Observations on The Sensitivity of Queen Conch to Water Quality: Implications For Coastal Development

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ABSTRACT

The queen conch (*Strombus gigas*) supports the second-most valuable demersal fishery in the Caribbean region. As fishing pressure has increased, local conch populations have declined, resulting in the imposition of strict harvest regulations. In Florida, the recreational queen conch fishery was closed in 1986 in response to concerns about the depleted stock. Our observations in the laboratory and field suggest that anthropogenic activities may adversely affect queen conch viability. In the laboratory, growth rates and densities of conch larvae were enhanced by ozonation of seawater, which increases the oxidation-reduction potential (ORP) of seawater. Low ORP is indicative of increased eutrophication. Additionally, field studies suggest that eutrophication may negatively affect conch reproductive potential. In Florida, adult conch spawn only in offshore regions and are isolated from adult conch in nearshore areas by a deep-water channel that has unsuitable benthic habitat. Anecdotal reports indicate, however, that conch recently spawned in nearshore locations. Histological examinations showed deficits in the condition of gonads from nearshore females and males relative to the gonads in their offshore counterparts. This evidence, coupled with the well-documented nutrient gradients from nearshore to offshore, suggest that conch spawning populations may be adversely affected by eutrophication.

As the south Florida and Caribbean human populations expand, so too will the burden on the marine resources resulting in the inevitable conflict between users of those resources and promoters of coastal development. If Caribbean conch fisheries are to remain viable and if the Florida fishery is to reopen, it is critical that an accurate assessment of the potential effects of these activities on queen conch populations is conducted.

KEY WORDS: Pollution, reproduction, *Strombus gigas*

INTRODUCTION

The queen conch (*Strombus gigas*) supports the second-most valuable, single-species fishery in the Caribbean region, with an annual harvest worth an estimated U.S. $40,000,000 (Appeldoorn, 1994). As a result of increased fishing pressure, local conch populations have declined, and strict harvest regulations have been imposed throughout the region. In the 1980's, the Convention on International Trade in Threatened and Endangered Species (CITES) listed queen conch as commercially threatened. This status was further downgraded in 1992 when the species was listed in Appendix II of CITES. This listing recognized that the survival of the species is predicated upon well-conceived management strategies. Many nations now have strict regulations regarding the harvest of conch in order to preserve their stocks. Appeldoorn (1994) reported that conch stocks in 8 of 14 nations were overfished and several others were approaching that status. In south Florida, queen conch populations have declined dramatically since the mid-1960s (Stevely and Warner, 1978) and have not recovered on their own despite a moratorium on harvest enacted in 1985 (Glazer and Berg, 1994; Berg and Glazer, 1995; Glazer and Anderson, in press).

In 1990, the Florida Keys National Marine Sanctuary and Protection Act (Public Law 101 - 605) was enacted. It resulted, in part, from documented declines in water quality in the Florida Keys (National Oceanic and Atmospheric Administration, 1996). Since the establishment of the Sanctuary, more evidence has emerged linking the degradation of critical habitats to declines in water quality. The water-quality deterioration has been attributed to various causes, including sewage effluents (LaPointe *et al.*, 1990), fertilizer runoff from agriculture in south Florida (Tomasko and LaPointe, 1994), pesticides used in mosquito control (Bird *et al.*, 1996), oil discharges from ships traversing the Florida Keys (Romero *et al.*, 1981; Zheng and Van Vleet, 1988), and diverted water flow from the Everglades (Fourqurean *et al.*, 1993).

The adverse effects of these activities on marine organisms are well documented (*vide* Kennish, 1997). The responses of molluscs to these stressors include retarded growth, depression of gametogenesis, cell lysis, mantle recession, and atypical shell development (Sindermann, 1996). Research has focused on the chronic exposure of larval molluscs, including the American oyster (Calabrese *et al.* 1973) and periwinkles (Dixon and Pollard, 1985), to pollutants. Recently, the emphasis for this research has shifted to endocrine disruption and the effects of environmental perturbations on spawning activity in temperate species. Reed (1993) suggested that chemical exposure may have been responsible for the masculinization of females and deformities in males of the fighting conch (*S. pugilis*) and queen conch (*S. gigas*). The effects on larval strombids of chronic exposure to pollutants has not been documented.

