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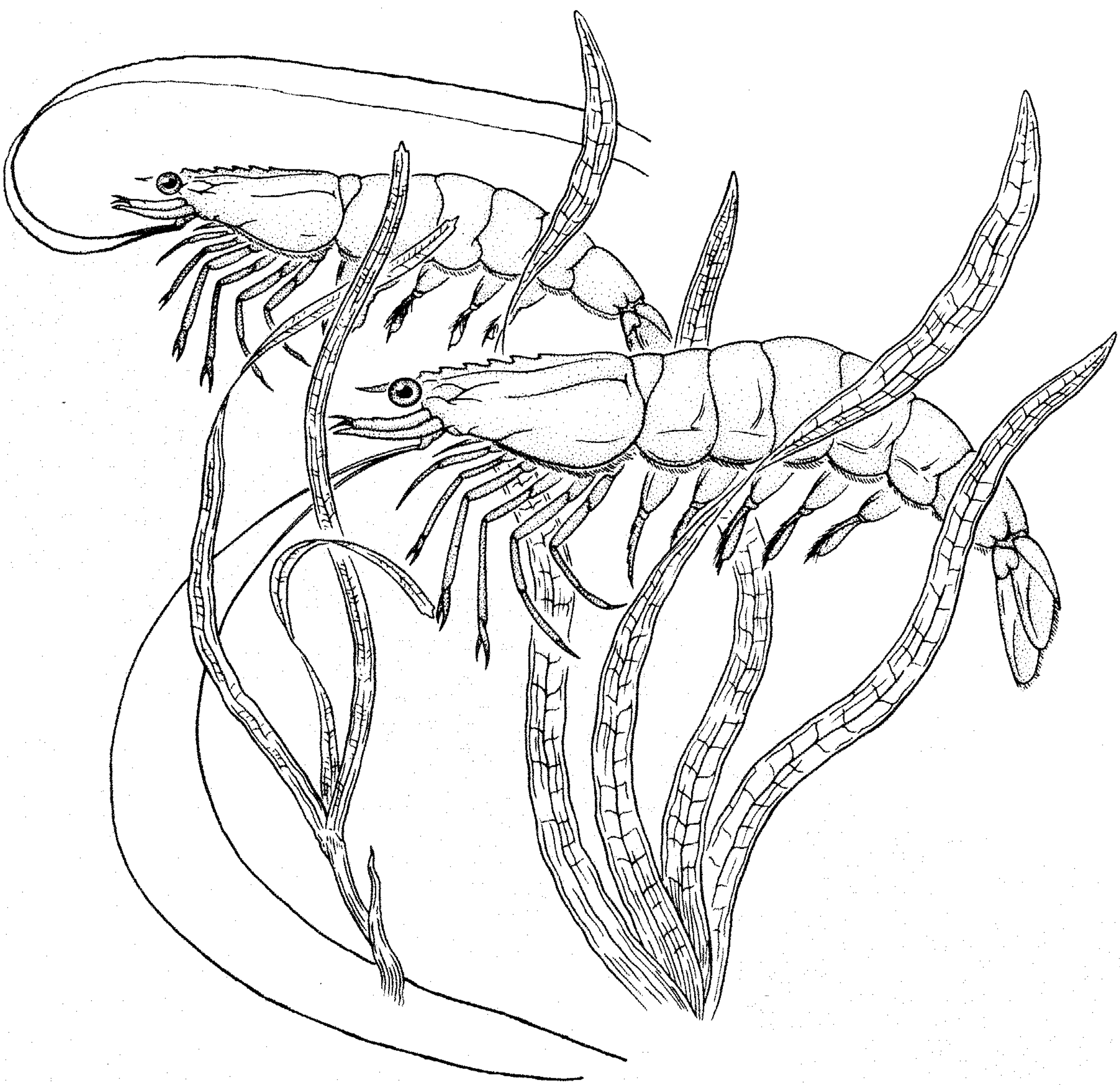
HABITAT SUITABILITY INDEX MODELS: PINK SHRIMP



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HABITAT SUITABILITY INDEX MODELS: PINK SHRIMP

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PREFACE

The habitat suitability index (HSI) model in this report on the pink shrimp is intended for use in the habitat evaluation procedures (HEP) developed by the U.S. Fish and Wildlife Service (1980) for impact assessment and habitat management. The model was developed from a review and synthesis of existing information and is scaled to produce an index of habitat suitability between 0 (unsuitable habitat) and 1 (optimally suitable habitat). Assumptions involved in developing the HSI model and guidelines for model applications, including methods for measuring model variables, are described.

This model is a hypothesis of species-habitat relationships, not a statement of proven cause and effect relationships. The model has not been field-tested. 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 HSI model to the following address.

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CONTENTS

ACKNOWLEDGMENTS

Development of the habitat suitability index model for the pink shrimp was reviewed and constructively criticized by Mr. Donald M. Allen, National Marine Fisheries Service, Southeast Fisheries Center, Miami, Florida; and Mr. K. Neal Baxter, National Marine Fisheries Service, Galveston Laboratory, Galveston, Texas. Thorough evaluations of model structure and functional relationships were provided by personnel of the U.S. Fish and Wildlife Service's (FWS) National Coastal Ecosystems Team (NCET). Michael S. Brody served as project officer at NCET. Supportive narrative and model reviews also were provided by Regional personnel of the U.S. Fish and Wildlife Service; the Florida Department of Natural Resources; Dr. R. Eugene Turner, Louisiana State University, Baton Rouge; and Mr. Michael B. Robblee, Marine Biologist, South Florida Research Center, Everglades National Park, Homestead, Florida. Funding for model development and publication was provided by the FWS. The cover illustration was prepared by Patrick J. Lynch.

PINK SHRIMP (*Penaeus duorarum*)

INTRODUCTION

Shrimp support the most valuable seafood industry in the United States (Roedel 1973; National Marine Fisheries Service 1983). The three most important commercial species are the white shrimp (*Penaeus setiferus* L.), brown shrimp (*P. aztecus* Ives), and pink shrimp (*P. duorarum* Burkenroad). Adult pink shrimp are caught in commercial quantities throughout most of the geographic range of the species (Lindner 1957), and juveniles support a sizable bait shrimp industry along the Florida coast and throughout the Gulf of Mexico (Saloman 1965).

