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# A Technical Review on Estimating Biomass of Fishes and Mammals: Non-Acoustic and Acoustic Approaches

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**Abstract:** In marine ecosystem management, estimating biomass of marine species is the most significant challenge to control the ecology and biodiversity of a specified marine area and commercial fishery management. Many top-notch researches have been conducted for estimating the biomass of fishes and mammals. Most of the researches followed mainly two methods namely non-acoustics and acoustics techniques to estimate biomass. The non-acoustic technique is a very old terminology and many environmental conditions are to be considered as constant but in the acoustics method it is a much easier and error can be eliminated by different means of transforms. acoustic techniques can be classified in to two types, i.e., active acoustic techniques, and passive acoustic techniques. In this paper, we have reviewed the major acoustic and non-acoustic techniques for estimating biomass of fish and mammals. At the same time, performance analysis among these techniques has been discussed here. An introduction to the diversity in biomass estimation techniques of fishes and mammals is the aim of our investigation.

**Keywords:** Acoustics Signal, Signal Processing, Fisheries, Aquatics Science, Marine Technology

## 1. Introduction

The term "biomass" signifies the total quantity or weight of organisms in a given area or volume. Biomass of fish and mammals is the key concern to the scientists, ecologists and people engaged with commercial fishery managements. As the term is intimately related to ecological balance, a slight change to it can bring a disaster to our existence. Fishes and mammals are key elements of marine ecology. For millennia, mankind has had a close tie with them because they supply us food and numerous necessities. Millions of people rely on fishing or fish breeding for livelihood. Living with an amazing diversity of fish species, marine mammals form a diverse group of 129 species that has depended on the ocean to survive [1-2].

Over thousands of years, too many fishes and mammals have been taken. Many fishing areas have been over-fished [3-5]. Lack of early knowledge about the population and diversity of species as well as haphazardly fishing can make the ecosystem imbalanced [6-7]. Hence, a proper estimation of their biomass is a mandatory task to maintain the ecological balance. Information about the distribution of a species is a critical component of understanding their ecology and extinction risks and is important for conservation of populations [8]. Not only for ecological purposes but also for commercial reasons an accurate estimation of the biomass of fishes is necessary. Billions of dollar business is conducted daily in numerous fish industries. Most importantly, they supply us our required protein daily as our preferred food. However, it is quite hard to estimate the exact biomass of fishes and mammals in any particular area of the ocean. The dynamics of their population and the harsh condition of the ocean represent the main difficulties in obtaining accurate data. Numerous investigations were carried out to estimate their biomass. We have classified the approaches of these biomass estimation techniques in to two types, i.e., non-acoustic approaches of biomass estimation and acoustic approaches of biomass estimation.

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In the past, most of the techniques used non acoustic methods to estimate biomass. But lately, the researchers emphasize on acoustic methods and currently, copious researches are underway using acoustic methods for estimating biomass. The non-acoustics methods used mainly mechanicals ways to estimate biomass in a certain area. Acoustic techniques of biomass estimation are classified in to two ways, i.e., active acoustic measurement of biomass estimation and passive acoustic measurement of biomass estimation.

Active acoustic techniques use sound generated actively by transducers and the acoustic scattering properties of fish and mammals to image individual fish/mammal and biomass of fish and mammals [9]. Passive acoustic techniques rely on listening to the sounds produced by fish/mammals with a hydrophone to assume their distribution and behavior [9]. For passive acoustic techniques to be useful a fish must make a sound, thus, this technique is limited to species that produce sounds and to the times and places where they produce them. These techniques have typically been used independently, depending on the situation and goals of the study. In this paper, we have investigated the major non-acoustic and acoustic methods for estimating the biomass of fishes and mammals. Firstly, we will review the conventional non acoustic methods of biomass estimation and then we will review active and passive acoustic methods of biomass estimation. Finally, a typical analysis on these three methods, i.e., non-acoustic, active acoustic and passive acoustic methods, will be conducted. However, an introduction with different techniques of conventional biomass estimation as well as recent researches on biomass estimation is the cardinal goal of this paper.

## 2. Non-Acoustic Methods of Biomass Estimation

Different types of non-acoustic methods were investigated in the past. Some of those are: visual sampling techniques, Raft and Floating Radio Frequency Identification (RFID) tag systems, minnow traps, removal method of population estimation, environmental DNA technique, prediction-based macro ecological theory etc. A discussion on major non acoustic methods for biomass estimation is conducted bellow.

### 2.1 Biomass Estimation with Visual Census Techniques

Visual census techniques are mainly used to estimate reef fish biomass [10-13]. It easily collects the data without disturbing inherent with compare with other destructive sampling techniques [14]. Visual census consists of many techniques used to estimate reef fish biomass. Belt transect method was first described by Brock [15], has been adopted by the LTMP to estimate reef fish biomass. In its simplest form, the belt transects method for visual census of fish biomass involves an observer, equipped with SCUBA gear, estimating the biomass of fish within a given area (the belt transect) [15]. A large number of factors, i.e., fish mobility and habitat complexity, etc., affected the estimation procedure [16]. Further errors in biomass estimations are likely to be introduced through observer bias. As a result, any program using more than one observer might ensure that differences in bias between observers were minimized, to allow comparisons of data collected by different observers. The following protocol has been adopted by the LTMP as the standard methodology for undertaking visual census. Strict adherence to this protocol, combined with annual inter-observer training and standardization ensures that the resulting data are of high quality with maximal power to detect change over time [17].

However, at least of three people are required for the collection of visual census data using this technique [14]. One person conducts the surveys, while a second person lies a tape measure along the centre line of each transects. The third person should stay in the boat to give surface support [14]. The impact of observer presence; observer speed; and the impact that multiple surveys had on the number of counted fish in a visual census survey in a typical Mediterranean rocky habitat is illustrated in [18]. However, Willis (2001) found that Visual census underestimated the number of species present and the density of common species by up to 91% [19].

### 2.2 Environmental DNA (eDNA) Technique

It investigates the potential of using meta-bar-coding of environmental DNA (eDNA) obtained directly from seawater samples to account for marine fish biodiversity [20-23]. This eDNA approach has recently been used successfully in freshwater environments, but never in marine settings. It was performed by isolating eDNA from ½-litre seawater samples collected in a temperate marine ecosystem in Denmark. Using next-generation DNA sequencing of PCR amp icons, eDNA was obtained from 15 different fish species where the species rarely or never recorded by conventional monitoring. eDNA was also detected from a rare vagrant species in the area; European pilchard (*Sardina pilchardus)* [21]. To investigate the efficiency of the eDNA approach, a comparison of its performance with 9 methods conventionally used in marine fish surveys was performed. Fig. 1 shows corresponding results from eDNA degradation experiment.

Auspiciously, eDNA covered the fish diversity better than or equal to any of the applied conventional methods. Even small samples of seawater contain eDNA from a wide range of local fish species [20-21]. Although further studies are needed to validate the eDNA approach in varying environmental conditions, these findings provide a proof-of-concept with perspectives for future monitoring of marine biodiversity and resources [20-22]. A challenge in applying eDNA monitoring in flowing waters is that a species' DNA can be transported downstream [24-25]. Deiner & Altermatt (2014) tested for downstream detection of eDNA for two invertebrate species, *Daphnia longispina* and *Unio tumidus* [24].

*Eichmiller et al., (2015) evaluated the* centrifugation and filtration eDNA capture methods and six commercially available DNA extraction kits for their ability to detect and quantify common carp (*Cyprinus carpio*) mitochondrial DNA using quantitative PCR [26]. *On the other hand*, Maruyama et al., (2014) examined the effect of fish developmental stage on eDNA release rate. Smart et al., (2015) claimed that eDNA techniques are more sensitive than traditional techniques [27]. However, this technique can ensure accuracy but suffers from regulation complexity, high-cost and over sensitivity [28]. Since it is a sensitive technique, several regulations must be obeyed during its practical implementation [28].

