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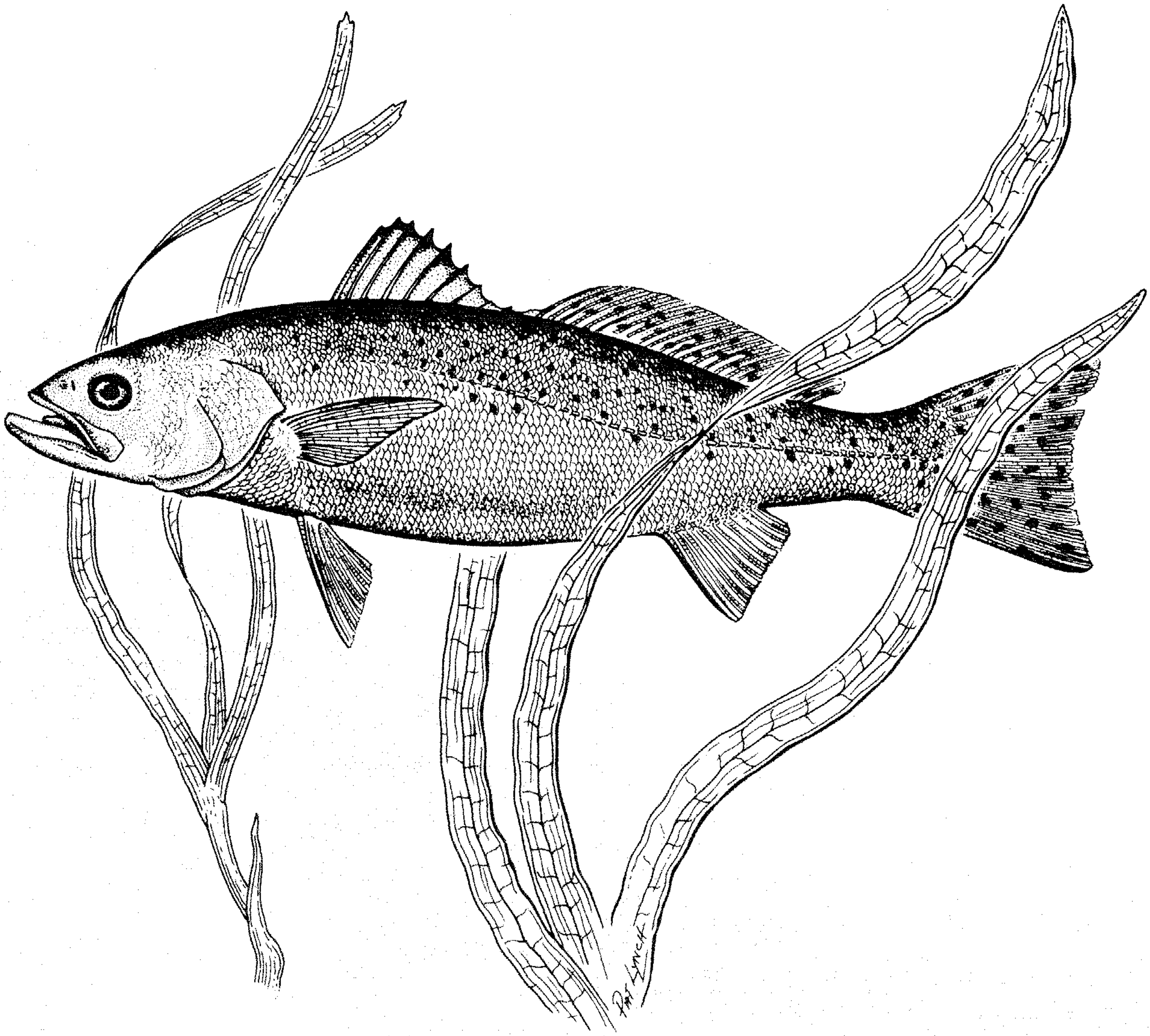
HABITAT SUITABILITY INDEX MODELS: SPOTTED SEATROUT



ı and Wildlife Service

Department of the Interior

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HABITAT SUITABILITY INDEX MODELS: SPOTTED SEATROUT

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PREFACE

The spotted seatrout habitat suitability index (HSI) model 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 relations, not a statement of proven cause and effect, and 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 or suggestions to the following address.

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CONTENTS

ACKNOWLEDGMENTS

Development of the habitat suitability index model and narrative for the spotted seatrout was monitored by Dr. Henry Booke, Massachusetts Cooperative Fishery Research Unit, University of Massachusetts. Supportive information was provided by Dr. A. Keith Taniguchi, University of South Carolina and Daniel Roberts, Florida Department of Natural Resources, St. Petersburg. The model was expertly reviewed and constructively criticized during development by Louisiana Department of Wildlife and Fisheries employee Joe Shepard, Grand Terre Research Laboratory, and Vincent Guillory, Lyle St. Amant Marine Laboratory. The model's structure and functional relationships were evaluated by Floyd A. Nudi and Fred Werner, U.S. Fish and Wildlife Service (FWS), Ecological Services (ES), Houston, Texas, and Don Meineke, ES, Corpus Christi, Texas, as well as personnel of the National Coastal Ecosystems Team. The FWS funded the development of the model.

SPOTTED SEATROUT (*Cynoscion nebulosus*)

INTRODUCTION

The estuarine spotted seatrout, a primarily estuarine species, is one of the most important sport and commercial fishes in coastal Gulf of Mexico waters (Arnold et al. 1976). Spotted seatrout rank second by weight in catches by U.S. saltwater sport fishermen (National Marine Fisheries Services 1981).

