Hossain, Hossen, and Anower use a cross-correlation based signal processing approach in order to estimate damselfish in the sea.

Who should read this paper?
Those involved in acoustic signal processing research, marine ecological research, and commercial or occasional fishery management would be interested in this paper.

Why is it important?
A novel technique for estimating the abundance of valuable damselfish in the sea is outlined in this paper. The work is based on a statistical signal processing technique where the acoustic signals (chirps) from damselfish are captured by two acoustic sensors and then cross-correlated – a measure of similarity between two series as a function of the displacement of one relative to the other. In this research, chirp signals from a number of different damselfish are collected by two acoustic sensors separated by a certain distance in the region of interest. The received signals are summed at each of the two acoustic sensor locations with the two noise signals then being cross-correlated.

This innovative method can help overcome the major drawbacks of conventional techniques such as visual sampling, RFID tag systems, minnow traps, etc., which are complex and require human interaction as well as costly instruments and devices.

About the authors
Shaik Asif Hossain received his B.Sc. in Electronics and Telecommunication Engineering from Rajshahi University of Engineering and Technology on December 27, 2015. He is currently working towards his M.Sc. in Electronics and Communication Engineering at Khulna University of Engineering and Technology (KUET). His research interests include acoustic signal processing, wireless sensor network, underwater wireless communication, ocean technology, and photonic crystal fibre. Dr. Monir Hossen received his B.Sc. in Electrical and Electronic Engineering from KUET, Bangladesh, in 2002. In 2010, he completed his M.Sc. in Electronics Engineering at Kookmin University, Korea, and received his PhD from University of Yamanashi, Japan, in 2014. Currently he is working as a Professor in the Department of Electronics and Communication Engineering at KUET. His present research focuses on MAC protocol of wireless sensor network. Dr. Md. Shamim Anower received his B.Sc. and M.Sc. in Electrical and Electronic Engineering from Rajshahi University of Engineering and Technology in 2002 and 2007, respectively. He obtained his PhD degree from University of New South Wales, Australia, in 2012. His major research interests are underwater wireless communication, underwater optical communication, photonic crystal fibre, power line communication, signal processing for communications, power system analysis, and stability enhancement. At present, he is a Professor in the Department of Electrical and Electronic Engineering at Rajshahi University of Engineering and Technology.
ESTIMATION OF DAMSELFISH BIOMASS USING AN ACOUSTIC SIGNAL PROCESSING TECHNIQUE

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ABSTRACT

The popular aquarium fish called damselfish are valuable because of their commercial and ecological value. As the demand for these fishes is increasing, their estimation techniques carry great significance. Most conventional techniques for biomass estimation are visual sampling techniques, raft and floating radio frequency identification (RFID) tag systems, minnow traps, removal method of population estimation, etc., which are complex and require human interaction. Moreover, the instruments and devices used in these techniques are costly. With the aim of overcoming these difficulties, a cross-correlation based signal processing approach is presented in this research in order to estimate damselfish biomass in the sea. The estimation process is based on the production of an acoustic signal (called “chirp signal”) of these fish species during swimming within their territory. To evaluate the performance of the estimation, three different distributions of damselfish are considered in this paper. However, the chief goal of this investigation is to establish a new model of biomass estimation that will benefit research and commercial fishery management.

KEYWORDS

Damselfish; Bins; Chirp signal; Cross-correlation; Courtship; RFID
INTRODUCTION

Damselfish, also called demoiselle, are small, primarily tropical, marine fish of the family Pomacentridae (order Perciformes). It is found in the Atlantic and Indo-Pacific oceans and is composed of about 250 species. Damselfish are among the best studied soniferous fishes, with at least eight of the approximately 29 genera reported to produce sounds [Fish and Mowbray, 1970; Myrberg, 1981; Myrberg et al., 1986; Chen and Mok, 1988; Lobel and Mann, 1995; de Amorim, 1996; Lobel and Kerr, 1999; Picciulin et al., 2002; Maruska et al., 2007]. Many of them present a courtship behaviour known as the signal jump, in which they rise in the water column and then rapidly swim downward while producing a pulsed sound [Mann and Lobel, 1997]. The mechanism of sound production in this family is hypothesized to involve stridulation of the jaw apparatus (or other hard parts) and amplification and resonance by the swim bladder [Chen and Mok, 1988; Rice and Lobel, 2003].