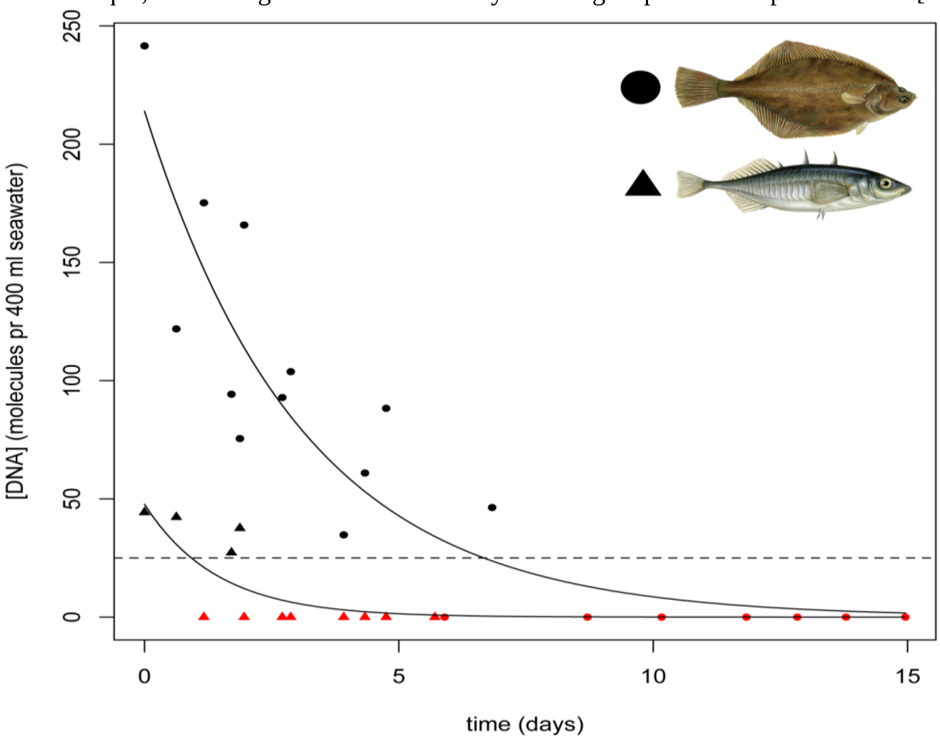



**Fig. 1 - Results from eDNA degradation experiment. eDNA concentration in seawater as a function of time for the two fish species; *Platichthys flesus* (circles) and *Gasterosteus aculeatus* (triangles), investigated in a 50 I aquarium [20].**

## 2.3 Estimation of Fish Biomass using Minnow Traps

The minnow trap is a popular practice to estimate fish biomass [29-31]. Minnow traps are normally consisting of two funnel-shaped entrances at either end of a mesh box or cylinder [29]. Minnow traps are a type of passive sampling gear because they rely on fish to willingly encounter and enter the trap [32]. They can be used to sample freshwater fish in a wide range of environments including lakes, wetlands, rivers and streams. The efficiency and selectivity of minnow traps is influenced by the probability that fish will encounter, enter and be retained within the trap until it is retrieved [33]. Bloom (1976) illustrated an evolution of minnow traps [34]. The size of fish captured in minnow traps is limited by the size of the entrances, which are normally very small (20–30 mm). Minnow traps are regarded as efficient for capturing small freshwater seals when baited unlike gill nets, most fish can be released alive after being captured in minnow traps and predation within the traps is probable to be less than with fyke nets [35]. Because of their small size, minnow traps can also be set amongst complex habitat and in very small and shallow pools of water [30]. The capture efficiency of minnow traps is primarily subjective to the diameter of the trap entrances and mesh size. Minnow traps can also be used to collect relative biomass data based on calculations of catch per unit effort (CPUE). Minnow trap CPUE, as with other passive netting methods, is usually expressed as number of fish caught per net per unit of time (e.g. hours or nights). The accuracy of CPUE as an index of biomass is primarily determined by whether catch efficiency, or catch ability, remains unaffected by other factors. Unvarying catch efficiency is one of the key assumptions made when assessing differences in relative biomass. In practice, a wide range of factors can influence catch efficiency when using minnow nets [36-37]. It is important to take a cautious approach and consider potential differences in catch efficiency when comparing relative abundance data over time and space.

## 2.4 Biomass Estimation from Underwater Video Sequences using Blob Counting and Shape Analysis

A method for biomass estimation from underwater video sequences (UWVS) using blob counting and shape analysis is described in [38-39] of which the system diagram is illustrated in Fig.2. The video sequences were obtained with a moving camera resulting in rapid viewpoint changes thus making it difficult to employ motion detection schemes in extracting fish images from background [38].

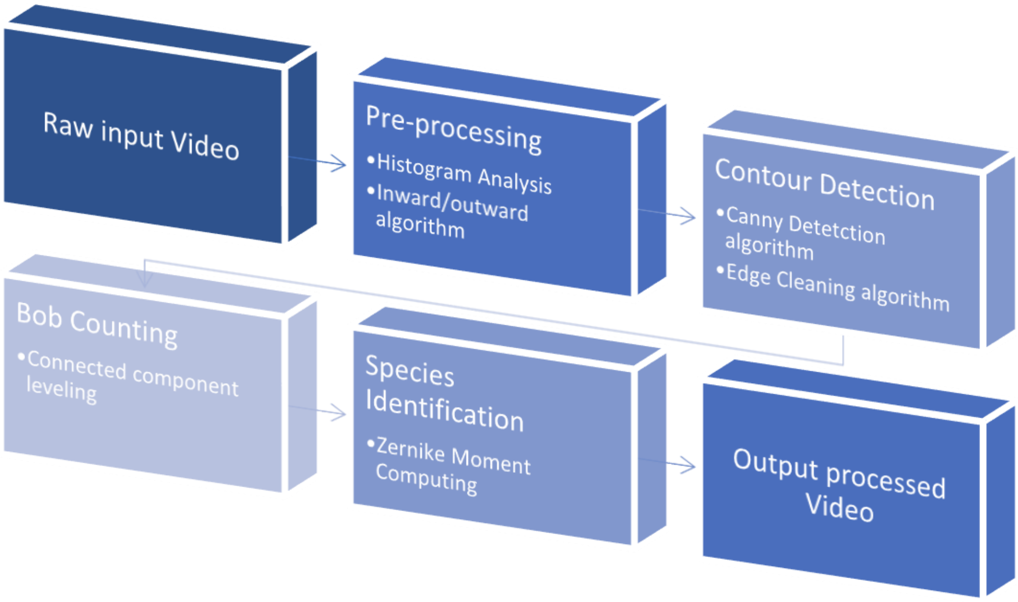



**Fig. 2 – System Flowchart**

Video preprocessing involved blackening out the corals from the underwater videos. This is done in order to effectively estimate fish biomass in the environment, though excluding those that are against a coral background [38]. A histogram comparison to initially blacken out the occlusions using blue and non-blue templates obtained randomly from the UWVS is then applied. An erasure procedure to further aid in removing the coral background for fish detection is then introduced. However, canny edge detection was applied to extract fish contours. After the latter have been delineated, blob counting is then employed in order to compute the fish biomass [38]. In this regard Morais et. al., (2005) emphasize on use of computer vision techniques for underwater visual tracking and counting of fishes in vivo [40]. Boom et al., (2013) presents a research tool that supports marine ecologists' research by allowing analysis of *long-term* and continuous fish monitoring video content [41].

## 2.5 Mark-Recapture Techniques for Biomass Estimation

Mark-recapture data to estimate the biomass of fish has evolved significantly since the adoption

of the single-census method [42-44]. Selecting a suitable model to ease optimal use of the available data is essential. Otis et al., (1978) suggested that the suitable model for biomass estimation is the simplest one, which does not contain assumptions that are not met [45]. The mark-and recapture method is generally favored over the depletion method and has been shown to be unbiased when more than 50% of a population is marked [46]. The mark and recapture method requires the following conditions: (a) Marked and unmarked fish have the same mortality rates; (b) Marked and unmarked fish are equally vulnerable to capture; (c) Marks are retained during the sampling period and all marks on recaptured fish are recognized; (d) Marked fish randomly mix with unmarked fish; (e) There is negligible immigration during the recapture period. Petersen's estimations were obtained using the unbiased estimator suggested previously (for sampling without replacement [46]:

$$N = \frac{(M+1)(C+1)}{(R+1)} - 1 \qquad (1)$$

where, $M$ = number of individuals marked during the tagging period, $C$ = total number of individuals captured during the recapture period, $R$ = number of marked individuals caught during the recapture period.

However, after conducting an investigation on crayfish, Nowwicki et al., (2000) suggested that Taking into consideration higher male catchabilities and sex ratio being invariably 1:1, it also seems beneficial to estimate only male numbers and double them to achieve total population sizes [47].

## 2.6 Removal Method of Fish Population Estimation

The removal method of population estimation has used for estimating small-mammal populations [48-50]. Certain number of kill traps is set for several trapping periods. Three Assumptions are taken for this method of estimation is:

i. The population must be essentially stationary
ii. The probability of capture during a trapping is the same for each animal exposed to capture.
iii. The probability of capture remains constant from trapping to tricking.