Distribution

In the western Atlantic, the pink shrimp ranges from the lower Chesapeake Bay southward along the coast to the Florida Keys and Gulf of Mexico. In the gulf, it ranges from the Dry Tortugas along the gulf coast of the United States and through the coastal waters of Mexico to Cape Catoche and south to Isla Mujeres. The densest populations of pink shrimp are off southwestern Florida and in the southeast portion of Golfo de Campeche (Perez Farfante 1969). Adults are most abundant at depths of 11 to 65 m (36 to 213 ft) (Huff and Cobb 1979), although the U.S. Bureau of Commercial Fisheries (1961) has reported their capture at depths as great as 110 m (360 ft).

Life History Overview

Life stages. Adult penaeid shrimp live and spawn in highly saline offshore waters (Subrahmanyam 1971). The demersal eggs (Perez Farfante 1969) hatch 12 to 16 hours after spawning (Cook and Murphy 1969). Upon hatching, the embryos enter the larval phase of development, during which they pass through five nauplial, three protozoeal, and three mysis stages (Dobkin 1961; Ewald 1965). Feeding begins during the first protozoeal stage when the larvae cease to live on yolk and begin to seek nourishment in the water (Dobkin 1961; Cook and Murphy 1969). The planktonic larvae develop at sea, and the young shrimp enter the estuarine nursery grounds as postlarvae about 8 mm (0.3 inch) total length (TL) (Copeland and Truitt 1966; Perez Farfante 1969). After reaching shallow inshore waters, the planktonic postlarvae settle to the bottom, usually in seagrass beds, and become benthic postlarvae (Costello and Allen 1970). The postlarvae become benthic at about 10 mm (0.4 inch) TL (Costello and Allen 1970) and develop into juveniles while in the estuaries. The difference between postlarval and juvenile stages has not been clearly defined, although Costello and Allen (1970) described juveniles as being more robust than postlarvae and as having proportionately shorter sixth abdominal segments. The juveniles spend 2 to 6 months in the nursery areas and gradually move toward deeper water as they develop (Costello and Allen 1970). When they are about 100 mm (4 inches) TL, they return to offshore waters to mature and spawn (Joyce 1965). The entire cycle is completed in about 12 months (Joyce and Eldred 1966).

Reproduction. Pink shrimp spawn year round in the Dry Tortugas area of Florida. In the more northerly latitudes (St. Petersburg, St. Augustine, Tampa), spawning does not begin until early spring (Joyce and Eldred 1966). In the Tampa Bay, Florida, area, the majority of spawning occurs from April to September (Eldred et al. 1961). Spawning occurs at water temperatures from 19.6° to 30.6°C (67° to 87°F) in Florida (Jones et al. 1964, 1970). The number of individuals spawning is affected by both absolute temperature and by temperature changes which occur in the spring and fall (Idyll and Jones 1965). Spawning takes place in waters from 3.7 to 47.5 m (12 to 156 ft) and probably also at greater depths (Perez Farfante 1969).

Martosubroto (1974) observed that fecundity in pink shrimp increased in almost direct proportion to body weight and as the cube of total length. His fecundity estimates ranged from 42,000 to 624,000 ova per female. He also suggested that one individual may spawn more than once during the spawning season.

Sexual dimorphism in pink shrimp is evident at mean lengths exceeding 100 mm (4 inches) TL (Williams 1955a); females predominate in the larger size classes (Huff and Cobb 1979). Saloman (1965) found a slight predominance of females collected for bait from Tampa Bay, Florida, but populations generally have sex ratios which approach equality (Idyll 1964; Huff and Cobb 1979).

Growth. Pink shrimp larvae increased in total length from about 0.35 mm (0.01 inch) in the first nauplial stage to 3.8 mm (0.1 inch) in the first postlarval stage over a period of 20 days at 26°C or 79°F (Dobkin 1961; Ewald 1965). Eldred et al. (1961) reported that pink shrimp grew at the rate of about 20 mm (0.8 inch) per month from the time of hatching until they reached about 65 mm (2.5 inches) TL; the growth rate then decreased. Growth rates vary with size, sex, and water temperature (Williams 1955a; Iverson and Jones 1961).

Mortality. Predation by fish is probably the most important cause of natural mortality among pink shrimp (Tabb et al. 1962; Perez Farfante 1969). Periodic physical catastrophes and disease further limit population size of penaeid shrimp (Couch 1978).

Movements. Planktonic larval pink shrimp migrate vertically in the water column in a daily cycle (Jones et al. 1970). They remain near the bottom during the day and move nearer the surface at night. As the larvae mature, they move farther from the bottom at night (Roessler et al. 1969; Jones et al. 1970).

Copeland and Truitt (1966) found a major influx of postlarvae into Texas bays when there was a net inflow of water from the gulf to the bays. Most postlarvae entered the bays during flood tides. Idyll and Jones (1965) reported similar movements in Florida Bay. Numbers of postlarvae increased somewhat at the beginning of the change in tides and then increased rapidly up to maximum flood-tide velocity. In Florida, Hughes (1969) found movements of postlarvae to be associated with salinity differences between tides. The postlarvae were active at higher salinities but became inactive and dropped to the bottom when the salinity decreased. As salinity decreased during ebb tide, the postlarvae remained on or near the substrate. Tabb et al. (1962) noted three kinds of shrimp movements in Florida Bay: daily movement with the tides within the bay system, short-term offshore movements to escape temperature drops, and mass offshore movements in response to abnormal water and weather conditions such as those associated with hurricanes.

As they mature, juvenile pink shrimp migrate from nursery areas back to offshore waters. Some shrimp travel at least 278 km (150 nautical miles) before being recovered on offshore grounds (Costello and Allen 1966). Although pink shrimp have broad migration routes, the shrimp leaving specific nursery areas migrate to specific large offshore areas (Costello and Allen 1966).

