Soundscapes

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LONG-TERM GOALS

To develop and validate a regional and global nowcast capability for ocean noise. The ambient noise field is, of course, a key part of the marine mammal habitat, and in turn can inform regulatory decisions by conservationists.

OBJECTIVES

Eventually this system will be coupled to global oceanographic models to provide hindcasts, nowcasts, and forecasts of the time-evolving soundscape. In terms of the types of sound sources, we will focus initially on commercial shipping and seismic exploration. As the research evolves we will gradually expand the capability to include many other types of sources.

APPROACH

The research has two principle thrusts: 1) the modeling of the soundscape, and 2) verification using datasets that have been collected around the Pacific and Atlantic Ocean basin. In terms of the modeling, we have begun with adiabatic normal modes (KRAKEN3D); in the adiabatic approximation, one assumes that the sound energy in any particular mode stays in that mode as the sound propagates radially from the source. This particular approach is extremely efficient. Longer term we will be including other models such as BELLHOP3D that can include mode coupling and 3D refractive effects.

Regardless of the model type, we first pre-calculate the transmission loss (TL) for a grid of hypothetical sources covering the globe. We then compute the noise level (NL) by convolving this TL data with a source level (SL) density. This two stage approach allows

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us to rapidly produce updated soundscapes as the SL density changes due to different source types or to temporal variations.

As a means of ensuring the calculations are correct, we have structured the algorithms so that all source types are first mapped into a SL density. This SL density represents the power spectral density in a 1-Hz band for a nominal 1-m source depth and per unit area (dB/Hz/m^2). These SL density maps are very informative in themselves to get a general sense of the energy the source is putting into the water column. As mentioned above, the final stage is then to convolve that SL distribution with the channel response to bring in the propagation effects.

WORK COMPLETED

As background we show first global soundscapes due to merchant shipping (Figure 1) and winds (Figure 2). These plots are slices out of a global database for frequencies of 50, 100, 200, 400, and 800 Hz; for receiver depths of 5, 15, 30, 200, 500, and 1000 m; and for wind speeds of 10, 25, and 40 knots. The plot shown for wind noise corresponds to a 10-knot wind; a receiver at 200 m depth; and a frequency of 100 Hz.

In a sense, these wind noise plots are easier to interpret than the shipping noise soundscapes since the source level density (the overhead 'lighting' or ensonification in the ocean) is uniform for our wind speed model. Thus the variations in level that result are strictly a function of the propagation conditions. That in turn depends on the bottom type and, to a lesser degree here, the oceanography. These effects are seen in the figure and there are some obvious features such as the mid-Atlantic ridge. One may compare these plots to those of the shipping alone to gauge the role of the variation in shipping density. However, one should consider that the wind noise is closer to the surface and this produces a dipole pattern with more energy propagating vertically.

In our global soundscape model, we had been using the World Ocean Atlas (WOA-2005) for the global oceanography (a climatology) and the Shuttle Radar Topography Mission (SRTM) for global bathymetry. A critical issue in the global soundscape modeling is the environmental information so we also integrated WOA-2013, GDEM (Generalized Digital Environmental Model) and DBDB-V (Digital Bathymetric Data Base) and compared the databases. The WOA in particular had been disappointing to us in some parts of the world we examined, e.g. the Baltic where there were few points in the sound speed profiles. Both WOA-2013 and GDEM have a spatial resolution of 0.25^o, whereas WOA-2005 was only 1.0^o, which is also an improvement.

It is difficult to draw firm conclusions about the quality of the different databases, but our sense was that GDEM offers a clearer picture of the oceanography, providing more points in depth. DBDB-V provided coarser resolution (2 arc minutes on the global scale), which was significantly coarser than the 30 arc second resolution in SRTM. All of these databases are now available in our software tools.

We have been doing increasingly more complex simulations with our software; e.g., a recent study with over 150,000 virtual source locations around Norway spaced every tenth of a degree over a large area. The handling of these large datasets becomes more complicated. This has led us to various optimizations. For instance, we now skip immediately any virtual source point where the source level density vanishes (typically over land, but also places where there are no ships). We also modified the noise file formats so that the record length is shortened.

To further optimize the calculations we have developed a 'locally-flat approximation' in which an analytic formula is used to generate the noise level due to an sheet of sources with a constant level. The analytic formula is used with the local source level density at each virtual source point. Thus, a soundscape is generated that varies over lat/lon taking into account the local propagation conditions and source level density by pretending that that local value is valid to infinite range. Thus the calculation is locally flat in both the environmental properties and the source level density. We will discuss the merits of this approach further in the 'RESULTS' section below.