This paper presents the results of more than a decade of laboratory and field observations on the health of larval and adult queen conch in relation to water quality. Two pieces of evidence are presented that suggest that queen conch are adversely affected by poor water quality. The first is derived from observations in our hatchery of the relationship between larval development and water quality. The second comes from field observations of the differences between the spawning behavior of adult conch in nearshore and that of offshore regions of the Florida Keys. Results of the histological examination of tissue sections of gonads from conch specimens collected from these two regions are presented. The implications for coastal development are discussed.

METHODS AND RESULTS

Larval observations

The Florida Department of Environmental Protection conch research hatchery was constructed in 1990 at the Keys Marine Laboratory on Long Key in the Florida Keys, U.S.A. Larval and juvenile conch are cultured at the hatchery from eggs collected from wild females following standard procedures adapted from Davis (1994). All seawater used at the facility is obtained from Florida Bay.

Conch larvae are cultured in 836-liter tanks with an integrated flow-through design. Prior to 1992, all seawater was filtered to a minimum of 5 µm and was sterilized with ultraviolet light. Since 1992, we have been treating the incoming seawater with ozone. The ozonation system was described in detail by Glazer *et al.* (1997). Ozone injection is controlled by instruments that measure the oxidation-reduction potential (ORP) of the seawater in millivolts (mv). The injection of ozone is set to produce seawater having ORP of approximately 395 mv. The redox potential of raw seawater delivered to the hatchery fluctuates between 150 mv and 240 mv.

Over a seven year period, we observed that the growth rates of conch larvae raised in non-ozonated seawater were lower than those of larvae cultured in ozonated water. Larval growth ceased altogether whenever ozonation was interrupted by failures in our water treatment systems. Rapid growth did not resume for approximately five days after ozonation was restarted. In many cases, it took more than 40 days for larvae in non-ozonated water to reach metamorphosis whereas it took approximately 24 days in ozonated seawater (Figure 1).

Larval densities were also affected by reduced ORPs. In non-ozonated cultures, maximal densities were approximately 0.5 - 1 individual per liter at metamorphosis; higher densities resulted in deceleration or cessation of growth rates. In contrast, those cultures in ozonated seawater had maximal larval densities of 10 - 20 individuals per liter at metamorphosis.

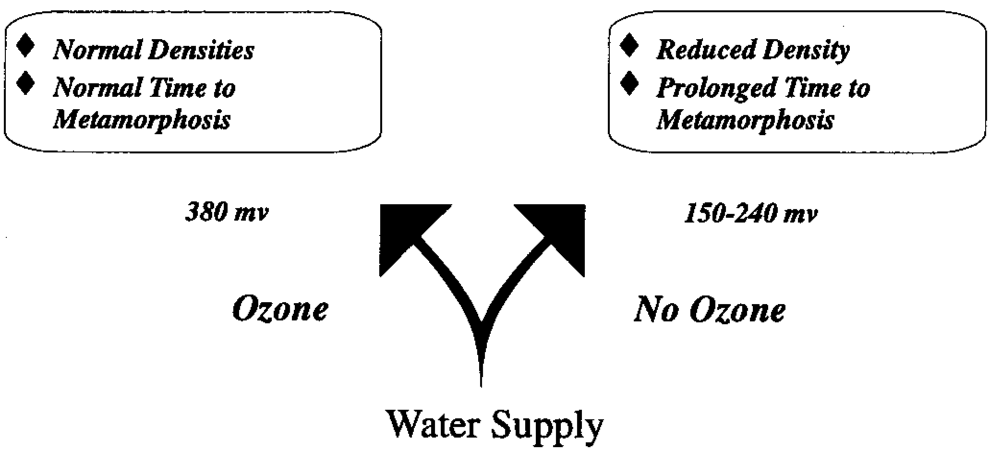

Figure 1. The effects of seawater treated with ozone on the culture of queen conch larvae at the Florida Department of Environmental Protection's queen conch hatchery on Long Key, Florida.

