Title

Advanced Acoustic Technologies for the Monitoring and Management of Sustainable Fisheries: A Practice Manual

Authors

Rowell, Timothy J
Erisman, Brad E
Cota-Nieto, Juan José
et al.

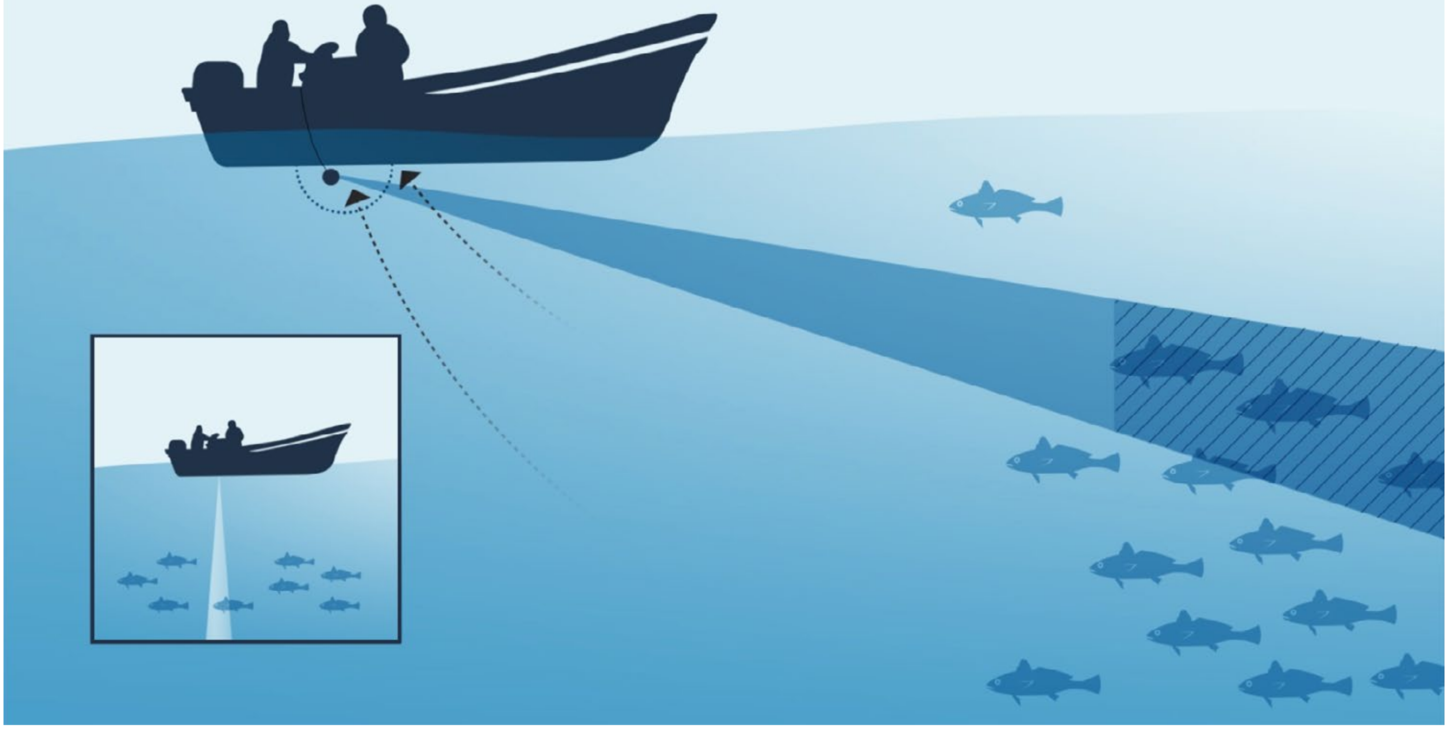
Publication Date

2019-06-02

Advanced Acoustic Technologies

FOR THE MONITORING AND MANAGEMENT OF SUSTAINABLE FISHERIES

A PRACTICAL MANUAL



PRODUCED BY THE GULF OF CALIFORNIA MARINE PROGRAM

Gulf of California
Marine Program

Photo | Octavio Aburto

Introduction

Determining the behavior, spatial distribution, abundance, and biomass of fish populations lies at the center of fisheries monitoring and management. In many environments, it is difficult to observe fishes underwater in their natural state using visual methods. For decades, researchers and managers have tried to overcome this challenge by relying on non-visual methods, such as mark-recapture, fisheries-dependent sampling, and fisheries-independent sampling (e.g. trawls, net surveys) to map fish habitats and distributions as well as estimate their abundances. However, these methods can be invasive, laborious, expensive, and inefficient or ineffective in many fish habitats, ranging from the shallow waters of estuaries to the demersal and pelagic waters of the open ocean. Additionally, these methods are often incapable of collecting data across large spatial scales and studying fish behaviors over long periods of time. Therefore, the ability to locate and count fishes and understand their behaviors effectively and efficiently across many environments and timeframes requires the use of alternative and advanced technologies.

Acoustics is one form of advanced technology that permits fish populations and behaviors to be studied across many environments, spatial scales, and temporal scales. Two types of acoustics that have experienced increases in appeal and use in fisheries science are active acoustics and passive acoustics. Active acoustics uses an echosounder and transducer to emit a beam of sound into the water column. Individual fish and populations of fishes within the acoustic beam are imaged and recorded along with information of their target strengths that can be used to estimate fish sizes and species present, if the acoustic scattering properties of the fish are known. Records of fish targets within the beam can be used to estimate the density, abundance, biomass, and spatial distribution of fish stocks, providing valuable information for fisheries managers. Passive acoustics uses underwater sound recording devices equipped with hydrophones to passively listen to and record the sounds produced by fishes and infer information on their distributions, relative abundances, and behaviors. As passive acoustics relies on the sounds produced by fishes, this acoustic method is only applicable to species that produce sounds and the times, places, and behavioral contexts in which they produce them. When studies and monitoring efforts are properly designed to meet specific objectives, active and passive acoustic methods can be used separately or jointly to better understand the behaviors, spatial distributions, abundances, and biomasses of fish stocks.

The objective of this training manual is to provide a practical background on the use and implementation of active and passive acoustic methods in fisheries science and management. Specifically, this manual will present detailed descriptions of active and passive acoustic methods that can be used by fisheries researchers and managers to understand the behaviors, spatial distributions, habitat use, abundances, and biomasses of targeted fish species. The information provided in this manual will provide a foundation for additional hands on training during field workshops as part of the Gulf of California Marine Program's goal of incorporating acoustic technologies into the management strategy of developing sustainable fisheries in Mexico.

Active Acoustics:

DETECTING FISH AS ACOUSTIC ECHOES

Background

The development of active acoustic techniques for detecting objects underwater largely began during World War I as a means to identify submarines. Shortly after this period of time, it became known that echosounders could be used to identify fish as echoes, prompting the expanded use of echosounders in commercial fisheries to find target species. As echosounders evolved, they remained a valuable technology for commercial fisheries, but they also gained a foothold within the scientific and resource management community, resulting in the development of scientific echosounders for use in the quantitative assessments of fish abundance and biomass.

Active acoustics are now widely used in stock assessments as they detect fish as echoes that can be quantified into estimates of density, abundance, and biomass. Active acoustics are beneficial for resource managers, because they function in deep or shallow waters, are minimally invasive, can survey large regions, and collect large datasets. Researchers and fisheries managements use these methods and resulting data to better assess the spatial distribution of stocks and estimate their biomasses. The resulting statistics can feed directly into stock assessment models or indirectly as an additional source of information on the status of a stock that aids in devising sustainable management strategies and establishing total allowable catches (see Fig. 23).

Equipment, Function, and Configuration

Active acoustic instrumentation consists of an echosounder made up of a computer processor, transceiver, transducer (Fig. 1), and often a GPS unit that will integrate geographic coordinates into the sampling data. Commerically available and widely used echosounders include scientific products marketed by Kongsberg, Simrad, and Biosonics. The computer processor is responsible for controlling the operation of the echosounder, such as pulse rate and power of the acoustic signal, as well as storing collected data. The transceiver generates the electrical source of the signal that will be emitted as an acoustic beam. The electrical signal is then transmitted to the transducer which converts the delivered electrical signal (voltage) to a pulse of sound that propagates in the form of a beam through the water column. Each pulse of sound corresponds to a "ping." Objects within the beam of each pulse, such as fish, zooplankton, or the seafloor, generate echoes with distinct echo strengths that are received by the transducer and communicated to the computer processor via the transceiver. The echosounder operates in this manner continually throughout a survey. The echoes and echo strengths recorded during a survey can be analyzed and enumerated to determine the density, abundance, biomass, and spatial distribution of target species of fish detected within the sampling volume. Moreover, changes in these estimations over time are useful for drawing inferences on fish behavior, such as daily, seasonal, or annual changes in their distributions, migrations, and habitat use.

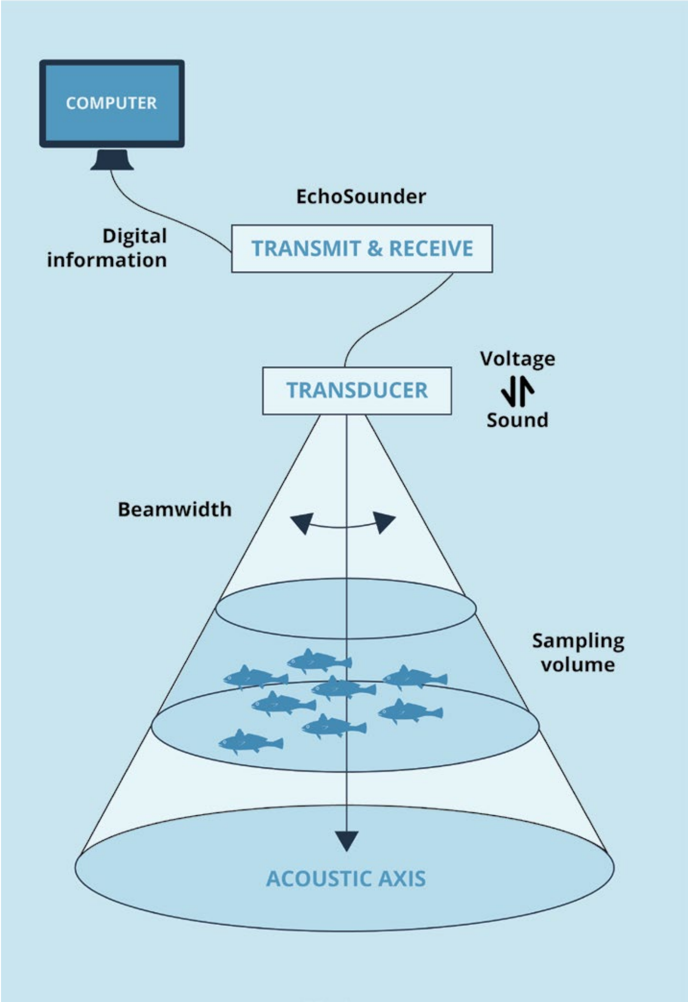


Figure 1. Equipment that makes up a scientific echosounder with their respective functions.

Transducers can be deployed on towed bodies, pole mounts, sonar tubes, and hull mounts to conduct surveys. During surveys, the beam can be directed downward, horizontal, or at a desired angle to meet survey goals and adapt to the survey environment and target species behavior (Fig. 2). In addition to determining the best deployment option and beam orientation, there are a variety of different transducers and configurations that can be used in active acoustic surveys and need to be considered. As previously mentioned, transducers produce pulses of sound that radiate as a beam through the water column. However, depending on the transducer, the frequency, width, and configuration of the beam can vary. Different options are described below.

