Atlantic States Marine Fisheries Commission

2013 Horseshoe Crab Stock Assessment Update

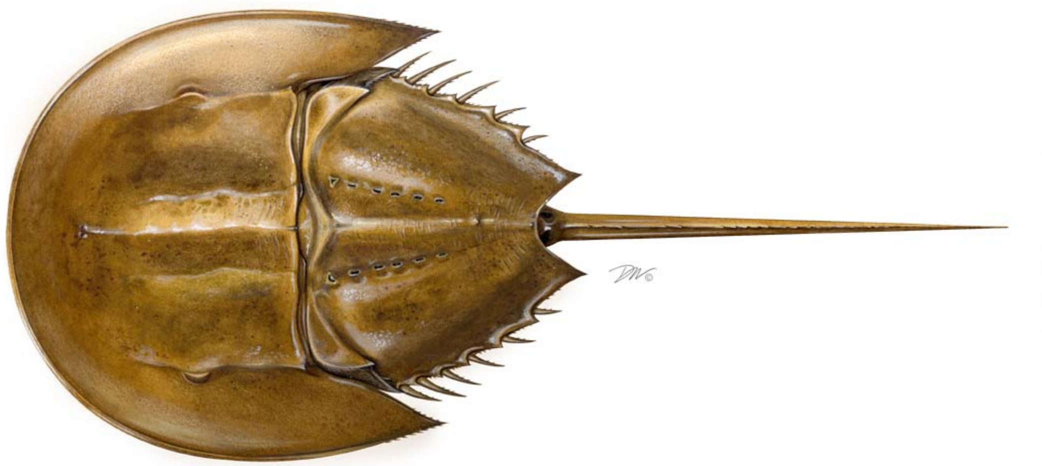

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Table of Contents

List of Tables

List of Figures

1.0 Introduction

The status of the horseshoe crab (*Limulus polyphemus*) population along the Atlantic coast is of interest to a variety of different stakeholders (Berkson and Shuster 1999; Walls *et al.* 2002; Odell *et al*. 2005). Horseshoe crabs play an important role in marine and estuarine ecosystems, and their eggs are a critical food source for many migratory shorebirds. In addition, the species serves as a primary bait source for several important commercial fisheries and is the backbone of a major biomedical process.

1.1 Brief Overview and History of Fisheries

Historically, horseshoe crabs were harvested commercially for fertilizer and livestock feed. Between the mid-1800s and mid-1900s harvest ranged from approximately 1 to 5 million crabs annually (Shuster 1960; Shuster 1982; Shuster and Botton 1985; Finn *et al*. 1991). Harvest numbers dropped to between 250,000 and 500,000 crabs annually in the 1950s (Shuster 1960) and 42,000 crabs were reported annually by the early 1960s (Finn *et al*. 1991). Early harvest records should be viewed with caution due to probable under-reporting. The substantial commercial-scale harvesting of horseshoe crabs ceased in the 1960s (Shuster 1996).
Since the mid to late 1900s, horseshoe crabs have been commercially harvested primarily for use as bait and to support a biomedical industry. Horseshoe crabs are used as bait in the conch (*Busycon spp*.) and American eel (*Anguilla rostrata*) pot fisheries, although they are also harvested to a lesser extent for use as bait in the catfish (*Ictalurus spp.*) and killifish (*Fundulus spp*.) fisheries. The biomedical fishery harvests the crabs for the manufacture of Limulus Amebocyte Lysate (LAL), a product used to test pharmaceuticals for the presence of gram-negative bacteria.

Between 1970 and 1990, commercial harvest ranged from less than 20,000 pounds to above 2 million pounds annually (Table 1, Figure 1). Reported harvest increased during the late 1990s to nearly 6 million pounds in 1997 (Table 1, Figure 1) and above 2.5 million crabs in 1998. Since state-by-state quotas took effect in 2001 through Addendum I to the Horseshoe Crab Fishery Management Plan (FMP), reported bait landings have averaged about 800,000 crabs per year (Table 2).

1.1.1 Bait Fishery

The horseshoe crab fishery supplies bait for the American eel, conch (whelk) and, to a lesser degree, catfish (*Ictaluridae*) fisheries. The American eel pot fishery prefers egg-laden female horseshoe crabs, while the conch pot fishery uses both male and female horseshoe crabs.
Most fishing effort for horseshoe crabs is concentrated within the mid-Atlantic coastal waters and adjacent federal waters. However, Massachusetts supports a significant fishery. The hand,

trawl and dredge fisheries accounted for about 85% of the 2012 reported commercial horseshoe crab bait landings by gear type (ASMFC 2013a). This is consistent with the distribution of landings by gear since 1998.

Commercial landings for horseshoe crab are collected by the NMFS by state, year, and gear type. Data is obtained from dealers, logbooks, and state agencies that require fishermen to report landings; however, NMFS records are often incomplete. In addition, the conversion factor used to convert numbers landed to pounds landed has been quite variable among the states and NMFS. Despite the inaccuracies in the data, all reported landings data show that commercial harvest of horseshoe crabs increased substantially from 1990 to 1998 and have generally declined since then (Table 1, Figure 1). Since 1998, states have been required to report annual landings to ASMFC through the compliance reporting process. These data are reliable and are shown in Table 2.

1.1.2 Biomedical Fishery

Research on horseshoe crabs for use in the biomedical industry began in the early 1900s (Shuster 1962). Scientists have used horseshoe crabs in eye research, surgical suture wound dressing development, and detection of bacterial endotoxins in pharmaceuticals (Hall 1992). Horseshoe crab blood has been found to be useful in cancer research. The current major biomedical use of horseshoe crabs is in the production of Limulus Amebocyte Lysate (LAL). LAL is a clotting agent in horseshoe crab blood that makes it possible to detect human pathogens such as spinal meningitis and gonorrhea in patients, drugs, and all intravenous devices. The LAL test was commercialized in the 1970s (J. Cooper, pers. comm.), and is currently the worldwide standard for screening medical equipment for bacterial contamination.

There are four companies along the Atlantic Coast that process horseshoe crab blood for use in manufacturing LAL: Associates of Cape Cod (MA), Lonza (MD, formerly Cambrex Bioscience), Wako Chemicals (VA), and Charles River Endosafe (SC). In addition, Limuli Labs (NJ) bleeds horseshoe crabs but does not manufacture LAL.

Blood from horseshoe crabs is obtained by collecting adult crabs, extracting a portion of their blood, and releasing them alive. Crabs collected for LAL production are typically collected by hand or trawl. Crabs are inspected to cull out damaged or moribund animals, and transported to the bleeding facility. Following bleeding, most crabs are returned to near the location of capture; however, since 2004, states have the ability to enter bled crabs into the bait market and count those crabs against the bait quota (ASMFC 2004).

Prior to 2004, no records were kept on biomedical harvest, although several sources estimate harvest during the 1990s around 200,000 to 250,000 crabs per year (D. Hochstein, pers. comm.; B. Swan, pers comm; Manion *et al*. 2000). Harvest records beginning in 2004 indicate an increase in biomedical harvest to more than 610,000 crabs in 2012. ASMFC assumes a constant 15% mortality rate for bled crabs that are not returned to the bait fishery.

1.2 Management Unit Definition

The fishery management unit includes the horseshoe crab stock(s) of the Atlantic Coast of the United States (Maine to eastern Florida). The coastwide stock is currently managed on state by state, multi-state (e.g., DE Bay region), and embayment levels. See section 1.6 Stock Definition for more information.

1.3 Regulatory History

Prior to 1998, horseshoe crab harvest was unregulated in most states. The Horseshoe Crab Management Board approved the Horseshoe Crab FMP in October 1998. The goal of the FMP is "management of horseshoe crab populations for continued use by: current and future generations of the fishing and non-fishing public (including the biomedical industry, scientific and educational research) migratory shorebirds; and other dependent fish and wildlife (including federally listed sea turtles)" (ASMFC 1998a). The FMP outlined a comprehensive monitoring program and maintained controls on the harvest of horseshoe crabs put in place by New Jersey, Delaware, and Maryland prior to the approval of the FMP. These measures were necessary to protect horseshoe crabs within and adjacent to the Delaware Bay, which is the epicenter of spawning activity along the Atlantic Coast. However, subsequent increased landings in other states largely negated these conservation efforts.

In April 2000, the Management Board approved Addendum I to the Horseshoe Crab FMP (ASMFC 2000a). This Addendum established a coastwide, state-by-state annual quota system to further reduce horseshoe crab landings. Through Addendum I the Board recommended to the federal government the creation of the Carl N. Schuster Jr. Horseshoe Crab Reserve, an area of nearly 1,500 square miles in federal waters off the mouth of Delaware Bay that is closed to horseshoe crab harvest. In May 2001, the Management Board approved Addendum II, which established criteria for voluntary quota transfers between states (ASMFC 2001). In March 2004, the Board approved Addendum III to the FMP (ASMFC 2004). The addendum sought to further the conservation of horseshoe crab and migratory shorebird populations in and around the Delaware Bay. It reduced harvest quotas, implemented seasonal bait harvest closures in New Jersey, Delaware, and Maryland, and revised monitoring components for all jurisdictions.

Addendum IV was approved in May 2006 (ASMFC 2006a). It further limited bait harvest in New Jersey and Delaware to 100,000 crabs (male only) and required a delayed harvest in Maryland and Virginia. Addendum V, adopted in September 2008, extended the provisions of Addendum IV through October 31, 2009 (ASMFC 2008a). Through a vote, the Board extended the provisions of Addendum IV through October 31, 2010. Addendum VI further extended

Addendum IV provisions through April 30, 2013. It also prohibited directed harvest and landing of all horseshoe crabs in New Jersey and Delaware from January 1 through June 7, and female horseshoe crabs in New Jersey and Delaware from June 8 through December 31 (ASMFC 2010). Addendum VI also mandated that no more than 40% of Virginia's annual quota may be harvested east of the COLREGS line in ocean waters. It also requires that horseshoe crabs harvested east of the COLREGS line and landed in Virginia must be comprised of a minimum male to female ratio of 2:1.

Addendum VII was approved in February 2012 (ASMFC 2012). This addendum implemented the ARM Framework for use during the 2013 fishing season and beyond. The Framework considers the abundance levels of horseshoe crabs and shorebirds in determining the optimized harvest level for the Delaware Bay states of New Jersey, Delaware, Maryland, and Virginia (east of the COLREGS).

1.4 Importation of Asian Crabs

Bait shortages and the resulting high prices for Atlantic horseshoe crabs have resulted in the importation of Asian horseshoe crabs (*Tachypleus gigas, Carcinoscorpius rotundicata and/or Tachypleus tridentatus*) into Atlantic coast states for use as bait. Concerns regarding the introduction of non-native parasites and pathogens, as well as concern regarding the potential human health risks associated with the neurotoxin tetrodotoxin (known to be present in *C. rotundicauda*), prompted the Commission to recommend that member states take measures to ban the importation and use of Asian horseshoe crabs (ASMFC 2013b).

1.5 Assessment History

The initial stock assessment for horseshoe crab was completed and peer reviewed in 1998 (ASMFC 1999; ASMFC 1998b). A new assessment framework was proposed in 2000 (ASMFC 2000b), and an internally peer-reviewed assessment was produced in 2004. The most recent externally peer-reviewed benchmark stock assessment was completed in 2009 (ASMFC 2009a). The Adaptive Resource Management Model currently used to provide management advice for horseshoe crab was also peer-reviewed at this time (ASMFC 2009b).

1.6 Stock Definitions

The horseshoe crab stock, for the purpose of this assessment, is defined as the horseshoe crabs ranging from the coasts of Maine to Florida seaward. However, data suggests there may be a regional or sub-regional population structure. Tag release and recapture data from the United States Fish and Wildlife horseshoe crab tagging database was used to examine if there were any trends in release and recapture location. Tag recaptures after >3 months at large were examined by release state and location versus recapture state and location. Results showed that releases in Massachusetts (MA) and Rhode Island (RI) were almost exclusively caught in MA or RI; releases from CT were recaptured in CT with a small percentage from non-coastal NY; releases from coastal NY were recaptured in coastal NY or coastal NJ; releases from New Jersey (NJ), Delaware (DE), Maryland (MD), and Virginia (VA) were almost exclusively caught in those states (many in DE Bay); releases from within Delaware Bay were recaptured largely within Delaware Bay and some from coastal NJ, DE, MD, VA, and NC; and releases from South Carolina (SC) were caught in SC and Georgia. These results suggest regional horseshoe crab populations. Rutecki *et al*. (2004) conclude that management of individual populations, possibly down to the embayment level, needs to consider harvest rates and population structures and abundances present.

Botton and Loveland (2003) examined abundance and dispersal of horseshoe crab larvae in Delaware Bay. They found a strong tendency for larvae to stay close to spawning beaches. This finding suggests that larvae dispersal is not the mechanism for mixing populations (Botton and Loveland 2003). Widener and Barlow (1999) studied a population of horseshoe crabs that appeared to be a local one. They concluded, "Harvesting large numbers of animals from such a local population would have significant impact on its size" (Widener and Barlow 1999). Genetic structure indicates that males disperse at higher rates than females, and female-mediated gene flow among embayments is limited (Pierce *et al*. 2000, King *et al*. 2005). King *et al*. (2005) suggested that the distribution of the American horseshoe crab is comprised of multiple population units divided among large geographic regions: Gulf of Maine, mid- mid-Atlantic, Atlantic Florida, Gulf Florida, and Mexico. Also, tagging data indicate that a majority of adult crabs remain within local regions and some overwinter in local embayments (ASMFC 2004; James-Pirri *et al*. 2005; Swan 2005; Smith *et al*. 2006; Moore and Perrin 2007). These data are further supported by stable isotope analyses, which indicate adult crabs are loyal to local feeding grounds (Carmichael *et al*. 2004, O'Connell *et al*. 2003). Trends in horseshoe crab abundance and population dynamics differ among regions (ASMFC 2004). In particular, smaller sized populations such as those in Cape Cod waters may be localized based on spawning densities, size structure, and movement patterns (Carmichael *et al*. 2003; James-Pirri *et al*. 2005). Since different types of harvest (bait, biomedical, or scientific) select for different size and sex segments of the population, different populations may experience different harvest pressures due to their location-specific population dynamics (Rutecki *et al*. 2004).

Finally, different embayments and regions are subject to different types and levels of harvest for different purposes. In Delaware Bay waters, commercial harvest is conducted by hand and dredge (Kraemer and Michels 2009), while in areas such as Cape Cod most harvest is conducted by hand from local beaches (Rutecki *et al*. 2004). In Delaware Bay, the majority of harvested crabs are collected for bait. In contrast, among Cape Cod populations, the primary purpose for which crabs are harvested (bait, biomedical, or scientific) varies by embayment (Rutecki *et al*. 2004) with bait harvest predominating except in Pleasant Bay where only biomedical harvest is permitted (A. Leschen, pers. comm.). Since mortality associated with each harvest type varies, the extent of harvest pressure and depletion by overharvest also necessarily varies among embayments (Widener and Barlow 1999; Rutecki *et al*. 2004). Hence, there is strong support for local management based on regional or sub-regional population structure and harvest pressures.

1.6.1 Genetics

King *et al*. (2003 and 2005) found that the correlation of genetic and geographic distance between horseshoe crab populations sampled along the Atlantic coast suggests isolation by distance as the driving force behind population structure. Their genetic analysis points to the possibility of four regional stocks within the United States: Northeast (Gulf of Maine), mid-Atlantic, Florida-Atlantic, and Florida-Gulf. A separate study showed possible subdivision between collections from the upper Chesapeake Bay and near the entrance of Delaware Bay (Pierce *et al*. 2000). However, this is in contrast to what King *et al*. found. Pierce *et al*. (2000) also suggest that the samples from the upper Chesapeake Bay show a resident population. 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.

1.6.2 Morphometric Information

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. Differences between the morphologic characteristics of discrete populations were seen among geographically distinct populations (Riska 1981). Larger animals and populations are reported 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). However, based on morphometric data collected in South Carolina the greatest mean adult size occurs in the South Atlantic Bight and decreases in size north and south (Shuster 1950; Thompson 1998). 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.