Distribution

Spotted seatrout are distributed mainly in coastal estuaries of the western Atlantic Ocean from New York to Florida (Hilderbrand and Cable 1934; Tabb 1966; Chao and Musick 1977) and throughout the Gulf of Mexico (Welsh and Breder 1924; Futch 1970), but they have been reported as far north as Cape Cod, Massachusetts (Welsh and Breder 1924; Tabb 1966). The species is commercially valuable from Virginia to Mexico (Hildebrand and Cable 1934; Iversen and Moffet 1962; Tabb 1966; Merriner 1980); fishing intensity increases from Virginia southward around Florida and along the gulf coast (Merriner 1980).

Life History Overview

Spotted seatrout are not considered migratory (Tabb 1966). They usually do not move more than 48 km (30 mi) from tagging sites and most fish may not leave their natal estuary (Moffett 1961; Ingle et al. 1962; Iversen and Moffett 1962; Topp 1963; Beaumariage 1964; Beaumariage and Wittich 1966). Some long-distance movements, however, have been reported (Moffett 1961). Movement appears to be associated with changing environmental conditions (e.g., temperature and salinity), spawning, and feeding (Figure 1). Spotted seatrout adapt to normal temperature fluctuations by moving from shallow areas to deeper channels within the estuary, or occasionally offshore (Tabb 1966). Simmons (1957) related inshore movements of spotted seatrout in Texas to spawning activity and water temperature from March to June. Pearson (1929) reported that large fish in the Gulf of Mexico enter the bays in early spring to feed. The young seek protection among submerged and emergent vegetation in shallow water (Miles 1950).

Although spotted seatrout may mature at 1 to 3 years of age (Lorio and Perret 1980), most mature after 2 years (Klima and Tabb 1959). Generally, fish vary in size at maturity from estuary to estuary. Males mature at a smaller size (Moody 1950; Tabb 1961; Perret et al. 1980) and earlier age (Guest and Gunter 1958) than females. Moody (1950) found that, in the Cedar Keys Estuary in Florida, females generally matured at 21-25 cm (8.3-9.8 inches) standard length (SL) and most spawned at 24-25 cm (9.5-9.8 inches) SL. Some ripe females observed were as small as 20 cm (7.9 inches). Klima and Tabb (1959)

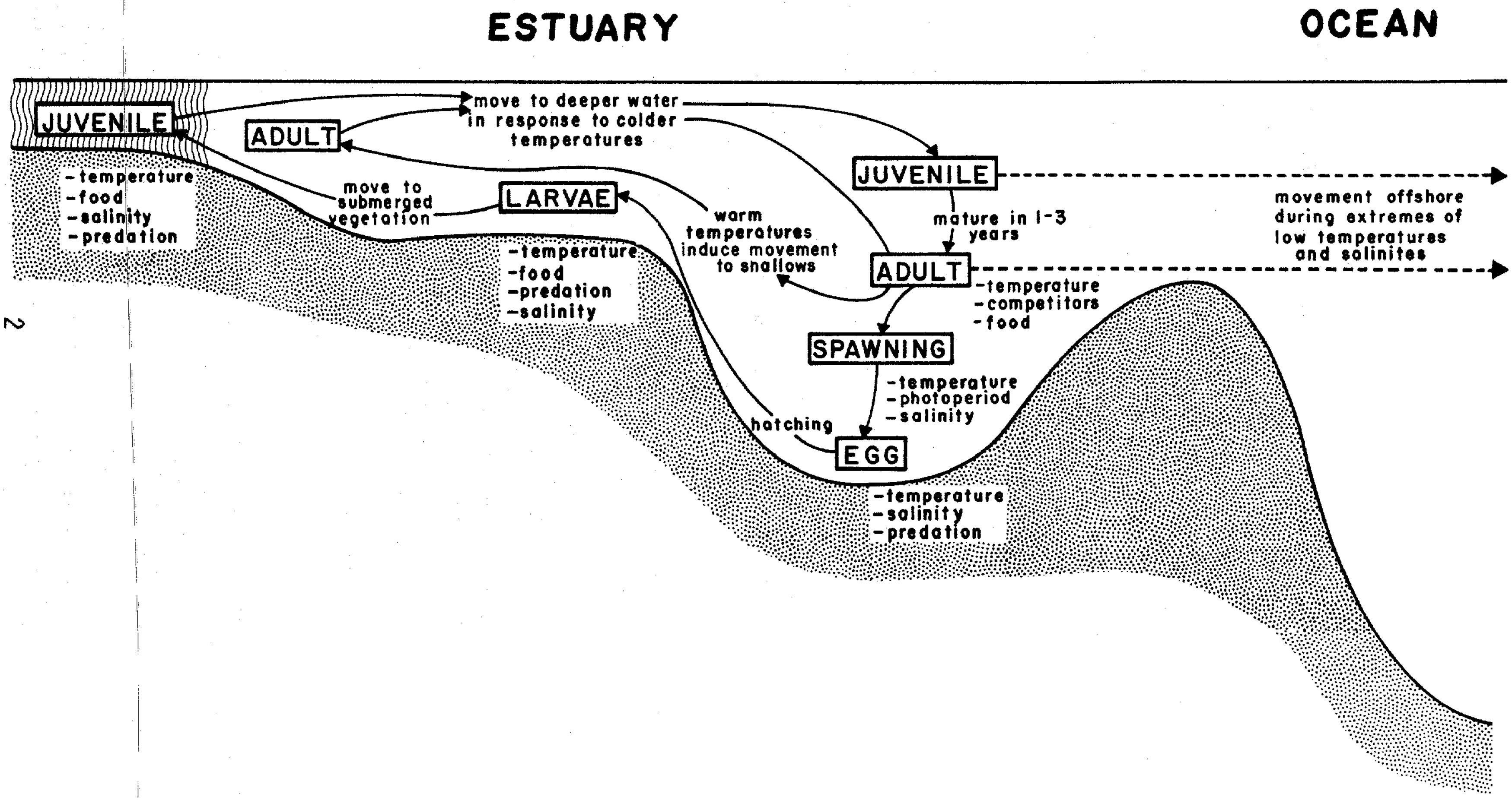


Figure 1. Diagrammatic life history model for spotted seatrout indicating the major life stages and important environmental variables influencing location and survival.

reported that all females in Apalachicola Bay, Florida, were mature at 27 cm (10.6 inches) SL and all males at 25 cm (9.8 inches); the lengths of the smallest ripe female and male were 21 cm (8.3 inches) and 18 cm (7.1 inches), respectively. Stewart (in Perret et al. 1980), however, reported that most fish in Florida Bay matured at 19-30 cm (7.5-11.8 inches) SL with no difference between sexes. Tabb (1961) found that spotted seatrout along the Atlantic coast of Florida matured at larger sizes than those along the gulf coast. Most females matured at lengths greater than 35 cm (13.8 inches) SL in the Indian River Lagoon along the Atlantic coast.

