Sensing with noise

Mandar Chitre
Most reef populations are replenished with recruits that settle out from an initially pelagic existence. The larvae of nearly all coral reef fish develop at sea for weeks to months before settling back to reefs as juveniles. Although larvae have the potential to disperse great distances, recent studies show a substantial portion recruit back to their natal reefs (1, 2). Larvae are not passively dispersed but develop a high level of swimming competence (3). How they use these capabilities to influence their dispersal is an open question. We show here that recruits respond actively to reef sounds, potentially providing a valuable management tool for the future.

Since the discovery that reef fish larvae are accomplished swimmers, focus has shifted to identifying cues that may influence their orientation. Sound has emerged as a leading presentation. Sound has emerged as a leading candidate, because it travels in water irrespective of current flow with little attenuation and because it can contribute up to one quarter of all individuals on reefs and the pomacentrids up to half of the total fish biomass (7). Analyses showed no site or date effects in our data, but both families settled in greater numbers on noisy patch reefs than on silent reefs (Fig. 1A). A preference for noisy patch reefs was also seen in less common fishes, with marginally more taxa (excluding apogonids and pomacentrids) on patch reefs with broadcast noise than on reefs without (Fig. 1B).

In December 2003, the experimental field site was used to compare the settlement of fishes to patch reefs where we broadcast primarily the high frequencies of reef noise (80% > 570 Hz, predominantly shrimp) or low frequencies of reef noise (80% < 570 Hz, predominantly fish) with settlement to silent reefs. This time, nearly four times as many recruits arrived (3111 fish), but the taxonomic composition was similar. Apogonids settled on high- and low-frequency patch reefs in equivalent numbers, but pomacentrids were preferentially attracted to reefs with high-frequency noise (Fig. 1C). Again, reefs without sound received less settlement from rarer taxa than reefs with broadcast sound (Fig. 1D).

This study provides direct evidence that settling reef fishes use sounds to orient toward and select reefs. Furthermore, there is an indication that some fish groups may be selectively using specific components of the reef sound to guide their settlement behavior. The important use of sound at this critical life history phase raises the possibility of potential adverse effects of increasing anthropogenic noise pollution (e.g., shipping and drilling), but it may also lead to the development of new tools for fisheries managers for restocking fisheries or newly established marine reserves.

References and Notes
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Fig. S1
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I. INTRODUCTION

Passive techniques field are useful when situations include a steady state situation. In this paper, a technique is described for integrating water column sound speed profile (SSP) and sea-floor parameters such as the sediment layer thickness, SSPs, densities, and attenuation values. The paper introduces a passive geoaoustic inversion algorithm for use with drifting vertical array (VLA) data. The sea surface-generated ambient noise observed by the VLA is used to invert for the sediment parameters. This inversion algorithm has two important features:

1. First, passive bathymetry and bottom loss measurements are used together. Passive bathymetry is a coherent technique that depends on the cross-correlation of upward and downward pointings beams and the bottom loss method is an incoherent technique that depends on the ratio of noise levels coming from different matched pairs of vertical arrival angles.

2. Inversion methods that use either one of these have different properties and performance characteristics. Thus, using both of them together is an attractive combination. Here, the fathometer is used to estimate the water depth, the number of layers, and sediment thicknesses. This is followed by an inversion that uses both bottom loss measurements, estimating the sound speed, attenuation, and density profiles in addition to refining the previously obtained sediment thickness values.

Second, compressive sensing (CS) is incorporated in the fathometer inversion. Here we take advantage of the sparse nature of sediment formations where there are a finite number of layers interfaces that create strong reflections. CS provides a theoretical framework that enables expressing the problem as a convex optimization problem which can then be solved efficiently.

In recent years, CS has been used in diverse fields. In that paper, it was shown that just one or two hydrophones are needed—given enough averaging time. This greatly reduces the averaging time required to extract the noise sources while emphasizing those directly overhead; beamforming is used to limit the contributions from distant noise sources. A more detailed derivation of the angularly shaded, coherent arrivals. A simplified derivation of the noise correlation function.

Results are also shown from two experiments. In this paper, the technique is demonstrated on drifting array data collected during the Boundary 2003 experiment. © 2014 Acoustical Society of America

II. COMPRESSIVE GEAOACUSTIC INVERSION USING AMBIENT NOISE

Geoaoustic inversion estimates ocean environment parameters such as the water column sound speed profile (SSP) and sea-floor parameters such as the sediment layer thickness, SSPs, densities, and attenuation values. This paper introduces a passive geoaoustic inversion algorithm for use with drifting vertical array (VLA) data. The sea surface-generated ambient noise observed by the VLA is used to invert for the sediment parameters. This inversion algorithm has two important features:

1. First, passive bathymetry and bottom loss measurements are used together. Passive bathymetry is a coherent technique that depends on the cross-correlation of upward and downward pointings beams and the bottom loss method is an incoherent technique that depends on the ratio of noise levels coming from different matched pairs of vertical arrival angles.

