The Relationship Between Protected Coastal Areas and Marine Fisheries Genetic Resources

William E. Odum
University of Virginia
Charlottesville, Virginia, USA

ABSTRACT. *The fisheries of the world appear to have reached a plateau in total annual catch between 70 and 80 million metric tons, and are unlikely to exceed 100 million tons per year in the future; between 50 and 75 percent of the commercial fish catch comes from species which utilize coastal and estuarine waters. This paper reviews the scientific evidence which indicates a strong connection between critical coastal habitats and fisheries production, discusses the need for protection of these critical habitats and reviews a few examples where protected coastal areas contribute significantly to coastal fisheries. The key to effective habitat preservation for benefit of fisheries genetic resources is to protect the complete sequence of critical habitat types encompassing the entire salinity gradient; the preservation of one type of habitat without consideration of functionally connected habitats may lead to disruptions in life-history cycles and long-term decline in fishery production.*

1. INTRODUCTION

The conventional fisheries of the world appear to have reached a plateau in total annual catch betwen 70 and 80 million metric tons (see the FAO Fisheries Statistics Yearbooks for the years 1970-80) and are not likely to exceed 100 million tons per year in the future (Ryther, 1969). There are many reasons for this apparent approach to some sort of maximum yield; these include, but are not restricted to: the establishment of 200 mile fishing zones; the increased cost of fuel; the full or overexploitation of most traditional fisheries (e.g. the Peruvian anchovetta); and the pollution, degradation, or loss of critical coastal habitat.

The relative importance of critical habitat loss to the world fisheries catch has not been well documented. There is no doubt that serious alteration of many coastal areas has caused fisheries to decline locally. It is difficult to demonstrate conclusively whether this, in turn, has affected the world fish catch significantly. The circumstantial evidence, however, strongly suggests that this is an important factor and will become even more critical in the future as an expanding world human population generates increasing developmental pressure on coastal regions.

We know that between 50% and 75% of the world commercial fish catch comes from fish and shellfish species which utilize coastal and estuarine waters (FAO, 1980). Further, we know that most of these organisms utilize a variety of critical, shallow-water habitat types (e.g. seagrass beds, coastal marshes, mangrove swamps, mudflats, etc.) during some stage of their life history. Finally, it is increasingly obvious that much of this critical habitat is threatened with serious alteration or destruction. For example, Krishnamurthy and Jeyaseelan (1980) report that most of the mangrove swamps of India have been destroyed or altered to the extent that prawn production has been seriously reduced.

In this paper, I briefly review the scientific evidence which indicates a strong connection between critical coastal habitat and fisheries production. Second, I discuss the need for protection of this critical habitat. Finally, I review a few examples where protected coastal areas contribute significantly to coastal fisheries. Both scientific evidence and examples come largely from the American literature since I have the greatest familiarity with these sources. This basic information, however, should apply in principle to all regions of the world.

2. IMPORTANCE OF COASTAL AND ESTUARINE AREAS TO FISHERIES

The fisheries and shellfish of coastal and estuarine waters fall into two general groups: permanent residents; and non-permanent residents or visitors. Typically, the permanent residents are smaller, feed on smaller items, and may, in fact, function as prey for the visitors (Werme, 1981). The visitor group includes species which visit shallow water and estuaries largely on feeding forays (e.g. mackerel *Scombrus* spp.) and species which use the estuary for extensive periods of their life cycles (e.g. menhaden *Brevoortia* spp.). Since the permanent residents function primarily as forage (exceptions include oysters and scallops), this discussion will concentrate on the species which visit estuaries for a portion of their life cycles. It is this group of estuarine-dependent organisms which provides much of the world's commercial and sport fishery catch.