Field Observations/Histological Examinations

In Florida, adult conch populations occur in two distinct and isolated regions: nearshore and offshore (Figure 2). Conch in these two locations are physically isolated from each other by Hawk Channel, a deep-water, silt-laden barrier. While larval exchange may occur, our surveys have indicated that juveniles and adults do not traverse the barrier because of the suboptimal benthic habitat within the channel.

Field observations of adult queen conch and preliminary evidence from histological examination of the gonads suggest that reproduction may be adversely affected in inshore waters. Since 1996, we have conducted more than 400 surveys of the nearshore areas and have seen no evidence of conch spawning in these areas. Anecdotal reports indicate, however, that conch spawned relatively recently in these locations (B. LaPointe, Harbor Branch Oceanographic Institution, personal communication, 29 April 1998). However, egg production now occurs exclusively offshore.

We examined gonadal tissue histologically from a few adult conch specimens collected from offshore and nearshore areas to determine if spawning deficits in nearshore conch may be driven by behavioral or physiological factors. Presumably, if gonadal development was deficient in the nearshore conch, physiological rather than behavioral processes could be to blame. Two adult females and one adult male conch were collected from an offshore site at Alligator Reef on 31 May 1996. An additional two females and one male were collected from Tingler's Island (nearshore) on 4 June 1996. The gonads were surgically removed and fixed in 4% formaldehyde in 0.1 M phosphate buffer (pH = 7.4). The samples were shipped to the Florida Marine Research Institute laboratory in St. Petersburg for processing and interpretation. Tissue sections were taken at distal, central, and proximal locations in the gonads. Tissues were dehydrated in a graded ethanol series, infiltrated, and embedded in glycol methacrylate resin (JB-4®). Tissue sections 3.5 µm thick were cut using an LKB Historange microtome and stained with thionin or periodic acid-Schiff's/hematoxylin/metanil yellow.

There were marked differences between the reproductive condition of females collected from offshore and those from nearshore aggregations (Figure 3). Microscopic examination of the gonads from nearshore females revealed little polysaccharide deposition (weak PAS staining) in the signet tissue. Oocytes were either absent or in the process of resorption. There was, however, significant mitotic activity in the poorly developed follicles. No signs of disease or heavy parasitism were evident. The offshore females had well-developed oocytes, an indication of ripening gonads, and a strong PAS-positive staining reaction in the signet tissue.

The gonads were also underdeveloped in the male collected nearshore.

Signet tissues were spent, as evidenced by the weak PAS-positive staining of polysaccharides, which are utilized for energy. Male follicles from the specimen collected offshore were filled with both apyrene and eupyrene sperm. Signet tissues had a strong PAS-positive staining reaction.