Although spotted seatrout spawn throughout the year in tropical south Florida (Rutherford et al. 1982), the usual spawning season in the Gulf of Mexico is February through October (Lorio and Perret 1980). Some investigators have suggested bimodal spawning peaks, in late spring and in summer or early fall (Janke 1971; Perret el al. 1980; Rutherford et al. 1982) (Table 1).

Spotted seatrout may spawn well within the estuary, in the tidal streams, or above tidal influence (Pearson 1929; Tabb 1966). There is evidence that spawning takes place in the tidal areas (Tabb 1966), in open bays (Hildebrand and Cable 1934), near barrier island passes (Perret et al. 1980; Lassuy 1982), or outside estuaries (Tabb and Manning 1961). Spawning occurs at night (Tabb 1966).

The extensive variation in fecundity reported in the literature suggests individual or estuary-to-estuary differences (Lassuy 1982). Fecundity estimates have ranged from 14,000 or 15,000 eggs (Tabb 1961; Sundararaj and Suttkus 1962) to 1.5 million eggs per spawn (Pearson 1929; Tabb 1961; Sundararaj and Suttkus 1962). Sundararaj and Suttkus (1962) suggested that spotted seatrout near Lake Borgne, Louisiana, were more fecund at the same age than those in Texas or Florida waters. They reported the mean number of eggs (millions) per female as 0.14 at age I, 0.35 at II, 0.66 at III, and 1.14 at IV. The mean length of females ranged from 283 mm (11.1 inches) total length (TL) at age I to 504 mm (19.8 inches) TL at age IV. Sundararaj and Suttkus (1962) also found that age I fish contributed little to the annual egg supply. Fish of ages II to IV contributed about 92% of the eggs, those of age III contributing the largest percentage (40.6).

Spotted seatrout eggs have a clear and unsculptured chorion (Arnold et al. 1976; Fable et al. 1978) and are spherical; average diameter is 0.73-0.82 mm (0.030-0.032 inch) (Fable et al. 1978). Miles (1950) reported egg diameter as 0.76-0.98 mm (0.030-0.039 inch). The width of the perivitelline space was 4% of the egg diameter (Fable et al. 1978). The eggs generally contained one oil globule 0.18-0.26 mm (0.007-0.010 inch) in diameter, but some had two or three (Fable et al. 1978).

The presence of oil globules suggests that spotted seatrout eggs are buoyant, but the literature is conflicting. Miles (1950) suggested that the eggs are demersal. Tabb (1966), however, stated that the eggs were buoyant and thus pelagic; he was supported by Fable et al. (1978) and Arnold et al. (1976). Pearson (1929) suggested that the buoyancy serves as a mechanism to deposit newly hatched larvae over shallow, grassy areas that provide protection. A

Table 1. Location and spawning period of spotted seatrout.

Location and spawning period	Reference
Southern Florida	
All months	Stewart 1961, Janke 1971
May-June (peak)	Klima and Tabb 1959
Spring, summer or fall (bimodal peaks)	Janke 1971, Rutherford et al. 1982
Louisiana	
July to September	Sundararaj and Suttkus 1962
May to October	Lorio and Perret 1980
Texas	
July (peak)	Miles 1950
Georgia	
May (peak)	Mahood 1974
Gulf of Mexico	
April to July (peak)	Pearson 1929, Tabb 1966
February to October	Lorio and Perret 1980

statement by Taniguchi (pers. comm., in Perret et al. 1980) that spotted seatrout eggs sink at a salinity of 25 parts per thousand (ppt) but float at 30 ppt may explain these discrepancies; therefore, eggs may be pelagic or demersal because of differences in salinities in estuaries. Hatching success of demersal and pelagic eggs has not been compared.

For this report, the larval stage corresponds to a period from hatching to reaching a length of about 10-15 mm (0.39-0.59 inch) SL--the size of larvae at their first appearance around grass beds and other submerged vegetation (Perret et al. 1980). Growth to this length has been attained in 12 days under laboratory conditions (Taniguchi 1981), but would probably require a longer period under natural conditions. Spotted seatrout larvae hatch at 1.30-1.56 mm (0.05-0.06 inch) SL (Fable et al. 1978). The mouth is formed at 40 h post-hatching at 25° C (77° F), and the yok sac is completely absorbed by 60 h (Fable et al. 1978). Taniguchi (pers. comm., in Perret et al. 1980) stated that, at 25-ppt salinity, newly hatched larvae swim upward in the water column, but move to the bottom after 4-7 days. Arnold et al. (1976) reported dispersion of young in the water column after 3-7 days. This initial swimming behavior may help transport the young into shallow grass flats in the estuary.

Larvae of spotted seatrout begin feeding actively after the yolk sac is absorbed, about 60-80 h posthatching (Arnold et al. 1976). Initially, larvae feed on prey within a radius of one or two body lengths; after 7 to 14 days they swim actively and stalk food organisms (Arnold et al. 1976; Fable et al. 1978; Taniguchi 1981).

Larval spotted seatrout grow an average of 3.0-4.5 mm (0.12-0.18 inch) SL in about 15 days in the laboratory (Fable et al. 1978). Taniguchi (1980) reported significantly faster laboratory growth rates for larvae fed rotifers than for those fed zooplankton. He also showed that food density was directly related to growth rates. Growth rate was fastest at 32° C (90° F), when larvae gained an average of 76.5% of body weight per day.