There is evidence that the “chirp,” a sound commonly produced by males of the bicolour damselfish (family: Pomacentridae), possesses an anatomical constraint [Myrberg et al., 1993]. In response, females make aggressive sounds. Two types of aggressive sounds are produced, pops and chirps. Pops are more commonly made towards heterospecifics than conspecifics, and aggressive chirps are made most often towards conspecifics [Mann and Lobel, 1998]. We use the term “aggressive sounds” because they are two sound types associated with aggressive behaviour. The pulse rate of aggressive chirps is faster than signal jump sounds. The most complete studies on damselfish sound production have been performed with members of the Stegastes genus, with the most detailed description of the bicolour damselfish, Stegastes partitus [Ha, 1973; Myrberg, 1972; Myrberg et al., 1986; Spanier, 1979]. It is known from field experiments [Myrberg et al., 1986] that a larger male appeared to be more attractive to females than a smaller one, as he had more egg batches in his nest. In his first playback experiment, a contrast between two damselfish was observed where one is 4 mm larger than the other. The peak frequency of chirps from the larger male was smaller than that of a smaller male damselfish [Hopp et al., 2012].

Different species of damselfish have different importance such as aquarium purposes, food purposes in the Indian subcontinent, and ecological purposes such as cleaning sea water. As a result, great importance is put on the process of searching and estimating damselfish abundance in the sea. Searching for new species and estimating fish abundance are two important criteria for research and commercial fishery management. However, it is quite difficult to estimate the actual number of fish. The dynamics of fish population and the harsh condition of the ocean represent the main difficulties in obtaining accurate data. Numerous studies have been conducted with the purpose of estimating fish abundances. A method called removal method of population estimation has been used to estimate small-mammal populations; a certain number of kill traps are set for numerous trapping periods in Zippin [1958]. The minnow trap is a passive gear for catching small fish...
species and has long been used in order to estimate fish population characteristics [He and Lodge, 1990].

Visual census techniques have been used for many years to assess reef fish populations. The technique is suitable for monitoring the abundance of coral reef fish. It certainly collects the data without disruption compared with other destructive sampling techniques [Halford and Thomson, 1994]. Visual census consists of many techniques used to estimate reef fish populations, as first described by Brock [1954], and has been adopted by long term monitoring programs in order to assess reef fish populations.

However, the Northwest Atlantic Fisheries Organization sets annual quotas for high abundance commercial species and maximum allowable percentages by-catch for low abundance species. The whole process is performed under monitoring. Before 1991, the estimation processes of fish abundance were performed using catch effort data reported by commercial fishing units described in Chen et al. [2004]. Unfortunately, the processes were unreliable because of many factors, including vessel and gear type, under-reporting, crew experience, etc. Hence, those methods used for fish estimation purposes so far are similar to the method of catch effort data reported by commercial fishing units. These methods are not only human interactive but also costly. This is why a simpler cross-correlation based estimation process is proposed here as an alternative. Each damselfish in the estimation area is considered a source of chirp signal and two acoustic sensors are used to receive these signals. The technique is based on cross-correlating the chirp signals, which is a similar method to the signal processing approach of node estimation investigated in Anower [2012] and Anower et al. [2013].

In this paper, we have worked with three different distributions (Exponential, Normal and Rayleigh) of damselfish to analyze the performance of the proposed technique.

As a simulation-based research, the paper will first introduce a theoretical method of estimation and then the theory will be proved by MATLAB simulation. At the same time, analysis of the performance of the proposed technique for different damselfish distributions is also a goal.

**Chirp Signal**

Commonly, croaker fish produce a sound, which is akin to a chirp signal. Damselfish generate chirp signals while swimming within their territory. While damselfish are not known to possess adaptations to enhance detection of the sound pressure component of acoustic stimuli, several western Atlantic Stegastes species do respond to sound pressure at frequencies of >300 Hz [Myrberg and Spires, 1980]. 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 durations varying from 0·6 to 1·27 ms; peak frequency varied from 3400 to 4100 Hz [Parmentier et al., 2006]. However, a chirp signal is a swept-frequency signal that has a time varying frequency. Such a signal can be expressed as:
Where $f_1$ is the starting frequency in Hz, $f_2$ is the ending frequency, $d$ is the duration in seconds, $P$ is the starting phase, and $A$ is the amplitude.