SPECIFIC HABITAT REQUIREMENTS

Inshore nursery areas are necessary for the growth and development of pink shrimp. As much as available literature allowed, the following sections concentrate on the characteristics of nursery areas and on the habitat requirements of postlarval and juvenile pink shrimp. The information on substrate is a combination of adult and juvenile preferences.

Substrate

It is common knowledge among shrimp fishermen that pink, brown, and white shrimp are generally associated with certain bottom types. In the Gulf of Mexico, pink shrimp are found in greater densities over calcareous mud and sands or mixtures of shell and sand (Hildebrand 1954, 1955; Springer and Bullis 1954). In contrast, white and brown shrimp occur in greater densities over bottoms of terrigenous silt. Pink shrimp are scarce on the soft muddy bottoms from Mississippi to Texas but very abundant on the firmer bottoms off the Tortugas Islands and southeastern portion of Golfo de Campeche (Perez Farfante 1969). Kennedy and Barber (1981) considered the disjunct distribution of adult pink shrimp stocks along the southeastern U.S. coast to be a likely result of the disjunct occurrence of acceptable sediments (> 50% calcium carbonate) at suitable depths. In the laboratory, juvenile shrimp had similar substrate preferences (Williams 1958). Juvenile pink shrimp occurred most often on shell-sand substrate whereas juvenile white and brown shrimp were found most frequently on softer, muddier substrates. Unlike white and brown shrimp, pink shrimp can burrow into extremely coarse sediment (Williams 1958; Fuss and Ogren 1966). The distribution of pink shrimp closely follows that of sand, shell-sand, or coral mud substrate (Williams 1965). The importance of substrate as it relates to food or cover has not been established (Costello and Allen 1970). The selection of substrate by juvenile shrimp may involve food availability or sediment grain size (Rulifson 1981).

Vegetation

Cover is one of the most essential requirements for a shrimp nursery area (Williams 1955a). The type of cover varies, but salt marshes, mangroves, and seagrasses all provide shrimp with protection from predators and with a plentiful food source (Thayer et al. 1978). Pink shrimp feed mostly on the bottom and, like other penaeids, are omnivorous. They ingest algae and fragments of higher plants as well as feed on a variety of animals (Perez Farfante 1969). The importance to shrimp of the vegetated shore zone-marsh habitat surrounding most estuaries cannot be overemphasized. The young of most penaeid shrimp, including pink shrimp, use these areas for food and protection (Kutkuhn 1966). In shrimp harvesting areas from Florida to Louisiana, the size of catch was positively related to the area of intertidal vegetation (Turner 1977). Zimmerman et al. (1982) observed that shrimp were not only associated with vegetation but also that as the density of wetland vegetation increased, the numbers of shrimp increased. Numerous studies have demonstrated an association between young pink shrimp and seagrass (de Sylva 1954; Hildebrand 1955; Williams 1955a; Woodburn et al. 1957; Phillips 1960; Hoese and Jones 1963; Saloman 1965; Hudson et al. 1970; Allen et al. 1980). The destruction of seagrass beds has been cited as the primary reason for the decline in the pink shrimp fishery in Tampa Bay, Florida (Saloman 1965).

Salinity

Williams and Deubler (1968) found postlarval pink shrimp at salinities of 0.50 to 36.73 parts per thousand (ppt), and Tabb et al. (1962) collected postlarvae in salinities of 12 to 43 ppt. Williams (1960) observed significantly poorer survival (62.5%, $p = 0.05$) of juvenile pink shrimp (35 to 100 mm or 1.4 to 3.9 inches TL) at 10 ppt than at higher salinities. Percent survival at 15 to 30 ppt did not differ significantly ($p = 0.05$).

Shrimp size and salinity are positively correlated (Williams 1955a; Tabb et al. 1962). Williams (1955a) noted that the smallest shrimp occupied the less saline portions of the nursery grounds and that progressively larger ones occupied areas nearer the sea. Tabb et al. (1962) caught juvenile pink shrimp with carapace lengths of 28 to 32 mm (1.1 to 1.3 inches) in water with salinities of 25 to 45 ppt and juveniles with carapace lengths of 10 to 17 mm (0.4 to 0.7 inch) in water having no measurable salinity.

Temperature

Temperature is one of the principal factors governing growth and survival of pink shrimp (Perez Farfante 1969). Aldrich (1964) reported zero survival of grooved postlarval shrimp at 3° and 43°C (37° and 109°F), regardless of the salinity. Copeland and Bechtel (1974) reported catches of pink shrimp at temperatures of 5° to 38°C (41° to 100°F); optimum catches were at 20° to 38°C (68° to 100°F). Williams (1955b) collected juveniles at 4° to 35°C (39° to 95°F) in North Carolina, but the shrimp were almost completely narcotized at water temperatures below 10°C (50°F). Eldred et al. (1961) believed that the minimum survival temperature for pink shrimp in Florida waters was near 12°C (54°F).

Reynolds and Casterlin (1979), who tested juvenile pink shrimp in the laboratory to determine their thermoregulatory capabilities (temperature preference and avoidance behavior), reported that within a potentially available range of 0° to 50°C (32° to 122°F) shrimp voluntarily occupied water of 22° to 36°C (72° to 97°F) at night and 17° to 38°C (63° to 100°F) during the day. The 24-hour mean preferendum was 30.3° ± 0.2°C (86.5° ± 0.4°F) and the range was 17° to 38°C (63° to 100°F). Active juvenile pink shrimp spent little time at temperatures exceeding 35°C (95°F) or at temperatures below 24°C (75°F), whereas inactive shrimp tolerated temperatures as low as 17°C (63°F).

Temperature-Salinity Interaction

Pink shrimp occur over a wide range of temperatures and salinities. Little information is available on the combined effect of temperature and salinity on shrimp survival. Williams (1960) found that juvenile pink shrimp survived at a salinity range of 10 to 30 ppt, but that osmotic regulatory ability decreased as temperature decreased. Osmotic regulatory ability was impaired at 8.75° to 8.8°C (47.7° to 47.8°F). At low water temperatures, survival of juvenile pink shrimp improved with increasing salinity.