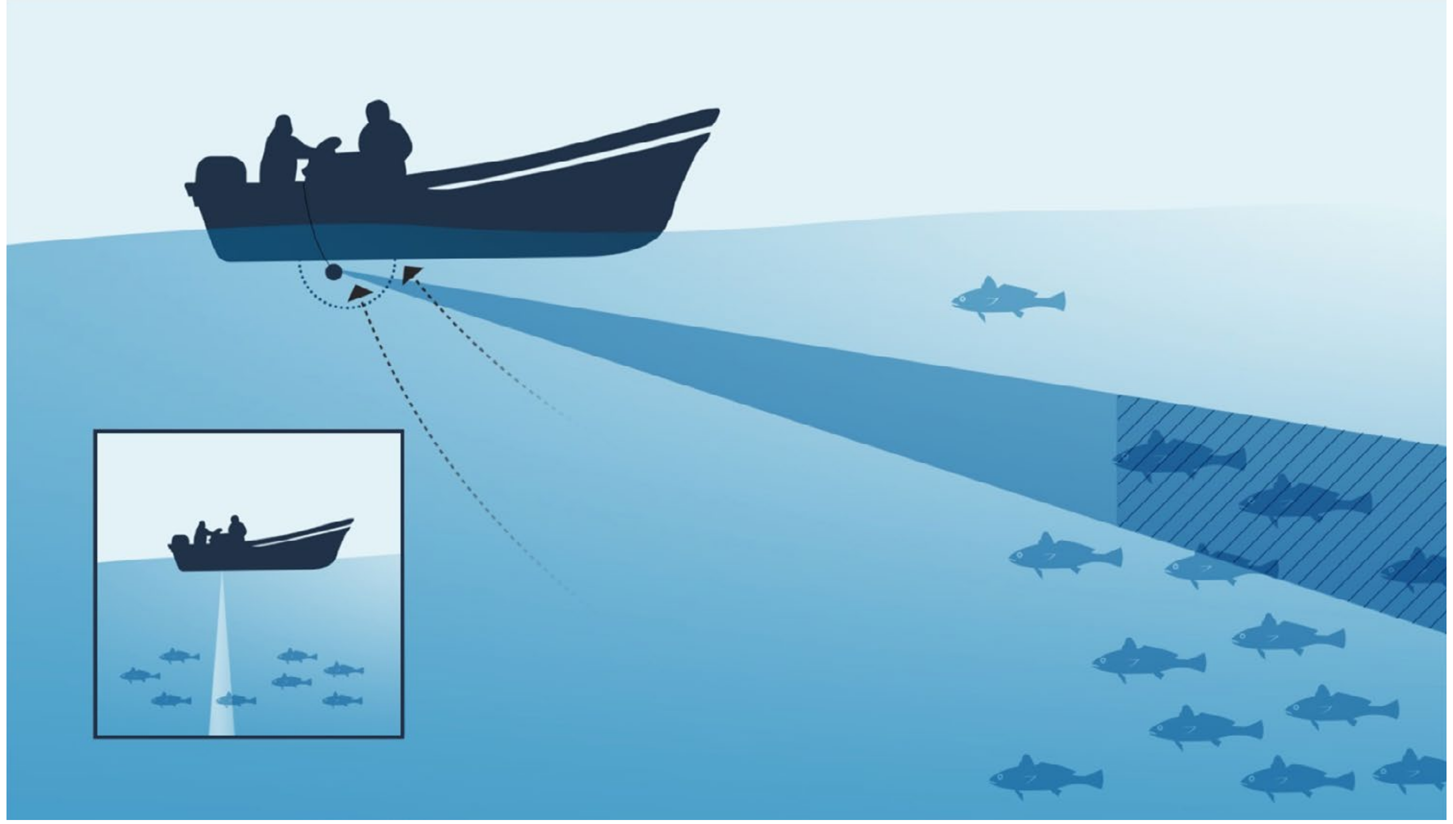


Figure 2. Different beam orientations. The acoustic beam can be oriented downward or horizontally depending on survey goals and challenges.

Most often transducers emit a single acoustic frequency. The acoustic frequencies of transducers used in fisheries acoustics are typically 38, 70, 120, 200, and 420 kHz. When selecting the appropriate transducer frequency there are a few items to consider. First, lower frequencies can travel further, an important consideration for deep water surveys, but due to large wavelengths have a difficult time resolving small fishes and invertebrates. Alternatively, higher frequency transducers can only generate acoustic beams over shorter ranges, but allow for smaller targets to be resolved within the sampling volume. Thus, a balance of desired range and resolution required to meet the objectives of surveys largely dictate the appropriate frequency and transducer. The commonly used transducer frequencies are 120 kHz and 200 kHz for coastal fisheries purposes.

Secondly, transducers used in fisheries acoustic can have a variety of beamwidths and may have conical or elliptical beam patterns. Conical beams have the same beamwidth in all directions and are commonly used in down looking beaming applications. Typical beam widths for conical transducers range from 6° to 12°. Narrower beam widths have a smaller sampling volume but allow for greater horizontal resolution. In contrast, wider beamwidths have a larger sampling volume, an attribute suitable for surveying low density fishes, but decreased resolution. Elliptical beams are often used in shallow water applications, where the transducer beams horizontally during surveys to increase the sampling volume (Fig. 3). Elliptical beams have two beamwidths, a major and a minor. Commonly used elliptical transducers are 4° x 10°.

Lastly, there are three common beam configurations for transducers available for scientific echosounders: single-beam, dual-beam, and split-beam (Fig. 4). Single-beam transducers are only capable of detected the target depth within the beam, thereby limiting the accuracy of the echo strength and target strength measurements. Dual-beam transducers have two beams and provide information on the depth and position relative to the beam axis of echoes detected in the beam, but they cannot identify where exactly a target is within the beam. Split-beam transducers are divided into four quadrants and allow for the position of echoes in the beam to be determined in three dimensions and used to best estimate the target strength of the echo. For fisheries acoustics, split-beam transducers are recommended given their increased capabilities compared to other configurations.

While not included here, multi-beam and side-scan echosounders are also readily available, but currently they are limited to applications of bottom and habitat mapping due to procedural difficulties in enumerating fish in the water column. Efforts to develop methods to use mulit-beam and side-scan sonars for estimates of fish abundance are ongoing, and these technologies may prove effective for fish surveys in the future.

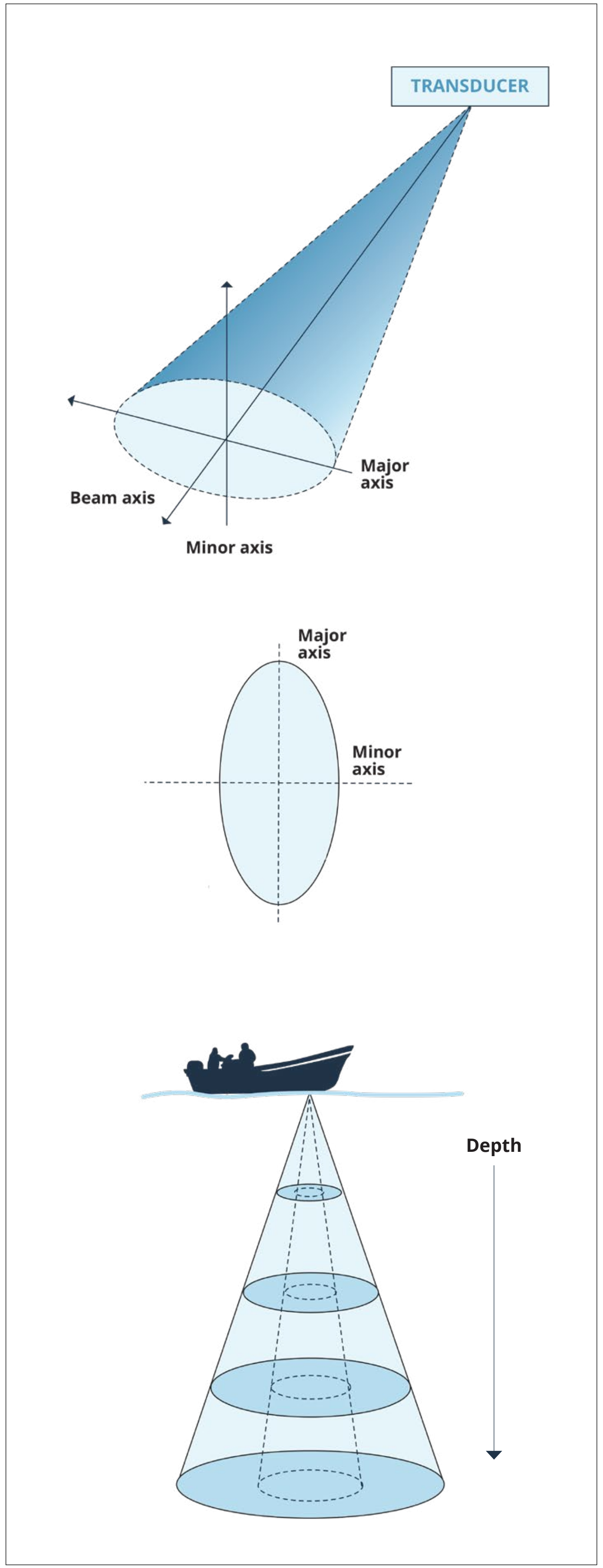


Figure 3. Examples of different transducer beam. Often conical beams are sufficient, but elliptical beam patterns have been found useful for shallow water environments.

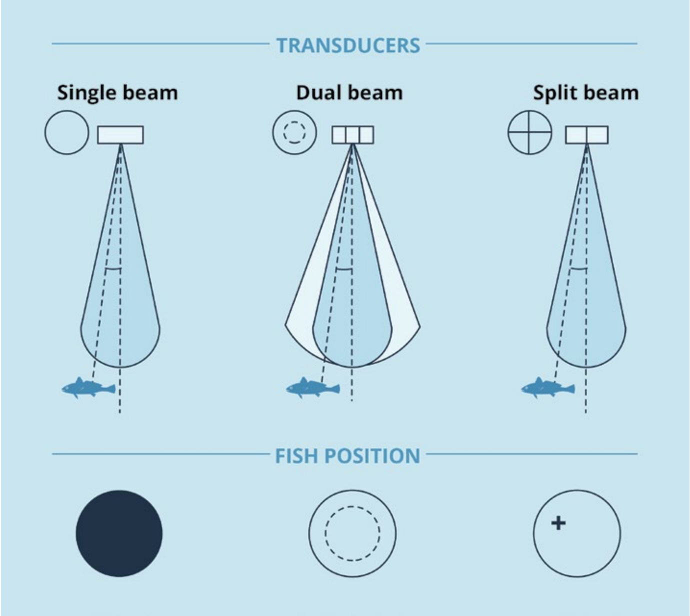


Figure 4. Different types of beams and ability to resolve position of fish with the beam.

Survey Design

Design Considerations

Prior to designing the appropriate survey, the objectives, anticipated location of the work, and target species need to be clearly defined and understood. First, it needs to be decided whether the objective of the survey is to estimate the relative or total abundance of a fish stock, map the spatial distribution of a population, or assess the behavior of a fish species. Secondly, the area in which the survey will be conducted needs to be determined, and challenges, such as currents, water depth, and sea states, need to be identified. After anticipating the area that needs to be covered, the total time required to complete the survey can be estimated and evaluated for feasibility. Lastly, some understanding of the behavior of the target species should be researched. For example, understanding whether the target species is pelagic or demersal, has diel or seasonal changes in habitat use, is largely dispersed or found in high density aggregations are essential pieces of information for designing an appropriate survey. With this information at hand the following survey designs can be considered.

Types of Survey Designs

Common survey designs used in fisheries acoustics include systematic zig-zag transects, fully random parallel transects, stratified sampling with parallel transects, and systematic parallel transects. Each design has benefits and limitations. The figures below (Figs. 5-8) provide descriptions of each survey design, including some benefits and limitations.