$$X(t) = A \cos(2 \pi (f_2 - f_1)t^2/(2d) + f_1t + P)$$

Figure 1 shows a simulated form of chirp signal: (a) represents a simple form of chirp with a 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.
**Different Distributions of Damselfish**

For the estimation process, we have considered three distributions of damselfish: exponential distribution (Probability density function (PDF) is \( y = f(x|\mu) = \frac{1}{\mu} e^{-\frac{x}{\mu}} \) where \( \mu = \text{mean parameter} \)); Rayleigh distribution (Probability density function (PDF) is \( y = f(x|\beta) = \frac{x}{\beta^2} e^{-\frac{x^2}{2\beta^2}} \) where \( \beta = \text{scale parameter} \)); and normal distribution (Probability density function PDF is \( y = f(x|\mu,\sigma) = \frac{1}{\alpha\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \) where \( \mu = \text{mean} \) and \( \sigma = \text{standard deviation} \)).

**CROSS-CORRELATION FUNCTION (CCF) FORMULATION**

In signal processing, cross-correlation is a measure of similarity between two series as a function of the displacement of one relative to the other. This is also known as a sliding dot product or sliding inner-product. However, a brief procedure of the method is as follows: firstly, the chirp signals from a number of different damselfish are collected by two acoustic sensors separated by a certain distance in the region of interest; secondly, the received signals are summed at each of the two acoustic sensor locations; and finally, these two noise signals are cross-correlated.

**A Typical Analysis of Cross-Correlation Function (CCF)**

The cross-correlation function of a time-delayed version of infinity in length unity strength Gaussian signal is expressed by a delta function, whose amplitude relies on the attenuation. At the same time, its position will be the delay difference of the signals from the centre of the CCF.

Then the CCF for the first signal source is:

\[
C_1(\tau) = \alpha_{11} \alpha_{12} \delta \left( \tau - \frac{d_{11} - d_{12}}{S_p} \right)
\]  

Where \( \alpha_{11} \) and \( \alpha_{12} \) are the attenuations due to absorption, \( d_{11} = \text{Distance between first signal source and first receiver} \) and second receiver \( d_{12} = \text{Distance between first signal source and second receiver and} \ S_p \) is the speed of wave propagation.

Assuming the strength of the source signal is high enough to overcome the attenuation, the CCF for first signal source becomes:

\[
C_1(\tau) = \delta \left( \tau - \frac{d_{11} - d_{12}}{S_p} \right)
\]  

Likewise, CCF for \( N^{th} = \text{signal source} \) is:

\[
C_N(\tau) = \delta \left( \tau - \frac{d_{N1} - d_{N2}}{S_p} \right)
\]  

Then the CCF for \( N \) number of signal sources:

\[
C(\tau) = \sum_{n=1}^{N} \delta \left( \tau - \frac{d_{n1} - d_{n2}}{S_p} \right)
\]  

It is intuitive that if \( N \) is larger than the number of bins, \( b \), which is usually the case, the bins are occupied by more than one delta due to the same delay differences. This increases the amplitude of the deltas in the bins, and thus the CCF is expressed in terms of bins as:

\[
C_i(\tau) = \sum_{m=1}^{b} \delta_i
\]  

Where \( \delta_i = \text{amplitude of the delta}, \ \delta_j \text{ is the } j^{th} \text{ bin.}

The above analysis is verified by simulation in Figure 2, where the number of sources, \( N=32 \) and \( \text{bin}=19 \), is considered. As the number of signal sources is larger than bins, there is a
possibility that some bins can be occupied by more than one source and some bins can be empty for the time delay difference. From Figure 2, $p_1$ values are:

$$p_1 = p_{19} = 4, \quad p_4 = p_{10} = p_{13} = 3,$$

and so on.

Using the moving-average technique of cross-correlation [Hanson and Yang, 2008a; 2008b], we can express the CCF generally as follows:

$$C(\tau) = \frac{1}{N_s-\tau} \sum_{i=1}^{N_s-\tau} x_i y_{i+\tau} - \left( \frac{1}{N_s} \sum_{i=1}^{N_s} x_i \right) \left( \frac{1}{N_s} \sum_{i=1}^{N_s} y_i \right)$$  \hspace{1cm} (7)