HABITAT SUITABILITY INDEX (HSI) MODEL

Model Applicability

Geographic area. The model is applicable to the estuaries and bays of the Gulf of Mexico, including southern Florida.

Life history stages. Only the postlarval and juvenile life stages of pink shrimp in estuarine habitats are included in the model.

Season. The model can be applied throughout the year.

Cover types. This model can be used to evaluate estuarine subtidal and intertidal areas including aquatic beds (seagrass beds), emergent wetlands (brackish and salt marshes), and scrub-shrub wetlands (mangroves) as described by Cowardin et al. (1979). The model is not designed for use in open bay bottom (unvegetated) areas.

Minimum habitat area. No information is available on the minimum area required for postlarval and juvenile pink shrimp to grow and develop; however, they do need estuarine areas having open connections with the ocean.

Verification level. The acceptable model output is an index value between 0.0 and 1.0 that reflects the habitat potential for postlarval and juvenile pink shrimp. The model has not been field-tested. Hypothetical data sets were used to verify that the model output was reasonable. Reviewers' comments (see Acknowledgments) have been incorporated, but the author is responsible for the final version of this model.

Model Description

Overview. The model applies to the postlarval and juvenile life stages and is based on four habitat variables (substrate, vegetative cover, salinity, and temperature) aggregated into two life requisites--food-cover and water quality (Figure 1). The model is not designed to evaluate the effects of toxic chemicals. A brief description of the habitat variables used in the model follows.

Food-cover component. The substrate class (V_1) is important in determining shrimp distribution. Although pink shrimp can burrow into very coarse sediments, such sediments may contain little organic material for food. A firm bottom with incorporated organic material was assigned the highest suitability index and very soft bottom (silt, clay) the lowest. Hard bottoms with little organic material were assigned an intermediate index.

The percentage of the estuarine area covered with vegetation (V_2) is the most important variable in the pink shrimp HSI model. Vegetation provides both food and cover and is an essential element of optimal habitat. This variable has two options: option V_{2a} applies to estuarine areas with seagrasses and option V_{2b} applies to estuarine areas with emergent grasses and/or mangroves. If both options apply to a specific area, a weighted suitability index must be calculated.

Water quality component. Since postlarval and juvenile pink shrimp occur in bays and estuaries throughout the year, salinity (V_3) over the entire period is important to pink shrimp survival. Salinities of 15 to 35 ppt were considered optimal. Water temperature (V_4) affects the growth and survival of postlarval and juvenile shrimp, and temperature tolerance may vary with latitude. While active, juvenile pink shrimp voluntarily occupy temperatures of 24° to 35°C (75° to 95°F). Temperatures above or below this range were considered suboptimal. Temporary fluctuations have little effect since shrimp are capable of moving to more suitable areas. Salinity usually does not fluctuate suddenly in an area unless there is a catastrophic event such as a hurricane.

Suitability Index (SI) Graphs for Model Variables

The relationships between habitat variables and habitat suitability are depicted graphically for estuarine (E) habitats. The suitability index (SI) values are read directly from the graph. Optimum suitability for a variable is 1.0. Data sources and assumptions associated with the graphs are given in Table 1.