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(a) Coherently (cross-correlation of upward/downward propagating noise using a minimum variance distortionless response fathometer) and incoherently (bottom loss vs frequency and angle using a conventional beamformer) to obtain the bottom properties. Compressive sensing is used to invert for the number of sediment layer interfaces and their depths using coherent passive fathometry. Then the incoherent bottom loss estimate is used to refine the sediment thickness, sound speed, density, and attenuation values. Compressive sensing fathometry enables automatic determination of the number of interfaces. It also tightens the sediment thickness priors for the incoherent bottom loss inversion which reduces the search space. The method is demonstrated on drifting array data collected during the Boundary 2003 experiment. © 2014 Acoustical Society of America

III. HIGH-FREQUENCY GEOACUSTIC INVERSION OF AMBIENT NOISE DATA USING SHORT ARRAYS

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Abstract. Ocean ambient noise is generated in many ways such as from winds, rain and shipping. A technique has recently been developed (Harrison and Simons, J. Acoust. Soc. Am., Vol. 112 no. 4, 2002) that uses the vertical directionality of ambient noise to determine seabed properties. It was shown that taking a ratio of upward looking beams to downward produces an estimate of the reflection loss. This technique was applied in data to the 3.5 kHz band using a 16 vertical array. Extending this to higher frequencies allows the array length to be substantially shortened and greatly reduces interference from shipping. If array lengths can be reduced to about 1 m then it may be possible to mount or tow such an array from a surface ship or submarine vehicle (an autonomous underwater vehicle). Although this seems attractive the noise is primarily generated by wind which in turn causes a rough sea-surface and bubbles and these factors combined with increased volume attenuation may degrade this type of reflection loss estimate at high frequencies. In this paper, we examine measured noise data from the October 2003 ElbaEX experiment using a 5.5 m array in the 1–4 kHz frequency band. Results indicate the noise field is predictable with modeling and the ratio of upward looking to downward looking beams produces an approximation to the reflection loss which can be inverted for seabed properties. For short arrays (a 1 m aperture is considered here), the beamforming is not ideal over a broad-band of frequencies. The beams are broadened and this leads to an up/down ratio that does not produce a good estimate of reflection loss. This is to be especially true for low grazing angles which is the part of the reflection loss curve that is often most important to estimate correctly. Techniques will be presented for mitigating the impact of beamwidth and grating lobes on estimating the seabed properties.

INTRODUCTION

Using measurements of ocean ambient noise to produce an estimate of seabed properties is attractive for several reasons. 1) Since ambient noise results from wind and rain interacting with the sea-surface the sound sources exist everywhere. 2) This sheet source provides an angular spread of plane-waves that have interacted with the bottom and therefore contain information about seabed properties. 3) Passive measurements not requiring a sound projector greatly simplify the design of an experiment or survey technique. 4) With concerns over the impact of sound on marine mammals, an environmentally friendly geoaoustic inversion method that does not require a human-made sound source is highly attractive.

Although the dependence of ambient noise on seabed properties has been widely reported, only recently has a method been developed that uses vertical directionality of
experiments. California, in August 1994 and October 1995, are discussed.

In this article, ADONIS is described briefly and a selection of investigations.

A multi-element reflector is an unusual design for an imaging system. In this case, if the beamwidth is greater than the spatial scale that is resolved in an acoustic daylight image will, of course, be determined by the beamwidth of the acoustic receiver. From the point of view of ambient noise, it has the advantage that the beam forming is performed without the acoustic detection system, in accord with the Rayleigh criterion. To create a multiple-pixel image, some phase or time delays are necessary. Sound incident on the dish from a given direction is focused onto a particular region of the spherical reflector. This and many other design features of the dish assembly provide the dish with structural rigidity. The dish assembly canister where filtering is performed and frames are constructed.

Mechanically, the system consists of a spherical reflector that is countered with a parabolic dish. Off-axis sensors are rather less pronounced than those entered with the rim of the dish. A spherical reflector is rather more flexible in the horizontal plane than a parabolic dish, and the object space, and for monitoring the horizontal direction, it is capable of rotating the dish around a full 360 degrees in both the vertical and horizontal plane.