Spotted seatrout from different estuaries vary greatly in growth rate and maximum sizes (Welsh and Breder 1924; Klima and Tabb 1959; Moffett 1961; Tabb 1966). Individuals within a year class in the same estuary also vary greatly in growth rate (Perret et al. 1980); consequently, size classes do not always correspond to age classes. Lassuy (1982) suggested that these differences in growth rate may not be significant since yearly variation cannot be ruled out as their primary source. In addition, differences in growth rates among estuarine stocks may be due to qualitative environmental variation (Klima and Tabb 1959). Electrophoretic evidence, however, suggests that there are significant genetic differences between estuarine stocks (Weinstein and Yerger 1976a, 1976b).

Spotted seatrout reach 190-248 mm (7.5-9.8 inches) SL by the second year (Welsh and Breder 1924; Pearson 1929; Klima and Tabb 1959). Males grow slower than females (Guest and Gunter 1958; Tabb 1966; Rutherford et al. 1982) and have a shorter life span. This results in a smaller proportion of males in subsequent year classes: 80% males at age I, 50% at ages II and II, and 0% at age V and older (Klima and Tabb 1959; Tabb 1958; Moffett 1961; Tabb 1961, 1966).

SPECIFIC HABITAT REQUIREMENTS

Several factors have been suggested as important in determining habitat suitability for spotted seatrout. Tabb (1958) believed the following to be of greatest importance:

1. the presence of large areas of shallow, quiet, brackish water (bays and lagoons)
2. the absence of predators
3. the absence of competitors
4. the presence of large areas of submerged aquatic vegetation
5. an abundance of grazing crustaceans and fishes of suitable size to be eaten throughout the year
6. a stable temperature, ranging between about 15.6° and 26.7° C (60° and 80° F)
7. adequate areas adjacent to grass flats having a depth of 3-6 m (10-20 ft) that can be used as refuge from winter cold.

Spotted seatrout are primarily estuarine, rarely leaving their natal estuary. The species is therefore adapted to the estuarine environment and is relatively tolerant of a wide range in physicochemical factors. Most of the present knowledge of habitat requirements for spotted seatrout is related to temperature and salinity.

Little is known about the range of environmental conditions tolerated by juvenile spotted seatrout. For the purposes of this report, it is assumed that habitat requirements for juveniles are similar to those for adults because juveniles and adults generally inhabit similar areas of the estuary.

Temperature

Water temperature is an important factor limiting growth and production of spotted seatrout (Tabb 1966). Tabb (1958) identified 16°-27° C (61°-81° F) as suitable for adults. The fish actively feed at temperatures between 4° and 33° C (39° and 92° F) (Simmons 1957). However, temperatures between 7° and 10° C (45° and 50° F) have been identified as adverse (Tabb 1966). Tempera- tures below 4° C (39° F) appear to be lethal, although mortalities may occur at higher temperatures (<7° C or 45° F) if a temperature decrease to this level is abrupt or persists (Storey and Grudger 1936; Gunter and Hildebrand 1951; Tabb 1958).

Selection of spawning sites may be related more to temperature and salinity than to other physical variables (Perret et al. 1980). Spawning reportedly occurs in estuaries at temperatures of 21.0°-28.3° C (70°-83° F). Spawning in Texas begins at a water temperature of 21° C (Simmons 1951). Tabb (1966) reported spawning at 25.5°-28.3° C (78°-83° F). Arnold et al. (1976) reported optimal spawning temperatures at 20°-30° C (68°-86° F).

On the basis of laboratory studies, Taniguchi (1980) predicted 100% egg survival within a temperature range of about 23°-32° C (74°-90° F). Length of time to hatching also depends on temperature. Smith (1907) reported that spotted seatrout eggs hatch in 40 h at 25° C (77° F), 15 h at 27° C (80° F), and 21 h at 23° C (74° F).

Recent studies have indicated that optimal temperatures for larvae are the same as for eggs (Arnold et al. 1976; Taniguchi 1980).

Salinity

Tabb (1966) reported that the common factor in all productive spotted seatrout habitat was seasonally fluctuating salinity. Seatrout reportedly inhabit water with salinities of 0.2-77 ppt (Tabb 1966). Like decreases in temperature, abrupt decreases in salinity may cause mass movement out of the estuary (at 10-15 ppt) or mortality (at <5 ppt).

Spotted seatrout spawn in a wide range of salinities. Optimal spawning salinities have been reported to be 20-35 ppt in the laboratory by Arnold et al. (1976) and 28.1 ppt by Taniguchi (1980). Spawning peaked in Florida at 30-35 ppt (Tabb 1958, 1966). Simmons (1957) reported no spawning in Texas at salinities greater than 45 ppt.

Salinity is also critical to egg survival. Taniguchi (1980) reported that survival was 100% at 18.6-37.5 ppt salinity. The effect of salinities above and below this range on egg survival is unknown. Optimal salinities for larvae appear to be the same as for eggs (Arnold et al. 1976; Taniguchi 1980).

Food

Adult spotted seatrout are opportunistic carnivores whose food habits change with size (Perret et al. 1980). The major food items of adults are penaeid shrimp and numerous fishes such as the striped mullet (*Mugil cephalus*), anchovies (*Anchoa* sp.), and pinfish (*Lagodon rhomboides*) (Tabb 1966). Seatrout probably feed sporadically, but mostly during the morning (Darnell 1958).

Survival of larval spotted seatrout in the laboratory is related to food availability (Taniguchi 1980). Fish larvae must be near a relatively high density of appropriate-sized food organisms (Hunter and Thomas 1974; Laurence 1974; Houde 1977; Beyer 1976; Taniguchi 1980; Hunter 1982). The presence of adequate food is especially important during the critical period after yolk-sac resorption when the larvae begin feeding. Thus, food abundance in the estuary may significantly influence the survival of larvae.

