long-term dissolved oxygen requisites of gulf menhaden inhabiting estuaries by the authors of this report.	

Habitat	Variable	Description	Suitability Graph
E	V_{11}	Marsh acreage. It is assumed that the number of unobstructed bayous, tidal creeks, and other tributaries accessible to larval menhaden is directly proportional to the available acreages of tidal marsh in the drainage basin. The SI graph classes are based on estimation and professional interpretation of suitable marsh cover for larval gulf menhaden in the northern Gulf of Mexico by the authors of this report. A) > 1000 acres B) > 500 to 1000 acres C) > 50 to 500 acres D) ≤ 50 acres	
E	V_{12}	Estuarine water color. It is assumed that the assessment of long-term historical water color reflects the presence of nutrients that promote growth of suitable food organisms for estuarine gulf menhaden life stages. The SI graph is based on the estimation of suitable menhaden food requirements by the authors. Water color variable V_4 is substituted in food life requisite computations in the marine model. A) Brown B) Green C) Clear	

Habitat	Variable	Description	Suitability Graph
E,M	V_{13}	Highest monthly average summer water temperature. It is assumed that summer (June through August) water temperature is one factor governing water quality suitability for adult gulf menhaden in estuaries, and for adults and juveniles inhabiting nearshore marine waters. The SI graph is based on estimation of suitable gulf menhaden water temperature requirements by the authors of this report.	
E,M	V_{14}	Average annual salinity. It is assumed that salinity is the second most important factor governing water quality suitability for adult menhaden in estuaries, and for adults and juveniles inhabiting nearshore marine waters. The SI graph is based on habitat information of Perret et al. (1971), Swingle (1971), Christmas and Waller (1973), and Christmas and Etzold (1977) and estimation of suitable gulf menhaden salinity requirements by the authors of this report.	

Life Requisite and HSI Equations

To obtain HSI values for gulf menhaden habitats, SI values for the habitat being evaluated must be combined. The suggested equations to aggregrate SI values for each life requisite in both habitats are as follows:

Estuarine.

Life requisite	Equation
Water quality	$\dfrac{(V_8 \times V_{13})^{1/2} + (V_9 \times V_{14})^{1/2} + V_{10}}{3}$
Food	$[(V_3)^2 \times (V_{12})^2 \times V_5]^{1/5}$
Cover	V_{11}

The following equation is used to determine an HSI for gulf menhaden in estuarine habitats:

$$\text{HSI} = [\text{Water quality} \times (\text{Food})^2 \times \text{Cover}]^{1/4}$$

Eight sample data sets from which suitability index, life requisite, and habitat suitability index values have been calculated using the estuarine model equations are illustrated in Table 1. The HSI's calculated from these data sets generally reflect relative carrying capacity for which the authors of this report believe are appropriate for estuaries of the northern Gulf of Mexico.

Marine.

Life requisite	Equation
Water quality	$\dfrac{(V_1 \times V_6 \times V_{13})^{1/3} + (V_2 \times V_7 \times V_{14})^{1/3}}{2}$
Food	$[(V_3)^2 \times (V_4)^2 \times V_5]^{1/5}$

The following equation is used to determine an HSI for gulf menhaden in nearshore marine habitats:

$$\text{HSI} = [\text{Water quality} \times (\text{Food})^2]^{1/3}$$

Five sample data sets from which SI, life requisite, and HSI values have been calculated by using the marine model equations are presented in Table 2. The HSI's calculated from these data sets generally reflect relative carrying capacity for gulf menhaden, which the authors of this report believe are appropriate for nearshore marine waters of the northern Gulf of Mexico.

Table 1. Estuarine model data sets, suitability indices (SI), water quality (WQ), food (F), cover (C), and habitat suitability indices (HSI) for eight Gulf of Mexico localities.