2.0 Fishery-Dependent Data Sources

Commercial fisheries for horseshoe crab consist primarily of directed trawls and hand harvest fisheries for use as bait and are the major source of fishery-dependent data for the stock. Landings for horseshoe crabs have been reported since 1970 and fishery-dependent data of the catches have been collected since 1998. Crabs are also commercially collected for use in the biomedical industry. While fishery-dependent data have been collected from this fishery, landings data is not well documented. Fishery-independent data sources for horseshoe crab exist primarily as trawl survey data collected by various states and the federal government where horseshoe crab is not the target species.

2.1 Commercial Bait Fishery

The commercial bait fishery consists primarily of trawl, hand harvest, and dredge fisheries. State and federal governments collected the fishery-dependent data included in this summary. Since 1998, ASMFC has compiled landings by state in the annual FMP review report.

2.1.1 Data Collection and Treatment

2.1.1.1 Survey Methods

Commercial horseshoe crab landings data collection is a joint state and federal responsibility. The cooperative state-federal fishery data collection systems obtain landings data from state mandated fishery or mollusk trip-tickets, landing weigh out reports provided by seafood dealers, federal logbooks of fishery catch and effort, shipboard and portside interview and biological sampling of catches. State fishery agencies are usually the primary collectors of landings data, but in some states NMFS and state personnel cooperatively collect the data. Statistics for each state represent a census of the horseshoe crabs landed, rather than an expanded estimate of landings based on sampling data. Although the NMFS reports landings in pounds, adoption of the Interstate Fishery Management Plan for Horseshoe Crab (FMP) in 1998 required states to collect and report all horseshoe crab harvest by numbers, pounds, sex and harvest method (ASMFC 1998a). All states with an operating fishery require mandatory reporting. Horseshoe crab landings reported after 1997 were expressed as numbers of crabs and were obtained directly from the states.

Commercial sampling intensity varies from state to state. Most jurisdictions have implemented mandatory monthly or weekly reporting. Though reporting compliance has substantially improved since adoption of the FMP, some states do not currently provide landings by sex.

2.1.1.2 Biological Sampling Methods

Under the 1998 FMP states are required to characterize a portion of the commercial catch based on prosomal width and sex. Though many states implemented this compliance component, sampling intensity was inconsistent between states and between years. Some states used spawning survey data to characterize their shore-based fishery. The SAS agreed to use such information if it can be shown that this strategy would yield the same quality information.

Under the proposed framework for a horseshoe crab stock assessment states will be required to characterize their landings by sex and maturity (identification of new recruits to the spawning population). Development of a technique for determining maturity is underway. Prosomal width measurements were available from the Delaware horseshoe crab hand fishery, the Georgia whelk/crab fishery (bycatch, 2000-2006 and 2011), the Maryland horseshoe crab biomedical harvest, the Massachusetts horseshoe crab bait fishery, the New York horseshoe crab trawl fishery, and the South Carolina biomedical landings. Concern was expressed that with quotas being monitored by number, harvesters may select for larger horseshoe crabs or that harvesters would begin landing immature crabs if adult numbers declined and demand remained high.

2.1.1.3 Aging Methods

There are currently no direct methods to reliably age horseshoe crabs. According to Smith et al. (2009a), the ageing of horseshoe crabs using lipofuscin accumulation has not yet been shown to be reliable. Shuster (2000) developed a method for assigning general age based on shell wear and appearance. Botton and Ropes (1988) indirectly aged horseshoe crabs using slipper shells attached to the horseshoe crab to establish a minimum age. Researchers at the Virginia Tech Horseshoe Crab Research Center distinguish sex and maturity (immature, newly mature, and multiparous) in horseshoe crabs using genital papillae, modified pedipalps, rub marks and presence/absence of eggs.

2.1.1.4 Catch Estimation Methods

Reference period landings (RPL) were based on each state's best estimate of their commercial horseshoe crab bait landings (in numbers of crabs) for the period between 1995 and 1997. Some states used a single year's landings while other states used an average of landings within that timeframe (ASMFC 2000a). The Horseshoe Crab Technical Committee reviewed and approved each state's RPL.

The ASMFC quota is based on a 25% reduction in state-by-state RPL. Quotas were based on numbers of horseshoe crabs landed (not pounds).

Mean prosomal widths were obtained from various fisheries. Width measurements were segregated by gender since mature females are generally larger than males.

2.1.2 Commercial Bait landings

NMFS reported commercial horseshoe crab landings increased to record levels in the mid to late1990s (Table 1. Reported Atlantic coast horseshoe crab landings and value, 1970 – 2011 (NMFS Commercial Fishery Landings Database, accessed on 8/5/2013)., Figure 1. Reported Atlantic coast horseshoe crab landings (metric tons), 1970 – 2011 (NMFS Commercial Landings Database, August 2013).). Though the NMFS coastwide landings database suffers inadequacies, state-specific landings data support increased landings and effort in the horseshoe crab fishery during this period (ASMFC 1999a). Reported NMFS landings since 1998 substantially declined. These landings include all harvest types (i.e. biomedical, bait fishery, marine life) reported to NMFS. The adoption of the FMP in 1998 improved harvest monitoring through mandatory reporting. The adoption of Addendum I to the FMP established reference period landings for the bait fishery that allowed for the implementation of quotas and served as a benchmark to evaluate subsequent bait landings (Table 2. State by state Atlantic coast horseshoe crab landings reported through ASMFC, 1998 – 2012. [Note: The ASMFC quota was initiated in 2001 through

Addendum 1 and has since been adjusted in 2003 through Addendum III and in 2006 through Addendum IV.). Addendum III (2004), IV (2006), and V (2008) further reduced harvest quotas, implemented seasonal bait harvest closures, and mandated male only fisheries in some or all of the states in which harvest impacted the Delaware Bay population of horseshoe crabs (DE, MD, NJ, and VA). Addendum VII (2012) approved management of horseshoe crabs in the Delaware Bay area according to the Adaptive Resource Management (ARM) framework (ASMFC 2009b). For the 2013 harvest season, a total of 500,000 Delaware Bay origin male horseshoe crabs were allowed to be harvested by DE, MD, NJ, and VA combined. Additional horseshoe crabs were allowed to be harvested by MD and VA as it was recognized that not all horseshoe crabs harvested in these states' water are of Delaware Bay origin.

2.1.3 Commercial Bait Discards/Bycatch

Horseshoe crabs are taken as bycatch in a number of fisheries. However, if landed, these crabs must be reported under the requirements of the FMP and are included in the coastwide horseshoe crab landings.

Commercial discard has not been quantified. Discard mortality is known to occur in various dredge fisheries. This mortality may vary seasonally with temperature/crab activity and impacts both mature and immature horseshoe crabs.

2.1.4 Commercial Bait Catch Rates

Commercial catch rates are available for the states of Delaware and Georgia (Table 3. Commercial catch rates (CPUE) of horseshoe crabs in Delaware and Georgia.). Delaware commercial catch rates were calculated by dividing the number of horseshoe crabs landed in the dredge and hand fishery by the respective number of trips for each fishery. Georgia provided catch rates on horseshoe crabs taken as bycatch by their whelk/crab dredge fishery up until 2006 and then in 2010 and 2011.

Commercial catch rates in the Delaware horseshoe crab dredge fishery peaked in 1996 and were lowest in 2003. Since 2003, the dredge fishery CPUE rose until 2007, but has been below this level since then. No dredge trips were made in 2008 and 2009. Catch rates in the Delaware horseshoe crab hand fishery peaked in 1997 and were lowest in 2012. CPUE in the hand fishery tracks well with the dredge fishery (Table 3. Commercial catch rates (CPUE) of horseshoe crabs in Delaware and Georgia.).

Interpretation of these catch rates are complicated by the imposition of regulations after 1997. For example, after 1997 trip limits were established on the dredge fishery of 1,500 crabs per day and the hand fishery was restricted to 300 ft^3 per day. In addition, the dredge fishery, which was capped at five permits issued annually to fishermen that had traditionally harvested using this gear became subject to a lottery that included non-traditional participants. These non-traditional fishermen tended to be less efficient while they learned various gear nuisances and locations of horseshoe crab concentrations. Further harvest restrictions were imposed from 2004 and on. Commercial catch rates of horseshoe crabs taken as bycatch by Georgia whelk/crab dredgers from 2000 thru 2006 were highest in 2000 (w/o TEDs) and 2005(w/ TEDs). CPUE was lowest in 2003 (Table 3. Commercial catch rates (CPUE) of horseshoe crabs in Delaware and Georgia.). The Georgia catch rates were complicated by the addition of turtle excluder devices (TEDs) after 2000. Observers indicated that some crabs escape through the TEDs upon net retrieval.

2.1.5 Commercial Bait Prosomal Widths

Mean prosomal width data from various fisheries are presented in Table 4. Trends in female and male horseshoe crab prosomal width (mm) from fishery dependent surveys. and Figure 2. Trends in horseshoe crab prosomal widths from fishery-dependent data sources. There were some significant ($P < 0.05$) declines in the mean prosomal widths of harvested males and females (Table 4. Trends in female and male horseshoe crab prosomal width (mm) from fishery dependent surveys.), however, prosomal widths in Maryland showed a decrease followed by and increase starting in 2007. These declines may indicate changes in the size selectivities of the fisheries or a change in the population in response to fishing pressure.

2.1.6 Potential biases, Uncertainty, and Measures of Precision

NMFS reported horseshoe crab landings are difficult to reliably interpret. These landings may include biomedical, live trade and bait fishery harvest. Prior to passage of the FMP few states required horseshoe crab reporting. Further, harvesters generally reported landings in pieces or baits (1 female or 2 males = 1 bait) and it was unclear whether consistent or adequate conversion factors were used to convert these landings to pounds.

2.2 Commercial Biomedical Fishery

Blood from horseshoe crabs is obtained by collecting adult crabs, extracting a portion of their blood, and releasing them alive. Crabs collected for LAL production are typically collected by hand or trawl. Crabs are inspected to cull out damaged or moribund animals, and transported to the bleeding facility. Following bleeding, most crabs are returned to near the location of capture; however, since 2004, states have the ability to enter bled crabs into the bait market and count those crabs against the bait quota (ASMFC 2004).

Estimates of biomedical harvest prior to 2004 are uncertain due to lack of standardized reporting; however, estimates from several sources are consistent, lending some credence to the estimates. The FDA estimated medical usage increased from 130,000 crabs in 1989 to 260,000 in 1997 (D. Hochstein, pers. comm.). This was consistent with other estimates ranging between 200,000 and 250,000 crabs per year on the Atlantic coast (Swan, pers. comm.; Manion et al. 2000). A survey of biomedical companies conducted by the Horseshoe Crab Technical Committee in 2001 indicated that about 280,000 crabs were bled in 1998 and 2000. Annual reported harvest of crabs for biomedical use in South Carolina has increased over 300% since reporting requirements were established in 1991 (Thompson 1998).

Since 2004, ASMFC has required states to monitor the biomedical use of horseshoe crabs to determine the source of crabs, track total harvest, characterize pre- and post-bleeding mortality, and determine fate (bait or release) of crabs used for biomedical purposes. The total number of crabs delivered to biomedical facilities has increased roughly 78%, from approximately 340,000 crabs in 2004 to 612,000 crabs in 2012 (Table 5. Coastwide annual harvest, use, and mortality of horseshoe crabs used for biomedical purposes.). The proportion of bled crabs coming from the bait market increased from 15% in 2004 to 22% by 2009, and has decreased to 13% by 2013. Actual use of crabs for bleeding increased 77% from 275,000 in 2004 to 486,000 crabs in 2012. Mortality in the biomedical fishery is computed in two steps. First, pre-bleeding mortality is determined from harvest and use reports provided by the biomedical harvesters. Second, a 15% mortality rate is applied to all bled crabs to determine the post-bleeding mortality. The two values are summed to provide a coastwide estimate of mortality from the harvest, transport, handling, and bleeding of horseshoe crabs used for biomedical purposes. Pre-bleeding mortality declined from 2004, to less than 3,000 crabs in 2008, but has more than doubles by 2012 (Table 5. Coastwide annual harvest, use, and mortality of horseshoe crabs used for biomedical purposes.). Total mortality has increased by 75% from 2004 to 2012 assuming a constant rate (15%) of post-bleeding mortality. Biomedical mortality ranged between 6 – 11% of total (bait and biomedical) coastwide mortality in from 2004 – 2012 (10% in 2012).

The 1998 FMP (ASMFC 1998a) establishes a biomedical mortality threshold of 57,500 crabs which, if exceeded, triggers the Management Board to consider action. The threshold has been exceeded every year since 2007 with biomedical mortality averaging 70,600 crabs. At the Management Board's request, the Horseshoe Crab Technical Committee reviewed available literature and other information on mortality associated with the biomedical fishery (ASMFC 2008b). Despite limitations in study methodology and regional differences in results, the Technical Committee endorsed the use of a constant 15% mortality rate. The Technical Committee also provided suggestions for future research areas and discussed the potential for developing "best practice" guidelines for storage and handling of horseshoe crabs to minimize mortality.

2.3 Recreational

There is no recreational fishery for horseshoe crabs. Some states allow a minimal number of crabs to be retained for personal use. Landings of this type are not quantified.

3. Fishery-Independent Data

Many states and the federal government conduct surveys encounter horseshoe crabs. Since 1999 several surveys have been developed to target horseshoe crabs. Data sets are listed in Table 6. Details of the fishery independent surveys are summarized in Appendix B.

4. Methods

This coastwide stock assessment update consists of trend analyses using autoregressive integrated moving averages (ARIMA). In previous assessments (ASFMC 2009a, 2004), linear trend analyses were also conducted and a meta-analysis (Manly 2001) was used to evaluate consensus among trends. The peer-review panel for the 2009 assessment felt the ARIMA modeling was a good advancement in trend analysis and supersedes other trend analysis (ASMFC 2009c); therefore, these other simpler trend analyses were not conducted for this stock assessment update.

The 2009 stock assessment also included the application of a surplus production model (Prager 1994) and a catch-survey model (Collie and Sissenwine 1983) for the Delaware Bay region. These models are not included in this stock assessment update. Previous application of these models to the Delaware Bay region did not include mortality due the biomedical industry – an oversight in the previous assessment. The stock assessment sub-committee felt that any application of these models needed to include this source of mortality because it may account for a significant portion of the annual exploitation of horseshoe crabs in the Delaware Bay region. However, including this source of mortality during a stock assessment update would have basically resulted in new stock assessment models applied to horseshoe crabs, which is contrary to ASMFC policy for stock assessment updates. Therefore, the surplus production model and catch-survey model are not included in this update, but will be revised to include the biomedical mortality in the next coastwide horseshoe crab benchmark assessment.

Multi-species models have been developed to support adaptive management of horseshoe crab harvest and recovery of the migratory shorebird populations that rely on horseshoe crab eggs in Delaware Bay (primarily Red Knot). The predictive horseshoe crab models are stage-based models based on Sweka et al. (2007). The adaptive management resource management (ARM) framework is described in separate reports developed by the ARM workgroup and reported through the Delaware Bay Ecosystem Technical Committee.

4.1 Autoregressive Integrative Moving Average Description

Fishery independent surveys for horseshoe crabs can be quite variable, making inferences about population trends uncertain. Observed time series of abundance indices represents true changes in abundance, within survey sampling error, and varying catchability over time. One approach to minimize measurement error in the survey estimates is by using autoregressive integrated moving average models (ARIMA, Box and Jenkins 1976). The ARIMA approach derives fitted estimates of abundance over the entire time series whose variance is less than the variance of the observed series (Pennington 1986). This approach is commonly used to gain insight in stock assessments where enough data for size or age-structured assessments (e.g. yield per recruit, catch at age) is not yet available.