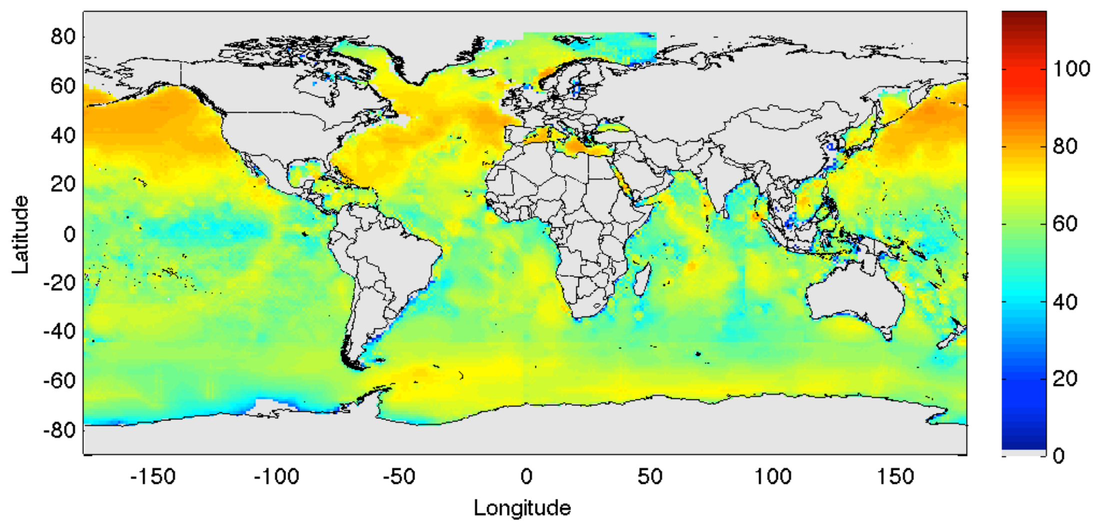

Figure 1. *Modeled noise spectrum level at 200 Hz and 200 m depth due to merchant shipping for the year 2004.*

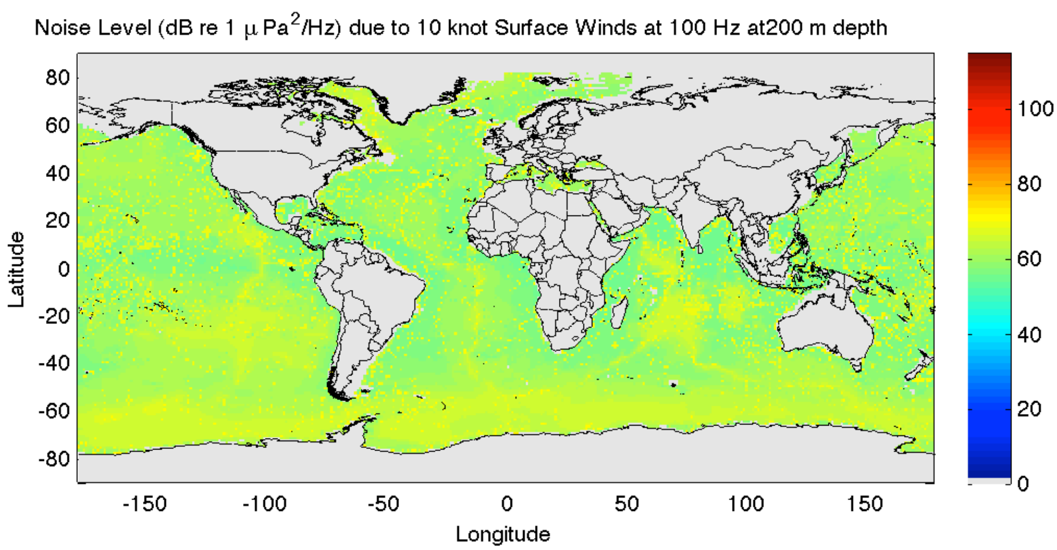

Figure 2. *Modeled noise spectrum level at 100 Hz and 200 m depth due to a uniform wind field at 10 knots.*

RESULTS

We focus here on modeling results off the coast of California that includes the Channel Islands National Marine Sanctuary. This is an area we have also been using for validation tests, comparing modeled noise levels to measurements with in the field. Figure 3 introduces us to the environmental conditions, showing the bathymetry and bottom type for the area. The bottom type is presented in a simplified form with just one division between soft and hard bottom types. The final sound map is shown in the lower part of Figure 3 where we each point on the map accumulates the noise out to a range of 50 km. For computational reasons, we prefer not to integrate noise out to longer ranges.

