Fishery Management Report No. 32
of the

Atlantic States Marine Fisheries Commission

Interstate Fishery Management Plan for Horseshoe Crab

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Prepared by the

Atlantic States Marine Fisheries Commission
Horseshoe Crab Plan Development Team

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EXECUTIVE SUMMARY

The horseshoe crab is a benthic or bottom-dwelling arthropod that utilizes both estuarine and continental shelf habitats. The horseshoe crab is an ecological generalist and although it is called a "crab," it is not a true crab, but rather is more closely related to the arachnids. Horseshoe crabs range from the Yucatan peninsula to northern Maine. Horseshoe crabs were traditionally used for fertilizer and livestock food in the late 1800s and early 1900s. During this period of time, harvest was substantial (over 4 million crabs were landed annually in Delaware Bay). However, evidence suggests that stocks were depleted by the 1940s and commercial harvesting of horseshoe crabs ceased in the 1960s. By the late 1970s, observations of spawning horseshoe crabs indicated that the population had substantially recovered. Recently, renewed commercial interest in horseshoe crabs has been driven by their use as bait in the American eel and conch pot fisheries, and use of horseshoe crab blood by the biomedical industry. Between 1990 and 1996, reported harvest in several states (e.g., New Jersey, Delaware, and Maryland) has increased. During this period of time, several cases of apparent localized population declines may have occurred within the Delaware Bay.

The goal of this plan is to conserve and protect the horseshoe crab resource to maintain sustainable levels of spawning stock biomass to ensure its continued role in the ecology of coastal ecosystems, while providing for continued use over time. Specifically, the goal includes management of horseshoe crab populations for their continued use by:

- current and future generations of the fishing and non-fishing public;
- migrating shorebirds; and,
- other dependent wildlife, including federally listed sea turtles.

The status of the horseshoe crab populations along the Atlantic Coast are poorly understood due to the limited amount of information collected regarding stock levels. Other than the National Marine Fisheries Service commercial landings data and trawl surveys, little information was collected until the late 1980s when independent spawning surveys and trawl surveys were initiated, primarily in the Delaware Bay. Concern over growing exploitation of the horseshoe crab resource has been expressed by state and federal fishery resource agencies, conservation organizations, and fisheries interests. Horseshoe crabs are important to migrating shorebirds that feed on the eggs; and are critical to the biomedical industry. Since horseshoe crabs are slow to mature, they are susceptible to overharvest and exploitation may adversely affect these other resources.

Currently, horseshoe crabs are commercially harvested for use as American eel, conch (or whelk), bait fish (e.g., minnows), and catfish bait along certain portions of the Atlantic coast. The horseshoe crab fishery is unique in that crabs are easily harvested during the spawning season with minimal financial expense. The eel and conch fishery is currently dependent on sustained harvest of horseshoe crabs. The eel fishery targets female horseshoe crabs with eggs, while the conch fishery uses both males and females. The reported harvest has increased dramatically in the last five years. However, improved reporting may be an important component of increased harvest records.

Horseshoe crabs are an important food source for migrating shorebirds, finfish, and Atlantic loggerhead turtles, a species federally listed as threatened pursuant to the Endangered Species Act (87 Stat. 884, as amended; 16 U.S.C. 1531 *et seq*.), which use the Chesapeake Bay as a summer nursery area. Evidence suggests that the Delaware Bay provides sea turtle nursery habitat as well. The Delaware Bay is reported to be an important breeding location for horseshoe crabs and is also the second largest staging area for shorebirds in North America.

Beach areas provide essential spawning habitat for horseshoe crab adults. In addition, nearshore, shallow water, intertidal, and subtidal flats are considered essential habitat for the development of juvenile horseshoe crabs. Deep water areas are used by larger juveniles and adults to forage for food. Of the habitats used by horseshoe crabs, beaches provide the most critical habitat as this is where spawning and egg deposition occurs. The primary threats to essential habitat include coastal erosion combined with human development (particularly shoreline stabilization structures such as bulkheads and revetments) along the estuaries of the Atlantic Coast.

In order to collect information to assist in future management decisions, a comprehensive monitoring plan must be instituted throughout the Atlantic Coast. Such monitoring efforts should be standardized and occur in *each* of the cooperating states within the Atlantic States Marine Fisheries Commission. Components of the monitoring plan include mandatory monthly reporting, continuing existing benthic sampling programs, establishing pilot programs to survey spawning horseshoe crabs and egg density, evaluating post-release mortality of horseshoe crabs used by the biomedical industry, and identifying potential horseshoe crab habitat in each state.

Each state is responsible for implementing management measures and protecting horseshoe crab habitat within its jurisdiction to ensure the sustainability of the population that either is produced or resides within state boundaries. The Management Board will develop a cap on landings for commercial bait fisheries with consideration of an effort cap during 1999, to be implemented in 2000. States are encouraged to cap landings for commercial bait fisheries in 1999. The States of New Jersey, Delaware, and Maryland shall maintain their existing state laws and regulations relative to the harvest and landings of horseshoe crabs. All other jurisdictions, besides New Jersey, Delaware and Maryland are encouraged to implement a two day per week closure during the period of April 15 to June 15, on the harvest of horseshoe crabs within 1,000 feet of mean low water; however, this measure is not mandatory unless required by the Management Board and implemented by addendum to the Plan.

Protection of essential habitat such as spawning beaches and juvenile nursery habitat is vital to the continued survival of horseshoe crabs. Each state must identify potential horseshoe crab habitat (both spawning and nursery habitat). Additionally, states should attempt to categorize and prioritize essential horseshoe crab habitat (both spawning and nursery habitat) within areas of its jurisdiction. State fisheries agency(s) must actively intervene to the extent of its authority to ensure that federal, state, and local regulatory agencies are aware of the potential loss in horseshoe crab productivity associated with water quality degradation and habitat loss. States should also consider obtaining land adjacent to critical spawning beaches to ensure the long-term protection of these beaches. Protection of essential habitat should be pursued through acquisition, deed restrictions, or conservation easements. In addition, states should pursue restricting all-terrain vehicles and beach watercraft activity (e.g., jet skis) on spawning beaches during the spawning season (with the exception of emergency vehicles) to minimize mortality of horseshoe crab embryos and larvae.

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LIST OF ACRONYMS AND ABBREVIATIONS

Board	Horseshoe Crab Management Board
DNREC	Delaware Department of Natural Resources and Environmental Control
FDA	U.S. Food and Drug Administration
Maryland DNR	Maryland Department of Natural Resources
NMFS	National Marine Fisheries Service
Plan	Horseshoe Crab Fishery Management Plan
PRP	Horseshoe Crab Peer Review Panel
PRT	Horseshoe Crab Plan Review Team
SAS	Horseshoe Crab Technical Committee's Stock Assessment Subcommittee
USFWS	U.S. Fish and Wildlife Service

1.0. STATUS OF THE HORSESHOE CRAB RESOURCE

1.1. INTRODUCTION

The Atlantic States Marine Fisheries Commission (Commission) develops management plans for the various fishery resources within state and federal waters. The Commission is a compact of the fifteen Atlantic Coast states, created "to promote the better utilization of the fisheries, marine, shell, and anadromous, of the Atlantic seaboard by the development of a joint program for the promotion and protections of such fisheries."

At its annual meeting in October 1997, the Commission voted to initiate an independent fishery management plan for the horseshoe crab (*Limulus polyphemus*). Initially, the Commission horseshoe crab and the American eel (*Anguilla rostrata*) fishery management plans were to be addressed in a single fishery management plan because horseshoe crabs are used as a bait source in the eel pot fishery. This draft Horseshoe Crab Fishery Management Plan (Plan) contains discussions of horseshoe crab life history, the ecological significance of the horseshoe crab, the problems associated with the species' possible decline, status of stocks, and current fisheries including biomedical use. This Plan also identifies the condition of existing horseshoe crab habitat and its current threats. Finally, this Plan identifies management, monitoring, and information needs to ensure the continued role of the horseshoe crab resource in the ecology of coastal ecosystems, while providing the opportunity for commercial, recreational, medical, scientific, and educational use over time. A species profile is provided in an appendix of the Plan.

1.1.1. Statement of the Problem

The status of horseshoe crab populations along the Atlantic Seaboard is poorly understood and is based on independent spawning surveys, egg counts, and trawl surveys, primarily conducted in the Delaware Bay region. Concern over increased exploitation of horseshoe crabs, particularly in the mid-Atlantic States, has been expressed by state and federal fishery resource agencies, conservation organizations, and fisheries interests. Horseshoe crabs are important to migrating shorebirds and federally listed sea turtles as sources of food, and are critical to biomedical research and pharmaceutical testing. Because horseshoe crabs are slow to mature and easily harvested with minimal financial investments, populations are sensitive to harvest pressure.

Upon completion and approval of a management plan, states are obliged to implement its mandatory requirements. If a state does not comply with the mandatory measures of the Commission fishery management plan, the law allows the U.S. Secretary of Commerce to impose a moratorium in that state's particular fishery. All Commission fishery management plans must include specific measurable standards to improve the status of the stocks and to determine the state's compliance with those standards.

1.1.2. Benefits of Implementation

The purpose of a comprehensive horseshoe crab fishery management plan for the Atlantic states and adjacent federal waters is to provide consistent management and regulation for both the long-term viability of the horseshoe crab resource and use of the resource by current and future generations of the fishing and non-fishing public. Current management strategies implemented by various states (e.g., New Hampshire, New Jersey, Delaware, Maryland, and Virginia) provide piecemeal efforts in protecting the horseshoe crab resource. These current state management practices have not been coordinated and cannot control the substantial harvest that may occur in "unregulated" federal waters. A coordinated and consistent management strategy throughout state and federal waters along the Atlantic Coast would help promote the long-term viability of horseshoe crab populations.

Implementing a coastwide fishery management plan would benefit commercial fisheries, such as the American eel and conch (*Busycon carica* and *B. canaliculatum*) fisheries, by providing the long-term supply of a bait source. Successful management also may avoid future harvest moratoriums as experienced in New Jersey during 1997 and piecemeal harvest reduction measures as experienced in New Jersey, Delaware, and Maryland in 1998. A management strategy also would benefit dependent fish and wildlife resources, such as shorebirds and the federally listed (threatened) loggerhead turtle (*Caretta caretta*), by ensuring a readily available and continuing supply of adult horseshoe crabs and horseshoe crab eggs. However, overprotection of horseshoe crabs could adversely impact surf clam (*Spisula solidissima*) resources via heavy predation by horseshoe crabs on surf clam seed beds. Also, management will ensure an essential and adequate supply of horseshoe crabs for the biomedical industry. The use of horseshoe crab blood is critical in testing pharmaceutical drugs and equipment for bacterial contamination.

1.2. DESCRIPTION OF THE RESOURCE

The horseshoe crab life history was developed from available scientific literature and state natural resource agency documents and is intended to provide the reader with the basic information to understand the life cycle and habitat requirements of horseshoe crabs. Additional information is provided in the Species Profile section of the plan.

There is currently no available stock assessment review of horseshoe crabs along the Atlantic Coast. As a result, stock assessment summaries are based on scientific literature and existing resource data collected during independent spawning surveys, trawl, and egg count surveys. The Horseshoe Crab Stock Assessment Committee reviewed and summarized the available data in a report. The Committee concluded that the horseshoe crab population in the mid-Atlantic region has remained stable in recent years, while reported commercial landings data show a substantial increase in harvest during the 1990s (Atlantic States Marine Fisheries Commission, 1998). The Stock Assessment Committee commented that the Delaware trawl survey shows a decreasing trend between 1990 and 1997. The Stock Assessment Committee also identified that many of the surveys collecting information on horseshoe crabs have significant design inadequacies.

1.2.1. Species Life History

Horseshoe crabs are benthic (or bottom-dwelling) arthropods that use both estuarine and continental shelf habitats. Although it is called a "crab," it is neither a decopod or crustacean, rather horseshoe crabs are grouped in their own class (Merostomata), which is more closely related to the arachnids. Horseshoe crabs, ranging from the Yucatan peninsula to northern Maine, are most abundant between Virginia and New Jersey, with the largest population of spawning horseshoe crabs in the world found in the Delaware Bay (Shuster, pers. comm., 1995). While adult horseshoe crabs have been found as far as 35 miles offshore, 74 percent of the horseshoe crabs caught in bottom trawl surveys conducted by the National Marine Fisheries Service (NMFS), Northeast Fisheries Center were taken in water shallower than 20 meters (Botton and Ropes, 1987a). Horseshoe crabs are ecological generalists and can survive within a wide range of environmental conditions.

Studies suggest that each spring, adult horseshoe crabs migrate from deep bay waters and the Atlantic continental shelf to spawn on intertidal sandy beaches. Beaches within estuaries, such as the Delaware and Chesapeake Bay, are preferred because they are low energy environments and are protected from the surf, thus reducing the risks of stranding during spawning events. Spawning generally occurs from March through July, with the peak spawning activity occurring on the evening new and full moon high tides in May and June (Shuster and Botton, 1985). In the Delaware Bay and the Chesapeake Bay, spawning activity gradually increases prior to the full and new moon, peaking on the day of the full and new moon, then gradually decreases (Maio, *et al*., 1998; Maryland Department of Natural Resources, 1998). However, in the Chesapeake Bay, peak horseshoe crab spawning does not occur consistently on any one day around the full and new moons (Maryland Department of Natural Resources, 1998). In South Carolina, spawning occurs from March to July, with peak spawning in May during night high tides greater than 6.0 feet above mean high water (Thompson, 1998). In Florida, spawning occurs between March and November, with peak spawning occurring between mid-June and the end of August (Rudloe, 1980).

Horseshoe crabs are characterized by high fecundity, high egg and larval mortality, and low adult mortality (Botton and Loveland, 1989; Loveland *et al*., 1996). Horseshoe crabs spawn multiple times per season, laying approximately 3,650 to 4,000 eggs in a cluster. Adult females lay an estimated 88,000 eggs annually (Shuster, 1982). Egg development is dependent on temperature, moisture, and oxygen content of the nest environment.

Eggs hatch between 14 and 30 days after fertilization (Sekiguchi, *et al*., 1982; Jegla and Costlow, 1982; Botton, 1995). Survival between hatching and sexual maturity remains unknown. Loveland *et al*. (1996) identify that egg and larval mortality is substantial, primarily due to predation. Some "trilobite" larvae delay emergence and overwinter within beach sediments, emerging the following spring (Botton *et al*., 1992). Larvae typically settle in shallow water areas to molt (Shuster, 1982). Juvenile horseshoe crabs generally spend their first and second summer on the intertidal flats, usually near breeding beaches (Shuster, 1982). Older individuals move out of intertidal areas to a few miles offshore, except during breeding migrations (Botton and Ropes 1987a). However, some adult horseshoe crabs reside in the coastal bays year-round (O'Connell, pers. comm., 1997). The horseshoe crab must molt or shed its chitinous exoskeleton to grow. Molting occurs several times during the first two to three years. As the horseshoe crab grows larger, there are longer periods between molts. Horseshoe crabs molt at least 16 to 17 times over 9 to 11 years to reach sexual maturity (Shuster, 1950). Based on growth of epifaunal slipper shells (*Crepidula fornicata*) on their prosoma, horseshoe crabs live at least 17 to 19 years in the northern part of their range, (Botton and Ropes, 1988).

Larvae feed on a variety of small polychaetes and nematodes (Shuster, 1982). Juvenile and adult horseshoe crabs feed mainly on molluscs including razor clam (*Ensis* spp.), macoma clam (*Macoma* spp.), surf clam (*Spisula solidissima*), blue mussel (*Mytilus edulis*), wedge clam (*Tellina* spp.), and fragile razor clam (*Siliqua costata*). Horseshoe crabs also prey on a wide variety of benthic organisms including arthropods, annelids, and nemertean worms (Botton, 1984a; Botton and Haskin, 1984). Botton (1984a) also found vascular plant material in nearly 90 percent of all individuals.

Factors contributing to natural mortality include age; excessive energy expenditure during spawning, which can result in stranding, desiccation, and predation. Loveland *et al*. (1996) believe that the natural mortality rate in adults is probably low. However, horseshoe crab mortality due to predation from sea turtles and other marine animals remains unknown. Shorebirds feed on horseshoe crab eggs in areas of high spawning densities such as the Delaware Bay. Horseshoe crab eggs are considered essential food for several shorebird species in the Delaware Bay, which is the second largest migratory staging area for shorebirds in North America. Despite significant shorebird predation on horseshoe crab eggs, such activity probably has little impact on the horseshoe crab population (Botton *et al*., 1994). Horseshoe crabs place egg clusters at depths greater than 10 centimeters, which is deeper than most short-billed shorebirds can penetrate. Many eggs are brought to the surface by wave action and burrowing activity by spawning horseshoe crabs. These surface eggs consumed by birds would not survive, due to desiccation (Botton *et al*., 1994). A significant decrease in the number of horseshoe crabs could leave a large portion of migrating shorebirds without necessary food resources to complete migration and successfully reproduce on arctic breeding grounds.

Adult and juvenile horseshoe crabs make up a portion of the loggerhead sea turtle's (*Caretta caretta*) diet in the Chesapeake Bay (Musick, *et al*. 1983). Horseshoe crab eggs and larvae are also a seasonally preferred food item of a variety of invertebrates and finfish, including sharks (*Squaliformes*) (Shuster, 1982).

Human activity probably accounts for the greatest proportion of adult horseshoe crab mortality. Between the 1850s and the 1920s, over one million horseshoe crabs (4 million pounds using a conversion rate of 4 pounds / individual) were harvested annually for fertilizer and livestock feed (Shuster, 1982; Shuster and Botton, 1985). Shuster (1996) reports harvest in the 1870s of over four million horseshoe crabs per year (16 million pounds). More recently horseshoe crabs have been taken in substantial numbers (e.g., over 5 million pounds in 1996) to provide bait for other fisheries, including (primarily) the American eel and conch fisheries. Horseshoe crabs, particularly females, are sectioned and placed in American eel pots as bait. The conch fishery uses horseshoe crabs of either sex. Horseshoe crabs are collected by the biomedical industry to produce Limulus Amebocyte Lysate. This industry bleeds individuals and releases the animals live after the bleeding procedure. Two studies estimate 10 to 15 percent of animals do not survive the bleeding procedure (Rudloe, 1983; Thompson, 1998). Entrapment in or by man-made structures, such as rip-rap, bulkheads, revetments, jetties, and stationary fishing devices, may account for additional mortality.