In these methods, same number of traps are set over several nights of trapping, following the assumptions listed above, the number caught and removed the first night is greater than the number caught and removed the second night. So we can say that as the population becomes depleted the size of catch will reduce from night to night [48]. There are several ways in which actual observed catches may be treated in order to obtain estimates of the original population size, Hayne (1958) suggested drawing a graph that plots the size of catch during a given trapping against the total number of animals previously captured [51]. A straight line drawn by eye through the plotted points will cut the horizontal axis at a point that represents the estimate of population size. A second method, which fits the line to the points, the method of least squares has been shown by Zippin (1958), proposed a formula, for 2 trappings [48],

$$N = \frac{y_1^2}{y_1 - y_2} \qquad (2)$$

To obtain the proper estimation using (2), *N* is the estimate of population size, $y_1$ and $y_2$ are the numbers of animals captured during the first and second trappings, respectively.

## 2.7 The Two-Catch Methods

The two-catch method is another method to estimate fish population [52-53]. The usual Leslie (or De Lury) estimates of total original populations depend upon a large series of data on catch and fishing effort; each individual unit of fishing effort has, by itself, little effect upon the population and is considered to be independent of the others. The errors are considered to be of the Poisson type and population estimates are usually made by fitting a regression line to data of catch-per-unit-effort plotted against accumulated catch [53]. Where the individual fishing's catch a significant proportion of the population, however, binomial statistics are more appropriate [53]. Let, *n* = the population size to be estimated. The method depends upon the following conditions:

a) Probability is large enough to have a significant effect upon *n*,
b) that Probability is constant, or, in other words, that the fishing effort is the same for the two catches and the fish remaining after the first fishing are as vulnerable to capture as were those that were caught in the first fishing,
c) there is no recruitment, mortality, immigration or emigration between the times of the two fishing's,
d) the first catch is removed from the population or, if returned alive, the individuals are marked so that they can be ignored in counting the second catch. In electrical fishing, it is possible that probability may vary with the size of fish

## 3. Acoustic Techniques of Biomass Estimation

Acoustic techniques of biomass estimation are burgeoning. However, we previously knew that estimation of biomass using acoustics can be categorized in to two types, i.e., active and passive acoustic techniques. A review on active acoustic techniques is illustrated below:

## 3.1 Active Acoustic Techniques

Through the field of fisheries acoustics has its own roots in this history, scientific management and applications of acoustics for biomass estimation was possible after the improvements in computer and electronic technology. Active acoustic techniques generally rely on transmitting sound pulses and receiving echoes. Rallier du Baty (1927) was one of the first to attribute echoes to Atlantic cod (*Gadus morhua*) [54], and Kimura (1929) performed experiments that confirmed fish could be responsible for these echoes [55]. Commercial fishers began using echo sounders to locate many species of fish, and the use of echo sounders revolutionized commercial fishing [56-57].

At first, an electrical impulse from a transmitter is converted into a sound wave by an underwater transducer, called hydrophones. This sound wave is then sent underwater. When the wave hits a fish, it is reflected back and displays size, composition, and shape of the fish. The frequency and the power of the transmitted pulses play the key role here. If we know the speed of the wave in the water, the distance to the fish that reflected the wave can be measured. Generally, the speed of sound through the water column depends on the temperature, pressure and salinity.

This can be calculated from the following equation

$$c = 1404.85 + 4.618T - 0.0523T^2 + 1.25S + 0.017D \qquad (3)$$

where $c$ = sound speed (m/s), $T$ = temperature (degrees Celsius), $S$ = salinity (per mile) and $D$ = depth [58]. In commercial fishery estimation, the typical value of *c* is 1500m/s. Fig. 3 shows a scientific echo sounder.

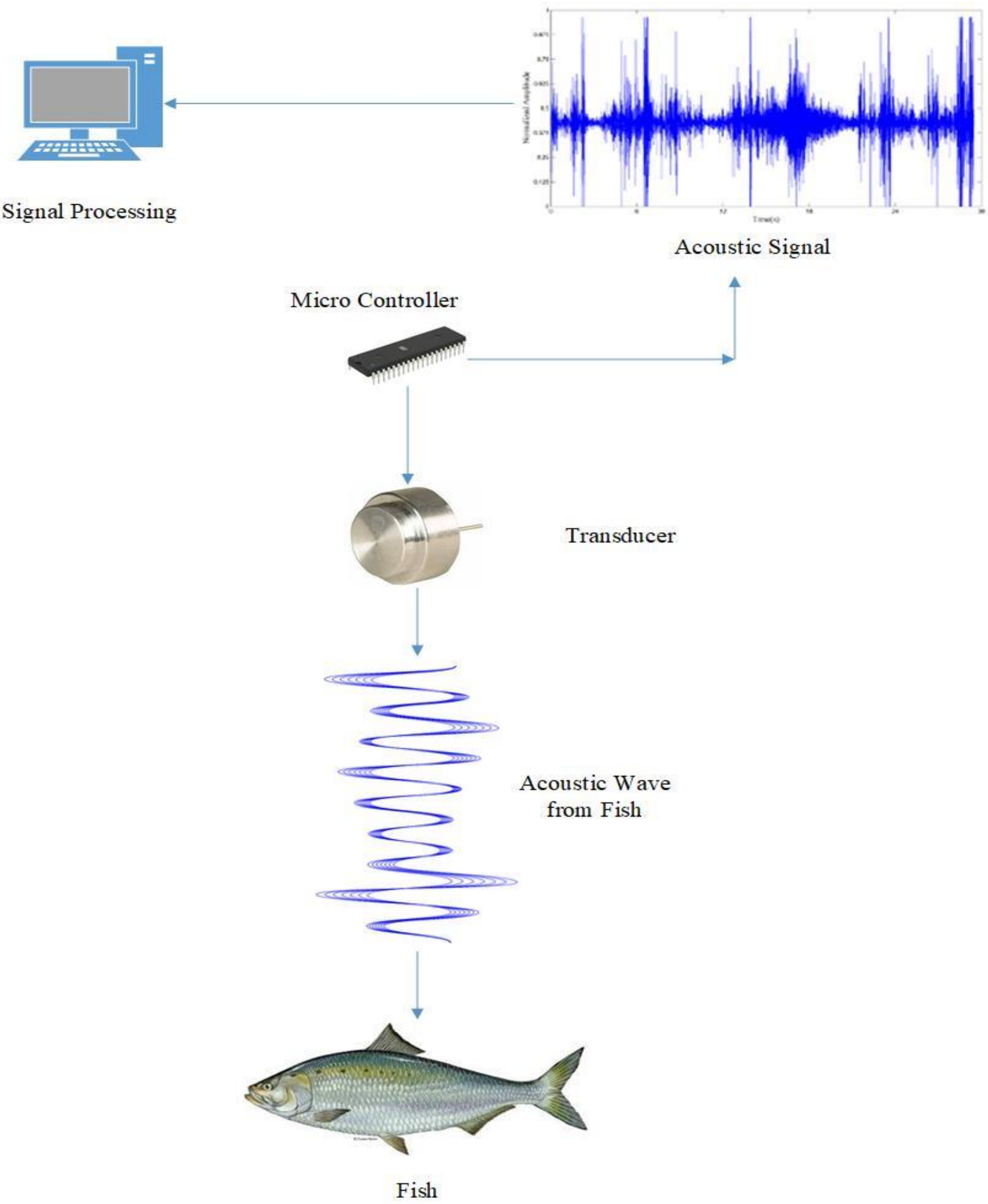



**Fig. 3 - Schematic cartoon showing the major components of a scientific echosounder and acoustic beam**

Generally, the process is repeated up to 40 times per second which results in the bottom of the ocean being displayed versus time. However, it is easier to achieve more detail at screen when the frequency is high. Commercial fishery estimators normally use low-frequency which is in between 50-200 KHz [57]. On the other hand, modern fishery estimators use multiple frequencies to find a split screen result. A review on conventional fish estimation techniques using active acoustic methods is illustrated below.

### 3.1.1 Echo Counting Techniques

Fisheries scientists use active acoustics to estimate fish biomass; evaluate spatial and temporal distributions; and measure size distributions and biomass structure. In addition, these methods can also be used to characterize habitats and study behaviors such as migration, spawning, feeding, and schooling [59]. Scientific echo-sounders operate similarly to commercially available “fish finders” by producing a brief, focused pulse of sound and listening for echoes. When the sound encounters objects that are of different acoustic impedance than the surrounding water, such as fish or the seafloor, some of the sound energy is reflected back to the transducer and translated into a digital output on a monitor (echogram). An echogram can include images of both single objects and groups of objects [60].