Model component	Mobile Bay, AL[a]		Little Lagoon, AL		Mobile River, AL		Davis Bayou, MS		Trinity Bay, TX		Barataria Bay, LA		Timbalier Bay, LA		Upper Laguna Madre, TX	
	Data	SI	Data	SI	Data	SI	Data	SI	Data	SI	Data	SI	Data	SI	Data	SI
V1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
V2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
V3	15	1.00	19	1.00	7	1.00	19	1.00	10	1.00	20	1.00	22	0.90	50	0.10
V4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
V5	Sand	0.10	Sand	0.10	Mud	1.00	Sandy mud	0.50	Sandy mud	0.50	Mud	1.00	Mud	1.00	Sandy mud	0.50
V6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
V7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
V8	9	1.00	11	1.00	8	1.00	12	1.00	13	1.00	11	1.00	13.4	1.00	16.3	1.00
V9	3	0.50	18	0.10	3	0.60	7	1.00	4	0.80	7	1.00	22.3	0.00	30	0.00
V10	8	1.00	10	1.00	6	1.00	5	0.80	7	1.00	6	1.00		1.00		1.00
V11	Moderate	0.50	Little	0.10	Extensive	1.00	Moderate	0.50	Large	0.80	Extensive	1.00	Extensive	1.00	Little	0.10
V12	Brown	1.00	Green	0.50	Brown	1.00	Brown	1.00	Brown	1.00	Brown	1.00	Brown	1.00	Brown	1.00
V13	29	1.00	19	1.00	30	1.00	31	1.00	32	1.00	29	1.00	29.8	1.00	30.4	1.00
V14	15	1.00	10	1.00	7	0.75	19	1.00	10	1.00	20	1.00	22	1.00	50	0.10
WQ		0.90		0.77		0.89		0.93		0.96		1.00		0.67		0.67
F		0.63		0.48		1.00		0.87		0.87		1.00		0.96		0.35
C		0.50		0.10		1.00		0.50		0.80		1.00		1.00		0.10
HSI		0.65		0.36		0.97		0.77		0.87		1.00		0.88		0.30

[a] Between Dog and Fowl Rivers.

Table 2. Nearshore marine model data sets, suitability indices (SI), water quality (WQ), food (F), and habitat suitability indices (HSI) for five Gulf of Mexico localities.

Model component	Gulf of Mexico[a] Data	Gulf of Mexico[a] SI	Gulf of Mexico[b] Data	Gulf of Mexico[b] SI	Tarpon Springs, FL[c] Data	Tarpon Springs, FL[c] SI	Apalachee Bay, FL Data	Apalachee Bay, FL SI	Mustang Island, TX Data	Mustang Island, TX SI
V1	14.2	1.00	13	0.70	13.3	0.80	9	0.10	19	1.00
V2	24	1.00	27	1.00	31	1.00	22	0.95	31.5	1.00
V3	31	0.50	29	0.60	34	0.35	20	1.00	30	0.55
V4	Green	1.00	Green	1.00	Turquoise	0.50	Turquoise	0.50	Brown	1.00
V5	Sandy mud	0.50	Mud	1.00	Sand	0.10	Sand	0.10	Sand	0.10
V6	14.2	0.90	13	0.50	13.3	0.60	9	0.00	19	1.00
V7	24	1.00	27	1.00	31	0.90	22	1.00	31.5	0.90
V8	-	-	-	-	-	-	-	-	-	-
V9	-	-	-	-	-	-	-	-	-	-
V10	-	-	-	-	-	-	-	-	-	-
V11	-	-	-	-	-	-	-	-	-	-
V12	-	-	-	-	-	-	-	-	-	-
V13	28	1.00	30	1.00	27.7	1.00	31	1.00	32	1.00
V14	31	1.00	29	1.00	34	1.00	20	1.00	30	1.00
WQ		0.98		0.85		0.87		0.49		0.98
F		0.66		0.82		0.31		0.48		0.50
HSI		0.75		0.83		0.44		0.48		0.62

[a] 20 mi south of Horn Island, MS.
[b] 2 mi south of Horn Island, MS.
[c] 5 fathoms offshore.

Model Use Considerations

These complex HSI models have been designed to reflect gulf menhaden habitat requirements. The models primarily rely on data previously collected for most habitat variables. This should produce a satisfactory application of the models with minimal expense, given that the model assumptions have not been violated. The biological and hydrographic data required for the use of these models are most frequently available from published or resource agency sources. The closer in both time and space that biological and hydrographic studies are to the project site, the better the reliability of HSI values.