1.2.2. Stock Assessment Summary

The status of horseshoe crab populations along the Atlantic Seaboard is poorly understood due to the limited amount of information collected regarding stock levels. In addition, basic information regarding age and growth rates, recruitment, and population dynamics is lacking. Other than the NMFS trawl survey data, little information was collected until the late 1980s when independent spawning surveys and trawl surveys were initiated, primarily in the Delaware Bay region. However, the NMFS trawl survey data is confounded by a gear change and the location of the survey areas (i.e., surveys were not conducted in shallow waters). Concern over perceived growing exploitation of horseshoe crab has been expressed by state and federal fishery resource agencies, conservation organizations and fisheries interests.

1.2.2.1. *Distribution*

Horseshoe crabs, ranging from the Yucatan Peninsula to Maine, are most abundant between Virginia and New Jersey (Shuster, 1982). In New Jersey and Delaware, horseshoe crab abundance decreases with distance north and south of the Delaware Bay (Botton and Haskin, 1984). Within the Delaware Bay, the largest concentration of horseshoe crabs traditionally was found along the Cape May shore of New Jersey (Shuster and Botton, 1985). Spawning densities of over 30 animals per meter occurred on the New Jersey side of the Delaware Bay based on 1986 spawning counts along 15 meter segments (Botton, *et al*., 1988). Since 1993, the majority of horseshoe crab spawning activity has occurred on the Delaware shores of the Delaware Bay (Swan, unpublished data, 1998). Annual variation in spawning concentrations may be the result of weather or habitat changes. In the Chesapeake Bay, spawning densities only exceed one per meter on the most heavily used beaches, based on counts using similar methodology. During peak spawning, densities exceeded three per meter on these preferred beaches (Maryland Department of Natural Resources, 1998). Rudloe (1980) and Thompson (1998) reported spawning densities in Florida and South Carolina as three and one animal per meter, respectively.

1.2.2.2. *Sex and Age Ratio*

Sex ratios at spawning beaches have been reported by Rudloe (1980) in Florida to range from 1 to 14 males per female with a mean of 3.6 males per female. Limuli Laboratories' annual census reports sex ratios in New Jersey and Delaware averaging 2.8 male per female between 1990 and 1995 (Swan, pers. comm., 1998). Shuster and Botton (1985) report sex ratios on spawning beaches in New Jersey and Delaware varying between 5:1 and 3:1 (male : female). Thompson (1998) reported average sex ratios on spawning beaches in South Carolina of 3.5:1. Barlow *et al*. (1986) found sex ratios of 2.5:1 in Massachusetts in 1986. Maryland Department of Natural Resources (1998) reported a 2:1 sex ratio in 1994 and 1995, based on spawning surveys. The sex ratio in 1996 and 1997 was 4:1 (Maryland Department of Natural Resources, 1998). However, the sex ratio cannot be ascertained readily from spawning counts because the mating behavior of the males is to concentrate along the shoreline, whereas females generally move into deeper water after spawning (Shuster, 1996). The abundance of males may be an adaptation to favor genetic diversity and to maximize fertilization, because fertilization is external and males compete to fertilize eggs (Brockmann, 1990; Shuster, 1996). Offshore trawl collections indicate a reversed sex ratio, with females outnumbering males from 3:2 to 2:1 (Rudloe, 1980) or an even sex ratio 1.17 males per female (Swan *et al.*, 1993). The New Jersey Division of Fish, Game and Wildlife (1997) identified a female dominated sex ratio of 1:1.4 based on 1996 trawl surveys. Rudloe (1980) and Thompson (1998) concluded that the overall sex ratio may be 1:1.

Shuster (1996) suggested that a shift in the normal 1:1 sex ratio toward less than one female per male becomes an important criterion, pointing specifically to overfishing of females. In South Carolina, the 1997 male to female ratio was higher for each estuary sampled than the preceding years (i.e., 1996 and 1995) (Thompson, 1998), indicating a population changing due to environmental conditions or overharvesting. Trawling in the Delaware Bay by the Delaware Division of Fish and Wildlife (1997) identified annual sex ratios of approximately 1:1 for 1990 through 1996, except in 1993 and 1994 when 1.6:1 was noted (significant at ($p<0.05$) from 1:1).

1.2.2.3. *Stock Assessment*

Lacking the information necessary for a comprehensive coastwide stock assessment, the Horseshoe Crab Technical Committee's Stock Assessment Subcommittee (SAS) and the Peer Review Panel (PRP) reviewed available horseshoe crab data to investigate recent trends and patterns in stock abundance and fishery performance (Atlantic States Marine Fisheries Commission, 1998a; Atlantic States Marine Fisheries Commission 1998b). In its review, the SAS and PRP considered horseshoe crab population data collected by the NMFS and state trawl surveys, egg count surveys, and spawning surveys. State trawl surveys include the Rhode Island trawl survey, trawl surveys in Massachusetts, the Connecticut Department of Environmental Protection marine finfish trawl survey, the large mesh and Peconic Bay small mesh trawl surveys in New York, the New Jersey Ocean Stock Assessment Program coastal nearshore trawl survey, the 30-foot otter trawl and 16-foot otter trawl surveys in Delaware, and the coastal bays trawl survey in Maryland. The NMFS / Northeast Fisheries Science Center conducts seasonal Atlantic Coast benthic surveys (spring and fall) between Maine and North Carolina. Egg counts were conducted by Dr. Robert Loveland and Dr. Mark Botton in New Jersey based on the total number of eggs / standardized core within the upper layer of the substrate (0-5 cm) and the lower layer of the substrate (15-20 cm). Several spawning surveys have been conducted in the mid-Atlantic Bight including the Delaware Bay spawning survey (coordinated by Limuli Laboratories), the State of Maryland spawning surveys, and spawning surveys conducted by Maio *et al*. (1998) in Maryland. The State of New Jersey conducts a surf clam survey along the Atlantic Coast of New Jersey using a commercial hydraulic clam dredge with a 72-inch knife. Tagging data are collected in New Jersey, Maryland, and South Carolina. The sample areas, design methodology, and survey time series vary among data sets.

Although differences were noted as to the appropriateness of the surveys used in the assessments, the SAS and PRP concluded that a conservative, risk-averse management strategy is necessary. This conclusion was based on increases in catch and effort, coupled with several surveys that suggested localized declines in relative abundance. In addition, horseshoe crabs are less resilient to overharvest due to their slow maturation rates. The SAS and PRP also identified the need for additional research and monitoring and recommended specific monitoring programs to allow for future stock assessments. Additional information regarding available population and harvest data and the SAS and PRP review is provided in the SAS and PRP reports (Atlantic States Marine Fisheries Commission, 1998a; Atlantic States Marine Fisheries Commission 1998b).

1.3. DESCRIPTION OF THE FISHERY

Fishing effort for horseshoe crabs is generally concentrated within the mid-Atlantic area, specifically New Jersey, Delaware, Maryland, Virginia, and adjacent federal waters. Since there is no known recreational fishery for horseshoe crabs, fishing mortality of horseshoe crabs is predominantly from the commercial fisheries including the bait fishery and the biomedical fishery.

1.3.1. Current Fishery Regulations

Current fishing regulations vary dramatically among the Atlantic coastal states. Generally, fishing regulations for horseshoe crabs are minimal or nonexistent in comparison with other fisheries (Table 1). However, several states (e.g., New Hampshire, New Jersey, Delaware, Maryland, and Virginia) have recently initiated or proposed more restrictive harvest regulations. The State of South Carolina has prohibited harvest except for the biomedical industry since 1991.

1.3.2. Commercial Fishery

Between the 1850s and the 1920s, over 1 million horseshoe crabs were harvested annually for fertilizer and livestock feed (Shuster, 1982; Shuster and Botton, 1985). Reported harvests in the 1870s were 4 million horseshoe crabs annually, and 1.5 to 1.8 million horseshoe crabs annually between 1880s and 1920s (Finn *et al*., 1991). Shuster (1960) reports that in the late 1920s and early 1930s 4 to 5 million crabs were harvested annually. Shuster (1960) reports over 1 million crabs were harvested during the 1940s and 500,000 to 250,000 horseshoe crabs were harvested in the 1950s. By the 1960s, only 42,000 horseshoe crabs were reported to be harvested annually (Finn *et al*., 1991). Early harvest records are suspect due to under-reporting. The period of time between 1950 and 1960 is considered the nadir of horseshoe crab abundance. The substantial commercial-scale harvesting of horseshoe crabs ceased in the 1960s (Shuster, 1996).

1.3.2.1. *Bait Fishery*

Currently, horseshoe crabs are commercially harvested for use as American eel, conch (or whelk), and catfish bait along certain portions of the Atlantic coast. The horseshoe crab fishery is unique in that crabs can be easily harvested during their spawning season and can be caught with a minimal financial expense. The eel fishery is highly dependent on sustained populations of horseshoe crabs and prefers female horseshoe crabs with eggs. The conch fishery also is dependent on horseshoe crabs, but uses both male and female horseshoe crabs.

Commercial landings data for horseshoe crabs (i.e., metric tons, pounds, and price) are collected by the NMFS by state, year, and gear type. Commercial landings data may include harvest for both the bait and biomedical fisheries. However, the NMFS data are relatively incomplete and disjunct. For example, in several years that NMFS reports no landings in states such as Delaware, state biologists report that landings did occur (Michels, pers. comm., 1997). In 1994 and 1995, the NMFS reported Maryland's harvest at 232,000 and 117,000 pounds, respectively. Based on State landing records, actual Maryland harvest was approximately 1 million pounds during these years (O'Connell, pers. comm., 1998). In many cases, horseshoe crabs are harvested and used directly by eel fishers, whelk fishers, or catfish fishers without going through a dealer (where NMFS gets much of its information) or arrangements are made for harvesters to sell directly to such fisheries without going to dealers. Since such private sales are not reported, NMFS fishery statistics underestimate the catch. Based on NMFS data, commercial harvest from the northeastern Atlantic coast has ranged between 10,000 pounds (in 1969) to over 5.0 million pounds (in 1996) (NMFS, 1998). Since 1988, commercial landings have averaged 1,436,808 pounds. Botton and Ropes (1987b) estimated the total number of horseshoe crabs harvested by comparing the total number of pounds landed with the average weight of an adult horseshoe crab, which is approximately 4 pounds. However, the NMFS used a different conversion factor to estimate the number of pounds landed (e.g., 2.6 pounds per crab). The total average horseshoe crab catch (animals/year) for the Atlantic Coast (assuming an adult horseshoe crab is 4 pounds) has increased from 476,515 in 1993 to 1,288,408 in 1996 (NMFS, 1998). This increase is similar to increases reported by Michels (unpublished data, 1997) for the Delaware Bay harvest, which ranged from 330,333 in 1993 to 896,540 in 1996. However, Michels (unpublished data, 1997) did not include the Maryland harvest (which can be substantial). These statistics provide further evidence that the NMFS data represent an underestimate of actual harvest. Regardless of the data set used, all data show a significant increase in harvest between 1990 and 1996.

The SAS and the PRP concluded that commercial landings data show a substantial increase in reported harvest during the 1990s (Atlantic States Marine Fisheries Commission, 1998a; 1998b). This increase could be, in part, a function of increased harvest reporting efficiency. The states of Delaware, Maryland, New Jersey, and New York represent the largest harvest of horseshoe crabs recently. Estimates in Delaware, Maryland, New Jersey, New York, and Rhode Island indicate a rapid increase in fishery growth, based primarily on use as bait for the American eel and whelk fisheries and the shift in pressure from declining traditional fisheries (Michels, unpublished data, 1997; NMFS, 1998; Thompson, 1998). However, the States of Connecticut, Massachusetts, North Carolina, and Virginia indicate declines in current harvest compared with harvest in the late 1970s and early 1980s (NMFS, 1998).

Table 1. Current fishing regulations for horseshoe crabs by State.

State	Regulations
MAINE	No regulations regarding harvest (Sorksen, pers. comm., 1997).
NEW HAMPSHIRE	Possession limit of 10 per day per person. License required to sell or distribute and mandatory monthly reporting is required (Nelson, pers. comm., 1997).
RHODE ISLAND	No regulations regarding harvest; however, to sell commercially, a commercial fishing license is required ($200/year). A moratorium on commercial licenses is currently in place (Sisson, pers. comm., 1997).
MASSACHUSETTS	No regulations regarding harvest; however, to sell commercially, a commercial fishing license is required ($65/year-residents, $130/year-nonresidents) (Coates, pers. comm., 1997).
CONNECTICUT	No regulations regarding harvest (Babey, pers. comm., 1997).
NEW YORK	No regulations regarding harvest; however, to sell commercially, or to take and land more than 50, a license is required ($30/year-residents, $50/year-nonresidents (Colvin, pers. comm., 1997).
NEW JERSEY	Harvest requires a horseshoe crab permit and mandatory monthly reporting. The following persons are exempt from obtaining a permit: (1) property owners removing dead horseshoe crabs from their property for the purpose of disposal, (2) scientific collection with appropriate scientific collecting permit, and (3) individuals in possession of a miniature fyke, lobster, or fish pot license and written verification that horseshoe crabs were obtained from a legal source. In order to qualify for a horseshoe crab permit, individuals must have had a miniature fyke, lobster, or fish pot license; a horseshoe crab permit; and reported landings for at least 2 years between 1993 and 1997. Harvest by any other means than by hand (i.e., trawling or dredging) is prohibited. Harvest season is April 1 to August 15. No harvest is allowed from the beaches and shoreline and the adjacent waters and uplands within 1,000 feet of mean high water along the Delaware Bay. Hand-harvest is permitted in areas other than the abovementioned areas only two days / week (Tuesday and Thursday) (Himchak, pers. comm., 1997).
PENNSYLVANIA	No regulations regarding harvest (Snyder, pers. comm., 1998).

Table 1. (continued)

State	Regulations
DELAWARE	No collection on State or federal land (horseshoe crab sanctuaries) between May 1 and June 30, except Tuesdays and Thursdays on state owned lands east of State Road Number 89 by persons with valid horseshoe crab collecting permits or American eel licenses. No collection on private land between May 1 and June 30 except permittees on Monday, Wednesday, and Friday. Hand harvest by persons with valid commercial eel fishing licenses requires mandatory reporting and horseshoe crabs must be for personal, non-commercial use. Dredging is prohibited in leased shellfish grounds except on one's own leased shellfish grounds or with permission from the owner of leased shellfish grounds. Harvest by vessels is limited to 1,500 horseshoe crabs / 24 hours. Harvest by dredging is prohibited between May 1 and June 30. Trawling is prohibited in State waters. Monthly reporting is required by all permittees. Containment or transport of more than 300 cubic feet of space occupied by horseshoe crabs is prohibited. Permittees must have secured at least 2 valid horseshoe crab collecting permits from previous years. If collecting permits drops to 45 or below, a lottery will be held to increase commercial collecting permits to 50. Permit fees are $100/year-resident and $1,000/year-non-resident (Manus, pers. comm., 1998).
MARYLAND	The annual total allowable landings of horseshoe crabs for the commercial fishery is 750,000 pounds. Harvest requires a horseshoe crab catch and landing permit. In order to qualify for a permit, a person must be licensed in accordance with Natural Resources Article S4-701, Annotated Code of Maryland and reported catching and landing horseshoe crabs in Maryland during 1996. A person may not catch or land horseshoe crabs in Maryland between December 1 and March 31. A person may not catch horseshoe crabs within 1 mile of the Atlantic Coast, Chesapeake Bay and coastal bays from April 1 through June 30. A person may catch and land horseshoe crabs on Monday through Friday from outside of 1 mile of the Atlantic Coast between April 1 and June 30 in accordance to the following catch limits: (1) 100 horseshoe crabs for a permittee; and (2) 25 horseshoe crabs for a non-permittee. A person may catch and land horseshoe crabs on Monday through Friday from the tidal waters of the State between July 1 and November 30 in accordance to the following catch limits: (1) the daily catch limit for permittees shall be based on the ratio of landings for 1996 as applied to the annual total allowable landings for the present year; and (2) 25 horseshoe crabs for a non-permittee. A person who catches and lands horseshoe crabs in Maryland shall report catch and landing information on the forms provided by the Department. A person authorized to catch and release horseshoe crabs for purposes of scientific research shall be exempt from these regulations, but must return the horseshoe crabs live within 48 hours to the waters from which the horseshoe crabs were taken (O'Connell, pers. comm., 1998).
VIRGINIA	Harvest by means of trawling or dredging is prohibited. However, special scientific collection permits have been issued to trawler to catch horseshoe crabs for medical purposes. License required to hand-harvest ($15/year) in addition, to obtain a license the applicant must be a registered waterman ($150/year). No limits for hand-harvesting (Travelstead, pers. comm., 1997).

Table 1. (continued)

State	Regulations
DISTRICT OF COLUMBIA	No regulations regarding harvest.
POTOMAC RIVER FISHERIES COMMISSION	No regulations regarding harvest.
NORTH CAROLINA	No regulations regarding harvest (Daniel, pers. comm., 1997).
SOUTH CAROLINA	Special permits required for harvest and / or possession. Harvest of horseshoe crabs is limited to biomedical industry (production of LAL) and to scientific, educational, or commercial display. Harvesting vessels must be properly licensed in addition to being permitted. Permits may be conditioned as to lawful fishing areas; minimum size requirements for horseshoe crabs; mesh size and dimensions of nets and other harvesting devices; bycatch provisions; fishing times or periods; catch reporting requirements; holding facilities, conditions, and periods; and any other conditions the State determines appropriate. Horseshoe crabs harvested for LAL production must be returned unharmed to State waters of comparable salinity and water quality after they are bled. Penalties for violating permit conditions, upon conviction, may include monetary fines, suspension or revocation of the permit(s), and seizure and sale of the permittee's vessel (Cupka, pers. comm., 1998).
GEORGIA	No regulations regarding harvest; however, experimental fishing contract may be required for significant commercial fishery activities (Evans, pers. comm., 1997).
FLORIDA	No regulations regarding harvest; however, to sell commercially, a salt-water products license is required ($50/year-residents) (Vale, pers. comm., 1997).
FEDERAL WATERS	No regulations regarding harvest (Maney, pers. comm., 1997).