The principal factor affecting food selection of postlarvae and juvenile spotted seatrout appears to be the relative size of the food organism (Moody 1950). Postlarvae feed on larval shrimp, copepods, small fishes, and crabs (Lorio and Perret 1980). Juveniles feed predominantly on fishes, penaeids, mysids, copepods, and carideans (Moody 1950). Moody (1950) reported an ontogenetic shift in the diet of fish at 150 mm (5.9 inches) SL from the smaller caridean shrimp to fishes and the larger penaeids. In areas with sparse grass beds and high turbidity, spotted seatrout may feed on different fauna. Darnell (1958) found that juvenile seatrout in Lake Pontchartrain, Louisiana, fed on schizopods and amphipods rather than on caridean shrimp. These fish also shifted to an adult diet of primarily fish after they reached a length of 100 mm (3.9 inches) SL. Tabb (1966), however, believed that the food preferences attributed to this species only indicate changing food availability.

Cover

The preferred habitat of juvenile spotted seatrout is the shallow, vegetated area of the estuary, most notable at the edges of grass flats (Pearson 1929; Tabb 1966). At 10-15 mm (0.40-0.59 inch) juveniles are found in increasing numbers in or adjacent to submerged vegetation such as *Ruppia maritima*, *Halodule wrightii*, and *Thalassia testudinum* (Perret et al. 1980). Juveniles remain in the submerged vegetation during summer but apparently move to deeper water as the water cools in winter (Pearson 1929; Miles 1950; Moody 1950).

Water Depth and Turbidity

Pearson (1929) reported that spotted seatrout in Texas spawned in bays and lagoons. He believed that they spawned in the deeper areas at depths of

3.0-4.6 m (9.8-15.1 ft). Tabb (1966) observed spawning in deep holes and channels in grass flats.

Spotted seatrout prefer water of low turbidity (Pearson 1929). Some mortality in estuaries has been attributed to high turbidity resulting from hurricanes (Tabb and Manning 1961; Perret et al. 1980). The effect of turbidity on egg survival is not known.

Special Considerations

The spotted seatrout is tolerant of relatively wide variations in environmental conditions; this tolerance may permit the species to occupy a niche that is intolerable to most marine predators and competitors (Tabb 1966). However, to what degree the absence or presence of competitors affects the carrying capacity of a particular habitat is unknown.

Because few spotted seatrout move from one estuary to another, losses of larval and juvenile fish can result in the loss of that year class to the fishery. Population increases by outside recruitment is not a factor (Lorio and Perret 1980).

HABITAT SUITABILITY INDEX (HSI) MODEL

Model Applicability

A model's usefulness is related to the range of its application, and generalization of the model's components increases this range. Overgeneralization can weaken the model, but too much specificity limits its application and decrease its value as a management tool. The spotted seatrout model was constructed primarily on the basis of generalized habitat requirements and is therefore applicable to all estuarine spotted seatrout habitats. Few generalizations concerning habitat requirements are precisely correct in all situations. Therefore, care should be taken to insure that model assumptions are acceptable for a particular habitat.

No attempt was made to incorporate environmental contaminants as habitat variables. Although the effects of some pollutants on spotted seatrout eggs and larvae have been studied (Johnson et al. 1977; Giam et al. 1978; Johnson et al. 1979), few specific data exist. Environmental contaminant variables may be incorporated into the model as more information becomes available. Until that time, however, it is not appropriate to apply the model to habitats affected by contaminants.

Geographic area. The model has been generalized for year-round application in estuarine spotted seatrout habitats along the Atlantic and Gulf of Mexico coasts of the United States.

Cover types. The spotted seatrout is primarily associated with estuarine environments. Therefore, this model is applicable to all estuarine subtidal habitat classes as defined by Cowardin et al. (1979).

Minimum habitat area. The minimum habitat area is the area of contiguous suitable habitat that is required for spotted seatrout to live and reproduce. No attempt was made to establish minimum habitat size for spotted seatrout.

Verification level. Two biologists outside the U.S. Fish and Wildlife Service reviewed and evaluated the spotted seatrout HSI model. They are Louisiana Department of Wildlife and Fisheries employees Joe Shepard, Grand Terre Research Laboratory, and Vincent Guillory, Lyle St. Amant Marine Laboratory. Their ideas and suggestions were incorporated when feasible, but the author is responsible for the final version of the model.

Hypothetical data sets were used to verify the acceptability of the spotted seatrout HSI model outputs. The model has not been field tested.

Model Description

The HSI model considers the suitability of habitat for the egg, larval, and juvenile life stages. These stages are the most sensitive to environmental variation, and their survival is assumed to be most important in contributing to population size. An index of habitat suitability between 0 (unsuitable) and 1.0 (optimally suitable) is generated by the model.

The HSI model was developed by using habitat variables based on two life requisite components--water quality and food/cover. The model assumes that these are the primary factors determining habitat quality for the spotted seatrout. The relations between habitat variables and life requisites are illustrated in Figure 2.

Water quality. The value of the water quality component is determined by salinity and temperature. The salinity variables--lowest monthly mean winter-spring (December-May) salinity (V_1) and highest monthly mean summer (June-September) salinity (V_2)--are assumed to be important to all life stages, but eggs and larvae are the most sensitive. Salinities between 19 and 38 ppt are considered optimal and salinities above 45 ppt and below 5 ppt unsuitable.

The relationship between lowest monthly mean winter (December-March) temperature (V_3) and highest monthly mean summer (June-September) temperature (V_4) is the second factor governing suitable water quality conditions. Like salinity, water temperature is more important to eggs and larvae than to later life stages. Temperatures between 20° and 32° C (68° and 90° F) are considered optimal. Temperatures below 4° C (39° F) and above 40° C (104° F) are unsuitable.

