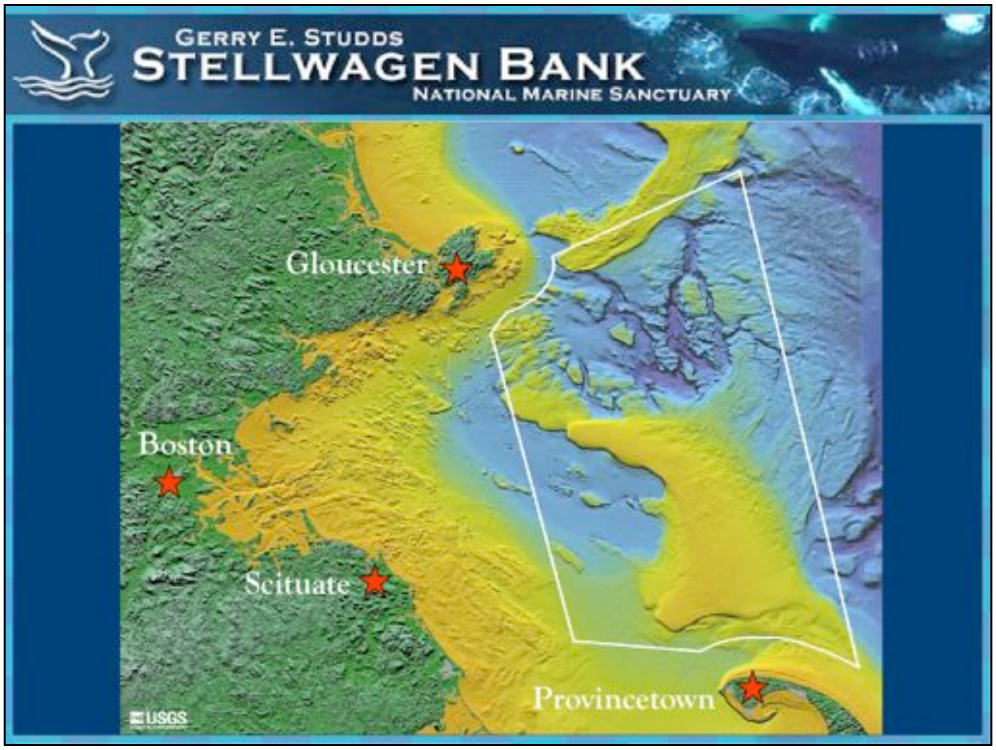
It’s a pleasure to be here.

Today I would like to present the pioneering acoustic tools and concepts which we have developed for monitoring and reducing the impacts of underwater noise in our sanctuary—Stellwagen Bank National Marine Sanctuary.



Stellwagen Bank Sanctuary is one of the most urban sanctuaries, situated at the mouth of Massachusetts Bay, off the coast between Cape Cod and Cape Ann. Our boundaries are located approximately 25 miles from Boston, and 3 miles from Provincetown and Gloucester. The sanctuary encompasses 842 square miles (638 sq nautical miles).

The bank itself, which is the central feature of the Sanctuary, is an underwater plateau of sand and gravel that produces upwelling of nutrients, leading to high productivity that has, until very recently, supported one of the oldest and highest capacity fisheries in the world.

You can see from this map why we refer to Stellwagen as an urban sanctuary, as it is located in close proximity to a large population density coastal zone.

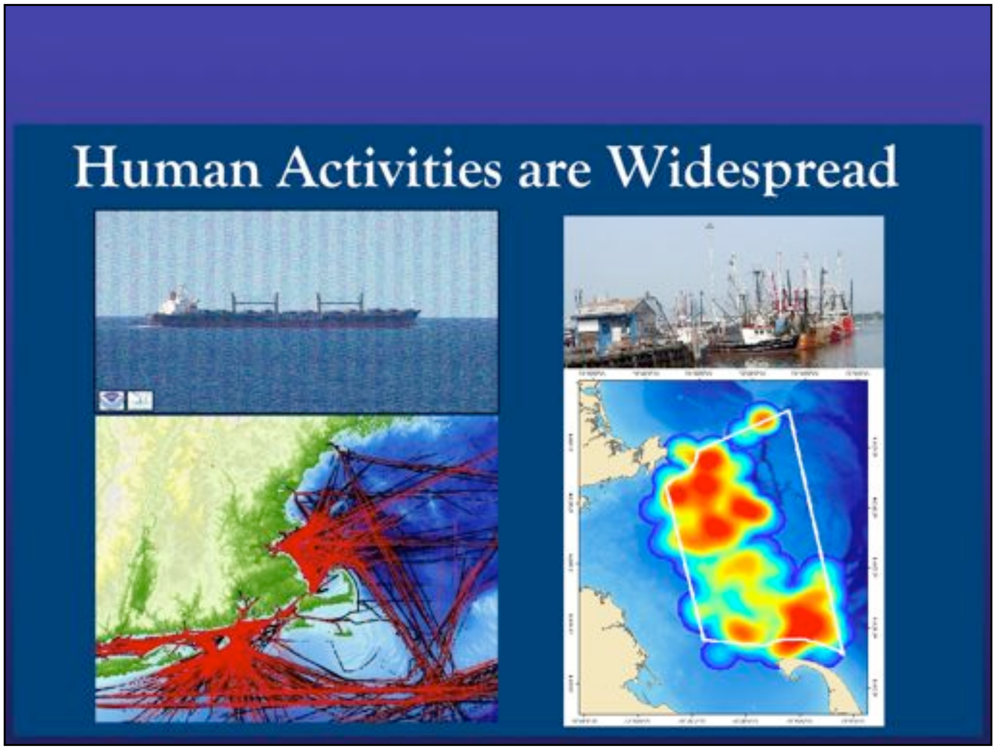
The Sanctuary is home to diverse marine life. The same upwelling and productivity has also made the Bank a seasonal migratory destination of feeding baleen whales, including several endangered species.

At least 22 species of marine mammals visit or reside in the Sanctuary, including 6 species of baleen whales, 11 species of odontocetes (common dolphin, striped dolphin, harbor porp,etc), and 5 species of phocid seals (harbor, gray, harp, hooded, ringed)

The Sanctuary is also home to a variety of human marine activities, including whale watching, fishing, shipping, and other commercial activities. In addition to recreational and commercial traffic, a variety of commercial activities take place on the western boundary of the Sanctuary, in what we are increasingly terming the "industrial triangle". These activities include two LNG terminals, Boston Harbor Outfall tunnel, Mass Bay ocean disposal site, and shipping lanes into Boston.

(Background map info:This triangle is created between the line between the three nautical mile line designating state and federal waters, two state-designated marine sanctuaries, and the national marine sanctuary. The southern boundary of the sanctuary is created by the traffic separation scheme or shipping lanes that are designated suggested routes for traffic arriving and departing to the port of Boston. There are also a few other features of note here including

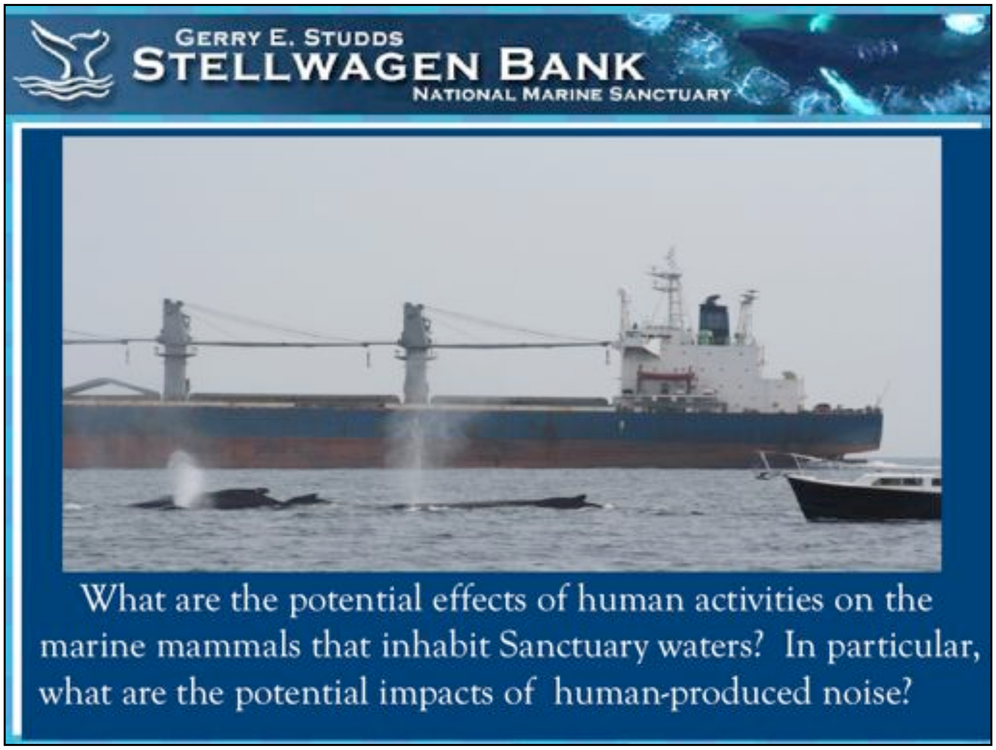
The current location of the ***Massachusetts Bay ocean disposal site is in orange****, and* ***shipping lanes into Boston are in purple****. In addition you are seeing a* ***green line represents the Boston Harbour Outfall Tunnel which discharges ~300 million gallons of treated effluent per day*** *twelve miles west of the Sanctuary's western border, and the Hub line which transports gas down the coast.*
Finally, the U.S. Coast Guard has been evaluating ***two proposals to build liquefied natural gas (LNG) terminals in Massachusetts Bay****. This map shows the locations proposed by two companies on the western border of the Sanctuary. Excelerate's proposals in green and Neptune's proposals are in yellow.)*



And our activities are widespread. To give you an idea of their distribution:

…on the left, we are looking at a plot of large commercial shipping traffic in the Northeast for two months in spring, (April and May 2006) tracked using the US Coast Guard's Automatic Identification System or "AIS".

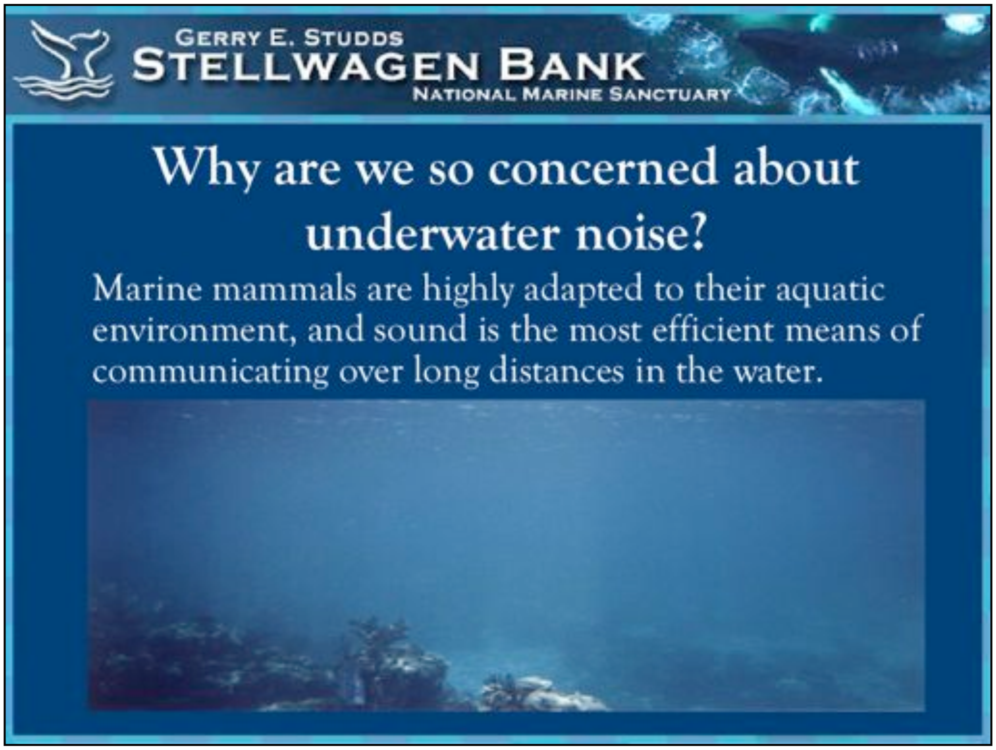
… on the right, we are looking at the density of mobile fishing gear throughout the sanctuary. Approximately 440 *commercial* fishing vessels traverse our waters each year using mobile and fixed gear throughout the water column and on the bottom.



Human activities may come at a cost to marine life in the area. The risk of being struck by ships, harassment by tourists, and disruption of critical feeding and breeding activities are among the more obvious costs.

However, in recent years concern over the impact of human-generated sound on marine mammals has been steadily increasing, as our oceans get noisier. This is especially of concern in areas that suffer from high levels of human activities, such as our urban sanctuary. Much of our current research is geared towards better understanding the impacts that anthropogenic noise may have on marine mammals.