Based on reported landings in New Jersey alone, horseshoe crab harvests have increased in the last three years from approximately 250,000 in 1993 to over 600,800 in 1996. The Delaware Division of Fish and Wildlife (1997) reports increases in landings between 1990 (under 250,000 pounds) and 1997 (over 1,500,000 pounds). The Delaware Division of Fish and Wildlife (1997) also reports increases in effort as represented by issuance of beach collection permits, which increased from 18 in 1991 to 131 in 1997. However, prior to 1991 little or no reporting occurred within the Delaware Bay. Thus, the increase in horseshoe crab harvest during the 1990s may be partly related to mandatory reporting requirements.

Primary harvest was identified in Rhode Island, New Jersey, Delaware, Maryland, and Virginia. Little to no harvesting of horseshoe crabs was reported in Maine, New Hampshire, or Connecticut (Botton and Ropes, 1987b). The Chesapeake Bay in Maryland and Virginia likely has a substantial harvest, but without quantitative studies, the catch remains under-reported.

Maryland has been responsible for 23 to 78 percent of the total commercial catch of horseshoe crabs from the northeastern Atlantic coast since 1980 (NMFS, 1998). Maryland averaged 357,000 pounds between 1981 and 1991 from a small directed ocean fishery and bycatch from the clam fishery. Since 1992, harvest has increased significantly in Maryland with 2.6 million pounds landed in 1996. Maryland's fishery is primarily an offshore trawl fishery; more than 95 percent of the harvest occurs from July through November. In 1996, 96 percent of Maryland's harvest was from waters outside of 1 mile (52 percent from State waters [1-3 miles] and 44 percent from federal waters [3+ miles]), 3 percent from the coastal bays, and <1 percent from the Chesapeake Bay (O'Connell, pers. comm., 1998).

In Virginia, horseshoe crab harvest averaged 190,000 pounds between 1980 and 1988. With a ban on trawling in state waters since 1989, horseshoe crab landings have decreased considerably, averaging 22,000 pounds (Butowski, 1994) and only increasing to 86,294 pounds in 1996 (NMFS, 1998). Demand has increased in Virginia as indicated by whelk landings, which have increased from 75,000 pounds in 1994 to 750,000 pounds in 1995 (Petrocci, 1997).

Reported dockside value from the northeastern Atlantic coast has ranged between $289 (1967) and $1,541,260 (1996). Fishery statistics (Table 2) for the period 1970 through 1997 indicate a variable fishery. As previously identified, fishery statistics probably underestimate the catch of horseshoe crabs, because the sale of crabs for bait is often arranged between private individuals (i.e., unreported in NMFS landing statistics) rather than through centralized dealers (Botton and Ropes 1987b).

In 1997, the majority (85 percent) of horseshoe crabs in Delaware were landed by hand harvest, while dredge harvest made up approximately 15 percent (Delaware Division of Fish and Wildlife, 1997). Between 1991 and 1996 the majority of the horseshoe crabs were landed by hand-harvest (63 percent) compared to dredging (37 percent) (Delaware Division of Fish and Wildlife, 1997), except for 1991 when the dredge harvest dominated the catch (56 percent). The increased harvest noted in Delaware mirrored increases in the number of hand-collection permits issued (Delaware Division of Fish and Wildlife, 1997). NMFS data compiled by Delaware Division of Fish and Wildlife (1997) identified that among the northeastern and mid-Atlantic States, Maryland, New Jersey, and Delaware harvest the majority of horseshoe crabs (36, 31, and 14 percent, respectively).

The shrimp trawl fishery in the South Atlantic Bight may contribute to horseshoe crab mortality via bycatch (Thompson, 1998), but the amount of bycatch harvest remains unreported. The amount of horseshoe crab bycatch has become very small, since the use of turtle excluder devices became mandatory in the shrimp trawl fishery (Cupka, pers. comm., 1998).

Table 2. Atlantic states landings for horseshoe crab for the period 1970 - 1997.

ATLANTIC STATES LANDINGS (MAINE - FLORIDA)		
Year	Pounds	Value (in $1000s)
1970	15,900	7.79
1971	11,900	3.01
1972	42,000	2.63
1973	88,700	5.54
1974	16,700	6.90
1975	62,800	18.90
1976	2,043,100	63.96
1977	473,000	16.58
1978	728,500	45.59
1979	1,215,630	148.24
1980	566,447	79.02
1981	326,695	55.97
1982	510,060	44.95
1983	440,959	35.83
1984	152,392	15.36
1985	522,199	41.46
1986	507,814	47.82
1987	462,663	67.82
1988	636,252	71.23
1989	1,087,912	131.72
1990	908,130	101.81
1991	1,089,045	121.50
1992	1,000,619	109.71
1993	1,906,059	207.22
1994	1,401,656	228.60
1995	2,547,987	378.99
1996	5,156,126	1541.26
1997	6,146,487	1228.56

Source: National Marine Fisheries Service (1998)

Note: National Marine Fisheries Service data is an underestimate of the true coastwide harvest due to the lack of mandatory reporting in all states.

Note: All dollars are 1992 dollars, adjusted by the implicit price deflator (GDP). All life stages are included.

1.3.2.2. *Biomedical Fishery*

Scientists have used horseshoe crabs in eye research, surgical sutures wound dressing development, and detection of bacterial endotoxins in drugs and intravenous devices (Hall, 1992). Limulus Amoebocyte Lysate (LAL), a clotting agent in horseshoe crab blood, has made it possible to detect human pathogens such as spinal meningitis and gonorrhea in patients, drugs, and all intravenous devices. In 1964, researchers discovered that horseshoe crab blood coagulates in the presence of minute quantities of gram-negative bacterial endotoxin and the LAL industry was initiated. By 1979, the U.S. Food and Drug Administration (FDA) issued draft guidelines for the use of LAL as an end-product pyrogen test for endotoxin in medical devices and injectable drugs. The LAL test is currently the worldwide standard for screening medical equipment for bacterial contamination; any drug produced by a pharmaceutical company must pass an LAL screening. No other known procedure has the same accuracy as the LAL test. If LAL became unavailable, it could take years to find a universally accepted replacement. To obtain LAL, manufacturing companies catch primarily adult horseshoe crabs, collect a portion of their blood, and then release them alive.

In 1989, the FDA reported that 130,000 horseshoe crabs were used in the biomedical industry. The current estimate of medical usage is between 200,000 and 250,000 horseshoe crabs per year on the Atlantic Coast (Swan, pers. comm., 1998; McCormick, pers. comm., 1998). The FDA mandates conservation by requiring the return of horseshoe crabs to the environment. Most labs return bled crabs to their habitat within 72 hours of capture, but may or may not release crabs at the collection site (Botton, 1995). Approximately 10 percent of the crabs do not survive the bleeding procedure, which comprises a source of mortality that is not included in the commercial catch statistics (Rudloe, 1983). Based on a tagging and controlled mortality study, Thompson (1998) reported similar post-processing mortality of horseshoe crabs (10 to 15 percent). Mortality due to the bleeding procedure may be lower (e.g., 0 to 4 percent), depending on the biomedical facility (Swan, pers. comm., 1998), but the mortality associated with collection, shipping, and handling remains unknown. This mortality is minimal compared to that from the commercial bait fishery.

In South Carolina, live horseshoe crabs may be taken only for use in LAL production, with animals returned to natural habitat after bleeding. Landings in South Carolina by hand-harvest and trawl has increased since the late 1980s. The annual reported harvest in South Carolina has increased over 300 percent since reporting requirements were established in 1991 (Thompson, 1998). Presumably, this increase in harvest was driven by the biomedical industry's demand for more horseshoe crabs.

Horseshoe crabs are used also to make chitin filament for suturing (Hall, 1992). Since the mid-1950s medical researchers have known that chitin-coated suture material enhanced healing time by 35-50 percent. Currently, horseshoe crabs are harvested on a limited basis to manufacture chitin-coated suture material and chitin wound dressings (Hall, 1992). Horseshoe crab blood is also beneficial in cancer research; the LAL could lead to controlled cancer therapy. Endotoxins and other substances in horseshoe crab blood may have the potential for diagnosing leukemia.

1.3.3. Recreational Fishery

There are no known recreational fisheries for the horseshoe crab.

1.4. ECOLOGICAL IMPORTANCE OF HORSESHOE CRABS

Horseshoe crabs play an important ecological role in the food web for migrating shorebirds, finfish, and Atlantic loggerhead turtles, a federally listed (threatened) species that uses the Chesapeake Bay as a summer nursery area (Keinath *et al*. 1987).

1.4.1. Shorebirds

The Delaware Estuary is the largest staging area for shorebirds in the Atlantic Flyway and is the second largest staging site in North America (New Jersey Division of Fish, Game and Wildlife, 1994). An estimated 425,000 to 1,000,000 migratory shorebirds converge on the Delaware Bay to feed and rebuild energy reserves prior to flying an additional 4,000 kilometers to complete their northward migration (Wander and Dunne, 1982; Dunne *et al*., 1982; Clark *et al*., 1993). Migratory shorebirds arrive in Delaware Bay and adjacent areas along the Atlantic coast at the peak of horseshoe crab mating in mid-May through early-June, typically spending two weeks in the area. Clark (1996) states that the number of shorebirds coming to the Delaware Bay on spring migrations is between 900,000 and 1.5 million of six species. At least 11 species of migratory birds use horseshoe crab eggs to replenish their fat supply during their trip from South American wintering areas to Arctic breeding grounds (Myers, 1986). The principle shorebirds observed include ruddy turnstone (*Arenaria interpres*), red knot (*Calidris canutus*), semipalmated sandpiper (*Calidris pusilla*), sanderling (*Calidris alba*), dowitcher (*Limnodromus* spp.), and dunlin (*Calidris alpina*) (Dunne *et al*., 1982). Other shorebirds frequenting sandy beaches include western sandpiper (*Calidris mauri*), the federally listed (threatened) piping plover (*Charadrius melodus*), black-bellied plover (*Pluvialis squatarola*), semipalmated plover (*Charadrius semipalmatus*), and willet (*Catoptrophorus semipalmatus*) (Burger, *et al.*, 1977). The dominant species of shorebirds that use the Delaware Bay for staging are the red knot, ruddy turnstone, semipalmated sandpiper, and sanderling, representing approximately 88 percent of all shorebirds within the Delaware Bay (Gelvin-Innvaer, 1996). The Delaware Bay staging area is unique and of particular importance to shorebirds for the following reasons: shorebirds use few major stopovers during the spring migration; shorebirds arrive at stopover sites with little or no fat reserves; and, shorebirds demonstrate fidelity to staging areas (Wander and Dunne, 1982). An estimated 80 percent and 30 percent of the hemispheric population of red knots and sanderlings, respectively, use the Delaware Bay as a staging area (American Bird Conservancy, 1997).

Despite high shorebird abundance within the Delaware Bay, counts of sanderlings and semipalmated sandpipers declined significantly over a 7-year period from 1985 to 1992 (Clark *et al*., 1993). The decline in shorebirds in the Delaware Bay between 1986 and 1997 is statistically significant ($p<0.05$) (Clark and Niles, unpublished data, 1997). The Delaware Division of Fish and Wildlife also reports a 45 percent decline in peak counts of shorebirds from 1990-1996 compared to data from 1986-1989. The International Shorebird Survey also indicated a decline in sanderlings between 1975 and 1983. Declines in shorebird numbers may be the result of several threats, including the potential overharvest of horseshoe crabs.

During the 2-3 week staging period, shorebirds undergo weight gains of 40 percent or more (e.g., increasing body weight from 54 to 79 grams over 3 weeks) (Myers, 1986). Much of this weight gain results from feeding on horseshoe crab eggs. In particular, sanderlings are estimated to consume as much as 30.9 grams of eggs per day per bird (approximately 8,300 eggs / day / bird). However, the estimated overall metabolic efficiency is low (i.e., 39 percent) and is among the lowest recorded value of a vertebrate feeding on food of animal origin, based on experiments on captive birds (Castro *et al*., 1989). Low metabolic efficiency is attributable to the high percentage of eggs that pass through the bird's digestive tract unbroken. Metabolic efficiency of broken horseshoe crabs eggs is much higher (e.g., 69 percent) than the metabolic efficiency of unbroken horseshoe crab eggs (Castro *et al*., 1989). Tsipoura and Burger (1998) indicate that under natural conditions, assimilation efficiency of horseshoe crab eggs may be higher than suggested by Castro *et al*. (1989) because sand in the diet may assist in breaking and grinding down horseshoe crab eggs.

Shorebirds require high daily energy inputs due to their high basal metabolic rates. In addition, shorebirds typically have high daily energy expenditures, and are among the longest-distance migrant animals in the world (Kersten and Piersma, 1987; Myers *et al*., 1985). Castro *et al*. (1989) concluded that sanderlings (and possibly other shorebirds) compensate for low metabolizable energy of horseshoe crab eggs by consuming large quantities of eggs. This is possibly due to the sheer abundance of eggs, the ease in obtaining them, and the rapidity in which they pass through the digestive tract.

Rather than probing below the surface of the substrate, shorebirds typically forage for horseshoe crab eggs as the eggs are uncovered by successive waves of nesting crabs and erosion from localized storms (Botton *et al*., 1994). Horseshoe crab eggs are the most abundant food item on Delaware Bay beaches during the migratory staging of shorebirds. Botton *et al*. (1994) found few other available macroinvertebrates and concluded that shorebirds are feeding primarily on horseshoe crab eggs, largely because of their abundance. However, it is likely that shorebirds supplement their diet with ingestion of other food items during the stopover period (Botton, 1984b).

Macroinvertebrate densities on the Delaware Bay beaches rarely exceeded 200/m^2 during horseshoe crab spawning season and are several orders of magnitude less than horseshoe crab egg densities. As a result, shorebirds showed a preference for beaches with higher number of horseshoe crab eggs (Botton *et al*., 1994). Access to horseshoe crab eggs by shorebirds may be limited by tidal cycle, human disturbance, and competition among shorebirds and gulls. Burger *et al*. (1996) concluded that a mosaic of habitat types ranging from mudflats to high marshes is essential to sustain the high population of shorebirds using Delaware Bay during spring migration. In addition, Burger *et al*. (1996) documented the importance of marshes for foraging in several species of shorebirds. Shorebirds do abandon beaches at night to roost in isolated marshes. This is believed to be related to reducing risk of predation by nocturnal wildlife (Bryant and Pennock, 1991). Clark *et al*. (1993) estimated that only 15-20 percent of semipalmated sandpipers and up to 30 percent of dunlins were observed in salt marshes (feeding on prey other than horseshoe crab eggs), as opposed to beaches.

Forage data (stomach contents) collected from sanderlings, ruddy turnstones, least sandpipers, semipalmated sandpipers, dunlins, and red knots on Delaware Bay beaches along the New Jersey coast (N=70) indicate that horseshoe crab eggs represent the majority of food items taken by shorebirds (15 to 95 percent) in 1996 and 1997, averaging 57.3 percent (Tsipoura and Burger, 1998). As such, horseshoe crab eggs were not taken to the exclusion of other items, such as polychaete worms and arthropods. Based on fat-free weights, red knot, ruddy turnstone, sanderling, and semipalmated sandpiper increased body mass up to 70 to 80 percent while staging on Delaware Bay (Tsipoura and Burger, 1998). This rate of weight gain is the highest recorded for any stopover site in the world and is considered to be the result of feeding on horseshoe crab eggs. Additionally, Tsipoura and Burger (1998) reported that the mass movement of shorebirds (from the New Jersey side to the Delaware side of the Delaware Bay) is correlated with availability of horseshoe crab eggs. The ruddy turnstone provides one possible exception to the interaction between horseshoe crab egg availability and bird distribution. These birds use their bill to dig into the sand and make holes that are several inches deep, thereby reaching the eggs that are buried deeper in the substrate. Tsipoura and Burger (1998) found high concentrations of egg membranes in gut samples of ruddy turnstones that were captured on Thompson's Beach, New Jersey and hypothesized that the decline in abundance of surface eggs may not have been a deterrent to the foraging success of this species, as long as there were still sufficient numbers of eggs available in the lower strata.

Despite significant shorebird predation on horseshoe crab eggs, such activity probably has little impact on the horseshoe crab population (Botton *et al*., 1994). Horseshoe crabs place egg clusters at depths greater than 10 centimeters, which is deeper than most short-billed shorebirds can reach. Horseshoe crab eggs brought to the surface by wave action and burrowing activity by spawning horseshoe crabs that are available for shorebird predation would probably not survive to hatching due to heat stress or desiccation (Botton *et al*., 1994). Additionally, horseshoe crabs continue to spawn at least one month after the departure of most of the shorebirds. Horseshoe crab larval densities have been observed regularly exceeding 100,000/m^2 in July and August (Botton *et al*., 1992). For these reasons, it is unlikely that shorebird predation has a substantial adverse impact on the reproductive success of horseshoe crabs in Delaware Bay.

The food supply provided by horseshoe crab eggs in Delaware has been estimated at 320 tons (Delaware Department of Natural Resources and Environmental Control, 1987). Castro and Myers (1993) estimated the total energy requirement of shorebirds and calculated that 539 metric tons of horseshoe crab eggs would be needed to sustain the spring migration of shorebirds through the Delaware Bay (assuming the shorebirds ate only horseshoe crab eggs). Based on this estimate, Castro and Myers (1993) estimated that the total number of females needed to lay the eggs consumed by shorebirds is approximately 1,820,000. Assuming a sex ratio of 1:1, approximately 3,640,000 horseshoe crabs are required to sustain the shorebird migration stopover in Delaware Bay. However, these calculations assume that shorebirds feed exclusively on horseshoe crab eggs. Tsipoura and Burger (1998) indicated that horseshoe crab eggs are a significant part of shorebirds diet, but that diet is supplemented by other food resources. Botton *et al*. (1994) estimated that an average of 44,000 eggs/m^2 would be needed to sustain the entire shorebird population in the Delaware Bay. Their data indicate these densities currently occur within most Delaware Bay beaches. A significant decrease in the number of horseshoe crabs could leave a large portion of migrating shorebirds without either the necessary food resources to complete their trip to the Arctic breeding grounds or the necessary fat reserves upon arrival to initiate egg laying and incubation.

