The Horseshoe Crab, *Limulus polyphemus*, Fishery and Resource in the United States

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ABSTRACT—The American horseshoe crab, Limulus polyphemus, *is a focus for increasing economic and scientific importance because its blood has important biomedical applications and because the crab is used as bait in several fisheries. In addition, horseshoe crab eggs may be critical as a source of food for migratory shorebird populations of the Delaware Bay region, and adult crabs are predators of valuable clam resources. Fishing-related mortality in the United States is estimated minimally at 350,000 crabs per year, mostly in the middle Atlantic and southern New England states. Bait operations apparently kill (10-20 times the number of animals killed for bleeding to obtain the valuable* Limulus *amoebocyte lysate (LAL). Based on National Marine Fisheries Service groundfish trawl surveys, the population of horseshoe crabs on the middle Atlantic continental shelf has remained relatively constant since 1975 at 2.3-4.1 million individuals. Exploitation may not be trivial, particularly if local populations are targeted during the spawning period; we suggest several foci for further investigations on this species. There is no evidence that current levels of harvesting are depleting the resource. It is important, however, to continue monitoring activity, particularly if levels of exploitation increase.*

Introduction

The American horseshoe crab, *Limulus polyphemus* (L.), has long been economically important despite its lack of food value to humans (Wells *et al.*, 1983). Crabs were ground into livestock feed and fertilizer between the 1870's and 1920's; the industry, centered in Delaware Bay, reported annual harvests of over 1 million crabs (Shuster and Botton, 1985). Economic considerations, public complaints about offensive odors, and possibly diminishing stocks contributed to the decline of this industry.

Commercial interest in the species was revived by the discovery that its blood coagulates in the presence of minute quantities of gram-negative bacterial endotoxin (Novitsky, 1984). This unique property has been exploited to develop a sensitive bioassay product called *Limulus* amoebocyte lysate (LAL). Biomedical applications of LAL include testing of pharmaceutical products, monitoring water purity in clinical laboratories, and screening for human diseases caused by gram-negative bacteria, including gonorrhea and spinal meningitis (Novitsky, 1984). According to industry sources[1], the demand for LAL may double by 1990.

The fishing mortality rate for horseshoe crab populations has not been estimated. Adult crabs are collected as bait for American eel, *Anguilla rostrata*; whelk, *Busycon* sp.; and other fisheries (Pearson and Weary, 1980). Crabs are also destroyed purposely by fishermen aware of their importance as predators on soft-shell clams, *Mya arenaria* (Smith et al., 1955), and surf clams, *Spisula solidissima* (Botton and Haskin, 1984). Mortalities of horseshoe crabs collected for blood extraction will be minimized in the future because the crabs must now be returned to the habitat within 72 hours after capture under a mandated conservation measure by the U.S. Food and Drug Administration (FDA). Only adult crabs are bled and relatively few succumb to the treatment. Rudloe (1983) estimated a 10 percent mortality among bled animals compared with unbled controls.

Adult horseshoe crabs are easily harvested during the spring-summer mating season. Animals spawn in the middle to upper intertidal zone of sandy estuarine beaches, with the largest populations occurring in the middle Atlantic region, particularly Delaware Bay (Shuster, 1982). They can be caught with a minimum of financial expense, since no special dredges or nets are required. At other times of the year, the crabs are subtidal, and are a common by-catch in otter trawls and clam dredges.

The value of horseshoe crabs cannot be measured solely in biomedical or economic terms. In particular, their breeding cycle in Delaware Bay coincides with the Arctic-bound migration of at least 20 species of shorebirds (Wander and Dunne, 1981; Botton, 1984). Delaware Bay is a critical "staging area" for many of these birds (Myers, 1983; Morrison, 1984; Dunne et al. 1982), and horseshoe crab eggs are probably their most important food item (Wander and Dunne, 1981; Botton, 1984).

As a species, horseshoe crabs have persisted for more than 200 million years;

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[1]J. Finn, Marine Biologicals Inc., Personal commun. Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

in spite of this, it is reasonable to ask whether the species would be resilient to intensified exploitation (Bang, 1979). This review considers the importance of commercial exploitation of horseshoe crabs based on their abundance, distribution, and natural history. We discuss possible effects of habitat degradation on horseshoe crabs and define critical gaps in the knowledge of the population ecology of horseshoe crabs requisite to conserve this valuable species.