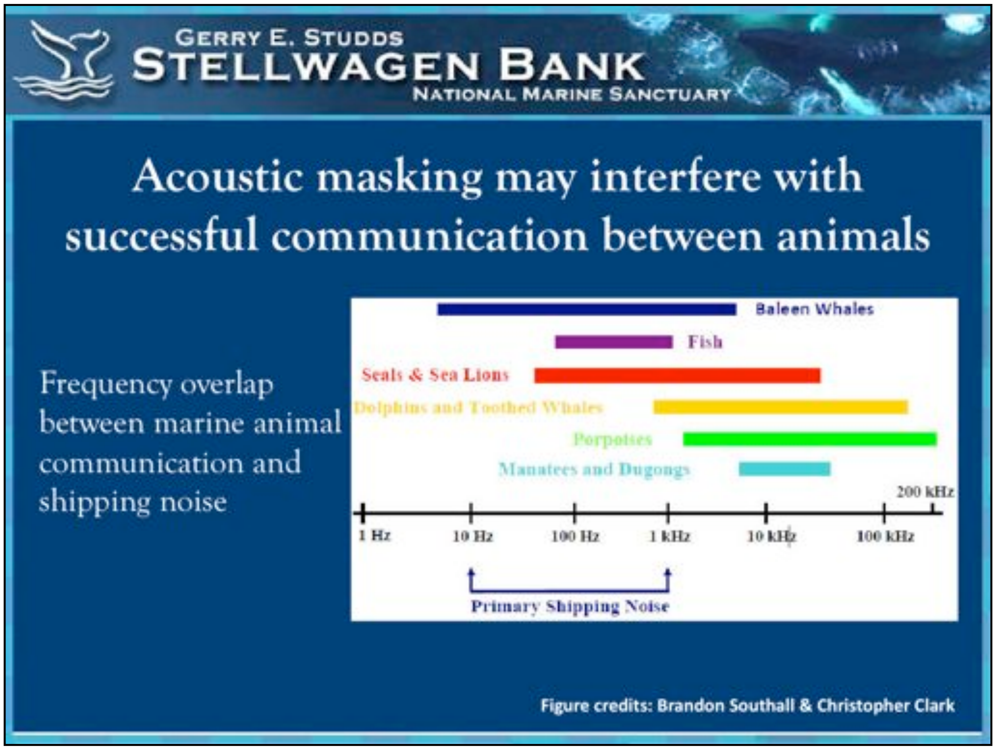
The bottom line is that animals and humans share this space and often overlap here.



But why are we so concerned about underwater noise in particular? As you can see from this picture, light does not travel very well underwater, which means that vision is not very effective for communicating in the sea. Sound, however, is a highly efficient means of communication over long distances in the water, and marine mammals are highly adapted to their aquatic environment.

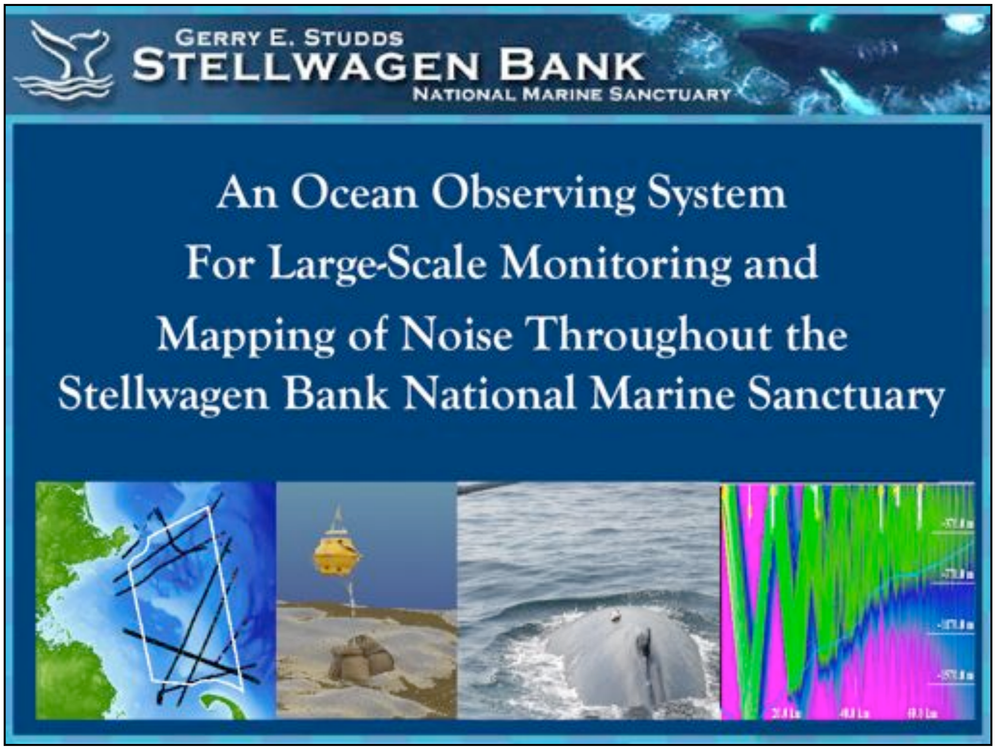
Sound is therefore very important for communication, and human activities that interfere with animals' abilities to hear one another may cause serious problems. You can think of this as "acoustic masking".

NOISE POLLUTION – ACOUSTIC SMOG

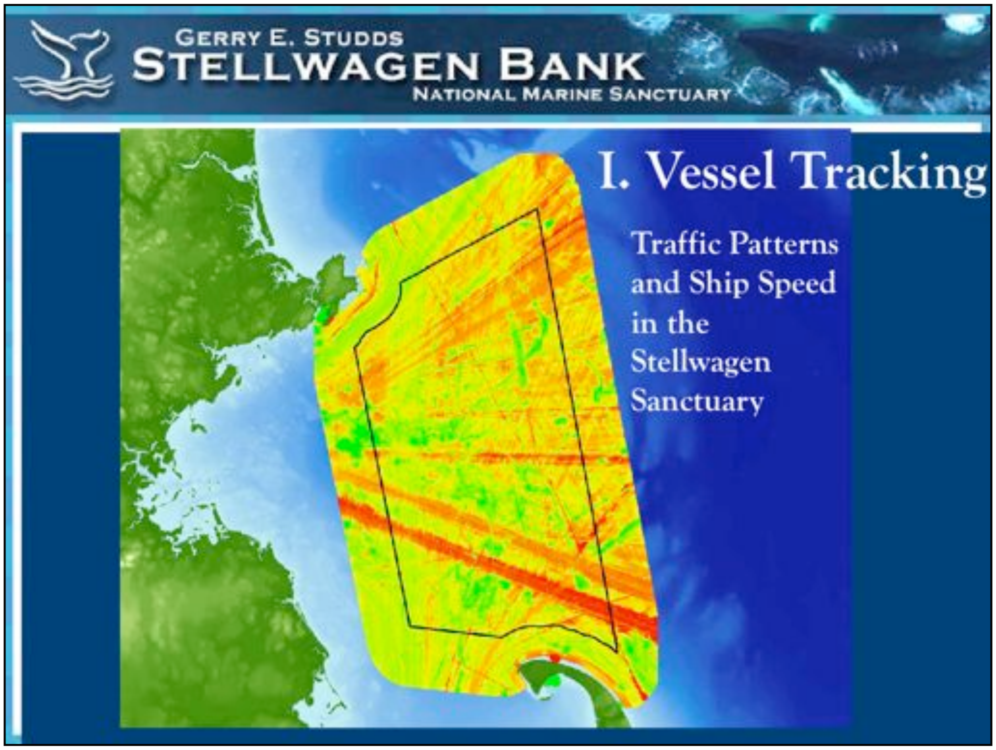


You are already familiar with the concept of acoustic masking – this is what happens when you are standing in a crowded room and can't hear the person talking next to you because of the noise all around you.

The same phenomenon happens in the ocean – only instead of a hundred people talking, we have a hundred ships traveling into Boston harbor. In the frequencies where this noise overlaps with animal communication, it may impede their ability to hear one another – potentially affecting communication involved in foraging, mating, or migrating. As you can see from the diagram on the top, shipping noise overlaps with the frequencies used by baleen whales, as well as some fish and pinnipeds.



To better understand the **soundscape** of our sanctuary and the overlap between human and cetacean activities, **we are engaged in multidimensional research incorporating a number of different data collection techniques,** including vessel tracking, passive acoustic recording, the use of digital recording tags, and the modeling of sound transmission (or sound propagation modeling).



Beginning with information that we can gain from vessel tracking: the use of AIS (automatic identification system) data allows us to look at traffic patterns for all large commercial vessels over **300 gross tons or carrying more than 165 passengers**.

(Background from Leila: United Nations' International Maritime Organization mandates that all large ocean-going vessels (see below) carry AIS transponders so that they can be tracked in coastal waters by shore-based receivers and so that they can see each other when in range. The system is mandated mainly for collision avoidance and for after the fact investigations by national coast guards when collisions occur.

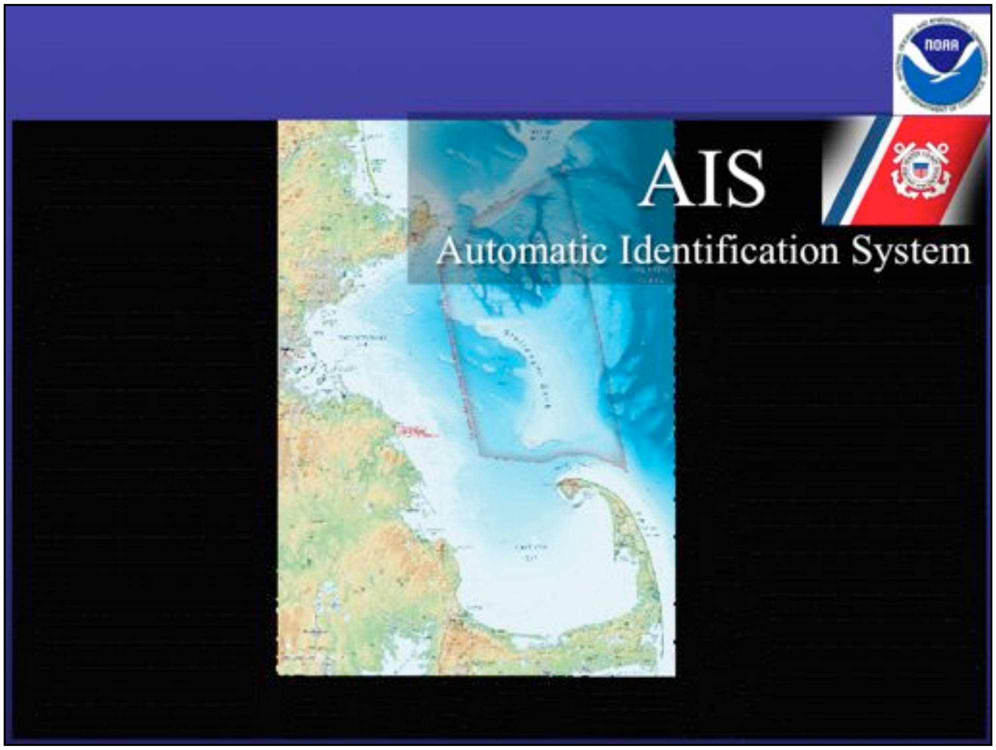
Carriage A requirements:

AIS tracks all tugs and towing vessels, all commercial tankers and cargo ships over 300 gross tons and all passenger vessels carrying over 165 passengers.

Developed as a system to aid in collision avoidance and accident reconstruction, AIS reports location data, including position accuracy and vessel attribute information, as often as every 2 seconds

These data can be received over an average of 40 nautical miles from shore-based receiver stations, transmitted via VHF, which allows the Coast Guard to use them monitor coastal vessel traffic real-time.

Carriage B has more recently been mandated for medium-sized vessels and is slowly being implemented in coastal waters around the world.)



Now, since we know ships are the main problem in ship strike ☺

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We needed to come up with a better way of analyzing ship traffic.

Starting back in 2005 the sanctuary worked with the Coast Guard Research & Development Center to install an Automatic Identification System or AIS to record ship traffic in and around the sanctuary.