1.4.2. Finfish

Horseshoe crab eggs and larvae are a seasonal food item of invertebrates and finfish. In the Delaware River from May through August, striped bass (*Morone saxatilis*) and white perch (*Morone americana*) eat horseshoe crab eggs. American eel (*Anguilla rostrata*), killifish (*Fundulus* spp.), silver perch (*Bairdiella chrysoura*), weakfish (*Cynoscion regalis*), kingfish (*Menticirrhus saxatilis*), silversides (*Menidia menidia*), summer flounder (*Paralichthys dentatus*), and winter flounder (*Pleuronectes americanus*) also eat eggs and larvae (Shuster, 1982). All crab species and several gastropods, including whelks, feed on horseshoe crab eggs and larvae. Shuster (1982) reported a large leopard shark (*Triakis semifasciatum*) preying on adult horseshoe crabs in southern Florida.

1.4.3. Sea Turtles

Lutcavage and Musick (1985) examined the stomach contents or excreta from 527 loggerhead turtles from Chesapeake Bay and nearby coastal waters and found that the most common prey was horseshoe crab. Musick *et al*. (1983) examined 27 loggerhead turtles and found horseshoe crabs commonly in stomach contents. Similarly, Lutcavage (1981) found that horseshoe crabs represented up to 42 percent of the diet of loggerhead turtles from Chesapeake Bay (N=6), averaging 22 percent. Data collected by the NMFS Sea Turtle Stranding and Salvage Network along the Atlantic Coast identified horseshoe crabs in 75 percent of loggerhead stomach contents in 1996 (N=8) and 55 percent in 1997 (N=11) (Evans, pers. comm., 1998). Morreale and Standora (1993) found no evidence of horseshoe crabs in loggerhead turtle diets in New York's Long Island Sound; however, diet largely depends on the relative abundance of prey species. Maintaining abundant stocks of adult horseshoe crabs may be an important component of ensuring the long-term survival of loggerhead sea turtles in the Chesapeake Bay area.

1.5. HABITAT CONSIDERATIONS

1.5.1. Description of Habitat

Essential habitat is defined as those waters and substrate necessary for fish spawning, breeding, feeding, or growth to maturity. Horseshoe crabs use a different habitat at different life stages. Protected beaches provide essential habitat for horseshoe crab spawning efforts, while nearshore shallow waters are essential for nursery habitat.

1.5.1.1. *Spawning Habitat*

Spawning adults prefer sandy beach areas within bays and coves that are protected from wave energy. Beach habitat also must include porous, well-oxygenated sediments to provide a suitable environment for egg survival and development (Botton, *et al*., 1988). Optimal spawning areas are limited by the availability of suitable sandy beach habitat. However, spawning may occur along peat banks if there is sand in the upper intertidal regions and along the mouths of salt marsh creeks (Botton, 1995). Shuster (1996) states that spawning may occur along muddy tidal stream banks, but not on peat banks because adults are sensitive to hydrogen sulfide and anaerobic conditions. Spawning habitat varies throughout the horseshoe crab range. In Massachusetts, New Jersey, and Delaware, beaches are typically coarse-grained and well-drained as opposed to Florida beaches, which are typically fine-grained and poorly drained. These differences affect nest-site selection and nesting synchrony (Penn and Brockmann, 1994). Thompson (1998) found that preferentially selected spawning sites were located adjacent to large intertidal sand flat areas, which provide protection from wave energy and an abundance of food for juveniles. A Habitat Suitability Index model was developed for horseshoe crab spawning habitat within the Delaware Bay; however, this model is currently in draft form and has not completed peer review, testing, or publication by the U.S. Fish and Wildlife Service (USFWS) (Brady and Schrading, 1996).

1.5.1.2. *Nursery Habitat*

The shoalwater and shallow water areas of bays (e.g., Delaware Bay and Chesapeake Bay) are essential nursery areas (Botton, 1995). Juveniles usually spend their first two years on intertidal sand flats (Rudloe, 1981). Thompson (1998) also found significant use of sand flats by juvenile horseshoe crabs in South Carolina. However, older juveniles and adults are exclusively subtidal, except during spawning.

1.5.1.3. *Adult Habitat*

Specific requirements for adult habitat are not known. Although horseshoe crabs have been taken at depths >200 meters, Botton and Ropes (1987a) suggest that adults prefer depths <30 meters. The NMFS Northeast Fishery Center bottom trawl surveys collected 92 percent of their horseshoe crabs at these depths, even though 73 percent of the sampling effort was expended in depths >27 meters. During spawning season adults typically inhabit bay areas adjacent to spawning beaches and feed on bivalves. In the fall, adults may remain in bay areas or migrate into the Atlantic Ocean to overwinter on the continental shelf.

1.5.2. Identification and Distribution of Essential Habitat

Beach areas that provide spawning habitat are considered essential habitats for adult horseshoe crabs. Nearshore, shallow water, intertidal flats are considered essential habitats for the juvenile development. Delaware Division of Fish and Wildlife's 16-foot bottom trawl survey data indicated that over 99 percent of juvenile horseshoe crabs (<160 mm prosomal width) were taken at salinities >5 parts per thousand (Michels, 1997). Larger juveniles and adults use deep water habitats to forage for food, but these are not considered essential habitat. Of these habitats, the beaches are the most critical (Shuster, 1994). Optimal spawning beaches may be a limiting reproductive factor for the horseshoe crab population. Based on geomorphology Botton, *et al*. (1992) estimated that only 10 percent of the New Jersey shore adjacent to Delaware Bay provided optimal horseshoe crab spawning habitat. The densest concentrations of horseshoe crabs in New Jersey occur on small sandy beaches surrounded by salt marshes or bulkheaded areas (Loveland *et al*., 1996).

Prime spawning habitat is widely distributed throughout Maryland's Chesapeake and coastal bays, including tributaries. Horseshoe crabs are restricted to areas that exceed 7 parts per thousand salinity (Maryland Department of Natural Resources, 1998). In the Chesapeake Bay, spawning habitat generally extends to the mouth of the Chester River, but can occur farther north during years of above normal salinity levels. Prime spawning beaches within the Delaware Bay consist of sand beaches between Maurice River and the Cape May Canal in New Jersey and between Bowers Beach and Lewes in Delaware (Shuster, 1994).

1.5.3. Present Condition of Habitats and Essential Habitats

1.5.3.1. *Quantity*

The United States has approximately 100,400 acres of marine intertidal shoreline, based on 1980s estimates (Frayer, 1991). However, this estimate includes marine intertidal habitat on the Pacific Coast and does not necessarily represent potential horseshoe crab spawning habitat. Within the southeastern United States (from North Carolina to Florida), there were 49,100 acres of marine intertidal habitat based on an estimate in the 1980s (Hefner, *et al*., 1994). These values represent maximum potential spawning habitat for horseshoe crabs. Actual spawning habitat used by horseshoe crabs is considerably less because horseshoe crabs typically select beaches based on geochemical criteria. For example, Botton, *et al*. (1988) conducted beach surveys on approximately 80 kilometers of beach along the New Jersey side of the Delaware Bay. Only 10.6 percent (8.5 kilometers) provided optimal spawning habitat and only 21.1 percent (17.0 kilometers) provided suitable spawning habitat.

1.5.3.2. *Quality*

As discussed in section 1.5.3.1., studies conducted by Botton, *et al*. (1988), showed that only 31.7 percent of marine intertidal habitat surveyed provided optimal or suitable spawning habitat for horseshoe crabs. Viable spawning habitat throughout the Atlantic coast is probably only a fraction of total marine intertidal areas.

1.5.3.3. *Loss and Degradation*

Habitat degradation is likely an important component of the population dynamics of horseshoe crabs. Groins and bulkheads may adversely impact horseshoe crab spawning habitat. Bulkheads may block access to intertidal spawning beaches, while groins and seawalls intensify local shoreline erosion and prevent natural beach migration. An estimated 10 percent of the New Jersey shoreline adjacent to the Delaware Bay has been severely disturbed by shoreline protection structures (Botton, *et al.*, 1988). Rip-rap and revetments also adversely impact horseshoe crabs by minimizing potential spawning sites and by entrapping and stranding them. A contributing factor in the decline of horseshoe crabs in the Delaware Bay between 1871 and 1981 may be the increased number of jetties and residential development (Shuster and Botton, 1985).

Shoreline erosion combined with shoreline development results in the loss of potentially suitable spawning beaches. Beach migration is a coastwide phenomenon, where beaches move landward associated with erosional events. However, hard structures (e.g., bulkheads, seawalls, revetments) associated with beach development interfere with the natural beach migration causing habitat loss. Beaches along the New Jersey shore of the Delaware Bay have generally eroded at varying rates ranging from 1 to 12 feet per year for the last 100 years (U.S. Army Corps of Engineers, 1997). Erosion rates from 1 to 26 feet per year, averaging approximately 3 to 5 feet per year and the existence of hard structures limiting beach migration have resulted in a decline in Delaware beaches (U.S. Army Corps of Engineers, 1991). McCormick and McCormick (1998) report that the annual rate of erosion in the Chesapeake Bay averages 1 foot per year. Shoreline areas with high concentrations of silt or peat are less favorable to horseshoe crabs because the anaerobic conditions reduce egg survivability. Horseshoe crabs may detect hydrogen sulfide (which is produced in the anaerobic conditions of peat substrates) or low oxygen conditions, and actively avoid such areas (Botton *et al*., 1988). Erosion affects spawning by influencing beach characteristics that are most important in site selection, such as beach topography, sediment texture, and geochemistry (Botton *et al*., 1988).

1.5.3.4. *Current Threats*

The rate at which coastal wetlands and beach areas are lost is directly related to human population density (Gosselink and Baumann, 1980). Impacts on beaches from development and related infrastructure (e.g., bulkheads, groins, revetments, and seawalls) continue to degrade essential horseshoe crab habitat. By reducing the amount of wave action sustained by a particular beach, jetties may benefit horseshoe crab spawning activities (Maryland Department of Natural Resources, unpublished data, 1998). Erosion and shoreline protection structures (e.g., bulkheads, seawalls, revetments constructed to minimize erosion impacts) compromise the integrity of essential habitat through both the erosional process itself and interference with natural beach migration. Channel dredging and overboard spoil disposal are common throughout the Atlantic coast, but effects on horseshoe crabs are currently unknown.

Horseshoe crabs are relatively tolerant of petroleum hydrocarbons, but the tolerance decreases with increasing temperature. However, Nelson (pers. comm., 1997) reports that high density number 6 oil resulted in adult horseshoe crab mortality in New Hampshire possibly due to fouling of the book gills. Exposure to oil and chlorinated hydrocarbons resulted in delayed molting and elevated oxygen consumption in horseshoe crab eggs and juveniles (Laughlin and Neff, 1977). Maghini (1996) found trace metal and organochlorine concentrations to be relatively low in shorebird, horseshoe crab, and substrate samples from Delaware beaches and concluded that existing concentrations were of low toxicological concern. Red tide events may result in significant mortality, particularly to juveniles inhabiting intertidal areas and tidal flats (Rudloe, pers. comm., 1998).

In the Delaware Bay, Burger (1997) identified low levels of mercury (27 to 93 ppb) in horseshoe crab eggs between

1993 and 1995 and low cadmium levels in 1993 and 1995 (17 ppb and 24 ppb, respectively), but relatively higher levels in 1994 (310 ppb). Lead (558 to 87 ppb), chromium (5,059 to 250 ppb), and manganese (18,371 to 7,118 ppb) levels in eggs generally decreased from 1993 to 1995 in the Delaware Bay, while selenium levels (1,965 to 3,472 ppb) increased in those years (Burger, 1997). Burger (1997) concluded that the additional stress from heavy metals on horseshoe crab eggs could impair reproduction.

Because the Delaware estuary is a major petrochemical center on the East Coast (Sharp, 1988), oil spills during the horseshoe crab spawning season could threaten populations in the Delaware Bay. In addition, mercury, lead, zinc, and cadmium may be of concern in some coastal estuaries and rivers, such as the Cohansey (New Jersey) and Saint Jones (Delaware) Rivers (Sharp, 1988). Delaware Division of Fish and Wildlife's 16-foot trawl survey data indicate the area off the Saint Jones River is a major nursery area for horseshoe crabs.

1.6. IMPACTS OF THE FISHERY MANAGEMENT PROGRAM

1.6.1. Biological and Environmental Impacts

Several factors contribute to the risk that harvesting may adversely effect horseshoe crab populations: (1) horseshoe crabs mature slowly, requiring 9 to 11 years to attain sexual maturity (Shuster and Botton, 1985); (2) some bait harvesters prefer gravid females; (3) horseshoe crabs aggregate inshore seasonally to spawn making them especially vulnerable to exploitation; and, (4) changes in abundance (increases or decreases) are not readily recognizable because they occur over a period of years (Shuster, 1996). Population data indicate that after harvesting ceases, horseshoe crabs do not rebound for approximately one decade, corresponding to the time required for horseshoe crabs to reach sexual maturity (Shuster, 1994).

The commercial fishery competes with fish and wildlife resource needs, particularly shorebirds and sea turtles. Identifying and maintaining optimal sustainable yield may not be adequate to meet the needs of both fish and wildlife resources and the commercial fishery. Shorebirds primarily feed on horseshoe crab eggs exposed on the surface, which do not contribute to the horseshoe crab population (Botton *et al*., 1994). Sufficient surface eggs are available only if horseshoe crabs are spawning at high densities. Therefore, adequate spawning densities must be maintained to ensure availability of horseshoe crab eggs for shorebirds. Sea turtles feed on adult horseshoe crabs, but their diet depends on relative abundance of the prey species. Appropriate coastwide management of the horseshoe crab population would ensure the long-term viability of the population for continued harvest and would provide necessary quantities of adults and eggs for fish and wildlife resources.

1.6.2. Socioeconomic Impacts

Horseshoe crabs are the primary bait for the American eel and conch fisheries in many mid-Atlantic States. In Maryland, the estimated value of the horseshoe crab fishery in 1996 for 10 horseshoe crab harvesters was $398,596 (Maryland Department of Natural Resources, 1998). Also in 1996, one Maryland seafood dealer who supplies horseshoe crabs to 20 American eel and 25 conch harvesters, estimated that the value of horseshoe crabs for these fisheries was $151,200. Horseshoe crab prices vary and are reported to be between $0.65 to $0.75 per horseshoe crab (Maryland Department of Natural Resources, 1998).

In 1997, American eel and conch harvesters in Delaware used an average of 4,714 and 20,502 horseshoe crabs per season per harvester, respectively; while in New Jersey, American eel and conch harvesters used an average of 4,005 and 22,654 horseshoe crabs per season per harvester, respectively (Munson, 1998). Many conch and American eel harvesters in New Jersey and Delaware harvest their own bait, supplying 18 to 65 percent of their bait needs (Munson, 1998). While only 9 percent of the fishing income (of respondents in the Delaware Bay Watermen's study) is attributable to the direct sale of horseshoe crabs, an average of 58 percent of the eel and conch fishing income depends on using horseshoe crabs as bait (Munson, 1998). American eel harvesters in Delaware Bay report about 21 percent of their total fishing income is attributable to eeling, while conch harvesters report an average of 53 percent of their total fishing income depends on the conch fishery (Munson, 1998). In 1996, the commercial harvest of horseshoe crabs was estimated to be a $1.5 million industry.

Horseshoe crabs are vital to medical research and the pharmaceutical products industry. The worldwide market for LAL is currently estimated to be approximately $50 million per year. This estimate is based on bleeding 250,000 horseshoe crabs per year, generating approximately $200 per crab in revenue for the biomedical industry. The biomedical industry either directly collects horseshoe crabs on spawning beaches or purchases horseshoe crabs at prices up to $3.00 per crab. The biomedical industry pays approximately $375,000 per year for horseshoe crabs based on using an estimated 250,000 horseshoe crabs at an average price of $1.50 per crab.
Eco-tourism is critical to many states economies (e.g., New Jersey and Delaware) and depends on the abundance and health of ecosystems within the region. In 1988, over 90,000 "birders" spent $5.5 million in Cape May, New Jersey (Kerlinger and Weidner, 1991) to watch the interaction between spawning horseshoe crabs and migrating shorebirds. In 1996, approximately 606,000 people in New Jersey and Delaware took trips away from their residence (> 1 mile) for the primary purpose of wildlife watching (e.g., observing, photographing). Of these people, 409,000 people identified watching shorebirds from a list of birds that included raptors, waterfowl, and songbirds (U.S. Bureau of Census and USFWS, 1998). In 1996, New Jersey and Delaware wildlife watchers spent between 9 and 12 days per year (on average) away from home (> 1 mile) watching wildlife (U.S. Bureau of Census and USFWS, 1998). Total expenditures (including food, lodging, transportation, and equipment) in 1996 for the primary purpose of wildlife watching in New Jersey and Delaware was $639,992,000 (USFWS, 1998). However, the type of wildlife watched was not identified. The 1996 regional economic impact resulting from expenditures by wildlife watchers in New Jersey and Delaware is the creation of 15,127 jobs and the generation of a total household-income of $399 million (USFWS, 1998).

2.0. GOALS AND OBJECTIVES

The goal of this Plan is to conserve and protect the horseshoe crab resource to maintain sustainable levels of spawning stock biomass to ensure its continued role in the ecology of the coastal ecosystem, while providing for continued use over time. Specifically, the goal includes management of horseshoe crab populations for continued use by:

- o current and future generations of the fishing and non-fishing public (including the biomedical industry, scientific and educational research);

- o migrating shorebirds; and,

- o other dependent fish and wildlife, including federally listed (threatened) sea turtles.