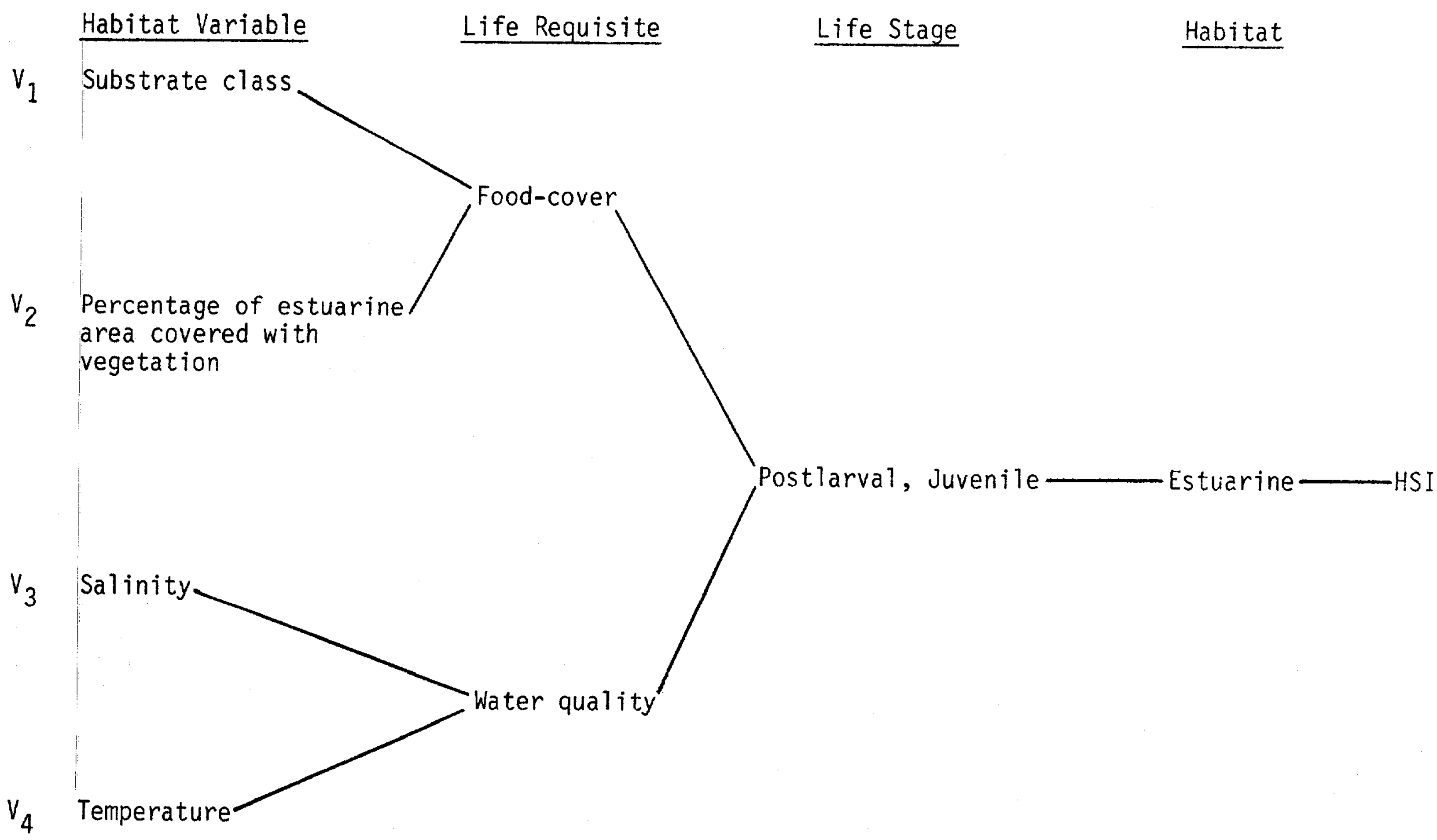
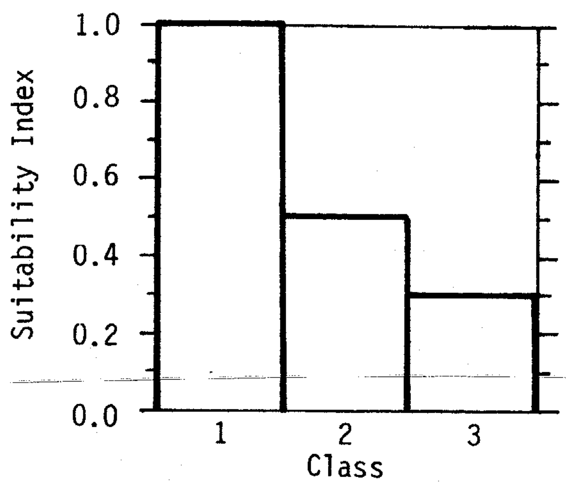
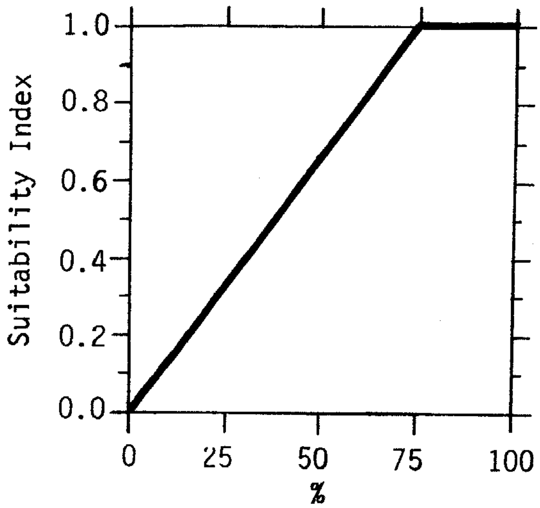
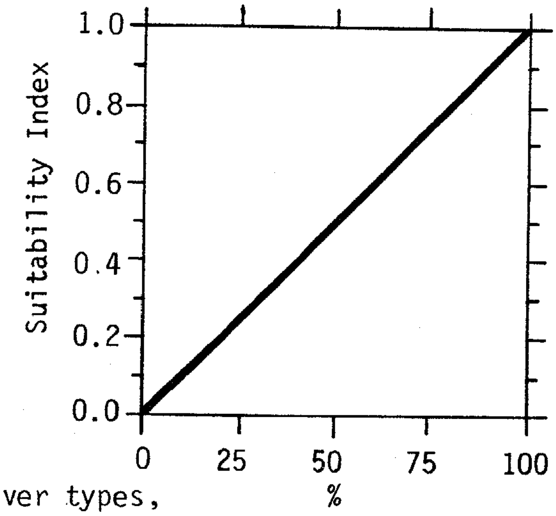


Figure 1. Relationship of habitat variables and life requisites to the habitat suitability index (HSI) for postlarval and juvenile pink shrimp in estuarine habitats.

Table 1. Data sources and assumptions for postlarval and juvenile pink shrimp suitability indices.

Variable and source		Assumption
V_1	Hildebrand 1954, 1955 Springer and Bullis 1954 Williams 1958 Perez Farfante 1969 Kennedy and Barber 1981	Substrate affects the distribution of pink shrimp. Pink shrimp are more numerous on firm bottoms with some organic material than on soft, muddy bottoms.
V_2	de Sylva 1954; Hildebrand 1955 Williams 1955a; Woodburn et al. 1957 Phillips 1960; Saloman 1965 Kutkuhn 1966; Hudson et al. 1970 Thayer et al. 1978; Allen et al. 1980	The availability of vegetative cover is one of the most essential requirements for a satisfactory nursery area. Vegetation provides food and cover.
V_3	Williams 1960 Tabb et al. 1962 Williams and Deubler 1968 Copeland and Bechtel 1974	Salinity levels affect growth and survival of pink shrimp.
V_4	Reynolds and Casterlin 1979	Temperature levels affect growth and survival. Optimal temperatures for pink shrimp are those that support rapid growth.