Methods

Published National Marine Fisheries Service (NMFS) statistical resumes from 1964 to 1977, and unpublished statistical summaries at the Woods Hole Laboratory of the NMFS Northeast Fisheries Center, through 1984, were used to document the estimated catch and value of horseshoe crabs in the United States, exclusive of the LAL industry. Data reported as weight landed were converted to approximate number of crabs by assuming an average body weight of 1.8 kg (4 pounds) (Ropes et al.[2]). Fisheries statistics probably underestimate the catch, because most sales of crabs for bait are arranged between private individuals, rather than through centralized dealers (R. Schultz, personal commun.). Therefore, we used fisheries statistics as conservative estimates, and supplemented these data with the results of mail and telephone surveys of individuals with first-hand knowledge of horseshoe crab fishing within their local areas.

Questionnaires were mailed to 96 persons or companies 1) active in the bait or LAL industries, 2) affiliated with Federal or State fisheries agencies, or 3) active in scientific research with horseshoe crabs. Respondents were asked about 1) the approximate number of crabs caught in their local areas, 2) the season(s) in which they were caught, 3) the type of gear used, 4) the use(s) to which the animals were put, and 5) whether these catches were, to their knowledge, included in the NMFS fisheries statistics (to avoid possible duplication of numbers).

To estimate horseshoe crab abundance, we analyzed data from NMFS groundfish surveys which sampled the continental shelf from Cape Fear, N.C., north to the Gulf of Maine and Georges Bank (Botton and Ropes, In press; Ropes et al.[2]). Stations were selected following a stratified random design (Grosslein, 1969) which delineates strata based on depth and area. Stratified mean numbers per tow of horseshoe crabs were converted into an estimate of standing stock by using the "area swept" by a standard survey trawl in relation to catch (in numbers) as an estimate of minimum absolute density. Total populations were estimated by expanding the average stratified mean catch per tow by the ratio of total area surveyed to the area sampled by an average tow. Fall (September-early December) and Spring (March-May) surveys provided the most thorough coverage of the middle Atlantic region, where crabs are most abundant; population estimates from 1975 to 1983 are included in this report. Most of the crabs retained by the trawl were adult size (Botton and Ropes, unpubl. data). Estimates must be considered as minimum population estimates because the trawls are equipped with rollers and do not sample crabs with 100 percent efficiency; furthermore, horseshoe crabs occurring shoreward of the NMFS strata would not be included. Gear specifications and further analyses of the groundfish trawl data are available in Ropes et al.[2] and Botton and Ropes (In press). Estimates of horseshoe crab populations in several estuaries were obtained from published sources.

Results

Of 96 questionnaires mailed, we received 53 responses (55 percent), of which 46 (48 percent) provided detailed answers to most or all questions. Of these 46 respondents, 10 were affiliated with private industry, 10 with state or local fisheries programs, 9 with the Federal government, and 17 with marine research facilities. Seventy-six percent of the respondents were from the middle Atlantic and southern New England regions, where commercial exploitation of the species is highest. Seven NMFS Fisheries Reporting Specialists (persons responsible for gathering commercial fisheries statistics) responded to our survey in writing or orally.

According to many of our sources, and the monthly fisheries statistics from the middle Atlantic states, most horseshoe crabs are caught during spring and summer (Table 1), the seasons during which crabs are reproductively active. Many are caught by hand from the breeding beaches. Egg-bearing females are regarded as superior bait for eels and whelks, and many fishermen will not use males in their traps unless the supply of females is depleted.

Table 1.—Estimated average horseshoe crab catch (animals/year) in the United States, exclusive of animals used in LAL operations. Capture methods and uses are presented in order of importance.