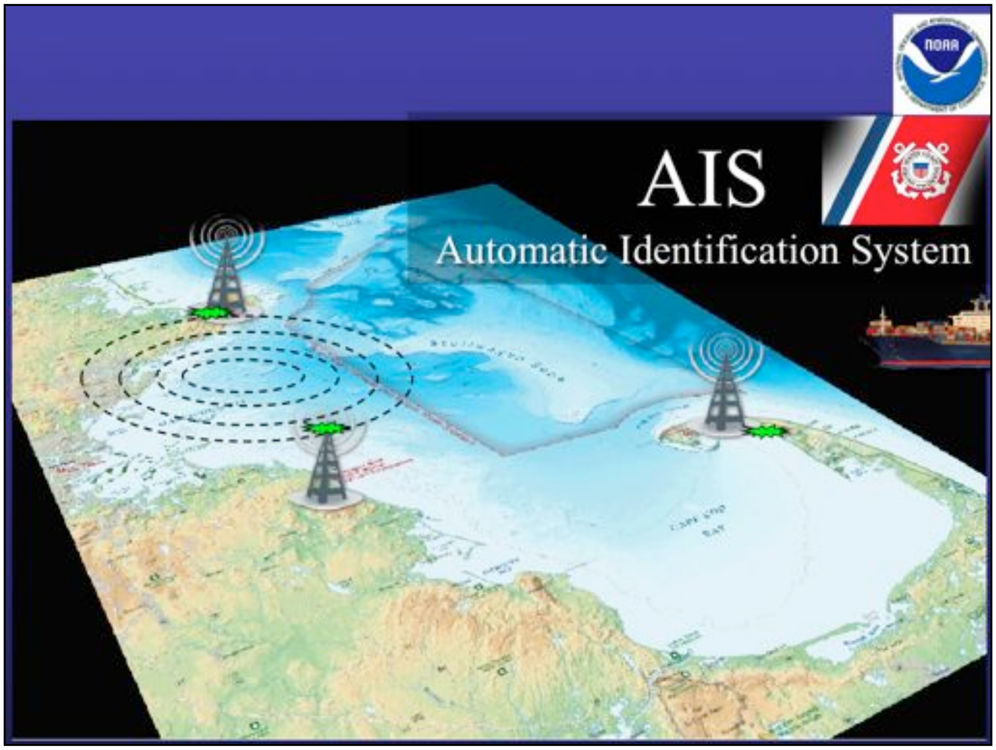
We did this by installing 3 receivers around the sanctuary to make sure we'd get full coverage.

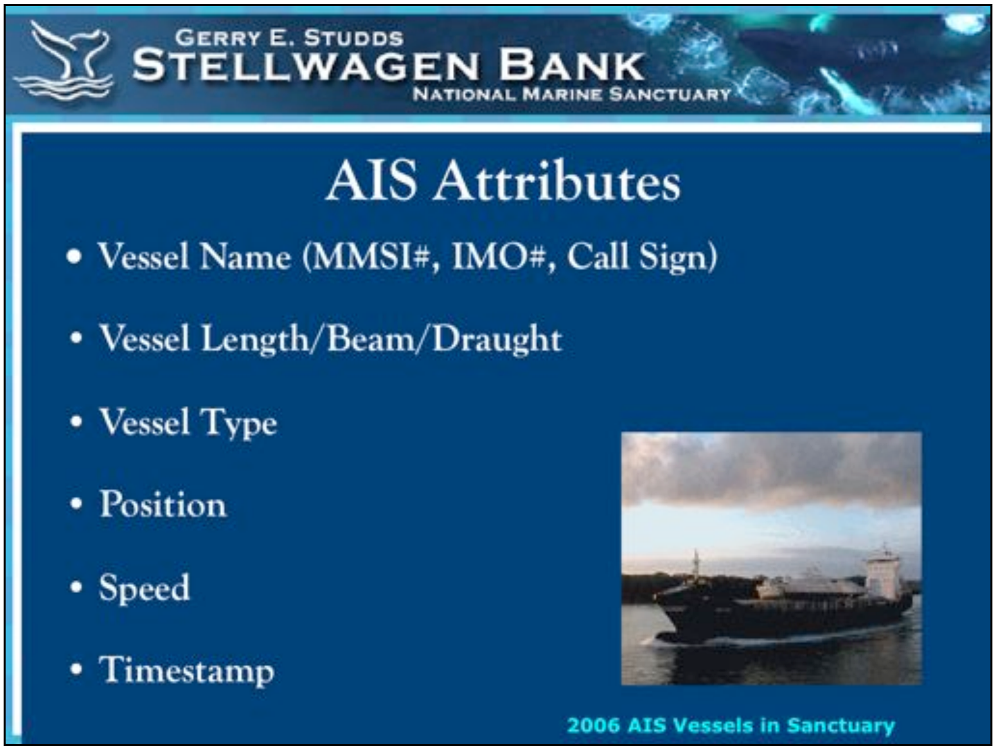
One was installed at our office in Scituate followed by another Cape Cod and Cape Ann.

Under the current IMO regulations, all 300 gross ton or larger vessels are require to carry AIS transmitters. So, as ships travel across the Sanctuary it continually transmits it's time, location, and speed as every two seconds.

As those signals are received at each site, they are then sent to our AIS server at the Sanctuary Office. Where we are able to load the …. LARge amounts of data into GIS. Which….

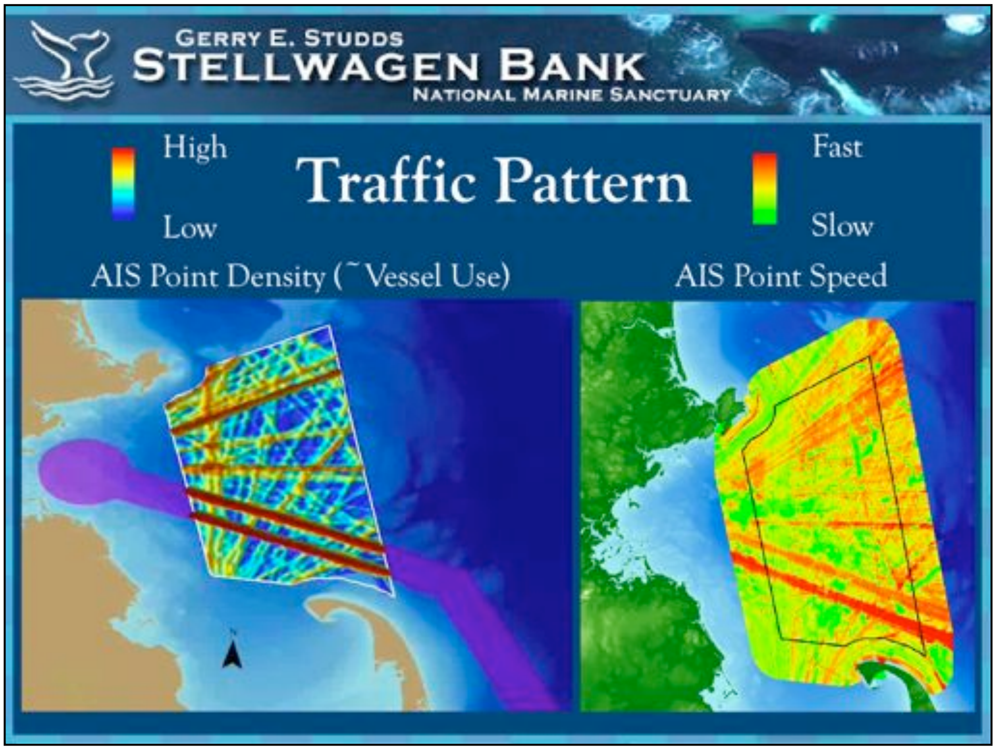
Next slide


AIS
Automatic Identification System

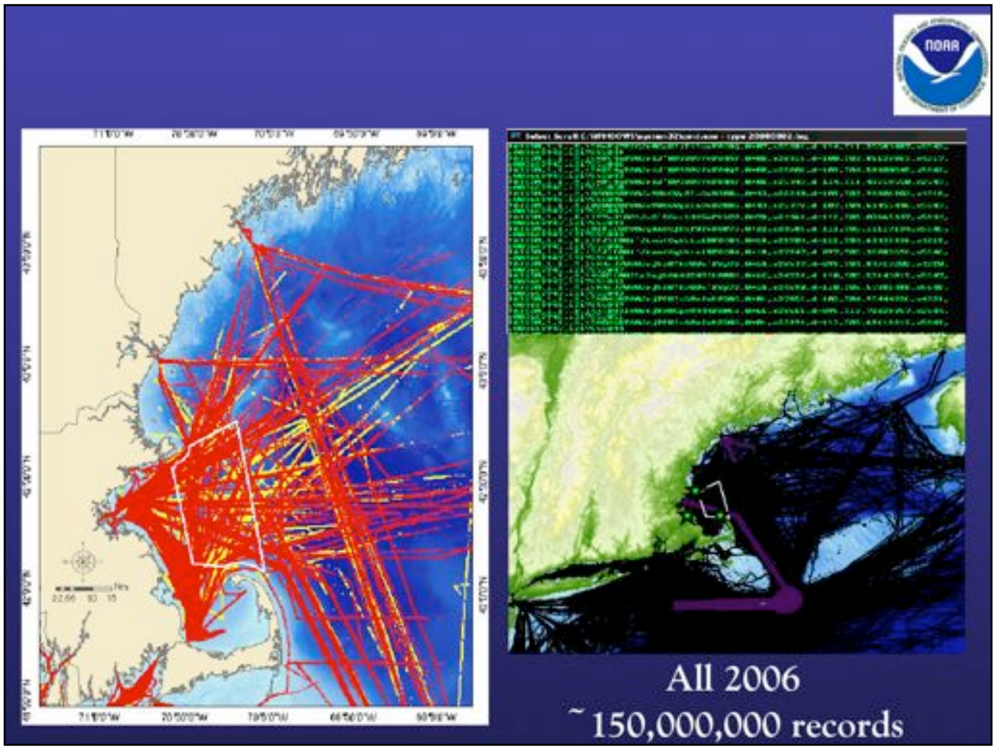


Types of information or attributes of AIS data include:

The vessels shown in the lower right hand side of the slider are 916 vessels tracked with these attributes over a year.



AIS can give a clear picture of traffic patterns. The density of vessel use is shown on the left and speed of vessels is shown on the right. One can clearly see the high use through the shipping lances.



Ends up being A LOT of data! Each year we collect over 150 million records from our three sites alone. It quickly becomes a daunting task to visualize or analyze the data.

The graphic on left is showing a sample of only two months of AIS data. April and May. (May in red)

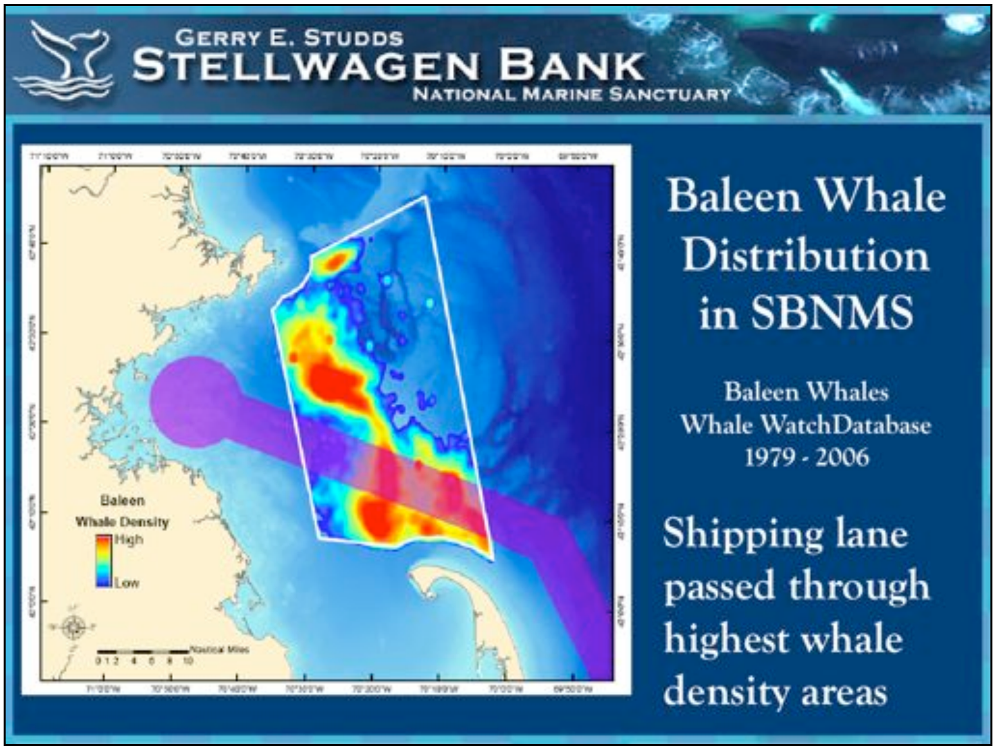
And the almost all black graphic on the right is a screenshot of all the 150 million data points we logged that year.

Background: Of course looking at data this way isn't very helpful, so we I generated these two maps to help us better understand what we're seeing. Ship tracks in the SBNMS and western GoM for the months of April and May 2006 (derived from USCG AIS). The data consist of more than 36 million position records generated along vessel paths at several second intervals from a total of 916 ships. Yellow represents the April tracks overlaid by the May tracks in red.