A total of 130 receive-only beams, which are distributed in the bottom right panel of their Fig. 12, which is comparable with the results of Buckingham et al. 

\[ \frac{12}{H_20850} \]

\[ \frac{5}{H_20850} \]

\[ \frac{10}{H_20850} \]

\[ \frac{3}{H_20849} \]

\[ \frac{3}{H_20849} \]
partially placing it in the middle of ADONIS' field of view. In the center of mass of each drum were anchored to fix orientation and distance from the axis of the dish. The drums were suspended simultaneously from a 4-m-long surface floats weighted to make it negatively buoyant, and suspended from the sand drum, the water drum, and the foam drum, respectively. These drums were deployed in the water column, suspended from surface flotation units, and also partially buoyant. These drums were attached to the base of the foam drum to make it negatively buoyant. Each drum was clamped with 6.4-mm-diam connecting rods between steel endplates, 6.4 mm thick, and weights activating rods between steel endplates, 6.4 mm thick..

Once it was in place on the seabed, the clearance between the top of the dish and the sea surface was about 3 m. Figure 5 shows the deployment configuration, with ADONIS beneath the ORB looking towards the targets. The noise produced by dockside machinery and shore activities can be significant, with levels of 110–120 dB or higher, and may be a hundred meters distant from the experimental site also make a minor contribution to the background noise field, but this activity, and boat traffic. Marine mammals in pens several hundred meters distant from the experimental site also make noise which is often louder at dawn and dusk.

As an additional check, the dish was periodically panned to confirm the alignment of the in-water beam patterns of ADONIS. This is an important test of the integrity of the imaging system, since it ensures that the target positions within an image were localized to within one pixel. Incidentally, this same source was used for determining the source and hence the receiver with the targets. Thus, the source and hence the attention was paid to balancing the 126 channels because the acoustic contrast in most acoustic daylight images is generated by sources with a minor contribution to the background noise field, but this activity, and boat traffic. Marine mammals in pens several hundred meters distant from the experimental site also make noise which is often louder at dawn and dusk. The noise produced by dockside machinery and shore activities can be significant, with levels of 110–120 dB or higher, and may be hundred meters distant from the experimental site also make a minor contribution to the background noise field, but this activity, and boat traffic. Marine mammals in pens several hundred meters distant from the experimental site also make noise which is often louder at dawn and dusk.

In general, snapping shrimp do not swim well, and they tend to cluster in colonies around pier pilings, outcrops of rock, kelp holdfasts, and similar habitats which offer the animal shelter from predators. Source levels may be as high as 190 dB re 1 μPa at 1 m with a duration of the order of 5 ms or less. Typically, snapping shrimp, including Synalpheus lockingtoni, Alpheus clamator A. bellimanus, and Alpheus acutus, are found at night and are more abundant in the cold, nutrient-rich waters of the bottom waters of the northwestern Atlantic, and have little effect on the acoustic daylight experiments. Of the three main sources, the pulses from snapping shrimp feature a narrow bandwidth, and are capable of producing extremely energetic, very brief pulses with peak pressures that can exceed 1000 psi. The frequency range of ADONIS are snapping shrimp, industrial noise, and marine mammal noise. Marine mammal noise is typically less than 4 dB, implying that even small errors in equalization of the channels. Considerable attention was paid to balancing the 126 channels because the acoustic contrast in most acoustic daylight images is generated in calibration or equalization of the channels. The sound from snapping shrimp is of poor directional integrity, and the sound is often louder at dawn and dusk. The noise produced by dockside machinery and shore activities can be significant, with levels of 110–120 dB or higher, and may be hundred meters distant from the experimental site also make a minor contribution to the background noise field, but this activity, and boat traffic. Marine mammals in pens several hundred meters distant from the experimental site also make noise which is often louder at dawn and dusk.

In a number of the water column deployments, several syntactic foam (density 3215 kg/m³) cages were attached to the base of the foam drum to make it negatively buoyant. Each drum was clamped with 6.4-mm-diam connecting rods between steel endplates, 6.4 mm thick, and weights activating rods between steel endplates, 6.4 mm thick.

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Coastal warm waters

Source: Johnson et al. (1947)
SNAPPING SHRIMP AND UNDERWATER NOISE

Ever, they are very unlike the common shrimp. The snapping shrimp family Crangonidae (Alpheidae, see Rathbun, 1904) comprises about 27 genera and numerous species. Of these only the species of two genera, viz., Crangon (also called Aipheus by many authors) and Synaipheus, are capable of vigorous snapping. In the literature there are recorded about 215 species of Crangon and 150 species of Synaipheus. Two species of these genera are shown in Figures 1 and 2.

The claw structure, however, indicates that all the species do snap to some extent. The species range in size from about 2 cm. to a giant species, C. strenuus, attaining a length of 8 cm., but it is clear that size is not necessarily correlated with the noise produced. The few direct sound measurements available of isolated specimens indicate, for example, that Synaipheus lockingtoni may produce a louder snap than its larger relative Crangon dentipes. The average peak pressure level of Crangon for a distance of a meter was 115 db above 0.0002 dyne/cm²; whereas it was about 124 db for Synaipheus. While the difference may be real, the present observations are too few, and the spread too great, to confirm this.

