Assessing the use of acoustic sampling for locating horseshoe crabs during migrations using side scan sonar.

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Abstract

Acoustic data collection in fisheries is a growing method of no-take biological assessment and especially well-suited when the target population is endangered or otherwise listed as a state, federal or regional species of concern. To our knowledge, acoustic sampling has not been tested for *Limulis polyphemus*, horseshoe crabs. The Stockton University Marine Field Station (MFS) proposes a method to provide acoustic sampling approaches to assess the utility of side scan sonar for detecting and quantifying the movement of *Limulis polyphemus*, horseshoe crabs, onto the beach areas during periods of migration and egg-laying for environmental interaction.

Overview

Background information about the species is appropriate and necessary to be able to understand the movement and spawning processes observed and documented previously by tagging and observations made by scientists. This will help define the parameters of how to use acoustic methods, to find and identify aspects of crab behavior. While sonar can see fish underwater, for example, tracking their random movement is an exercise better quantified in time versus dollars spent. What sonar can do, if the species can be seen and verified by acoustic sampling is understand their environment and any associated behaviors while reaching a beach for nesting and laying eggs.

The horseshoe crab's name is somewhat misleading. Although it is shaped like a horseshoe, it is no crab. The horseshoe crab is an arachnid, a class of arthropods that also includes scorpions, spiders, mites and ticks. (Ballesteros 2019) With two main eyes, two simple (light sensing only) eyes and a mouth on the bottom, the horseshoe crab is well suited to life on the bottom. A brownish segmented shell offers protection and a pointed tail helps the animal right itself; it's not used for attacking or even self-defense.

Often called "living fossils," horseshoe crab ancestors can be traced back through the geologic record to around 445 million years ago, 200 million years before dinosaurs existed. Only one species, *Limulus polyphemus*, is found in North America along the Atlantic and Gulf coasts from Maine to Mexico.

Horseshoe crabs are known for their large nesting aggregations, or groups, and often spawn during neap tides (Penn and Brockmann, 1994; Cavanaugh, 1975; Barlow *et al.*, 1986) on beaches particularly in mid-Atlantic states such as Delaware, New Jersey and Maryland. This process is known as spawning. It appears that crabs start of their inshore movement from the deep bay and coastal waters appears to be triggered by lengthening daylight hours. This happens in late May and can coincide with high tide during full or new moons.

When mating, the smaller male crab attaches himself to the top of the larger female's shell by using his specialized front claws, and together they crawl to the beach. The male fertilizes the eggs as the female lays them in a nest in the sand. Some males (called satellite males) do not attach to females but still have success in fertilizing the female's eggs as they crowd around the attached pair.

The mechanism by which horseshoe crabs locate preferred spawning habitat is not completely understood. While horseshoe crabs spawn in greater numbers and with greater fecundity along sandy beaches, horseshoe crabs can tolerate a wide range of physical and chemical environmental conditions, and they will spawn in less suitable habitats if ideal conditions are not encountered. Therefore, the presence of large numbers of horseshoe crabs on a beach is not necessarily an indicator of habitat suitability (Shuster, 1994
In addition to the intertidal zone used for spawning, horseshoe crabs also use shallow water areas such as intertidal flats in their juvenile life stages. Horseshoe crabs may congregate on intertidal flats to wait for full moon high tides because these flats provide protection from wave energy. Scientists identified that preferentially selected spawning sites were located adjacent to large intertidal sand flat areas. In addition to providing protection from wave energy, sand flats typically provide an abundance of available food for juvenile horseshoe crabs. Since several tidal cycles may be required to complete spawning, offshore intertidal flats may provide safe areas to rest between tide cycles. (Thompson 1998)

According to the National Marine Fisheries Service's Northeast Fishery Center during the spawning season, adults typically inhabit bay areas adjacent to spawning beaches and feed on bivalves. Horseshoe crabs swim or crawl as their primary means of locomotion. Both larvae and juveniles are more active at night than during the day (Rudloe, 1979; Shuster, 1982: Thompson, 1998). Juveniles typically feed prior to the daytime low tide, then burrow into the sand, remaining inactive for the remainder of the day (Rudloe, 1981; Thompson, 1998).

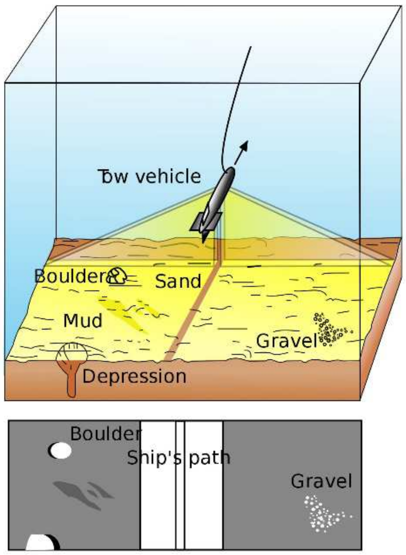
Horseshoe crabs are an important part of the ecology of coastal communities. Their eggs are the major food source for northward-migrating shorebirds, including the federally threatened red knot. These shorebirds have evolved to time their migrations to coincide with peak horseshoe crab spawning activity, especially in the Delaware and Chesapeake Bay areas. The Horseshoe Crab, an important keystone species of the Delaware Bay, is an animal that is very much depended upon by many other species participating in the ecosystem. Shorebirds such as the Red Knot (*Calidris canutus*), Ruddy Turnstone (*Arenaria interpres*), and the Sanderling (*Calidris alba*) depend upon Horseshoe Crab eggs deposited along the banks of the Delaware Bay for their own nutritional welfare.

It was for this ecological concern, where shellfish research, commercial oyster farming and natural interaction along the shoreline of migratory birds and horseshoe carb nesting that Stockton was asked if it were possible to identify crab populations using sonar in studying crab migration and nesting along a New Jersey beach in Delaware Bay.

Methods

Research has not found published evidence that any scientist or organization has used sonar to acoustically survey a species like horseshoe crabs in shallow intertidal coastal waters, so there are no known criteria for evaluating data. So, then the problem would how could crabs be imaged? Sonar operates by emitting a conical or fan-shaped sound pulses down toward the seafloor across a wide angle perpendicular to the path of the sensor through the water, which may be towed from a surface vessel or mounted on the ship's hull. The microprocessor in the sonar knows the speed of

the hundreds of pulses sent and can calculate the time it takes to travel to the seafloor bounce back to the sonar transducer or signal emitting device. The differences in travel time of that sound pulse to and from a target and the strength of the bounced signal can tell an operator how "loud" the return echo is and paints a picture of the bottom much like a sonogram
does for pregnancy imaging. Any object with any three-dimensional size will be painted by the sonar pulse and thru the micro-processor develop an image of the seafloor and targets. In Figure one the tow vehicle sends a sonar signal out to a determined range, while on screen the sonar image is flattened to show ships path and objects detected by sonar.