Food/cover. There is no easy method to quantify food abundance for estuarine fishes. One method relates estuarine productivity to freshwater input during the spring and the extent of salt marsh (Bain and Bain 1982). This approach is not appropriate for spotted seatrout because this species is commonly found in coastal lagoons (e.g., Laguna Madre), where there is no freshwater input. Carrying capacity may be greater in these lagoons than in similar estuaries with freshwater input (Matlock and Weaver 1978; Hegen and Matlock 1980). In this model, a positive relation is assumed between primary and secondary productivity in an aquatic ecosystem, whether it be a coastal

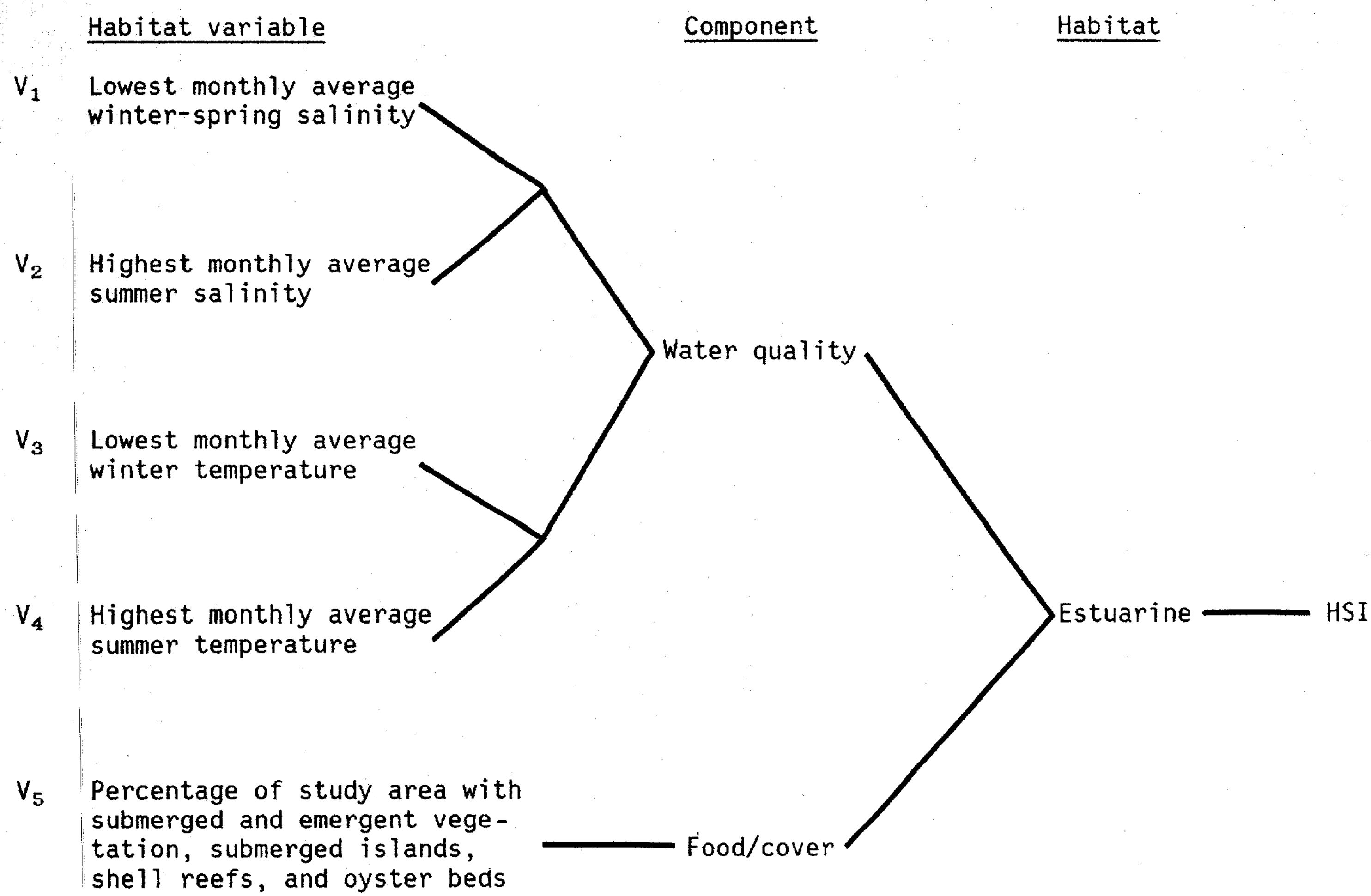


Figure 2. The relation of habitat variables, life requisite components, habitat type, and the habitat suitability index (HSI) for spotted seatrout.

lagoon or estuary. It is assumed that the amount of vegetation is a qualitative estimate of secondary productivity.

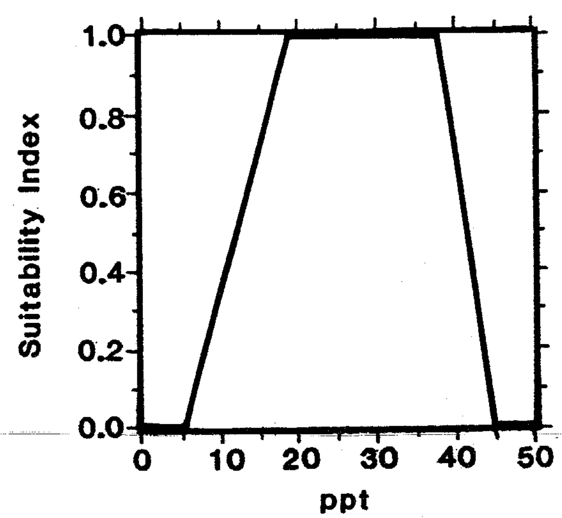
Seagrass beds and emergent vegetation provide living space for a rich epifauna of mobile and sessile organisms (Harlin 1980). Many of these organisms (e.g., penaeid shrimp) are important items in the diet of spotted seatrout. The influence of seagrass beds on the abundance and distribution of shrimp is fairly well established (Yokel 1975; Williams 1965; Zieman 1982). In addition, densities of spotted seatrout forage fishes are typically greater in grass bed habitat within estuaries and lagoons than elsewhere (Reid 1954; Tabb et al. 1962; Roessler 1965; Roessler and Beardsley 1974; Yokel 1975; Weinstein et al. 1977).

