Introduction to seafloor mapping
Seafloor maps have a wide variety of uses for scientists and coastal planning needs. Some of these uses include biological assessment (seafloor habitat mapping), ecological linkages (fish and marine mammal distributions related to topographic information), geological characteristics (surficial sediment composition, geologic hazards, natural resource reserves, and morphology), and marine archeology (location of shipwrecks). In addition to these uses, an accurate knowledge of the seafloor is important for economically for maritime navigation to ensure a safe movement of goods (Batista & O’Brien, 2015). Multi-beam sonar is one way that is very useful for imaging the seafloor.

Seafloor data collection using Multi-beam sonar
Multi-beam sonar is a type of active remote sensing that uses a sound transmitting and receiving system. These systems send a sound pulse through the water, which bounces back up to the receiver. The longer the signal takes to return to the receiver, the deeper the water column is (Brown et al., 2012). Multi-beam sonar gets its name because it sends out multiple signals at one time, which allows for a larger area to be mapped at one time. Multi-beam systems can acquire two main types of data: bathymetry data and backscatter data (Brown et al., 2012). Bathymetry data gives the depth of the water column. Backscatter data returns the intensity of the signal. Using the intensity of the signal acquired from backscatter data, the composition of the seafloor can be determined (Innangi et al, 2016). For example, if the signal comes back very weak, that means that more of the signal was absorbed so the seafloor in that area is likely to be a soft mud. In contrast, if the signal come back very strong, the seafloor in that area is likely a hard bedrock. This collected data can come back as a raster dataset and it can then be brought into ArcGIS for analysis.

Integration into GIS
Once the seafloor data is acquired via the seafloor mapping method, it can then be brought into a GIS software to do various analyses. One example of this is using GIS to analyze backscatter data. One study used high-resolution backscatter data to present a seabed map of a volcanic environment, a task that was ground breaking for its time (Innangi et al, 2016). In order to create this map, they collected both backscatter data and bathymetry data using multibeam SONAR. In addition to the seafloor data, they also collected seven sea-bottom sediments which allowed them to describe the lithologic features and classify the sediments by grain size. The result was a ground trothing data set. Once they had collected all of this data, it could be brought into GIS to analyze. It was brought into GIS as a raster dataset. Lines could then be digitized around backscatter data boundaries and it was then converted into a polygon vector dataset which made it much simpler to read. Maps like the end result of this study can be used in many different ways including as the basis of seafloor mapping studies.

Combination of applications
There are many complex ways that remotely sensed seafloor data can be integrated into GIS. One such way comes from a surficial geological habitat mapping study that was done off the coast of Oregon (Lanier et al., 2007). In this study, the authors use multiple datasets integrated into GIS as the basis of their study. The approach they took in this study was to use two separate but parallel datasets with the plan of eventually merging them for one comprehensive seafloor geological habitat map. The two basic datasets they used were a physiographic dataset and a lithologic dataset which were both created from multiple sets of existing data. Once the two layers were created, a simple GIS intersect created a seafloor geologic habitat map which was used as the basis of the rest of their study. With maps that are created by this multidisciplinary approach to seafloor mapping, better information can be generated for scientists, the public, stakeholders, and policy makers alike (Meidinger et al., 2013). Maps like this can even be integrated into web-GIS to make the data widely viewable.

**Use of AUV for Multibeam SONAR**

As seafloor mapping technology continually improves, new ways of employing multibeam SONAR are coming about. An Automated Underwater Vehicle (AUV) processes outstanding advantages over a standard research vessel to collect seafloor data. Since AUVs operate underwater, external disturbances such as wind and waves are no longer a problem so the underwater robot is more stable than a research vessel. In addition, AUVs can get very close to the sea bottom which will increase the resolution of the data collected. It also takes much less human power to operate an AUV, decreasing the need to use expensive research vessels. There are still ways that the technology can be improved as it is a very complex process to properly attach a multibeam sensor to a AUV. Various ways to improve the application of multibeam sensors on AUVs such as the interface, installation, acoustic synchronization, system error correction, and survey line design are challenges that are being worked on (Ji & Liu, 2015). Once these problems are addressed, multibeam SONAR attached to AUVs and ROVs may be the future of seafloor mapping.

**Future of seafloor mapping**

The use and integration of GIS in remotely sensed seafloor data is still a relatively new and emerging field. Studies done have shown that GIS can be a powerful tool when interpreting spatial seafloor data. Everything from examining the topology of an area to determining the makeup of the seafloor are the results of GIS integration. One of the most useful ways I found GIS to be used in seafloor mapping is by simply making the data easy to read. This is important when passing the data along to a policy maker or a politician so that they can easily make an informed decision regarding protected seafloor habitats. In addition, seafloor mapping resolution continues to be improved allowing scientists to gain a better visualization of local seafloor processes (Roman et al, 2012). As this technology continues to strengthen, more and more of the ocean floor will be revealed. Although multibeam SONAR is used on research vessels most of the time, the implantation of the technology on AUVs and ROVs is starting to increase. The use of this technology on these vehicles can take away many of the problems that scientists are faced with currently by using multibeam on ships. Finally, there are other methods that are being developed in addition to multibeam SONAR, such as Side Scan SONAR,
which are going to continue to push the field of seafloor mapping, and its integration into GIS, to new heights. Although its integration into GIS today can be scarce outside of habitat mapping, the increased technology is showing that it can be integrated into oceanographic studies of almost any discipline.