(Figure 1 side scan sonar illustration, Courtesy USGS)

Hard areas of the sea floor like rocks reflect more sound and have a stronger or louder return signal than softer areas like sand or mud. Areas with loud echoes are darker than areas with quiet echoes. Objects or features that rise above the sea floor also cast shadows in the sonar image where no sound hits. The size of the shadow can be measured to approximate the size of the feature. Knowing this, how will the horseshoe crab's carapace reflect the sonar pulse, as it would a rock or will the sound be absorbed by the sound pulse and not show any sonar return? This is the first important question to be answered. (Sonar description Citation??)

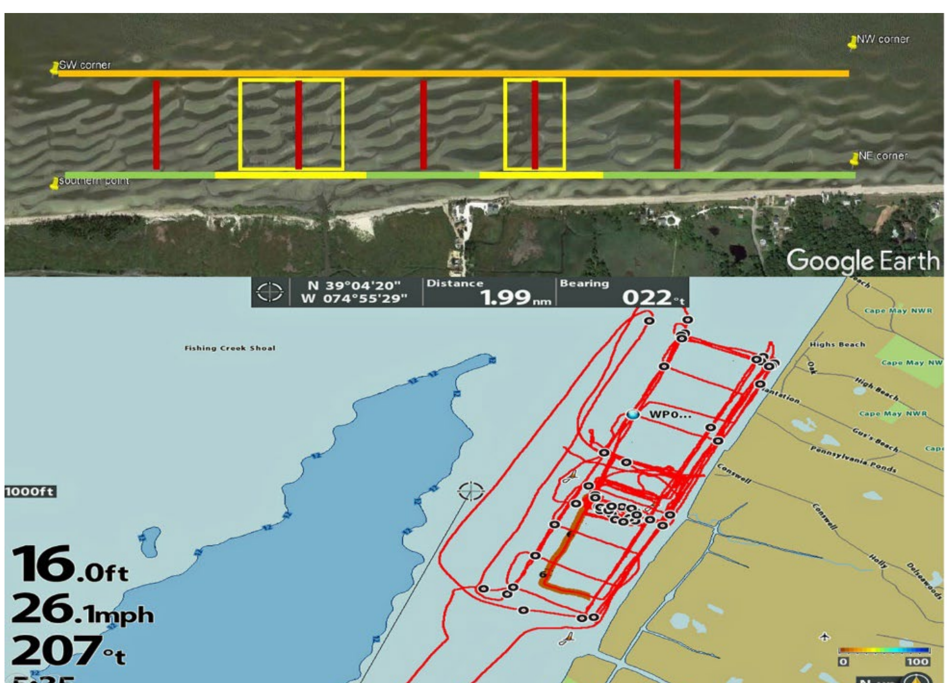
Crab presence, absence, movement and potentially numbers of crabs will be assessed acoustically using a Klein 3900 dual frequency side scan sonar and a Humminbird Mega 1200Mhz side imaging sonar. These sonar systems will utilize survey-grade positioning and will be operated from a 24' survey boat. These sonars are capable of imaging small targets in 20-80 meter swaths (depending on conditions) with image detection of individual crabs possible and masses of crab's probable. The ability to detect the crab masses will be dependent on density, bottom types, bathymetry and other possible factors.

Two sonars were selected for this survey. The Klein 3900 side scan sonar which is a high frequency 455/900 kHz and is a towed array sonar. It is the usual tool for many commercial and academic sonar mapping surveys, but it requires advanced operating knowledge and post-processing software for data interpretation. Humminbird Helix MEGA is a recreational fishing unit with medium resolution and with available sonar frequencies ranging from 50/83/200/455/800 kHz & 1.2 MHz. It is simple to use, less expensive can be set-up quickly and easily on most any type of vessel. Each sonar has advantages for this application in the data they can collect, ultimately Stockton chose to use the Humminbird Helix due to its adaptability for small vessel operation in shallow water. The towed sonar while producing high resolution images was problematic is shallow intertidal waters near the beach in 3 feet of water or less. The Humminbird was the simplest and most effective solution for this shallow water survey.

(Figure 2 Klein 3900 side scan sonar and Humminbird Helix Mega. Images Courtesy of Klein & Associates and Johnson Outdoors.)

While snapshots can be saved from screen captures, the best interpretation of sonar data is through post processing software for both the Klein and Humminbird sonars. Stockton used Sonar Pro for data collected by the Klein 3900 and SAR HAWK software for the Humminbird. SAR HAWK was developed for the many search and recovery rescue squads and police departments. It is easy to use and inexpensive and is getting wider uses in academic environments.

Transect lines were developed along a north-south line along the shoreline between Rutgers Cape Laboratory and Green Creek. This comprises approximately 1 nm of shoreline that is a mix of aquaculture and open flats. The surveys were designed in direct consultation with the project biologists following discussion on anticipated data outcomes and sampling strategies. Survey speeds will average 4-6 knots, allowing 3nm transect lines to be run in approximately 30 minutes, or as seen in (Figure 1) 4nm lines in approximately 40 minutes. Four hours of survey time around the high tide will provide over 20nm of transect line data for analysis.



(Figure 3 Survey area planned vs actual. Image courtesy of Stockton University)

Running longshore survey lines just outside of the fixed gear oyster farms and north and south of those areas will provide data on crab mass approaches to those areas (presence/absence as seen in the imaging). Stockton researchers are confident that crab masses will be detectable with the Klein 3900 and with the HB sonar, but it is noted that this has not been shown and this initial investigation is a pilot study.

Acoustic image interpretations were ground-truthed by the deployment of a small oyster trawl dredge after test survey lines. It is anticipated that areas of crab masses can be delineated in post-processing software much like bottom classification work. Delineation of crab mass sizes may be used to suggest the number of crabs in each event if data exists or is attainable for an average of crabs per square meter when amassed. This crab number versus mass data would need to be provided by the project biologists and is considered secondary to the acoustic detection of presence/absence and movement in relation to shoreline features. Wherever possible side-by-side comparisons of shoreline stretches with and without gear that are immediately adjacent to each other will be made.