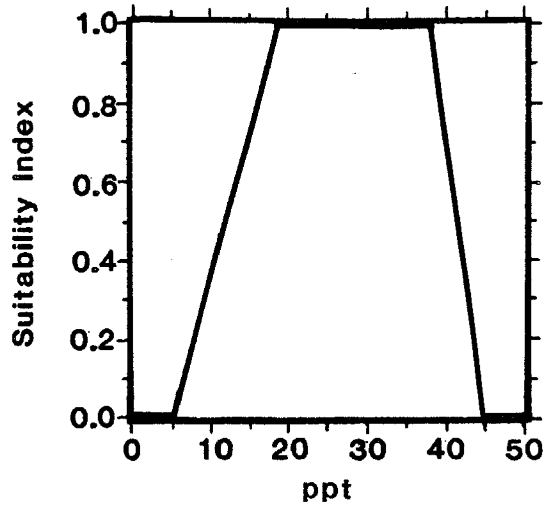
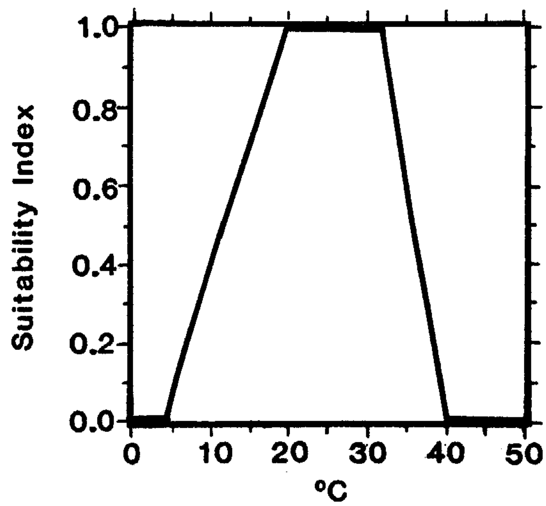
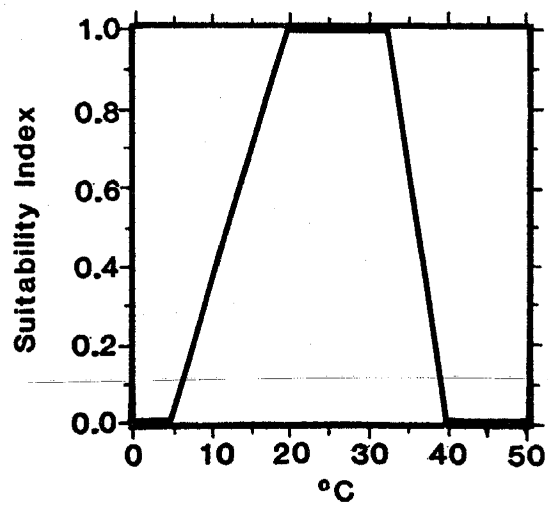
Areas of submerged and emergent vegetation also provide shelter and protection for larval and juvenile spotted seatrout. In areas with little naturally occurring submerged vegetation, such as those in coastal Louisiana, fish depend on habitat near or over submerged or emergent islands, shell reefs, or oyster beds for shelter (Hoese and Moore 1977; Perret et al. 1980).

Food and cover values of spotted seatrout habitat are combined into a single variable that refers to the percentage of the estuarine area covered by submerged and/or emergent vegetation, submerged islands (water less than 3 m or 10 ft deep), oyster beds, or shell reefs (V_5). The model assumes that cover over more than 50% of the total area is optimum.

Suitability Index (SI) Graphs for Habitat Variables

This section provides graphic representations of the relations previously described between the habitat variables and estuarine (E) habitat suitability for spotted seatrout. An SI value of 1.0 indicates optimal conditions and a value of 0 indicates unsuitable conditions. Data sources and assumptions associated with documentation of the SI graphs are listed in Table 2.

Habitat	Variable		Suitability Graph
E	V_1	Lowest monthly mean winter and spring salinity.	

Habitat	Variable		Suitability Graph
E	V_2	Highest monthly mean summer salinity.	
E	V_3	Lowest monthly mean winter water temperature.	
E	V_4	Highest monthly mean summer water temperature.	

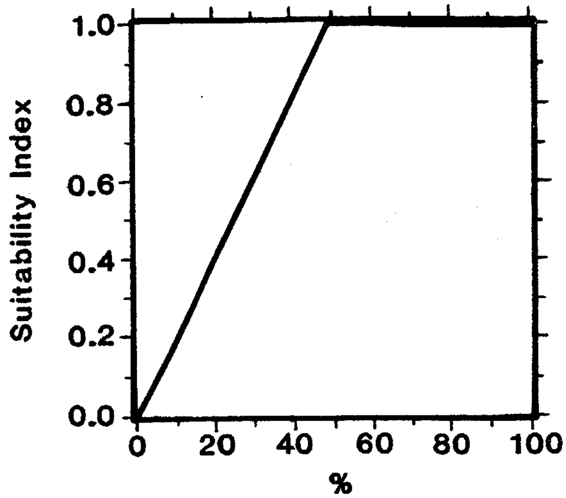
Habitat	Variable		Suitability Graph
E	V_5	Percentage of area with submerged and/or emergent vegetation, submerged islands, shell reefs, or oyster beds.	

Table 2. Data sources and assumptions for habitat variables included in the spotted seatrout HSI model.