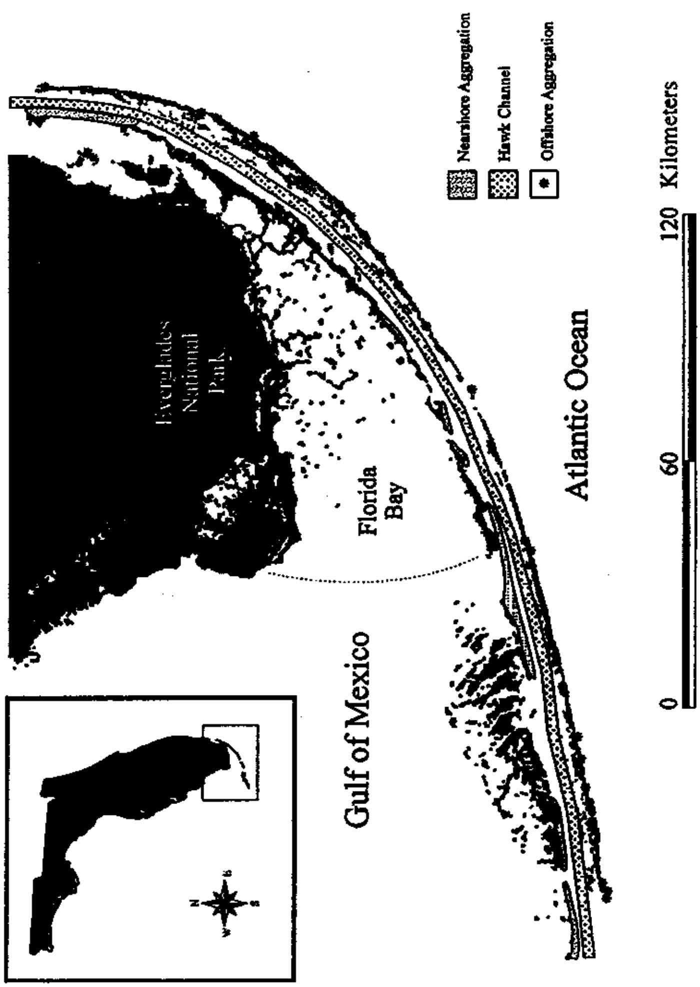

Figure 2. Queen conch distribution within the Florida Keys region. Nearshore, non-spawning populations are indicated with stipples. The offshore, spawning aggregations are indicated with asterisks. The two populations are isolated by Hawk Channel which is indicated with the cross-hatches.

Figure 3. Sections of gonads of adult queen conch collected from nearshore (left) and offshore (right) aggregations. Top left: female collected near shore; note the large signet tissue (st)-to-follicle (small arrow) ratio. Insert: undeveloped follicle. Top right: Oocyte (o)-filled follicles (small arrow) in a reproductive female collected offshore; note the small signet tissue-to-follicle ratio. Bottom left: Poorly developed follicles (f) in the gonad from a male specimen collected nearshore. Insert: sperm (arrow head) and spermatogonia (¿) inside a follicle. Bottom right: Apyrene and eupyrene sperm in gonadal follicles (f) of a reproductive male collected offshore. Scale bars: large = 200 μm, small = 20 μm.

DISCUSSION

Despite the economic importance of queen conch to the Caribbean region, nothing is known about the effects of anthropogenic activities on queen conch larvae and adults in the wild. Eutrophication of nearshore waters may directly and indirectly affect conch abundance and distribution in Florida. Our laboratory observations indicate that poor water quality adversely affects queen conch larvae. The reproductive condition of nearshore adult specimens may also be affected. We realize, however, that our results must be interpreted as preliminary because directed investigations were not conducted. Further work needs to be carried out to confirm the linkage between water quality and queen conch health.

Our experience with laboratory larval cultures of conch suggests that water quality has a direct effect on larval condition. Our observations indicate that larvae grow better and can be cultured at higher densities in water that more closely resembles seawater found in offshore locations than in water that resembles seawater from nearshore areas. Low seawater oxidation-reduction potentials (ORP) are commonly found in nearshore waters in the Florida Keys. ORP measures the dissolved organic chemicals in the water and is related, in part, to nutrient discharge from point and nonpoint sources. Low ORP conditions are common in nutrient-rich waters, whereas tropical oceanic waters have relatively high ORP values. Water supplied to our hatchery from a Florida Bay source typically has ORP values ranging from 150 mv to 240 mv, whereas seawater at offshore reefs (*e.g.*, Looe Key) has ORP values approaching 400 mv.