To achieve this goal, the following objectives must be met:

(a) prevent overfishing and establish a sustainable population;

(b) achieve compatible and equitable management measures among jurisdictions throughout the fishery management unit;

(c) establish the appropriate target mortality rates that prevent overfishing and maintain adequate spawning stocks to supply the needs of migratory shorebirds;

(d) coordinate and promote cooperative interstate research, monitoring, and law enforcement;

(e) identify and protect, to the extent practicable, critical habitats and environmental factors that limit long-term productivity of horseshoe crabs;

(f) adopt and promote standards of environmental quality necessary for the long-term maintenance and productivity of horseshoe crabs throughout their range; and,

(g) establish standards and procedures for implementing the Plan and criteria for determining compliance with Plan provisions.

The fishery management unit includes the horseshoe crab stock(s) of the Atlantic Coast of the United States (Maine to eastern Florida). To facilitate implementation, the management unit may be subdivided into New England estuaries and shoreline (Maine through Connecticut), Long Island Sound and New York Bight, Delaware Bay, and Chesapeake Bay including the Delmarva Coast (New York to Virginia), and the South Atlantic Bight (North Carolina to Florida). These subdivisions are based on harvest pressure, recognizably separate populations, and abundance of horseshoe crabs.

3.0. MANAGEMENT PROGRAM SPECIFICATIONS / ELEMENTS

Management of the species will be based on scientific advice provided by state and federal biologists, as well as input from public hearings and an Advisory Panel. Management will strive for long-term viable populations supporting sustainable fisheries (including the biomedical industry) and dependent fish and wildlife resources. Effective management may require monitoring coupled with controls on fishing mortality and habitat degradation. The measures outlined below are designed to facilitate the management process. As new data become available and new assessments are completed, management activities will be adjusted accordingly.

3.1. ECOLOGICAL CONSIDERATIONS

Horseshoe crabs are an important component of the ecosystem. A certain amount of egg and adult biomass must be maintained to meet the needs of those species for which the horseshoe crab is an important food source.

Shorebirds rely on horseshoe crab eggs to replenish their fat reserves to continue their spring migration. Based on total energy requirements of sanderlings, Castro and Myers (1993) projected that 539 metric tons of horseshoe crab eggs would be needed to sustain the spring migration of shorebirds through the Delaware Bay (assuming the shorebirds ate only horseshoe crab eggs). To meet this need, Castro and Myers (1993) estimated that approximately 3,640,000 horseshoe crabs (assuming a sex ratio of 1:1) are required to meet this need. Recent work by Tsipoura and Burger (1998) shows that shorebird diet during spring stopovers does not consist entirely of horseshoe crab eggs. While the 539 metric tons may be an overestimate of the need, the importance of horseshoe crab eggs to the diet of shorebirds is not diminished.

Horseshoe crab eggs and larvae are a seasonal food item of various finfish, such as striped bass and white perch, as well as all crab species and several gastropods (Shuster, 1982). The degree of dependence upon horseshoe crab eggs and larvae by these species is unknown.

Horseshoe crabs are dietary components of the federally listed (threatened) loggerhead turtle. The extent to which loggerhead turtles rely on horseshoe crabs is unknown, but data collected in the mid-Atlantic coast region by NMFS and other researchers showed that a majority of loggerhead turtle stomachs examined contained horseshoe crabs. Federally listed species are afforded protection under the Endangered Species Act (87 Stat. 884, as amended; 16 U.S.C. 1531 *et seq*.) pursuant to Section 7(a)(2), which requires every federal agency to ensure that any action it authorizes, funds, or carries out is not likely to jeopardize the continued existence of any listed species or result in the destruction or adverse modification of critical habitat. Jurisdiction for loggerhead turtle population management resides with the NMFS (marine environment) or the USFWS (onshore environment); therefore, the Commission should initiate consultations regarding potential impacts of this Plan on loggerhead turtles.

3.2. ASSESSING ANNUAL RECRUITMENT

Little is known about annual recruitment in horseshoe crabs. Known factors include the following: maximum fecundity can be estimated (Shuster, 1982); most eggs that remain buried, and are not subject to shorebird predation, survive to hatching (Rudloe, 1979); and larval mortality from predation is substantial (Loveland *et al*., 1996). However, the number of larvae that survive to sexual maturity remains unknown. Because horseshoe crabs are slow maturing, long-lived, and repetitive spawners, current juvenile indexing techniques may have limited applicability. Additional information regarding larval and juvenile survival and mortality is essential to assessing annual recruitment. In addition, the total number of adult, sexually mature horseshoe crabs along the Atlantic Coast must be known to estimate annual recruitment.

3.3. ASSESSING SPAWNING STOCK BIOMASS

The spawning stock biomass for horseshoe crab populations along the Atlantic Coast is unknown due to a lack of information. Coastwide spawning survey data has been identified by the PRP as the highest research priority.

Botton and Ropes (1987a) provided a conservative adult horseshoe crab estimate of 2.3 to 4.5 million for the Atlantic Coast between New Jersey and Virginia, based on the NMFS Northeast Fisheries Center trawl survey data. This region of the Atlantic Coast makes up the majority of the horseshoe crab population within the Atlantic Coast (Botton and Ropes, 1987a). Trawl survey data from New Jersey indicates that a preponderance of horseshoe crabs occur inshore of the areas sampled by NMFS. In addition, the gear type used by NMFS may not adequately sample horseshoe crabs. Therefore, the estimate of abundance identified by Botton and Ropes (1987a) is considered extremely conservative.

3.4. ASSESSING MORTALITY

Horseshoe crab mortality has three components: natural mortality, mortality associated with commercial biomedical applications, and bait fishing mortality. Natural mortality includes beach strandings, predation, and other factors such as disease. Beach strandings may account for 10 percent of the adult horseshoe crab population in Delaware Bay (Botton and Loveland, 1989). Stranding mortality may be higher than the reported 10 percent in areas where rip-rap and revetments entrap horseshoe crabs. In other areas, strandings may account for a much lower percentage (Rudloe, pers. comm., 1998). Shorebird predation on eggs may simply remove excess production (i.e., surface eggs). Adult horseshoe crabs provide a component of loggerhead turtle diets as evidenced by stomach content analyses. The percent natural mortality attributable to other factors is unknown.

Of the estimated 200,000 to 250,000 crabs bled by the biomedical industry each year, perhaps as many as 10 to 15 percent of the crabs do not survive the bleeding procedure, which comprises a source of mortality not included in the commercial landing statistics (Rudloe, 1983; Thompson, 1998). Mortality due to the bleeding procedure may be lower (e.g., 0 to 4 percent), depending on the individual biomedical facility (Swan, pers. comm., 1998). However, the mortality associated with collecting, shipping, and handling remains unknown. Currently, the biomedical industry is estimated to account for the mortality of 20,000 to 37,500 horseshoe crabs per year (10 to 15 percent).

Fishing mortality is the rate at which fish are removed from the population by human activities and may include directed fishing mortality (e.g., intentional legal harvest) and nonharvest mortality (e.g., poaching and bycatch). The 1996 fishing mortality accounted for at least 2 million individuals throughout the Atlantic Coast, with at least 1.7 million individuals being taken between New Jersey and Virginia based on landings data provided by individual states and the NMFS (1998). Reported commercial landings data show a substantial increase in harvest during the 1990s, which may be a function of an increase in fishing effort and an increase in reporting. Fishing mortality is not presently available due to a lack of information (Atlantic States Marine Fisheries Commission, 1998b).

3.5. SUMMARY OF MONITORING PROGRAMS

Numerous state and federal agencies, universities, and private organizations are involved in data-collection efforts to ascertain horseshoe crab population status. Monitoring and evaluation efforts specific for horseshoe crabs include egg counts in Delaware Bay (New Jersey and Delaware) by Dr. Robert Loveland of Rutgers University and Dr. Mark Botton of Fordham University, egg counts by Dr. Richard Weber of the University of Delaware, spawning surveys in Delaware Bay (New Jersey and Delaware) by Limuli Laboratories, spawning surveys in New Hampshire by Great Bay National Estuarine Research Reserve, and spawning surveys in Maryland's Chesapeake and coastal bays by Maryland Department of Natural Resources. Trawl surveys are conducted along the New Jersey Atlantic Coast by New Jersey Division of Fish, Game and Wildlife and within the Delaware Bay by the Delaware Division of Fish and Wildlife. Trawl surveys have been conducted along Maryland's Atlantic Coast bays by Maryland Department of Natural Resources, and in Peconic Bay, New York by New York State Department of Environmental Conservation. The NMFS Northeast Fishery Center, the State of Massachusetts, and the Connecticut Department of Environmental Protection also conduct trawl surveys. South Carolina Department of Natural Resource's Crustacean Management Section conducts trawl surveys in five estuaries in South Carolina. The National Oceanic and Atmospheric Administration / SEAMAP conducts shallow water trawl surveys between South Carolina and Florida. Limuli Laboratories and Maryland Department of Natural Resources also conduct tagging studies. Concurrently, several shorebird monitoring efforts are being conducted, including aerial surveys, diet / weight-gain studies, and banding studies by state and educational research institutions.

While each of the above-mentioned monitoring programs are useful in identifying general trends within specific areas, each is complicated by factors that may bias the data, such as sampling error, inappropriate equipment, or incomplete sampling effort. The independent monitoring programs also lack a comprehensive data collection goal. The goal of a comprehensive horseshoe crab monitoring program should be to produce data necessary to develop a stock assessment for the Atlantic Coast horseshoe crab populations that can be used in future management decisions.

To collect information to assist in future management decisions, a comprehensive monitoring plan must be developed throughout the Atlantic Coast. Such monitoring efforts should be standardized and occur in *each* of the cooperating states within the Commission. Monitoring efforts must recognize the need to compare existing survey information with future survey information, but not at the expense of adequate design. Recommendations for such a monitoring program include the following components:

Component A. Continue or initiate mandatory monthly reporting of all harvest (including, but not limited to bait fisheries, bycatch, biomedical industry, and scientific and educational research harvest). Reporting requirements should consist of numbers landed and pounds landed by sex and harvest method. Each state must characterize a portion of the commercial catch based on prosomal width by sex. The approximate location of horseshoe crab harvests is required to determine where fishing effort is concentrated. If horseshoe crabs are captured for biomedical use, all states also must monitor and report monthly and annual harvest of horseshoe crabs by biomedical facilities (i.e., numbers), identify percent of mortality up to the point of release (including harvest, shipping, handling, and bleeding mortality), and certify that harvested horseshoe crabs are being used by biomedical facilities and not for other purposes. The use and harvest of horseshoe crabs for scientific and educational research should also be monitored and reported by all states.

Component B. Continue existing benthic sampling programs in the following states: Rhode Island, Massachusetts, Connecticut, New York, New Jersey, Delaware, Maryland, North Carolina, South Carolina, and Georgia. Benthic sampling programs should record weight, number, and prosomal width by sex of individuals collected. States that currently collect data from juvenile trawl surveys should include these data in annual monitoring reports. Juvenile sampling programs should record number and prosomal width (other data are not required).

Component C. Participate in a coastwide workshop to formulate standardized and statistically robust methodologies (e.g., method of collection, survey time, location, method of counting), survey cost, and schedule for implementation for horseshoe crab egg counts to identify trends in the annual spawning horseshoe crab population and eggs available to shorebirds. Implement a pilot program to survey horseshoe crab eggs in New Jersey and Delaware by the 1999 horseshoe crab spawning season.

Component D. Participate in a coastwide workshop to formulate standardized and statistically robust methodologies (e.g., stratified random sampling design described in Maio *et al*. (1998) or comparable statistically robust methodology), survey cost, and schedule for implementation for

horseshoe crab spawning surveys. Implement a pilot program to survey horseshoe crab spawning in New Jersey, Delaware, and Maryland by the 1999 horseshoe crab spawning season.

Component E. Evaluate the post-release mortality of horseshoe crabs used by the biomedical industry by initiating a tagging program. A coordinated tagging program shall be developed by the Technical Committee (possibly including release site location, numbers tagged, and numbers recaptured) and implemented by the biomedical industry. States that have biomedical industries would be required to ensure that the subject biomedical industries implement the tagging program and report results of the tagging program to the states. States shall include results of the tagging program in their annual report.

Component F. Identify potential horseshoe crab habitat (both spawning and nursery habitat) within each state by December 31, 1999. Data provided to the USFWS's Delaware Bay Estuary Program in a compatible format will be incorporated into a Geographic Information System database.

Each state must implement at least components A, B, E, and F identified above, to provide information on horseshoe crab landings, post-release mortality, and trends from year to year. The States of New Jersey and Delaware must implement Component C and the States of New Jersey, Delaware, and Maryland must implement Component D. The Horseshoe Crab Technical Committee will provide guidance regarding the formulation of appropriate methodologies (including appropriate equipment) for egg count surveys, spawning surveys, and benthic sampling programs. Such a comprehensive monitoring program must be initiated and continue for several consecutive years to provide the most reliable data on horseshoe crab population stocks. The monitoring program then should be reevaluated and potentially conducted on a less frequent basis.

If a state wants to be relieved of mandatory monitoring program components, the state has the option to prohibit all commercial bait harvest within its jurisdiction; however, monitoring requirements related to the biomedical industry (if one exists) are still required.

3.6. BYCATCH REDUCTION

The shrimp trawl fishery in the South Atlantic Bight may contribute to horseshoe crab mortality via bycatch (Thompson, 1998). Bycatch of horseshoe crabs has been greatly reduced with the mandatory requirement to use turtle excluder devices in the shrimp trawl fishery (Cupka, pers. comm., 1998). Dredging for whelk in Virginia also may result in substantial bycatch of horseshoe crabs. The amount of bycatch harvest remains unknown. Additional information would be required to determine the significance of bycatch. It is likely that bycatch horseshoe crabs are sold for bait and may be reported in total harvest. States and federal agencies must assess the magnitude of bycatch mortality occurring in waters under their jurisdiction.

3.7. HABITAT IMPACTS

Potential loss of spawning habitat would result in significant impacts on horseshoe crabs. Threats to horseshoe crab populations and spawning habitat include sea level rise / land subsidence, coastal erosion, channel dredging, and contaminants. Global warming and the subsequent rise in sea level could adversely affect horseshoe crab spawning activities. Sea level is predicted to rise above current levels by approximately 50 centimeters to 1 meter by the year 2100 (Oerlemans 1989; Titus *et al*., 1991). Land subsidence along the Atlantic Coast adds to the effect of sea level rise, resulting in an increase of 25-30 centimeters greater than the global average (Hull and Titus, 1986).

Coastal erosion is a natural process and causes beaches to retreat landward over time. Combined with shoreline development, erosion adversely affects horseshoe crab spawning beaches. Development adjacent to shorelines prevents the natural migration of beaches landward. Construction of bulkheads, groins, revetments, and seawalls protect shorelines by preventing natural migration of beaches. Optimally, beaches should be permitted to naturally migrate landward, but the presence of commercial and residential development along the Atlantic Coast, makes this infeasible in many areas. State and federal agencies charged with shoreline protection are currently using beach nourishment as the preferred shoreline protection strategy. Beach nourishment protects development and infrastructure and may provide habitat for horseshoe crab spawning. However, if beach nourishment projects do not keep pace with erosion in developed areas, potential horseshoe crab spawning beaches may be reduced. Ultimately, the long-term and short-term benefits and potential adverse impacts from beach nourishment projects on horseshoe crabs must be assessed.

Channel dredging and overboard spoil disposal are common throughout the Atlantic coast, but currently have unknown effects on horseshoe crabs. Changes in salinity as a result of dredging projects could alter horseshoe crab distribution. Additionally, dredging associated with whelk and other fisheries may damage horseshoe crab benthic habitat; however, the significance of this impact also remains unknown.

Pollution has the potential to adversely impact the horseshoe crab population or its habitat. Currently, there are no data to suggest unusual sensitivity by horseshoe crabs to urban or agricultural contaminants (e.g., pesticides and herbicides) (Botton, 1995). However, mosquito control agencies in New Jersey and Delaware have recently expanded their use of the mosquito larvicide methoprene, an insect growth regulator (IGR) that mimics juvenile growth hormones. Insecticides such as IGRs have been found to adversely effect crustaceans when they attempt to molt, based on laboratory experiments at levels of exposure higher than applied in the field (Kas'yanov and Costlow, 1984). However, due to the low concentrations of IGRs applied in the field, low potential for bioaccumulation, short half life, and low probability of direct exposure to horseshoe crabs, it is unlikely that IGRs have any measurable adverse impacts on horseshoe crabs (Meredith, pers. comm., 1998). Additional information should be collected to determine if there are any impacts on horseshoe crabs from actual or simulated operational use under normal field conditions of mosquito larvicides applied in coastal marshes. Maghini (1996) found concentrations of trace metals and organochlorines to be relatively low in shorebird, horseshoe crab, and substrate samples from Delaware beaches and concluded that existing concentrations were of low toxicological concern. Oil is also a potential threat to horseshoe crab habitat and populations. The impacts of an oil spill on spawning beaches during the spawning season could be catastrophic for horseshoe crabs and shorebirds.

4.0. MANAGEMENT PROGRAM IMPLEMENTATION

The Commission encourages all states to implement uniform standards for managing the horseshoe crab along the Atlantic Coast. Each state is responsible for implementing management measures and protecting horseshoe crab habitat within its jurisdiction to ensure the viability of the population segment, either produced or residing within its boundaries.

4.1. RECREATIONAL FISHERIES MANAGEMENT MEASURES

Since there are no known recreational fisheries for the horseshoe crab, no recreational fisheries management measures are proposed.

4.2. COMMERCIAL FISHERIES MANAGEMENT MEASURES

Commercial landings data show a substantial increase in reported harvest during the 1990s, which may be a result of improved reporting and / or increased fishing effort. Due to the uncertainty of the stock assessment and reported harvest data, the selection of conservative commercial fisheries management measures is essential.

4.2.1. Harvest Level Threshold

The Management Board will develop a cap on landings for commercial bait fisheries with consideration of an effort cap during 1999, to be implemented in 2000 through the adaptive management procedures identified in Section 4.5. States are encouraged to cap landings for commercial bait fisheries in 1999.