Helser and Hayes (1995) extended Pennington's (1986) application of ARIMA models to fisheries survey data to infer population status relative to an index-based reference point. This methodology yields a probability of the fitted index value of a particular year being less than the reference point [P($index_t$<reference)]. Helser et al. (2002) suggested using a two-tiered approach when evaluating reference points whereby not only is the probability of being below (or above) the reference point is estimated, the statistical level of confidence is also specified. The confidence level can be thought of as a one-tailed *a*-probability from typical statistical hypothesis testing. For example, if the P($index_t$<reference) = 0.90 at an 80% confidence level, there is strong evidence that the index of the year in question is less than the reference point. This methodology characterizes both the uncertainty in the index of abundance and in the chosen reference point. Helser and Hayes (1995) suggested the lower quartile (25th percentile) of the fitted abundance index as the reference point in an analysis of Atlantic wolfish (*Anarhichas lupus*) data. The use of the lower quartile as a reference point is arbitrary, but does provide a reasonable reference point for comparison for data with relatively high and low abundance over a range of years.

The purpose of this analysis was to fit ARIMA models to time series of horseshoe crab abundance indices to infer the status of the population(s).

4.2 Autoregressive Integrative Moving Average Configuration

Relative abundance indices included in this analysis are shown in Table 6. Fishery-independent surveys used in the coastwide horseshoe crab assessment update.. [Note: An ARIMA model was not fit to NEAMAP data because of the low number of years contained by this relatively new survey.] The ARIMA model fitting procedure of Pennington (1986) and bootstrapped estimates of the probability of being less than an index-based reference point (Helser and Hayes 1995) and corresponding levels of confidence (Helser et al. 2002) were coded in R (R code developed by Gary Nelson, Massachusetts Division of Marine Fisheries). An 80% confidence level was chosen for evaluating P($index_t$<reference). Two index-based reference points were considered: 1) the lower quartile of the fitted abundance index (q25) as proposed by Helser and Hayes (1995); and 2) the fitted abundance index from 1998 – the time of development of the ASMFC Interstate Management Plan for horseshoe crabs. The use of two reference points allowed evaluation of the status of the horseshoe crabs with respect to historic levels, and just prior to the implementation of harvest restrictions to determine if such restrictions have resulted in an increase in abundance. Index values were ln (or ln + 0.01 in cases where "0" values were observed) transformed prior to ARIMA model fitting.

5.0 Results

The ARIMA models provided adequate fits to the majority of horseshoe crab indices. In a few cases (Table 7. Results of autogregressive integrated moving average (ARIMA) models for horsehoe crab surveys. W is the Shapiro-Wilk test statistic for normality of residuals (p value in parentheses); n is the number of years in the time series; r1, r2, and r3 are the first three autocorrelations; θ is the moving average parameter; SE is the standard error of θ; and σ^2_c is the variance of the index.), residuals from the ARIMA model fits were not normally distributed and subsequent bootstrapped probabilities of being below reference point values should be considered with caution. The surveys whose residuals were not normally distributed included the

Rhode Island Stout Survey, the Connecticut Long Island Trawl survey (both Fall and Spring), the Maryland Coastal Bay survey (when 1989 is included), and the NMFS bottom trawl survey (Spring). In the case of the Maryland Coastal Bay Survey, the first year of the survey (1989) had an unusually high index value, which decreased substantially by 1990. When 1989 is excluded from the analysis, residuals from the fitted ARIMA model were normally distributed.

Trends in fitted abundance indices from ARIMA models showed much variation among surveys (Figure 3. New England region horseshoe crab ARIMA model fits. The solid line represents the observed ln transformed indices and the dashed line represents the fitted indices. The red horizontal line represents the Q_{25} reference point and the blue horizontal line represents the 1998 reference point. – 8). Surveys with time series extending back into the to the mid-1990's generally showed a decreasing trend through the early 2000's, but showed mixed results from the mid 2000's through 2012, with some indices increasing (e.g. SEAMAP Trawl Survey, Figure 8. Southeast region horseshoe crab ARIMA model fits. The solid line represents the observed ln transformed indices and the dashed line represents the fitted indices. The red horizontal line represents the Q_{25} reference point (The Virginia Tech Trawl survey began after 1998).), remaining stable (e.g. Delaware Bay 30 ft. trawl, Figure 6), or continuing to decrease (e.g. University of Rhode Island – Graduate School of Oceanography, Figure 3. New England region horseshoe crab ARIMA model fits. The solid line represents the observed ln transformed indices and the dashed line represents the fitted indices. The red horizontal line represents the Q_{25} reference point and the blue horizontal line represents the 1998 reference point.). Within the Delaware Bay region, Virginia Tech Trawl Survey values increased from 2004 – 2007, but then decreased in 2008 and 2009, and showed some increase in 2010 and 2011 (Figure 7. Virginia Tech Trawl (Delaware Bay region) horseshoe crab ARIMA model fits. The solid line represents the observed ln transformed indices and the dashed line represents the fitted indices. The red horizontal line represents the Q_{25} reference point (The Virginia Tech Trawl survey began after 1998).). New Jersey trawl surveys have shown mixed results, with the New Jersey Surf Clam survey values showing a consistent increase since 2000, but the New Jersey Ocean Trawl survey values decreasing from 2004 – 2010 with some increases in 2011 - 2012 (Figure 5. Delaware Bay region horseshoe crab ARIMA model fits. The solid line represents the observed ln transformed indices and the dashed line represents the fitted indices. The red horizontal line represents the Q_{25} reference point and the blue horizontal line represents the 1998 reference point.). Delaware's trawl surveys remained stable in recent years (Figure 5. Delaware Bay region horseshoe crab ARIMA model fits. The solid line represents the observed ln transformed indices and the dashed line represents the fitted indices. The red horizontal line represents the Q_{25} reference point and the blue horizontal line represents the 1998 reference point.- 6). Bootstrapped probabilities that 2011 or 2012 indices were below reference points also varied greatly among surveys (Table 8. Reference points from the ARIMA model for each survey and the probability that the terminal year's fitted index (i_f) is below the reference point. The 1998 reference is i_{1998} and the lower quartile reference is Q_{25}. Reference points are based on ln transformed index values. Surveys that began after 1998 do not have a 1998 reference value.). To generalize the probabilities of 2011 or 2012 indices being below reference points, we considered a probability of ≥0.50 as being "likely" to be below reference points (Table 9. Number of surveys with terminal year having a greater than 0.50 probability of being less than the reference point (i.e. likely less than the reference point). Time series were only included in this summary if the terminal year was 2011 or 2012 and residuals from ARIMA model fits were normally distributed. Those that ended earlier are not included. Also, those surveys that did not begin until after 1998 were not included in the P(if<i1998)>0.50 summary. Similar data summaries from the 2009 ASMFC stock assessment are also provided for reference.). We also considered only those surveys whose residuals from fitted ARIMA indices were normally distributed. Coast-wide, 9 out of 33 surveys (27%) had 2011 or 2012 indices that were likely less than Q_{25}, and 12 out of 24 surveys (50%) were likely less than the 1998 reference point. (The number of surveys available to compare to the 1998 reference point is less than the number available to compare to the other reference points because several surveys were not initiated until after 1998.) In the New England region, 6 out of 7 surveys (86%) were likely below the Q_{25} reference point and 5 out of 6 (83%) were likely below the 1998 reference point. In the New York region, 1 out of 5 surveys (20%) was likely below the Q_{25} reference point and 3 out of 5 (60%) were likely below the 1998 reference point. Within the Delaware Bay region, 2 out of 16 surveys (13%) had 2011 or 2012 indices that were likely less than Q_{25}, and 4 out of 11 (36%) were likely less than the 1998 reference point. No surveys in the Southeast region were below their reference points.

One problem when evaluating the status of a population in relation to the Q_{25} reference point is that this index based reference point is not fixed and will vary depending on the length of the time series of data as well as the trajectory of the population. In data sets with long time series showing both increases and decreases throughout their length, the Q_{25} reference point may remain fairly stable as more years of data are added. However, if the index shows consistent monotonic trends or is of a short duration, the Q_{25} reference point will change as more years of data are added. The 1998 reference point was fixed and will not change as the length of index time series increases.

6.0 Stock Status

6.1 Current Overfishing, Overfished/Depleted Definitions

No overfishing or overfished definitions have been adopted by the Management Board. Models that could be used in determining overfishing and overfished status were not run as part of this stock assessment update.

6.2 Stock Status Determination

As stated in the 2004 assessment, the coast-wide horseshoe crab population is subdivided into regional populations. Genetic studies have identified multiple isolated subpopulations. Tagging studies have supported the presence of subpopulations and also showed a finer, regional structure. Observed movement rates at larger scales allow for genetic mixing, but do not coincide with large-scale population shifts. Population indices show unique trends between some regional populations, suggesting dynamics might result from regional factor(s). Factors could include regional differences in harvest, habitat quality, prey availability, pollution, or other stressors.

Coast-wide biomedical harvest increased since the 2009 stock assessment and has remained in excess of 57,500 crabs (the 1998 FMP threshold to trigger management action) since 2006. The regional differences highlight the potential for localized overharvesting. *Management regulations and population assessment should be implemented on a regional scale. Monitoring and research should reflect the regional differences.*

Horseshoe crab abundance trends varied regionally/sub-regionally. Positive trends were observed in the Southeast and for some indices in Delaware Bay regions. In the Southeast region there was evidence that abundance has remained stable or continued to increase since the 2009 stock assessment. In Delaware Bay, there was evidence for demographic-specific increases in abundance through the time series of data, but trends have been largely stable since the 2009 stock assessment. An exception is the continued sharp increase in abundance indices from the New Jersey Surf Clam dredge.

Declining abundance was evident in the New York and New England regions. These declines were evident in the previous 2004 and 2009 stock assessments, and trends have not reversed. The status of horseshoe crabs in the New England region appears worse than what it was during the 2009 stock assessment, with more indices now likely less than their Q_{25} and 1998 reference points.

The region-specific trends reinforce the importance of management, regulations, and monitoring on a regional scale. Decreased harvest of the Delaware Bay population has redirected harvest to other regions, particularly New York and New England. While the recent evidence from the Delaware Bay population suggests population rebuilding or at least stabilization, the evidence from New York and New England suggests that current harvest within those regions is not sustainable. *Continued precautionary management is therefore recommended coastwide to anticipate effects of redirecting harvest from Delaware Bay to outlying populations.*

Advancements in the assessment and management of horseshoe crabs have been made in the Delaware Bay since the 2009 stock assessment. Although not included in this stock assessment update because of the need to include biomedical mortality, the catch-survey model showed promise as a management tool to obtain total population estimates in the Delaware Bay region. This model will be developed further in the next benchmark assessment. Also, the ARM framework that links the population dynamics of horseshoe crabs and red knots is now being used for annual horseshoe crab harvest decisions. However, assessment approaches to make informed management decisions are lacking in the New York and New England region, where trends in abundance indices continue to suggest exploitation in these regions is not sustainable. Monitoring and management in the New York and New England areas should be given a higher priority to reverse or at least stabilize abundance trends in these areas.

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Table 1. Reported Atlantic coast horseshoe crab landings and value, 1970 – 2011 (NMFS Commercial Fishery Landings Database, accessed on 8/5/2013).

Year	Metric tons	Pounds	Value ($)	value/pound
1970	7	15,900	2,383	0.15
1971	5	11,900	970	0.08
1972	19	42,000	880	0.02
1973	40	88,700	1,960	0.02
1974	8	16,700	2,656	0.16
1975	29	62,800	7,974	0.13
1976	927	2,043,100	28,524	0.01
1977	215	473,000	7,859	0.02
1978	330	728,500	23,251	0.03
1979	551	1,215,630	81,977	0.07
1980	257	566,447	47,731	0.08
1981	148	326,695	36,885	0.11
1982	239	526,700	46,647	0.09
1983	213	468,600	37,901	0.08
1984	102	225,112	22,834	0.10
1985	279	614,939	54,903	0.09
1986	288	635,823	69,773	0.11
1987	232	511,758	77,058	0.15
1988	313	688,839	86,706	0.13
1989	502	1,106,645	140,889	0.13
1990	235	519,057	61,878	0.12
1991	175	385,487	39,674	0.10
1992	146	321,995	34,730	0.11
1993	373	821,205	85,808	0.10
1994	531	1,171,571	131,175	0.11
1995	1,096	2,416,168	309,467	0.13
1996	2,340	5,159,326	1,542,092	0.30
1997	2,714	5,983,033	1,182,375	0.20
1998	3,101	6,835,305	2,109,723	0.31
1999	2,514	5,542,506	1,397,354	0.25
2000	1,704	3,756,475	960,117	0.26
2001	1,060	2,336,645	667,018	0.29
2002	1,257	2,772,010	540,037	0.19
2003	1,190	2,624,248	695,338	0.26
2004	442	974,425	432,702	0.44
2005	645	1,421,957	514,418	0.36
2006	703	1,548,900	821,017	0.53
2007	819	1,804,968	1,147,833	0.64
2008	597	1,315,963	837,330	0.64
2009	830	1,830,506	1,126,440	0.62
2010	543	1,197,883	723,263	0.60
2011	684	1,508,615	924,469	0.61

Table 2. State by state Atlantic coast horseshoe crab landings reported through ASMFC, 1998 – 2012. [Note: The ASMFC quota was initiated in 2001 through Addendum 1 and has since been adjusted in 2003 through Addendum III and in 2006 through Addendum IV.]

	ME	NH	MA	RI	CT	NY	NJ	PA	DE	MD	VA	NC	SC	GA	FL	Total
RPL	13,500	350	440,503	26,053	64,919	488,362	604,049		482,401	613,225	203,326	24,036		29,312	9,455	2,999,491
Addendum IV Quota	13,500	350	330,377	26,053	48,689	366,272	100,000	0	100,000	170,653	152,495	24,036	0	29,312	9,455	1,371,192
1998	13,500	200	400,000		34,583	352,462	241,456	70,000	479,634	114,458	1,015,700	21,392			200	2,743,585
1999	1,500	350	545,715	26,053	45,050	394,026	297,680	0	428,980	134,068	650,640	28,094	0	29,312	19,446	2,600,914
2000	1,391	180	272,930	13,809	15,921	628,442	398,629	0	2,490	152,275	145,465	14,973	0	0	10,462	1,656,967
2001	100	0	134,143	3,490	12,175	129,074	261,239	0	244,813	170,653	48,880	9,130	0	0	0	1,013,697
2002	150	120	138,613	3,886	32,080	177,271	281,134	0	298,319	278,211	42,954	12,988	0	0	200	1,265,926
2003	98	0	125,364	5,824	15,186	134,264	113,940	0	356,380	168,865	106,577	24,367	0	0	1,628	1,052,493
2004	0	0	69,436	6,030	23,723	142,279	46,569	0	127,208	161,928	94,713	9,437	0	0	0	681,323
2005	0	0	73,740	8,260	15,311	155,108	87,250	0	154,269	169,821	97,957	7,713	0	0	0	769,429
2006	0	0	171,906	15,274	26,889	172,381	3,444	0	147,813	136,733	155,704	10,331	0	0	469	840,944
2007	0	5	150,829	15,564	25,098	298,222	0	0	76,663	172,117	79,570	9,300	0	0	186	827,554
2008	0	0	103,963	15,549	32,565	148,719	0	0	102,113	163,495	68,338	26,191	0	0	50	660,983
2009	0	41	98,332	18,729	27,065	123,653	0	0	102,659	165,434	248,327	33,025	0	0	0	817,265
2010	0	0	54,782	12,502	30,036	124,808	0	0	61,751	165,344	145,357	9,938	0	0	993	605,511
2011	0	0	67,087	12,632	24,466	146,995	0	0	95,663	167,053	121,650	27,076	0	0	0	662,622
2012	0	0	106,821	19,306	18,958	167,723	0	0	100,255	169,087	124,048	22,902	0	0	0	729,100

Table 3. Commercial catch rates (CPUE) of horseshoe crabs in Delaware and Georgia.