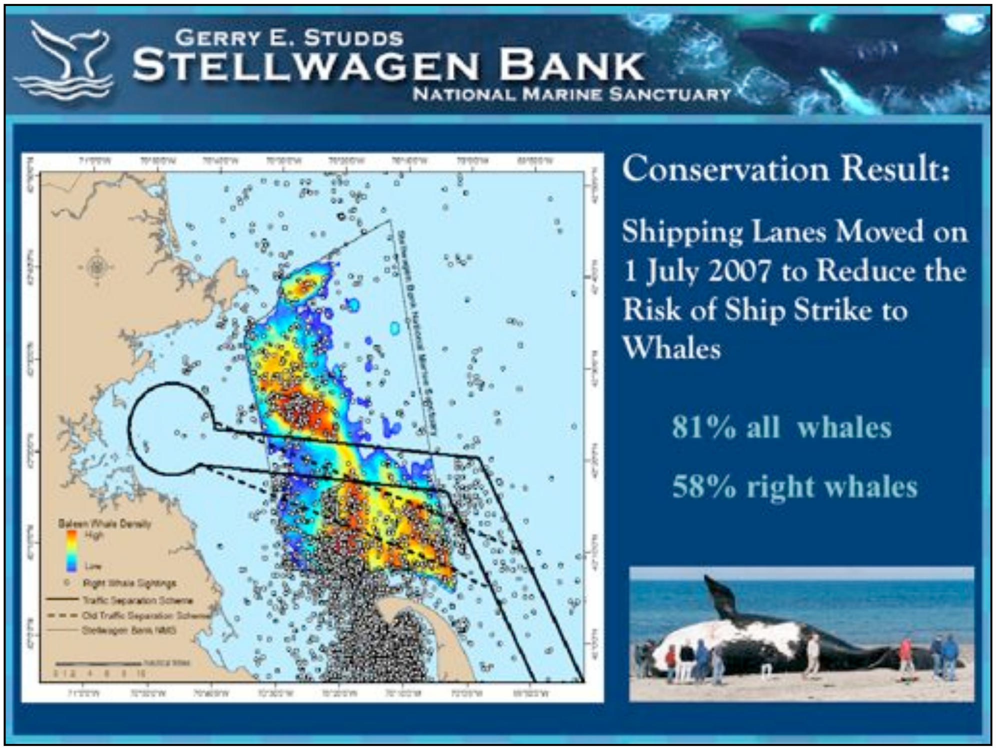
Collision with large commercial ships constitute the majority of human-cause mortality of Eg. NOAA Fisheries and the USCG established the Mandatory Ship Reporting System (MSRS) in July 1999 to reduce this threat. Under this system, all commercial ships, 300 gross tons or greater, are required to report to a shore-based station when entering critical habitat areas (i.e. Great South Channel).

SBNMS is working in partnership with the USCG to adapt the AIS, originally developed for tracking vessels in real time to reduce the risk of vessel collisions, as a means to analyize vessel traffic patterns across the sanctuary.

The AIS data portrayed indicate that the sanctuary, because of its proximity to the port of Boston, received more commercial shipping traffic than any other location within U.S,.



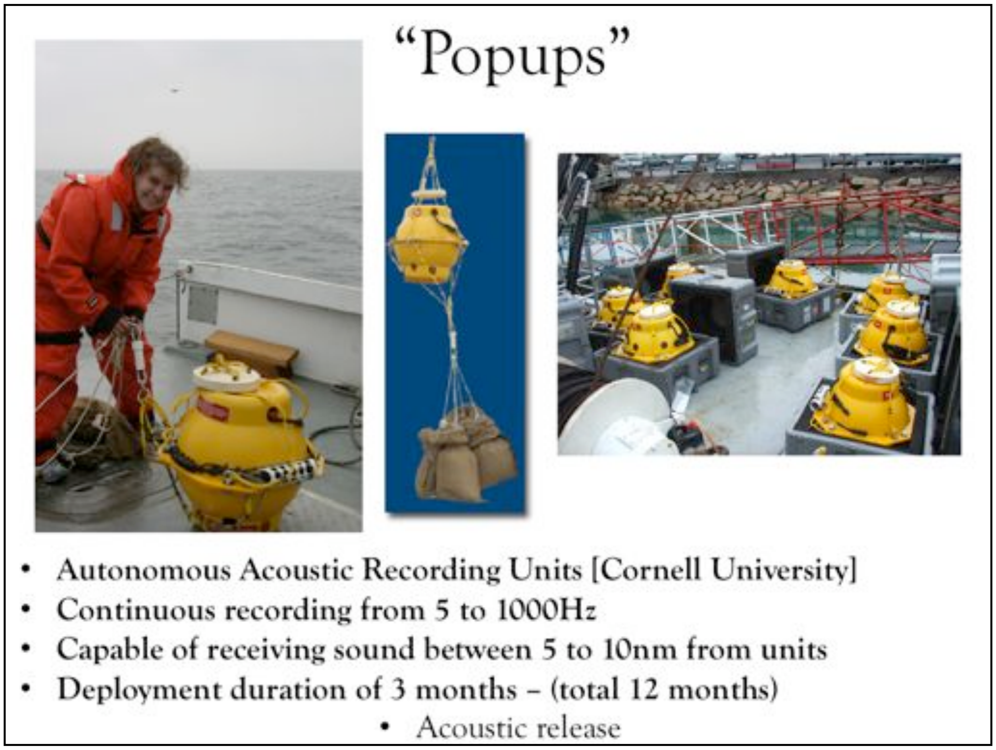
We compared traffic pattern data to baleen whale distribution within the sanctuary and found that the shipping lane into Boston harbor passed directly through the areas of highest whale density.



….So we embarked on a mission to shift the shipping lane through an area with lower whale density. This had the direct conservation result of reducing the risk of ship strike to whales by 81%, as well as generally decreasing the amount of ship noise that many animals may be exposed to.

The cornerstone of much of our work involves acoustic monitoring, which is conducted using Marine Autonomous Recording Units, or MARUs, which were developed by Cornell University. These units essentially include a glass sphere which encloses a laptop hard drive and some sophisticated circuitry, connected to a hydrophone and enclosed in a protective hard plastic casing. The units can record continuously for up to several months, can be deployed to the seafloor and left in place, which gives us great flexibility in our ability to collect data.

(some info: units are currently programmed to record at a 2kHz sampling rate, which gives us a 1kHz bandwidth. This is fine for right whales and ship noise, and gives us about 3months of recording time. However, in the summer we had them programmed at 10kHz, to give us a 5kHz bandwidth, more appropriate for humpbacks – we had those deployed for only 3 weeks but were able to capture much more of the frequency information in their vocalizations.)



Most ubiquitous problem in the S is ocean noise. To try and understand ocean noise, we started a project to determine WHAT is **the noise budget for the S, both biological and anthropogenic— (these components include diff types of ships, whales, fish, etc**

So partnering with Cornell University, we put down an array of pop up buoys capable of

Continuous recording from 5-1000 HZ,

Cappable of receiving sound from between 5-10 nm from the units

And deployable for 3 months.

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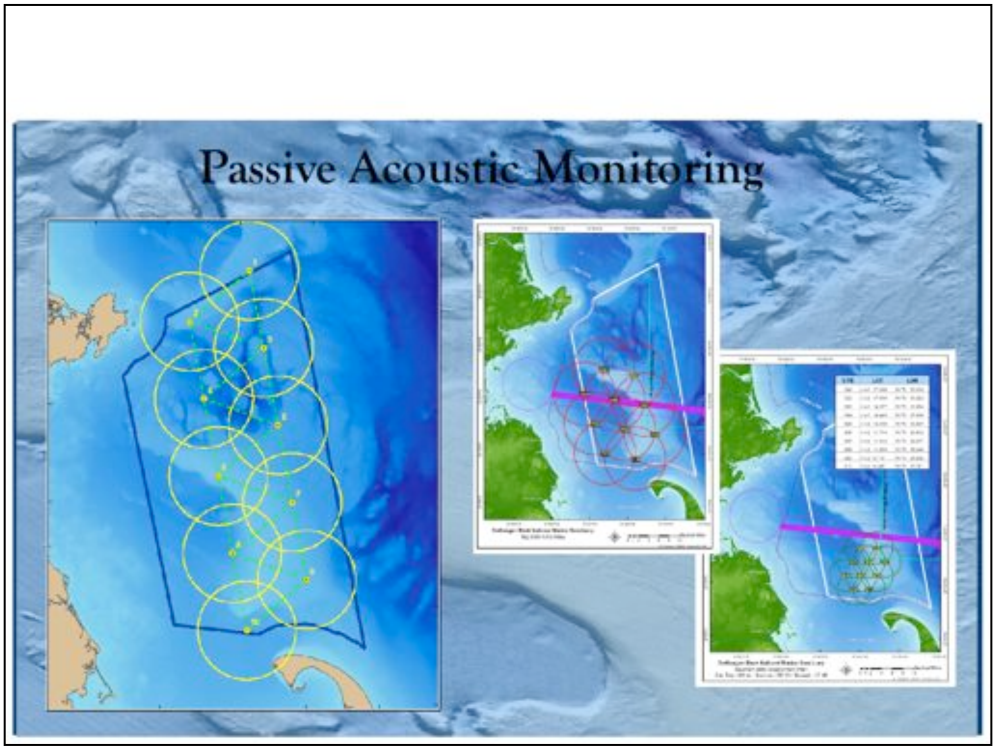
Buoys are tethered/anchored to burlap-covered sand bags. Upon retrieval, they send an acoustic signal which burns the release mechanism to let buoys come to the surface so that we can retrieve data. (Each sonobuoy cost @ $12,000.)



In 2006 we began a pilot project in which we **deployed these units across the sanctuary to look at broad-scale spatial and temporal distribution of marine mammal**s.

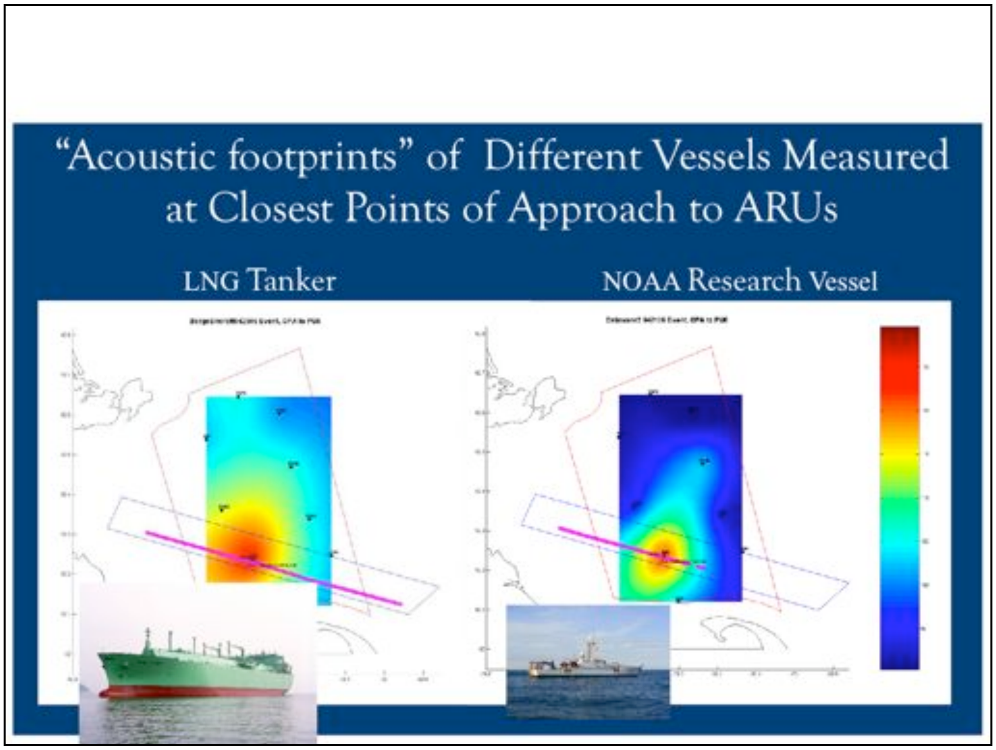
We are currently building on this effort through a three-year project to map underwater noise throughout the sanctuary (title: An Ocean Observing System for Large-Scale Monitoring and Mapping of Noise Throughout the Stellwagen Bank National Marine Sanctuary).

To look at distribution of whales and calclate a noise budget (AIS = ships going through, we deployed 10 buoys in the sanctuary in 2006. There is 85% vcoverage in the S.

Depending on db level and frequency, they can pickup things up to 8 nm (5 m really) away …

Our current array can triangulate on right whales only 3 miles apart.