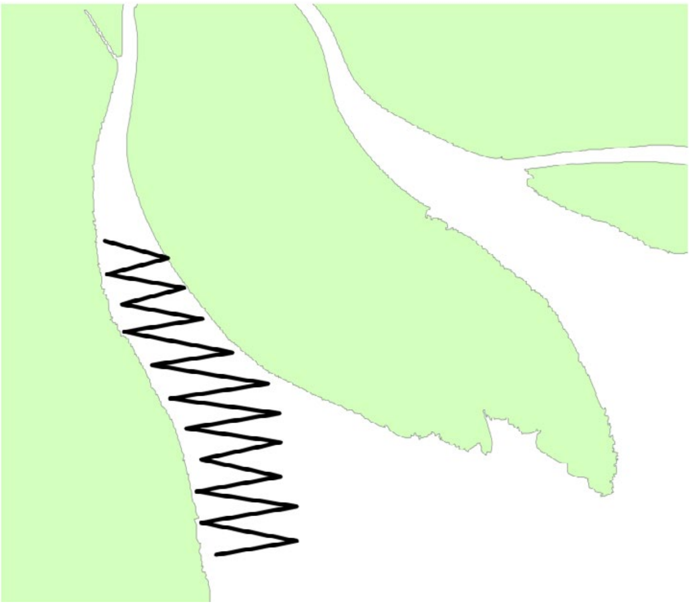


Figure 5. Systematic zig-zag transects. The starting points of each zig and zag are equally spaced. While this design is efficient, the analysis of the data is quite complicated as many statistical assumptions are not met. In most studies, this design is not appropriate.

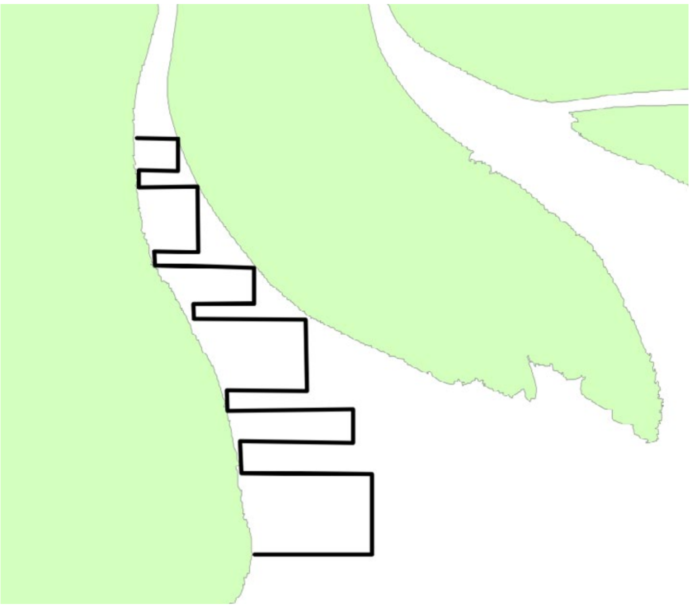


Figure 6. Fully random parallel transects. The starting points of transects are randomly chosen within the survey area. All transects are conducted parallel to each other. This design allows for classical analytical processes, but it does not allow for equal sampling effort across the survey area.

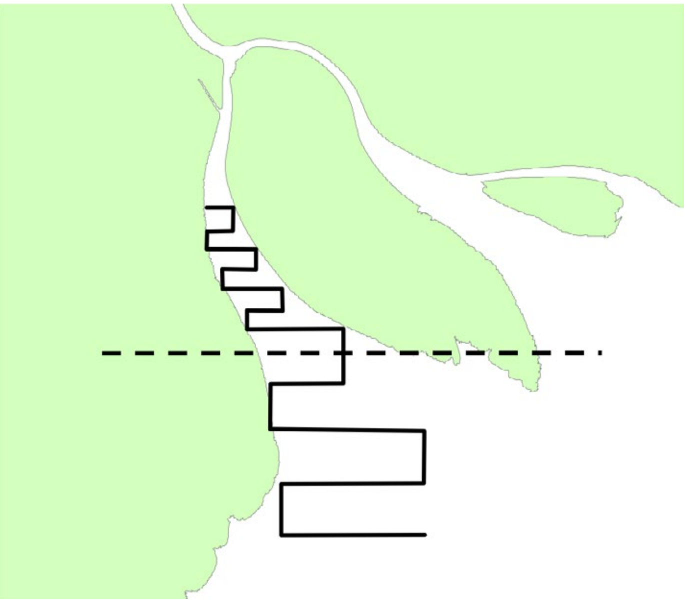


Figure 7. Stratified sampling with parallel transects. Strata (dotted lines) are predetermined based on prior knowledge, such as bathymetry, habitat, etc. Strata need to be determined prior to the survey and data collection. Within each stratum transects are either randomly or systematically positioned. This method allows for some randomization, while allowing for semi-equal sampling coverage throughout the survey area. This method is a good approach if the objective of the study is to survey a large region over a fixed duration but wishes to increase sampling effort in regions where fish are more likely to be encountered.

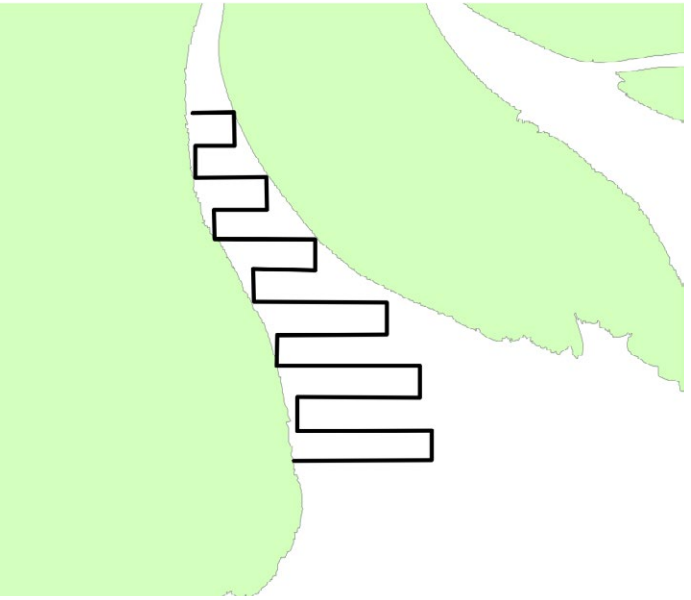


Figure 8. Systematic parallel transects. The starting points are transects are equally spaced within the survey area. All transects are conducted parallel to each other and are equally spaced apart. This design is one of the easiest to conduct and analyze.

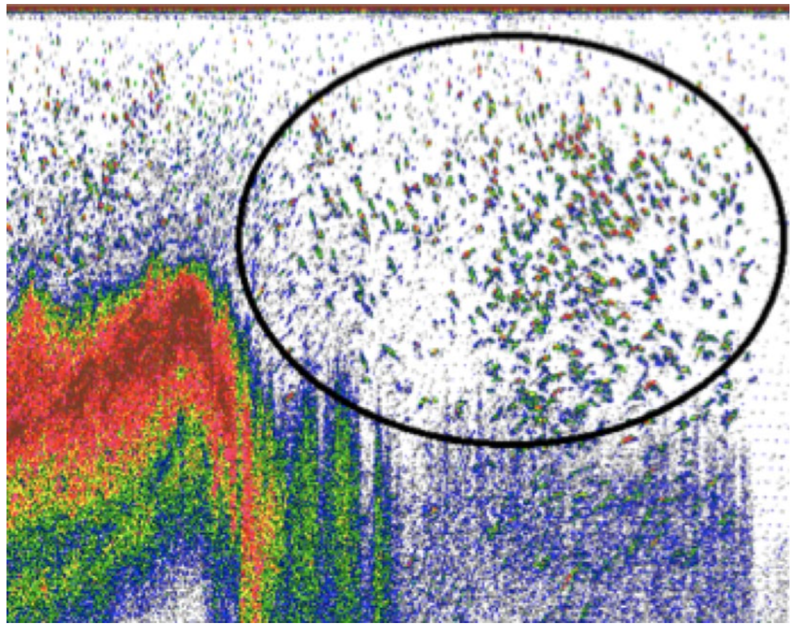


Figure 9. An echogram of active acoustic data collected with a split-beam transducer. Individual fish can be observed within the water column (circled area), while the bottom is seen below the water column. Red signifies the strongest signals; blue are the weakest.

Surveys and Data Acquisition

Calibration

Prior to beginning a survey, the entire echosounder system needs to be calibrated to make sure the system is working properly and to document its parameters. The calibration of a system can change over time and in different environmental conditions. Therefore, routine calibrations are required and recommended. The calibration of echosounders generally follows the standard-target method outlined by Foote et al. 1987 and Demer et al. 2015 that compares measurements recorded by the echosounder to a known standard, usually a metallic sphere such as tungsten carbide. The standard-target method calibrates the echosounder, transducer, and cable and results in a classification of the on-axis sensitivity and beam-pattern. These measurements are used to calibrate the gain parameters of the system and determine the beamwidth and angle-offset values. The calibration process has been thoroughly tested and outlined in a number studies. Further information can be found in Foote et al. 1987 and Demer et al. 2015.

Survey preparation

Once the survey equipment is properly installed onto the survey platform or vessel, a few additional pieces of data need to be collected prior to starting a survey. First, the position of the transducer and depth of the transducer should be measured and recorded to assist with post-survey data processing. Secondly, the ping duration, interval, and rate need to be selected and recorded. Thirdly, the environmental parameters of the survey area need to be measured and recorded. This generally is done with a CTD cast to record temperature and salinity profiles. With all equipment properly installed and these pieces of information recorded into the survey log, surveys can commence.

Surveys and Data Collection

Surveys should start at the time and location designated during planning. The personnel conducting the surveys should ensure that all equipment is working properly prior to collecting data along the survey transects. With all equipment turned on and the echosounder pinging into the water column (transducers should never ping into the air as damage will be incurred), the computer processor should be observed to make sure that data are being generated and can be visualized in an active echogram (Fig. 9). During this time, it is appropriate to determine if there are any issues in the functionality of the system by looking for anomalies in the echogram. As the survey vessel drifts, it is important to make sure that the GPS component of the system is accurately updating the position. Additionally, it is important to make sure that data are being saved to the appropriate directory on the computer processor. With all these safety-checks completed, the survey should begin and follow the survey design until its completion. The speed at which surveys should be conducted will reflect sea conditions, currents, and the objectives of the survey. Throughout the survey the echogram, incoming data, and survey track should be monitored.

Data Analysis

In general, data recorded by echosounders need to be uploaded and processed in a specialized computer software. A number of softwares are commercially available and include Echoview, BioSonics Visual Analyzer, and others. Prior to purchasing a software, the advantages and limitations of each software should be examined based on the objectives of the surveys being conducted. Most softwares offer training workshops or tutorials that are valuable in learning processing techniques for echosounder data.

Fisheries researchers and managers commonly use active acoustics to understand the behaviors, spatial distributions, habitat use, abundances, and biomasses of targeted fish species. Given these objectives, the two most important analytical tools to grasp are:

(1) Identifying the species of interest in the dataset, and

(2) Estimating their densities, abundance, biomass within regions of a dataset or across entire survey areas.