(Figure 4 Trawl Ground-truth. Image courtesy Stockton University)

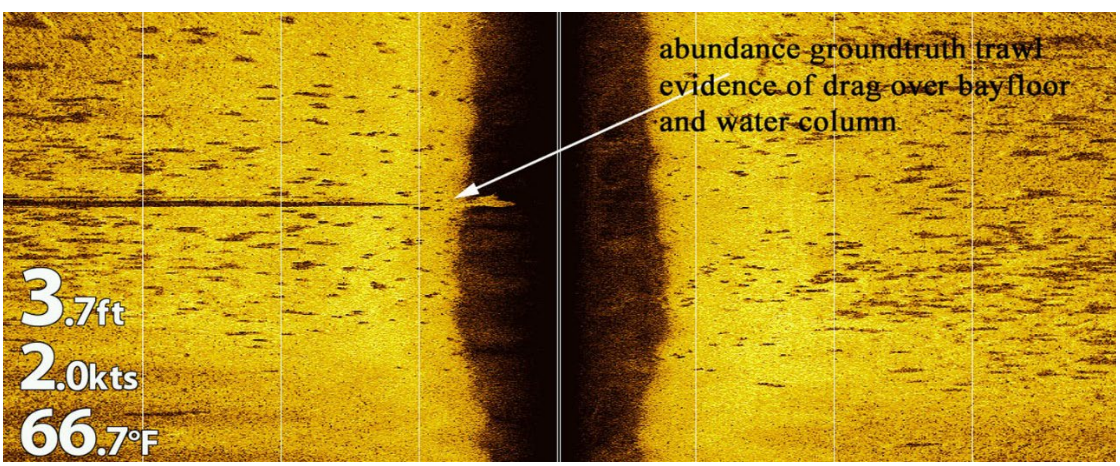


Figure 5 Klein sonar image of ground truth trawl. In this image individual and mating crab pairs are visible as bright spot followed by a dark shadow trail, evidence of the sonar movement from bottom to top in this image. Courtesy of Stockton University.

Key research questions were to determine relative abundance and ingress/egress movement timing to/from beaches of horseshoe crabs in areas with aquaculture gear and without. Using side-scan sonar, horseshoe crab abundance/density will be measured in pre-defined areas that are inshore and offshore of control and aquaculture gear areas that will help determine whether crabs primarily move through gear or around it. A secondary goal will be to measure the rate of movement – e.g. on a rising tide do horseshoe crab arrive inshore of gear at the same time as they arriving in control areas? And the same goes for a falling tide on the offshore side of gear.

Results

The survey area was described by researchers and local fishermen to be mostly flat with very little relief from natural objects (rocks, coral or man-made detritus). Nautical charts indicate mostly sandy bottom with some area of slight depressions that had some sediment fill (mud). The site was ground truthed during dead low tides, as fishermen and researchers can walk out to gear or use all-terrain vehicles for oyster farming gear maintenance. There is one section of the survey area that was known to have oyster farming gear set-up which was geographically known and marked. This area would be part of the survey so carefully planned lines needed to be calculated so as not to hit and possibly adversely affect research or fishermen gear. This area needed to be included to understand how crab movement might be affected for the in-place gear.

While the targets exhibit characteristics of a sonar refection, having some idea of habitat conditions. A rock, piece of metal trash or crab will all reflect differently based upon surface hardness-reflectivity making it identifiable, however knowing the terrain beforehand simplifies identification. With this information Stockton survey team had high-confidence that any 'targets' should then be marine life or seafloor biologicals of some type. Also considered was the background science of horseshoe crab behavior during spawning, their apparent preferences for gradual sloping approaches to beaches for egg-laying, abundance of food and hard bottom for easier movement by the crabs for is an arduous trek.

Three sonar surveys were made during the month of May and one in June based upon high tides and changed for weather conditions. The survey area is inaccessible by beach for easy boat deployments, and this forced launching from the Cape May Canal and a 30-minute transit to site each day. The initial survey took place on late evening of May 18th, 2018 on the RV Osprey. This was the only trip where both Klein sonar and the Humminbird were used jointly. Ground truthing was done along two transects, one where many targets were imaged and one where there were none. In both instances the trawl proved the sonar data correct. (Figures 4 & 5) Surveying in shallow water with man-made gear made towing sonar potentially hazardous to both gear and sonar and the Humminbird was delivering the same acceptable results, so the decision was made to forego towed sonar and run exclusively with the transom mounted Humminbird side imaging sonar.
Our initial swath runs were 20-40 meters which later changed to as shallow water and wind-driven sea conditions limited sonar swaths to 10 to 20 meters. Wave height affect's the sonar returns and can distort data, so slow and low with shorter range helped to better collect useable data.

May 24th, 2018 was the second day of survey. Surface conditions were the worse on this survey date than all the others, very windy and choppy seas, all of which affected data collection. Factors besides wind and seas that alter returns and data recording can be a combination of, the depth of water, boat speed, transducer placement, angle of beam and frequency of the sonar beam. All of these played into the data recording, while images were useful the amount of interference does make the data suspect. We could see the same numbers of potential targets but the sea conditions made measurements difficult. High tide was 6 o'clock, so the survey runs would start at 2:30 PM and end at 6:00 PM and cover all transects. The survey started with the north to south offshore transects to determine if more crabs were incoming on the rising tide. No crabs were recorded on the first offshore transect. The sonar survey finished with an inshore transect running from south to north. Many crabs spotted along the beach. This was when running our transect lines many craters or divots were recorded as seen in Figure ##. We weren't sure what these meant, however going back to the crab research data, we understood that crabs might have completed their inshore migration and waited near the beach lying dormant and dug into the bottom to feed and wait until the right time to make their run onto the beaches to lay eggs.

May 30th the third survey started at 6:20 PM with high tide at 9:00PM, with light easterly winds, calm seas. As per our plan we ran the offshore transect lines and gradually worked out way inshore as high tide approached. Like last week, many crabs were spotted on the beach.

June 12 will be the last survey. The survey started at 5:00 PM with high tide again at 9:00PM, with light easterly winds, calm seas. As per our plan we ran the offshore transect lines and gradually worked out way inshore as high tide approached. Like last week, many crabs were spotted on the beach but on this survey many more holes or craters were recorded along the inshore transects which can be seen in Figure ##. In the following images (Figures 6-7-8) the Sonar transducer is in the center of the sonar recording image to make the data stand out clearer the track was removed (it can be put back in SAR HAWK). As the sonar pulse travels away from center anything in its path is illuminated by the sound pulse creating a shadow as it hits a reflective surface. We established that the carapace of the crabs reflect sonar just as a rock or shipwreck would. We further established that the survey area was devoid of rocks, or other human debris other than gear cages for oyster farmers, so any sonar return would have to be from a marine organism or crab. Crab targets on the left side of the image are identified by long shadow 'behind' the lighter target. Craters or divots seem to suggest adaptions of the crabs to burrow into sandy bottom. The horseshoe crabs are one of the largest organisms that burrow in sandy environments so that it can feed on organisms in the seafloor and lay its eggs in the sediment.