It is recommended that model users consult local fishery biologists to insure the data sources being utilized will most accurately reflect gulf menhaden habitat conditions in a given area. Suggested methods for measuring the habitat variables are given in Table 3.

Field sampling of habitat variables on a one-time basis is not recommended. The estuarine and nearshore marine habitats considered in the HSI models are subject to large fluctuations in water quality conditions. It is assumed that mean values derived for appropriate seasons from literature sources for many of the habitat variables give the best indication of critical values and should be used in determining the suitability indices.

Any or all habitat variables may be estimated for preliminary applications of the models. Subjective estimates will decrease model reliability and replicability. When estimates are used, the basis on which they are made should be documented as completely as possible.

Interpreting Model Outputs

The HSI values produced by the models are relative and are used for comparison only. If two areas, or the same area at different times, have different HSI values, then the area with the higher HSI should be interpreted to have the potential to support more gulf menhaden than that with the lower HSI. These models aggregate 14 habitat variables into single index values, with no quantitative information on how the variables in combination affect carrying capacity. Furthermore, HSI values determined by application of these models may not always reflect current gulf menhaden abundances because factors other than local habitat-related ones may affect gulf menhaden populations.

ADDITIONAL HABITAT MODELS

No other models for gulf menhaden are known to exist. Of potential interest, however, is a recruit-environmental model for Atlantic menhaden of the Atlantic Bight that has been constructed by Nelson et al. (1977). This multiple regression model was developed to relate menhaden larval recruitment to three environmental variables (larval transport, temperature, and river discharge). The model produces a survival index computed by dividing observed recruits by expected recruits. The model also can produce an initial prediction of the number of recruits about 1 year before they become available to the Atlantic menhaden fishery. The model is based on sample data for the period 1955-1970. It focuses on factors which influence larval distribution and transport larvae into the vicinity of estuarine nursery grounds, thereby increasing survival. Major sources of variation, however, such as food availability and predation have not been considered (Nelson et al. 1977).

Table 3. Suggested methods for measurement of variables for habitat information to be used in the gulf menhaden HSI models.

Variable	Method
V_1	Winter water temperature (lowest monthly average) for December through February can be determined by consulting existing data or published literature sources. It is recommended that model users consult local fishery biologists to insure the data sources being utilized will most accurately reflect gulf menhaden habitat conditions.
V_2, V_3	Same methods as V_1.
V_4	Marine water color can be qualitatively estimated or determined by consulting local fishery biologists knowledgeable of long-term water conditions.
V_5	Substrate composition can be determined by consulting existing data or published literature sources. An alternate, qualitative measurement is to wash a known weight of substrate through a 63-μ (Tyler series No. 250) sieve. Silt and clays pass through the sieve, and sand and shells do not.
V_6, V_7, V_8, V_9	Same methods as V_1.
V_{10}	Dissolved oxygen (DO) can best be determined by consulting existing data or published literature sources. An alternate method is to conduct a field sampling program where DO is measured using Winkler titrations or an oxygen meter.
V_{11}	Define the evaluation area and local drainage basin on topographic maps, habitat maps, aerial photographs, or navigation charts. Accessible tidal marsh acreage can be determined by either planimetry or a cut and weigh method.
V_{12}	Estuarine water color can be determined by the same methods as for V_4.
V_{13}, V_{14}	These habitat variables can be determined by consulting existing data or published literature sources. It is recommended that model users consult local fishery biologists to insure the data sources being utilized will most accurately reflect gulf menhaden habitat conditions.

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16. Abstract (Limit: 200 words)

A review and synthesis of existing information were used to develop both an estuarine and marine habitat model for the gulf menhaden (Brevoortia patronus). The models are scaled to produce an index of habitat suitability between 0.0 (unsuitable habitat) and 1.0 (optimally suitable habitat) for estuarine and marine areas of the northern Gulf of Mexico. Assumptions used to transform habitat use information into the models and guidelines for model applications were also developed. Habitat suitability indices are designed for use with the Habitat Evaluation Procedures previously developed by the U.S. Fish and Wildlife Service.

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