Identifying the species of interest

Fish detected within the acoustic beam will be recorded with information of their echo strength. Specifically, each echo will return a measurement of the acoustic backscattering cross-section and its target strength, both of which are a function of the size, orientation, and the acoustic scattering properties of the fish. The main source of acoustic backscattering cross-section is the swim bladder of fishes. Besides having an understanding of the behavior and habitat use of the species, the target strength of echoes greatly aid in identifying fish of interest and estimating their sizes within the dataset. In general, target strengths increase as a function of fish length (Fig. 10). However, the relationship between target strength and fish length is often species specific and needs to be derived via target strength modeling. With a known target strength range of the species of interest identified, fish targets within that range can be identified. However, assuming that all targets within this range are a single species is often difficult to prove and often require additional evidence of the sources of the targets. Supporting evidence can include net collections or camera footage of the fish assemblage within the survey area.

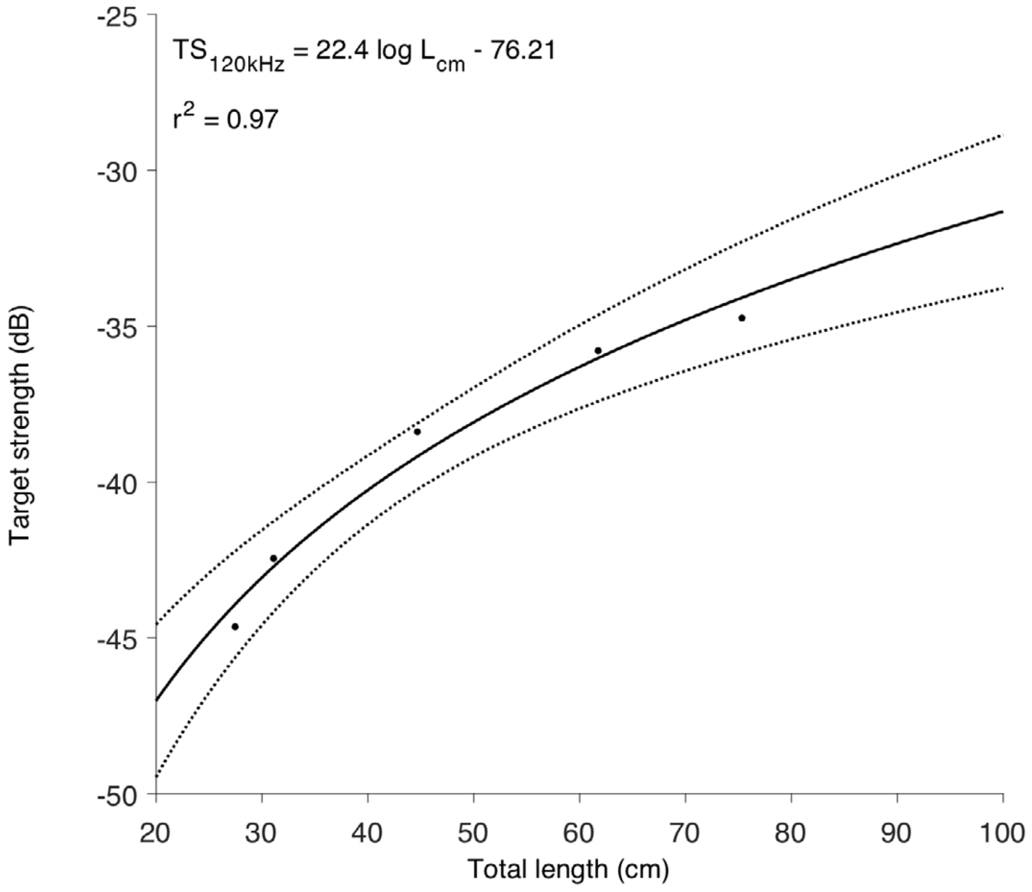


Figure 10. Target strength (TS) vs. fish total length. TS increases as a function of fish length. However, the relationship between the two parameters is often species specific. This plot is an example of the relationship for broadside TS for Gulf Corvina (*Cynoscion othonopterus*) and is not valid for other species or transducer orientations.

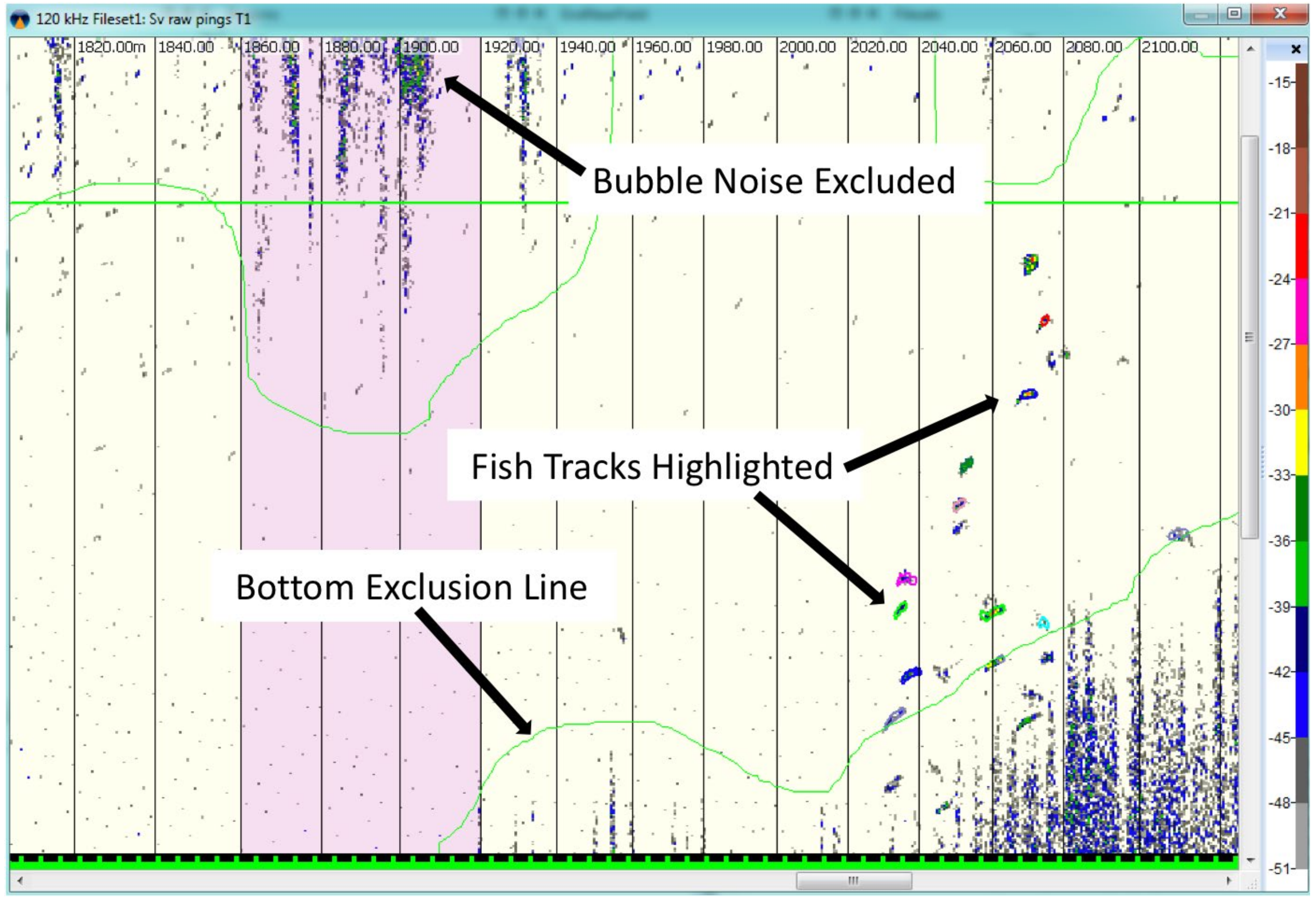


Figure 11. Echogram of volume backscattering strength from data collected with a split-beam transducer. Regions below the seafloor (e.g. bottom) and bubble noise have been identified and removed from the analysis. Individual fish tracks are detected and highlighted to estimate fish density using an echo counting approach.

Estimating density, abundance, and biomass

Once the ability to properly identify the targets of interest has been achieved, further processing is needed to estimates their densities and abundance. Initial steps required include identifying the surface (near field) and sea bottom exclusion zones and areas of unwanted noise, for example electrical or bubble noise (Fig. 11). These regions need to be eliminated from the analysis. This process is usually done while analyzing and viewing an echogram and can be described as “cleaning” the data. Afterwards, algorithms can be used to identify single targets within the survey volume using a series of thresholds and settings pertinent to the species of interest, such as target strength minimum thresholds. At this point in time, it may be appropriate to divide the survey data into regions or bins, depending on the spatial scale estimates are desired and if different species are distributed over different depths or regions.

To estimate the density of fish within selected regions or survey areas, there are two options that are readily used: echo integration and echo counting. Echo integration involves the summation of the backscattering cross-section (σ_{bs}) of all targets over a given sampling volume (v_s in m^3; Fig. 12). This provides an estimate of the volume backscattering coefficient (s_v in m^2/m^3). To estimate the density of individuals within a volume of water, s_v is divided by the mean backscattering cross-section of a single individual ($\langle\sigma_{bs}\rangle$in m^2), yielding an estimate of total number of fish per volume of water (ρ_v in fish/m^3). This estimate of density can then be extrapolated over survey distances or regions and multiplied by total volume of the survey or habitat to provide an estimate of abundance. Similar approaches can be made to estimate fish densities over survey areas instead of volumes (Fig. 12). If area densities are desired, the volume backscattering coefficient (s_v in m^2/m^3) is integrated over a measurement range or depth to estimate the area backscattering coefficient (s_a in m^2/m^2). To estimate the density of individuals within an area of water, s_a is divided by the expected or mean backscattering cross-section of a single individual ($\langle\sigma_{bs}\rangle$in m^2), yielding an estimate of total number of fish per area of water (ρ_a in fish/m^2). Abundances can then be estimated by multiplying by the total area of the survey or habitat.