Component A in Section 3.5 requires all states to continue or initiate mandatory monthly reporting of all harvest (including, but not limited to bait fisheries, bycatch, biomedical industry, and scientific and educational research harvest). A cap on landings for commercial bait fisheries would be based in part on information collected pursuant to Component A.

Additional management options that were considered by the Management Board are identified in Appendix A. Reference period landings specified in some of the management options are identified in Appendix B.

4.2.2. Other Management Measures

4.2.2.1. *New Jersey, Delaware, and Maryland*

The States of New Jersey, Delaware, and Maryland shall maintain their existing state laws and regulations relative to the harvest and landings of horseshoe crabs.

This management measure is necessary to protect horseshoe crab spawning within and adjacent to the Delaware Bay, which is the epicenter of spawning activity on the Atlantic Coast. Any changes to such programs must first be approved by the Management Board.

4.2.2.2. *Other Jurisdictions*

All other jurisdictions, besides New Jersey, Delaware, and Maryland are encouraged to implement a two day per week closure during the period of April 15 to June 15, on the harvest of horseshoe crabs within 1,000 feet of mean low water. However, this measure is not mandatory unless required by the Management Board and implemented by addendum to the Plan.

The purpose of this closure is to provide some level of protection in spawning areas.

4.2.3. Exceptions (Biomedical Applications; Scientific and Educational Research)

The current estimate of commercial harvest for biomedical applications is between 200,000 and 250,000 horseshoe crabs per year on the Atlantic Coast (Swan, pers. comm., 1998, McCormick, pers. comm., 1998). This harvest has increased from 130,000 in 1989 according to the FDA. The FDA and the South Carolina Department of Natural Resources require the return of horseshoe crabs to the environment. Most labs return bled crabs to their habitat within 72 hours of capture (Botton, 1995). As many as 20,000 to 37,500 horseshoe crabs (10 to 15 percent) do not survive the bleeding procedure. The reported 10 to 15 percent may be a maximum bleeding mortality rate (Swan, pers. comm., 1998; McCormick, pers. comm., 1998). However, the mortality associated with collecting, shipping, and handling remains unknown.

Because both the number of horseshoe crabs captured per year and the reported mortality are low, the horseshoe crab fishery for biomedical use is not subject to the potential limitations contained in Section 4.2.1 and 4.2.2., subject to the following restrictions. States must issue a special permit, or other specific authorization, for harvests for biomedical purposes. Horseshoe crabs taken for biomedical purposes shall be returned to the same state or federal waters from which they were collected. If horseshoe crab mortality associated with collecting, shipping, handling, or use by the biomedical industry exceeds 57,500 horseshoe crabs per year, the Commission would reevaluate potential restrictions on horseshoe crab harvest by the biomedical industry.

The use of horseshoe crabs for scientific and educational research remains unreported; however, the number of horseshoe crabs harvested for these purposes is considered to be small. No harvest or landing restrictions are currently recommended for scientific and educational research. If harvest or use of horseshoe crabs for scientific and educational research increases by a factor of two from 1999 levels, the Commission would reevaluate potential restrictions on horseshoe crab harvest and use for such purposes.

The use of horseshoe crabs for scientific research (e.g., benthic sampling program investigations) may allow harvest based on a set-aside quota. The scientific research set-aside quota must be under the harvest threshold level established in Section 4.2.1. and would be determined by the Management Board.

4.2.4. Management Measures in Federal Waters

Harvest of horseshoe crabs in federal waters that are not landed in states, but exchanged directly to a dependent fishery (e.g., conch fishers), must be evaluated. Therefore, to comply with the selected management option, the Commission recommends that the Secretary of Commerce address and initiate controls over harvest and use of horseshoe crabs in federal waters that are not landed in states. In addition, the Commission recommends that the Secretary of Commerce ensure that horseshoe crabs harvested in federal waters that are landed in any state be done so in accordance with applicable State laws.

4.3. HABITAT CONSERVATION AND RESTORATION

Protection of essential habitat such as spawning beaches is critical to the continued survival of horseshoe crabs. Each state must institute the following measures to protect horseshoe crab habitat:

(a) Identify potential horseshoe crab habitat (both spawning and nursery habitat) by December 31, 1999 (as defined in Section 3.5, Component F).

(b) State fisheries agency(s) must actively intervene to the extent of its authority to ensure that federal, state, and local regulatory agencies are aware of the potential loss in horseshoe crab productivity associated with water quality degradation and habitat loss.

Additionally, states should also attempt to categorize and prioritize essential horseshoe crab habitat (both spawning and nursery habitat) within areas of its jurisdiction. Periodic monitoring should be designed and implemented to ensure the long-term viability of critical horseshoe crab spawning beaches.

States should consider obtaining land adjacent to critical spawning beaches to ensure the long-term protection of these beaches. Protection of essential habitat should be pursued through acquisition, deed restrictions, or conservation easements. In addition, states should pursue restricting all-terrain vehicles and beach watercraft activity (e.g., jet skis) on spawning beaches during the spawning season (with the exception of emergency vehicles) to minimize mortality of horseshoe crab embryos and larvae.

As evidenced by erosion rates over the last 70 to 100 years, beach erosion and limits on natural beach migration will continue to threaten horseshoe crab essential habitat (U.S. Army Corps of Engineers, 1991; U.S. Army Corps of Engineers, 1997; Thompson, 1998). Residential and commercial development adjacent to critical horseshoe crab spawning habitat should be discouraged to allow natural migration of beaches landward and to avoid potential shoreline protection in the form of bulkheads, revetments, and rip-rap. In areas where residential and commercial development is adjacent to horseshoe crab spawning habitat, remedial action (e.g., beach nourishment) should be implemented in cooperation with agencies charged with shoreline protection (e.g., U.S. Army Corps of Engineers and state coastal engineering agencies) to ensure that critical spawning beaches are not lost to coastal erosion.

Specifically, Section 1135(b) of the Water Resources Development Act of 1986, as amended (33 U.S.C. 2201 *et seq*.; 100 Stat. 4082) allows the U.S. Army Corps of Engineers (Corps) to investigate, study, modify, and construct projects for the restoration of fish and wildlife habitats where degradation is attributable to existing federal water resources projects (e.g., dredging, groin construction, bulkheads, seawalls) previously constructed by the Corps. Additionally, Section 206 of the Water Resources Development Act of 1996 (33 U.S.C. 2201 *et seq*.) allows the

Corps to investigate, study, modify, and construct projects for the restoration of aquatic habitats, where degradation is not directly attributable to an existing federal water resource project.

Beach nourishment may restore or improve spawning habitat, provided measures are implemented to minimize adverse project-related impacts on horseshoe crabs and other resources. Specifically, borrow areas for beach nourishment should be located offshore to avoid adverse impacts on essential juvenile habitat (nearshore, shallow water, subtidal flats). The grain size of renourishment material should be similar in size to the grain size that currently exists on the beach. Construction activities should avoid critical spawning and juvenile development periods. In the mid-Atlantic region, the generally recommended seasonal restriction is from April 15 to August 30. However, the specific seasonal restriction dates for any particular area should be based on site-specific data and appropriate monitoring.

4.4. ALTERNATIVE STATE MANAGEMENT REGIMES

With approval of the Horseshoe Crab Management Board, a state may vary its regulatory specifications contained in Section 4.2., so long as that state can show to the Board's satisfaction that the target fishing mortality will not be exceeded. Under no circumstances will states be allowed to institute management regimes that compromise the minimum number of horseshoe crabs necessary to sustain dependent fish and wildlife resources. Although additional data must be collected to accurately determine the number of horseshoe crabs necessary to sustain dependent fish and wildlife resources, the best scientific information currently available must be used to ensure that horseshoe crabs and their eggs are available to sustain fish and wildlife resources.

Procedures to modify state regulations include the following:

(a) A state may submit a proposal for a change to its regulatory program or any mandatory compliance measure under the Plan to the Commission. Changes shall be submitted to the Commission staff, who will

distribute the proposal to the Management Board, the Plan Review Team, the Technical Committee, the Stock Assessment Committee, and the Advisory Panel.

(b) States must submit a proposal at least two weeks prior to the Technical Committee's spring or fall meeting.

(c) The Plan Review Team is responsible for gathering the comments of the Technical Committee, the Stock Assessment Committee, and the Advisory Panel, and presenting these comments to the Management Board for action.

(d) The Management Board will approve the state proposal for an alternative management program if it determines that the alternative management program is consistent with the target fishing mortality rate, and meets the goals and objectives of this Plan.

4.5. ADAPTIVE MANAGEMENT

Under adaptive management, the Horseshoe Crab Management Board may vary the requirements specified in the Plan to achieve the goals and objectives specified in Section 2. Specifically, the Management Board may change target fishing mortality rates and harvest restrictions. Such changes will be effective on January 1 (or on the first fishing day of the year), but may be put in place on an alternative date when deemed necessary by the Management Board.

Procedures to implement adaptive management are as follows:

(a) The Plan Review Team (PRT) will continually monitor the status of the fishery and the resource and report to the Management Board on or about March 15. The PRT will consult with the Technical Committee, the Stock Assessment Committee, and the Advisory Panel, in making their review and report. The report will contain recommendations concerning proposed adaptive revisions to the management program.

(b) The Management Board will review the PRT report, and may consult independently with the Technical Committee, the Stock Assessment Committee, or the Advisory Panel. The Management Board may direct the PRT to prepare an addendum to affect changes it deems necessary. The addendum shall contain a schedule for the states to implement its provisions.

(c) The PRT will prepare a draft addendum as directed by the Management Board, and shall distribute it to all states for review and comment. A public hearing will be held in any state that requests one. The PRT will also request comment from federal agencies and the public at large. After a 30-day review period, the PRT will summarize the comments and prepare a final version of the addendum for the Management Board.

(d) The Management Board shall review the final version of the addendum prepared by the PRT, and also shall consider the public comments received and the recommendations of the Technical Committee, the Stock Assessment Committee, and the Advisory Panel; it shall then decide whether to adopt or revise the addendum.

(e) Upon adoption of an addendum, states shall prepare plans to carry out the addendum and submit them to the Management Board for approval, according to the schedule contained in the addendum.

4.6. MANAGEMENT INSTITUTIONS

4.6.1. Atlantic States Marine Fisheries Commission and ISFMP Policy Board

The Commission and the Interstate Fisheries Management Program (ISFMP) Policy Board are responsible for the oversight and management of the Commission's fisheries management activities. The Commission must approve all fishery management plans and amendments thereto, and must make final determinations concerning state compliance or noncompliance. The ISFMP Policy Board reviews recommendations of the various Management Boards and, if it concurs, forwards them to the Commission for action.

4.6.2. Management Board

The Management Board is responsible for the development of a fishery management plan or amendment. The Management Board shall provide the ISFMP Policy Board with review and recommendations based on the fishery management plan. The Management Board may, after the necessary plan or amendment has been approved by the Commission, continue to monitor the implementation and enforcement of the fishery management plan or amendment, advise the ISFMP Policy Board of its effectiveness, or take other actions specified in the fishery management plan that are necessary to ensure its full and effective implementation.

4.6.3. Plan Review Team

The PRT is a small group whose responsibility is to provide staff support necessary to carry out and document the decisions of the Management Board. The PRT is directly responsible to the Management Board for providing information and documentation necessary to carry out the Board's decisions.

4.6.4. Technical Committee

The Technical Committee will consist of one representative from each jurisdiction and federal agency with an interest in the horseshoe crab fishery. Its role is to act as a liaison to the individual state agencies, providing information to the management process and review and recommendations concerning the management program. The Technical Committee will report to the Management Board, normally through the PRT.

4.6.5. Stock Assessment Committee

The Stock Assessment Committee will consist of those scientists with expertise in the assessment of horseshoe crab populations. Its role is to assess horseshoe crab populations and provide scientific advice concerning the implications of proposed management alternatives, or to respond to other scientific questions of the Management Board. The Stock Assessment Committee will report to both the Management Board and the Technical Committee.

4.6.6. Advisory Panel

The Horseshoe Crab Advisory Panel is established according to the Commission Advisory Committee Charter. Members of the Advisory Panel are citizens who represent a cross-section of commercial and recreational fishing interests and others concerned about horseshoe crab conservation and management. The Advisory Panel provides the Management Board with advice directly concerning the Commission's horseshoe crab management program. Normally, the Advisory Panels meetings will be held at and in conjunction with selected Management Board meetings.

4.6.7. Departments of Commerce and Interior

The Commission has accorded NMFS (Department of Commerce) and the USFWS (Department of the Interior) voting status on the ISFMP Policy Board and the Horseshoe Crab Management Board. These federal agencies participate on the PRT, the Technical Committee, and the Stock Assessment Committee.

5.0. COMPLIANCE

Upon completion and approval of a management plan, states are obliged to implement its requirements. If a state does not comply with the conservation measures of the Commission fishery management plan, the law allows the U.S. Secretary of Commerce to impose a moratorium on that state’s particular fishery. All Commission fishery management plans must include specific measurable standards to improve the status of the stocks and to determine if the states comply with the standards.

5.1. MANDATORY COMPLIANCE ELEMENTS FOR STATES

A state will be found out of compliance if:

- its regulatory and management programs for horseshoe crab have not been approved by the Management Board;
- it fails to meet any implementation schedule established or any addendum prepared under adaptive

management (see Section 4.5);

- o it has failed to implement a change to its program when determined necessary by the Management Board; or,

- o it fails to adequately enforce any aspect of its regulatory and management programs.

5.1.1. Mandatory Elements of State Programs

5.1.1.1. *Regulatory Requirements*

All state programs must include a regime of restrictions on commercial fisheries and / or habitat impacts consistent with the requirements of Section 4.2. and 4.3.; except that a state may propose an alternative management program under Section 4.4. If approved by the Management Board, the state's proposal may be implemented as an alternative regulatory requirement for compliance under the law.

5.1.1.2. *Monitoring Requirements*

All state programs must include the mandatory monitoring requirements contained in Sections 3.5 and 4.2 of the Plan. States must submit proposals to the Commission for any intended changes to the required monitoring programs if the change may affect the quality of the data or the ability of the program to fulfill the needs of the fishery management plan. State proposals for modifications to required monitoring programs will be submitted to the Technical Committee at least two weeks prior to its spring or fall meetings. Proposals must be on a calendar year basis. The Technical Committee will make recommendations to the Management Board concerning whether the proposals are consistent with the Plan.

If a state realizes it will be unable to fulfill its independent fishery monitoring requirements, it should immediately notify the Commission in writing. The Commission must be notified by the planned commencement date of the monitoring program. The Commission will work with the state to develop a plan to secure funding or to plan an alternative program that will satisfy the needs outlined in the Plan. If the Plan is not implemented within 90 days after its adoption, the state will be found out of compliance with the Plan.

5.1.1.3. *Enforcement Requirements*

All state programs must include law enforcement capabilities adequate for successfully implementing the jurisdiction's horseshoe crab regulations.

5.1.2. State Reporting and Compliance Schedule

Each state must submit an annual report concerning its horseshoe crab fisheries and management program on or before March 1 each year, beginning March 1, 1999. The report shall cover:

(a) the previous calendar year's fishery and management program, including activity and results of monitoring (as identified in Section 3.5 of the Plan), regulations that were in effect and harvest, including estimates of nonharvest losses; and,

(b) the planned management program for the current calendar year (summarizing regulations that will be in effect and monitoring programs to be performed) highlighting any changes from the previous year.

States must implement this Plan according to the following schedule:

February 15, 1999: States must submit state programs to implement the Plan for approval by the Management Board. Programs, including monitoring programs, must be implemented upon approval by the Management Board.

March 15, 1999: States with approved management programs shall begin implementing the Plan.

5.2. PROCEDURES FOR DETERMINING COMPLIANCE

A. The PRT will continually review the status of state implementation of the Plan, and advise the Management Board whenever a question arises concerning state compliance. The PRT will review state reports submitted under Section 5.1.2. and prepare a report by May 1 for the Management Board, summarizing the status of the resource and fishery and the status of state compliance on a state-by-state basis.

B. Upon receipt of a report from the PRT, or at any time by request from a member of the Management Board, the Management Board will review the status of an individual state's compliance. If the Management Board finds that a state's regulatory and management program fails to meet the requirements of this section, it may recommend that the state is out of compliance. The recommendation must include a specific list of the state's deficiencies in implementing and enforcing the Plan and the actions that the state must take in order to come back into compliance.

C. If the Management Board recommends that a state is out of compliance, as referred to in the preceding paragraph, it shall report that recommendation to the ISFMP Policy Board for further review according to the ISFMP Charter.

D. A state that is out of compliance or subject to a recommendation by the Management Board under the preceding subsection may request at any time that the Management Board reevaluate its program. The state shall provide a written statement concerning its actions to justify a reevaluation. The Management Board shall promptly conduct such reevaluation (e.g., within 30 days), and if it agrees with the state, the Management Board shall recommend to the ISFMP Policy Board that the determination of noncompliance be withdrawn. The ISFMP Policy Board and the Commission shall address the Management Board's recommendation according to the ISFMP Charter.

6.0. MANAGEMENT RESEARCH NEEDS

6.1. STOCK ASSESSMENT AND POPULATION DYNAMICS

In order to collect information to assist in future management decisions, a comprehensive monitoring plan must be developed throughout the Atlantic Coast as described in section 3.5. In addition to the comprehensive monitoring plan, additional stock assessment and population dynamics information should be collected to assist in future management decisions. Priority research needs are highlighted in bold.

(a) Formulate a coastwide benthic sampling program for horseshoe crabs using standardized and statistically robust methodologies (including equipment appropriate to collect adult horseshoe crabs [e.g., benthic sled]). Survey cost, agency responsibility, schedule for implementation must also be identified for the subject coastwide horseshoe crab benthic sampling programs.

(b) Determine if geographic subpopulations exist, which may have implications for management.

(c) Conduct additional stock assessments and determine harvest mortality rates (F). Use these data to develop a more reliable sustainable harvest rate.

(d) Investigate larval and juvenile survival and mortality to assist in the assessment of annual recruitment. Such research could be aided by continuing and initiating new tagging programs within individual states.