(Info: Most of our deployments are 3 months, with the exception of the summer deployment which is usually about 3 weeks (see previous slide). We move the position of the array and spacing between units depending on who we are targeting. For example, in the winter we are targeting right whales near Jeffrey's, and right whales are not very loud, so we have a pretty tight array in the northeast corner of the sanctuary, with the units about 3 nmi apart. In the summer we are targeting humpbacks on the bank itself, so we are trying to cover more area and therefore put the units about 6 nmi apart…)

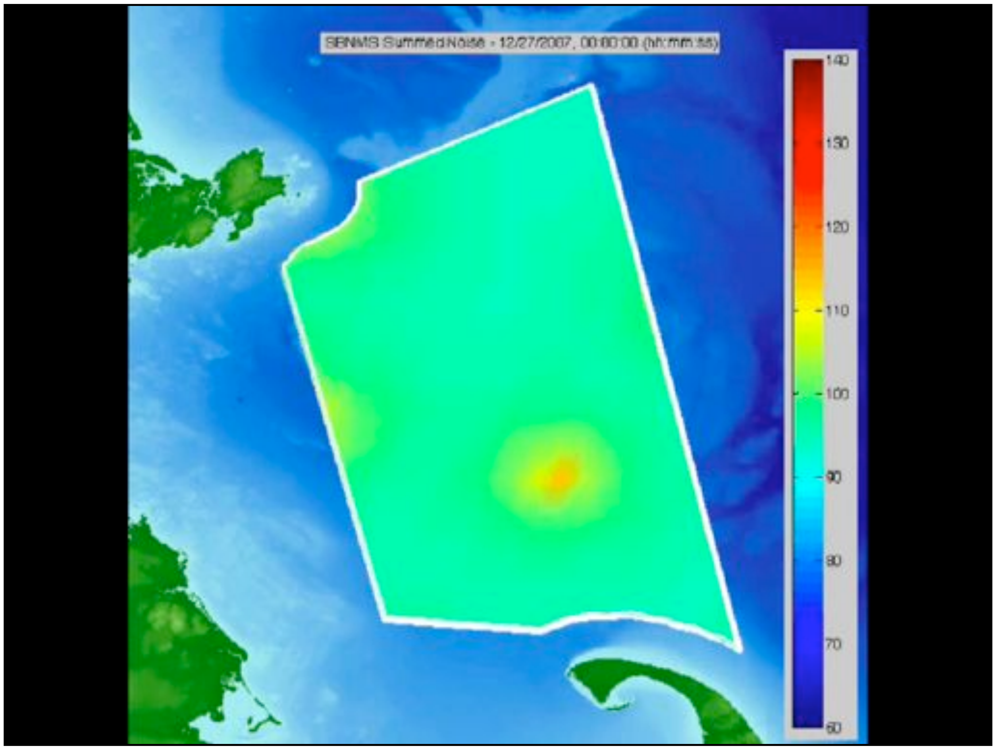


By **combining the passive acoustic data with modeling of sound propagation**, we can calculate the **acoustic footprints** of different types of vessels and evaluate the extent to which they are heard throughout the sanctuary. So, for example, you can see that the LNG tanker on the left has a much larger acoustic footprint than the research vessel on the right. You can see visually the area of the sanctuary throughout which it is heard.

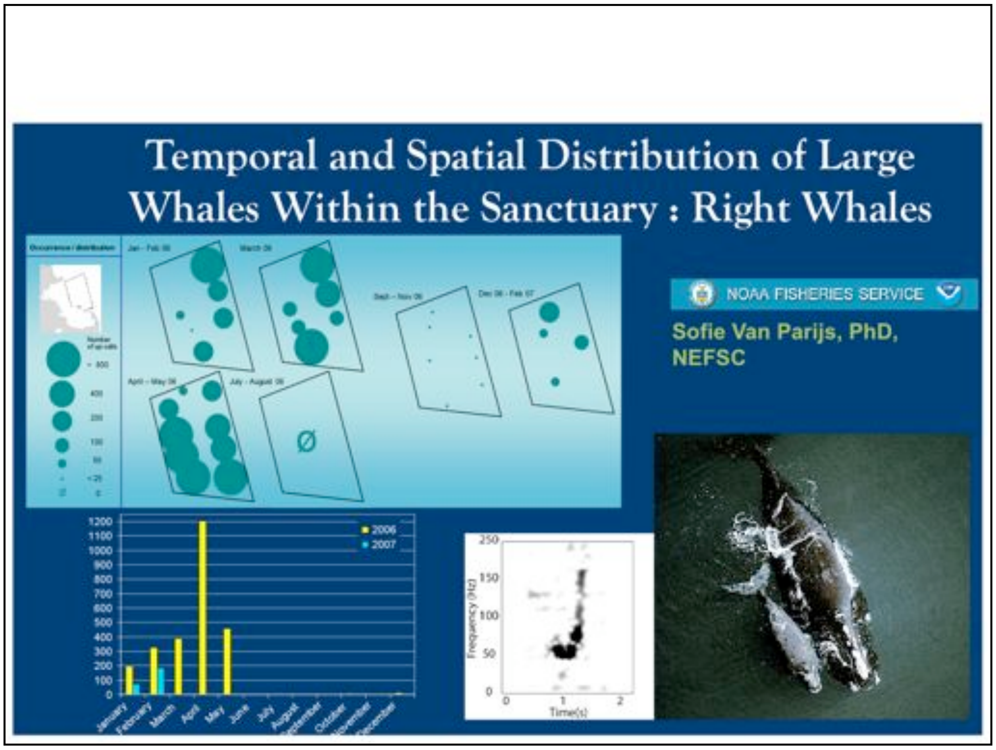
The kriged acoustic footprints of two vessels at their closest points of approach (CPAs) to an ARU in the array: **(a)**, a liquefied natural gas carrier **(b)**, and a NOAA research vessel. The color scale, from blue (low) to red (high), represents the intensity of sound at each location in dB referencing 1 µPa at 1 meter. The light blue rectangle represents the current shipping lane for the port of Boston.

Source level to Tanker = 189.7 dB (Distance to 120 dB = 23.8 nautical miles

Source level of NOAA research Vessel 176 dB (distance to 120 dB = 3.1 nautical miles)

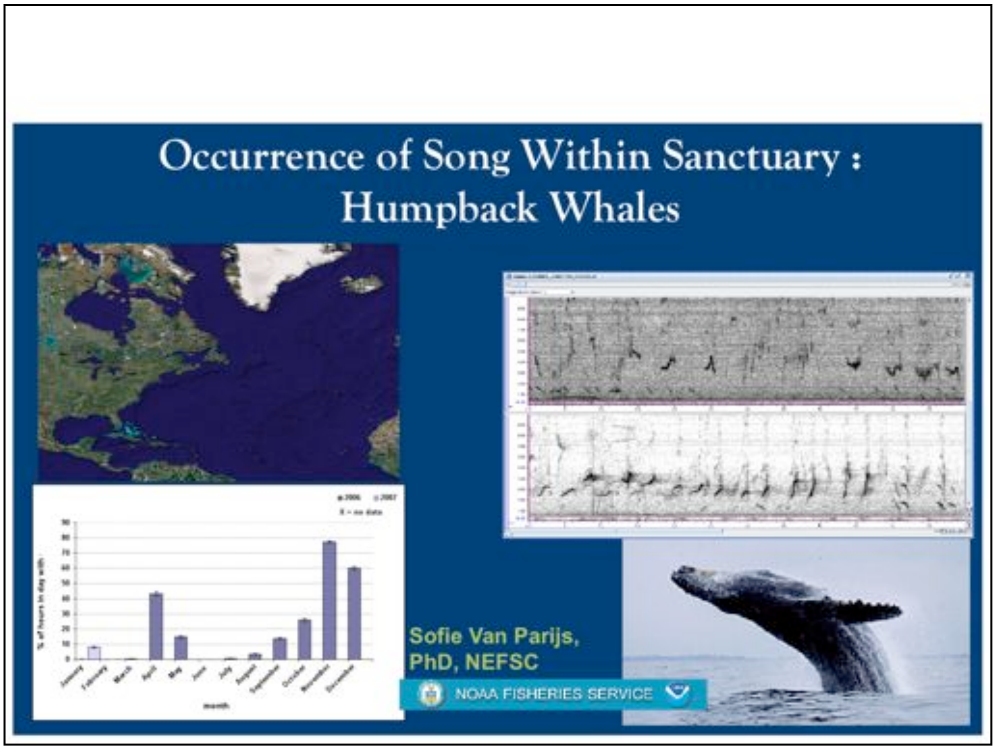


This slide shows intensity of vessel traffic, recorded from on unit in the sanctuary, over a 24 hour period.

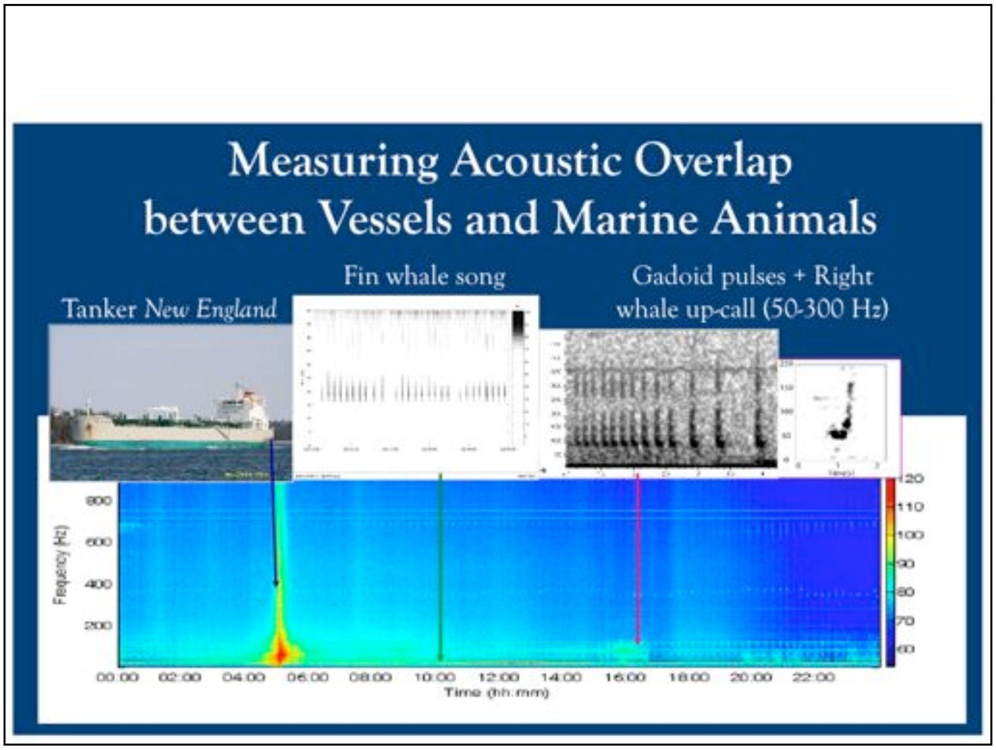


We **are using these data to analyze the "acoustic ecology" of various species**. For example, For example, using the data from the pilot year (2006) we were able to **evaluate the spatial and temporal distribution of large whale species within the sanctuary**. Collaborators in the NEFSC **analyzed these data to learn when and where right whales are found in the sanctuary – and we can clearly see both a change in the spatial distribution of animals (*seen by the blue circles in the upper figure*) as well as a seasonal difference in the numbers of "up calls" detected (*yellow bar graph*).**

Just a thought: These types of analyses can be extrapolated to any area, for any species, depending on the question…



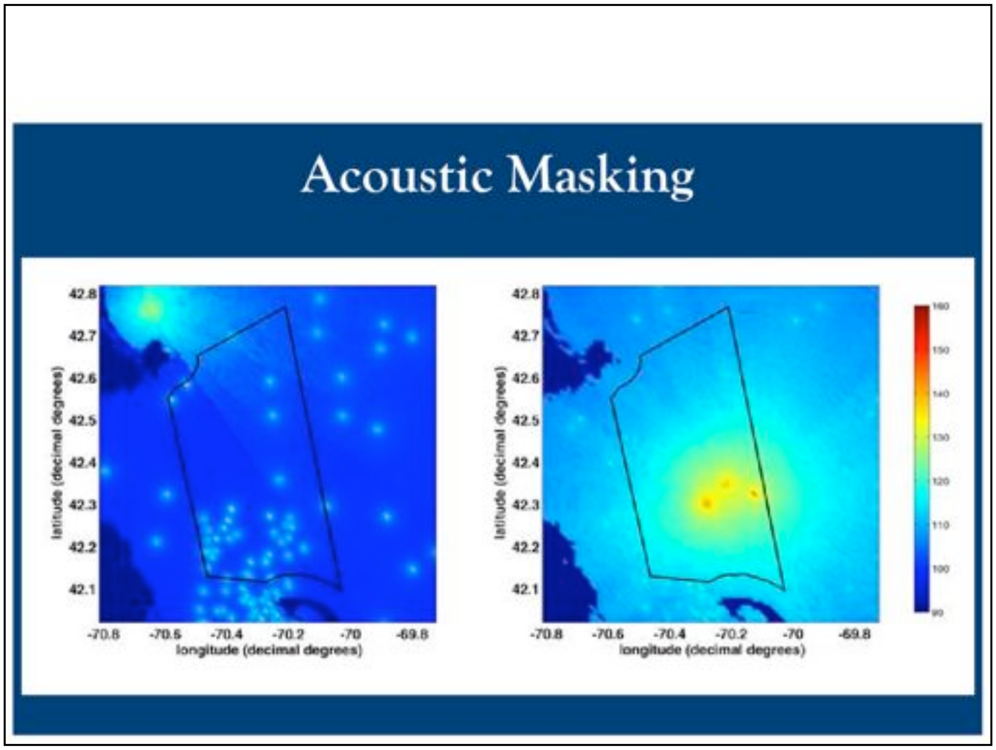
We have also used these **data to look at the seasonal occurrence of humpback song on the feeding grounds and compare it to song collected from the breeding** grounds**. Humpbacks return from the breeding season still singing (as seen by the occurrence of song in April)**, and then **ramp up again before the next breeding season in late fall (as seen by the occurrence of song in November/December). In the height of the feeding season, they are not singing** at all.