2.1. A gradient of conditions

Fundamental to an understanding of the life history cycles of the estuarine-dependent species is an appreciation of the biological needs of the organisms and the gradient of physical conditions which exist in estuaries. Typically these organisms, are spawned offshore and move into coastal waters and estuaries as postlarvae or early juveniles. Their two principal needs are food and protection from predation. As they enter the lower portion of the estuary, they encounter a gradient of conditions (Fig. 1) which ranges from near-oceanic salinities at the mouth of the estuary to freshwater at the head. Other factors such as sediment type, oxygen content of the water, and dissolved nutrients may vary along the same gradient (see Odum *et al.*, in press; Morris *et al.*, 1978).

As the postlarvae and juveniles move into the estuary, each species selects an optimal salinity regime and an optimal type of habitat (i.e. mud flats, marshes, sea grass beds, etc.). In general, there is a movement preferentially into low salinity areas first (Wagner, 1973; Chambers, 1980), although this is not the case with all species. The low salinity end of the estuary, encompassing the oligohaline and tidal freshwater zones, offers protection from many predaceous species which are unable to penetrate these regions due to an inablility to osmoregulate at such low salinities.

As a result of salinity gradient selection, the juveniles of many species are preferentially scattered along the gradient of salinity (Fig. 2) over distances as great as 100 km or more. Relative position along this gradient may change daily or seasonally in response to variations in freshwater runoff, food availablility, or the age of the fish. As the fishes mature, there is a general movement downstream into higher salinity regions of the estuary. For this reason, the highest numbers of postlarval and juvenile fishes are found at the low salinity end of the gradient and the highest biomass at the higher end of the gradient (Wagner, 1973). This pattern reflects the occurrence of large numbers of the very small fishes at the low salinity end and smaller numbers of older, larger juveniles at higher salinities.

2.2. Critical habitat

Coupled with the selection of a preferred salinity regime by postlarval and juvenile fishes and shellfish is the choice of suitable habitat. Each species has characteristic requirements including substrate type, water depth, water clarity, dissolved oxygen content, and type of structure (e.g., mangrove prop roots, marsh grass, or seagrass stems). This means that for each species there exists one or more types of "critical habitat" which are necessary during different stages of the life cycle.

Examples of critical habitat (Fig. 1) include, but are not restricted to: intertidal (low) marshes; high marsh tide pools; mangrove swamps; swamp and marsh creeks; mud and sand flats; passes or openings to the open ocean; open beaches; seagrass beds; macroalgae (e.g. kelp) beds; rocky shores and tide pools; and many types of coral reefs ranging from patch reefs to extensive barrier reefs. Each of these has a characteristic fish and invertebrate fauna made up of resident and visiting species; each performs an important nursery function for specific life history stages of certain species.

2.3. Examples of species use of salinity zones and critical habitat

A clearer picture of the relationship between life histories, position in the salinity gradient, and critical habitat can be gained with several examples. Weinstein *et al.*, (1980) describe the use of the estuary by two fishes, spot *Leiostomus xanthurus*, and croaker *Micropogonias undulatus*. Both fishes move up the estuary as postlarvae into low salinity or tidal freshwater. The croaker generally remain in deeper channels and small tidal rivers while the spot move into shallow water along the fringes of marshes and tidal creeks. As they grow, both species gradually move downstream into higher salinity water where they reside in seagreass beds and other vegetated habitat. Finally, as adults they migrate just beyond the mouth of the estuary to spawn, and the cycle repeats itself.

This is a common type of life history pattern in which the postlarvae and juveniles utilize a variety of low- and medium-salinity zones and move out of the estuary to spawn. In the process they may inhabit as many as 8-10 different types of critical habitat for periods of time ranging from a few hours to many months. On the east coast of the United States, organisms utilizing this life history pattern include: shrimp *Penaeus* spp.; the blue crab *Callinectes sapidus*; the mullet *Mugil cephalus*; and the Atlantic menhaden *Brevoortia tyrannus*.