State	Estimated catch	Time of Year[1]	Methods of capture	Major uses	Data sources[2]
ME	Negligible				FS, PC
NH	1,200	2,3	Hand	Research	PC
MA	7,500	2,3,4	Hand, dredge, trawl	Whelk and eel bait, research	PC
RI	125,000-150,000	2,3,4	Hand, dredge, trawl	Whelk and eel bait	PC
CT	0-4,000	2,3	Hand, dredge	Whelk and eel bait	PC
NY	<1,000	2,3,4	Dredge, trawl, pound net, hand	Whelk and eel bait	PC
NJ	10,000-15,000	2,3,4	Hand, dredge, trawl	Whelk and eel bait	PC
DE	100,000-500,000	2,3	Hand, dredge, trawl	Eel bait	FS, PC
MD	43,000-70,000	2,3	Dredge, trawl, hand	Eel and other bait	FS, PC
VA	60,000	All	Dredge, trawl, pound net	Eel bait, research	FS, PC
NC	400-8,000	All	Trawl	Eel bait	FS, PC
SC	Negligible				FS
GA	Unknown				PC
FL	1,000	All	Hand, trawl	Research	PC
Total	348,000-817,000				

[1]1 = winter, 2 = spring, 3 = summer, 4 = fall.
[2]FS = NMFS statistics, PC = personal communication.

[2]Ropes, J. W., C. N. Shuster, Jr., L. O'Brien, and R. Mayo. 1982. Data on the occurrence of horseshoe crabs, *Limulus polyphemus* (L.), in NMFS-NEFC survey samples. Woods Hole Lab. Ref. Doc. 82-23, 40 p.

Commercial Bait Fishery

In New England, there is little or no harvesting of horseshoe crabs in Maine, New Hampshire, or Connecticut. In recent NMFS statistics, Connecticut has reported no more than 4,000 crabs in any recent year; none have been reported from Maine or New Hampshire (Table 1). Born (1977) reported, however, that "adults by the truckload" were removed for bait from the Damariscotta River, Maine in 1976.

Elsewhere in New England, horseshoe crabs are collected from Cape Cod Bay, Pleasant Bay, Nantucket Sound, Nantucket Harbor, and Buzzard's Bay, Mass., and most significantly, Narragansett Bay, R.I. NMFS statistics have recorded very few crabs from both states between 1964 and 1984, although respondents to the questionnaire estimated annual catches of at least several thousand crabs in Massachusetts and over 100,000 in Rhode Island (Table 1). Recently, the demand for eels has been extremely variable; the demand for eel bait has fluctuated accordingly (B. Kelly, W. Sargent, personal commun.).

The largest horseshoe crab fishery is located in the middle Atlantic states, although we experienced some difficulty in estimating numbers. NMFS statistics from New York and New Jersey have recorded no more than a few hundred crabs per year since 1974. Three respondents from New York indicated the catch is probably larger than this, although definitive estimates could not be made. Six respondents from New Jersey estimated catches of about 10,000-15,000 crabs per year from all areas of the state, including Raritan Bay, Sandy Hook Bay and adjacent rivers, Delaware Bay, and offshore, principally from Atlantic City to Cape May.

As recently as 1979, up to 500,000 crabs were harvested annually from Delaware, primarily for processing into chicken feed (W. Brey, personal commun.). The plant doing this is no longer operational, but harvesting for eel bait continues. Both the Chesapeake Bay and the ocean provide Maryland and Virginia fishermen with a substantial horseshoe crab resource. Recent NMFS statistics documented catches of 43,000-70,000 crabs from Maryland and some 60,000 from Virginia (Table 1).

Several thousand horseshoe crabs are caught in North Carolina for eel bait; south of there, uses are limited to lysate extraction and scientific research (Table 1).

Commercial LAL Fishery

LAL manufacturers must return bled crabs to the habitat; hence, their crabs are not included in NMFS statistics. At present, eight companies have FDA licenses to manufacture LAL (Novitsky, 1984). While the exact number of animals bled by each firm is not available or is considered confidential, our questionnaire responses suggest an average of about 20,000 per year. Thus, the total number of crabs bled may be about 160,000.

Commercial Fishing Summary

The annual commercial catch of horseshoe crabs for bait is estimated at between 348,000 and 817,000 animals per year (Table 1). This figure omits possible contributions from states (New York, South Carolina, and Georgia) where either estimates were unavailable or too variable to utilize. The bleeding of crabs to obtain lysate imposes a 10 percent mortality (Rudloe, 1983); if about 160,000 crabs are bled annually, then bleeding operations for lysate production may kill about 16,000 crabs per year. Several respondents emphasized that destruction of crabs by fishermen in some locations may be as significant a source of mortality as either lysate bleeding or bait fishing.