Where $N_s$ = signal length in terms of samples, $\tau$ = time delay of the cross-correlated signals, $x_i$ and $y_i$ are $i^{th}$ samples of the two acoustic sensors’ signals. Here, assume Gaussian signal contains zero mean. So the product of their mean is zero. Hence, the CCF:

$$C(\tau) = \frac{1}{N_s-\tau} \sum_{i=1}^{N_s-\tau} x_i y_{i+\tau}$$  \hspace{1cm} (8)

This gives the peaks for the desired bins as follows:

$$P_1 = \frac{1}{N_s+\tau} \sum_{i=1}^{N_s+\tau} x_i y_{i-\tau}, \quad P_2 = \frac{1}{N_s+1} \sum_{i=1}^{N_s+1} x_i y_{i-1}, \quad P_3 = \frac{1}{N_s} \sum_{i=1}^{N_s} x_i y_{i-0}, \quad P_4 = \frac{1}{N_s-1} \sum_{i=1}^{N_s-1} x_i y_{i+1}, \quad P_5 = \frac{1}{N_s-\tau} \sum_{i=1}^{N_s-\tau} x_i y_{i+\tau}$$  \hspace{1cm} (9)

Where the peaks are the strengths of the deltas of Equation 6, which are [Anower, 2012]:

$$P_1 = \frac{1}{N_s+\tau} \sum_{i=1}^{N_s+\tau} x_i y_{i-\tau}$$  

Theoretical CCF is developed by putting these values to Equation 6 [Anower, 2012].

**Process of Cross-Correlation Function (CCF) Formulation**

The formulation of the cross-correlation of the chirp signal is like the formulation of cross-correlation of Gaussian signal in Anower [2012] and Anower et al. [2009; 2013], which is the starting point and method to estimate damselfish biomass. All the transmitted signals are received by the acoustic sensors and recorded in the associated computer in which cross-correlation is executed. Transmission and reception of signals are performed for a time frame, called “signal length” throughout this paper. Damselfish are considered as the sources of chirp signals and $N$ damselfish are distributed over the volume of a large sphere, the centre of which lies halfway between the acoustic sensors. A distribution of damselfish (simulation) is shown in Figure 3.
Where \( \tau_{11} \) and \( \tau_{12} \) are the corresponding time delays for the signal to reach each acoustic sensor. Assuming \( \tau_1 \) is the time shift in the cross-correlation, then the CCF is:

\[
C_1(\tau) = \int_{-\infty}^{\infty} S_{r_{11}}(t)S_{r_{12}}(t - \tau_1)d\tau
\]  

(13)

Figure 3: A flock of damselfish in 3D space where the two reds (+) indicate the acoustic sensors and each fish is considered as a source of chirp signal.

Figure 4: From a distribution of damselfish in 3D space, we consider one fish \( N_1 \), where \( H_1 \) and \( H_2 \) are the acoustic sensors.

Two acoustic sensors \( H_1, H_2 \), and a damselfish (chirp source) \( N_1 \) are used, as shown in Figure 4. The acoustic sensors \( H_1, H_2 \), and the fish \( N_1 \) are located at \((x_1, y_1, z_1), (x_2, y_2, z_2)\) and \((x_3, y_3, z_3)\), respectively. If the distance between two acoustic sensors is \( d_{DBS} \), then:

\[
d_{DBS} = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2}
\]  

(10)

A signal coming from \( N_1 \) is \( S_1(t) \), which is finite in length. As such, the signals received by \( H_1 \) and \( H_2 \) are correspondingly:

\[
S_{r_{11}}(t) = \alpha_{11}S_1(t - \tau_{11})
\]  

(11)

\[
S_{r_{12}}(t) = \alpha_{12}S_1(t - \tau_{12})
\]  

(12)

Where \( \tau_{11} = \frac{d_1}{S_p} \) and \( \tau_{12} = \frac{d_2}{S_p} \) are the corresponding time delays for the signal to reach each acoustic sensor.
Which takes the form of a delta function as it is a cross-correlation of two signals where one signal is fundamentally the delayed copy of other.

To find the CCF for $N$ damselfish, we have to take the total signals received by the acoustic sensors from each of the fish and sum them. As such, the total signals $S_{r_1}$ at acoustic sensor $H_1$ is:

$$S_{r_1} = \sum_{j=1}^{N} \alpha_{j_1} S_j(t - \tau_{j_1})$$

(14)

While the total signals at acoustic sensor $H_2$ by $S_{r_2}$ is:

$$S_{r_2} = \sum_{j=1}^{N} \alpha_{j_2} S_j(t - \tau_{j_2})$$

(15)

Where $\tau = \frac{d_{DBS}}{S_p}$ is the time shift in the cross-correlation. Hence, the final CCF between the signals at the acoustic sensors is:

$$C(\tau) = \int_{-\infty}^{\infty} S_{r_1}(t)S_{r_2}(t - \tau)d\tau$$

(16)

This takes the form of a series of delta functions as it is a cross-correlation of two signals, which is the summation of several chirp signals where one signal is fundamentally a delayed copy of the other.