The gray snapper *Lutjanus griseus* follows a somewhat different pattern (Stark and Schroeder, 1971). As shown in Figure 3, the young are spawned on the ocean-side of coral reefs. After about two weeks the postlarvae move inshore into seagrass beds where they find suitable food (small crustaceans) and protection. When the juveniles reach a length of approximately 70 mm, they move further inshore into the mangrove prop root habitat; they may move upstream into low salinity reaches or remain in relatively high salinity coastal water. As maturing adults they move back to the reef and eventually spawn. After spawning, certain adults remain on the reef and others return to the inshore mangrove prop root habitat. Not only does this species utilize several areas of critical habitat in succession, but they may move back and forth between habitat types on a diurnal basis. For example, the larger juveniles, which have moved to the mangrove prop root habitat, remain among the prop roots only during the daytime and rove through the seagrass beds at night in search of food. As a result, the prop root habitat provides protection and some food, while the grass beds supply the remainder of their food needs.

An example of an entirely different life history pattern is supplied by the striped bass *Morone saxatilus*, an anadromous species. Adult striped bass move upstream into tidal freshwater to spawn. The larvae and young juveniles remain in tidal freshwater before gradually moving downstream to higher salinities. Throughout this period they utilize a variety of habitats including submerged grass beds, marsh edges and creeks, and main river channels.

In these cases and many more, a pattern emerges of multiple habitat usage. No single community can be identified as "the critical habitat." No single salinity zone is of over-riding importance. Instead, the entire freshwater-estuarine-coastal gradient performs an important nursery function.

2.4. Correlations between critical habitat and fishery production

Because of these patterns of life history usage, certain sections of estuarine and coastal waters have far greater densities of fishes and invertebrates than other sections. For example, the shallow waters along the edges of marshes, including tidal creeks, have far more organisms present than nearby deeper water (Weinstein, 1979; Shenker and Dean, 1979; Bozeman and Dean, 1980). Similarly, mangrove swamps support large populations of fishes and invertebrates (see Odum *et al.*, 1982). Day *et al.* (in press) found that fish biomass was 6.8 to 11.5 times greater in shallow water marsh areas compared to adjacent open water.

Following this line of reasoning, it becomes apparent that regions with large expanses of critical habitat should produce greater amounts of fishery organisms than regions with little critical habitat. Consider, for example, the location of many of the world's principal fishing grounds. Commonly, these lie in close proximity to coastal areas with extensive marshes, mangrove swamps, and seagrass beds. In the Gulf of Mexico, the valuable Tortugas shrimp fishery lies adjacent to the mangrove swamps of the Everglades and the seagrass beds of Florida Bay; both areas function as nursery areas for post-larval and juvenile shrimp.

Further north, the rich finfish and shrimp fisheries of Louisianna are located near vast expanses of coastal marshes; Day *et al.* (in press) have shown that the marshes serve as nursery areas for most of the fish and invertebrates caught offshore. Sabins and Truesdale (1974) demonstrated the importance of coastal "passes" or gaps between barrier islands as routes by which these organisms migrate offshore as adults and inshore as postlarvae and juveniles.

In the same region (Louisianna and Texas), Moore *et al.* (1970) found that the greatest populations of fishery organisms occur offshore from areas of high freshwater input (creating a strong salinity gradient as shown in Figure 1) and large areas of coastal wetlands. Turner (1977) found a high correlation between shrimp yield (kg/ha) and intertidal wetland area on a world-wide basis. In the northern Gulf of Mexico, he found that yields of inshore shrimp are directly related to the area of estuarine vegetation.

To summarize, the evidence, although circumstantial, overwhelmingly supports the link between the presence of critical habitat (marshes, mangrove swamps, etc.) and high fishery production.

3. THE NEED TO PROTECT CRITICAL HABITAT

If we accept the premise that critical habitat and fishery production are intimately linked, what happens if the former is removed through some act of man? The answer, once again circumstantial, is that fishery production declines. As an example, Krishnamurthy and Jeyaseelan (1980) report that the prawn production from a partially protected Indian mangrove swamp was estimated to be 110 kg/ha/year; fish production was 150 kg/ha/year. In a nearby estuary where the mangroves were damaged or removed, prawn production was 20 kg/ha/year and fish production 100 kg/ha/year. Odum (1970) reports several cases from Florida in which sport and commercial fisheries declined after destruction or removal of mangrove forests and seagrass beds.