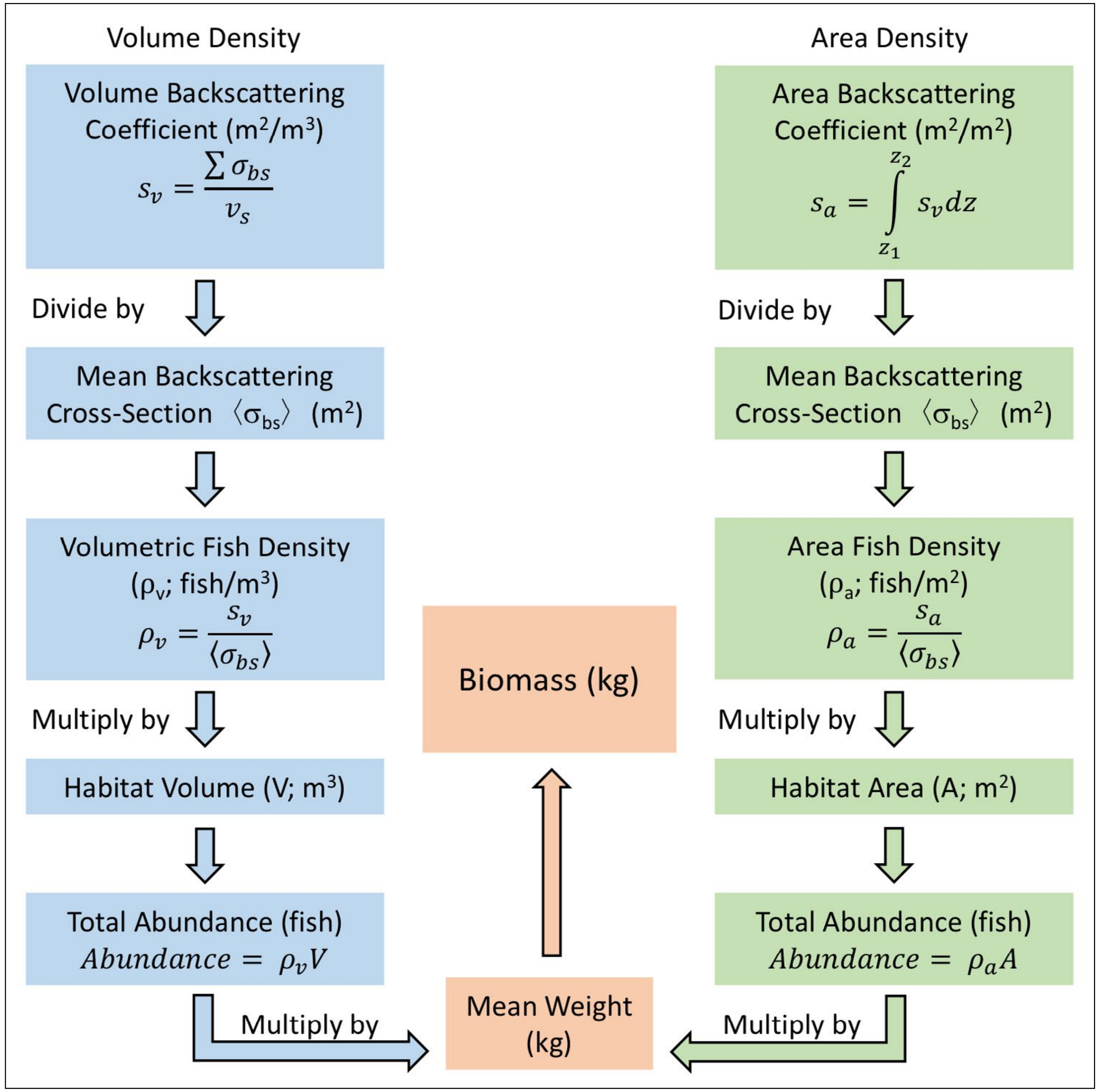


Figure 12. An outline of the process involved in using echo integration methods to estimate fish density, abundance, and biomass. Either volumetric or area densities can be used to estimate abundance and biomass.

A second method to estimate density and abundance is echo counting. Echo counting involves the identification of fish as individual targets or fish tracks followed by their summation (Fig. 11). Echo counting can only be used when fish densities are low enough that their echoes do not overlap and can be identified individually. Thus, this method cannot be used for highly dense aggregations. Fish targets or tracks can be identified using a series of algorithms built into data processing software. To estimate density using echo counting, identified targets or tracks attributable to fish are summed and divided by volume. As with echo integration, this estimate of density can be used to estimate abundance by multiplying density by the volume in which it has been estimated. Echo counting can also be used to estimate area densities by substituting in area terms for volume terms as outlined above in the discussion of echo integration.

Echo integration and echo counting, while different approaches, provide estimates of density and abundance that can be used to map the spatial distribution of fishes (Fig. 13) and estimate biomass. To estimate biomass, the mean weight of fishes surveyed needs to be estimated. This can be down by analyzing target strengths of fish targets within the acoustic dataset or through independent catch surveys. Once a mean weight is known, abundance and its uncertainty can be multiplied by mean weight to estimate biomass.

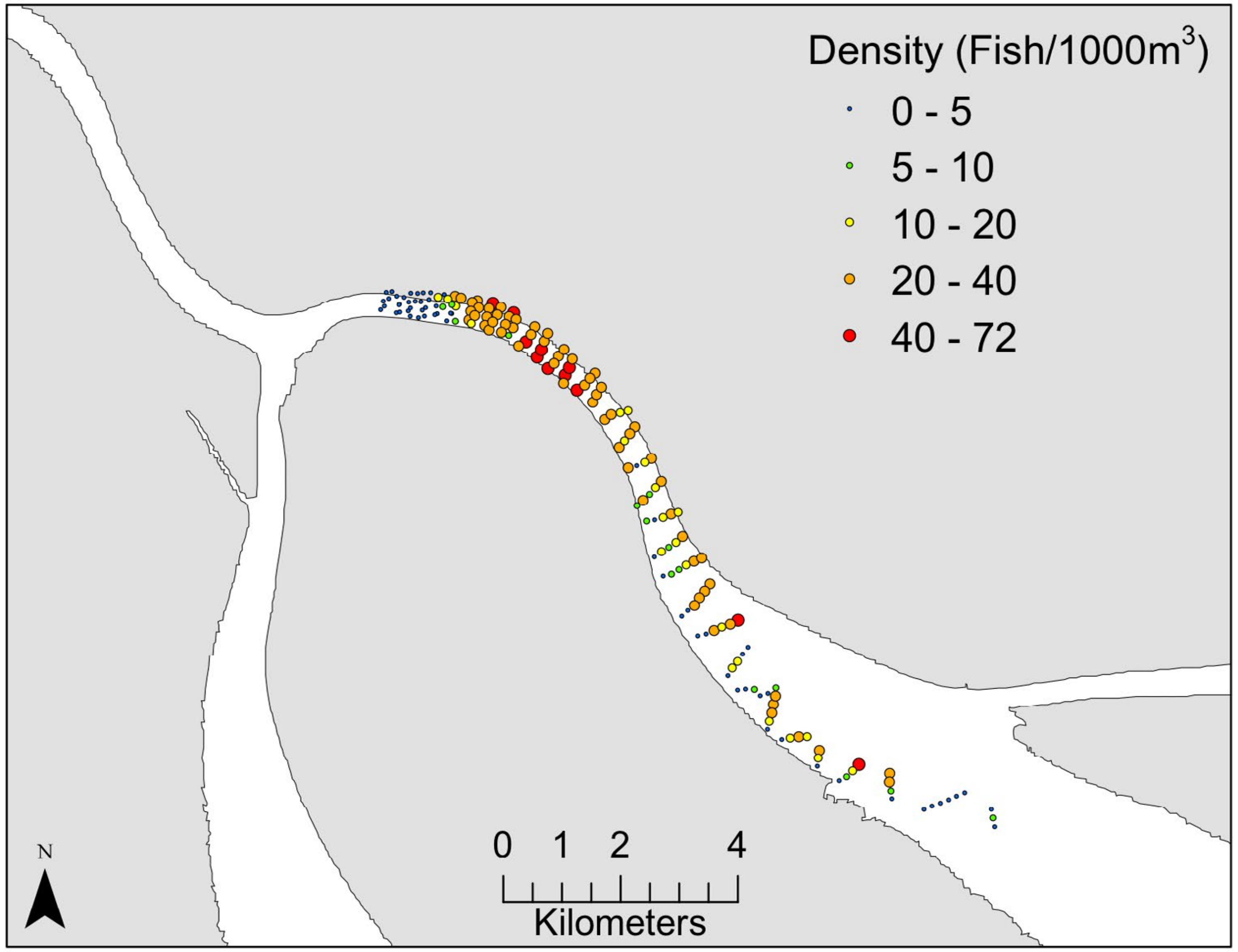


Figure 13. Map of Gulf Corvina densities distributed over their spawning grounds in the Colorado River Delta, Mexico. Densities were estimated using an echo counting approach.

Passive Acoustics:

RECORDING FISH SOUND PRODUCTION

Background

Despite being described by Aristotle over two thousand years ago and likely observed throughout history, sound production by fishes has only recently been the focus of published scientific investigations. Starting in the late 19th century, studies on the mechanisms behind fish sound production emerged, identifying the swim bladder and surrounding musculature as a common source of sound generation in many species. With the development of new recording technologies by the middle of the 20th century, the field of fish bioacoustics greatly expanded with the identification of new species-specific sounds associated with behaviors, such as courtship, spawning, defense, aggression, and feeding. These efforts have continued to the present, resulting in the recognition of sound production in over 100 families of marine fishes.

While fish sound production occurs across a number of behavioral contexts, sounds recorded at fish spawning aggregations (FSAs) that are associated with territoriality, courtship, and spawning can be used to increase our understanding of the reproductive biology of fishes and monitoring of spawning stocks using passive acoustic methods. Observations of fish sound production at FSAs have largely been used to identify the timing and location of spawning and courtship behaviors. Diel increases in sound production around the known time of spawning support the use of long-term, passive acoustic recordings to not only infer spawning seasonality but also temporal windows (e.g. days, hours) in which reproductive behaviors occur, yielding patterns of spawning activity at high resolution for consideration in future scientific, conservation, and management endeavors. For some stocks, spawning periods identified using passive acoustics can be protected, fully or partially, as a strategy to develop sustainable fisheries and populations.

Passive acoustics can also be used to monitor and estimate fish abundance and spatial distributions, especially during reproductive periods. Received sound levels have been used as indices of relative fish abundance at FSAs, where more fish are generally located in regions with louder sound levels during spawning activity. Currently, progress is being made to overcome the difficulties of relating sound levels to absolute fish density and abundance in attempts to develop density estimation models and use passive acoustic methods in population assessments. Previous works have exemplified the potential of using sound levels to estimate density and abundance through comparisons of sound production indices with CPUE of simultaneous trawls, densities of early stage eggs, and relative fish densities estimated with active acoustics and visual census. A recently completed study (Rowell et al. 2017) modeled a predictive relationship between Gulf Corvina (Cynosion othonopterus) density and sound production levels. As progress continues to developing relationships between density and sound levels, passive acoustics will increasingly be used to monitor and quantify populations.

Equipment, Function, and Configuration

The equipment needed to monitor and assess the reproductive activity, spatial distribution, and/or relative abundance of a sound producing species using passive acoustic methods is fundamentally made up of a hydrophone and data acquisition system (e.g. a recorder; Fig. 14). Hydrophones function like a microphone, converting sounds (pressures) produced by fishes underwater into a voltage that can be digitized, amplified, and recorded as files within a data acquisition system or recorder. As passive acoustic systems generate large amounts of data, data acquisition systems often include either a large internal hard drive or memory card, where recordings are written and saved. Files can later be analyzed by listening to the recordings or processing them with computer software.

Passive Acoustic Instrumentation

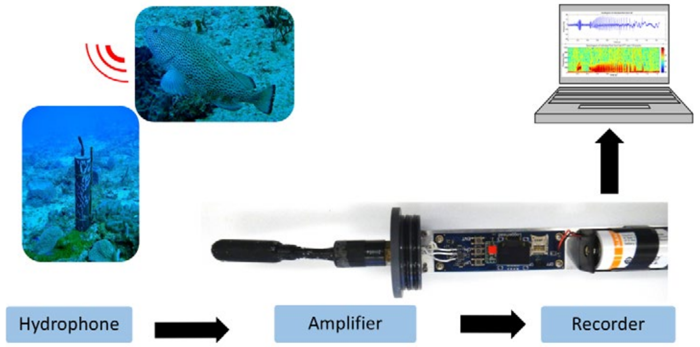


Figure 14. A schematic of a hydrophone and data acquisition system made up of an amplifier and recorder. Files recorded can then be processed and listened to on a computer. In the picture, a self-contained, long-term hydrophone is fixed to the ocean bottom.

Configurations of hydrophones and data acquisition systems vary greatly and can be customized to meet the goals of different studies and efforts. One type of configuration is a portable or mobile configuration, where a hydrophone attached to a cable is connected to a portable recorder that is powered by batteries or a cable connected to a power source (Fig. 15). These types of systems are generally inexpensive but are not waterproof. Therefore, they are most often used when making underwater recordings from a platform such as a boat, shoreline, dock, or pier. However, their portability make them a powerful tool for making short recordings as part of mobile surveys across different areas of interest. Portable hydrophones can be customized and sourced from a number of companies, such as High Tech Inc. Portable data acquisition systems, such as audio recorders or a computer, are also readily available from electronic suppliers. A simple audio recorder, such as those produced by TASCAM, can be used with a hydrophone, assuming the appropriate cable jacks are provided. However, these consumer-grade data acquisition systems need to be calibrated if precise measurements are desired.