Variable and source		Assumptions
V_1, V_2	Simmons 1957 Tabb 1958, 1966 Arnold et al. 1976 Fable et al. 1978 Taniguchi 1980, 1981	Although fairly tolerant to variations in salinity, stable and moderate (19-38 ppt) salinity levels are considered optimal for spotted seatrout. Lack of mobility in early life stages increases the fish's vulnerability to extremes.
V_3, V_4	Storey and Grudger 1936 Moody 1950 Simmons 1957 Tabb 1958, 1966 Arnold et al. 1976 Fable et al. 1978 Taniguchi 1980, 1981	Stable, moderate (20°-32° C or 68°-90° F) water temperatures are optimal. Extremely cold or warm water is not suitable.
V_5	Moody 1950 Reid 1954 Darnell 1958 Tabb et al. 1962 Tabb 1966 Yokel 1975 Arnold et al. 1976 Hunter 1982 Hunter and Thomas 1974 Fable et al. 1978 Taniguchi 1980, 1981	Many of the food items of the spotted seatrout, especially in the early life stages, are associated with submerged structures such as vegetation. The amount of this structure in an estuary will be a qualitattive estimate of the secondary production of the system. This same structure also provides cover for the larvae and juveniles.

Component Index Equations and HSI Determination

The HSI equation considers two life requisite components, water quality and food/cover. Water quality comprises salinity and temperature. To obtain an HSI for spotted seatrout, the SI values for habitat variables and components must be combined as follows:

Component	Equation
Water quality (WQ)	$(SI_{V_1} x SI_{V_2})^{½}$ or $(SI_{V_3} x SI_{V_4})^{½}$ whichever is lower
Food/cover (FC)	(SI_{V_5})

HSI = WQ or FC, whichever is lower

The water quality value is determined by calculating separate salinity and temperature values. It is assumed that there is no compensatory relationship between salinity and temperature and that the lowest value therefore limits water quality.

The relative importance of the water quality and food/cover components to the potential of a particular habitat to support spotted seatrout is not known. The model assumes that either component can act as a limiting factor. Therefore, the HSI for spotted seatrout in estuarine habitats is determined by the value of whichever component--water quality or food/cover--is lower.

Suitability indices, component indices, and habitat suitability index values have been generated by using the equations for four sample data sets (Table 3). Data set 1 represents conditions where all habitat variables are optimum for spotted seatrout; data set 2 a situation where temperatures significantly affect habitat suitability; data set 3 a situation where salinities are limiting; and data set 4 a situation where inadequate food/cover severely limits habitat potential.

Field Use of the Model

Model precision and accuracy will vary according to the level of input (variables) detail. The level of detail depends on the availability of time and money, which will also vary according to the particular application. Detailed evaluation of all variables yields the most reliable HSI values. However, the use of previously reported data usually yields satisfactory results with relatively little expense. The necessary data can be frequently gathered from published or unpublished resource agency sources (Table 4).

Average values have been used for some model variables. The literature suggests that the tolerance of spotted seatrout to changes in temperature and salinity depends on the rapidity of the change. Caution should therefore be used in calculating average values for waters where variability is extreme.

Table 3. Calculations of the suitability indices (SI) for habitat variables, component indices for water quality (WQ) and food/cover (FC), and habitat suitability indices for three hypothetical data sets using the spotted seatrout habitat variables (V) and HSI model equations.

Model component	Data set 1 Data	Data set 1 SI	Data set 2 Data	Data set 2 SI	Data set 3 Data	Data set 3 SI	Data set 4 Data	Data set 4 SI
V_1	20 ppt	1.00	22 ppt	1.00	8 ppt	0.21	25 ppt	1.00
V_2	32 ppt	1.00	34 ppt	1.00	43 ppt	0.29	35 ppt	1.00
V_3	21° C	1.00	10° C	0.38	20° C	1.00	20° C	1.00
V_4	29° C	1.00	35° C	0.62	30° C	1.00	30° C	1.00
V_5	63%	1.00	50%	1.00	82%	1.00	0%	0
WQ	1.00		0.48		0.25		1.00	
FC	1.00		1.00		1.00		0	
HSI	1.00		0.48		0.25		0	

Table 4. Suggested techniques for measuring variables in estuarine habitats for application in the spotted seatrout HSI model.[a]

Habitat variable	Technique
V_1, V_2	Salinities can be determined by consulting existing data, published literature sources or, directly, by using a refractometer, a conductivity meter, or titration.
V_3, V_4	Water temperatures can be determined by consulting existing data, published literature sources or, directly, using a thermometer or temperature probe.
V_5	The amount of submerged and emergent vegetation, submerged islands, shell reefs, and oyster beds can be determined by using historical maps and information, current topographical maps and data, and aerial photographs[b].

[a]All chemical methods are described in American Public Health Association (1976) and Strickland and Parsons (1968).
[b]Aerial photographs of U.S. coastal areas are available from the Map Information Office. Geological Survey, Department of the Interior, Washington, DC.

Interpreting Model Outputs

The proper interpretation of the HSI is one of comparison. This model can be used to compare different habitats or the same habitat at different times. The higher HSI should correspond to the area that could potentially support more spotted seatrout.

ADDITIONAL HABITAT MODELS

No other habitat models for spotted seatrout exist in the literature. However, a habitat suitability index model based on life stages for the spotted seatrout was developed in conjunction with the life requisites model presented here. It was not included because it is relatively complex and additional time and money would be required for application. This model is available from the National Coastal Ecosystems Team, NASA-Slidell Computer Complex, 1010 Gause Boulevard, Slidell, LA 70458.

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A review and synthesis of existing information were used to develop a habitat model for spotted seatrout (*Cynoscion nebulosus*). The model is scaled to produce an index of habitat suitability between 0 (unsuitable habitat) and 1.0 (optimally suitable habitat) for estuarine habitat along the Gulf of Mexico and Atlantic coasts. Habitat suitability indices are designed for use with the habitat evaluation procedures previously developed by the U.S. Fish and Wildlife Service. Guidelines for application of the spotted seatrout model and techniques for measuring model variables are described.

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