Moving on to **looking at noise and the acoustic overlap between vessels and marine animals**...

This slide is just an example of **how we can pick out different acoustic sources in our spectrograms**. The spectrogram at the bottom is **showing 24 hours of sound recorded from one unit, and we can highlight the different biological and anthropogenic contributors.**

For example, we can see the high sound intensity produced by the passage of a large tanker. We can also pick out fin whale song, right whale calls, and fish vocalizations.

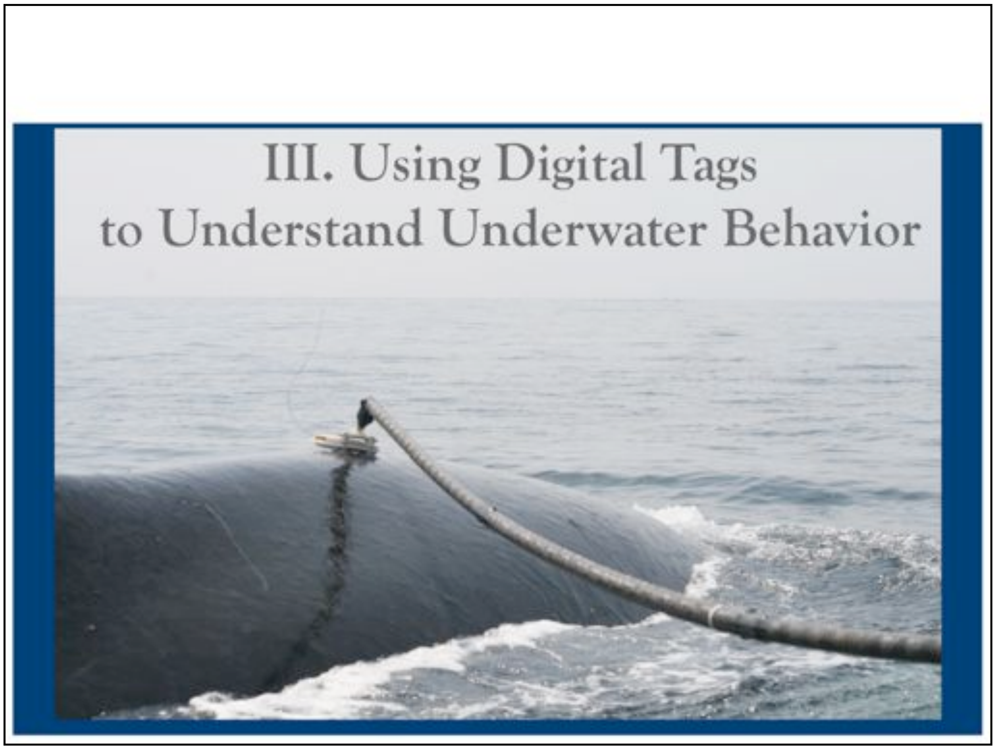


This is a compilation of much work that is still in progress. We are **now able to pull together our different "acoustic layers" to actually calculate the degree to which a vocalization by a particular animal is masked at any point in time.**

The **two images above show snapshots of the acoustic scene in Stellwagen Bank at two separate moments of time in April 2008.**

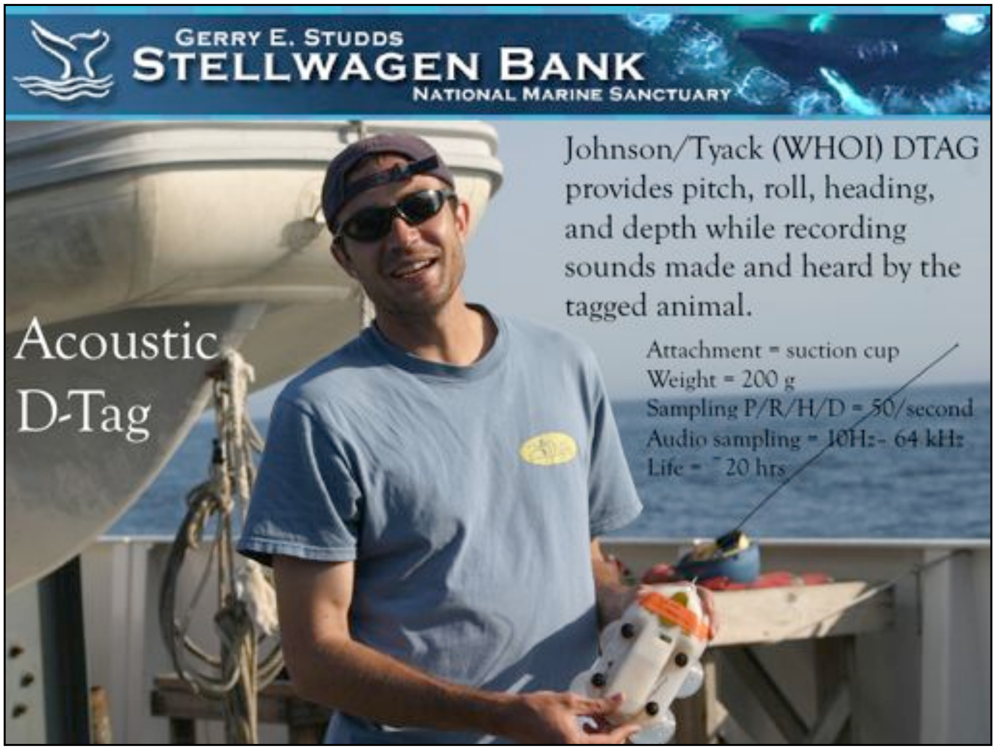
In the image on the **left, we see a relatively quiet scene**, in which the positions of right whales are shown by the small blue dots and a small vessel that is to the north of the sanctuary is represented by the brighter circle. We can see that this vessel is having little effect on the calling animals within the sanctuary.

In contrast, in the **image on the right, we see the combined acoustic fields of three vessels located within the sanctuary and our right whales are almost completely overshadowed by this noise.** In this case, the "**acoustic masking**" is very high for almost all animals in the sanctuary. We are in the process of doing these analyses for different species at different times of year.



Finally, we can put **these two acoustic players together—boats and whales — to ask about the response of individual animals to vessels.** This research is being done by a team of collaborators from the Sanctuary, WHOI, NOAA Fisheries, Duke University, the University of Hawaii and the University of New Hampshire.

This work involves the use of a **digital recording tag, which is attached to the animal's back with suction cups, and stays on for hours a day and provides very detailed information on the animal's movement in 4 dimensions (including pitch, roll, depth, time), and it also records the acoustic environment at the whale.**



One of the most ubiquitous threats in the S is ocean noise. Stellwagen and research partners are pioneering acoustic techniques to monitor humpback whales. **Until recently, we could only interpret behaviors that we see above the water; the acoustic tagging now allows us to "SEE" under water dimensions.**

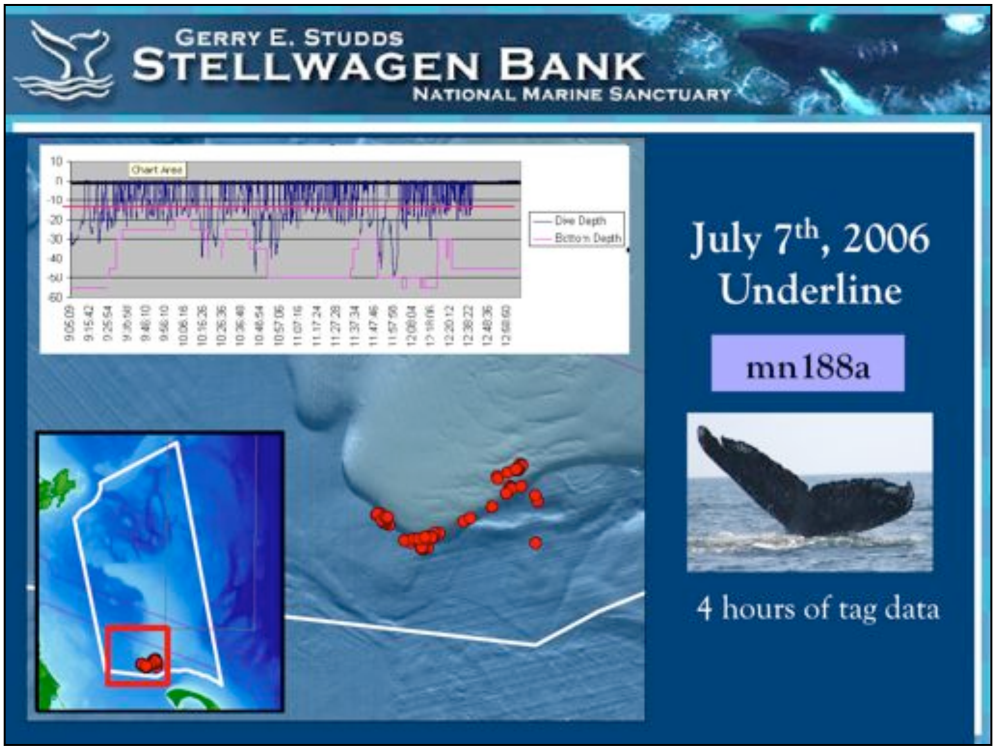
This is a **D-tag … a suction cup with a recording unit,** which is placed on the dorsal surface of the animal behind its blowholes. The acoustic tag measures 1) pitch (inclination), 2) roll, 3) headng and 4) depth …. multiples times per second, while simultaneously recording the sound the animal makes and hears. The tag **stores @ 20 hours of data; the tag is programmed to come off and is then retrieved by locating the VHF transmitter.**

using a shorter hand pole to approach the whale from the side and attach the tag as high up on the whale as possible. Here's a successful tag attachment made of of the small inflatable by Ari Friedlander of Duke University.

And here's **a quick clip of a successful tag attachment off of the inflatable, Baleena, using the 40 foot pole.**

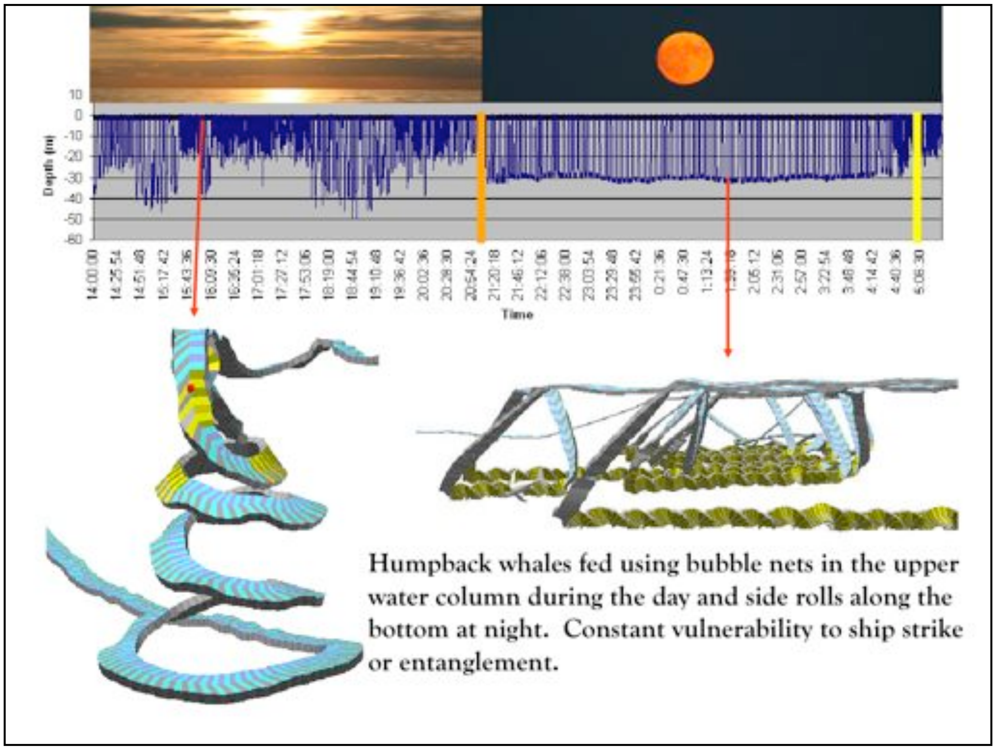
Next Slide…

And …



Although deeper divers, humpback whales are also very vulnerable to ship strikes.

This **dive profile for a tagged whale shows the proportion of its time spent at different depths, so the amount of time it spends within a “ship strike” zone can be calculated**. The red line in this case indicates average keel depth of the largest ships coming into Boston (about 12m deep).