The use of ozone, a highly reactive oxidant, to increase ORP levels of hatchery seawater to 400 mv has resulted in dramatically increased growth and survival of cultured larvae. Because ozone in seawater oxidizes organic chemical species, heavy metals, and pesticides by a complex process that ultimately removes these compounds from the water (Dore *et al.*, 1980; L'Hopitault and Pommery, 1982), we are suggesting that the removal of one or more of these chemicals is responsible for the increased health of the larvae. Both dissolved organic materials and pesticides may be present in the nearshore waters of the Florida Keys because of sewage discharge and the aerial application of pesticides for mosquito control.

The primary mechanism for sewage discharge in the Florida Keys is via permitted leach fields, numerous unpermitted cesspits, commercial discharges into minimum injection wells, and the discharge of secondary treated sewage by the City of Key West into nearshore waters. Recent studies have begun addressing the effects of these discharges on waters of the Florida Keys (Lapointe *et al.,* 1990; Lapointe and Clark, 1992; Szmant and Forrester, 1996). The fate of the associated nutrients in the environment is unknown; however, researchers from several organizations are currently studying the mechanisms that may influence nutrient transport.

Pesticides are used extensively as a method to control mosquito populations in the Florida Keys. Protocols for aerial application of pesticides in the Florida Keys require spraying methods that ensure that only targeted areas receive the pesticide application. Aerosol deposition and drift over non-targeted areas, however, is not uncommon (Bird *et al.*, 1996; Pierce *et al.*, 1996). Drift is an even greater concern now that ultra-low volume spraying (ULV) has been incorporated into the mosquito control program. A growing body of literature describes the toxicity of pesticides to a wide variety of invertebrates and vertebrates. Studies have generally focused on juvenile and adult stages of the test organisms (*sensu,* Müller and Lloyd, 1994), with emphasis on the chronic effects of pesticide exposure on the endocrine system and, consequently, on fecundity and reproduction (*vide* Kristensen, 1994; Müller and Lloyd, 1994). Unfortunately, few studies have been conducted on embryos and early-life-history stages of marine organisms despite the hypersensitivity of embryos to a wide range of chemicals (Kristensen, 1994). Before conch health can be linked to pesticide use, the distribution and fate of pesticides in nearshore waters must be better understood. Also, directed studies must examine the effects of acute and chronic toxicity of these chemicals on larval and adult queen conch.

The poor quality of nearshore waters may affect the development and condition of larval conch. Stoner *et al.* (1996) reported that larval abundances in nearshore waters in Florida were an order of magnitude lower than in offshore waters during two separate years. The higher densities offshore, however, may result from the juxtaposition of the surveys to spawning aggregations in the offshore locations. In another study, Stoner and Glazer (1998) reported extreme variation in abundance of juvenile conch in nearshore nurseries relative to offshore sites in Florida. These results may also be explained by an increase in larval mortality due to water quality degradation inshore. Recruitment success, localized current patterns, and post-settlement processes, however, may also help explain some of this variability. Directed studies are needed to help explain the role of water quality in the survival and settlement of conch larvae.

Our work, however, has revealed differences between the reproductive condition of specimens collected from inshore and that of specimens from offshore locations. Two studies have reported gradients of declining nutrient concentrations from nearshore to offshore (Lapointe and Clark, 1990; Szmant and Forrester, 1996). Lapointe and Clark (1990) also reported elevated levels of nutrients in coastal developments. An anecdotal report indicates that conch spawned recently in nearshore areas, but further studies are necessary to examine the correlation between water quality and the cessation of spawning in nearshore adult conch.

The explosive growth in the human population in the Florida Keys since the early 1950s (National Oceanic and Atmospheric Administration, 1996) is a result, in part, of increasing tourism. As the south Florida and Florida Keys human population has expanded, so too has the burden on the region's natural resources. This growth has adversely affected the Florida Keys ecosystem, and a decline in water quality is now irrefutable. The Florida Keys National Marine Sanctuary was established in part because of the deterioration of the ecosystem in the region. This deterioration also resulted in the formulation of a comprehensive management plan that specifically addresses water quality (National Oceanic and Atmospheric Administration, 1996).