	Delaware						Georgia		
Year	Hand Harvest	Trips	Hand CPUE	Dredge Harvest	Trips	Dredge CPUE	Bycatch	Net Hrs	CPUE
1991	17,457	62	281.6	22,158	16	1384.9			
1992	24,355	71	343	16,665	9	1851.7			
1993	29,867	44	678.8	20,466	17	1203.9			
1994	74,899	93	805.4	26,173	12	2181.1			
1995	133,586	172	776.7	38,515	30	1283.8			
1996	245,889	211	1165.4	50,470	14	3605.0			
1997	374,379	318	1177.3	53,052	33	1607.6			
1998	389,566	629	619.3	90,068	137	657.4			
1999	336,232	393	855.6	92,748	84	1104.1			
2000	192,993	301	641.2	55,945	51	1097.0	293	20.86	14.05
2001	160,028	420	381	84,785	157	540.0	543	55.89	9.72
2002	191,343	403	474.8	101,387	172	589.5	147	42.23	3.48
2003	302,101	845	357.5	54,279	220	246.7	13	36.45	0.36
2004	66,210	197	336.1	60,244	152	396.3	133	40.95	3.25
2005	96,832	161	601.4	57,437	117	490.9	754	89.49	8.43
2006	72,477	160	450.5	75,336	94	801.4	561	42	2.73
2007	59,429	124	566	17,234	19	907.1	0		
2008	102,113	150	680.8	0	0		0		
2009	102,659	202	508.2	0	0		0		
2010	55,329	146	379	6,422	19	338.0	40	79.2	0.51
2011	78,204	154	507.8	17,459	21	831.4	43	23.25	1.85
2012	45,274	170	266.3	54,981	74	743.0	0		

Table 4. Trends in female and male horseshoe crab prosomal width (mm) from fishery dependent surveys.

	DE-Hand		DE-Dredge		GA-Trawl Bycatch			MD			MA-Bait Fishery		NY-Bait Fishery		SC-Biomedical		VA-Dredge/Pound	
Year	Female*	Male*	Female	Male	TEDs ?	Female*	Male*	Source	Female*	Male*	Female*	Male	Female	Male	Female	Male	Female	Male
1993								COMM	317	251								
1994								COMM	235	223								
1995								COMM	245	211								
1996								COMM	248	202								
1997								COMM	243	204								
1998								COMM	242	207								
1999	265	227			No	267	269	COMM	254	211					308	237		
2000	260	227			No	275	235	COMM	239	199	265	201			314	241	264	224
2001	267	208			Yes	291	232	COMM	251	208	259	195			311	235	253	220
2002	266	206		265	Yes	281	218	COMM	234	212	264	200			301	235	267	222
2003	269	206			Yes	268	204	COMM	272	207	255	198			312	240	274	223
2004	266	207			Yes	197	177	COMM	236	217	250	199	284	219	314	240		
2005	262	208			Yes	229	212	BIO	204	170	254	191	260		306	236	287	223
2006	264	207			Yes	187	175	BIO	207	171	253	197	271		307	236	258	222
2007	231	207						BIO	221	180	255	198	236	214	302	233	265	222
2008		207						BIO	217	170	250	198	255	210	304	234	247	214
2009		205						BIO	219	180	246	196						
2010		206						BIO	230	179	239	196						
2011		203		159	Yes		216	BIO	254	208	246	201						
2012		204		198				BIO	259	210	239	199						

Table 5. Coastwide annual harvest, use, and mortality of horseshoe crabs used for biomedical purposes.

	2004	2005	2006	2007	2008	2009	2010	2011	2012
Number of crabs brought to biomedical facilities (bait and biomedical crabs)	343,126	323,149	367,914	500,251	511,478	512,552	548,751	628,476	611,827
Number of biomedical-only crabs harvested (not counted against state bait quotas)	292,760	283,720	309,289	428,872	423,614	402,202	482,704	545,164	530,797
Number of bait crabs bled	50,366	39,429	58,625	71,379	87,864	110,350	66,047	83,312	81,030
Estimated mortality of biomedical-only crabs prior to bleeding	4,391	4,256	4,639	3,599	2,973	6,298	9,665	6,917	6,891
Number of biomedical-only crabs bled	275,194	270,496	296,958	398,844	402,080	362,291	438,417	492,734	485,965
Estimated mortality of biomedical-only crabs during or after bleeding	41,279	40,574	44,543	59,833	60,312	54,344	65,763	73,910	72,895
Total estimated mortality on biomedical crabs not counted against state bait quotas	45,670	44,830	49,182	63,432	63,285	60,642	75,428	80,827	79,786

Table 6. Fishery-independent surveys used in the coastwide horseshoe crab assessment update.

Survey	Metric	N	First year	Last year
New England Region				
Massachusetts Inshore Bottom Trawl (Fall)	number per tow	35	1978	2012
Massachusetts Inshore Bottom Trawl (Spring)	numbe per tow	35	1978	2012
New Hampshire Spawning Survey (Spring)	number per distance (ft)	12	2001	2012
New Hampshire Spawning Survey (Spring - Summer)	number per distance (ft)	9	2001	2009
Rhode Island - Marine Research Inc.	arithmetic mean catch per tow	25	1988	2012
Rhode Island - Marine Research Inc. Providence River Impingment	number of crabs impinged	21	1992	2012
Rhode Island - Stout Survey	number of crabs	28	1975	2002
Rhode Island DFW Trawl	arithmetic mean catch per tow	15	1998	2012
University of Rhode Island - Graduate School of Oceanography	arithmetic mean catch per tow	54	1959	2012
New York Region				
CT Long Island Sound Trawl (Fall)	geometric mean kg per tow	21	1992	2012
CT Long Island Sound Trawl (Spring)	geometric mean kg per tow	21	1992	2012
NY Peconic Bay Trawl Survey	delta mean CPUE	26	1987	2012
NY Western Long Island Beach Seine - Jamaica Bay	geometric mean catch per haul	26	1987	2012
NY Western Long Island Beach Seine - Little Neck Bay	geometric mean catch per haul	26	1987	2012
NY Western Long Island Beach Seine - Manhasset Bay	geometric mean catch per haul	26	1987	2012
Delaware Bay Region				
Northeast Area Monitoring and Assessment Program (Fall)	geometric mean per tow	6	2007	2012
Northeast Area Monitoring and Assessment Program (Spring)	geometric mean per tow	5	2008	2012
Delaware 16 ft trawl (Juvenile)	geometric mean catch per tow	21	1992	2012
Delaware 16 ft trawl (YOY)	geometric mean catch per tow	21	1992	2012
Delaware 30 ft trawl (all HSC)	geometric mean catch per tow	23	1990	2012
Delaware 30 ft trawl (Female)	geometric mean catch per tow	23	1990	2012
Delaware 30 ft trawl (Male)	geometric mean catch per tow	23	1990	2012
Delaware Bay Spawning Survey (Female)	index of spawning activity	14	1999	2012
Delaware Bay Spawning Survey (Male)	index of spawning activity	14	1999	2012
Maryland Coastal Bay	geometric mean catch per tow	24	1989	2012
NJ Delaware Bay Trawl (Female)	gemetric mean catch per tow	15	1998	2012
NJ Delaware Bay Trawl (Male)	gemetric mean catch per tow	15	1998	2012
NJ Delaware Bay Trawl (all HSC)	gemetric mean catch per tow	15	1998	2012
NJ Delaware Bay Trawl (Juvenile)	gemetric mean catch per tow	15	1998	2012
NJ Ocean Trawl	stratified geometric mean	25	1988	2012
NJ Surf Clam Dredge	geometric mean per dredge	15	1998	2012
NMFS bottom trawl survey (Fall)	geometric mean catch per tow	21	1988	2008
NMFS bottom trawl survey (Spring)	geometric mean catch per tow	21	1988	2008
Virginia Tech Trawl (all HSC)	catch per tow	10	2002	2011
Virginia Tech Trawl (Female)	catch per tow	10	2002	2011
Virginia Tech Trawl (Male)	catch per tow	10	2002	2011
Southeast Region				
Florida Seahorse Key (Gulf) Spawning Survey	mean number per tide	11	1993	2010
Georgia Shrimp Trawl	arithmetic mean catch per tow	14	1999	2012
NC Pamlico Sound Neuse River Gill Net	geometric mean catch per set	12	2001	2012
SEAMAP Trawl Survey (Fall)	Geometric mean catch per tow	18	1995	2012
South Carolina Trawl	number per tow	18	1995	2012

Table 7. Results of autogregressive integrated moving average (ARIMA) models for horsehoe crab surveys. W is the Shapiro-Wilk test statistic for normality of residuals (p value in parentheses); n is the number of years in the time series; r1, r2, and r3 are the first three autocorrelations; θ is the moving average parameter; SE is the standard error of θ; and σ^2_c is the variance of the index.

Survey	Years	n	W	p	r_1	r_2	r_3	θ	SE	σ^2_c
New England Region										
Massachusetts Inshore Bottom Trawl (Fall)	1978-2012	35	0.97	0.52	-0.42	-0.06	-0.16	0.78	0.11	0.72
Massachusetts Inshore Bottom Trawl (Spring)[1]	1978-2012	35	0.95	0.08	-0.44	0.02	-0.12	0.75	0.16	0.69
New Hampshire Spawning Survey (Spring)	2001-2012	12	0.95	0.68	-0.22	-0.4	0.14	0.46	0.24	0.57
New Hampshire Spawning Survey (Spring - Summer)	2001-2009	9	0.98	0.96	-0.29	-0.54	0.37	0.49	0.29	0.33
Rhode Island - Marine Research Inc.	1988-2012	25	0.98	0.96	-0.51	0.57	-0.55	0.35	0.16	0.57
Rhode Island - Marine Research Inc. Providence River Impingment	1992-2012	25	0.98	0.96	-0.51	0.57	-0.55	0.35	0.16	0.57
Rhode Island - Stout Survey	1975-2002	28	0.91	0.02	-0.32	-0.02	0.33	0.27	0.16	0.24
Rhode Island DFW Trawl	1998-2012	15	0.96	0.61	-0.17	-0.27	0.17	0.16	0.38	0.21
University of Rhode Island - Graduate School of Oceanography	1959-2012	54	0.98	0.37	-0.38	0.31	-0.16	0.34	0.11	1.07
New York Region										
CT Long Island Sound Trawl (Fall)	1992-2012	20	0.90	0.04	-0.17	-0.24	-0.17	0.68	0.25	0.2
CT Long Island Sound Trawl (Spring)	1992-2012	21	0.88	0.02	-0.4	-0.03	-0.14	0.74	0.21	0.29
NY Peconic Bay Trawl Survey	1987-2012	26	0.99	0.96	-0.35	0.29	0.06	0.2	0.16	0.22
NY Western Long Island Beach Seine - Jamaica Bay	1987-2012	26	0.99	0.98	-0.51	-0.17	0.48	1	0.74	0.38
NY Western Long Island Beach Seine - Little Neck Bay	1987-2012	26	0.99	0.99	-0.53	0.2	-0.29	0.71	0.17	0.4
NY Western Long Island Beach Seine - Manhasset Bay	1987-2012	26	0.99	0.99	-0.53	0.26	-0.41	0.76	0.18	0.7
Delaware Bay Region										
Delaware 16 ft trawl (Juvenile)	1992-2012	21	0.94	0.23	-0.23	0.03	-0.14	0.26	0.23	0.59
Delaware 16 ft trawl (YOY)[1]	1992-2012	21	0.96	0.53	-0.29	-0.19	0.04	1	0.17	2.13
Delaware 30 ft trawl (all HSC)	1990-2012	23	0.92	0.07	-0.15	-0.16	0.13	0.61	0.18	1.04
Delaware 30 ft trawl (Female)	1990-2012	23	0.95	0.29	-0.19	-0.13	0.15	0.6	0.16	1.11
Delaware 30 ft trawl (Male)	1990-2012	23	0.91	0.05	-0.18	-0.29	0.14	0.66	0.17	1.52
Delaware Bay Spawning Survey (Female)	1999-2012	14	0.98	0.94	-0.42	-0.12	0.16	0.61	0.34	0.03
Delaware Bay Spawning Survey (Male)	1999-2012	14	0.96	0.79	-0.6	0.21	-0.06	0.78	0.27	0.05
Maryland Coastal Bay[2]	1990-2012	23	0.94	0.18	-0.5	-0.13	0.43	0.83	0.49	0.21
Maryland Coastal Bay[3]	1989-2012	24	0.91	0.04	-0.14	-0.09	0.13	0.79	0.18	0.34
NJ Delaware Bay Trawl (Female)	1998-2012	15	0.94	0.42	-0.65	0.23	0.11	1	0.56	0.3

Table 7. Continued.

Survey	Years	n	W	p	r_1	r_2	r_3	θ	SE	σ^2_c
Delaware Bay Region										
NJ Delaware Bay Trawl (Male)	1998-2012	15	0.95	0.52	-0.58	0.03	0.26	0.75	0.18	0.26
NJ Delaware Bay Trawl (all HSC)	1998-2012	15	0.95	0.50	-0.54	-0.17	0.43	0.79	0.18	0.5
NJ Delaware Bay Trawl (Juvenile)	1998-2012	15	0.96	0.61	-0.49	-0.16	0.34	0.77	0.26	1.2
NJ Ocean Trawl	1988-2012	25	0.97	0.67	0.01	-0.28	-0.14	0.21	0.31	0.14
NJ Surf Clam Dredge	1998-2012	15	0.94	0.34	-0.24	0.48	-0.17	0.29	0.17	0.4
NMFS bottom trawl survey (Fall)	1988-2008	21	0.93	0.16	-0.55	0.03	0.15	1	0.36	0.14
NMFS bottom trawl survey (Spring)	1988-2008	21	0.89	0.02	-0.62	0.2	0.1	1	0.16	0.92
Virginia Tech Trawl (all HSC)	2002-2011	10	0.85	0.06	0.13	-0.42	-0.49	0.1	0.42	0.19
Virginia Tech Trawl (Female)	2002-2011	10	0.95	0.69	0.03	-0.17	-0.44	0.01	0.41	0.19
Virginia Tech Trawl (Male)	2002-2011	10	0.90	0.23	0.17	-0.52	-0.5	0.18	0.39	0.2
Southeast Region										
Florida Seahorse Key (Gulf) Spawning Survey	1993-2010	11	0.95	0.66	0.02	-0.43	-0.01	0.14	0.38	0.45
Georgia Shrimp Trawl	1999-2012	14	0.98	0.95	-0.14	-0.34	0.04	0.55	0.3	0.21
NC Pamlico Sound Neuse River Gill Net	2001-2012	12	0.97	0.90	-0.28	-0.09	0.02	0.15	0.24	0.05
SEAMAP Trawl Survey	1995-2012	18	0.90	0.06	-0.18	0.06	-0.3	0.43	0.24	1.44
South Carolina Trawl	1995-2012	18	0.98	0.91	-0.13	-0.27	-0.12	0.09	0.34	0.24

[1]Time series contained 0 values; ln(+0.01) transformed data used in the ARIMA model

[2]1989 deleted because of an unusually high index value and residuals were not normally distributed

[3]1989 included

Table 8. Reference points from the ARIMA model for each survey and the probability that the terminal year's fitted index (i_f) is below the reference point. The 1998 reference is i_{1998} and the lower quartile reference is Q_{25}. Reference points are based on ln transformed index values. Surveys that began after 1998 do not have a 1998 reference value.