Figure 15. Portable hydrophone connected to a recorder. The cabled hydrophone is lowered off the side of the boat to record underwater sound, while the recorder saves the files for future processing. This configuration is appropriate for mobile surveys conducted off a boat.

Another type of configuration consists of self-contained hydrophone, data acquisition systems, and internal batteries (Fig. 16). These closed and complete systems are generally more expensive, but are designed to be waterproof and deployable for long periods of time. Thus, these systems are often deployed at fixed locations for long periods of time, up to 6 months in some circumstances. The ability to record over long durations at a specific site is one benefit of these systems, especially when there are specific locations of interest. Self-contained systems can also be purchased from suppliers such as Loggerhead Instruments (http://www.loggerhead.com) and Ocean Instruments (http://www.oceaninstruments.co.nz).

Figure 16. Self-contained hydrophone being deployed. These combined hydrophone and recorders enable to the collection of sound recordings over long periods of times at fixed locations.

Survey Design

Design Considerations

Surveys of fish sound production are often designed to answer the following questions:

1. What species are making sounds?
2. Where are they making sounds?
3. When are they making sounds?
4. Why are they making sound?
5. How many fish are making sounds?

Depending on which questions would like to be answered and the scope of the study, both temporally and spatially, surveys can be designed to record fish sound production using a mobile or fixed recording methods. Mobile surveys are normally performed using a boat that stops at select locations and makes recordings of ambient sound, often using portable hydrophones and recording devices (Fig. 15). At each stop GPS points or tracks should be recorded to enable future mapping of sound indices. Mobile surveys can cover large areas over short periods of time, but only provide records of sound production over short durations, for example minutes or hours. While mobile surveys are an efficient strategy to locate and map the distribution of sound production and spawning activity for soniferous fishes during discrete time periods, they can be inefficient for collecting acoustic data over long periods of time due to vessel and personnel requirements.

Alternatively, surveys that employ self-contained recorders at fixed locations are efficient at collecting acoustic data over long periods of time at discrete sites. By sampling ambient sound over long periods of time, researchers can gain a better understanding of the long-term patterns of sound production, spawning, and abundance at select locations. Additionally, the occurrence of sounds produced by a known species can be an indicator of their presence and potential site-fidelity, assuming recordings were made during periods when the species is making sound; fish may be present but not calling. However, without the funds to purchase and deploy an array of self-contained recorders, the long-term monitoring of numerous fixed locations is often not economically feasible. Thus, fixed recording locations are usually selected based on pre-existing knowledge of their importance, such as predictable spawning locations. Often these locations can be found via mobile surveys. Depending on the characteristics of selected locations, self-contained recorders can be deployed and secured in a number of manners. They can be attached to mooring lines, sand screws, or weighted platforms (Fig. 16, 17).

Documenting the locations of recorders with accurate GPS points and/or surface-subsurface buoys makes retrieval much easier. Retrieval options include the manual removal of the recorders via SCUBA or the hauling in of mooring line. Acoustic releases can also be used at sites where depth, low visibility, or water currents prevent SCUBA or placement of long mooring lines.

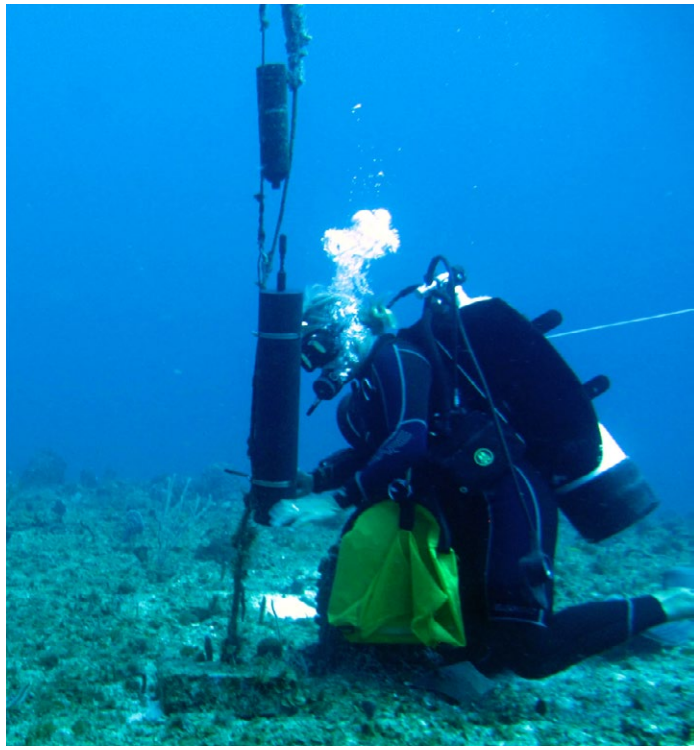


Figure 17. A self-contained hydrophone being deployed on a weighted mooring line.

Data Analysis

Once data are collected, the next step is to download the recording files and begin the analysis. The analysis of acoustic data collected in mobile or fixed surveys of fish sound production varies in degree of complexity. The simplest way to analyze the data is to listen to the acoustic recordings and make note of any sounds of interest. It is often valuable to listen to recordings while visualizing oscillograms and spectrograms of the recordings (Figure 18). Oscillograms are simply a waveform depiction of the recording where the amplitude of the signal indicates the strength (loudness) of the received sound. A spectrogram is a depiction of the frequency components of the recording and sounds recorded. By listening and seeing graphical representations of the recordings, fish sounds can be identified and counted. With knowledge of what different species sound like, counts of sounds produced by different species can be generated to answer what species are making sound and how many sounds are they producing within each recording or a selected time period. For mobile surveys, this information can be used to map out sound production by different species (Fig. 19). For data generated from long-term recorders at fixed locations, time-series can be constructed for different species to identify patterns in sound production, which often are related to patterns in reproductive activity (Fig. 20).

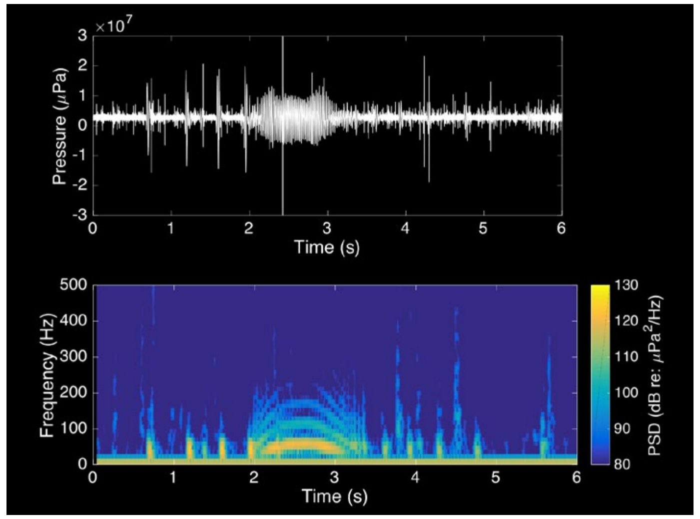


Figure 18. Oscillogram (top) and spectrogram (bottom) of a Gulf Grouper (*Mycteroperca jordani*) call recorded with passive acoustic instrumentation.

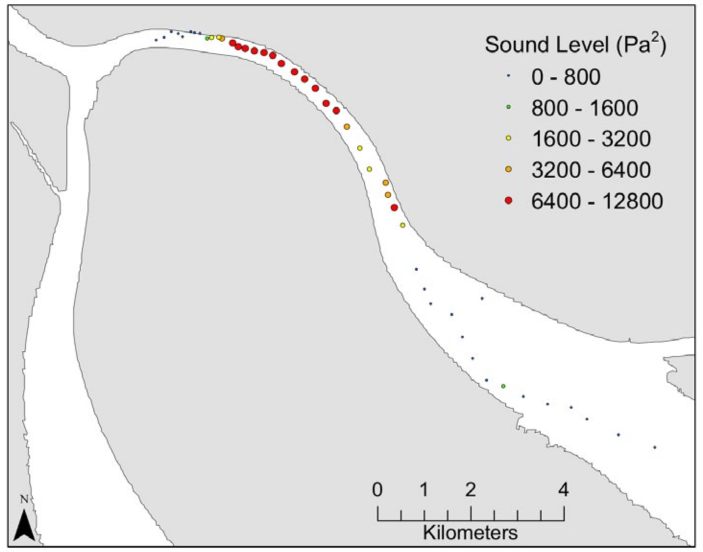


Figure 19. Map of sound levels produced by Gulf Corvina (*Cynoscion othonopterus*) at their spawning grounds in the Colorado River Delta, Mexico. Measurements were made during a mobile survey with a portable hydrophone and recorder.

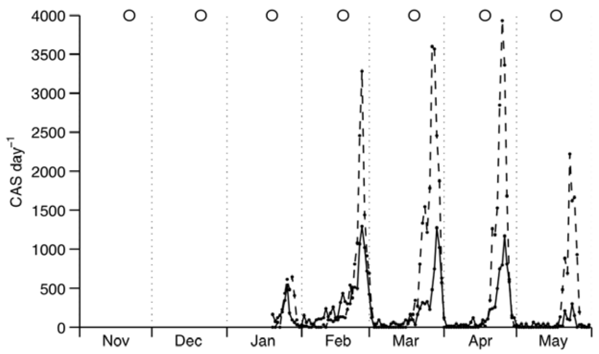


Figure 20. A time series of courtship associated sounds (CAS) per day for two different species of groupers. Recordings were made using a self-contained hydrophone and recorder at a single fixed location. Peaks in sound production and spawning occur after the full moons (open circles) in the months of January thru May (Rowell et al. 2015).

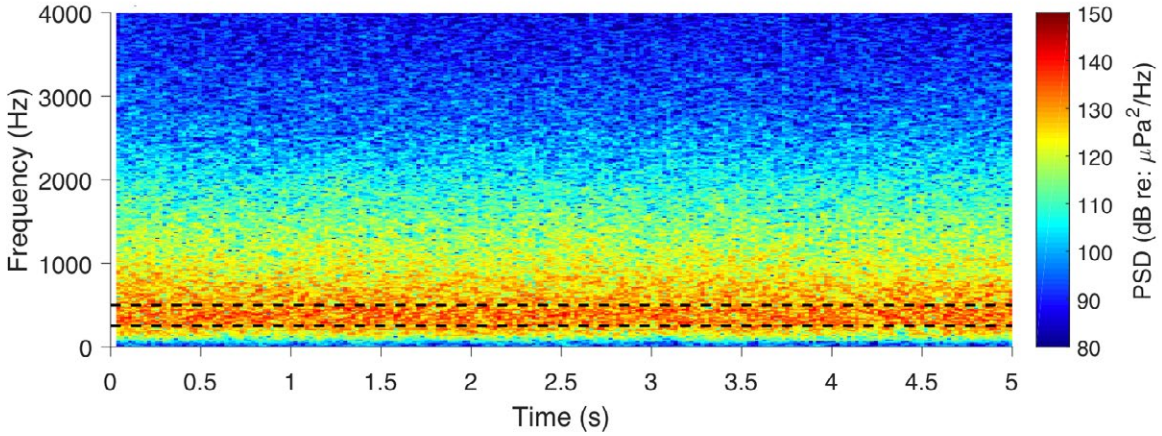


Figure 21. A spectrogram of Gulf Corvina (Cynoscion othonopterus) choruses. The dominant frequencies of chorusing are outlined in the dashed box and can be isolated using a bandpass filter to estimate the sound pressure levels attributable to the species.