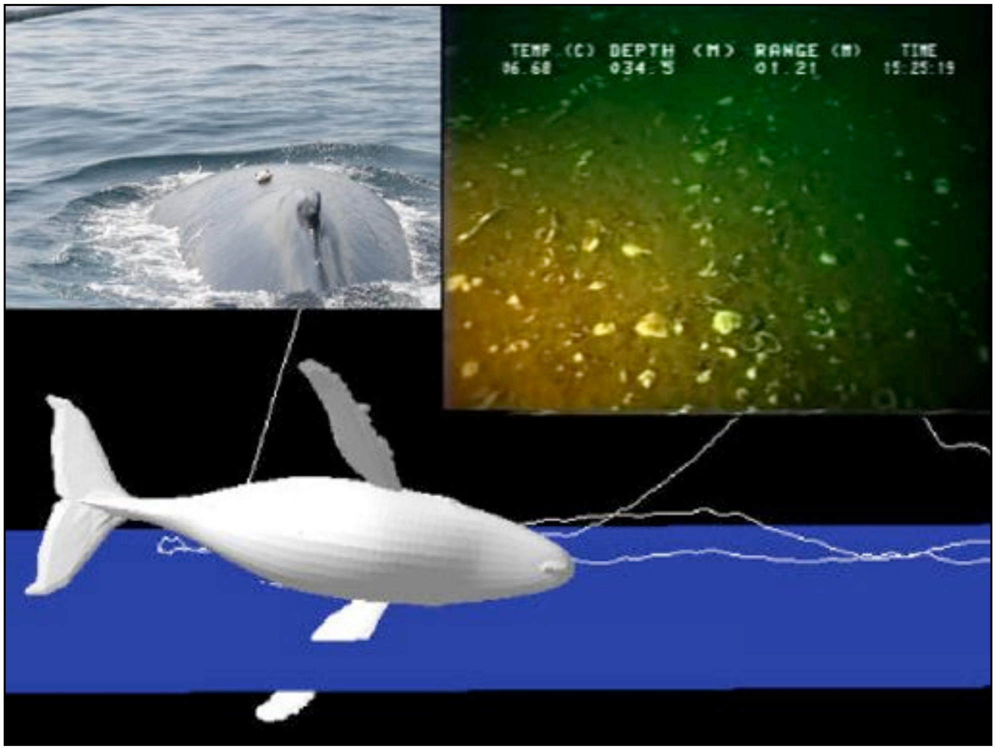
Humpback whales fed using bubble nets in the upper water column during the day and side rolls along the bottom at night. Constant vulnerability to ship strike or entanglement.

This **figure shows you what the tag can do when combined with data visualization software, called Track Plot**

Here's a **time/depth plot of this whales behavior over the course of the day. On the left you can see the surface-feeding,and a bubble net event during daylight hours.**

And on the **right (at night), one can see the mowing-the-lawn feeding along the bottom and side-roll behavior.** What's nice about having all the data spatially time series'd is that we know that at 16:00 the whale was bubble netting and at 1:30 in the morning it was feeding along the bottom.

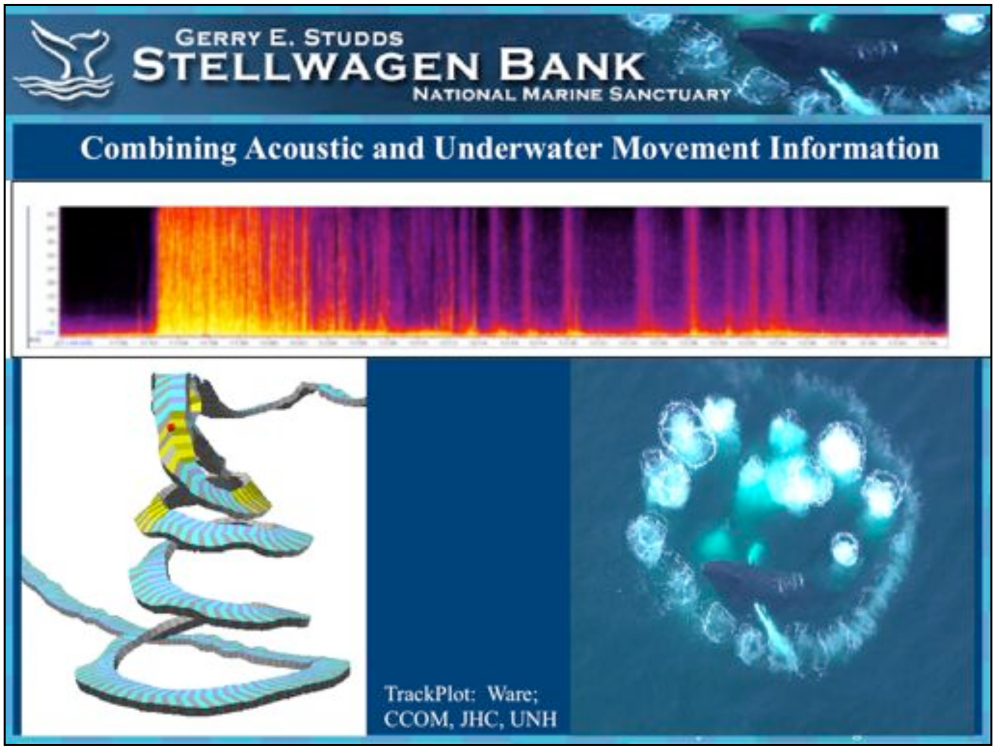
The **two lines here indicate sunrise and sunset. So the thought is that during the day their using the suns light to locate and corral bait.** Where all of the **bottom feeding is done during the night. Now what they're doing at night is very interesting because we always knew they were feeding at night but not sure how.**



1) The video clip on the **right, shows the preferred prey for humpbacks**— these are sand lance or sand eels (Ammodytes americanus) burrowing on sandy substrate, ,

2) The image in the **left hand corner illustrates a D-tag on a humpback**, and

3) Below the **visualization data as the whale swims along the bottom, rolling on its side, presumably flushing the sand lance from the bottom …. Scars on lower jaw confirm behavior.**



We can also **combine the multi-dimensional data from the tags with the acoustic data to address various questions.**

In this case, we are **using the tag data to better understand the production of bubbles (shown in the spectrogram in the top) with respect to feeding dives (a spiral net is shown on the left). The aerial photo on the right shows what the bubble pattern looks like from the surface.**

These type of analyses can also be done to evaluate movement and acoustic responses of individuals to anthropogenic stimuli, such as ships.

This brief clip (courtesy of our collaborators in the University of New Hampshire) is **the animation of real data collected from two animals who were tagged simultaneously, and were feeding together. We are using data such as these to understand how animals interact underwater.**

Do animals feed cooperatively? Note animal in pink line is blowing bubble net; animal following white line will RAID the bubble net.

This is another short animation of real data, this time visualized in a program called “track plot”, also courtesy of our collaborators at the University of New Hampshire. This type of ribbon display better indicates the pitch and roll of the animal, as recorded on the tag.

(movie = mn06_192a_2.wmv)

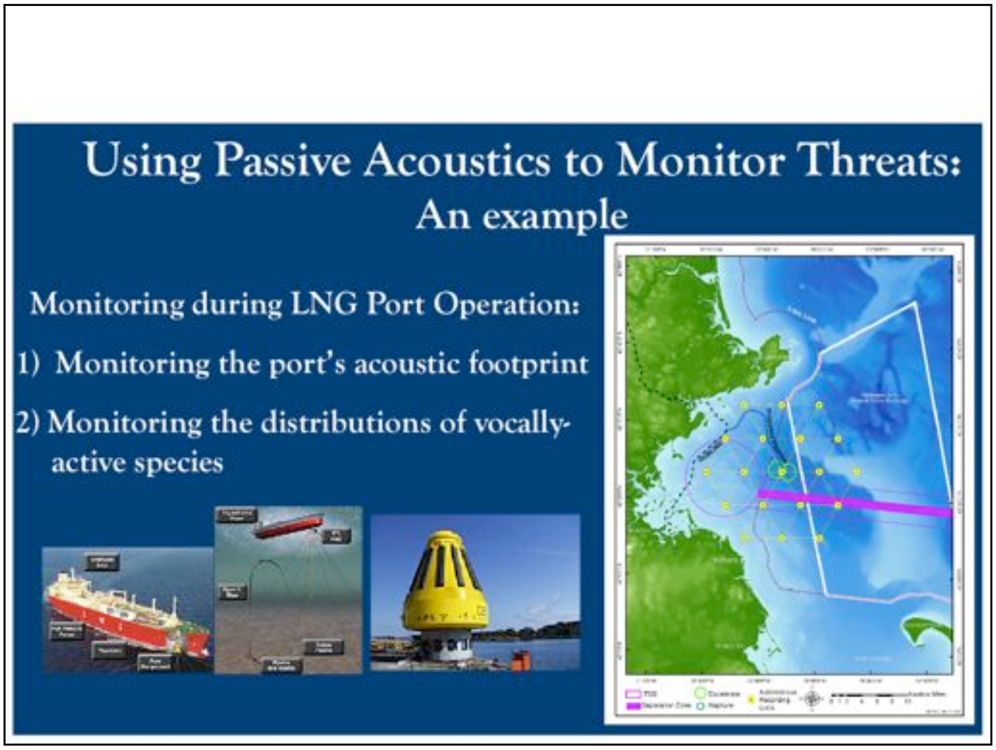
(movie file = Mn08_189_Teambubble.wmv)

And lastly, Liquified Natural Gas (LNG) tankers are not an uncommon site crossing through the sanctuary.

They proposed to build ports right outside of our sanctuary.

Our sanctuary is governed by the **US National Marine Sanctuaries Act** (passed in 1972), which provides multiple tools for protecting designated Sanctuaries. If the Secretary of Commerce **finds that an action is likely to "destroy, cause the loss of, or injure a sanctuary resource"**, the National Marine Sanctuary Program is required to recommend reasonable and prudent alternatives that will protect sanctuary resources. **(even those outside the sanctuary that could affect resources).**

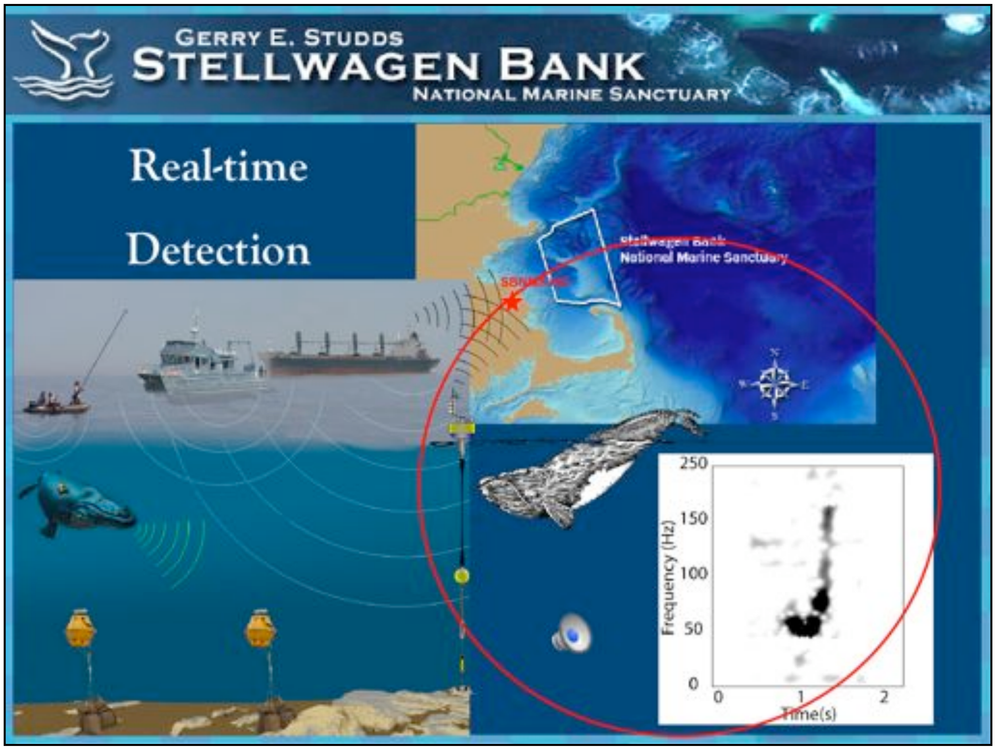
To protect marine resources, one must first identify possible threats that they face, thus, the Act calls on managers to identify activities that are likely to destroy cause the loss of, or injure a sanctuary resource.