Survey	i_f	i_{1998}	$P(i_f<i_{1998})$	Q_{25}	$P(i_f<Q_{25})$
New England Region					
Massachusetts Inshore Bottom Trawl (Fall)	-2.41	-1.68	0.91	-1.75	0.72
Massachusetts Inshore Bottom Trawl (Spring)	-2.64	-1.88	0.96	-2.45	0.55
New Hampshire Spawning Survey (Spring)	-4.23			-4.11	0.34
New Hampshire Spawning Survey (Spring - Summer)	-4.89			-4.67	0.47
Rhode Island - Marine Research Inc.	-1.75	-1.10	0.87	-1.57	0.53
Rhode Island - Marine Research Inc. Providence River Impingement	-0.94	-1.10	0.86	-1.57	0.52
Rhode Island - Stout Survey	1.91	1.20	0.01	1.89	0.25
Rhode Island DFW Trawl	-1.66	-1.88	0.18	-1.13	0.69
University of Rhode Island - Graduate School of Oceanography	-2.27	0.93	1.00	0.76	1.00
New York Region					
CT Long Island Sound Trawl (Fall)	0.05	0.06	0.22	-0.01	0.11
CT Long Island Sound Trawl (Spring)	-0.49	-0.63	0.11	-0.73	0.08
NY Peconic Bay Trawl Survey	-1.13	0.34	1.00	-0.48	0.93
NY Western Long Island Beach Seine - Jamaica Bay	-0.84	-0.99	0.03	-1.03	0.01
NY Western Long Island Beach Seine - Little Neck Bay	0.19	0.81	0.93	0.29	0.44
NY Western Long Island Beach Seine - Manhasset Bay	-0.37	0.27	0.82	-0.35	0.24
Delaware Bay Region					
Delaware 16 ft trawl (Juvenile)	-1.42	-1.26	0.42	-1.42	0.26
Delaware 16 ft trawl (YOY)[1]	-1.20	-0.77	0.38	-1.20	0.04
Delaware 30 ft trawl (all HSC)	-0.24	0.17	0.76	-0.26	0.20
Delaware 30 ft trawl (Female)	-1.99	-0.42	1.00	-1.49	0.61
Delaware 30 ft trawl (Male)	-1.17	-0.62	0.77	-1.18	0.21
Delaware Bay Spawning Survey (Female)	-0.40			-0.23	0.54
Delaware Bay Spawning Survey (Male)	1.14			1.06	0.05
Maryland Coastal Bay[2]	-1.51	-1.65	0.15	-1.70	0.08
Maryland Coastal Bay[3]	-1.47	-1.62	0.22	-1.68	0.16
NJ Delaware Bay Trawl (Female)	-1.42	-0.78	0.99	-1.52	0.19
NJ Delaware Bay Trawl (Male)	-0.26	-0.47	0.08	-0.63	0.02
NJ Delaware Bay Trawl (all HSC)	0.70	0.51	0.09	0.39	0.04
NJ Delaware Bay Trawl (Juvenile)	-0.78	-0.80	0.15	-0.97	0.08
NJ Ocean Trawl	-0.07	0.38	0.87	-0.07	0.28
NJ Surf Clam Dredge	2.29	-0.20	0.00	-0.39	0.00
NMFS bottom trawl survey (Fall)	-1.58	-1.67	0.05	-1.62	0.14
NMFS bottom trawl survey (Spring)	-2.93	-2.95	0.17	-3.06	0.05
Virginia Tech Trawl (all HSC)	3.92			3.48	0.10
Virginia Tech Trawl (Female)	2.51			2.31	0.19
Virginia Tech Trawl (Male)	3.64			3.15	0.06

Table 8. Continued.

Survey	i_f	i_{1998}	$P(i_f<i_{1998})$	Q_{25}	$P(i_f<Q_{25})$
Southeast Region					
Florida Seahorse Key (Gulf) Spawning Survey	7.00			4.51	0.00
Georgia Shrimp Trawl	0.27			0.06	0.06
NC Pamlico Sound Neuse River Gill Net	-1.00			-2.00	0.00
SEAMAP Trawl Survey	0.89	-1.90	0.00	-2.26	0.00
South Carolina Trawl	-0.39	-0.39	0.29	0.07	0.69

Table 9. Number of surveys with terminal year having a greater than 0.50 probability of being less than the reference point (i.e. likely less than the reference point). Time series were only included in this summary if the terminal year was 2011 or 2012 and residuals from ARIMA model fits were normally distributed. Those that ended earlier are not included. Also, those surveys that did not begin until after 1998 were not included in the P(if<i1998)>0.50 summary. Similar data summaries from the 2009 ASMFC stock assessment are also provided for reference.

	Current Update		**2009 Assessment**	
Region	**$P(i_f<i_{1998})>0.50$**	**$P(i_f<Q_{25})>0.50$**	**$P(i_f<i_{1998})>0.50$**	**$P(i_f<Q_{25})>0.50$**
New England	5 out of 6	6 out of 7	2 out of 3	2 out of 5
New York	3 out of 5	1 out of 5	1 out of 5	1 out of 5
Delaware Bay	4 out of 11	2 out of 16	5 out of 11	1 out of 19
Southeast	0 out of 2	0 out of 5	0 out of 5	0 out of 3
Coastwide	**12 out of 24**	**9 out of 33**	**8 out of 24**	**4 out of 32**

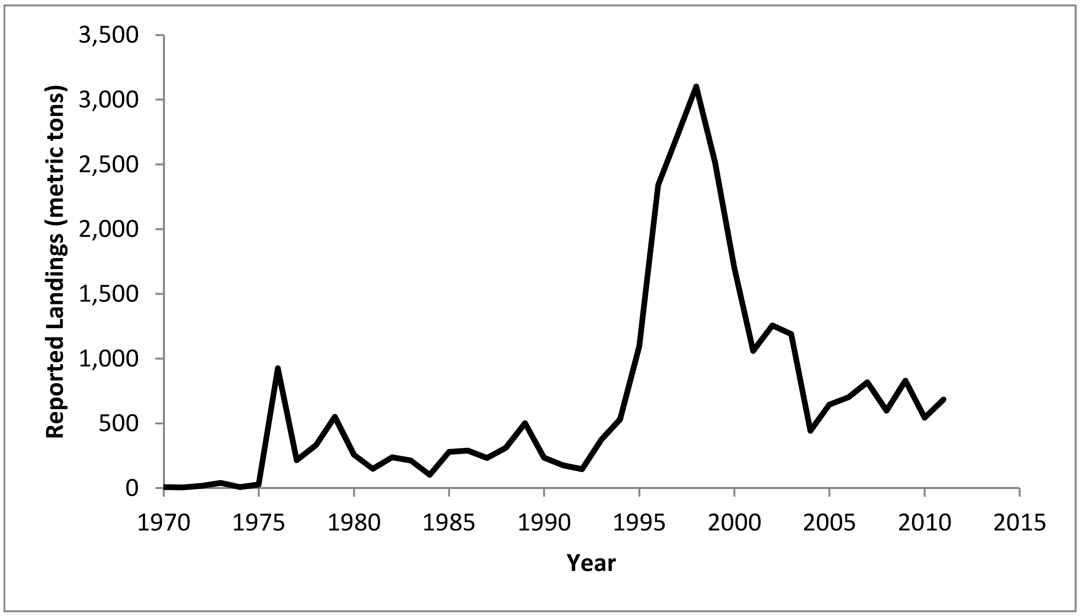

Figure 1. Reported Atlantic coast horseshoe crab landings (metric tons), 1970 – 2011 (NMFS Commercial Landings Database, August 2013).

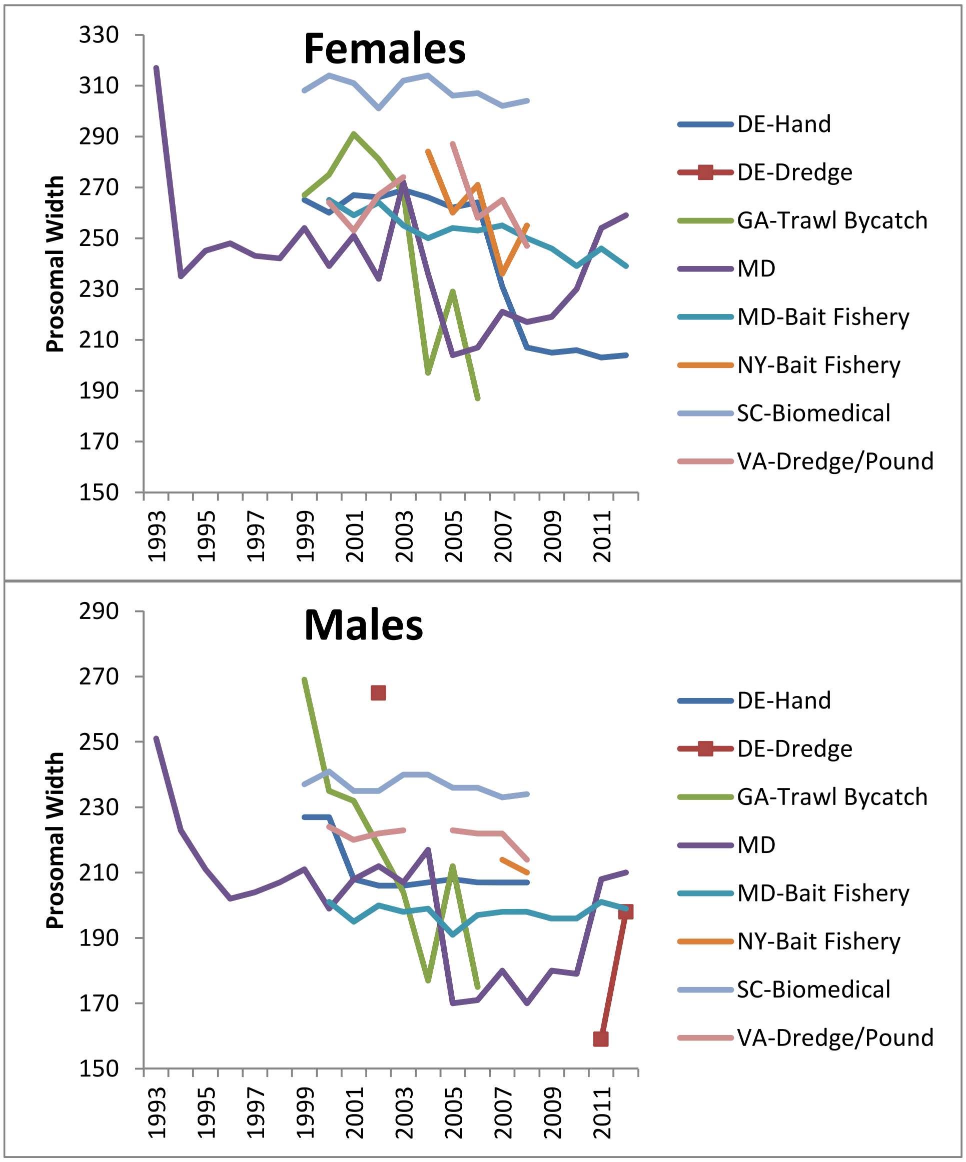

Figure 2. Trends in horseshoe crab prosomal widths from fishery-dependent data sources.

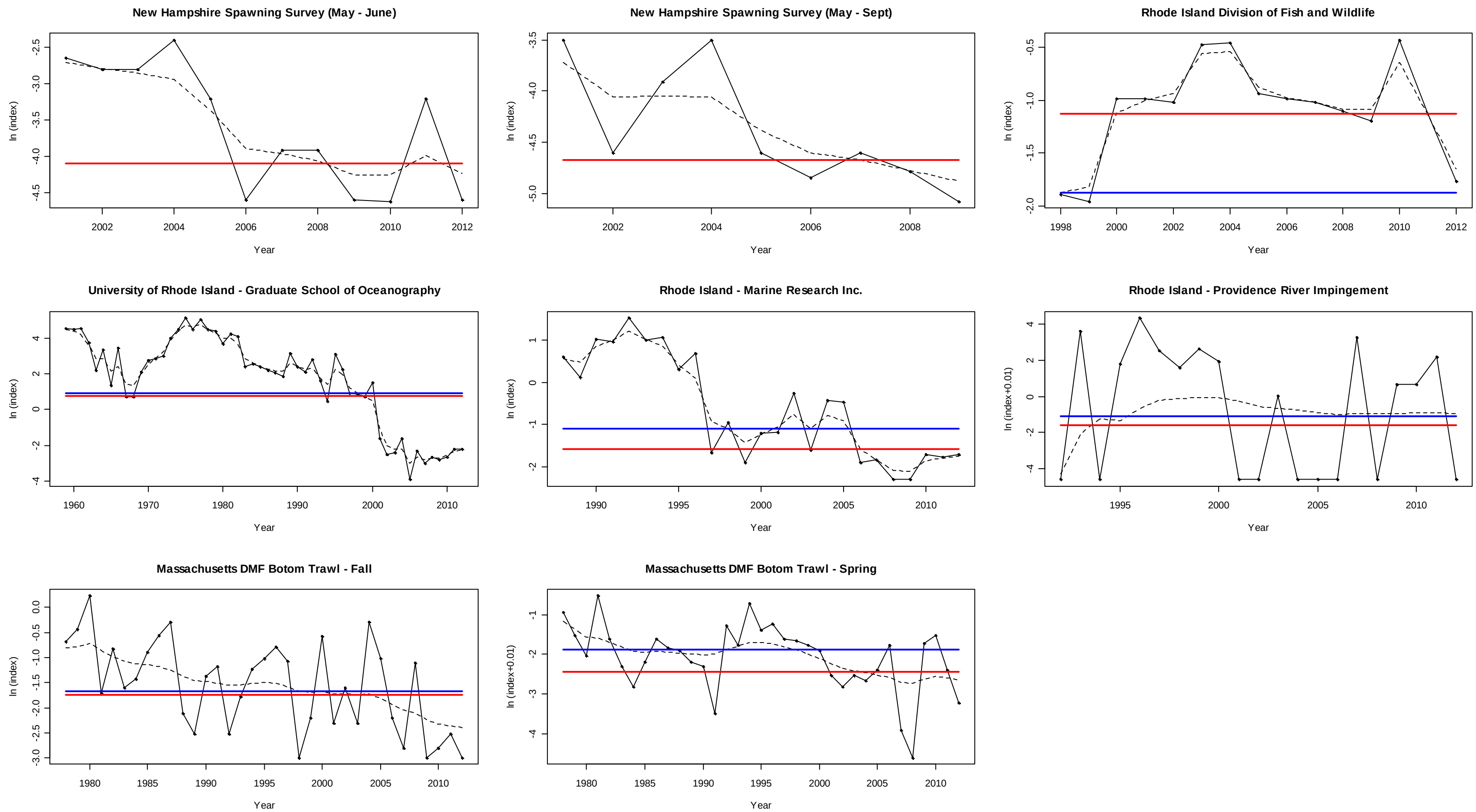

Figure 3. <u>New England region</u> horseshoe crab ARIMA model fits. The solid line represents the observed ln transformed indices and the dashed line represents the fitted indices. The red horizontal line represents the Q_{25} reference point and the blue horizontal line represents the 1998 reference point.