Digital signal processing techniques to measure fish sound production are also widely used to process data from mobile and fixed surveys. Data can be analyzed to determine how loud a recording is. This typically is done in a computer software, such as Matlab or R, and results in a measurement of sound pressure level in decibels (dB re 1uPa). This process is an efficient and widely used routine to identify patterns in sound levels at either different regions or times. However, as this is just a measurement of ambient sound and not necessarily fish sound production, recordings are often filtered prior to calculating sound pressure levels to isolate the frequencies over which fish sounds are produced (Fig. 21). By performing a bandpass filter, sound pressure levels over the frequencies of a species' sound can be measured, providing a more representative estimation of sound levels attributable to a specific species. Automatic call detectors can be designed using signal processing techniques to automatically count fish calls in large data sets with an estimated degree of accuracy. However, the use of automatic call detectors is not well developed for fish calls, but future efforts to create and validate detectors are expected and will greatly increase the efficiency of processing passive acoustic data.

Once measurements of fish sound production are made either at different locations or different time periods, results can be interpreted to address some or all of the following questions:

1. What species are making sounds?
2. Where are they making sounds?
3. When are they making sounds?
4. Why are they making sound?
5. How many fish are making sounds?

The proper identification of sound sources to a species is critical for further interpretation of data; the species contributing to call counts or sound pressure levels need to be known through independent studies or from previous documentation. Time-series or measurements at different locations allow investigators to identify where and when species are making calls. Understanding why species are making sounds at different locations or time periods requires an understanding of their biology, ecology, and behavior. Species may make sounds as part of courtship, spawning, territorial, or aggressive behaviors. Observations or succinct measurements, such as egg collections, visual surveys, video recordings, remotely operated vehicle (ROV) footage, and fish collections, can help to expose the behaviors associated with sound production. Lastly, if the behaviors of a species are well known, sound production measurements can be used to infer relative abundance for some species. To estimate absolute abundance from either call counts or sound pressure levels, comparisons of sound levels to independent estimates of density can be made to try to determine if counts and levels are related to actual fish abundance. One powerful method to estimate density is active acoustics. A study that compared fish sound levels and density estimated with active acoustics showed that sound levels can be used to estimate fish density and spawning activity (Fig. 22) if the dynamics of the stock are understood, providing a new fisheries-independent method to assess the abundance of fishes at FSAs .

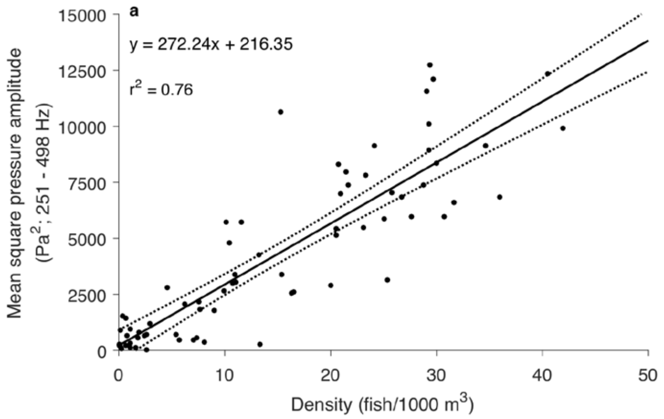


Figure 22. The relationships between sound levels (mean square pressure amplitude) and Gulf Corvina (Cynoscion othonopterus) density (Rowell et al. 2017).

Active and Passive Acoustics:

ROLE IN MANAGEMENT

Active and passive acoustics can be used jointly or separately to generate information that can be used to better understand and quantify the abundance, distribution, and behavior of species over different habitats and how these factors may shift over time or in relation to changes in environmental conditions or fishing pressure. Active acoustics provide direct measurements of stock abundance, biomass, and spatial distribution. Passive acoustics provide measurements that can be used to infer species abundance, behaviors (spawning), and spatial distribution. When combined relationships can be devised to estimate fish abundance from sound levels. The products generated by both acoustic technologies provide valuable information that can be used to supplement other stock assessment methods and feed into precautionary management decisions. As such, the incorporation of acoustic methods and results into fisheries assessment models and management may improve our ability to develop sustainable fisheries and coastal economies.

As one example, Figure 23 (below) illustrates how information generated by active and passive acoustic surveys could be integrated into the monitoring and management of the Gulf Corvina fishery in Mexico. The fishery is currently managed under a quota system, in which the total annual catch (TAC) is determined by a traditional catch model that uses estimates of catch-per-unit effort (CPUE) to estimate stock biomass, maximum sustainable yield (MSY), and maximum economic yield (MEY) from the previous years. This system is very logical, as it capitalizes on the most consistently generated and available data that are heavily monitored each fishing season: catch and effort data. However, the main challenge is that estimation of stock biomass is entirely dependent on the assumption that CPUE is directly proportional to fish abundance. More specifically, it assumes that estimates of CPUE are precise and that fluctuations in the stock size will be detected by changes in CPUE to the same degree. Unfortunately, for species like the Gulf Corvina that form massive spawning aggregations, large declines in stock size may occur without noticeable changes in CPUE. This scenario creates high levels of uncertainty in the estimate of the stock size and the determination of a sustainable quota based solely on CPUE information.

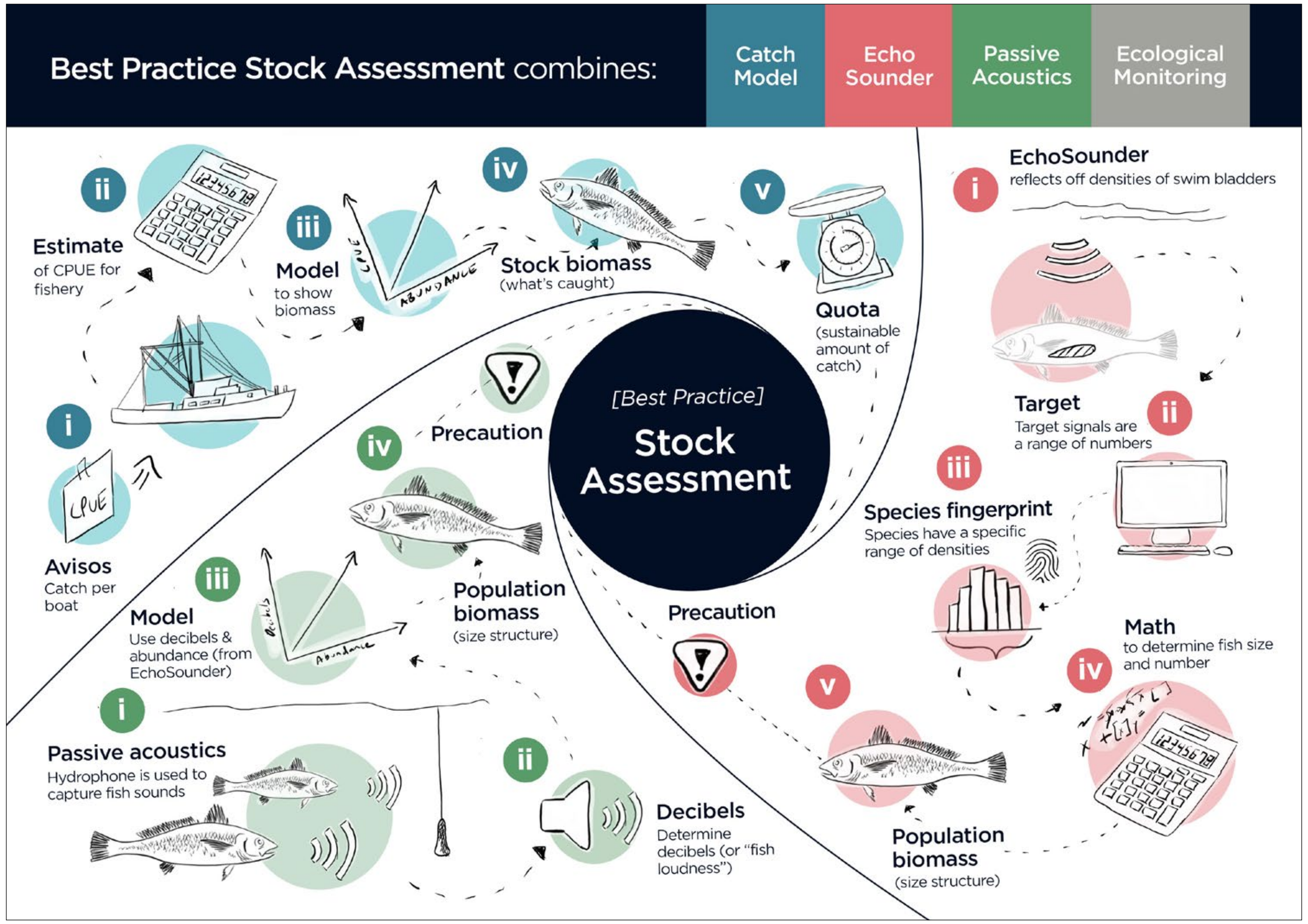


Figure 23. A holistic view of how to incorporate active and passive acoustics into stock assessments.

Fortunately, active and passive acoustic survey data are available for the fishery and can be used in a complimentary manner to increase precision of the current assessment models and insert additional precaution when setting the quota. Active acoustic surveys of the Corvina aggregations during the fishing season can be used to generate independent "snap shots" of the abundance, distribution, density, size distribution and biomass of the stock. By conducting surveys multiple times during a fishing season and across years, it is possible to generate robust, precise estimates to changes in the biomass or condition of the stock and make direct comparisons to estimates generated by the catch model. By doing so, fisheries scientists and managers are equipped with additional information to make small adjustments to the TAC that are more likely to result in the maintenance of sustainable harvest levels. Moreover, since recent work has shown that sound production in Corvina is proportional to changes in fish abundance, and the entire adult population of Corvina migrates to one location to spawn, an array of passive acoustic hydrophones could be set up each year at the spawning (fishing) area as a highly efficient, relatively low cost approach to estimate the total biomass of the stock (Fig. 24).