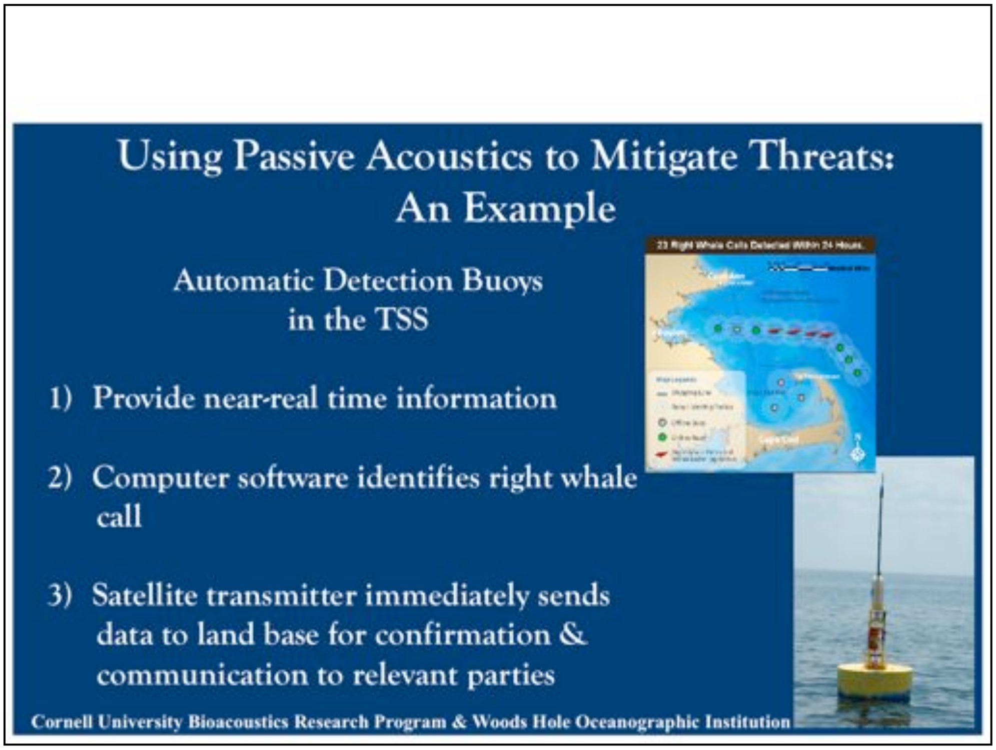
As an example of what can be gained through effective monitoring, I wanted to introduce you to the **monitoring associated with the development of LNG ports adjacent to the sanctuary.**

To capture the full acoustic footprint of the construction and operation of these ports (various components of which are shown in the photos at the bottom), **they are required to install a large array of marine autonomous acoustic recorders (MARUs or popups) on the ocean floor around the site of the port (indicated by the yellow dots on map). These data can be then be used to monitor the port's acoustic footprint as well as understand how noise associated with this port may affect the distribution of vocally-active species in the area.**

At nearest, these ports would be 1.4 miles from the western border of the Sanctuary and 3 miles at closest to each other. As the companies applied for licenses for these ports through the Maritime Administration and US Coast Guard, these federal agencies were required to consult with NOAA regarding their impact on marine species. The Sanctuary also entered formal consultation under the National Marine Sanctuaries Act, which mandates that the Sanctuary Program recommend specific actions that should be taken by the federal action agency, in this case the licensing agencies---the Coast Guard and Maritime Administration—to minimize or mitigate impacts on sanctuary resources.



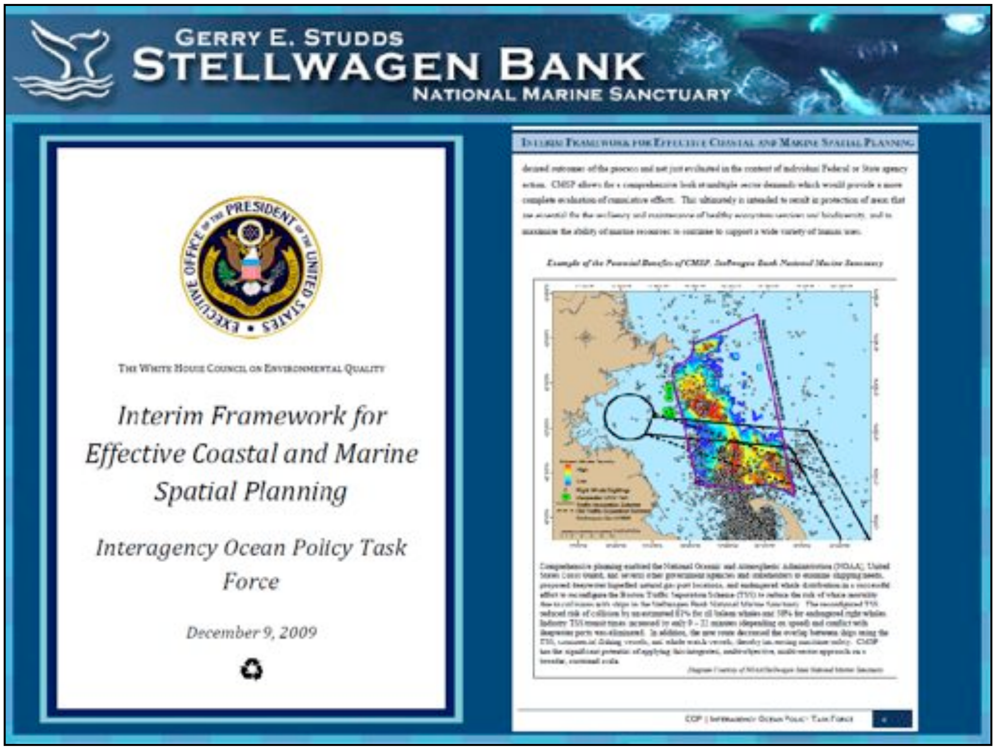
Before LNG claimed that only small percentage of right whales in the area. After use of acoustic deployments, shown that 50% of Right whale up calls in the area.



Real-time acoustic detections in the Boston area utilize surface buoys called automatic detection buoys, developed by Cornell University's Bioacoustics Research Program and moorings developed by Woods Hole Oceanographic Institution….

These **buoys detect right-whale up calls (or sounds that are similar) and transmit all likely detections to Cornell University via satellite.** Analysts at Cornell examine the candidate calls, and if **right whales are detected, they transmit that information to any LNG vessels that may be transiting within the shipping lanes.** When that occurs, the vessel operators are **required to slow to 10 kts and heighten visual observations on deck.**

Shows 227 right whale calls detected within 24 hour period. Can go to listening nettwork at: www.listenfor whales.org



Our research was recently highlighted in the Presidents Ocean Policy Task Force … a revolutionary tool for effective coastal and marine spatial planning,

GERRY E. STUDDS
STELLWAGEN BANK
NATIONAL MARINE SANCTUARY

In Summary:
Many new tools have been developed that enable us to learn about and evaluate the status of our marine acoustic environment.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Future Vision:
Joining forces between SBNMS and MM MPAs to better understand the impacts of noise on the endangered humpback whale and other species throughout an ocean basin.

I want to thank all of these collaborators for their work and for their help with this presentation.

Thanks to our funders:

NOPP National Oceanographic Partnership Program
Promoting Partnerships for the Future of Oceanography

NOAA National Oceanic and Atmospheric Administration

IFAW
www.ifaw.org

National Marine Sanctuary Foundation

MASSACHUSETTS ENVIRONMENTAL TRUST

Merci pour votre attention!

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Fulcrum dorsal before and after small vessel strike


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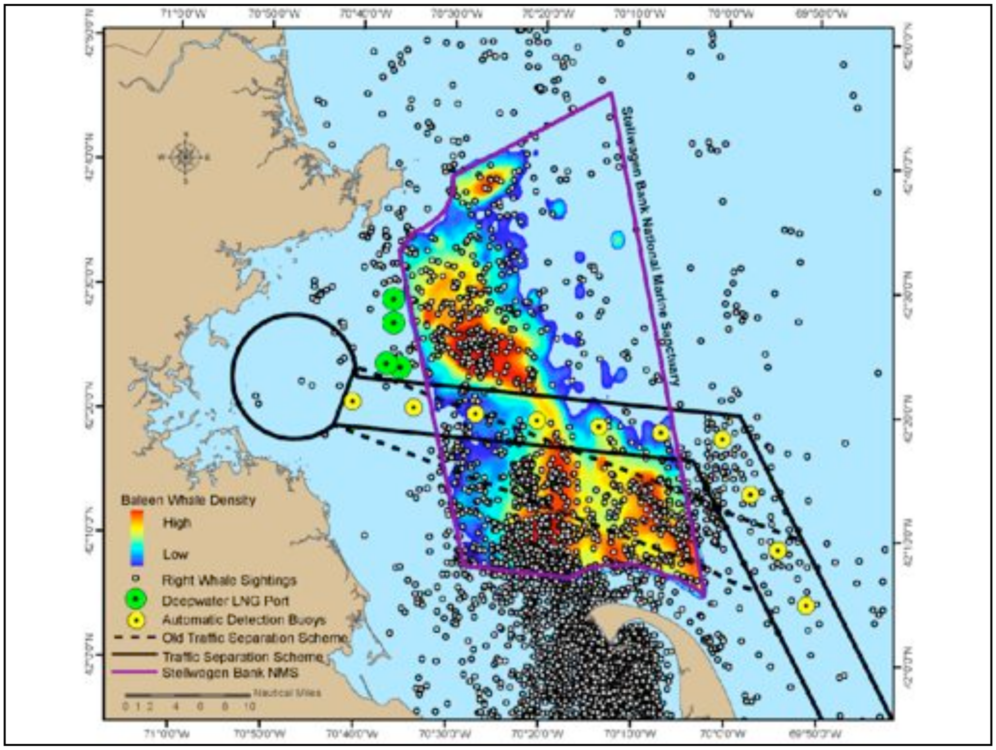
http://stellwagen.noaa.gov

YOCAH
Year of the Caribbean Humpback
(AGOA, DMMS, EC matching to SBNMS/GoM population)

I. Education/Outreach
- Citizen science
- Signature calf per island

II. Research (i.e., acoustic, aerial, satellite.radio tagging)

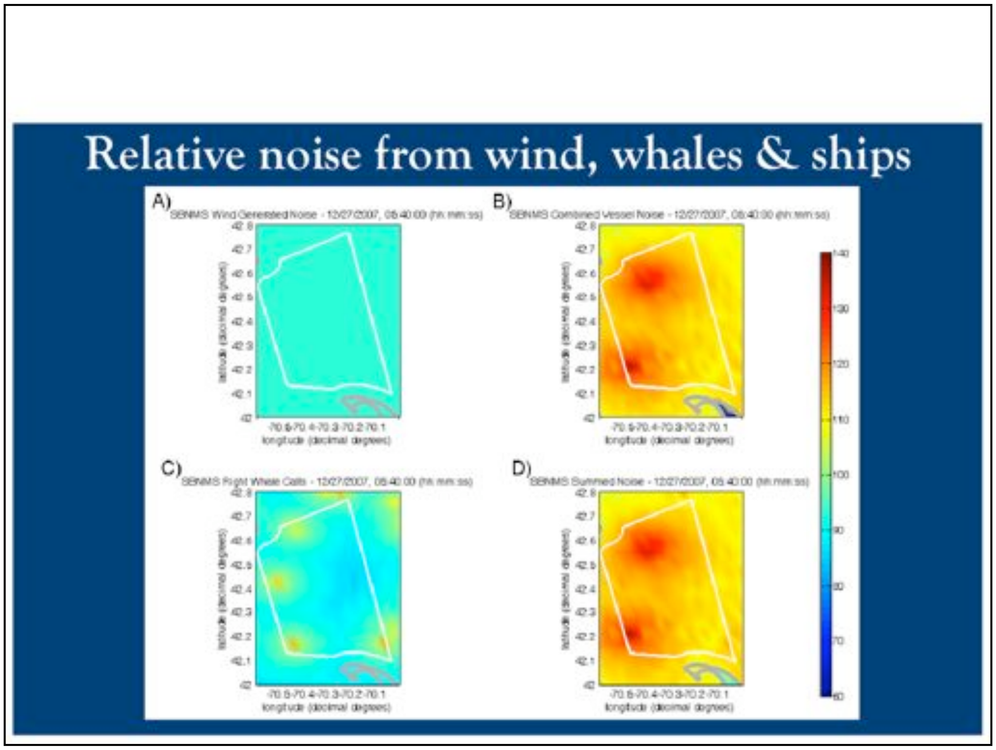
III. Management
- CAR/SPAW–MMAP: ecoregion framework for WCR



Marine Mammal Protection

Here's a great shot taken from last years Humpback Whale tagging cruise of Teapot and Tectonic surface feeding. One of the most intensive Geospatial projects we have is…

Next Slide



By compiling all of our data, we can look at the contributions of different sources to the acoustic landscape of Stellwagen Bank.

Again, we are looking at the sound fields produced by different sources in the sanctuary. The upper left-hand square shows the average sound produced by wind, the upper right-hand box shows the combined sound fields from a couple of vessels in the sanctuary. Compare this image to the one at the lower left, which shows the sound fields produced by calling right whales, and you can see that the vessels are not only much louder but are heard over a much bigger range than the whales. When we combine all of these data (lower right), you can see that the “soundscape” is dominated by the ship noise. What this means for marine mammal communication is of great concern.