There are many other examples, mostly with circumstantial, *post hoc* data, which indicate that the consequences of critical habitat destruction is a decline in fishery landings. This evidence suggests that protection of critical habitat is essential to maintenance of many coastal fisheries. This is often a challenging task.

One of the great difficulties in attempting to preserve habitat such as marshes, mangroves, and seagrass beds in support of fisheries, is that so many locations and types of habitat are involved. As shown in an earlier

section of this paper, most species utilize a variety of critical habitats during their life cycle; gray snapper use coral reefs, seagrass beds, and mangroves; striped bass need tidal freshwater channels and marshes along with higher salinity estuarine marshes, rivers and seagrass beds.

Proper management of striped bass may involve preservation, or at least protection, of a salinity gradient which may be in excess of 100 km in length in places such as the Potomac River. Wise management of gray snapper involves habitat many kilometres apart and at varying distances from shore. Individual pieces of critical habitat may lie in different political jurisdictions, even different countries.

4. STRATEGIES FOR PROTECTION AND PRESERVATION

Basically, there are three strategic approaches which can be followed in attempting to manage coastal habitat for fishery resources; each approach is significantly more difficult to implement than its predecessor.

The first and simplest approach is to protect the fishery organisms while they are located in critical habitat and while they exist at key life history stages. For example, in the southeastern United States, most states protect juvenile shrimp (*Penaeus* spp.) while they are within protected estuarine waters adjacent to marshes, mud flats, and mangroves. Shrimp fishing is either severely limited or totally excluded until the shrimp migrate through the passes between barrier islands and move offshore. This not only protects the shrimp while they are too small for effective marketing, but protects seagrass beds, mud flats, and other fragile habitats. Another example of this minimal approach to management is the attempt by the state of Maryland to protect adult migratory striped bass *Morone saxatilis* in tidal freshwater during the critical period for spawning. Recent evidence suggests that this has resulted in much higher recruitment of juveniles and may help a long-suffering fishery to partial recovery. These are examples of a management approach which is relatively easy to implement and, may be effective in a limited way, but does not protect the habitat upon which the fishery organisms depend for food and protection.

A second approach is to protect specific types of habitat. For example, in the state of Florida, a large stretch of healthy coral reef was preserved as the John Pennecamp Coral Reef State Park. Destruction of the reef was prohibited along with underwater spear fishing; recreational diving and hook and line fishing were permitted. The result of this action was that the reef remains in a reasonably healthy state and supports a high level of recreational activity. The weakness of the plan is that nearby seagrass beds and mangrove-lined shorelines were not preserved. Since many of the reef fishes use both these habitat types as nursery and feeding areas, their populations were not totally protected.

The third and optimal approach is to protect all habitat types along the salinity gradient shown in Figure 1. This holistic or ecosystem approach has the obvious advantage of encouraging the success of all life history stages and providing a reasonably steady, long-term fishery production. From a pragmatic and political standpoint, it is often impossible to create a preserved area which encompasses such a great area. I feel that this third approach, however, should be the primary objective in the management of coastal habitat for fishery resources.

5. EXAMPLES OF HOLISTIC HABITAT PRESERVATION

The state of Florida provides several useful examples of large-scale, holistic preservation. Although the Pennecamp Coral Reef Park proved to be too restricted in size, subsequent state legislation has provided reasonably strict protection of both seagrass beds and mangrove-lined shorelines throughout the state of Florida. The Everglades National Park was established in south Florida in 1947 and currently encompasses more than 500,000 ha of land and water. Although much of this area is composed of upland plant communities, a significant portion is mangrove, seagrass bed, or coastal marsh. All of these habitat types provide nursery areas for the extensive commercial and sport fisheries which operate in contiguous coastal waters. The great strength of the Everglades National Park is that it includes almost the entire gradient from upland freshwater, through the estuary, and offshore for many kilometres. The nearby Biscayne National Monument similarly includes coastal wetlands and mangroves, seagrass and macroalgae beds, barrier islands and passes, and offshore coral reefs. This means, for example, that the gray snapper *Lutjanus griseus*, which was discussed in an earlier section, is protected (except for hook and line fishing) at all points in its life history (i.e. offshore coral reefs, seagrass beds, and mangrove prop root habitat).