As the south Florida and Caribbean human populations expand, so too will the burden on the marine resources resulting in environmental impacts to coastal waters. Inevitably, conflicts will arise between users of these resources and promoters of coastal development. Except for Barbados, the Florida Keys has the highest human population density in the Caribbean (Figure 4). Many Caribbean nations have already been affected by anthropogenic activities (Figure 5). Coastal development is fueled in many cases by tourism, which in 1994, increased in all but three of the 28 countries or island groups in the region (Anonymous, 1996). Unfortunately, tourism has been linked to environmental degradation of the coastal zone through beach erosion, sediment-laden discharges, and agriculture-based discharges (i.e., fertilizers, pesticides, and herbicides). The quality of life must be balanced with the sustainability of coastal resources. Environmentally responsible development should be encouraged through a process that integrates the interests of coastal zone and fisheries managers with those of urban developers.

Recently, initiatives have been developed to address economic and social development while protecting marine resources. In 1983, the Cartegena Convention developed a legal basis for limiting pollution in the Caribbean Sea and the Gulf of Mexico. Environmental programs have used this convention as the mechanism for establishing controls on pollution in the region. Based in Jamaica, the Assessment and Management of Environmental Pollution Program (AMEP) was developed to control and manage environmental pollution in the Caribbean as well as to assist in environmental planning of coastal zone development. A recent UNEP/USAID project (Caribbean Environment Network Project) was established to promote development of environmentally responsible tourism in the Caribbean region.

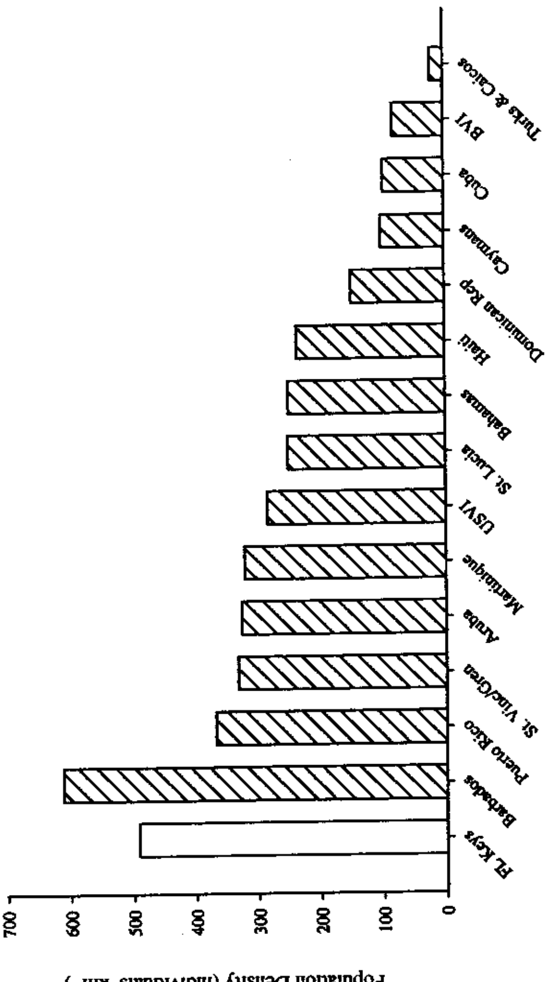

Figure 4. Human population density in the Florida Keys and the Caribbean region in individuals/km^2 (adapted from Hoagland *et al.* (1995) and National Oceanic and Atmospheric Administration (1996)).