Figure 6 shows the about one quarter nautical mile of survey area. In the image visible is Rutgers Cape Shore Laboratory (the end point of the survey area), the faint lines at the crossing of sonar mosaic lines are oyster gear some of transect lines and finally the 156 ft section of transect enlarged below.

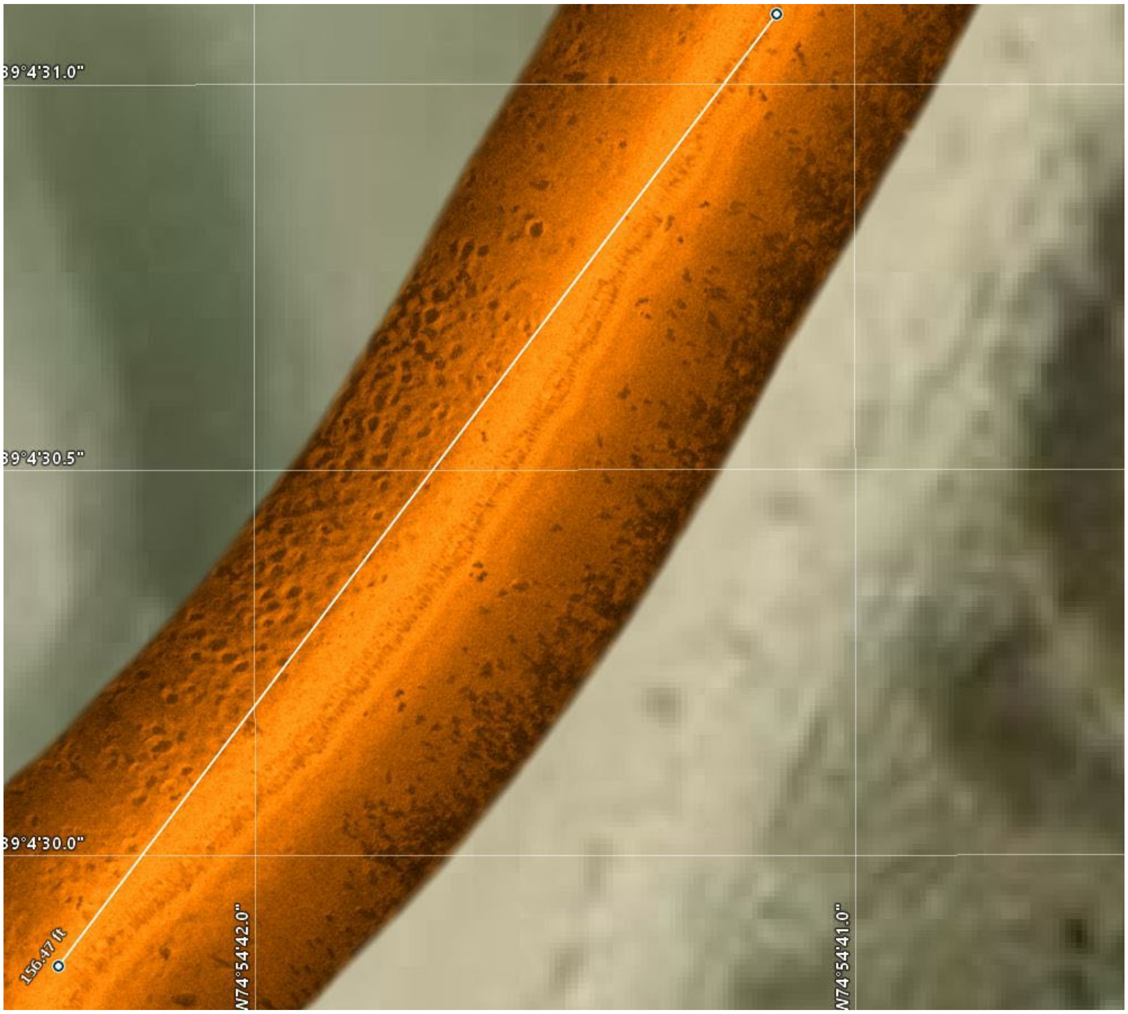


Figure 7 SAR Hawk software mosaic of sonar run. Courtesy of Stockton University.

Inshore sonar transects showing 156 feet of crab abundance (along the thin white line in the image) to the right side of the sonar mosaic close to the shoreline as the crabs move to nest. To the left of the center line are numerous craters. The swath width is 40 meters. We surmised that the crabs stayed in these, feeding and resting in-between visits to nesting areas on the beach. This can be confirmed by slight shadows that trail behind the light image. This is caused by the sonar travel along the center line in the mosaic and sending its sound pulse to the left and right. As the sound hits a target it registers an image. Since the sound cannot pass through the target it creates a shadow as the sound pulse travels over and around. Using the SAR HAWK post-processing software, the target and its shadow can be accurately measured. Interesting that the left side of the sonar track shows only craters while the right side shows large abundance of crabs quite near the surf line. Supposition is the crabs are leaving their dug in resting area and are moving to spawn on the beach.

Discussion

The primary objective of this survey was to see if horseshoe crabs could be imaged using side scan sonar and be able to track their migration to the beach egg-laying areas. A side issue would be to determine if oyster cage gear deployed in the flat sand off the beaches would affect the crab migration. N.J. State law says that cage gear needs to be supported to a height of 6-12 inches so animals can move underneath the equipment. (NJDEP-Proposed Amendments, new rules and repeals: N.J.A.25A, Oysters. Any impediment for the crabs reaching nesting areas along the beach could have an impact on shore bird feeding on the beaches after horseshoe crab egg-laying.

What we needed to understand going into this project;
one, will sonar be reflected or absorbed by the crab? If sonar pulses are reflected, then the crabs would appear as targets by the sonar and could presumably be tracked as they move along the bay bottom. If the sound pulses were being absorbed the crabs might be undetectable by sonar.