Unfortunately, there are factors which cannot be totally controlled, even in a preserved area as large as the Everglades National Park. For example the watershed draining into the park extends far beyond the park boundaries. This means that activities outside the park, but within the watershed, may have serious effects within the park. For example, irrigation, water diversion, and introduction of pollutants may have negative impacts on the park, but still be beyond the control of park managers. Fish and shrimp populations within the Everglades estuary fluctuate in response to annual patterns of freshwater inflow. Without control of this inflow, it is impossible to completely protect and manage these fishery resources.

The conclusion to be drawn from the Everglades National Park is that no matter how large and seemingly complete a preserved area may appear, there will always be larger scale influences which affect resources within

the park. In short, these managed areas are not closed ecosystems and will always be subject to effects from adjacent unmanaged ecosystems.

There is one interesting example in the United States of an attempt to preserve and manage almost all the land and variables affecting a coastal ecosystm. The Apalachicola River and Bay Sanctuary is a joint project by both federal and state (Florida) governments to protect a barrier island, bay, estuary, and river complex (Livingstone, 1981). The sanctuary, consisting of about 80,000 ha, was set aside for a long-term scientific and educational purposes. In addition, this estuarine complex provides between 80% to 90% of the oysters harvested in Florida and functions as a nursery area for many finfish and crabs which are caught in nearby coastal waters. This is certainly an example of holistic preservation since not only coastal habitat is preserved but also bottom-land hardwood forests and freshwater habitat for many kilometres upstream. Unfortunately, not even this sanctuary is complete, since the rivers feeding the Apalachicola estuary originate more than 500 km inland.

Large, holistic preserved areas supporting coastal fisheries are by no means restricted to the United States; a number of examples exist in other parts of the world. In almost all of these cases, a multiplicity of habitat types have been preserved, but all are subject to adverse external influences. It seems that totally holistic habitat preservation is not feasible from a pragmatic and political standpoint; however, attempts to protect and manage complete sets of critical coastal habitat can be successful and are reasonably common.

6. CONCLUSIONS

In this paper I have attempted to demonstrate the connection between different types of coastal habitat and the complex life history stages of most coastal organisms of commercial interest. I have emphasized that preservation of one type of habitat, for example a reef, without thought to functionally connected habitat such as seagrass beds or mangrove forests, may lead to disruptions in life history cycles and long-term declines in fishery production.

The key to effective habitat preservation is to protect the complete sequence of critical habitat types encompassing the entire salinity gradient. Although this is often difficult to accomplish, particularly in areas with dense human populations, there are numerous successful examples from many parts of the world. The one step which seems virtually impossible and impractical is to preserve such an extensive tract of land that deleterious external influences are totally excluded.