Target strength is a measure of how much a fish, plankton, or other object in the water column scatters sound towards a transducer. When individual targets are spaced far enough apart, the number of fish can be estimated by counting the number of individual targets. This is called echo-counting and is the historical way to estimate fisheries biomass [61-65]. However, the pelagic fishes aggregate most often. This makes the echo-counting technique very difficult. To solve the problem, echo integration technique was introduced [66].

### 3.1.2 Echo Integration Technique

To overcome the limitation of echo counting technique, echo integration technique was introduced to estimate biomass [67-70]. Echo-integration uses the total backscattered acoustic energy, divided by a previously determined volume backscattering coefficient in order to estimate fish biomass [71]. An echo-integrator equation relates fish biomass to echo energy integrated over a time gate corresponding to the depth channel of interest. Parameters include the equivalent beam angle, the expected backscattering cross section per fish, equipment sensitivity, and a time-varied-gain correction factor [72]. However, the choice of frequency plays the most important role in this technique [73].

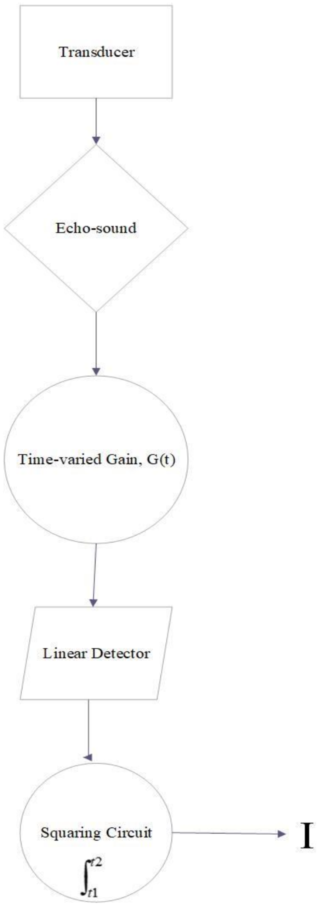



**Fig. 4 – Block diagram of echo integrator**

Fig. 4 shows the block diagram of echo integrator. Generally, Lower frequencies have longer transmission ranges and sampling volumes than higher frequencies. But, higher frequencies have higher resolution. Similarly, higher frequencies are able of detecting smaller targets [74].

### 3.1.3 Dual-frequency Identification Sonar (DIDSON) Techniques

Dual-frequency identification sonar (DIDSON) has been used in environmental management for a decade [75-80]. It was first designed for military purposes [75-76]. In this technique, acoustic camera uses higher frequencies and more sub-beams than common hydro-acoustic tools, which improves image resolution and then enables observation of fish morphology and swimming behavior. The ability to subtract static echoes from echograms and directly measure fish length improve species-identification process. Generally, DIDSON provides an automated fish counting and sizing tool. Han et al., (2009) investigated a fully automated acoustic method to count and size farmed fish during fish transfer by using DIDSON imaging [78]. However, performance analysis of this technique was conducted in several researches [81-83]. Analysis pathways implemented in echo-view is shown in Fig. 5.

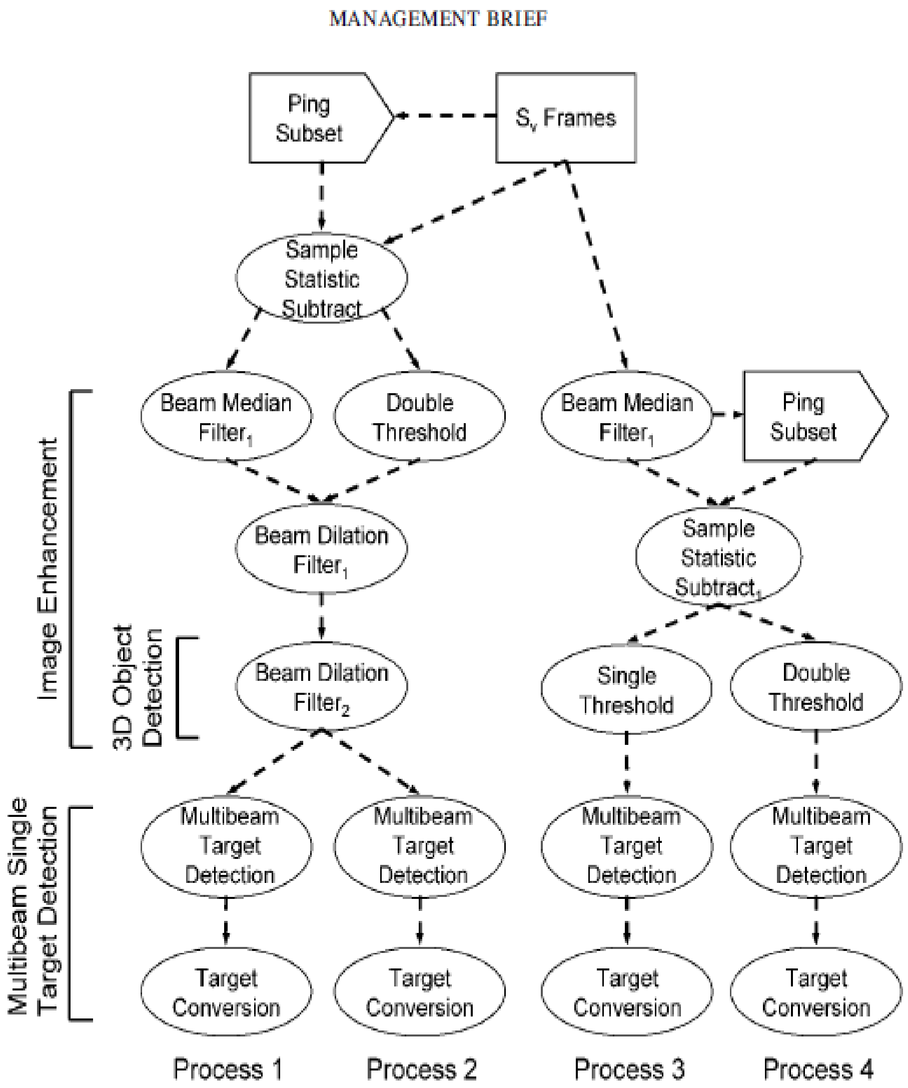



**Fig. 5 - Analysis pathways implemented in echo-view (version 4.1). Four parallel processes are presented that provide similar outcomes even though they are used to optimize analyses under various conditions [75].**

### 3.1.4 Other Techniques

De Rosny and Roux, (2001) proposed technique which is renowned as multiple scattering in a reflecting cavity technique to locate fish biomass [85]. A pulse was transmitted in the tank using a single source; the echoes from the reverberations into the tank were recorded on receivers simultaneously. The recorded echoes have been reverberated by boundaries of the tank, and scattered by fish [85]. For these experiments, the pulses consisted of 50 ms long chirps between 60 and 130 kHz, transmitted every other second. The process is in details in [85]. $\sigma_t$ is estimated from the slope of $R(t)$ in logarithmic domain. From the exponential decay of $R(t)$. From $R(t)$, we easily found the number of fish abundance. This is defined as:

$$R(t) = e^{\frac{-N\sigma_t tc}{v}} \tag{4}$$

Where, $R(t)$ is the total scattering cross section of one fish, N the number of fish in the tank, $V$ the volume of the tank, $c$ the sound speed in water, $\sigma_t$ can be estimated from the exponential decay of the ratio of the measured coherent and incoherent intensities in the tank. However, these techniques need large number of fish to be captured, so these directly affects inhabits of the fish and mammals.

Biomass estimation using analysis of echo peak pdf from single-transducer sonar is described in [86]. However, with numerous advantages, active acoustic methods have some limitations, such as, harming the inhabitation of marine species.