The habit of snapping is associated with defensive and offensive activities. In closing the snapping claw, a vigorous jet of water is produced by means of a plunger arrangement described below. This sudden gush of water serves to frighten away enemies approaching too near. The antagonist may also be driven

Source: Johnson et al. (1947)
The beamwidth of 0.75 degrees gives an areal coverage of approximately 0.5 m\(^2\) at the target range, or in other words, four beams intersect each 1 m\(^2\) target panel. The noise spectra in three pixels, one on and the other two off the target, are illustrated in Fig. 8, where it can be seen that the acoustic contrast, represented by the difference between the curves, tends to increase with increasing frequency. Figure 8 shows another raw image, formed in this case from an average of the top three frequency bins 57 to 75 kHz. The improvement in resolution obtained at the higher frequencies is quite evident on comparing Fig. 8 and shows another raw image, formed in this case from an average of the top three frequency bins 57 to 75 kHz. When interpolation is applied to the data in Fig. 8, the image in Fig. 8 is obtained. At these higher frequencies, the target is front ensonified from snapping shrimp on the pier pilings. Although the target is visible in the raw, broadband data shown in Fig. 8, the low resolution resulting from the lower frequencies, combined with the granular pixel structure, give rise to a rather poor quality image. A distinct improvement in resolution can be seen in Fig. 8, where the low frequencies have been removed. Visually, the smoothing introduced by interpolation leads to a further improvement in image quality, as evident in Fig. 8, where the elongated shape of the bar is recognizable. As the directionality of noise varies, for whatever reason, the appearance of the images changes accordingly. Thus, there is no typical acoustic daylight image of a particular target, in the same way that there is no typical photograph of a given scene in daylight. In both cases, front and back illumination, for example, create different shadowing structures and hence different visual effects. The point is well illustrated by the low- and high-frequency, interpolated images of the bar target shown in Fig. 9. The low-frequency image in Fig. 9 is an admittedly crude silhouette, formed by back ensonification from the naval loading dock on the far side of San Diego Harbor. In the higher-frequency image the bar is front ensonified, probably from local snapping shrimp on the MarFac Pier pilings. Although the images in Fig. 9 are both of rather poor quality, the low-frequency silhouette can be seen to align with the high-frequency front-lit image of the bar. It is interesting that the effect seen in these two images is rarely observed in photography, namely, front illumination in one spectral band and, simultaneously, back illumination in another.

B. The fenestrated cross

Figure 10 shows another planar target, in the form of a fenestrated cross. The panels, aluminum faced with neoprene foam, were the same as those forming the bar target in Fig. 8. Again, the range was 38 m and the foam side of the panels was facing ADONIS. At the time of the deployment, the target was at a range of 38 m. The fenestrated cross is shown in Fig. 10a. Schematic of the scene falling within the field of view of ADONIS is shown in Fig. 10b. Example of a poor quality, high-frequency interpolated, intensity mapped image formed by averaging data over the top three frequency bins 57 to 75 kHz is shown in Fig. 10c. Spectrum, in dB re 1 Pa\(^2\)/Hz, of the noise in pixels, as identified in Fig. 10b, on a target panel 1, in the central window 2, and off the target 3. Example of a good quality, high-frequency, interpolated, intensity mapped image formed by averaging data from the top three frequency bins 57 to 75 kHz is shown in Fig. 10d. The target is shown at 38 m range.
Source: Chitre et al. (2012)
The 3D volumetric data processing is highly computation intensive and it increases with increase in volume resolution.

Figure 5.13 shows one time instant of 3D visualization video where the target test frame is clearly seen. Acoustic 3D imaging helps to visualize multiple underwater objects with more details, especially separation and distance between them can be visualised.

5.7 Summary

In this chapter, novel ANI technique using joint source localization is presented. The technique works by first detecting a snap on several sensors in the imaging array. The snap is then localized by using the time of arrival of the snap at all the sensors in the array and assuming that the snap originates near the sea bottom. Once the snap is localized in time and space, it is used as a known source in a bi-static sonar system to detect and locate a target. After a target is detected, an image can be formed using the beamformer output from the sensor array. Finally, multiple images of a target can be combined to produce a high quality image. This technique is able to not only produce high quality images of a passive target using ambient noise due to snapping shrimp,
A number of deployments were also been done in a bottom-mounted configuration, with the array attached on top of the 4-meter tall tripod. The entire system was placed on the seabed as shown in Figure 35. The electronics housing was attached at the lower end of vertical pole using a customized fitting. With the tetrahedral array mounted 4 meters above the seabed, we were able to map more than 20,000m$^2$ of area centered at the tripod.