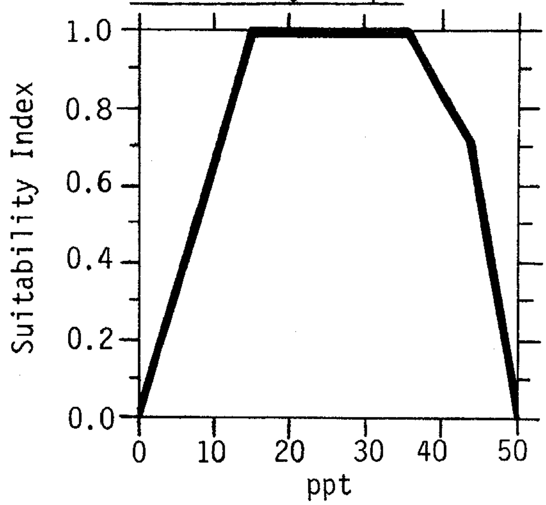
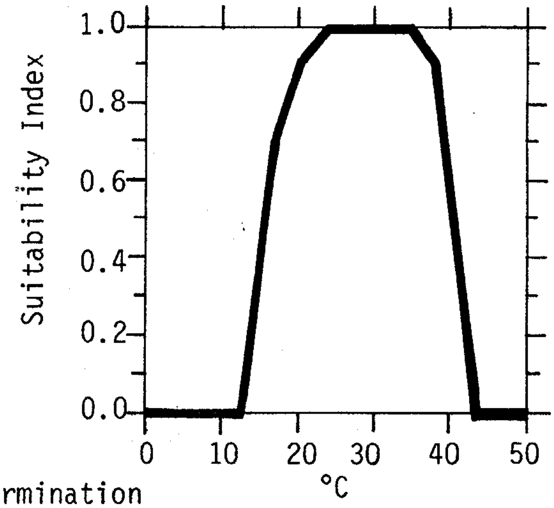
Habitat	Variable	Description	Suitability Graph
E	V_1	Substrate class: 1) firm bottom with some organic material--sandy silt, silty sand 2) hard bottom with little organic material--sand, gravel, shell 3) soft bottom--silt, clay.	

Habitat	Variable	Description	Suitability Graph
E	V_{2a}	Percentage of openwater/seagrass zone covered with seagrasses.	
E	V_{2b}	Percentage of emergent wetland zone covered with herbaceous emergent vegetation or mangroves. (Emergent wetland zone is bounded on seaward edge by the extent of emergent vegetation and includes tidal creeks and ponds.)	

If area contains only one of the above two cover types, then $SI_{V_2} = SI_{V_{2a}}$ or $SI_{V_{2b}}$.
If area contains both seagrasses and emergent vegetation, then SI_{V_2} =

$$\frac{P_a\,(SI_{V_{2a}}) + P_b\,(SI_{V_{2b}})}{100}$$

where P_a = percentage of total area that is openwater/ seagrass zone and P_b = percentage of total area that is emergent wetland zone.

Habitat	Variable	Description	Suitability Graph
E	V_3	Mean annual salinity.	
E	V_4	Mean annual water temperature.	

Component Index (CI) Equations and HSI Determination

To obtain an HSI for postlarval and juvenile pink shrimp, one must combine the SI values for each habitat variable. The suitability index for vegetation coverage (SIV_2) is squared, indicating its importance to shrimp. The suggested equations for calculating the food-cover component index (FC) and water quality component index (WQ) follow.

Component	Equation
Food-Cover	$(SI_{V_1} X (SI_{V_2})^2)^{1/3}$
Water quality	$(SI_{V_3} X SI_{V_4})^{1/2}$

HSI = FC or WQ, whichever value is lowest.

Three sample data sets from which values for the $\bar{S}I$, CI, and HSI have been calculated are given in Table 2.

Table 2. Calculations of suitability indices (SI), component indices (CI), and habitat suitability index (HSI) for three hypothetical data sets on the basis of habitat variables (V) and model equations.

Model component	Data set 1		Data set 2		Data set 3	
	Data	SI	Data	SI	Data	SI
V_1	firm bottom	1.0	hard bottom	0.5	soft bottom	0.3
V_{2a}	75%[a]	1.0	-	-	50%[c]	0.7
V_{2b}	-	-	60%[b]	0.6	80%	
V_3	30 ppt	1.0	10 ppt	0.67	20 ppt	1.0
V_4	20° C	0.90	45° C	0.0	30° C	1.0
FC	1.0		0.56		0.53	
WQ	0.95		0.0		1.0	
HSI	0.95		0.0		0.53	

[a]All open water, no emergent wetland.
[b]All emergent wetland, no open water.
[c]75% open water, 25% emergent wetland.

Interpreting Model Outputs

The pink shrimp HSI determined by use of these models will not necessarily represent the population of pink shrimp in an area. The HSI scores are useful primarily as a means of comparison. Habitats with high HSI's would, on average, be expected to have higher populations of pink shrimp than would habitats with low HSI's. A close correlation between population size and HSI is unlikely.

Field Use of Model

This model is designed for use in vegetated or partly vegetated estuarine areas. It is not applicable to completely unvegetated areas or to open ocean areas. The reliability of the calculated HSI values can be only as good as the data used for their calculation. Estimates of habitat variables cannot replace actual field measurements of variables. HSI values are most useful when the habitat variables are measured in the specific evaluation area. Existing water quality information for the area should be used if it is available and accurate. Shrimp are very mobile; accordingly, temporary fluctuations in water quality may not influence habitat suitability. It is best to use long-term data whenever possible to evaluate the suitability of an area for pink shrimp. Model users are advised to consult local fishery biologists to insure that the data sources being utilized most accurately reflect local habitat conditions. If subjective estimates must be used, they should be made by experienced professionals familiar with the evaluation area and be accompanied by full documentation of the basis on which they were made. Suggested methods for measuring model variables are described in Table 3.

ADDITIONAL HABITAT MODELS

Turner (1977) developed a model for predicting commercial yields of penaeid shrimp that was based on the amount of vegetated marsh area and latitude. Another model, based on the relationship of the previous winter's water temperature and spring landings of pink shrimp, was developed in North Carolina (Hettler and Chester 1982). A strong relation was observed between landings and the average water temperature of the two coldest consecutive weeks of each year.

Table 3. Suggested methods for measurement of variables for habitat information to be used in HSI model for postlarval and juvenile pink shrimp.

Variable	Technique
V_1	Substrate class can be determined by visual inspection of area or by using a bottom grab sampler and sieve.
V_2	Percentage of vegetative cover can be determined by on-site inspections or by using aerial photographs and a planimeter.
V_3	Use existing data, or salinity can be measured by titration, refractometer, or salinity meter.
V_4	Use existing data, or temperature can be measured by thermometer or temperature probe.