Two active acoustic methods are: backscatter from individual targets, and volume backscatter. When organisms are discrete, it is possible to obtain echoes from individuals. In this case, the method of echo counting can be used to derive a numeric density [no. $m^{-3}$] estimate [87], as well as measure the acoustic backscattering cross-sectional area bs $m^2$ and target strength TS = 10 $\log_{10\ bs}$ dB) of the individuals [88]. Abundance is estimated by multiplying the numeric density by the volume of water in the survey area

### 3.1.5 Echo Sounders

Echo-sounders have progressed from single-beam systems developed after World War II to the multi-frequency [89-92], multi-beam systems in use today [93]. Multi-beam echo-sounders, originally developed for mapping the seafloor, project a fan of narrow sound beams outward into the water and record echoes in each beam [89-92]. This system covers a wide swath at high resolution [91]. Split-beam echo-sounders, operating in a frequency range of 12 to 200 KHz, are the standard equipment for hydro-acoustic fisheries assessments [94-95]. On the other hand, Split-beam echo-sounders receive echoes in four quadrants on the transducer face, allowing the position of the target or the depth and range of a layer to be determined in three dimensions [94-95]. Split-beam echo-sounders can sample to water depths of 100 m to greater than 500 m [96]. Generally, Conventional echo sounders operate at discrete frequencies ranging from 38 to 420 kHz [97]. Horne and Jech, (1999) investigated the applicability and accuracy of length-based population estimates using commercially available acoustic frequencies and the inverse approach under ideal conditions [1]. However, multi frequency echo sounder estimation techniques are quite familiar in this perspective [98-99]. Multi-Frequency System is a dynamic, digital split-beam and single-beam hydro-acoustic system. It is a combination of powerful digital signal processing hardware with a user interface [98].

To overcome different lacking of non-acoustic methods of biomass estimation, fishery research and commercial activities rely on active acoustic techniques. These techniques have potential to overcome mechanical complexities but sometimes suffer from protocol complexities

## 3.2 Passive Acoustic Techniques

Passive acoustic techniques depend on the sounds produced by fish and mammals to eavesdrop on their behavior. Generally, fish acoustics are generated by aggression, courtship, and spawning. The robust study on fish acoustics was firstly introduced by Fish and Mowbray (1970) [100]. To become familiar with passive acoustics methods, one should be familiar with acoustic behaviors in the fish and mammals.

### 3.2.1 Mechanisms of Sound Production among Fishes and Mammals

There is diversity in the mechanisms of sound production among fish and mammals. In some fish species, the swim bladder is used as a sound-generating organ. A muscle attached to the swim bladder (the sonic muscle) contracts and relaxes in a rapid sequence. This action causes the swim bladder to vibrate and produce a low-pitched drumming sound [102]. Another way in which fish produce sounds is by stridulating [102]; a process in which hard body parts like bones or teeth hit each other. Body movements that create water currents or splashes are also used to create sounds for communication [103]. Cavitation sounds are produced during the feeding of the fish with a piece of food. A rapid drop of the pressure inside of the oral cavity can lead to the appearance of small cavitation bubbles. Reduction of their volume occurs for a short time, and it is accompanied by a sound pulse [104].

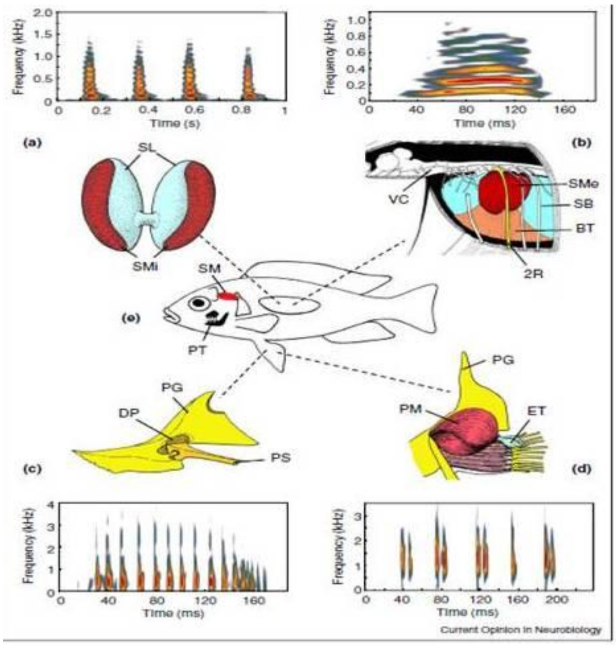
### 3.2.2 Diversity of Acoustic in Fish and Mammals

Vocalizations of different species are different with respect to special parameters like, frequency, amplitude etc. Different sound types are categorized in different names. Some of the common types of sounds are chirps, pops, grunts, growls, hoots, whistles, clicks, etc.

However, croaker kinds of fish produce a sound, which is akin to a chirp signal. Likewise, some species of whale including humpback whales (*Megaptera novaeangliae*) [107], some dolphin species, including bottelnose dolphins [108], some mammals species like dugongs (Dugong dugon) [109] etc. can produce chirp like sound. From a sound analysis of *Plectroglyphidodon lacrymatus* and *Dascyllus aruanus* species of damselfish, it was found that their generated chirps consisted of trains of 12–42 short pulses of three to six cycles, with a duration from 0·6 to 1·27 ms; and the peak frequency varied from 3400 to 4100 Hz [110].

Northern searobin (*Prionotus carolinus*), Southern striped searobin (*P. evolans*) [111-114], Black Sea gurnard [115], etc. can produce cluck like sound. The cluck, generated by Northern searobin (*Prionotus carolinus*) has a frequency range of 40-2400 Hz with duration of 100 ms [111-114].

Japanese gurnard (*Chelidonichthys kumu*) [116], Grey gurnard (*Eutrigla gurnardus*) [117], the oyster toadfish *Opsanus tau* [118-119], gulf toadfish *O. beta* [120-121], *Porichthys notatus* nesting males [122] etc. species can produce a grunt like sound. The haddocks emit grunts lasted less than 75 ms and comprised 3–4 pulses whereas the grunts produced by codfish had durations were typically smaller than 150 ms and consisted of around 9 pulses. Grunts are broadband (up to 3 kHz) pulsed sounds which have a lasting of 300 ms approximately. *Pollimyrus adspersus*, *Cichlasoma* *centrarchu* [123] etc. produce a growl like sound. The growls are broadband (100 Hz – 2 kHz) pulsed sounds, variable in duration, and with the typical pulse repetition rate of 25 pps (pulses per second) [124].



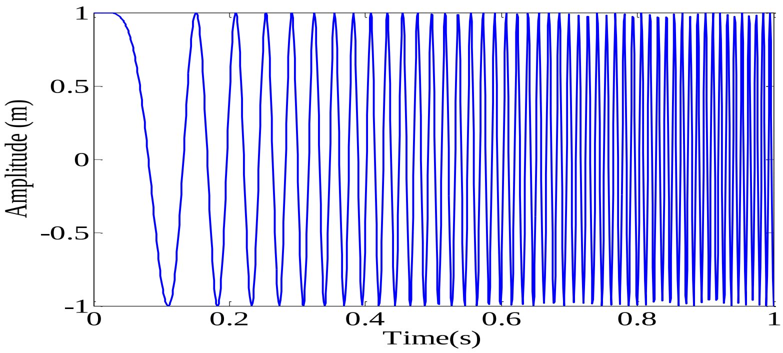

| Acronym | Full Form |
|---|---|
| SMi | Intrinsic Sonic Muscles |
| SL | Swim Bladder Lobes |
| SMe | Extrinsic Sonic Muscles |
| 2R | Second Rib |
| BT | Broad Tendon |
| DP | Dorsal Process |
| PS | Pectoral Spine |
| SG | Shoulder Girdle |
| ETs | Enhanced Pectoral Fin Tendons |
| PT | Pharyngeal Teeth |
| SM | Sonic Muscle |
| VC | Vertebral Column |

**Fig. 6 - Diversity of sound generating mechanisms in fish and sonograms of sounds produced by these mechanisms (a) SMi attached to both SL in the Lusitanian toadfish *Halobatrachus didactylus*, (b) SMe originating at the 2R and inserting on a BT ventrally of the swim bladder in the black piranha *Serrasalmus rhombeus*, (c) in the stridulatory mechanism in catfish a ridged DP of the PS rubs in a groove of the SG, (d) ETs are plucked similar to guitar strings in the croaking gourami Trichopsisvittata, (e) PT stridulation in damselfish, sunfish, among others, and pectoral girdle vibration in sculpins by a SM originating at the skull and inserting at the dorsal part of the pectoral girdle. All sonagrams show sounds produced in agonistic contexts.**

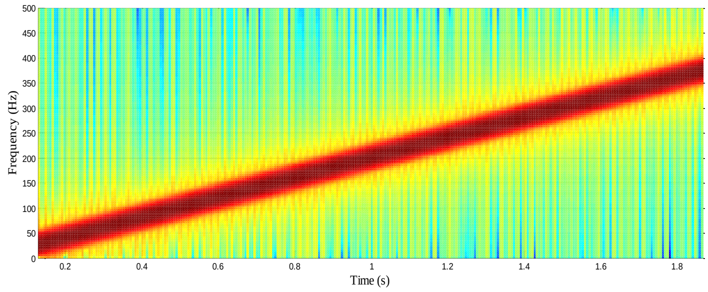
Besides, Hydrodynamic mechanisms of sound production are also prominent ones among fish and mammals. They are called swimming sound also because their origin is connected both with the movement of water against the external surface of the fish and with the movement of internal structures of the fish [105]. On the other hand, the sounds produced by respiratory mechanisms are similar to claps and knocks. Most of the cases, they belong to unspecialized sounds [106]. However, forced flow through a small orifice mechanism, percussion on a substrate mechanism, etc., are also known as major sound producing strategies among fish and mammals. Sonograms of sounds produced by different mechanisms in fishes is shown in Fig. 6.