In Figure 4 we show the result using the 'locally-flat' approximation, which is a calculation that can be done much more rapidly. The upper and lower plots are done using a noise disk with a radius of 10 km and 320 km respectively. In general, the larger the radius, the more accurate the result— larger radii include noise sources out to longer ranges and as we increase the radius the result converges asymptotically.

The result is of mixed quality. In many areas it does a good job of replicating the full calculation. However, in areas where there are more rapid changes in either the environment or the shipping density it lacks the smoothing that results from averaging over those surfaces.

How far in range must we go to obtain convergence? The locally-flat approximation provides a convenient way to get a sense of that since it can be run with any radius of integration. The formula provides an analytic result for any range of interest and very rapidly. Thus, we can calculate the noise level for a variety of radii and see what radius is required to obtain a noise level that is within 1 dB of the converged value. The result is a measure of the noise footprint as seen in Figure 5. This result is very useful. It confirms that the 50-km radius used for the full noise calculation is adequate for most of the domain. We see that the radius tends to be larger as we go further offshore into deeper water. It also shows that the radius is larger over harder bottoms which allow sound propagation to longer ranges.

In Figure 6, we apply the locally-flat approximation to calculate the noise footprint for the entire globe. One can interpret many features on this plot; however, the most obvious one is the larger noise footprint near the poles. This is a result of the sound channel axis coming closer to the surface in polar regions. One may also see this signature of that shoaling sound channel in the resulting noise level map, e.g. in Figure 2.