LITERATURE CITED

Aldrich, D. V. 1964. Behavior and tolerances. U.S. Fish Wildl. Serv. Circ. No. 183:61-64.

Allen, D. M., J. H. Hudson, and T. J. Costello. 1980. Postlarval shrimp (Penaeus) in the Florida Keys: species, size, and seasonal abundance. Bull. Mar. Sci. 30:21-33.

Cook, H. L., and M. A. Murphy. 1969. The culture of larval penaeid shrimp. Trans. Am. Fish. Soc. 98:751-754.

Copeland, B. J., and T. J. Bechtel. 1974. Some environmental limits of six gulf coast estuarine organisms. Contrib. Mar. Sci. 18:169-204.

Copeland, B. J., and M. V. Truitt. 1966. Fauna of the Aransas Pass Inlet, Texas. II. Penaeid shrimp postlarvae. Tex. J. Sci. 18:65-74.

Costello, T. J., and D. M. Allen. 1966. Migrations and geographic distribution of pink shrimp, *Penaeus duorarum*, of the Tortugas and Sanibel grounds, Florida. U.S. Fish Wildl. Serv. Fish. Bull. 65:449-459.

Costello, T. J., and D. M. Allen. 1970. Synopsis of biological data on the pink shrimp *Penaeus duorarum duorarum* Burkenroad, 1939. FAO Fish. Rep. 57:1499-1537.

Couch, J. A. 1978. Diseases, parasites, and toxic responses of commercial penaeid shrimps of the Gulf of Mexico and South Atlantic coasts of North America. U.S. Natl. Mar. Fish. Serv. Fish. Bull. 76:1-44.

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. Biol. Serv. Program. FWS/OBS-79/31. 103 pp.

de Sylva, D. P. 1954. The live bait shrimp fishery of the northeast coast of Florida. Fla. State Board Conserv. Mar. Res. Lab. Tech. Ser. No. 11. 35 pp.

Dobkin, S. 1961. Early developmental stages of pink shrimp, *Penaeus duorarum*, from Florida waters. U.S. Fish Wildl. Serv. Fish. Bull. 61:321-349.

Eldred, B., R. M. Ingle, K. D. Woodburn, R. F. Hutton, and H. Jones. 1961. Biological observations on the commercial shrimp, Penaeus duorarum Burkenroad, in Florida waters. Fla. State Board Conserv. Mar. Res. Lab. Prof. Pap. Ser. No. 3. 139 pp.

Ewald, J. J. 1965. The laboratory rearing of pink shrimp, Penaeus duorarum Burkenroad. Bull. Mar. Sci. 15:436-449.

Fuss, C. M., Jr., and L. H. Ogren. 1966. Factors affecting activity and burrowing habits of the pink shrimp, Penaeus duorarum Burkenroad. Biol. Bull. (Woods Hole) 130:170-191.

Hettler, W. F., and A. J. Chester. 1982. The relationship of winter temperature and spring landings of pink shrimp, Penaeus duorarum, in North Carolina. U.S. Natl. Mar. Fish. Serv. Fish. Bull. 80:761-768.

Hildebrand, H. H. 1954. A study of the fauna of the brown shrimp (Penaeus aztecus Ives) grounds in the western Gulf of Mexico. Publ. Inst. Mar. Sci. Univ. Tex. 3:231-366.

Hildebrand, H. H. 1955. A study of the fauna of the pink shrimp (Penaeus duorarum Burkenroad) grounds in the Gulf of Campeche. Publ. Inst. Mar. Sci. Univ. Tex. 4(1):169-232.

Hoese, H. D., and R. S. Jones. 1963. Seasonality of larger animals in a Texas turtle grass community. Publ. Inst. Mar. Sci. Univ. Tex. 9:37-47.

Hudson, J. H., D. M. Allen, and T. J. Costello. 1970. The flora and fauna of a basin in central Florida Bay. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. No. 604. 14 pp.

Huff, J. A., and S. P. Cobb. 1979. Penaeid and sergestoid shrimps (Crustacea: Decapoda). Fla. Dep. Nat. Resour. Mar. Res. Lab. Mem. Hourglass Cruises 5(4):1-102.

Hughes, D. A. 1969. Responses to salinity change as a tidal transport mechanism of pink shrimp, Penaeus duorarum. Biol. Bull. (Woods Hole) 136:43-53.

Idyll, C. P. 1964. The juvenile phase of the life history of the pink shrimp Penaeus duorarum on the Everglades National Park nursery grounds. U.S. Fish Wildl. Serv. Circ. No. 183:83-85.

Idyll, C. P., and A. C. Jones. 1965. Abundance and distribution of pink shrimp larvae and postlarvae in southwest Florida waters. U.S. Fish Wildl. Serv. Circ. No. 230:25-27.

Iverson, E. S., and A. C. Jones. 1961. Growth and migration of the Tortugas pink shrimp, Penaeus duorarum, and changes in the catch per unit of effort of the fishery. Fla. State Board Conserv. Mar. Res. Lab. Tech. Ser. No. 34. 30 pp.

Jones, A. C., D. Dimitriou, and J. Ewald. 1964. Abundance and distribution of pink shrimp larvae on the Tortugas Shelf of Florida. U.S. Fish Wildl. Serv. Circ. No. 183:86-88.

Jones, A. C., D. E. Dimitriou, J. J. Ewald, and J. H. Tweedy. 1970. Distribution of early developmental stages of pink shrimp, Penaeus duorarum, in Florida waters. Bull. Mar. Sci. 20:634-661.

Joyce, E. A., Jr. 1965. The commercial shrimps of the northeast coast of Florida. Fla. State Board Conserv. Mar. Res. Lab. Prof. Pap. Ser. No. 6. 224 pp.

Joyce, E. A., Jr., and B. Eldred. 1966. The Florida shrimping industry. Fla. State Board Conserv. Mar. Res. Lab. Educ. Ser. No. 15. 47 pp.