However, Figure 5 shows the block diagram to achieve the mean of CCF for $N$ damselfish.

ESTIMATION PROCESS OF DAMSELFISH BIOMASS

We know that chirp pulses are generated by a school of damselfish during swimming within their territory. A relationship between sound characteristics and swimming behaviour during the signal jump could be produced by four mechanisms [Mann and Lobel, 1998]. (1) The number of pulses that could be produced in a signal jump of a given length could be limited so that longer signal jumps had more pulses. (2) There could be a correlation between the energy available for producing rapid pulsation and swimming speed. (3) The air-water interface is an almost perfect reflective surface that produces echoes detectable by fish [Fay et al., 1983]. Information on the depth of the sound-producing fish (and thus swimming distance and rate between pulses in sound) could theoretically be contained in changes in the delay of echoes from the surface as the fish swim down. (4) The volume of the swim-bladder could change with increasing depth, affecting the dominant frequency of the sound.

However, to ease the simulation we have considered a negligible power difference between the chirp pulses transmitted by each damselfish.

No Doppler effect, which might occur due to the movement of damselfish, is considered in this research. Due to the Doppler effect, there will be a slight variation in the propagation
wavelength and, thus, in propagation delay which can affect the placing of balls in the bins of the cross-correlation process and might lead to fractional-sample delays being created. However, the effect of fractional samples has no significant effect on estimation.

We have used the mean, $m$, of CCF of the fish as the estimation parameter instead of the ratio of standard deviation to the mean of the CCFs, $R = \sigma \div \mu \sqrt{\frac{b-1}{N}}$, as proposed in Anower et al. [2013], where $\sigma$ = standard deviation, $\mu$ = mean, and $b$ = number of bins.

THEORETICAL ESTIMATION OF DAMSELFISH BIOMASS USING CROSS-CORRELATION TECHNIQUE

The mean of CCF is expressed by an ensemble average of the signals at cross-correlation in Roux et al. [2005]:

$$\langle C(t) \rangle = Q_T T_r v \int_{-\infty}^{+\infty} d\tilde{r}_S \times \delta \left( t + \frac{|\tilde{r}_a - \tilde{r}_s|}{s_p} - \frac{|\tilde{r}_b - \tilde{r}_s|}{s_p} \right)$$

(17)

Where $Q_T$ represents the acoustic power of the received signals from the sources taken to be constant over time and space, $v$ is the creation rate of the sources whose unit is unit time per unit volume, $T_r$ is the total recording time, $\tilde{r}_s$ is the path length of sources from the origin, $r_a$ is the path length of the first acoustic sensor from the origin, and $r_b$ is the path length of the second acoustic sensor from the origin.

The cross-correlation technique can be reframed to a probability problem using the well-known occupancy problem which follows the binomial probability distribution from which a parameter is chosen to estimate damselfish biomass in the sea. Considering each delta function as a ball, this occupies a bin according to the delay difference of corresponding recorded signals in the acoustic sensors. It is simple to model as the problem of placing $N$ balls in $b$ bins. It is known from Vogt [2002] that the occupancy problem follows the binomial probability distribution in which the parameters are the number of balls i.e., damselfish, $N$, and the inverse of the number of bins, $b$. Occupancy problems deal with the pairings of objects and have a wide range of applications in different fields containing probabilistic and statistical properties.

The basic occupancy problem is about placing $N$ balls into $b$ bins [Feller, 1957]. If one threw some balls randomly towards several bins, the bins would be randomly filled by the balls, resulting in some bins being occupied by more than one ball, some by one, while some may have none. In this research, the cross-correlation process for damselfish estimation is reframed as this occupancy problem. To obtain a CCF, $N$ damselfish create $N$ number of delta functions which occupy the place in the correlation length where the length is divided by $b$ number of bins as shown in Figure 6. Some bins are empty (i.e., not occupied by any delta function); some are occupied by only one; and others are more than one. The formation of cross-correlation function to perform damselfish estimation satisfies the characteristics of binomial distribution as the number of trials (i.e., the number of damselfish) is fixed. Trials are independent in
that damselfish are sending independent chirp signals: there exist only two possible outcomes – success or failure – for every trial which indicates that delta for a particular damselfish is occupying a bin or not. Each trial has the same probability of success which is one over the number of bins, \( b \). As the cross-correlation function follows the binomial distribution, its mean is easy to obtain as discussed below.