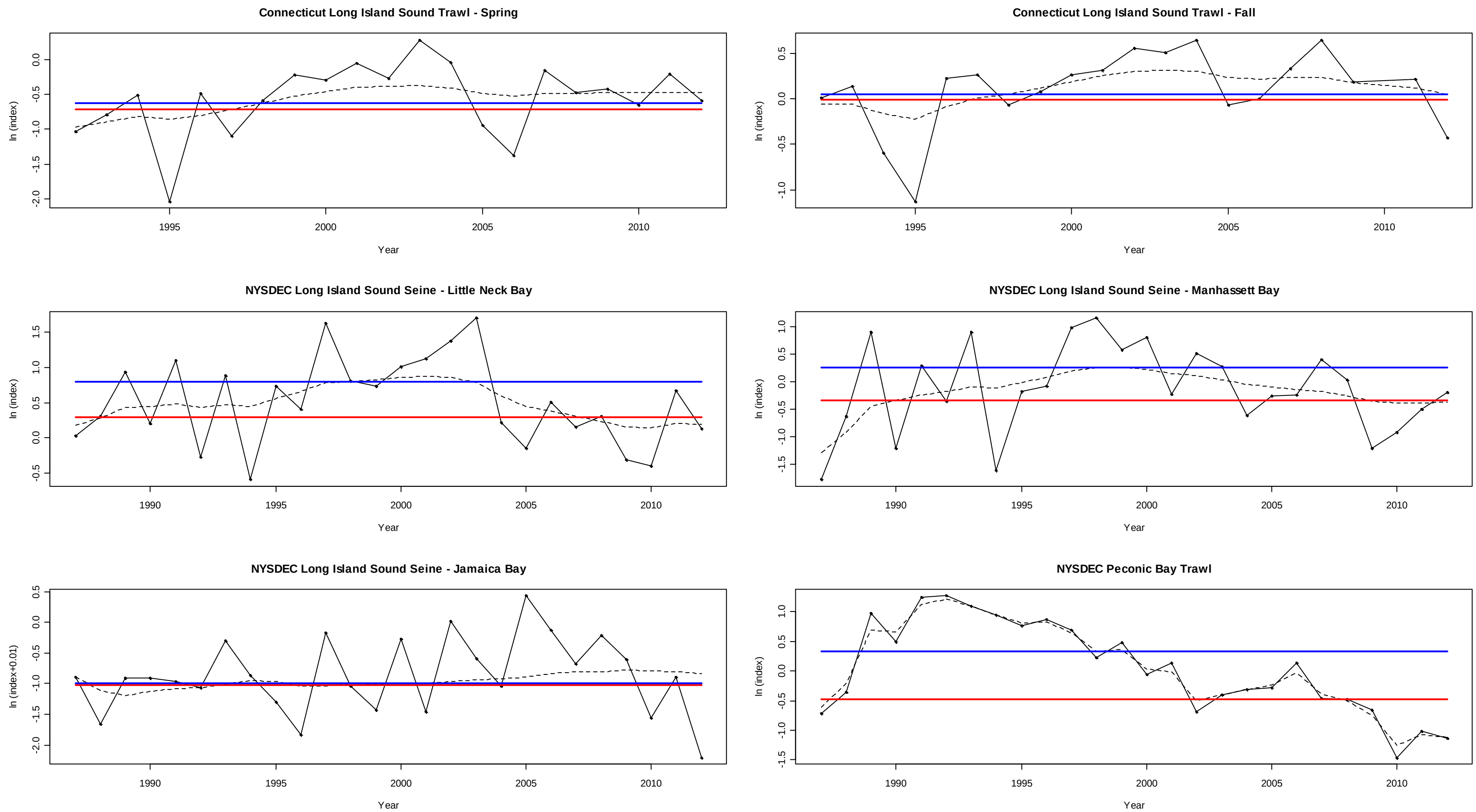

Figure 4. <u>New York region</u> horseshoe crab ARIMA model fits. The solid line represents the observed ln transformed indices and the dashed line represents the fitted indices. The red horizontal line represents the Q_{25} reference point and the blue horizontal line represents the 1998 reference point.

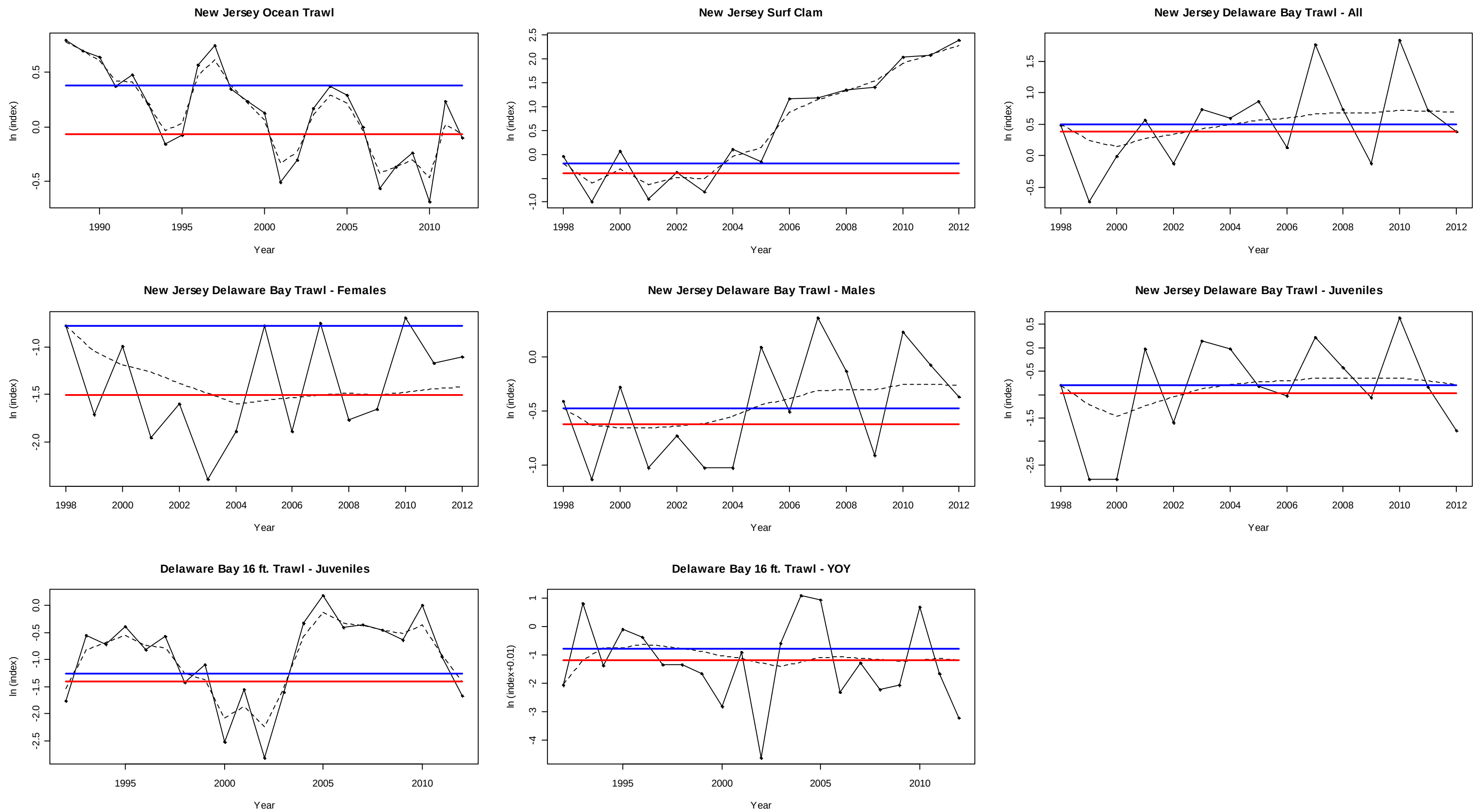

Figure 5. Delaware Bay region horseshoe crab ARIMA model fits. The solid line represents the observed ln transformed indices and the dashed line represents the fitted indices. The red horizontal line represents the Q_{25} reference point and the blue horizontal line represents the 1998 reference point.

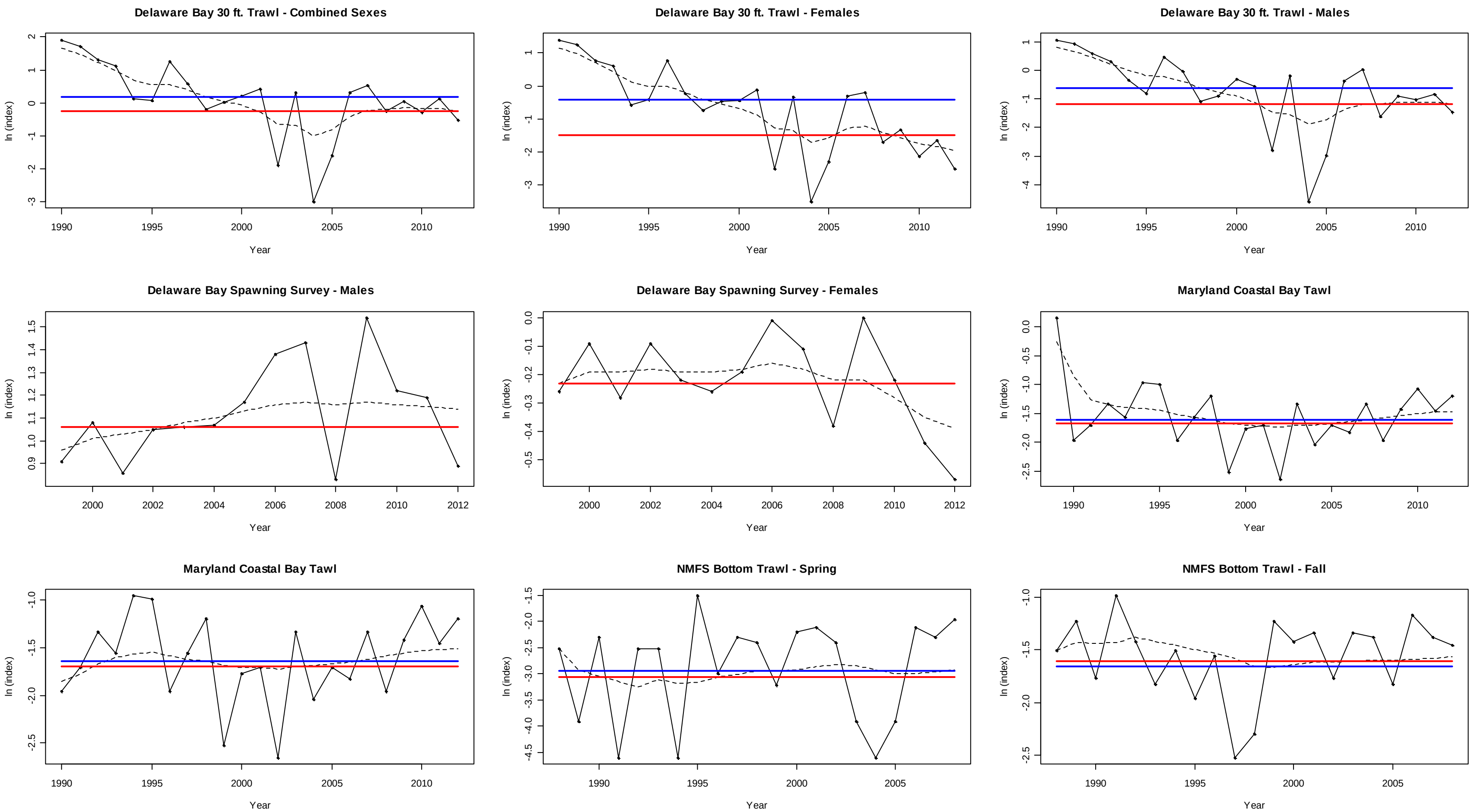

Figure 6. Delaware Bay region (continued) horseshoe crab ARIMA model fits. The solid line represents the observed ln transformed indices and the dashed line represents the fitted indices. The red horizontal line represents the Q_{25} reference point and the blue horizontal line represents the 1998 reference point.

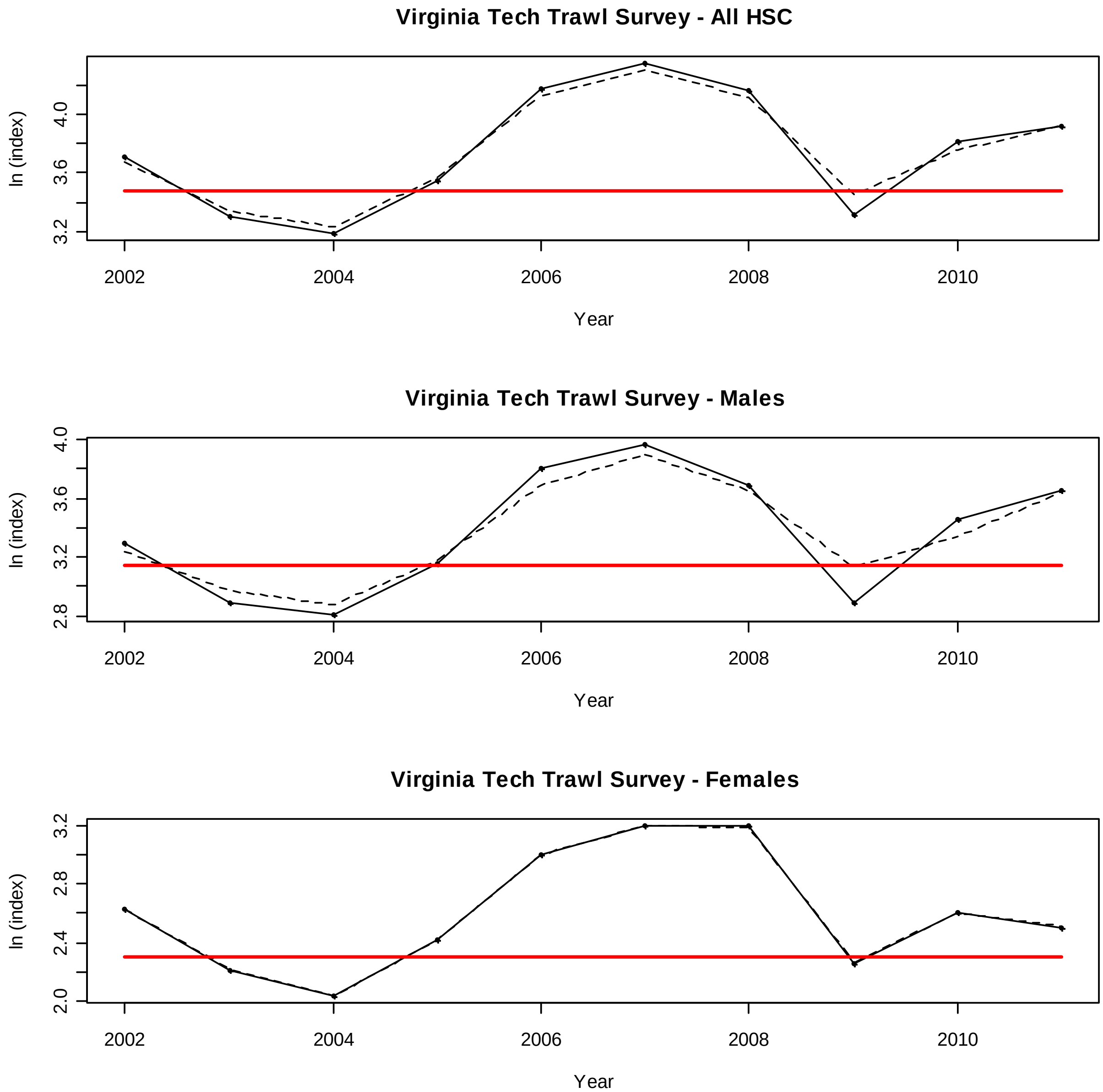

Figure 7. Virginia Tech Trawl (Delaware Bay region) horseshoe crab ARIMA model fits. The solid line represents the observed ln transformed indices and the dashed line represents the fitted indices. The red horizontal line represents the Q_{25} reference point (The Virginia Tech Trawl survey began after 1998).