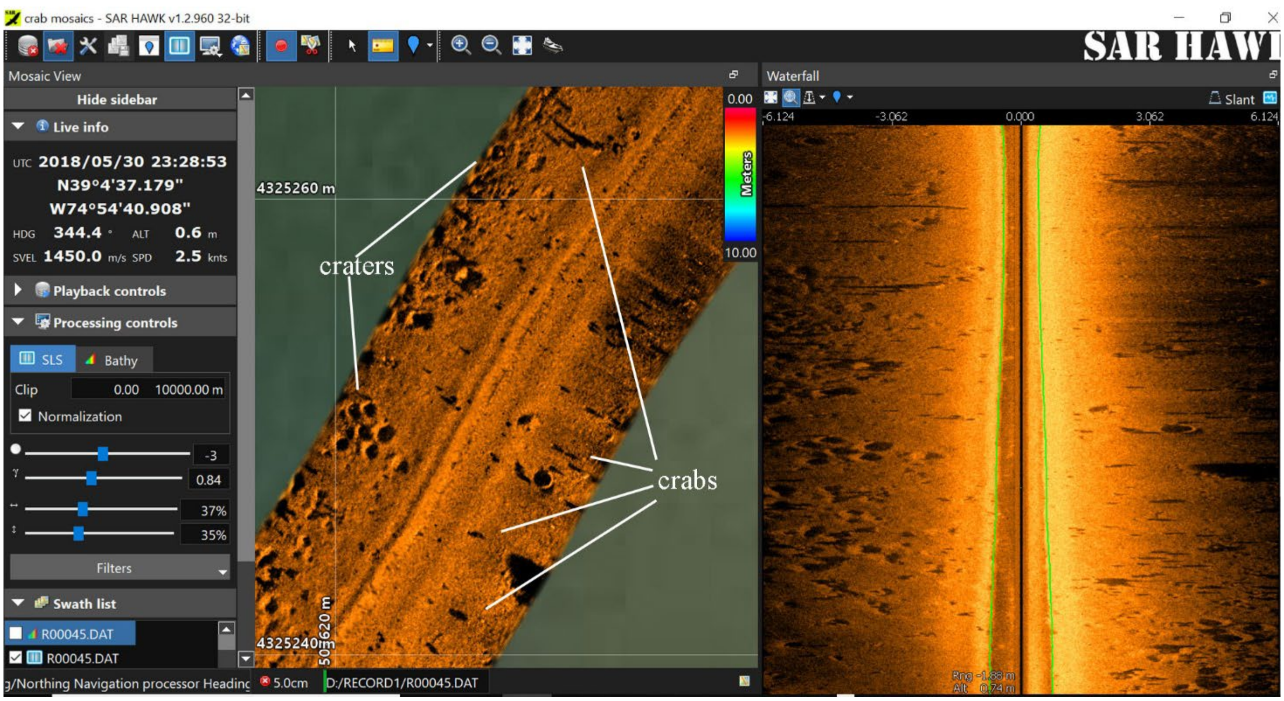


Figure 8 screen grab from SAR HAWK software screen showing crabs and craters or burrows. Courtesy of Stockton University.

Two, we understood by chart and observation that the bay bottom in our survey area was flat, comprised of both hard sand and some muddy sedimented depression areas with a gentle slope from the deep waters of the bay to the beach. Presumably, ideal habitat. We also knew that little to no rock formations or human debris other than oyster cages for farming and research. At a dead low tide, researchers and oyster farmers could walk or ride all-terrain vehicles out to research locations in the near shore bay. In Figure 9 below is a recent Google Earth image of our survey area. The images confirms most of what local researchers and fisherman have stated about conditions in this area. Hard sand bottom some contours but very little in the way of rocky out cropping's or human debris. A convenient location to test the theory that horseshoe carbs can be images using acoustic technologies for research and data gathering.

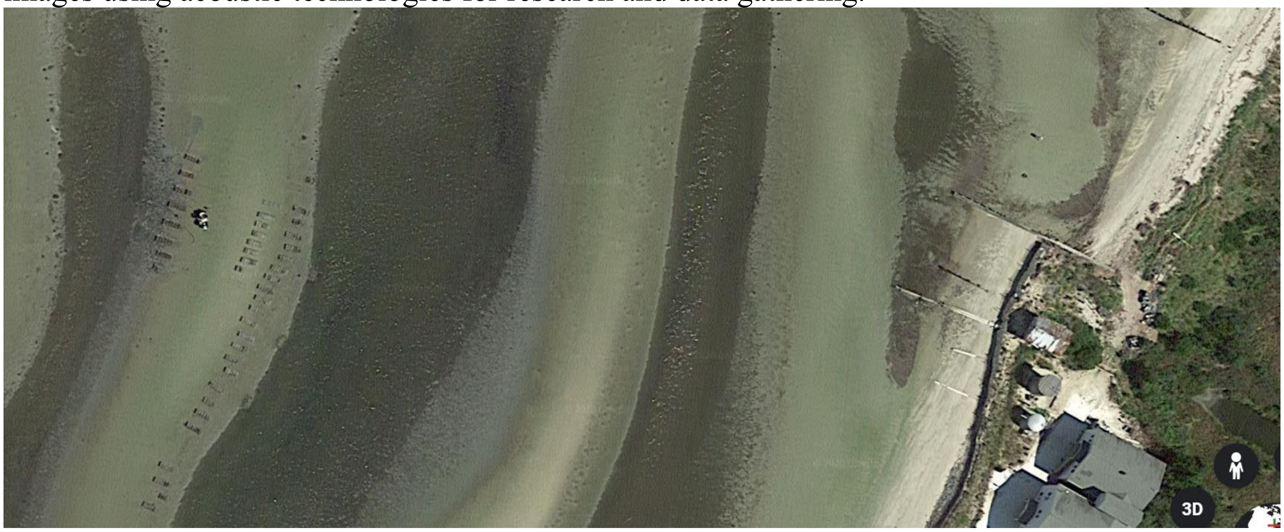


Figure 9 Google Earth image 5/29/20 showing a large part of the survey area just offshore of the Rutgers Cape Shore Laboratory.

Three, what would a 'migration of horseshoe crabs' actually look like on a sonar screen? How could one crab be distinguished from another and what type of density mass of crabs would be present? Initially, our expectations were that we could catch or image the crabs entering the area from deeper waters offshore in the bay.