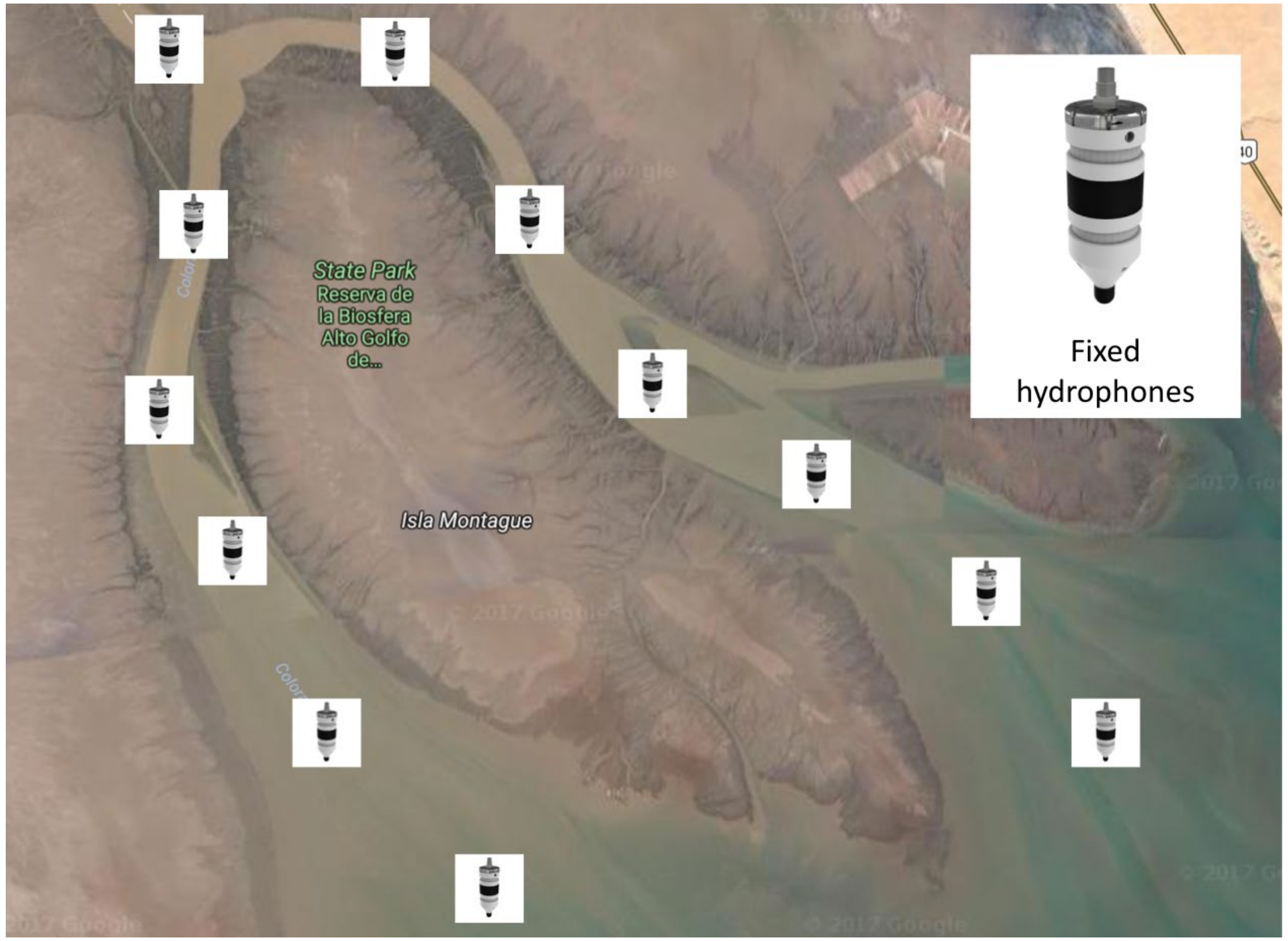


Figure 24. Future arrays of fixed hydrophones can be deployed throughout the spawning grounds of different species, like Gulf Corvina here, to record sounds produced by fishes and estimate their biomasses.

Resources for Further Information

Boswell KM, Wilson MP, Wilson CA (2007) Hydroacoustics as a tool for assessing fish biomass and size distribution associated with discrete shallow water estuarine habitats in Louisiana. *Estuaries and Coasts* 30:607–617

Costa B, Taylor JC, Kracker L, Battista T, Pittman S (2014) Mapping reef fish and the seascape: using acoustics and spatial modeling to guide coastal management. *PLoS ONE* 9:e85555

Demer DA, Zwolinski JP, Byers KA, Cutter GR, Renfree JS, Sessions TS, Macewicz BJ (2012) Prediction and confirmation of seasonal migration of Pacific sardine (Sardinops sagax) in the California Current Ecosystem. *Fishery Bulletin* 110:52–70

Demer DA, et al. (2015) Calibration of Acoustic Instruments. ICES Cooperative Research Report No. 326

Draštík V, Kubečka J (2005) Fish avoidance of acoustic survey boat in shallow waters. *Fisheries Research* 72:219–228

Foote KG, Knudsen FR, Vestnes G, MacLennan DN, Simmonds EJ (1987) Calibration of Acoustic Instruments for Fish Density Estimation: a Practical Guide. ICES Cooperative Research Report No. 144

Gannon DP, Gannon JG (2009) Assessing trends in the density of Atlantic croaker (*Micropogonias undulatus*): a comparison of passive acoustic and trawl methods. *Fishery Bulletin* 108:106–116

Gannon DP (2008) Passive acoustic techniques in fisheries science: a review and prospectus. *Transactions of the American Fisheries* Society 137:638–656

Harley SJ, Myers RA, Field CA (2004) Hierarchical models improve abundance estimates: Spawning biomass of hoki in Cook Strait, New Zealand. *Ecological Applications* 14:1479–1494

Horne JK (2000) Acoustic approaches to remote species identification: a review. *Fisheries Oceanography* 9:356–371

Jolly GM, Hampton I (1990) A Stratified Random Transect Design for Acoustic Surveys of Fish Stocks. Canadian Journal of Fisheries and Aquatic Sciences 47:1282–1291

Kieser R, Mulligan TJ (1984) Analysis of Echo Counting Data: A Model. *Canadian Journal of Fisheries and Aquatic Sciences* 41:451–458

Kubecka J, Wittingerova M (1998) Horizontal beaming as a crucial component of acoustic fish stock assessment in freshwater reservoirs. *Fisheries Research* 35:99–106

Locascio JV, Mann DA (2008) Diel Periodicity of Fish Sound Production in Charlotte Harbor, Florida. *Transactions of the American Fisheries Society* 137:606–615

Locascio JV, Burghart S, Mann DA (2012) Quantitative and temporal relationships of egg production and sound production by black drum *Pogonias cromis*. *Journal of Fish Biology* 81:1175–1191

Luczkovich JJ, Mann DA, Rountree RA (2008) Passive acoustics as a tool in fisheries science. *Transactions of the American Fisheries Society* 137:533–541

Luczkovich JJ, Sprague MW, Johnson SE, Pullinger RC (1999) Delimiting spawning areas of weakfish *Cynoscion regalis* (Family Sciaenidae) in Pamlico Sound, North Carolina using passive hydroacoustic surveys. *Bioacoustics* 10:143–160

MacLennan D (2002) A consistent approach to definitions and symbols in fisheries acoustics. *ICES Journal of Marine Science* 59:365–369

Mann, DA, Hawkins AD, Jech, JM (2008) Active and passive acoustics to locate and study fish In *Fish Bioacoustics* (eds. Webb, J. F., Popper, A. N. & Fay, R. R.) 279-309 (Springer, 2008)

Mann D, Locascio J, Mann D, Nemeth M, Appeldoorn R (2010) Sound production by red hind Epinephelus guttatus in spatially segregated spawning aggregations. *Aquatic Biology* 10:149–154

Mann DA, Locascio JV, Coleman FC, Koenig CC (2009) Goliath grouper *Epinephelus itajara* sound production and movement patterns on aggregation sites. Endangered Species Research 7:229–236

Marques TA, et al. (2013) Estimating animal population density using passive acoustics. *Biological Reviews* 88:287–309

Mok HK, Yu HY, Ueng JP, Wei RC (2009) Characterization of sounds of the blackspotted croaker Protonibea diacanthus (Sciaenidae) and localization of its spawning sites in estuarine coastal waters of Taiwan. *Zoological Studies* 48:325-333

Nelson MD, Koenig CC, Coleman FC, Mann DA (2011) Sound production of red grouper *Epinephelus morio* on the West Florida Shelf. *Aquatic Biology* 12:97–108

Parker-Stetter SL, Rudstam LG, Sullivan PJ, Warner DM (2009) Standard operating procedures for fisheries acoustic surveys in the Great Lakes. *Great Lakes Fishery Commission Special Publication* 09-01

Reid D, Scalabrin C, Petitgas P, Masse J, Aukland R, Carrera P, Georgakarakos S (2000) Standard protocols for the analysis of school based data from echo sounder surveys. *Fisheries Research* 47:125–136

Rountree RA, Gilmore RG, Goudey CA, Hawkins AD, Luczkovich JJ, Mann DA (2006) Listening to Fish. *Fisheries* 31:433–446

Rowell TJ, Demer DA, Aburto-Oropeza O, Jose Cota-Nieto J, Hyde JR, Erisman BE (2017) Estimating fish abundance at spawning aggregations from courtship sound levels. *Scientific Reports* 7:3340

Rowell TJ, Nemeth RS, Schaerer MT, Appeldoorn RS (2015) Fish sound production and acoustic telemetry reveal behaviors and spatial patterns associated with spawning aggregations of two Caribbean groupers. *Marine Ecology Progress Series* 518:239–254

Rowell TJ, Schärer MT, Appeldoorn RS, Nemeth MI, Mann DA, Rivera JA (2012) Sound production as an indicator of red hind density at a spawning aggregation. *Marine Ecology Progress Series* 462:241–250

Schärer MT, Nemeth MI, Mann D, Locascio J, Appeldoorn RS, Rowell TJ (2012) Sound Production and Reproductive Behavior of Yellowfin Grouper, *Mycteroperca venenosa* (Serranidae) at a Spawning Aggregation. *Copeia* 2012:135–144

Schärer MT, Rowell TJ, Nemeth MI, Appeldoorn RS (2012) Sound production associated with reproductive behavior of Nassau grouper *Epinephelus striatus* at spawning aggregations. *Endangered Species Research* 19:29–38

Simmonds EJ (1996) Fisheries and plankton acoustics - Introduction. *ICES Journal of Marine Science* 53:129–129

Simmonds EJ, Armstrong F, Copland PJ (1996) Species identification using wideband backscatter with neural network and discriminant analysis. *ICES Journal of Marine Science* 53:189–195

Simmonds EJ, Fryer RJ (1996) Which are better, random or systematic acoustic surveys? A simulation using North Sea herring as an example. *ICES Journal of Marine Science* 53:39–50

Simmonds J, MacLennan D (2005) *Fisheries Acoustics: Theory and Practice* (eds. Simmonds, J. & MacLennan, D.) 1-437 (Blackwell Science Ltd, 2005).

Širović A, Cutter GR, Butler JL, Demer DA (2009) Rockfish sounds and their potential use for population monitoring in the Southern California Bight. *ICES Journal of Marine Science* 66:981–990 (2009).

Širović A, Demer DA (2009) Sounds of Captive Rockfishes. *Copeia* 2009:502–509

Walters S, Lowerre-Barbieri S, Bickford J, Mann D (2009) Using a passive acoustic survey to identify spotted seatrout spawning sites and associated habitat in Tampa Bay, Florida. *Transactions of the American Fisheries Society 138:88–98*

Wilson LJ, Burrows MT, Hastie GD, Wilson B (2014) Temporal variation and characterization of grunt sounds produced by Atlantic cod *Gadus morhua* and pollack *Pollachius pollachius* during the spawning season. *Journal of Fish Biology* 84:1014–1030

Zwolinski JP, Demer DA, Byers KA, Cutter GR, Renfree JS, Sessions TS, Macewicz BJ (2012) Distributions and abundances of Pacific sardine (Sardinops sagax) and other pelagic fishes in the California Current Ecosystem during spring 2006, 2008, and 2010, estimated from acoustic-trawl surveys. *Fishery Bulletin* 110:110–122

Authorship:

Timothy J. Rowell – Scripps Institution of Oceanography, University of California San Diego, 9500 Gilman Drive, La Jolla, CA, 92093, USA

Brad E. Erisman – Marine Science Institute, The University of Texas at Austin, 750 Channel View Drive, Port Aransas, TX, 78373, USA

Juan José Cota-Nieto – Centro Para la Biodiversidad Marina y Conservación A.C., Calle del Pirata, # 420, Fracción Benito Juárez, La Paz, Baja California Sur, 23090, Mexico

Octavio Aburto-Oropeza – Scripps Institution of Oceanography, University of California San Diego, 9500 Gilman Drive, La Jolla, CA, 92093, USA

Catalina López-Sagástegui – Gulf of California Marine Program, UC MEXUS, University of California Riverside, Riverside, CA, 92521, USA

Illustrations and Graphic Design – Madeline Wukusick, Communiqué; www.communique.design

Citation:

Rowell, T.J., B.E. Erisman, J.J. Cota-Nieto, O. Aburto-Oropeza, C. López-Sagástegui. 2018. Advanced acoustic technologies for the monitoring and management of sustainable fisheries: a practical manual. Gulf of California Marine Program, La Jolla, CA. 20 p.

PRODUCED BY THE GULF OF CALIFORNIA MARINE PROGRAM

Gulf of California
Marine Program