Population Estimates

Based on NMFS surveys of the middle Atlantic continental shelf between 1975 and 1983, there is a minimum population of some 2.3-4.1 million horseshoe crabs (Table 2). Although several surveys, notably Spring 1976 and Spring 1977, had considerably larger totals, there is no consistent trend in population size over the 9-year interval. About 98 percent of the population is located between Cape Hatteras (lat. 35°N) and New Jersey (lat. 41°N), mostly at depths shallower than 20 m (Botton and Ropes, In press).

Table 2.—Estimated horseshoe crab population size (in millions of individuals) on the middle Atlantic continental shelf, Virginia to New Jersey, by year and season, based on National Marine Fisheries Service groundfish surveys. "Inshore" refers to continental shelf strata from the shoalward limit (8 m) to 27 m; "offshore" strata are deeper than 27 m.

		Horseshoe crab population		
Year	Season	Inshore	Offshore	Total
1975	Spring	n/a	0.000	n/a
	Fall	1.265	0.065	1.330
1976	Spring	7.376	5.100	12.476
	Fall	1.948	0.565	2.512
1977	Spring	4.707	3.346	8.053
	Fall	2.530	0.906	3.436
1978	Spring	1.688	0.502	2.190
	Fall	0.991	0.000	0.991
1979	Spring	2.832	0.771	3.603
	Fall	2.818	0.622	3.440
1980	Spring	1.126	1.465	2.591
	Fall	1.041	0.613	1.654
1981	Spring	5.009	1.013	6.022
	Fall	1.820	0.615	2.435
1982	Spring	1.214	0.725	1.939
	Fall	2.465	1.094	3.559
1983	Spring	0.869	0.081	0.950
	Fall	1.987	0.288	2.275
Mean Spring		3.103	1.034	4.137
Mean Fall		1.874	0.418	2.292

Horseshoe crab populations from Plum Island Sound, Massachusetts, Cape Cod Bay, Delaware Bay, Cold Spring Harbor, New York, and a portion of the Gulf of Mexico have been estimated previously (Table 3). A total estimate of the horseshoe crab population inshore of the NMFS surveys is difficult to obtain because of the discrepancies in methods and the time interval between the survey dates. Moreover, there have been no quantitative studies in several key locations, such as Chesapeake Bay, where horseshoe crabs are abundant (Shuster[3]).

Of the estuaries studied, Delaware Bay has the largest population. Shuster and Botton (1985) estimated some 250,000 animals spawning on one spring tide in June 1977, with a total adult population (over the entire spawning season) probably several times this number. Thus, the total adult population size over all estuaries is several million individuals. Since crabs migrate between the estuaries and shelf (Botton and Haskin, 1984), one should not simply add the estuarine and shelf estimates to estimate the total popu-

[3]Shuster, C. N., Jr. 1985. Introductory remarks on the distribution and abundance of the American horseshoe crab, *Limulus polyphemus*, spawning in the Chesapeake Bay area. Pap. pres. at Natl. Mar. Educ. Conf. 30 July-3 August 1985, Williamsburg, Va.

Table 3.—Previous horseshoe crab population estimates. Methods employed were (1) mark-recapture; (2) direct counts of animals along breeding beaches.

Location	Survey date	Survey method	Estimated population	Authority
Cape Cod Bay	1949-1950	1	50,000-100,000	Shuster, 1950
Plum Island Sound, Mass.	1952-1955	1	151,000-1,000,000	Baptist et al., 1957
Cold Spring Harbor, N.Y.	1957	1	10,000-15,000	Sokoloff, 1978
Marshes Sand Beach, Fla.	1976-1977	1	33,000	Rudloe, 1980
Delaware Bay	June 1977	2	274,000[1]	Shuster and Botton, 1985

[1]Estimate of the spawning population on one of several peaks during the mating season; total population in the bay was not estimated.

lation, as that would create the potential for double-counting an unknown portion of the population.

Discussion

Do present levels of exploitation compromise the survival of a horseshoe crab population large enough to sustain commercial enterprises? In recent years some 348,000 to 817,000 adult crabs per year have been used for bait and feed, about 16,000 killed during LAL operations, and an unknown quantity destroyed by clammers. Relative to an estimated standing stock of some 2-4 million animals on the continental shelf, and an estuarine population of the same order of magnitude, exploitation is not a small factor in the crab's demographic makeup.