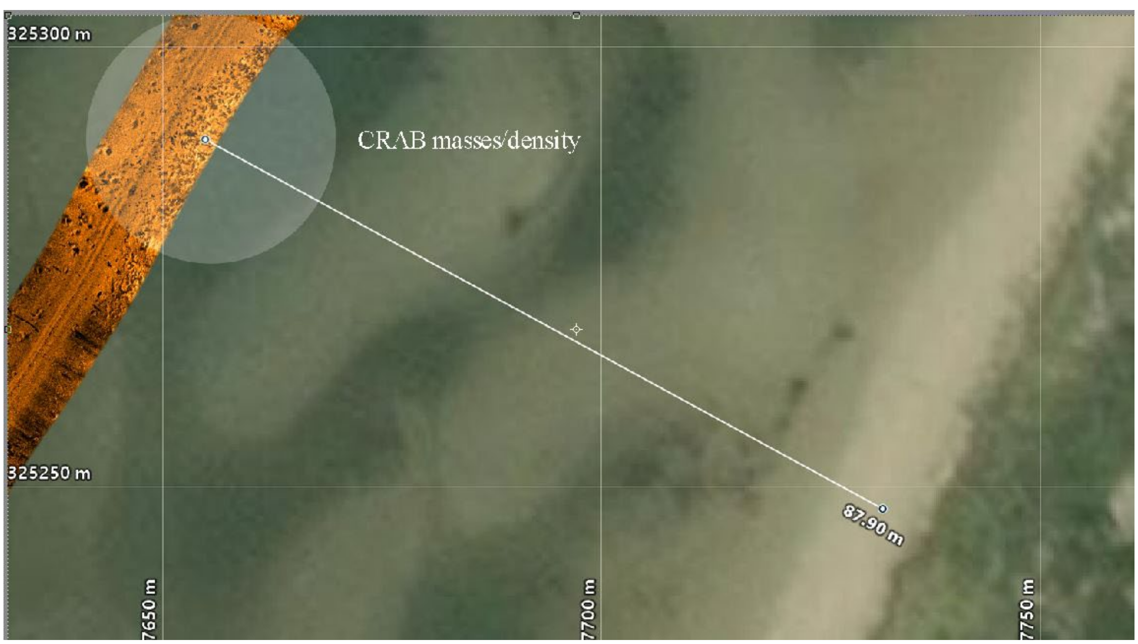


Figure 10 Sonar mosaic showing crab density along an inshore transect 89 meters from the beach SAR HAWK software automatically grabs Google Earth or any pre-loaded chart to the background in the sonar mosaic. Courtesy of Stockton University.

Figure 10 is a very good example an image of a side scan sonar transect line. The range of this line is 40 meters, 20 meters on either side of the sonars path. In the highlighted circle, on the right side (the inshore side) of the center path of the sonar are targets or crabs. Their density can be approximated by taking a square meter in SAR HAWK software and counting the crabs. This data can then be extrapolated to make a better estimate over a larger area. On the left side of the path or the offshore side, numerous craters or burrows can be seen. Our hypothesis is that the crabs burrowed in for a time and at the time and time extracted themselves for the walk to the nesting areas on the beach. In Figure 11 below an image of a cart that sits in what was left of crater or burrow.

Figure 11 Cart in a crater or burrow in the survey area just one day after a evening sonar run. Courtesy Stockton University.

As we completed more survey lines and gained some experience interpreting the data, we began to see more crab behavior and habitat that helped us understand the migration and movement along the bay bottom during mating and nesting. Figures 12 and 13 show sections of our sonar mosaics (transect lines) In Figure 12 particularly there are many empty burrows, what we began to notice was some still have a animal in the burrow. How can we know this? The sonar pulse passes over a burrow or any type of depression in a straight line. As the sonar pulse passes over the hole, it doesn't see the first edge but captures the backside creating that shadow, like the craters on the moon in sunlight. Many burrows show a dark hole. But some show a bright image in them. This means that as the sound pulse passes over, that bright spot was high enough to be captured by the sonar. Does this mean it's a crab? Not necessarily, it just means that there is something in the burrow other than an empty hole. Our hypothesis is that it is a crab in the process of digging itself out. The data says there is something there, we feel the only things that fits is a horseshow crab. Of course, it can also be a mound of sand or sediment from the crab's self-extraction. But it fits our theory that these 'crater eyes' have a biologic animal inside.

On the right and left side of the transect line there are crabs. Notice the bright spot, followed by a shadow as the sonar reflects off the crab and passes around creating the trailing shadow. This effect is how sonar technicians can recognize objects on the seafloor and be able to measure their length, width and height using the post-processing software. The arrows in Figure 13 indicate the direction of the boats travel and the sonar transducer. Note than both the Humminbird and Klein have captured similar data and imaging.

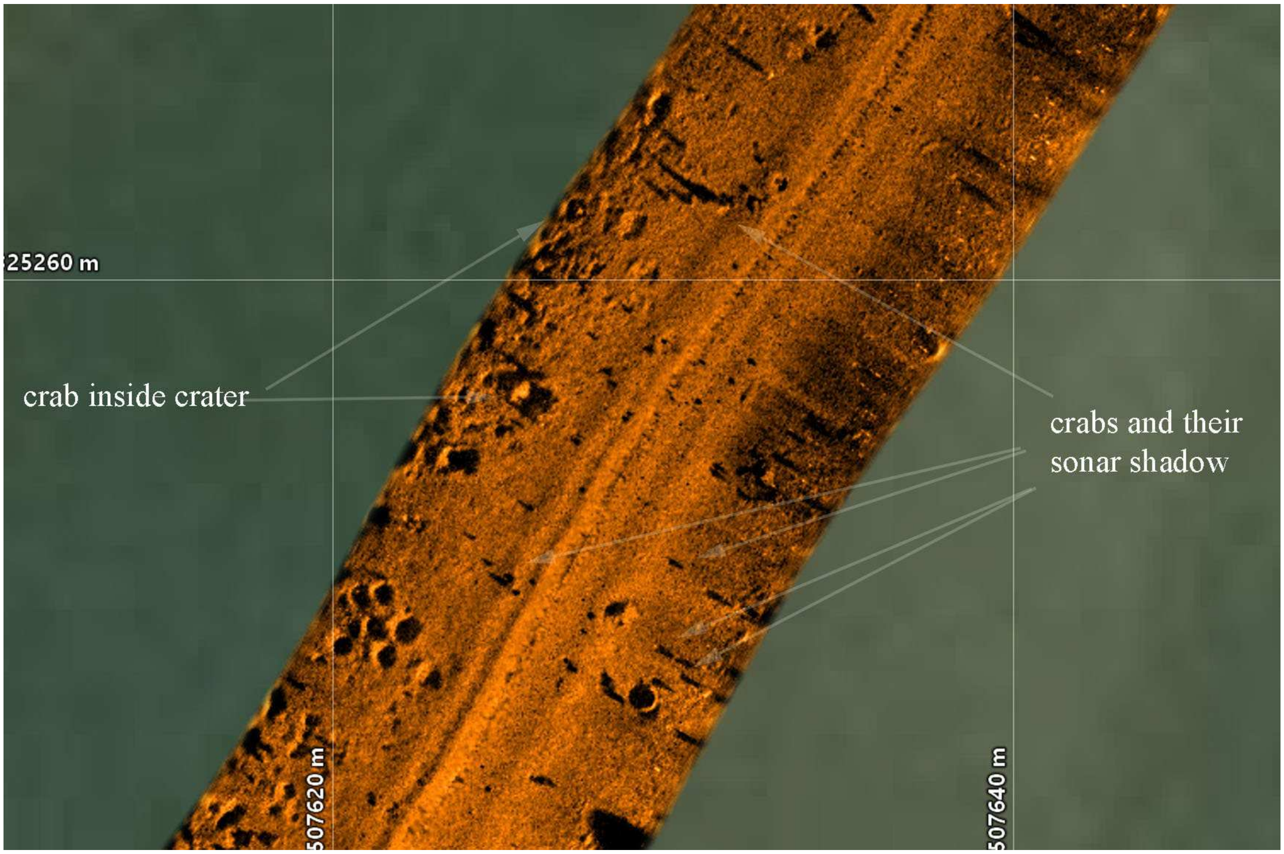


Figure 12. Humminbird sonar mosaic of craters or burrows that are empty and possibly have crabs still in them. Courtesy of Stockton University.