Kennedy, F. S., Jr., and D. G. Barber. 1981. Spawning and recruitment of pink shrimp, Penaeus duorarum, off eastern Florida. J. Crustacean Biol. 1:474-485.

Kutkuhn, J. H. 1966. The role of estuaries in the development and perpetuation of commercial shrimp resources. Pages 16-36 in R. F. Smith, A. H. Swartz, and W. H. Massmann, eds. A symposium on estuarine fisheries. Am. Fish. Soc. Spec. Publ. 3.

Lindner, M. J. 1957. Survey of shrimp fisheries of Central and South America. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. No. 235. 166 pp.

Martosubroto, P. 1974. Fecundity of pink shrimp, Penaeus duorarum Burkenroad. Bull. Mar. Sci. 24:606-627.

National Marine Fisheries Service. 1983. Fisheries of the United States, 1982. U.S. Natl. Mar. Fish. Serv. Curr. Fish. Stat. No. 8300. 117 pp.

Perez Farfante, I. 1969. Western Atlantic shrimps of the genus Penaeus. U.S. Fish Wildl. Serv. Fish. Bull. 67:461-591.

Phillips, R. C. 1960. Observations on the ecology and distribution of the Florida seagrasses. Fla. State Board Conserv. Mar. Res. Lab. Prof. Pap. Ser. No. 2. 72 pp.

Reynolds, W. W., and M. E. Casterlin. 1979. Thermoregulatory behavior of the pink shrimp Penaeus duorarum Burkenroad. Hydrobiologia 67:179-182.

Roedel, P. M. 1973. Shrimp '73--a billion dollar business. Mar. Fish. Rev. 35(3-4):1-2.

Roessler, M. A., A. C. Jones, and J. L. Munro. 1969. Larval and postlarval pink shrimp Penaeus duorarum in south Florida. Proc. World Sci. Conf. Biol. Cult. Shrimps and Prawns. FAO Fish. Rep. 47:859-866.

Rulifson, R. A. 1981. Substrate preferences of juvenile penaeid shrimps in estuarine habitats. Contrib. Mar. Sci. 24:35-52.

Saloman, C. H. 1965. Bait shrimp (Penaeus duorarum) in Tampa Bay, Florida--biology, fishery economics, and changing habitat. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. No. 520. 16 pp.

Springer, S., and H. R. Bullis. 1954. Exploratory shrimp fishery in the Gulf of Mexico, summary report for 1952-1954. Commer. Fish. Rev. 16(10):1-16.

Subrahmanyam, C. B. 1971. The relative abundance and distribution of penaeid shrimp larvae off the Mississippi coast. Gulf Res. Rep. 3:291-345.

Tabb, D. C., D. L. Dubrow, and A. E. Jones. 1962. Studies on the biology of the pink shrimp, Penaeus duorarum Burkenroad, in Everglades National Park, Florida. Fla. State Board Conserv. Mar. Res. Lab. Tech. Ser. No. 37. 32 pp.

Thayer, G. W., H. H. Stuart, W. J. Kenworthy, J. F. Ustach, and A. B. Hall. 1978. Habitat values of salt marshes, mangroves, and seagrasses for aquatic organisms. Pages 235-247 in P. E. Greeson, J. R. Clark, and J. E. Clark, eds. Wetland functions and values: the state of our understanding. Am. Water Resources Assoc., Minneapolis, Minn.

Turner, R. E. 1977. Intertidal vegetation and commercial yields of penaeid shrimp. Trans. Am. Fish. Soc. 106:411-416.

U.S. Bureau of Commercial Fisheries. 1961. Extensive survey made off Florida east coast for stocks of shrimp and scallops: M/V Silver Bay Cruise 26. U.S. Fish Wildl. Serv. Commer. Fish. Rev. 23(1):32-34.

U. S. Fish and Wildlife Service. 1980. Habitat evaluation procedures (HEP). ESM 102. Washington, D.C. n.p.

Williams, A. B. 1955a. A contribution to the life histories of commercial shrimps (Penaeidae) in North Carolina. Bull. Mar. Sci. Gulf Caribb. 5:116-146.

Williams, A. B. 1955b. A survey of the North Carolina shrimp nursery grounds. J. Elisha Mitchell Sci. Soc. 71:200-207.

Williams, A. B. 1958. Substrates as a factor in shrimp distribution. Limnol. Oceanogr. 3:283-290.

Williams, A. B. 1960. The influence of temperature on osmotic regulation in two species of estuarine shrimps (Penaeus). Biol. Bull. (Woods Hole) 119:560-571.

Williams, A. B. 1965. Marine decapod crustaceans of the Carolinas. U.S. Fish Wildl. Serv. Fish. Bull. 65:1-298.

Williams, A. B., and E. E. Deubler, Jr. 1968. A ten-year study of meroplankton in North Carolina estuaries: assessment of environmental factors and sampling success among bothid flounders and penaeid shrimps. Chesapeake Sci. 9:27-41.

Woodburn, K. D., B. Eldred, E. Clark, R. F. Hutton, and R. M. Ingle. 1957. The live bait shrimp industry of the west coast of Florida (Cedar Key to Naples). Fla. State Board Conserv. Mar. Res. Lab. Tech. Ser. No. 21. 33 pp.

Zimmerman, R. J., T. J. Minello, and G. Zamora. 1982. Habitat selection by penaeid shrimp within a Texas salt marsh. Am. Zool. 22:882.

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16. Abstract (Limit: 200 words)

A review and synthesis of existing information were used to develop a model suitable for evaluating estuarine habitat for pink shrimp (Penaeus duorarum). The model is scaled to produce an index of habitat suitability between 0 (unsuitable habitat) and 1 (optimally suitable habitat) for the northern Gulf of Mexico. Habitat suitability indices are designed for use with the Habitat Evaluation Procedures previously developed by the U.S. Fish and Wildlife Service.

17. Document Analysis a. Descriptors

Mathematical models
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Estuaries
Habitat

b. Identifiers/Open-Ended Terms

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Penaeus duorarum

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