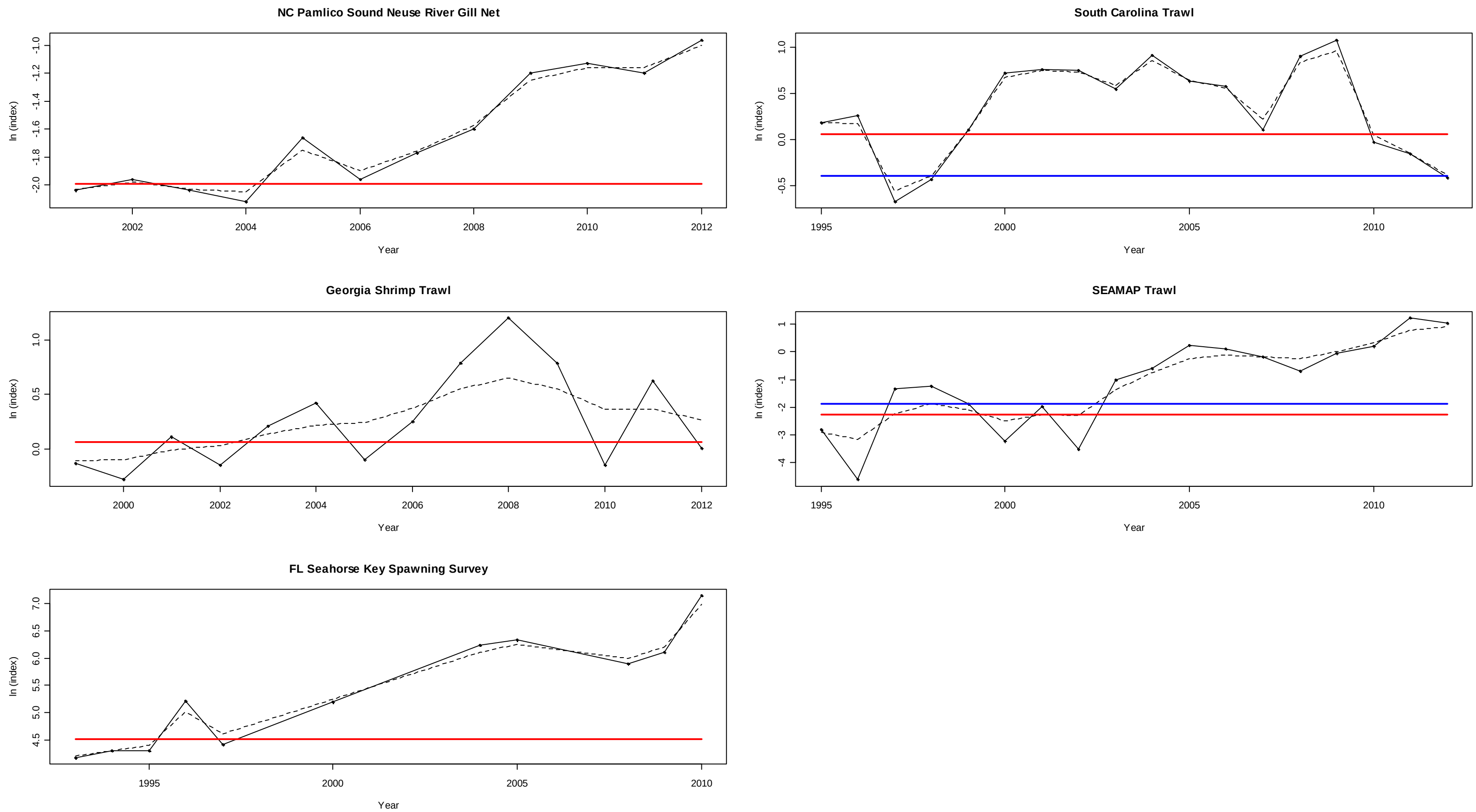

Figure 8. <u>Southeast region</u> horseshoe crab ARIMA model fits. The solid line represents the observed ln transformed indices and the dashed line represents the fitted indices. The red horizontal line represents the Q_{25} reference point (The Virginia Tech Trawl survey began after 1998).

Appendix A
List of Horseshoe Crab Stock Assessment Subcommittee Members

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Appendix B
Details of Fishery-Independent Surveys Used in Trend Analysis and ARIMA by Region

Southeast Region

South Carolina Trawl Survey Methodology

Years Sampled: 1995- present

Gear Type: Trawl (20’ head rope with 3/8” tickler chain, ½” bar mesh)
50’ research vessel at 2.5 knots for 15 minutes/tow

Spatial Coverage: Charleston Harbor area (Estuary code=1) south through North and South Edisto River (Est code=2), St. Helena Sound (Est code=3), Port Royal Sound (Est code=4), and Calibogue Sound (Est code=5)

Temporal Coverage: Biweekly-Monthly for Charleston Harbor; March, April, June, October, and December for other areas. Some months not sampled every year.

Sample Design: Fixed stations

Sample Frequency and Number: Approximately 200 per year

Information Collected: Sex, prosomal width, weight (since August 1998), temperature, Salinity

Changes in Sample Design: Starting in 2002, SC went from two trawls on one vessel to one trawl on a different vessel using the same rig. SC attempted to do side-by-side survey comparisons but did not catch enough HSCs to produce a conversion factor. CPUE has been doubled from 2002 on.

Georgia DNR Shrimp Assessment Survey

Years sampled**:** 1976 - present (horseshoe crab data since December 1998)

Gear type**:** Flat 40ft shrimp net with 1 7/8" stretched mesh throughout with no liner, with tickler Chain; Tow duration 15 minutes; Tow speed 2 - 2.5 knots; Average tow distance is about 1064 m currently using GADNR R/V Anna (60-ft)

Spatial coverage**:** 6 sound systems, with 2 offshore (out to 3 mi), 2 sound, and 2 creek/river stations in each system for a total of 36 fixed stations

Temporal coverage**:** monthly

Sample design**:** fixed stations

Sample frequency**:** 36 stations/month

Information collected**:** Since 1999: prosomal width (mm), weight (pounds), sex (M/F/Unk), total weight caught (lbs), total number caught, number measured; tow location, date, time, duration, tow direction (relative to channel; coded), tide stage (coded), tide height (ft), lunar phase (coded), wind direction (degrees), wind speed (coded), air temperature (C), surface water temperature (C), surface salinity (ppt), depth (ft)

SEAMAP Trawl Survey Methodology

Years Sampled: 1995 – present

Gear Type**:** The R/V Lady Lisa, a 75-ft (23-m) wooden-hulled, double-rigged, St. Augustine shrimp trawler owned and operated by the South Carolina Department of Natural Resources (SCDNR), was used to tow paired 75-ft (22.9-m) mongoose-type Falcon trawl nets (manufactured by Beaufort Marine Supply; Beaufort, S.C.) without TED's at a speed of approximately 2.5 knots. (Tow speed can be calculated from tow distance/tow duration). The body of the trawl was constructed of #15 twine with 1.875-in (47.6-mm) stretch mesh. The cod end of the net was constructed of #30 twine with 1.625-in (41.3-mm) stretch mesh and was protected by chafing gear of #84 twine with 4-in (10-cm) stretch "scallop" mesh. A 300 ft (91.4-m) three-lead bridle was attached to each of a pair of wooden chain doors which measured 10 ft x 40 in (3.0-m x 1.0-m), and to a tongue centered on the head-rope. The 86-ft (26.3-m) headrope, excluding the tongue, had one large (60-cm) Norwegian "polyball" float attached top center of the net between the end of the tongue and the tongue bridle cable and two 9-in (22.3-cm) PVC foam floats located one-quarter of the distance from each end of the net webbing. A 1-ft chain drop-back was used to attach the 89-ft foot-rope to the trawl door. A 0.25-in (0.6-cm) tickler chain, which was 3.0-ft (0.9-m) shorter than the combined length of the foot-rope and drop-back, was connected to the door alongside the foot-rope. Trawls were towed for twenty minutes, excluding wire-out and haul-back time, exclusively during daylight hours (1 hour after sunrise to 1 hour before sunset).

Spatial Coverage**:** Samples were taken by trawl from the coastal zone of the South Atlantic Bight (SAB) between Cape Hatteras, North Carolina, and Cape Canaveral, Florida. Each station is towed for approximately 0.8 nautical miles. For depth-zone coverage, see Sample Design.

Temporal Coverage**:** Multi-legged cruises were conducted in spring (early April - mid-May), summer (mid-July – early August), and fall (October - mid-November). Trawls were towed for twenty minutes, excluding wire-out and haul-back time, exclusively during daylight hours (1 hour after sunrise to 1 hour before sunset).

Sample Design**:** The coastal zone of the South Atlantic Bight between Cape Hatteras, North Carolina, and Cape Canaveral, Florida was divided into twenty-four shallow water strata. Additional latitudinal strata were sampled in deeper waters with station depths ranging from 10 to 19 m.

1995-2000

A total of 78 stations were sampled each season within twenty-four inner strata and the number of station towed within each stratum was constant from year to year. Fixed stations were randomly selected from a pool of trawlable stations within each stratum. Initially, the number of stations in each stratum was proportionally allocated according to the total surface area of the stratum. Inner or shallow strata were delineated by the 4 m depth contour inshore and the 10 m depth contour offshore. Additional stations were sampled in deeper strata with station depths ranging from 10 to 19 m. Twenty-seven stations located within ten outer strata in the southern half of the SAB were sampled only in spring to collect data on spawning of white shrimp.

Sixteen stations in the seven outer strata off North Carolina were sampled in fall to gather data on the reproductive condition of brown shrimp. No stations in the outer strata were sampled in summer.

2001-present
Fixed stations were randomly selected from a pool of stations within each stratum. The number of stations sampled in each stratum was determined annually by optimal allocation. A total of 102 stations were sampled each season within twenty-four shallow water strata, representing an increase from 78 stations previously sampled in those strata by the trawl survey (1990-2000). Strata were delineated by the 4 m depth contour inshore and the 10 m depth contour offshore. In previous years, stations were also sampled in deeper strata with station depths ranging from 10 to 19 m. Those strata were abandoned in 2001 in order to intensify sampling in the shallower depthzone.

Sample Frequency and Number**:** Each stratum is sampled seasonally. See Sample Design.
Information Collected**:** Prosoma width in mm, prosoma length (or total length in early collections) in mm, individual weight (g), and sex are recorded for each horseshoe collected. Although the measurement of prosoma width has been consistent, the techniques used to measure prosoma length have varied. Where information is blank, the individual was discarded before measurements were taken and only presence in trawl is recorded.

Hydrographic data collected at each station included surface and bottom temperature and salinity measurements taken with a Seabird SBE-19 CTD profiler, sampling depth, and an estimate of wave height. Additionally, atmospheric data on air temperature, barometric pressure, precipitation, and wind speed and direction were also noted at each station.

Florida Seahorse Key (Gulf) Spawning Survey
(Dr. H. Jane Brockmann, University of Florida)

Years sampled**:** 1992 to 2010 (except 1998, 1999, 2001-2003)

Gear type**:** Visual sighting

Spatial coverage**:** University of Florida Marine Laboratory at Seahorse Key (SHK), a 2-km long by 0.5-km wide (at its widest point) island 5.6 km from Cedar Key (29° 5' 47" N, 83° 3' 55" W**;** Fig. 1) in the Big Bend region of Florida's west coast.

Temporal coverage**:** Five to 7 tidal cycles during late Feb or early March to May. Tidal cycle defined as 2 day before to 5 days after spring tide. Spawning was observed on the two daily high tides.

Sample design**:** Beach was divided into 9 or 10 fixed segments (100 m in length); In 2010, beach was divided into 7 fixed segments (100 m in length)

Sample frequency**:** All beach segments were observed on the two daily high tides during the tidal cycle in late Feb or March to May

Information collected**:** Counts of spawning males and females. Spawning behavior, such as paired or unpaired status.

Delaware Bay Region

North Carolina Pamlico Sound/Neuse River Gillnet

Years sampled: 1999 – present

Gear type: Floating gill nets are used to sample shallow strata while sink nets are fished in deeper strata. Each net gang consists of 30-yard segments of 3, 3.5, 4, 4.5, 5, 5.5, 6, and 6.5 inch stretched mesh, for a total of 240 yards of nets combined.

Spatial coverage: Neuse River, Palmico River, and Pungo River

Temporal coverage: Sampling occurs each year from February 15th to December 14th

Sample design: Nets are deployed parallel or perpendicular to the shore based on the strata and common fishing techniques for the area. Gear is typically deployed within an one hour of sunset and fished the next morning to keep soak times within 12 hours.

Sample frequency and number: The catch from the gang of nets comprises a single sample. Each of the sampling areas within each region is sampled twice a month. Within a month, 32 core samples were completed (8 areas x twice a month x 2 samples) for F-70 and the same number completed in the PNWGNS river systems. For the southern area (New and Cape Fear rivers) 12 samples are completed, comprised of 8 from New River (2 areas-upper and lower x twice a month x 2 samples-shallow and deep) and 4 from Cape Fear (1 area x twice a month x 2 shallow samples)

Information collected: Numbers of horseshoe crabs, lengths, weights, sex, and CPUE

Changes in sample design: From 1999 to 2002 sampling was conducted year round; see Temporal Coverage for current sampling.

NMFS/NEFSC Spring & Autumn Trawl Surveys

Years sampled: Spring: 1968 – 2008; Fall: 1963 – present

Gear type: #36 Yankee Bottom Trawl; 100 ft. footrope/ 60 ft. headrope; 5 in. strech mesh wings and body; 4.5 in. stretch mesh codend; 0.5 in. mesh liner; 97 ft. fishing line ("traveler"); Sweep: 80 ft. - wing end sections 22.5 ft of 4 in. rubber cookies; 9.5 ft sections (2) and center 16 foot section with 16 in. diameter by 5 in. wide hard rubber rollers separated by two rubber spacers 5 in. diameter by 7 in. wide; 30 ft. leglines (upper legs 5/8 in wire / lower legs ½ in. chain); 9.5 ft. backstraps of ½ in Trawlex; 550 kg. BMV oval doors 1963 – 1984; 450 kg. polyvalent doors
1985 – 2008: 30-minute tows (24h basis); 3.5 knots (randomized direction); FRV Albatross IV or FRV Delaware II

Spatial coverage: Cape Hatteras – Canadian waters (5 to 200 Fathoms)

Temporal coverage: Spring: generally March and April; Fall: generally September and October

Sample design: Random stratified (depth)

Sample frequency and number: Approx. 300 annually

Information collected: Count, sex, prosomal width available some years, wave height, lat/lon, salinity, depth, temperature, weather.

Changes in sample design: BMV oval doors 1963 – 1984; Polyvalent doors 1985 – present; Research vessel switched to Henry B. Bigelow in 2009 which does not sample inshore strata; time series ends at 2008.

Virginia Tech Mid-Atlantic Benthic Trawl
Years sampled: 1999 – 2011

Gear type: 16.8 meter chartered commercial fishing vessel fitted with a two-seam flounder trawl of 18.3m headrope, 24.4m footrope, and Texas Sweep of 13mm link chain and a tickler chain. Net body is 6 inch stretched mesh and bag mesh is 5.5 inch stretched.

Spatial coverage: Atlantic City, NJ, to eastern shore area of Virginia from shore to 12 nautical miles out

Temporal coverage: From late September to mid October

Sample design: Survey area is stratified by distance from shore (0-3nm, 3-12nm) and bottom topography (trough, non-trough), following the results of the 2001 pilot study. Random stations sampled within each strata.

Sample frequency and number: Between 40 and 50 stations with one 15 minute bottom time tow per station

Information collected: number of crabs, prosomal width, sex, maturity, CPUE

Changes in sample design: In 2012, funding was not available to sample the entire DE Bay area. Only the inshore core area was sampled. Thus, the index ends in 2011.

New Jersey Ocean Trawl Survey Methodology

Years sampled: 1989 – present

Gear type: Three-in-one trawl (all tapers are three to one). The forward netting is 12 cm stretch mesh, rear netting is 8 cm, and liner is 6.4 mm bar mesh. The headrope is 25 m long and the footrope is 30.5 m long. The trawl bridle is 20 fathoms long, the top leg consisting of 0.5-inch wire rope and the bottom leg comprised of 0.75-inch wire rope covered with 2 3/8 inch diameter rubber cookies. A 10 fathom groundwire, also made of 0.75 inch wire rope with 2 3/8 inch diameter rubber cookies extends between the bridle and trawl doors. The trawl doors are wood with steel shoes, 8 ft x 4 ft 2 in, and weigh approximately 1000 lbs each. The net is towed for 20 minutes.

Spatial coverage: New Jersey waters from Ambrose Channel south to Cape Henlopen Channel. At depths between 5.5 m (3 fathom isobath) and 27.4 m (15 fathom isobath). This area is divided into 15 sampling strata.

Temporal coverage: Sampling is conducted in January, April, June, August, and October. The January and June surveys were excluded due to the unavailability of horseshoe crabs to the survey due to overwintering and spawning behavior.

Sample design: Stratified random design. Latitudinal boundaries of strata are identical to those used by NMFS Northwest Atlantic groundfish survey. Exceptions occurred at the extreme northern and southern strata, which were truncated to include only waters adjacent to NJ. Longitudinal boundaries consist of the 5, 10, and 15 fathom isobaths. Where these bottom contours were irregular the boundaries were smoothed, which results in the longitudinal boundaries being similar but not identical to NMFS.