(e) Further evaluate life table information including sex ratio and population age structure.

6.2. RESEARCH AND DATA NEEDS

Other research is required to assist in the management of the coastwide population of horseshoe crabs. Priority research needs are highlighted in bold.

(a) Investigate, encourage, and fund alternative bait sources (e.g., artificial bait) for eel and conch fisheries. Implement any alternative bait sources to reduce the need for commercial horseshoe crab harvesting. Alternative bait sources are currently being investigated by Nancy Targett (University of Delaware Graduate College of Marine Studies).

(b) Determine the relationship between horseshoe crab egg abundance and body condition, nutrient intakes, fecundity, and survival of dependent shorebirds (e.g., shorebird blood sample research as proposed by Barboza and Jorde).

(c) Continue or initiate shorebird surveys using standardized methodologies to determine weight gain during stopovers, shorebird habitat use as it relates to horseshoe crab essential habitat (e.g., shorebird numbers as it relates to horseshoe crab egg densities), population trends, and if possible a population estimate.

(d) Conduct economic studies to determine the value of the commercial fishery, biomedical, and ecotourism industries and the impact of regulatory management on these industries. Such economic studies should also include an assessment of economic impacts on other fisheries as they relate to horseshoe crabs.

(e) Evaluate the effect of mosquito control chemicals on horseshoe crabs in actual or simulated operational use under normal field conditions to determine if such activities impact horseshoe crab populations or individuals.

(f) Determine beach fidelity by horseshoe crabs to determine habitat use.

(g) Evaluate the effectiveness of currently used trawl gear for stock assessment.

(h) Evaluate the impacts of beach nourishment projects on horseshoe crab populations.

(i) Evaluate the importance of horseshoe crabs to other marine resources such as sea turtles.

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APPENDIX A

Additional Management Options For Bait Fisheries Considered By The Management Board

Option 1. Each state must establish a 25 percent reduction in its commercial fishery landings (numbers) based on reference period landings. The States of Delaware and New Jersey shall maintain their seasonal restriction / area restrictions on spawning beaches consistent with existing state laws. All other jurisdictions, besides Delaware and New Jersey shall implement a two day per week closure during the period of April 15 to June 15, on the harvest of horseshoe crabs within 1,000 feet of mean low water.

Option 2. Allow unrestricted harvest of horseshoe crabs (existing state laws regarding horseshoe crab harvest would be at the individual State's discretion). The Commission would conduct annual monitoring and recommend additional management measures as needed.

Option 3. Establish a coastwide cap 25 percent below the reference period landings from January 1 through December 31, 1999. Harvest or landing of horseshoe crabs between April 15 through June 15, 1999 shall be prohibited.[a]

Option 4. Establish a coastwide cap 10 percent below the reference period landings from January 1 through December 31, 1999. Restrict the harvest of horseshoe crabs to hand-harvest only between April 15 through June 15, 1999, such that hand-harvest during this period does not exceed 15 percent of the total allocation for the State.[a]

Option 5. Establish a coastwide cap 50 percent below the reference period landings from January 1 through December 31, 1999. Harvest or landing of horseshoe crabs between April 15 through June 15, 1999 shall be prohibited.[a]

Option 6. Maintain existing state laws (e.g., New Hampshire, New Jersey, Delaware, Maryland, Virginia, and South Carolina) regarding horseshoe crab harvest, but add a prohibition or phase-out of hand-harvest and establish a coastwide cap not to exceed reference period landings.

Option 7. Establish a moratorium on the commercial harvest of horseshoe crabs for one year. Continuance of such a moratorium would be evaluated on a yearly basis based on stock status. States would reopen fisheries upon approval of The Commission.

Option 8. Maintain existing state laws (e.g., New Hampshire, New Jersey, Delaware, Maryland, Virginia, and South Carolina) regarding horseshoe crab harvest and establish a coastwide cap not to exceed reference period landings.

Option 9. Establish a coastwide cap not to exceed reference period landings.

Option 10. Establish a coastwide cap 10 percent below the reference period landings from January 1 through December 31, 1999. Harvest or landing of horseshoe crabs between April 15 through June 15, 1999 shall be prohibited.[a]

Option 11. Establish a coastwide cap 75 percent below the reference period landings from January 1 through December 31, 1999. Harvest or landing of horseshoe crabs between April 15 through June 15, 1999 shall be prohibited.[a]

Option 12. Establish a coastwide cap of 10 percent below the reference period landings.[a]

Option 13. Establish a coastwide cap of 25 percent below the reference period landings.[a]

Option 14. Establish a coastwide cap of 50 percent below the reference period landings.[a]

Option 15. Establish a coastwide cap of 75 percent below the reference period landings.[a]

Option 16. Maintain existing state laws (e.g., New Hampshire, New Jersey, Delaware, Maryland, Virginia, and South Carolina) regarding horseshoe crab harvest, but add a prohibition against harvesting between February and July and establish a coastwide cap not to exceed reference period landings.

[a]Each state would be required to reduce harvest within its jurisdiction by the subject threshold level. The Board would review overharvest (i.e., overages) by states in any particular year and could subtract the overages from subsequent harvest thresholds. The closed harvest period (e.g., April 15 through June 15) established under the Plan may be lengthened or shortened, on an annual basis, following review by the Horseshoe Crab Technical Committee and final approval by the Board.

APPENDIX B

Reference period landings for commercial bait harvest of horseshoe crabs between 1995 - 1997.

State	Pounds	Numbers	Source
Maine	0	0	State (97)[1]
New Hampshire	0	0	State (97)[1]
Massachusetts	1,200,000	400,000	State (97)[1]
Rhode Island	490	184	NMFS (96-97 logbook)[2]
Connecticut	1,494	560	NMFS (95-97 logbook)[2]
New York	1,085,500	406,554	NMFS (95-97 landings)[3]
New Jersey	2,381,229	604,049	State (96)[4]
Pennsylvania	0	0	State (95-97)[1]
Delaware	2,065,764	482,401	State (95-97)[4]
Maryland	2,647,857	613,225	State (96)[4]
District of Columbia	0	0	NMFS (95-97 landings)[3]
Virginia	62,070	23,247	State (96-97)[4]
North Carolina	8,331	3,120	State (95-97)[1]
South Carolina	0	0	State (97)[1]
Georgia	-	-	State (97)[5]
Florida	0	0	NMFS (95-97 landings)[3]
TOTAL	**9,452,735**	**2,533,340**	

[1]State does not require mandatory reporting of horseshoe crab landings.
[2]National Marine Fisheries Service (1998) Vessel Trawl Logbook Data.
[3]National Marine Fisheries Service (1998) Horseshoe Crab Landings Data.
[4]State does require mandatory reporting of horseshoe crab landings.
[5]Data from the State is confidential (i.e., based on the low number of individuals reporting); however, harvest is minimal.

Source: National Marine Fisheries Service (1998) and individual state harvest records. The Horseshoe Crab Technical Committee reviewed and approved the reference period landings based on the reliability and accuracy of the best available data.

Note: The reference period landings may either be an average of several years or an individual year depending on data available. The Horseshoe Crab Technical Committee used the NMFS conversion rate of 2.67 lbs / individual for NMFS data and the following conversion rates for New Jersey and Delaware (males, 2.32 lbs / individual; females, 5.12 lbs / individual; both sexes, 3.72 lbs / individual). Maryland used either 4 or 5 lbs / individual based on composition of landings as determined by harvesters.

HORSESHOE CRAB SPECIES PROFILE

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I. SPECIES TAXONOMY AND MORPHOLOGY

Horseshoe crabs (Limulidae) are currently represented by four extant species including *Limulus polyphemus* found along the eastern coast of North and Central America and three Indo-Pacific species, *Tachypleus tridentatus*, *T. gigas*, and *Carcinoscorpius rotundicauda* (Shuster, 1982). One Asiatic species (*Tachypleus tridentatus*) is threatened in parts of its range due to overfishing, spawning habitat loss, and coastal pollution (Finn *et al*., 1991; Botton, 1995). All four species are similar in terms of ecology, morphology, and serology. Shuster (1955) identified that serological data from three of the four extant species indicates that the species are not congeneric (i.e., from the same genus). The following life history characteristics and discussion of horseshoe crabs will focus on *Limulus polyphemus*.

Horseshoe crabs are benthic (or bottom-dwelling) arthropods that use both estuarine and continental shelf habitats. Although it is called a "crab," it is neither a decopod or crustacean, rather horseshoe crabs are grouped in their own class (Merostomata), which is more closely related to the arachnids (Shuster, 1982). Horseshoe crabs have persisted for more that 200 million years (Botton and Ropes, 1987); however, Shuster (1996) identifies the evolutionary existence of horseshoe crabs to be over 400 million years.

Horseshoe crabs exhibit sexual dimorphism. Males are generally smaller than females at maturity (probably a result of females undergoing one more molt than males), with mean prosomal widths 75-79 percent of the adult female mean prosomal widths (Shuster, 1982). In addition, males have claspers that aid in attaching to females during amplexus (i.e., males coupled to females).

Shuster (1979) suggested that each major estuary along the coast had a discrete horseshoe crab population, which could be distinguished from one another by adult size, carapace color, and eye pigmentation. However, no significant differences between the morphologic characteristics of discrete populations are evident, based on high variability both within and among populations (Riska, 1981). In addition, based on electrophoretic evidence, gene flow does occur between widely separated populations, although considerable genetic variation exists within and between populations of horseshoe crabs (Selander, *et al*., 1970). Saunders *et al*. (1986) found no evidence for genetic divergence between New England and middle Atlantic populations based on mitochondrial DNA analysis. Larger animals and populations are located in the middle of the species' distribution (Maryland to New York) while smaller animals and populations are found in the southern and northern extent of its range (Shuster, 1982). Based on morphometric data collected in South Carolina, Thompson (1998) suggests that the greatest mean adult horseshoe crab size occurs in the South Atlantic Bight and decreases in size north and south. Thompson (1998) hypothesized that larger individuals occur in the South Atlantic Bight due to optimal temperature and salinity for horseshoe crab development in this region.

II. LIFE HISTORY CHARACTERISTICS OF THE HORSESHOE CRAB

A. SPATIAL AND SEASONAL DISTRIBUTION BY LIFE STAGE

Horseshoe crab distribution extends along the Atlantic coast from northern Maine (42ºN) to the Yucatan Peninsula (19ºN) and the Gulf of Mexico (Shuster, 1982). Horseshoe crabs are abundant between Virginia and New Jersey, with Delaware Bay at the center of the species distribution and the location of the largest population (Shuster and Botton, 1985; Botton and Ropes, 1987). Within Delaware Bay, the largest concentration of horseshoe crabs is found along the Cape May shore of New Jersey (Shuster and Botton 1985). Spawning densities of over 30 animals per meter occur within the Delaware Bay, based on 1986 spawning counts along 15 meter segments (Botton, *et al*., 1988). Horseshoe crab populations are smaller north of Cape Cod and south of Georgia, and individuals are smaller in size. The largest horseshoe crabs are found in estuaries from Georgia to New Jersey (Shuster, 1979). Spawning densities in Florida and South Carolina were reported as three and one animal per meter, respectively (Rudloe, 1980; Thompson, 1998). Even in New Jersey and Delaware, horseshoe crab abundance decreases with distance north and south of the Delaware Bay (Botton and Haskin, 1984).

Adult horseshoe crabs feed in coastal estuaries and along the Atlantic Coast throughout the summer. Adults either remain in the estuary or migrate to the continental shelf during the winter months. Migration is reinitiated in the spring, when horseshoe crabs move to beach areas to spawn. Juveniles hatch from the beach environment and spend the first two years in shallow, subtidal, flats near shore.

Horseshoe crab populations are typically associated with estuarine habitats. Important estuaries that support horseshoe crabs include Narragansett Bay in Rhode Island; Plum Island Sound, Cape Cod Bay, and Vineyard and Nantucket Sounds in Massachusetts; Long Island Sound in New York; Delaware Bay in New Jersey and Delaware; Chesapeake Bay in Maryland and Virginia; Beaufort Inlet in North Carolina; and, numerous estuaries within the South Atlantic Bight and Gulf Coast of Florida (Shuster, 1979; Rudloe, 1980).

Adult horseshoe crabs have been found as far as 35 miles offshore and in depths of over 290 meters (Botton and Ropes, 1987). However, 74 percent of the total number of horseshoe crabs caught in bottom trawl surveys compiled by the Northeast Fisheries Center were taken in water shallower than 20 meters and 92 percent were caught at depths less than 30 meters. Migration from beaches where horseshoe crabs have been tagged vary from a few kilometers in Florida to almost 34 kilometers in Massachusetts (Shuster, 1982). Horseshoe crabs remain dispersed over the continental shelf and on bay bottoms (e.g., Delaware Bay and Chesapeake Bay) for most of the year (Botton, 1995). However, trawl surveys in South Carolina found horseshoe crabs present on the continental shelf only during spring through fall. No animals were collected offshore during the summer trawling session (Thompson, 1998).

Based on a tagging and recovery program, Rudloe (1980) concluded that the mean distance travelled from a breeding beach in Florida was 7.6 kilometers with a range of 3.5 and 40.7 kilometers. Similarly, Shuster (1950) reported tagged horseshoe crab movements of up to 33.8 kilometers in Cape Cod Bay, Massachusetts. Thompson (1998) reported maximum distance covered by a tagged horseshoe crab was 4 kilometers in South Carolina. However, distance traveled may reflect movement of a fishing vessel rather than actual animal migration (Thompson, 1998).

B. ENVIRONMENTAL REQUIREMENTS

The distribution of horseshoe crabs is chiefly defined by water temperature, salinity, and depth, with temperature as a limiting factor for northern ranges (Shuster, 1982). Horseshoe crabs are ecological generalists and can survive within a wide range of environmental conditions. Horseshoe crabs are tolerant of a wide range of salinities; however, low salinities (<4 ppt) are lethal (Pearse, 1928). The horseshoe crab is also tolerant of a wide-range of oxygen levels. Physiological changes in the blood enable the horseshoe crab to survive hypoxic conditions on the continental shelf and when partially buried during spawning and in hyperoxic conditions when exposed to air (Shuster, 1982).

Optimal salinities from fertilization to hatching are in the range of 20 to 30 ppt; however, salinities of <20 ppt and

>30 ppt significantly prolong development. Temperature also has a significant effect on development. Embryonic development and time required to hatch is positively correlated with temperature; development occurs more rapidly in warmer temperatures (i.e., 35ºC) than colder temperatures (i.e., 20ºC) (Jegla and Costlow, 1982). Horseshoe crab larvae and embryos are characterized by extreme tolerance to hypoxic conditions, although embryos are slightly more tolerant to hypoxia than larvae. Development appears to stop at the onset of hypoxic conditions and resumes when normoxic conditions resume (Palumbi and Johnson, 1982). Currently, there are no data to suggest unusual sensitivity by horseshoe crabs to low dissolved oxygen, high turbidity, or urban or agricultural pollution (Botton, 1995).

C. SPAWNING

Migrating adults move inshore from deep bay and coastal waters in late spring to spawn. Inshore movement appears to be related to lengthening daylight hours. Spawning in the Chesapeake and Delaware Bays usually begins during the latter part of May when large numbers of horseshoe crabs move onto beaches to mate and lay eggs. The peak in spawning activity usually coincides with the high tide during the full moon and new moon in May and June in Delaware and New Jersey. However, in Florida breeding activity continues between March and November with peak spawning occurring as early as April (Brockmann, 1990) and as late as late August (Rudloe, 1980). In Massachusetts, spawning occurs between May and July (Barlow *et al*., 1986). Breeding activity is consistently higher during the full moon than the new moon and is also greater during the night as compared with the day tide (Rudloe, 1980). Thompson (1998) also found a significantly higher rate of spawning during the night in South Carolina. Thompson (1998) found that spawning horseshoe crabs responded to optimum tidal and solar conditions available during each lunar phase, rather than lunar phase itself. Barlow *et al*. (1986) in Massachusetts and Penn and Brockmann (1994) in Delaware found spawning activity greatest during the highest tides regardless of whether it was day or night. Brockmann and Penn (1992) found a significant tendency for horseshoe crabs tagged during the day to return to spawn during the day, while horseshoe crabs tagged during the night to return to spawn during the night. Lunar cycle, day of the year, and wave height are significantly correlated with horseshoe crab spawning activity (Rudloe, 1980). As a result of the high cost of spawning (i.e., mortality) Shuster and Botton (1985) observed that horseshoe crabs avoid spawning during rough weather, apparently overriding the impact of lunar periodicity.

Spawning activity is significantly greater at water temperatures of 20º C or greater in South Carolina (Thompson, 1998). At temperatures below 20º C, a state of dormancy is initiated and production of ecdysone is curtailed, which inhibits molting and development (Jegla, 1982).

While current tagging studies in New Jersey and South Carolina have not discounted the possibility of spawning site fidelity, horseshoe crabs are probably not loyal to one spawning site over successive years and generations (Thompson, 1998). However, spawning animals do display short-term fidelity to a spawning site, and return to the same site on numerous high tides until spawning is complete (Thompson, 1998; Brockmann, 1990). Shuster (1994) reports that while horseshoe crabs probably do not return to their natal beaches, a majority do return to the same estuary to spawn.

Adults prefer sandy beach areas within bays and coves that are protected from surf although spawning has been observed on mud, sod, and peat banks. In addition, horseshoe crabs may be capable of spawning in subtidal areas (Rudloe, pers. comm., 1998). Such low energy embayments include Tom's Cove (Chincoteague Bay, Virginia), Sandy Hook Bay (New Jersey), and Great Bay (New Hampshire) (Botton and Loveland, 1989). Optimum spawning areas are limited by the availability of sandy beach habitat. Eggs are laid in clusters or nest sites along the beach, usually between the tide marks. The average number of eggs per cluster is approximately 3,650 to 4,000 (Shuster 1982; Shuster and Botton, 1985)). Several egg clusters are made during one beach trip and females will return on successive tides to lay more eggs. A female will lay about 20 egg clusters each season in the Delaware Bay (Botton, 1995). However, Brockmann (1990) only identified up to 15 egg clusters each season in Florida. Fecundity, the total number of eggs per female per year, is approximately 88,000 (Shuster, 1982). Density of egg clusters has been reported to be as high as 50 egg clusters / linear meter (Shuster and Botton, 1985) and up to 500,000 eggs/m^2 (Botton *et al*., 1994). Egg development is dependent on temperature, moisture and oxygen and usually takes a month or more.