Acknowledgements

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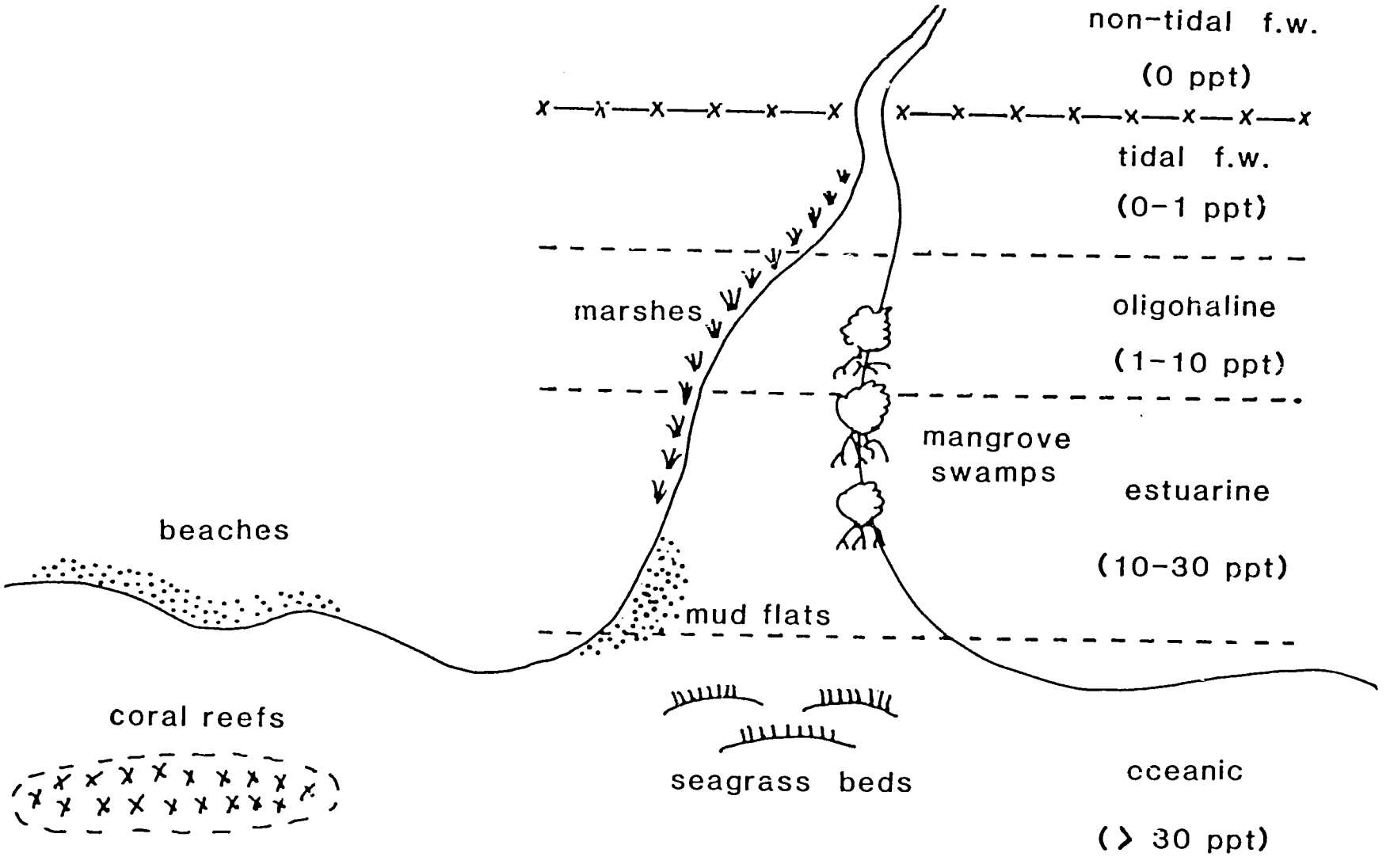

Figure 1. A schematic representation of the salinity gradient from nontidal freshwater to oceanic conditions. Salinity zones are shown in parts per thousand (ppt). Critical habitat types are depicted at characteristic locations.