It is acknowledged that the cross-correlation function follows the binomial probability distribution, detailed in Anower et al. [2013]. Accordingly, the parameters used here are the number of damselfish, \( N \), and the number of bins, \( b \). Then the expected value (i.e., the mean, \( m \)) of the CCF is defined as [Anower et al., 2013]:

\[
m = \frac{N}{b}
\]  

(18)

Where \( b \) is the number of bins in the cross-correlation process and is achieved from the sampling rate, \( S_R \), distance between acoustic sensors, \( d_{DBS} \) and speed of propagation, \( S_P \), which all are predefined as described in Anower et al. [2013]:

\[
b = \frac{2 \times d_{DBS} \times S_R}{S_P} - 1
\]  

(19)

So we can write:

\[N = b \times m\]  

(20)

This is the relationship between the number of damselfish, \( N \), and the mean, \( m \), of the CCF. Since \( b \) is known and \( m \) can be measured from the CCF, we can estimate damselfish, \( N \).
ESTIMATION OF DAMSELFISH BIOMASS FROM SIMULATION

Simulations are executed in this section where two acoustic sensors are deployed along a line on the centre of a sphere.

For each of the three types of distribution (exponential, normal and Rayleigh), three different means of CCFs versus number of sources (damselfish biomass) plots are obtained. All the simulations were accomplished by using MATLAB. The following parameters are used in the simulation.

The results will be shown for the estimated number of damselfish, \( N \) (estimated) with respect to exact or actual number of damselfish, \( N \) from three distributions of damselfish. Figure 8 shows the comparison of theoretical and simulated number of damselfish (for bin number 39). In this figure, the solid line indicates the theoretical results and the circles are correspondent to simulated results. From Figure 8, it is seen that the theoretical and simulated results are very close to each other, which signifies the strength of the biomass estimation method.

RESULTS AND DISCUSSION

The relative performance analysis between the three distributions is shown in Tables 2, 3, and 4. The less variation between the theoretical and simulated results illustrates the accuracy of the estimation method.

From Tables 2, 3, and 4, it can be seen that the estimation from exponential distribution of damselfish shows overall better performance at its biomass estimation.

After analyzing the simulations, it is seen that the results agree with the theoretical approach. We can use this simulation-based proposition for two different purposes: first, estimating the abundance of damselfish in a particular area; and second, determining the most possible abundant area of damselfish. Moreover, this process can be applied to the

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value (Exponential distribution)</th>
<th>Value (Normal distribution)</th>
<th>Value (Rayleigh distribution)</th>
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<td>Distance between the equidistant acoustic sensors, ( d_{\text{DAS}} )</td>
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<tr>
<td>Number of bins, ( b )</td>
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Table 1: Parameters used in the MATLAB simulation.
Figure 7: Number of damselfish, $N$, versus mean, $m$, of CCFs (a) exponential distribution, (b) normal distribution and (c) Rayleigh distribution, for $b=39$ and $d_{DBS}=0.5m$.

Figure 8: Variation of estimated number of damselfish from the actual quantity for (a) exponential distribution, (b) normal distribution and (c) Rayleigh distribution.
### Table 2: Experimental and theoretical data of CCF and percentage of error for exponential distribution.

<table>
<thead>
<tr>
<th>Actual number of damselfish, $N_a$</th>
<th>Mean of CCF from simulation</th>
<th>Estimated number of damselfish, $N_e$</th>
<th>Percentage of error $\left( \frac{N_a - N_e}{N_a} \right) \times 100%$</th>
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<td>60</td>
<td>1.478</td>
<td>57.65</td>
<td>3.92%</td>
</tr>
<tr>
<td>70</td>
<td>1.881</td>
<td>73.34</td>
<td>4.77%</td>
</tr>
<tr>
<td>80</td>
<td>1.963</td>
<td>76.57</td>
<td>4.25%</td>
</tr>
<tr>
<td>90</td>
<td>2.336</td>
<td>91.12</td>
<td>1.24%</td>
</tr>
<tr>
<td>100</td>
<td>2.621</td>
<td>102.23</td>
<td>2.33%</td>
</tr>
</tbody>
</table>