Hoots and pops are sounds heard exclusively in aggressive interactions. Hoots are made by *P. isidori* [125], *P. ballayi* [126] and *P. adspersus* [127], etc. and are relatively short sounds (30 ms), with frequencies lower than 1 kHz, and made up of nearly sinusoidal waveforms. Pops are made by species of *Chromis* chromis [128], Pollimyrus and by *Gnathonemus petersii* [128] etc., and consist of a series of pulse emissions with focal energies up to 2–3 kHz. Cod (*Gadus morhua*) can produce click like sound with peak frequency 55.95 $\pm$ 2.22 kHz; peak-to-peak duration 50.70 $\pm$ 60.45 ms [129-130]. Beluga (*Delphinapterus leucas*), bottlenose dolphin (*Tursiops truncatus*) [131], Sperm whale [132], etc. fish and mammals can produce similar sound-signal. Whistle is common among the Killer whale (*Orcinus orca*) [133], some species of dolphin like (*tursiops truncatus)* [134] and various species of mammals.

Fig. 7 shows simulated form of fish chirp signal where (a) represents a simple form of chirp with duration of 1s and (b) represents a chirp with linear instantaneous frequency deviation where the chirp is sampled at 1 KHz for 2 seconds. The instantaneous frequency is 0 at t = 0 and crosses 200 Hz at t = 1 second.

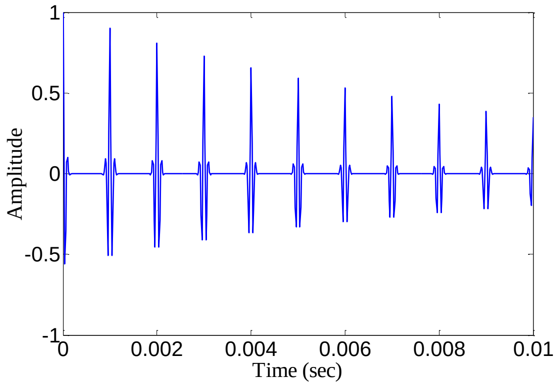



(a)

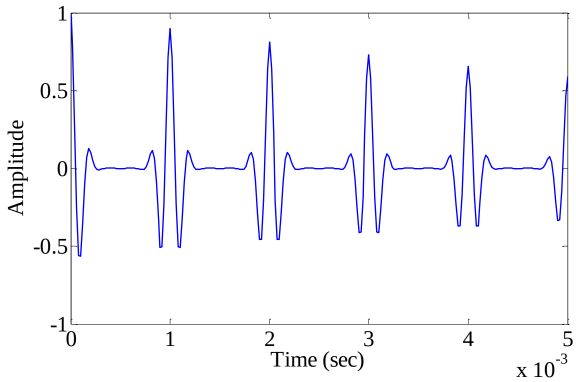



(b)

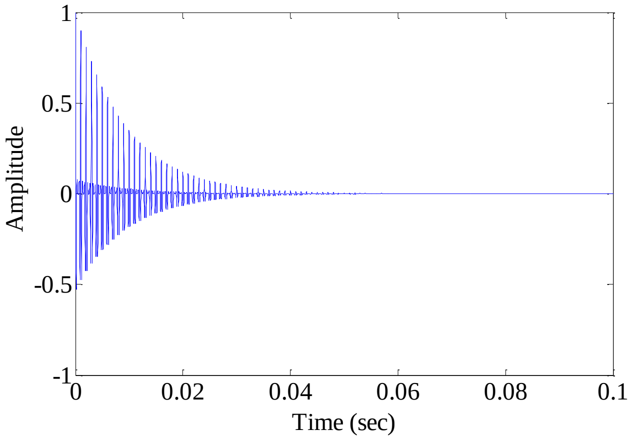
**Fig. 7 - Chirp signal from simulation, (a) a simple simulated form and (b) spectrogram of chirp with linear instantaneous frequency deviation.**




(a)




(b)




(c)

**Fig. 8 - Pulse train representation of acoustics of fish and mammals (a)10 KHz fish signal with 10 ms duration and (b) 5 KHz fish signal with 5 ms duration (c) 3 KHz. Fish signal with 100 ms duration.**

In Figs. 8(a), 8(b) and 8(c), the pulse repetition frequency is 1 KHz; sample rate is 50 KHz and the repetition amplitude should attenuate by 0.9 each time. Figs. 8 (a) and 8(b) has 80% bandwidth and Fig. 8 (c) has 90% bandwidth.

### 3.2.3 Different Algorithms used in Passive Acoustic Technique

Passive acoustic technique is a rising area in the ecological research. Estimation of fish biomass using passive acoustics technique is upgrading lately. From the discussion above, we can understand that different fish and mammals produce detectable sounds. In passive acoustic techniques, the fish acoustics are recorded by hydrophones (sometimes called acoustic sensors) and implement different algorithms to estimate biomass. Such algorithms are illustrated in [135-138].

Important aspects to choose an algorithm are structure of signal, variation of sounds in that particular area, nature of that sound, etc. By using hydrophone, different surveys were conducted to know the number, location, and inhabitation of fishes [139-142]. Rodney et al., (2006) investigated several developments in the study of passive acoustic measures [143]. In this addition, Luczkovich et al., (1999) conducted nocturnal hydrophone surveys at 12 locations in Pamlico Sound in May of 1996 and 1997 [144]. They found that passive hydroacoustic surveys can be used to delimit spawning areas for conservation and management purposes. Luczkovich et al., (1999) investigated prey behaviors with respect to predators by using passive acoustic techniques [145]. Gannon (2008) reviews passive acoustics in fisheries [146]. Van Parijs *et al*. (2009) present an overview of research and management applications of passive acoustics at sea [147]. Blumstein *et al*. (2011) assess the potential of acoustic monitoring in terrestrial habitats, noting its possible application for abundance estimation [148]. However, canonical density estimator for estimation of biomass is illustrated in [149-150]. A canonical density estimator equation for passive acoustic surveys can be written [150]:

$$D = \frac{n(1-f)}{par} \tag{5}$$

where $n$ is the number of detected 'objects' (vocalizations, groups, etc.), $f$ is the proportion of detections that are false positives, $p$ is the probability of detecting an object within the area $a$, and $r$ represents the multiplier(s) that converts object density to biomass.

Moretti *et al*. (2010) investigated a method which is based on counting dives of Blainville's beaked whale (*Mesoplodon densirostris*) to estimate their biomass at the Tongue of the Ocean, Bahamas, using 82 bottom-mounted hydrophones [151]. However, von Benda-Beckmann *et al*. (2010) improved a towed system for beaked whale detection [152]. Similarly, Li *et al*. (2009) suggest that their acoustic system could be used to estimate freshwater cetacean densities using nearly similar method as described by Benda-Beckmann *et al*. (2010) [153]. George *et al*. (2004) investigated a procedure in which acoustic detections were used to estimate the proportion of whales available for detection by visual observers [154]. Marques *et al*. (2011) presented an example of standard point transect sampling, in particular a cue-counting approach, to estimate right whale *Eubalaena japonica* density in the Bering Sea [155]. Given $n_u$ detected right whale calls in $T$ hours, animal density was estimated by

$$D = \frac{n_u(1-f_p)}{a_c PTr} \tag{6}$$

Where $a_c$ is the size of the covered area, $r$ the estimated call rate (in calls per hour), $P$ the estimated detection probability of a call produced within area $a_c$, and $f_p$ the estimated proportion of false positives (assumed to be zero in their example). Note that $n_u(1\text{-}f_p)/Tr$ corresponds to $n$ in equation (2), i.e. the number of detected calls must be 'corrected' to represent the biomass [155]. Sometimes, individual identification was also investigated by capturing acoustics, stated in [156]. This approach can be analogous with conventional mark recapture techniques.