This paper attempts to show the importance of seafloor mapping in coastal planning needs. The study in this paper focuses on the Long Island Sound. This area of this ocean is critical for many reasons especially towards the residents in the area. This paper shows the significance of a proper understanding of the seafloor in the area. They also discuss how GIS can be used to illustrate this significance. In the end, this paper produces a map using GIS that shows areas that have high and low spatial prioritization in the Long Island Sound. The authors explain the importance of seafloor mapping data to coastal management applications. My research drew upon the knowledge of this paper to point out ways in which seafloor mapping is important. This paper does an excellent job of explaining the importance of seafloor maps and the implications they have. This paper then explains that coastal management studies like this can be applied to many other coastal areas.


This paper addresses several different methods for collecting seafloor mapping data. In addition, it also explains some of the ways seafloor maps can be used for ocean management purposes. The paper starts out by explaining some of the ways that bathymetry, backscatter data, and ground truthing data can be gathered to create seafloor maps. Since this study takes a look at seafloor habitat mapping, it then went on to discuss some of the ways benthic communities can be classified and some of the models that exist for mapping them. This study also explained a little bit about how raster math can be used for some of their models. The use of this paper for me came out of the ways that seafloor data can be mapped. I used this paper to gain an understanding of bathymetry, backscatter, and ground truthing data. This study also provided a lot of maps that I could pull information from. This allowed me to visualize the difference between bathymetry and backscatter and incorporate that difference into my paper.


This paper focused on the potential applications of attaching multibeam sensors to Autonomous Underwater Vehicles. This paper addressed the many issues that traditional research vessels face when trying to collect seafloor data. The authors then went on to explain some of the problems that have been faced when implementing multibeam sensors on AUVs. They then went in depth on each of the issues and provided potential solutions. Using the solutions, they came up with, they did some field testing and acquired some very detailed maps, showing the validity of the techniques they used. This paper was used in my research as a way to show the future direction of seafloor mapping is taking. This paper does a great job

This study implements the use of GIS to map surficial geologic habitats off the coast of Oregon at various different scales. The first thing this study does is to gather many different datasets to create layers in GIS. Using these datasets gathered, they create two different layers in GIS: one of physiographic data and a layer of lithologic data. Using these two layers, they create a map of seafloor geologic habitats that is used for the basis of the study. They then go on to discuss methods that can be used in different scales of mapping and produce several maps at varying scales. This paper was good for my research because it showed how GIS can use seafloor data in a multidisciplinary approach. This paper also demonstrates the importance of using spatial analysis algorithms and GIS tools in interpreting seafloor data.


This paper focused on using cartography as an analytical technique for the management of marine protected areas. This paper started out by explaining how seafloor data can be acquired. It then went on to explain some of the types of maps that can be created using this technology. The paper then went into some of the diagnostic mapping that can be done of the seafloor. For example, the assessment of human activities can be examined using GIS. The paper finished by explaining some of the importance of using GIS in marine management and it explained some of the ways that can it can be shown to the public and policy makers via web maps. This paper was important for my research as a way to show the importance of seafloor maps. This paper did an excellent job explaining the importance of seafloor maps and of the importance on sharing the seafloor maps with the public. The paper also explained the outlook of marine management using GIS.


This was a short paper that looked into some of the ways that high-resolution seafloor mapping has been developed. The authors talked about the development of centimeter level mapping techniques for many different disciplines. It then went over some of the projects that have used high-resolution mapping recently for each of the disciplines it lists. Since this paper talks about the progression of seafloor mapping technology, it was useful for the future of
mapping section of my paper. The resolution of seafloor mapping technology is something that is always being worked on for improvement. This paper shows some of the ways seafloor mapping technology can continually progress. In addition, this paper was useful to see specific examples of seafloor mapping in different disciplines.


In this paper, Innangi et al use multibeam backscatter which is a form of remote sensing to put together a map of the seafloor. First, the authors collected both bathymetry data and backscatter data on a volcanic seafloor. In addition to the map data, they also gather sediments that were used for ground trotting the classifications. Using this data, they developed a raster image of the seafloor. They delineated lines around boundaries of the different sediments on the floor. They then converted that raster image into a vector polygon map which had several areas representing different sediments on the seafloor. This study was great for my research because it demonstrated that seafloor data can be integrated into GIS to make the properties of the seafloor easier to read. This paper also did a good job of explaining the concept of backscatter and how the acoustic signals react differently to different sediments.