### Table 3: Experimental and theoretical data of CCF and percentage of error for normal distribution.

<table>
<thead>
<tr>
<th>Actual number of damselfish, $N_a$</th>
<th>Mean of CCF from simulation</th>
<th>Estimated number of damselfish, $N_e$</th>
<th>Percentage of error $\left( \frac{N_a - N_e}{N_a} \right) \times 100%$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>0.235</td>
<td>9.16</td>
<td>8.4%</td>
</tr>
<tr>
<td>20</td>
<td>0.561</td>
<td>21.89</td>
<td>9.45%</td>
</tr>
<tr>
<td>30</td>
<td>0.852</td>
<td>33.23</td>
<td>10.76%</td>
</tr>
<tr>
<td>40</td>
<td>1.131</td>
<td>44.12</td>
<td>10.25%</td>
</tr>
<tr>
<td>50</td>
<td>1.209</td>
<td>47.18</td>
<td>7.64%</td>
</tr>
<tr>
<td>60</td>
<td>1.594</td>
<td>62.15</td>
<td>3.58%</td>
</tr>
<tr>
<td>70</td>
<td>1.713</td>
<td>66.79</td>
<td>4.58%</td>
</tr>
<tr>
<td>80</td>
<td>2.185</td>
<td>85.21</td>
<td>5.99%</td>
</tr>
<tr>
<td>90</td>
<td>2.257</td>
<td>88.02</td>
<td>2.2%</td>
</tr>
<tr>
<td>100</td>
<td>2.659</td>
<td>103.67</td>
<td>3.67%</td>
</tr>
</tbody>
</table>

### Table 4: Experimental and theoretical data of CCF and percentage of error for Rayleigh distribution.

<table>
<thead>
<tr>
<th>Actual number of damselfish, $N_a$</th>
<th>Mean of CCF from simulation</th>
<th>Estimated number of damselfish, $N_e$</th>
<th>Percentage of error $\left( \frac{N_a - N_e}{N_a} \right) \times 100%$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>0.291</td>
<td>11.36</td>
<td>11.36%</td>
</tr>
<tr>
<td>20</td>
<td>0.459</td>
<td>17.91</td>
<td>10.45%</td>
</tr>
<tr>
<td>30</td>
<td>0.6959</td>
<td>27.14</td>
<td>9.47%</td>
</tr>
<tr>
<td>40</td>
<td>1.125</td>
<td>43.86</td>
<td>9.65%</td>
</tr>
<tr>
<td>50</td>
<td>1.376</td>
<td>53.82</td>
<td>7.64%</td>
</tr>
<tr>
<td>60</td>
<td>1.444</td>
<td>56.32</td>
<td>6.13%</td>
</tr>
<tr>
<td>70</td>
<td>1.875</td>
<td>73.12</td>
<td>4.46%</td>
</tr>
<tr>
<td>80</td>
<td>2.188</td>
<td>85.32</td>
<td>6.65%</td>
</tr>
<tr>
<td>90</td>
<td>2.402</td>
<td>93.70</td>
<td>4.11%</td>
</tr>
<tr>
<td>100</td>
<td>2.492</td>
<td>97.17</td>
<td>2.83%</td>
</tr>
</tbody>
</table>
other valuable taxa generating chirp-like signals. However, this method has some limitations such as negligence of multipath interference [Anower et al., 2013] and assuming the delays to be integers.

EFFECT OF NOISE ON BIOMASS ESTIMATION

It is intuitive that wireless communication channels are subject to background noise and, in practice, the transmitters and receivers themselves have some internal noise which may affect the estimation process. It is important to know these effects in the proposed technique for estimating damselfish biomass because, in order for the chirp signals from the fish to be useful, they will have to be stronger than the noise and the range of their strengths could be decided from this analysis. In all types of noise cases, the added noises in the signals will take place in the cross-correlation i.e., if the signals are received with noise, the CCF will be due to both noise and signal. Thus, although the effect of noise in the proposed biomass estimation technique is similar for all types of noise (assuming additive white Gaussian noise), the noise strengths are different. The effect of noise is discussed for the internal noise of a receiver. Let us consider a signal (chirp) received by two noisy receivers (acoustic sensors) as:

\[
f_1(t) = S_1(t) + S_{n1}(t) \quad (21)
\]

\[
f_2(t) = S_2(t) + S_{n2}(t) \quad (22)
\]