Borchers and Efford (2008) capture–recapture models that use the capture locations to estimate animal locations and spatially referenced capture probability [157]. If the same sounds are detected at sensors array then Spatially explicit capture-recapture (SECR) technique has been applied. Marques et al. (2012) considered SECR to estimate the biomass of mink whales (Balaenoptera acutorostrata) [158]. McCauley & Jenner (2010) estimated the biomass of pygmy blue whales (Balaenoptera musculus brevicauda) using calibration technique described in [159]. Similarly, U.S. Navy SOSUS arrays of sensors, which were designed for military purposes, can be used to detect marine species that produce low frequency sounds [160-161]. However, to implement a passive acoustic technique, the most important task is to deploy a passive acoustic system. Fixed passive acoustic systems are elaborately described in [162]. Most autonomous sound recorders of the passive acoustic systems are developed by navy and different private companies [163-165].

A typical scenario of passive acoustic system is illustrated in Fig. 9. Normally, these systems are effectively deployed on boat or sometimes under the ocean to record not only bioacoustics but also ambient noise or surrounding information [166]. However, a typical passive acoustic technique procedure is described below which is known as cross-correlation based biomass estimation technique [167-168].

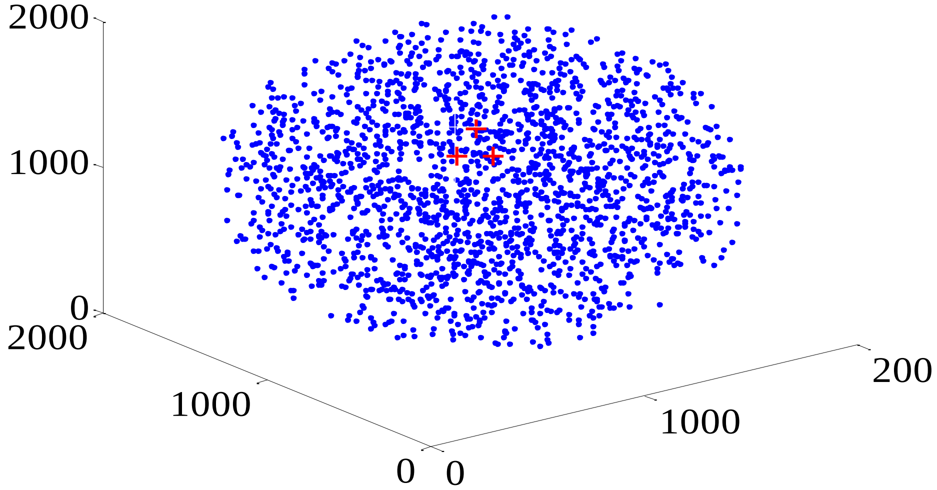



**Fig. 9 – A typical scenario of passive acoustic system where the three pluses (+++) indicates a triangular hydrophone array and the dots indicates fish and mammals.**

### 3.2.4 Cross-correlation Based Passive Acoustic Technique of Biomass Estimation

In this technique, a 3D estimation area is considered where vocalizing fish and mammals produce acoustic signals as a consequence of their acoustic activities. Transmitted acoustic signals from *N* fish and mammals are received by two acoustic sensors at different delay differences and summed at each sensor location forming composite signals. These two composite signals are then cross-correlated to formulate Cross-correlation function (CCF) that results a series of delta functions stated in [167-168]. Such an acquisition of CCF is shown bellow for 100 fish and mammals.

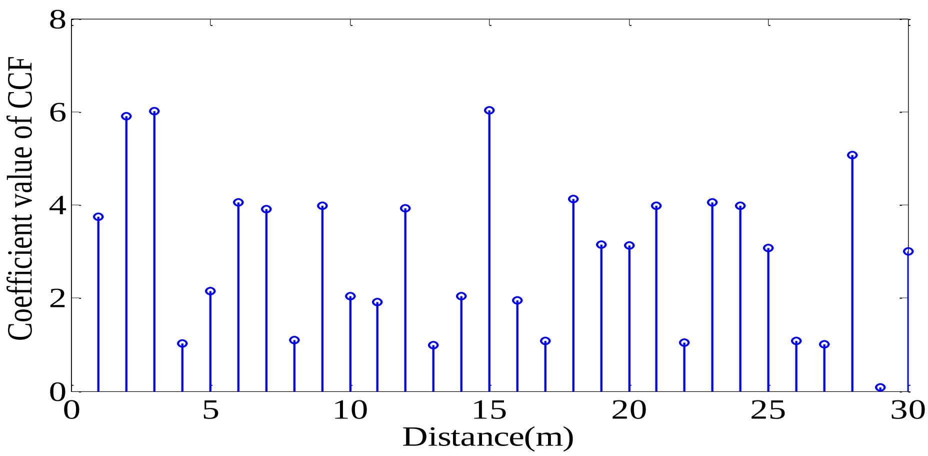



**Fig. 10 - Bins, *b* in the cross-correlation function [167].**

Bins, *b* in the CCF (as shown in Fig. 10) is defined as a place occupied by a delta inside a space of a width twice the distance between acoustic sensors and that place is determined by the delay difference of the signals coming to the acoustic sensors. The deltas of equal delay differences are placed in that particular bin. Number of bins, *b* is achieved from the sampling rate, $S_R$, distance between sensors, $d_{DBS}$, and speed of chirp propagation, $S_P$ which all are predefined described in [169-174].

$$b = \frac{2 \times d_{DBS} \times S_R}{S_P} - 1 \quad (7)$$

In cross-correlation based biomass estimation technique, we can use different estimation parameters (sum, mean [167], standard deviation, ratio of standard deviation to the mean [168] and ratio of mean to standard deviation) of CCF.

Direct calculation of these estimation parameters using statistical expression is convoluted. Hence, cross-correlation problem is reframed to a probability problem using the renowned occupancy problem that follows the binomial probability distribution, where the parameters are biomass of fish and mammals, *N* and 1/*b* [172]. By reframing, we can find the estimation parameter, i.e., ratio of standard deviation to mean, *R* as [172].

$$R = \frac{\sigma}{\mu} = \frac{\sqrt{N\times\frac{1}{b}\times(1-\frac{1}{b})}}{\frac{N}{b}} = \sqrt{\frac{b-1}{N}} \quad (8)$$

where, σ is the standard deviation of CCF and $\mu$ is the mean of CCF.

Similarly, we can find the estimation parameter $\mu$ as [29]

$$\mu = \frac{N}{b} \quad (3)$$

Thus, from equations (7) or (8), we can calculate *N* since we know *b* and *R* or $\mu$ can be calculated from CCF.