Sample frequency and number: 40 stations are sampled during each monthly survey.

Information collected: The total weight of each species is measured, and lengths of all individuals or a subsample (depending on catch size) are measured. The following physical information is collect at each site; salinity, dissolved oxygen, and surface and bottom water temperatures.

Changes in sample design: None

New Jersey Surf Clam Inventory

Years sampled: 1998 – present

Gear type: hydraulic clam dredge with 6' knife

Spatial coverage: Shark River to Cape May, NJ, shore to 3 nm

Temporal coverage: June – August

Sample design: stratified random with optimal allocation based on variance of target species from previous five years

Sample frequency and number: 320-330 stations annually

Information collected: Numbers of horseshoe crabs, prosomal widths, sex, and CPUE

Changes in sample design: None

New Jersey Delaware Bay Trawl

Years sampled: 1998 – present

Gear type: 16’ finfish trawl with ¼” codend liner

Spatial coverage: NJ portion of Delaware Bay, Cohansey River to The Villas, Cape May

Temporal coverage: April through October

Sample design: fixed stations

Sample frequency and number: 11 stations sampled monthly

Information collected: Numbers of horseshoe crabs, prosomal widths, sex, and CPUE

Changes in sample design: None

Maryland Coastal Bays Trawl Survey

Years sampled: 1972 – present (consistent sampling intensity since 1988)

Gear type: Bottom trawl; 17–foot headrope / 22-foot footrope; 1.25-inch stretch mesh in wings and body 1 ½; 0.5-inch stretch mesh liner inserted in cod end; footrope with 3/16-inch galvanized chain tied tight to footrope (no excluders or chaffing gear used); 12-inch x 24-inch plyboard doors with iron shoes; 6-minute tows; 3 – 3.5 knots; 23-foot Sea Hawk fiberglass 'V'-hull vessel powered by twin 70 hp outboards; 'A'-frame stern trawling rig

Spatial coverage: Throughout MD's Coastal Bays

Temporal coverage: April through October

Sample design: Fixed

Sample frequency and number: 20 stations per month

Information collected: Count, sex (where possible), prosomal width, tide stage, wave height, latitude/longitude, salinity, depth, temperature, dissolved oxygen, weather.

Changes in sample design: Variable sampling intensity (temporal, spatial, effort) prior to 1988.

Delaware 16" (Juvenile and YOY) Trawl Survey

Years sampled: 1992 – present (YOY & <160mm); 1998 – present (>160mm)

Gear type: Bottom trawl; 17–foot headrope / 21-foot footrope; 1.5-inch stretch mesh in wings and body; 0.5-inch stretch mesh liner inserted in cod end; footrope with 1/8-inch galvanized chain hung loop-style (no excluders or chaffing gear used); 12-inch x 24-inch plyboard doors with iron shoes; 10-minute tows (against tide); 2.5 – 3 knots; 23-foot aluminum 'V'-hull w/ 'A'-frame stern trawling rig

Spatial coverage: Western Delaware Bay and Delaware (Index stations from about C&D Canal – Fowler's Beach)

Temporal coverage: April through October (YOY Index months August – October)

Sample design: Fixed

Sample frequency and number: 40 stations per month (indices use 34 stations)

Information collected: Count, sex (where possible), , CPUE, prosomal width, tide stage, wave height, latitude/longitude, salinity, depth, temperature, dissolved oxygen, weather.

Comments: Juvenile (<160mm) relative abundance based on all months and stations; YOY relative abundance based on August through October data (when YOY recruit to the survey gear); Adult (> 160mm) based on all months. Six stations sampled in the DE River excluded from all indices as no horseshoe crabs have been collected at these stations.

Delaware 30-Foot Trawl Survey

Years sampled: 1990 – present

Gear type: Bottom trawl; 30.5–foot headrope / 39.5-foot footrope; 3-inch stretch mesh in wings and body; 2-inch stretch mesh cod end; footrope with ¼-inch galvanized chain hung loop-style (no excluders or chaffing gear used); 40-foot leglines; 54-inch x 28-inch wooden doors with iron shoes and weights; 20-minute tows (against tide); 2.5 – 3 knots; 65-foot wooden displacement-hulled vessel w/ eastern-rigged trawling system (side trawler)

Spatial coverage: Western Delaware Bay (Woodland Beach – Brown Shoal areas)

Temporal coverage: March through December (Index months April – July)

Sample design: Fixed

Sample frequency and number: 9 stations per month

Information collected: Count, sex, CPUE, prosomal width, weight, tide stage, wave height, latitude/longitude, salinity, depth, temperature, dissolved oxygen, weather.

Changes in sample design: August 2002 survey switched to 62-foot deep-'V' semi-displacement hull vessel with an 'A'-frame stern-rigged trawling rig. Some tow comparisons made with previous vessel, but not yet analyzed. Tows are made at depths greater than would be expected for hull displacement, engine noise, or prop wash to interfere with catches, particularly since HSCs are a slow-moving bottom dwelling organism. Retrieval speeds similar to previous survey.

Comments: Index includes both juvenile and adult horseshoe crabs

Delaware Bay Spawning Survey

Years sampled: 1990 – present

Gear type:
- 1990 to 1998: Counting within 50 m transects.
- 1999 to present: Counting within 1 sq m quadrats

Spatial coverage: Baywide from the mouth of the bay upriver to Woodland Beach on the Delaware side to Sea Breeze on the New Jersey side.

Temporal coverage:
- 1990 to 1998: Weekend day nearest to the new or full moon at the end of May.
- 1999 to present: Sampling occurs within 5 days of the new and full moons of May and June, i.e., surveys occur 2 days prior, the day of, and 2 days after the new and full moons.

Sample design:
- 1990 to 1998: informal sampling design
- 1999 to present: Multi-stage, stratified design. Strata are state (DE and NJ) and lunar period (5 day periods centered on the new and full moons in May and June). Selected beaches are subsampled by systematically placed 1 sq m quadrats.

Sample frequency and number:
- 1990 to 1998: each beach was sampled no more than a couple times during May and June.
- 1999 to present: Each beach is sampled at least 12 times during May and June.

Information collected: Counts of males and females.

Changes in sample design: Sampling design changed profoundly in 1999. Peak counts can be calculated from the redesigned survey; however, the index of spawning activity can not be calculated for years prior to 1999 because of insufficient sampling frequency and number. See Smith et al. (2002b) for more information.

New York Region

NYSDEC Peconic Bay Small Mesh Trawl Survey

Years sampled: 1987- present

Gear type: 4.8 meter semi-balloon shrimp trawl, the body has 3.8 cm mesh, the codend has 3.2 cm mesh, and the codend liner has 1.3 cm mesh. The footrope is 0.95 cm rope 6.4 m long, with legs extended 0.9m and wire rope thimbles spliced at each end, 0.6 cm chain hung in loop style on the footrope. The net was towed for 10 minutes at approximately 2.5 knots. The vessel used was a 10.7 meter lobster style workboat

Spatial coverage**:** Peconic Bay

Temporal coverage: May through October

Sample design: Random survey based on a block grid design. The survey area was divided into 77 sampling blocks with each block measuring 1' latitude and 1' longitude.

Sample frequency and number: 16 stations were randomly chosen each week to sample

Information collected: All finfish species identified and counted. Several macro-invertebrates were also recorded including horseshoe crabs (by number). Environmental information (surface and bottom temperature, salinity, dissolved oxygen, and secchi disc readings) were recorded at each station.

Changes in sample design: From 1987 to 1990 the net was set by hand and retrieved using a hydraulic lobster pot hauler. From 1991 to the present the net was set and retrieved using hydraulic trawl winches and an A-frame. Net haul back speed should not affect HSC GM.

NYSDEC Western Long Island Beach Seine Survey

Years sampled: 1984 - present, consistent methodology starting in 1987

Gear type**:** 200 ft x 10 ft beach seine with ¼ inch square mesh in the wings, and 3/16 inch square mesh in the bunt. From 1984 – 1998 a 500 ft x 12 ft seine with stretch mesh in the wings and stretch mesh in the bag was used for one sampling round generally in the spring. The seine is set by boat in a "U" shape along the beach and pulled in by hand.

Spatial coverage: Little Neck (LNB) and Manhasset Bay (MAN) on the north shore of Long Island (WLIS), and Jamaica Bay (JAM) on the south shore. Other bays have been sampled on a shorter time frame.

Temporal coverage: May through October. Pre-2000 sampling was conducted 2 times per month during May and June, once a month July through October; 2000 – 2002 2 times per month from May through October.

Sample design: Fixed site survey. Generally 5 – 10 seine sites are sampled in each Bay on each sampling trip.

Sample frequency and number: Generally 5 – 10 seine sites are sampled in each Bay on each sampling trip.

Information collected: All finfish species identified and counted, starting in 1987 invertebrates consistently counted. Since 1998 HSC have been counted, measured, and sex has been identified. Environmental information (air and water temperature, salinity, dissolved oxygen, tide stage, wind speed and direction, and wave height) has been recorded at each station. Bottom type, vegetation type, and percent cover have been recorded qualitatively since 1988.

Changes in sample design: Macro invertebrates not counted reliably until 1987, 500 ft seine discontinued in 1997 – this should not affect the HSC GM since the catch is standardized to the 200 ft seine, sampling frequency increased from one to two trips a month from July to October from 2000 to the present – this will not affect the HSC GM since index is based on only May and June catches.

CTDEP Long Island Sound Trawl Survey

Years sampled: 1984 – present

Gear type: 14 m high-rise otter trawl, 102 mm mesh in wings and belly, 76 mm mesh in the tailpiece and 51 mm mesh codend. Footrope is 14 m long with 13mm combination wire rope. Sweep is a combination type, 9.5 mm chain in belly and 7.9 mm chain in wing. Ground wires are 18.2 m, 6 x 7 wire, 9.5 mm diameter. Bottom legs are 27.4 m, rubber disc type, 38 mm diameter. Net was towed for 30 minutes at 3.5 knots. The vessel used was the 15.2 m aluminum R/V Dempsey.

Spatial coverage: Connecticut and New York waters of Long Island Sound from 5 to 46 m in depth.

Temporal coverage: Spring (April, May, June) and fall (Sept., Oct.)

Sample design: Stratified-random design. Sampling area is divided into 1x2 nautical mile sites with each site assigned to one of 12 strata defined by depth interval (0-9.0 m, 9.1-18.2 m, 18.3-27.3 m, or 27.4+ m) and bottom type (mud, sand, or transitional).

Sample frequency and number: 40 samples per month for a total of 200 sites annually.

Information collected: Catch is sorted by species. Finfish, lobsters and squid are counted and weighed in aggregate by species. Selected finfish, lobsters, and squid are measured. Starting in 1992 all species are weighed in aggregate by species. Horseshoe crab counts, weights, sex are sampled and CPUE are available.

Changes in sample design: Macro invertebrates (excluding lobsters) were not weighted until 1992, so the HSC time series starts in 1992. The total HSC sample at each station is weighed; individual crabs are counted in each tow starting in 2002.

New England Region

New Hampshire Spawning Survey

Years sampled: 2001 – present

Gear type: Sighting along 300 foot stretches of beach

Spatial coverage: Five survey locations around Great Bay

Temporal coverage: Annually May through September

Sample design: Count horseshoe crabs at each location during the new and full moons. Each survey is time as closely as possible to the high tide at each site.

Sample frequency and number: At each location, surveys during the new and full moons from May through September

Information collected: Number of crabs; spawning activity; subsample for sex, prosomal width, and weight; climatological parameters and water conditions

Changes in sample design: After 2009, sampling ended in June. Two indices are calculated: spring and spring-summer to continue the time series. The spring-summer time series ends in 2009.

Massachusetts Inshore Bottom Trawl Survey

Years sampled: 1978 – present (Spring and Autumn)

Gear type: ¾ North Atlantic Type Two Seam "Whiting" Trawl; 51 ft. footrope/ 39 ft. headrope; 0.5 in. stretch mesh liner; Sweep: Chain sweep (3.5 inch diameter rubber cookies); 60 ft. leglines; Wooden doors (40 in. x 72 in. / 325lb.); 20-minute tows (24h basis); 2.5 knots (randomized direction); F/V Frances Elizabeth (55 ft stern trawler) 1978–82; R/V Gloria Michelle (65 ft stern trawler) 1983 – 2002

Spatial coverage: MA Bay to Merrimac River, Cape Cod Bay, waters south and east of Cape Cod and Nantucket, Nantucket Sound and Buzzards Bay/Vineyard Sound.

Temporal coverage: Spring and Autumn

Sample design: Stratified (depth) random

Sample frequency and number: Approx. 94 annually

Information collected: Count, weight, sex, prosomal width available some years, wave height, lat/lon, salinity, depth, temperature, weather.

Changes in sample design: Vessel changed in 1982 – gear performance trials showed identical average fishing height and wingspread

URI/GSO Trawl Survey Methodology

Years Sampled**:** 1959-present

Gear Type**:** Trawl (34' head rope, 48.6' foot rope; 2.5" belly, 2" cod); 53' vessel at 2.0 knots for 30 minutes/tow

Spatial Coverage**:** Fox Island and Whale Rock stations in lower west passage of Narragansett Bay

Temporal Coverage**:** Two stations sampled weekly for 12 months

Sample Design**:** Fixed

Sample Frequency and Number**:** Approximately 100 tows per year

Information Collected**:** Number/tow for the entire time series, weight/tow beginning 1994. No prosomal width available.

Changes in Sample Design**:** None

Rhode Island - Marine Research Inc. Trawl Survey Methodology

Years Sampled**:** 1973-1974, 1988-present

Gear Type**:** Trawl (25’ head rope, 36’ foot rope; 4.8” belly, 1.5” cod end); 38’ vessel at 2.5 knots for 15 minutes/tow

Spatial Coverage**:** Mt. Hope Bay, RI

Temporal Coverage**:** April-October

Sample Design**:** Fixed

Sample Frequency and Number**:** Approximately 60 - 70 tows per 6 month sampling period.

Information Collected**:** Number / tow only

Changes in Sample Design**:** None

Rhode Island - Marine Research Inc. Power Plant Impingement

Years sampled: 1992 – present

Gear type: Traveling screens at 3 water intake units equipped with 9.5mm square mesh panels; 38mm mesh at Units 1 and 2 and 25mm at Unit 3 from May to October to reduce horseshoe crab impingement

Spatial coverage: 3 water intakes of the Brayton Point Station in the Mount Hope Bay

Temporal coverage: year round

Sample design: Screens are connected to an in-line collection tank. During sampling, water is diverted for a fixed period of time (typically 8 hours) to the collection tank, where fish are collected and processed.

Sample frequency and number: Sampling is performed 3 times per week (except during February 1997 to December 2003 when sampling was performed daily)

Information collected: number of horseshoe crabs

Changes in sample design: Sampling frequency increased from February 1997 and December 2003

RI DEM Marine Fisheries Trawl

Years sampled: 1979 – present (Horseshoe crabs began to be measured in 1998)

Gear type: Trawl net (see attached for net dimensions)

Spatial coverage: Narragansett Bay, RI Sound, Block Island Sound

Temporal coverage: Survey runs all year

Sample design: The survey is split in to 2 components, a random stratified "seasonal" component, and a fixed station monthly component; Sample frequency and number: There are approximately 84 random stratified stations done per year (42 in the spring and 42 in the fall) and approximately 150 fixed stations done per year (about 13 per month)

Information collected: Number of horseshoe crabs, prosomal widths, total weight, sex, and CPUE

Changes in sample design: The vessel was changed in 2005

Stout Survey Methodology

Years Sampled: 1975-2002

Gear Type: Visual count

Spatial Coverage: Pt. Judith Pond, RI; South Shore Rhode Island Coastal Pond

Temporal Coverage: Standard transect surveyed annually during spawning season.

Sample Design: Fixed

Sample Frequency and Number: 1 survey annually

Information Collected: Number of crabs observed within standard transect

Changes in Sample Design: None