Where \(S_1(t)\) is the delayed version of the signal transmitted from the source (damselfish 1) to receiver 1 (acoustic sensor 1), \(S_2(t)\) the delayed version of the signal transmitted from the source (damselfish 2) to receiver 2 (acoustic sensor 2), \(S_{n1}(t)\) the internal noise received in receiver 1, and \(S_{n2}(t)\) the internal noise received in receiver 2.

Then the CCF, \(C(\tau)\), is [Liu et al., 2009]:

\[
C(\tau) = \lim_{T \to \infty} \frac{1}{2T} \int_{-T}^{T} f_1(t)f_2(t-\tau)dt
\]

\[
= \lim_{T \to \infty} \left[ \frac{1}{2T} \int_{-T}^{T} S_1(t)S_2(t-\tau)dt + \frac{1}{2T} \int_{-T}^{T} S_1(t)S_{n2}(t-\tau)dt \right.
\]

\[
+ \frac{1}{2T} \int_{-T}^{T} S_{n1}(t)S_2(t-\tau)dt + \frac{1}{2T} \int_{-T}^{T} S_{n1}(t)S_{n2}(t-\tau)dt \]

\[
= C_{S_1S_2}(\tau) + C_{S_1S_{n2}}(\tau) + C_{S_{n1}S_2}(\tau) + C_{S_{n1}S_{n2}}(\tau)
\]

(23)

Where \(C_{S_1S_2}(\tau)\) is the CCF of \(S_1(t)\) with \(S_2(t)\)

\(C_{S_1S_{n2}}(\tau)\) is the CCF of \(S_1(t)\) with \(S_{n2}(t)\)

\(C_{S_{n1}S_2}(\tau)\) is the CCF of \(S_{n1}(t)\) with \(S_2(t)\)

\(C_{S_{n1}S_{n2}}(\tau)\) is the CCF of \(S_{n1}(t)\) with \(S_{n2}(t)\)

\(\tau\) is the time delay in the cross-correlation process.

As \(S_1(t)\) and \(S_{n2}(t)\), \(S_{n1}(t)\) and \(S_2(t)\), \(S_{n1}(t)\) and \(S_{n2}(t)\) and are independent random processes, their CCFs tend to be zero with the integration time extension and zero when the integration time is infinity. Thus, Equation 23 becomes \(C(\tau) \approx C_{S_{1}S_{2}}(\tau)\). But as in real-world problems, it is not possible to take an infinite time interval; it is appealing how the cross-correlation works with finite time integration.
However, to show the effect of noise in the biomass estimation technique, the simulations are executed by adding white Gaussian noise to the signals in the receivers. In the proposed biomass estimation technique, signal-to-noise ratio (SNR) is used as the ratio of voltage levels of signal and noise. Sometimes it is converted to dB as for example, SNR=1 indicates 0dB, SNR=10 indicate 20dB, and so on. Figure 9 shows the result for SNR=10 and SNR=1 with \( N_s = 100,000 \) samples for the cases with noise and the theoretical. The simulation parameters are identical as those used in the basic estimation technique with the noise taken into account.

To sum up, noise has an effect on the proposed biomass estimation technique in which the SNR plays a vital role.

CONCLUSIONS

In the sea, the estimation process of damselfish biomass is difficult using existing techniques due to the harsh underwater environment, the complexity of most techniques, and the reliance on human interaction. To overcome such limitations, we have proposed this statistics-based technique that uses an acoustic signal processing approach called cross-correlation. At the same time, we have measured its performance through three distributions of damselfish. Because of its simplicity and accuracy, the technique ensures its suitability for estimating not only damselfish but also all types of chirp sound generating taxa like prawn, dolphin, some croaker types of fish, etc. This technique can be used similarly for the other distributions of damselfish in the sea. Hence, it is proposed to use this non-human interactive technique in practical cases.

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REFERENCES


Hopp, S.L.; Owren, M.J.; and Evans, C.S. (Eds.). [2012]. *Animal acoustic
communication: sound analysis and research methods. Springer Science and Business Media.


Roux, P.; Sabra, K.G.; Kuperman, W.A.; and