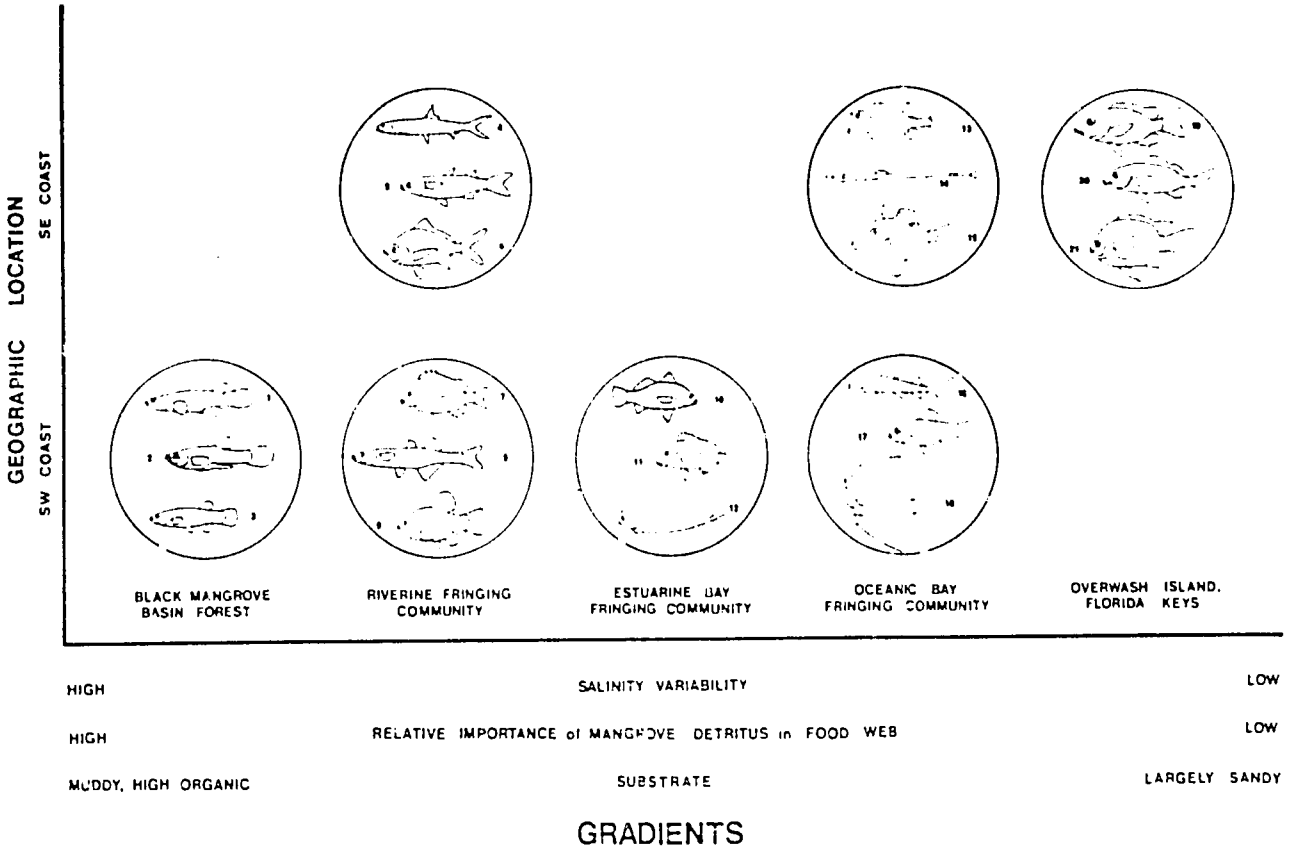

Figure 2. Gradient of mangrove-associated fish communities showing representative species from south Florida. 1 = rivulus, 2 = mosquitofish, 3 = marsh killifish, 4 = lady fish, 5 = striped mullet, 6 = yellowfin mokjarra, 7 = juvenile sheepshead, 8 = tidewater silversides, 9 = sheepshead minnow, 10 = silver perch, 11 = pigfish, 12 = blackcheek tonguefish, 13 = scrawled cowfish, 14 = fringed pipefish, 15 = fringed filefish, 16 = lemon shark, 17 = gold spotted killifish, 18 = southern stingray, 19 = juvenile schoolmaster snapper, 20 = juvenile tomtate, 21 = juvenile sergent major. Based on drawing by Carole McIvor published in Odum *et al.* (1982).