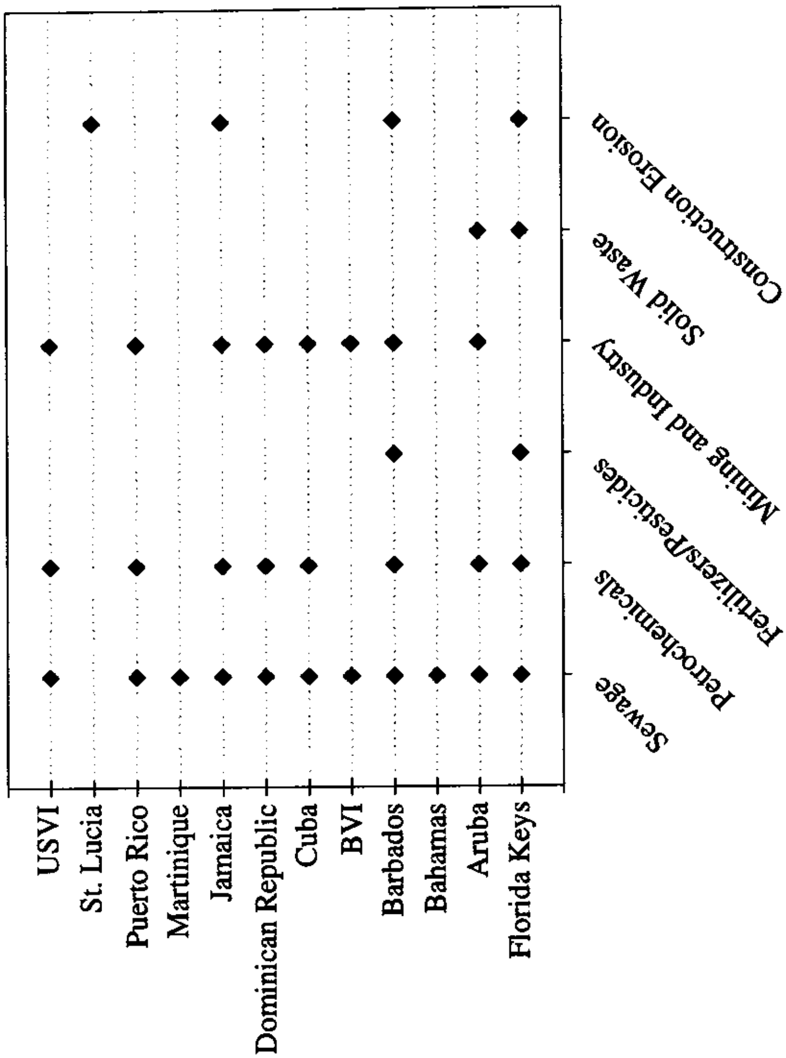

Figure 5. Sources affecting coastal resources in the Florida Keys and the Caribbean region (adapted from National Oceanic and Atmospheric Administration (1996) and Anonymous (1996).

In 1996, a regional meeting of fishery managers, biologists, and administrators was held in Puerto Rico to review queen conch management in the Caribbean. A declaration was drafted that outlined protocols and priorities for queen conch conservation. In this declaration, the regional importance of queen conch was emphasized along with the need to develop and promote regional cooperative management strategies in order to ensure the long-term sustainability of this resource. The delegates further emphasized the need to "take measures to protect critical habitats for *Strombus gigas*, including wetlands, seagrass beds, coral reefs, coastal areas, and oceanic banks from degradation" (Caribbean Fishery Management Council, 1996). If Caribbean conch fisheries are to remain viable and if the Florida fishery is to reopen, it is critical that interjurisdictional cooperative management agreements such as those developed in the Puerto Rico Declarations are encouraged and supported.

Future research initiatives must accurately assess the potential effects of anthropogenic activities on queen conch. Research by the Florida Department of Environmental Protection will continue to investigate the effects of a suite of pollutants on conch larval condition and viability. Studies will also be conducted in which conch from nearshore, non-spawning aggregations will be transplanted to the offshore spawning aggregations, and conch from the offshore spawning aggregations will be transplanted to the nearshore, non-spawning aggregations. In these studies, we hope to determine what, if any, effects the change in environment will have upon the reproductive viability of the trasplants.

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