Egg nests are located in a broad area between 3 meters from the low-water line to the spring high-tide line (Shuster, 1982). Geochemical characteristics of the beach are more relevant than distance downslope or elevation (Penn and Brockmann, 1994). There are differences in the distribution of egg nests within a beach, which may be dependent (in part) upon the amplitude of the tides and beach morphology (Shuster, 1982; Penn and Brockmann, 1994). Specifically, beach morphology (e.g., grain size) affects oxygen, temperature, and moisture gradients on the beach. Delaware Bay beaches are characterized as coarse-grained and well-drained, whereas Florida beaches are fine-grained and poorly drained (Penn and Brockmann, 1994). Since horseshoe crabs nest at beach elevations where egg development is maximized, Penn and Brockmann (1994) found the mean nesting location for horseshoe crabs on Delaware Bay beaches to be about equal to the mean high tide line. However, horseshoe crabs in Florida nest much higher up on the beach (than in the Delaware Bay) to avoid anaerobic conditions at the mean high tide line (Penn and Brockmann, 1994). Ultimately, eggs buried too high on the beach are subject to desiccation and those buried too low are subject to anoxic conditions (i.e., insufficient interstitial oxygen concentrations). Eggs are deposited in clusters in the upper portion of the intertidal zone. Depth of eggs in the sediment range from 5 to 20 centimeters below the surface (mean 11.5 ± 2.8 centimeters) (Rudloe, 1979; Brockmann, 1990). The mean nest depth in Delaware was found to be 9.3 ± 3.9 centimeters (Penn and Brockmann, 1994).

In Massachusetts, New Jersey, and Delaware, horseshoe crabs often spawn during neap tides (Penn and Brockmann, 1994; Cavanaugh, 1975; Barlow *et al*., 1986). However, in Florida, horseshoe crabs almost never spawn during neap tides (Rudloe, 1980). Penn and Brockmann (1994) conclude that the dissimilarity is due to differences in grain size (aerobic sediments occur at higher elevations in Florida than in Massachusetts, New Jersey, and Delaware). Additionally, neap tides are lower in Florida and flood tides rarely reach the aerobic zone of the beach, explaining why horseshoe crabs in Florida do not nest during neap tides (Penn and Brockmann, 1994).

Horseshoe crab reproductive success is greatest under the following conditions: (1) the egg clusters are moistened by water with salinity of at least 8 parts per thousand; (2) the substrate around the egg clusters is well oxygenated; (3) tides are sufficient to keep incubating eggs moist; (4) the beach surface is exposed to direct sunlight to provide sufficient incubation; and, (5) the slope of the beach is adequate for larvae to orient and travel downslope to the water upon hatching (Shuster, 1994).

Penn and Brockmann (1994) found that horseshoe crabs in Delaware tended to place their nests in sand that was about 3 percent saturated. Eggs that were buried above this zone were more likely to desiccate. The saturated sediments of the lower beach contained insufficient interstitial oxygen concentrations for egg development to occur. Moisture content of the sediment is related to grain size. The grain size of the beaches that had the greatest horseshoe crab spawning concentrations, as reported by Shuster and Botton (1985), had grain sizes of from 0.5 to 2.0 mm in diameter (Botton *et al*. 1994), with a medium grain size of 0.7 mm. Beaches used by spawning horseshoe crabs in South Carolina and Florida have much smaller grain sizes. In South Carolina, grain sizes on study beaches used by horseshoe crabs are between 0.2 and 0.4 mm (Thompson, 1998).

The mechanism by which horseshoe crabs locate preferred spawning habitat is not completely understood. While horseshoe crabs spawn in greater numbers and with greater fecundity along sandy beaches, horseshoe crabs can tolerate a wide range of physical and chemical environmental conditions, and will spawn in less suitable habitats if ideal conditions are not encountered. Therefore, the presence of large numbers of horseshoe crabs on a beach is not necessarily an indicator of habitat suitability (Shuster, 1994). It is known that shoreline areas with high concentrations of silt or peat are less favorable to horseshoe crabs, because the anaerobic conditions reduce egg survivability. It also appears that horseshoe crabs can detect hydrogen sulfide, which is produced in the anaerobic conditions of peat substrates, and that horseshoe crabs actively avoid such areas (Botton *et al*., 1988; Thompson, 1998). Jacobsen (pers. comm., 1996) believes that horseshoe crabs need at least 8 inches of sand over peat to occur to avoid anaerobic conditions that could prevent egg development, with 16 inches or more being optimal.

Beach slope is also thought to play an important role in determining the suitability of beaches for horseshoe crab spawning (Shuster, pers. comm., 1995). Horseshoe crabs generally travel downslope after spawning and appear to become disoriented on flat areas (Jacobsen, pers. comm., 1995). Field experiments by Botton and Loveland (1987) determined that beach slope is more significant than vision in orientation behavior and identified poor orientation performance on flat beaches. Horseshoe crabs show rapid seaward orientation on beaches with slopes of approximately 6 degrees (Botton and Loveland, 1987). Although the optimal beach slope is unknown, beaches commonly used by horseshoe crabs in New Jersey have slopes of between 3 and 7 degrees to seaward (U.S. Fish and Wildlife Service, 1995). Jacobsen (pers. comm., 1996) estimates the optimal slope to be about 7 percent. However, Thompson (1998) concluded that while parameters controlling site selection for spawning would normally favor beaches with an optimal slope (i.e., gentle seaward slope), beach slope itself is not likely to be the determining parameter selected by spawning horseshoe crabs.

Erosion is also an important component in spawning success. Erosion of the substrate in which eggs are deposited would increase egg and larval mortality. Thompson (1998) suggested that short-term, seasonal erosion characteristics may be more important than long-term conditions.

In addition to the intertidal zone used for spawning, horseshoe crabs also use shallow water areas (less than 12 feet deep) such as intertidal flats and shoal water as nursery habitat for juvenile life stages. Adult horseshoe crabs forage in deep water habitat during most of the year, except during the breeding season when they move into shallow and intertidal water.

The presence of offshore intertidal flats may also influence the use of certain beaches by spawning horseshoe crabs. Horseshoe crabs may congregate on intertidal flats to wait for full moon high tides, because these flats provide protection from wave energy. Thompson (1998) identified that preferentially selected spawning sites were located adjacent to large intertidal sand flat areas. In addition to providing protection from wave energy, sand flats typically provide an abundance of available food for juvenile horseshoe crabs. Since several tidal cycles may be required to complete spawning, offshore intertidal flats may provide safe areas to rest between tide cycles.

D. FEEDING AND GROWTH

Overcrowding or high-density egg clusters delay the time of hatching for horseshoe crabs (Barber and Itzkowitz, 1982). However, typically eggs hatch between 14 and 30 days after fertilization (Sekiguchi, et al., 1982; Jegla and Costlow, 1982; Botton, 1995). The optimum temperature for egg development has been estimated at between 30^{o} and 35^{o} C (Jegla and Costlow, 1982). Larvae emerge from the egg capsule and swim for a period of approximately 6 days. Larvae typically settle in shallow water areas after the free-swimming period to molt (Shuster, 1982). Larvae molt into the first juvenile instar approximately 20 days after emergence (Jegla and Costlow, 1982).

Some "trilobite" larvae delay emergence and overwinter within beach sediments, emerging the following spring (Botton *et al*., 1992). This was observed during the winters of 1989 to 1992 and included densities of between 1,000/m^2 and 10,000/m^2 of live trilobites in sediment depths greater than 15 centimeters. Overwintering larvae emerge in March and April the following year after spending 8 months in beach sediment. This phenomenon is reported in New Jersey and Massachusetts (Botton *et al*., 1992). While overwintering in beach sediment does risk mortality associated with erosion from coastal storms, the strategy does minimize avian predation and provides insurance in the event previous cohorts had poor survivorship (Botton *et al*., 1992)

Upon hatching, the larvae are motile and spend about 6 days swimming until they settle to the bottom and molt. Larvae move to the sand surface and emerge at spring high tide on full-moon nights in Florida; however, larvae are also released during storms with heavy surf (Rudloe, 1979). Larvae do not emerge during spring high tides (associated with the new moon) and appear to be nocturnally active (Rudloe, 1979). Although the free-swimming period provides the possibility of wide dispersion, most larvae settle in shallow, intertidal areas near the beaches where they were spawned. Juvenile horseshoe crabs generally spend their first and second summer on the intertidal flats, usually near breeding beaches (Rudloe, 1981; Shuster, 1982). Thompson (1998) found significant use of sand flats by juvenile horseshoe crabs in South Carolina. Older crabs move out of intertidal areas and are found a few miles offshore except during breeding migrations (Botton and Ropes, 1987). After larval stages leave the beach environment, horseshoe crabs do not return to the beach until they are sexually-active adults (Rudloe, 1979).

The horseshoe crab must molt, or shed its chitinous exoskeleton, to grow. Molting occurs several times during the first two to three years. As the horseshoe crab grows larger, more time exists between molts. Horseshoe crabs usually take at least 16 to 17 molts to reach sexual maturity over a period of 9 to 11 years (Shuster, 1950). However, the often cited age of sexual maturity is based on a series of exuviae from a single captive specimen. Females reach maturity one year later than males and, consequently, go through an additional molting stage (Shuster, 1955).

Once sexual maturity is reached, horseshoe crabs no longer molt (or molt rarely) and can live an additional 8 years based on growth of epifaunal slipper shells (*Crepidula fornicata*) on the horseshoe crab prosoma (Botton and Ropes, 1988). Therefore, longevity for horseshoe crabs may be at least 17 to 19 years in the northern part of their range, accepting the estimate of 9 to 11 years to reach sexual maturity (Shuster, 1950).

Horseshoe crabs swim or crawl as their primary means of locomotion. Both larvae and juveniles are more active at night than during the day (Rudloe, 1979; Shuster, 1982: Thompson, 1998). Juveniles typically feed prior to the daytime low tide, then burrow into the sand, remaining inactive during the remainder of the day (Rudloe, 1981; Thompson, 1998). Because horseshoe crabs lack jaws, they crush and pulverize food using the spiny bases of their legs, then move the food into the mouth.

Larvae feed on a variety of small polychaetes, nematodes, and nereis (Shuster, 1982). Juvenile and adult horseshoe crabs feed mainly on molluscs, including razor clam (*Ensis* spp.), macoma clam (*Macoma* spp.), surf clam (*Spisula solidissima*), blue mussel (*Mytilus edulis*), wedge clam (*Tellina* spp.), and fragile razor clam (*Siliqua costata*); however, horseshoe crabs also prey on a wide variety of benthic organisms including arthropods, annelids, nemertean, and polychaete worms (Botton, 1984; Botton and Haskin, 1984). In the Delaware Bay, horseshoe crabs prefer soft-shell clam (*Mya arenaria*) and small surf clam (*Mulinia lateralis*) over gem clam (*Gemma gemma*) despite the numerical dominance of the gem clam in the Delaware Bay (Botton, 1984). The horseshoe crab is also an important predator of soft-shell clams in Massachusetts. Shuster (1950) reported horseshoe crabs consuming sand worm (*Nereis* spp.), sand ribbon worm (*Cerebratulus* spp.), gem clam, macoma clam, razor clam, and soft-shell clam in Cape Cod Bay, Massachusetts. Botton (1984) found 56.4 percent of prey was infaunal burrowers, which included bivalves and polychaetes. Botton (1984) also found vascular plant material in nearly 90 percent of all individuals. Botton and Ropes (1989) hypothesized that horseshoe crabs may control species diversity, richness, and abundance in areas where they prey upon small molluscs and polychaetes. No differences between diet and food preference are apparent between male and female horseshoe crabs. Shuster (1996) identified that food for the horseshoe crab (e.g., bivalves, molluscs, and marine worms) are abundant on the continental shelf in areas where horseshoe crabs abound.

E. SOURCES OF NATURAL MORTALITY

1. Predation

Most eggs survive to hatching (Rudloe, 1979). However, Loveland *et al*. (1996) identify that mortality is extensive among eggs and larvae. Eggs and larvae are preyed upon by macroinvertebrates including sand shrimp (*Crangon septemspinosa*), blue crab (*Callinectes sapidus*), green crab (*Carcinus maenas*), and spider crab (*Libinia* spp.) (Shuster, 1982). Finfish also eat eggs and larvae including striped bass (*Morone saxatilis*), white perch (*Morone americana*), American eel (*Anguilla rostrata*), killifish (*Fundulus* spp.), silver perch (*Bairdiella chrysoura*), weakfish (*Cynoscion regalis*), kingfish (*Menticirrhus saxatilis*), silversides (*Menidia menidia*), summer flounder (*Paralichthys dentatus*), and winter flounder (*Pleuronectes americanus*) (Shuster, 1982). Shorebirds also feed on horseshoe crab eggs including semipalmated plover (*Charadrius semipalmatus*), black-bellied plover (*Pluvialis squatarola*), red knot (*Calidris canutus*), pectoral sandpiper (*Calidris melanotos*), least sandpiper (*Calidris minutilla*), semipalmated sandpiper (*Calidris pusilla*), dowitcher (*Limnodromus* spp.), sanderling (*Calidris alba*), ruddy turnstone (*Arenaria interpres*), and laughing gull (*Larus atricilla*). The willet (*Catoptrophorus semipalmatus*) is also a predator of horseshoe crab eggs and larvae (Rudloe, 1979).

Adult horseshoe crabs provide food for sharks (Squaliformes), gulls (*Larus* spp.), and boat-tailed grackles (*Quiscalus major*) (Shuster, 1982). In addition, adult and juvenile horseshoe crabs make up a portion of the loggerhead sea turtle's (*Caretta caretta*) diet in the Chesapeake Bay (Musick, *et al*. 1983). Shuster (1996) also identifies red fox (*Vulpes vulpes*) and raccoon (*Procyon lotor*) as potential predators of adult and juvenile horseshoe crabs. Despite potential predation, Loveland *et al*. (1996) identify that natural mortality among subtidal adults is probably low. However, horseshoe crab predation mortality from sea turtles and other marine animals remains unknown.

Between the 1850s and the 1920s, over 1 million horseshoe crabs were harvested annually for fertilizer and livestock feed (Shuster, 1982; Shuster and Botton, 1985). Reported harvests in the 1870s were 4 million horseshoe crabs annually, and 1.5 to 1.8 million horseshoe crabs annually between 1880s and 1920s (Finn *et al*., 1991). Shuster (1960) reports that in the late 1920s and early 1930s 4 to 5 million crabs were harvested annually. Shuster (1960) reports over 1 million crabs were harvested during the 1940s and 500,000 to 250,000 horseshoe crabs were harvested in the 1950s. By the 1960s, only 42,000 horseshoe crabs were reported to be harvested annually (Finn *et al*., 1991). More recently horseshoe crabs have been taken in substantial numbers to provide bait for other fisheries, including (primarily) the American eel and conch (*Busycon carica* and *B. canaliculatum*) fisheries. Horseshoe crabs, particularly females, are cut up and placed in American eel pots as bait. The conch fishery uses horseshoe crabs of either sex. Horseshoe crabs are also collected by the biomedical industry to support production of Limulus Amebocyte Lysate. However, this industry bleeds individuals and releases the animals live after the bleeding procedure. Approximately 10 to 15 percent of animals do not survive the bleeding procedure (Rudloe, 1983; Thompson, 1998).

2. Diseases and Parasites

Bacterial infection of horseshoe crabs may adversely affect individual horseshoe crabs. Infection may be caused by erosion of the carapace or injuries. Triclad flatworms and cyanobacteria have caused extensive gill pathology within horseshoe crabs (Groff and Leibovitz, 1982).

External parasites and ectocommensals do not commonly attach to horseshoe crabs due to the frequency of molting (Shuster, 1982). However, Thompson (1998) and Rudloe (pers. comm., 1998) identify that the *Bdelloura candida* flatworm is common on horseshoe crab gills and appendages, but is not known to be parasitic. A variety of other marine organisms including mussels, gnathobases, barnacles, and other sessile organisms may attach to horseshoe crabs. These species may be harmful if they attach to the ventral surface and interfere with feeding or locomotion (Shuster, 1982). Internal parasites such as the metacercariae may cause intense and massive internal infections (Shuster, 1982).

Horseshoe crabs may share a commensal relationship with pinfish (*Lagodon rhomboides)* and juvenile blue crabs (*Callinectes sapidus*). The pinfish and blue crab stay in close proximity to horseshoe crabs feeding on particles of detritus and small organisms stirred into the water column from the "ploughing" action of horseshoe crabs (Rudloe, 1985).

3. Stranding

Botton and Loveland (1989) identified that at least 190,000 horseshoe crabs died from beach stranding along the New Jersey shore of the Delaware Bay during the 1986 spawning season (May to June). This represents nearly 10 percent of the adult horseshoe crab population and is considered a substantial source of natural mortality. Rudloe (pers. comm., 1998) identifies that stranding mortality in Florida may be much lower based on personal observations. Natural mortality was estimated by Swan (pers. comm., 1998) to be up to 8 percent based on a mark and recapture study where 860 individuals were tagged. Stranded crabs typically succumb to factors such as hyperthermia, osmotic imbalance, excessive energy expenditure during spawning, desiccation, and predation by large predators (such as gulls) (Botton and Loveland, 1989). Entrapment in man-made structures such as rip-rap, bulkheads, and jetties also accounts for mortality. Telson abnormalities is related to beach stranding, because broken or shortened telsons prohibit crabs from righting themselves, resulting in stranding (Botton and Loveland, 1989). Stranding is also related to mating tactics and righting ability in male horseshoe crabs. Unattached males are more likely to become stranded than attached males because they do not have the larger female as an "anchor." Additionally, on average, older males are more likely to become stranded than younger males probably due to senescence and parasitism (Penn and Brockmann, 1995).

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