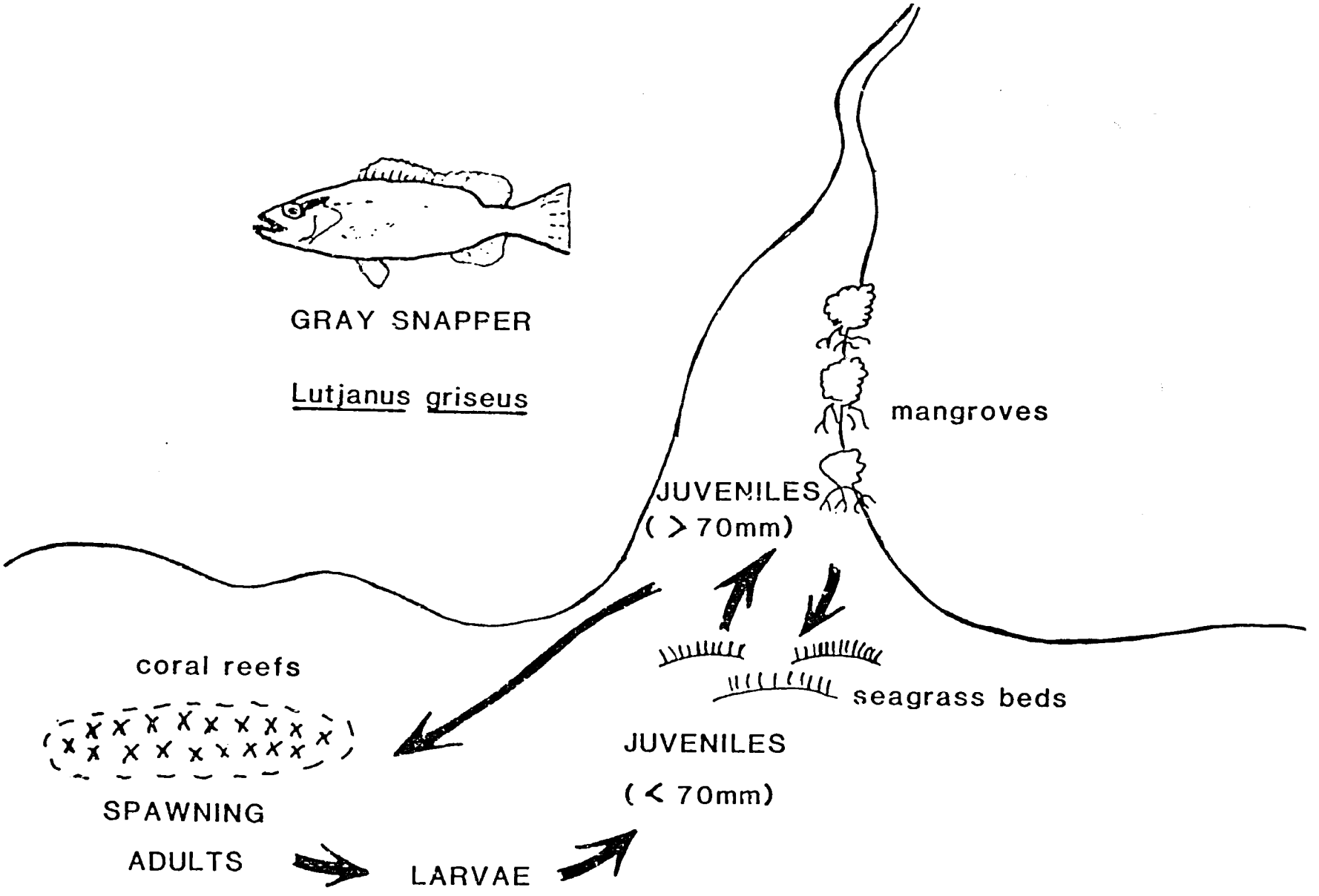

Figure 3. Schematic representation of the salinity gradient and location of different life-cycle stages of the gray snapper, *Lutjanus griseus*. Based on Stark and Schroeder (1971).