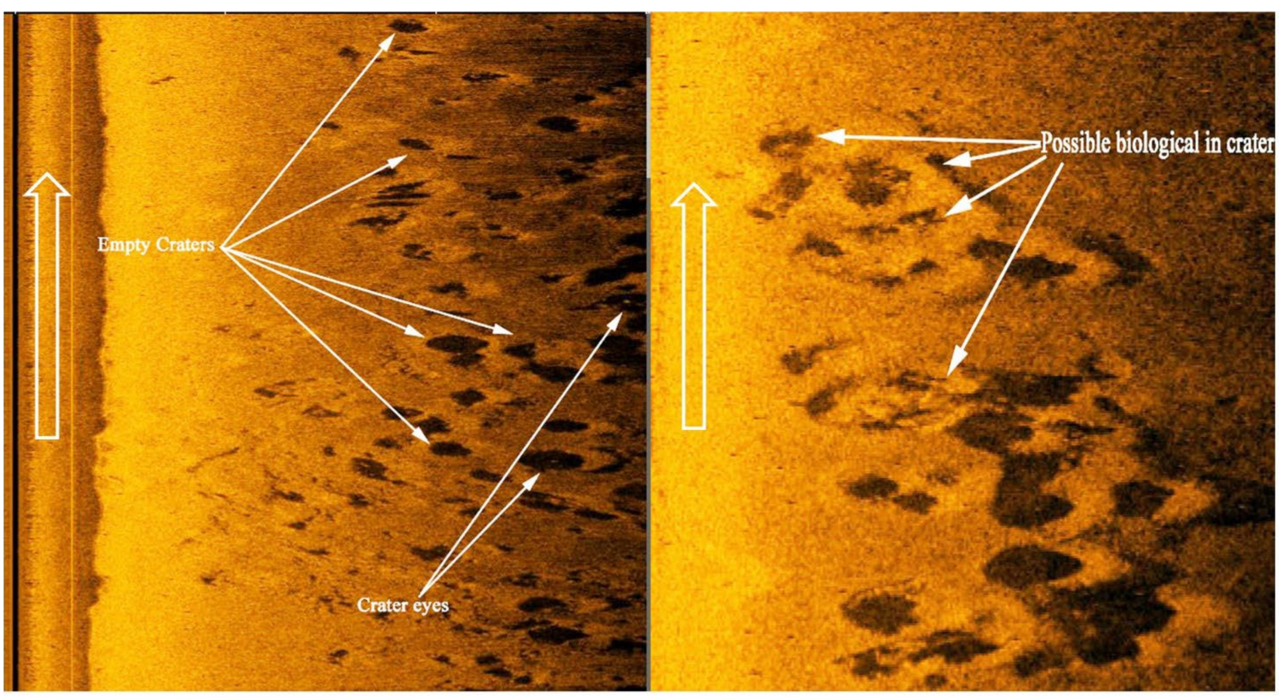


Figure 13. Klein 3900 side scan sonar images of bay bottom. Courtesy of Stockton University

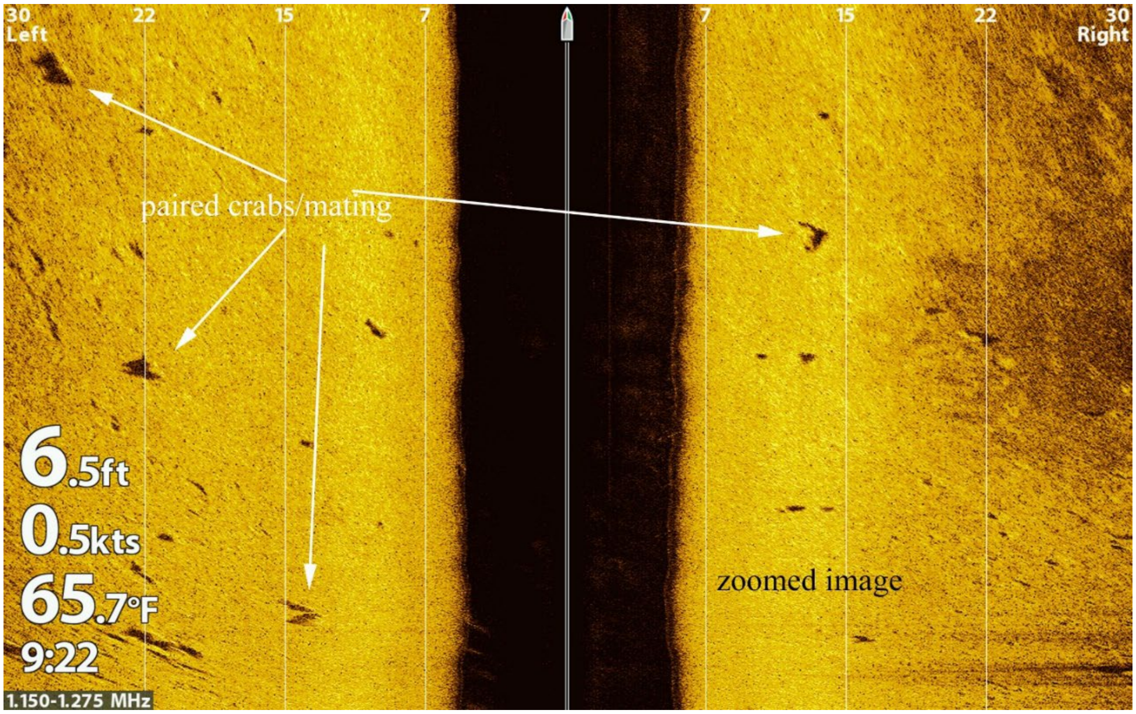


Figure 14. Klein 3900 sonar screen grab that seems to show pairs of crabs mating. Courtesy of Stockton University.

In Figure 14 three arrows indicate larger than normal targets, which by this time we believe ar horseshoe crabs. In each of three targets a split shadow can be see. We feel it indicates mating pairs, but it could also simply be two crabs travelling close together. However, the mating theory has more potential. During more than one trawl we did capture mated pairs of crabs. The larger female and the small male.