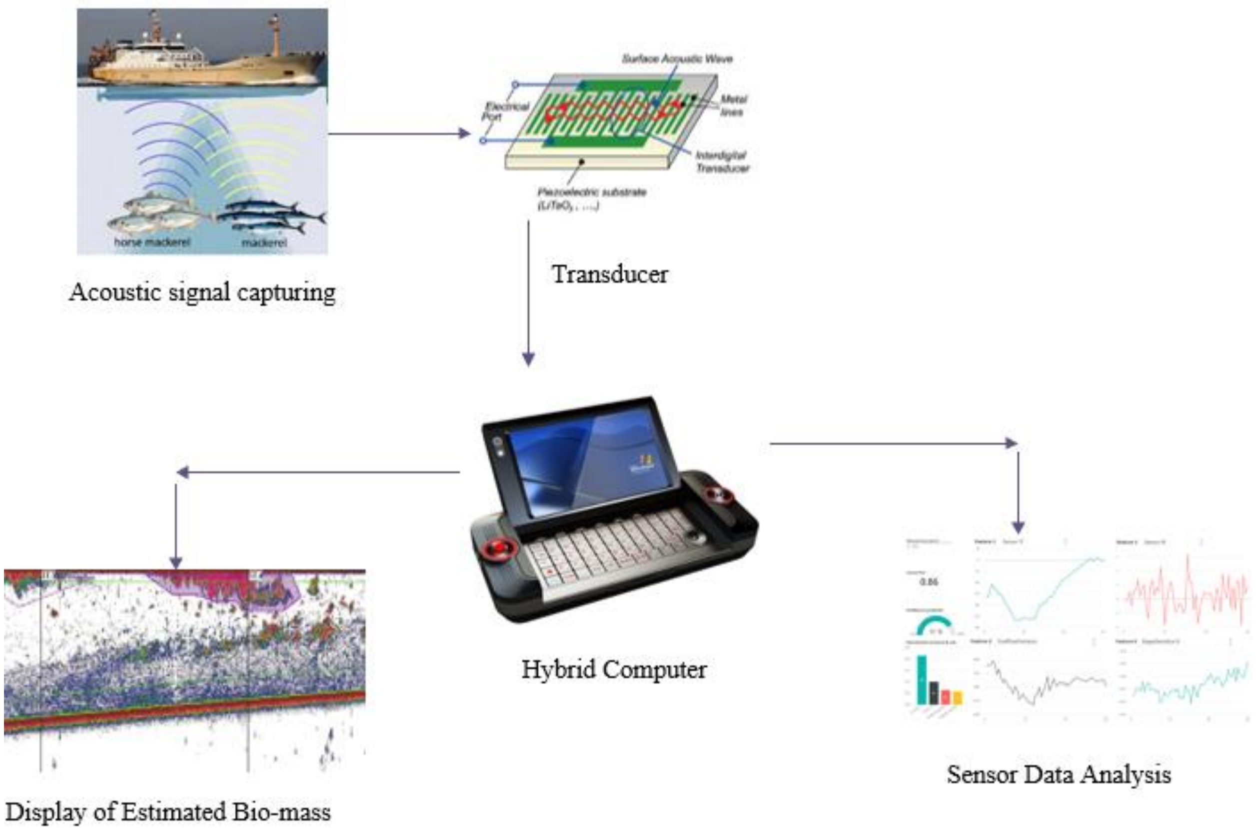



**Fig. 11 - Simplified block diagram of cross-correlation based biomass estimation technique.**

Fig. 11 shows the simplified block diagram of cross-correlation based passive acoustic technique of biomass estimation. However, the estimation results of cross-correlation based passive acoustic technique of biomass estimation are illustrated below [167]. A tabular representation of the estimation for exponential distribution of damselfish using this technique is illustrated bellow [167]. We can see that, for 90 damselfish, the simulated estimation shows 91.12 damselfish. The error is only 1.24%. This can signify the efficiency of this technique [167]. By the way, this method has some limitations like negligence of multipath interference and assuming the delays to be integer. However, the efficiency of a passive acoustic technique is depended on the acoustic behavior of fishes, nature of acoustics and strength of computing algorithms.

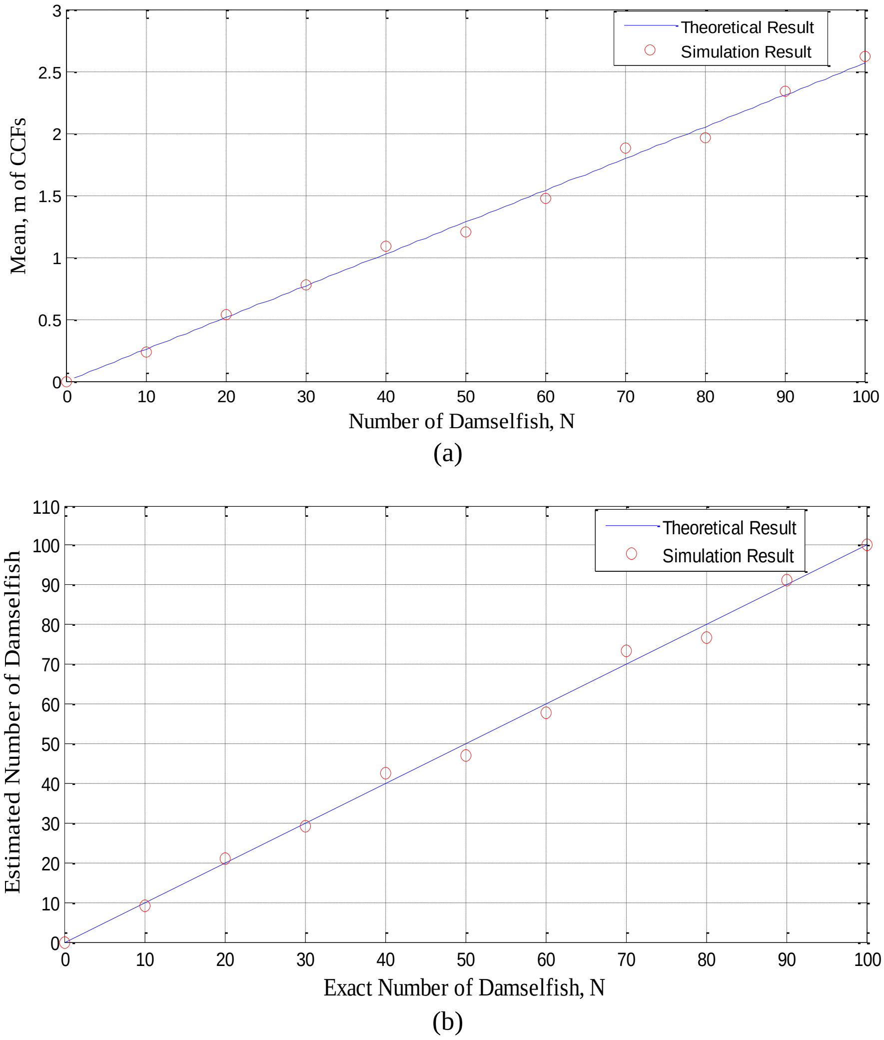



**Fig. 12 - Corresponding estimation results from Hossain et al. (2018) for exponential distribution of Damselfish, (a) Number of damselfish vs. mean of CCF, and (b) Variation of estimated number of damselfishes from the actual quantity [167].**

**Table 1 - Experimental & theoretical data of CCF and percentage of error for exponential distribution [167]**

| **Actual number of dam selfish,** $N_a$ | **Mean of CCF from simulation** | **Estimated number of damselfish,** $N_e$ | **Percentage of error** $\left\lvert \frac{N_a - N_e}{N_a} \right\rvert \times 100\%$ |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 10 | 0.237 | 9.23 | 7.7% |
| 20 | 0.538 | 20.93 | 4.65% |
| 30 | 0.745 | 29.17 | 2.77% |
| 40 | 1.091 | 42.56 | 6.4% |
| 50 | 1.208 | 47.12 | 5.76% |
| 60 | 1.478 | 57.65 | 3.92% |
| 70 | 1.881 | 73.34 | 4.77% |
| 80 | 1.963 | 76.57 | 4.25% |
| 90 | 2.336 | 91.12 | 1.24% |
| 100 | 2.621 | 102.23 | 2.33% |

## 4. Analysis and Discussions

Mechanical equipment based non acoustic methods of biomass estimations were suffered from various drawbacks like poor accuracy, mechanical complexity, mostly human interaction, low efficiency, etc. Hence, after arrival of acoustic techniques of biomass estimation, the researchers and modern commercial fishery managers began to use these. While active sonar's have been widely adopted in the past 20 years for estimating fish biomass, passive acoustics has not seen widespread adoption. The reason can be a scarcity of commercial passive acoustic technologies in the market [175]. Similarly, vast researches on passive acoustic based biomass estimation are underway. Auspiciously, it is expected that diverse commercial passive acoustic techniques will be available in the near future. A relative features and analysis of non-acoustic, active acoustic and passive acoustic techniques in conducted in Table 2.

**Table 2 - Features of non-acoustic non acoustic, active acoustic and passive acoustic techniques**

| Features | Non acoustic techniques | Active acoustic techniques | Passive acoustic techniques |
|---|---|---|---|
| Beginning periods | From ancient ages | Middle of $20^{th}$ century [56-57] | Recently developing |
| Efficiency | Poor | Better | Better |
| Complexity | Mainly high mechanical complexities | Protocol complexities | Relatively low complexities |
| Human interaction | Human interactive | Lower human interactive | Lower human interactive |
| Commercial availability | Available | Available | Unavailable [175] |
| Applicability | Most types of fishes | Most types of fishes | Only vocalizing fishes |
| Impact on ecology | Sometimes harms the inhabitation of fishes | Sometimes harms the inhabitation of fishes | Eco friendly (167) |
| Cost | Depends on mechanical equipments | Depends of fishery abundance and electronic equipments | Depends of acoustic sensors electronic systems |

It can be said that, the diversity of different methods of biomass estimation techniques aids ecological research and commercial fishery managements immensely. New researches are underway lately, of which most is on acoustic technique-based biomass estimation techniques.

## 5. Conclusions

Biomass estimation techniques in the past were mechanical based, called non acoustic technique based. Recently, with the development of electronic and computing technologies, a huge implementation of acoustic techniques is observed. Copious researches and investigations are underway using both acoustics methods, i.e., active and passive acoustic methods. We have reviewed the major techniques regarding biomass estimation as well as analyzed their features in this paper. A good knowledge on different biomass estimation techniques can boost the researches and commercial activities. Therefore, this paper will aid immensely to the marine researchers, commercial fishery managers, ecology researchers, occasional fishery associates, and ocean communities.

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