The LAL industry, whose handling of crabs is regulated by the FDA, contributes far less to mortality than does the bait industry. Caution must be advised, however, in reviewing these data. The estimate of bleeding mortality uncritically assumes Rudloe's (1983) finding that crabs bled during the spring in Florida had a 10 percent higher mortality than controls. It may be prudent to estimate bleeding mortality under a wider range of environmental conditions. We must also emphasize the difficulties we experienced in estimating the size of the bait fishery, because of the decentralized nature of these operations.

Habitat modification is considered to be a principal factor in the declining population of the ecologically similar Japanese horseshoe crab, *Tachypleus tridentatus* (Nishii, 1975). The Association for the Conservation of Horseshoe Crabs was established in 1978 to protect this species (Sekiguchi and Nakamura, 1979). The role of habitat degradation in the population dynamics of *Limulus polyphemus* may also be important. For example, beach stabilization practices in several communities along the New Jersey shore of Delaware Bay include the deposition of "clean fill" (bricks, cinderblocks, and coarse gravel) in the intertidal zone. This practice diminishes the suitability of the habitat for egg laying.

Furthermore, several estuaries with large horseshoe crab populations have been impacted by pollutants. In bioassays, horseshoe crab eggs and juveniles exhibited signs of sublethal stress (delayed moulting and elevated oxygen consumption) after exposure to oil or chlorinated hydrocarbons (Neff and Giam, 1977; Laughlin and Neff, 1977; Strobel and Brenowitz, 1981). Though, on balance, horseshoe crabs are more tolerant of degraded water quality than many other marine organisms (Laughlin and Neff, 1977), the long-term synergistic effects of pollutants should be investigated.

Life history statistics for horseshoe crabs are incompletely known, yet vital to an understanding of recruitment and population dynamics. For example, the estimated growth rate, 9-11 years to attain adult size, is based on evidence from a single aquarium specimen (Shuster, 1950). Knowledge of longevity (14-19 years) is based on the recoveries of seven tagged animals 4-6 years after release (Ropes, 1961). Estimates of fecundity are limited to seven females from Florida (Cohen and Brockmann, 1983) and 14 females from Delaware Bay (Shuster and Botton, 1985).

There is virtually no quantitative data on natural mortality in horseshoe crabs, although there are many potential predators of eggs and larvae, most notably shorebirds and fish (reviewed by Shuster, 1982; Wells et al., 1983). Extensive gill pathology caused by triclad flatworms (Groff and Leibovitz, 1982) and cyanobacteria (Leibovitz, In press) has been noted in both wild and captive crabs, but the possible significance of these diseases at the population level is unknown. Even if our estimates of population size and fishing-related mortality were completely reliable, predicting the possible outcome of harvesting cannot be made without fundamental life history data.

In our opinion, based on the present fishery and population size, there is no immediate threat to the survival of *Limulus polyphemus*. There is no evidence from the NMFS surveys of the middle Atlantic continental shelf that populations are declining under present harvest levels. This does not imply that populations cannot potentially be overfished. As early as the late 1880's, decreasing CPUE was recorded by the Delaware Bay crab fishery (Smith, 1889). The size of the Delaware Bay spawning population during the early 1950's was about one order of magnitude smaller than in the late 1970's (Shuster and Botton, 1985), suggesting that recovery from the intensive fertilizer industry required several decades. It is unlikely that present commercial uses of horseshoe crabs will ever remove as many individuals as did the fertilizer industry, even allowing for a considerable expansion of LAL uses, but this does not remove the potential for detrimental effects of intensive fishing on local populations. In particular, the NMFS trawl data strongly suggests that populations in New England are at least partially isolated from the large middle Atlantic population (Botton and Ropes, In press). It must also be recognized that critical spawning areas have been, or are likely to be, adversely impacted by coastal development and pollution. Moreover, the present bait fishery is selective for egg-bearing females, which could threaten both horseshoe crab reproductive success and the shorebirds (in Delaware Bay) dependent on these eggs. Finally, the relationships and importance of the crabs to the ecosystem are poorly understood but are important. Close scrutiny of the horseshoe crab resource will be necessary in the future so as to provide for appropriate management.

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