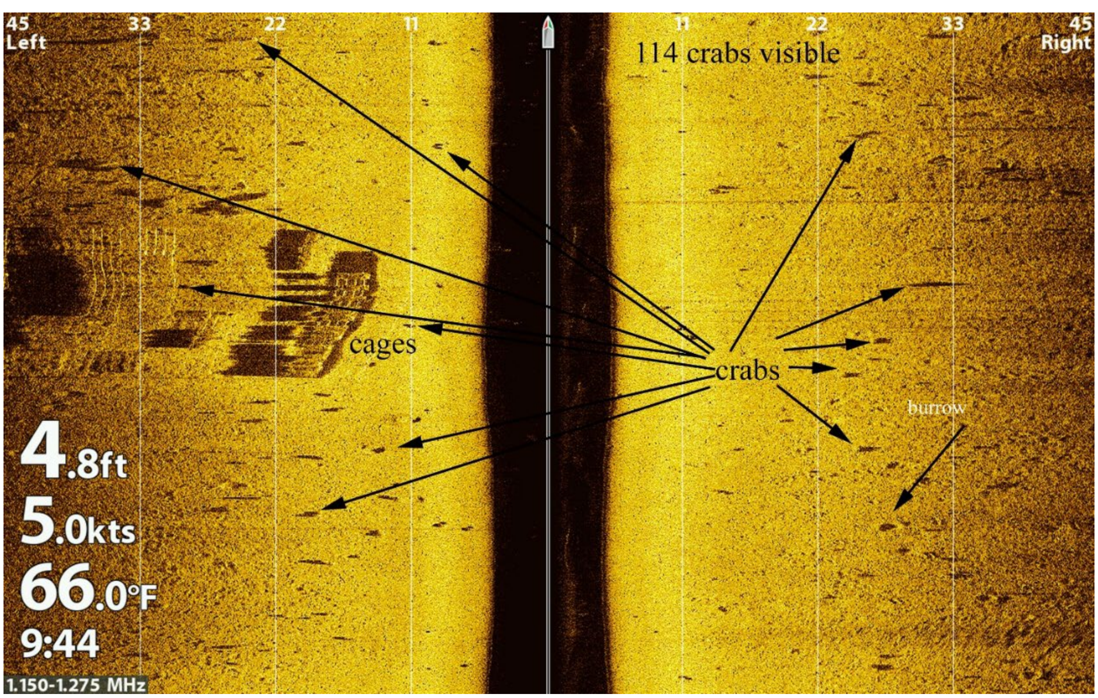


Figure 15. Klein 3900 sonar image of oyster cage farm with numerous possible crab targets. Courtesy of Stockton University

Another aspect of the survey was to evaluate if the oyster cage gear placed by fishermen and researchers impeded the crabs movements. In Figure 15 the cages are clearly visible with arrows pointing to crabs all around, very few travelling under or through the cages. Burrows are also noted along with crabs and trailing shadows. Once again, prior knowledge of the farming area indicated no structure other than cages, so any black spot can be considered a target (crab).

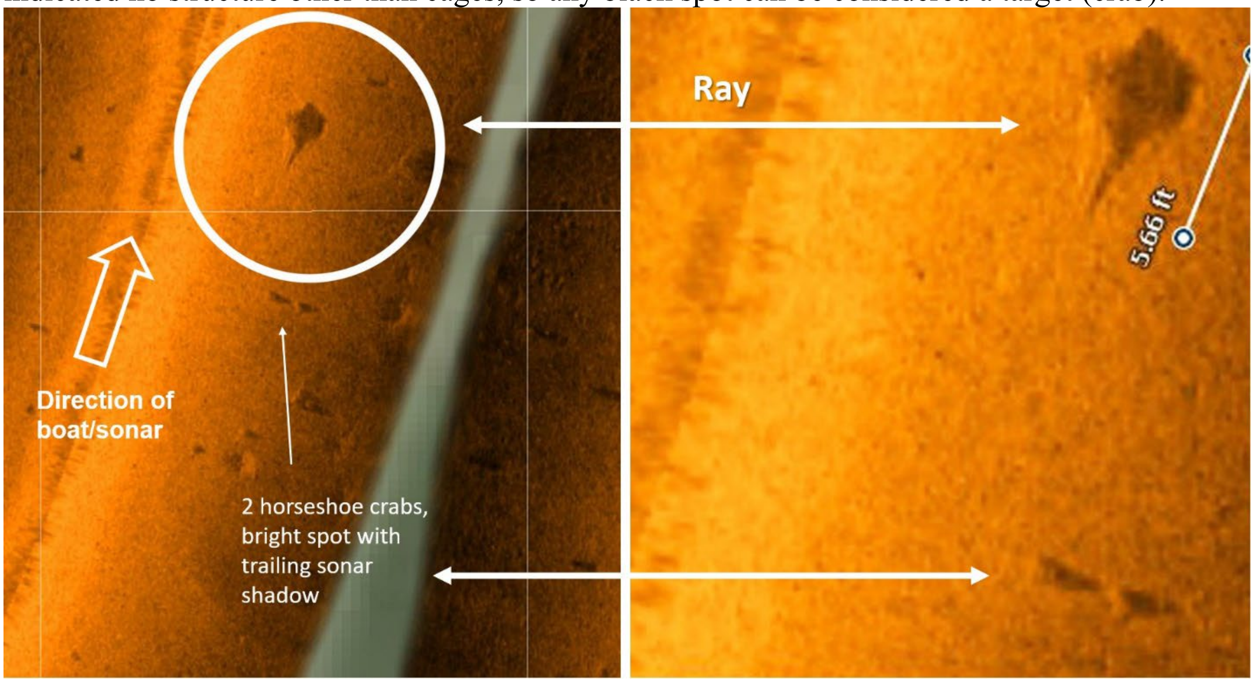


Figure 16. Image of some species of ray approximately 5 feet in size. Rays are predator of the horseshoe crab. Courtesy of Stockton University.

Sonar can also capture schooling fish, individual fish and other marine organisms. Tracking them is not feasible but they do occasionally show up and are a good indicator that as a predator, there is prey in the vicinity.

We believe that using acoustic imaging technology can be another tool for researchers to use when evaluating in this case horseshoe crabs movement in an environment. With the proper training and a small investment anyone can survey an area to understand what is happening. Can we track crab movement? Not an individually certainly, but we can survey an area and sample a population density using the sonar swaths. Capturing the data is the easiest part. Much more challenging is the data interpretation afterwards and developing a rubric for the search area that eliminates any other possibly other than your targeted species.

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