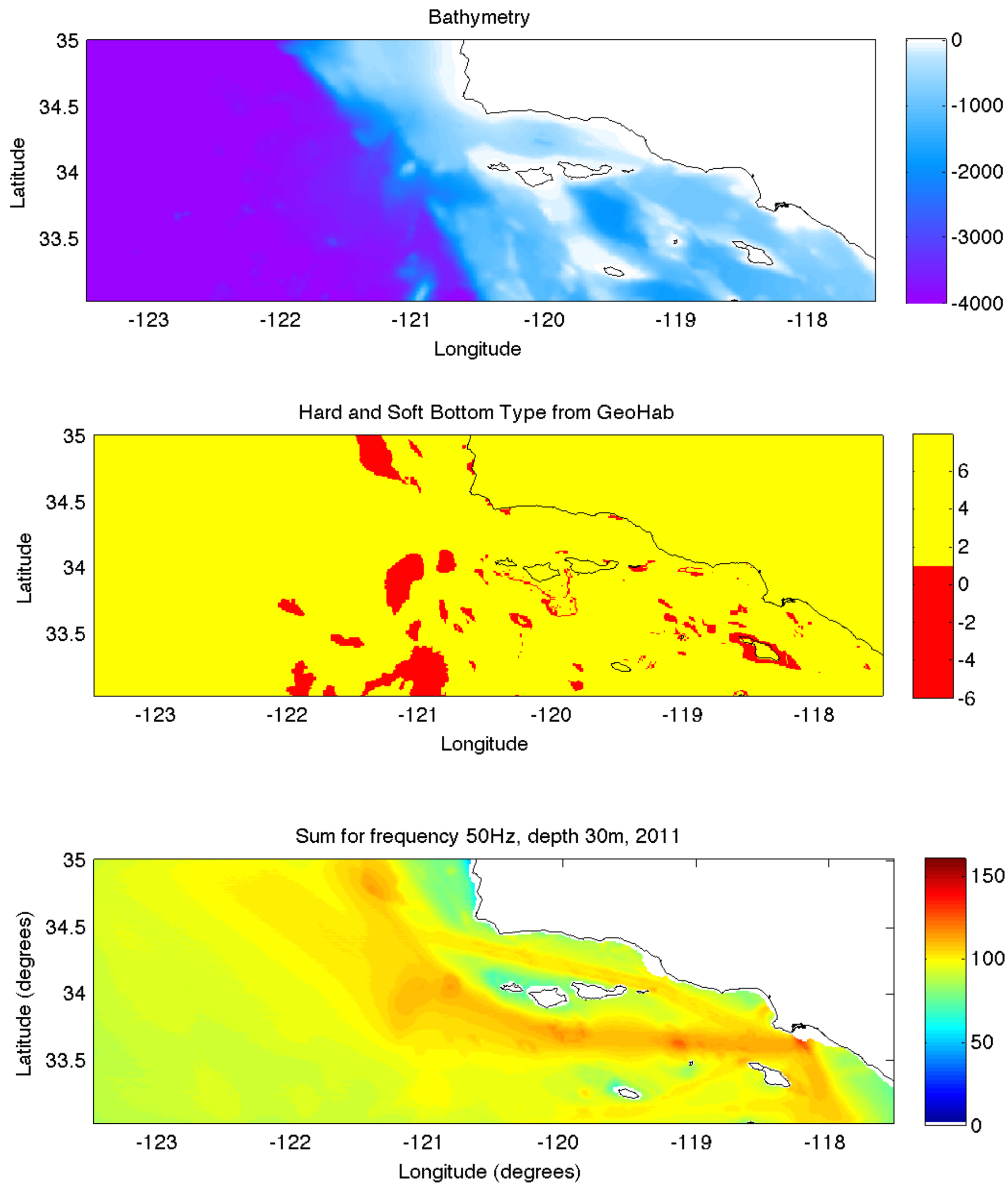

Figure 3. *Bathymetry (upper), bottom type (middle), and noise level (bottom). The noise level is for a 50-Hz frequency and a 30-m receiver depth.*

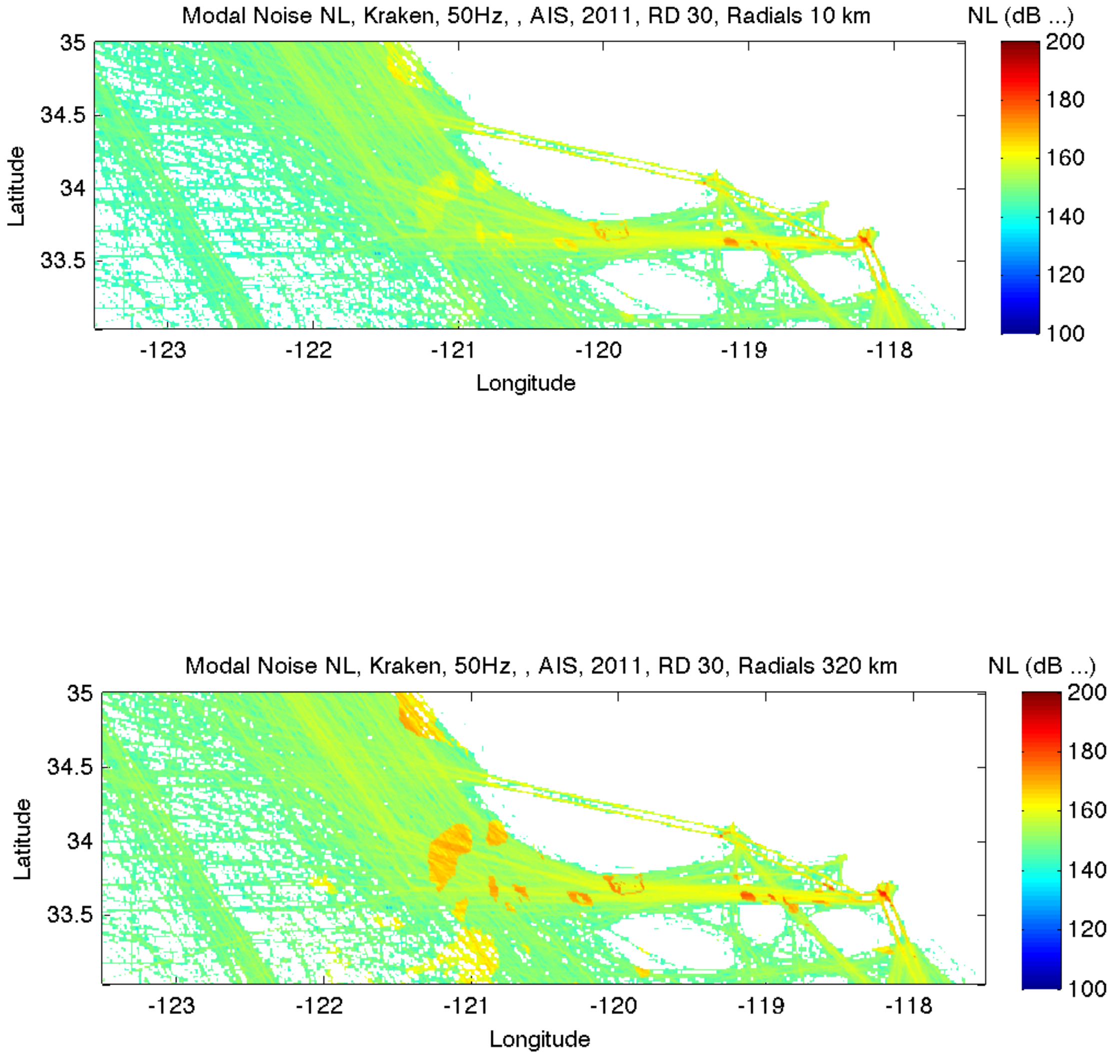

Figure 4. *Locally-flat approximation to the noise map. The upper and lower plots accumulate noise sources out to a ranges of 10 km and 320 km respectively.*

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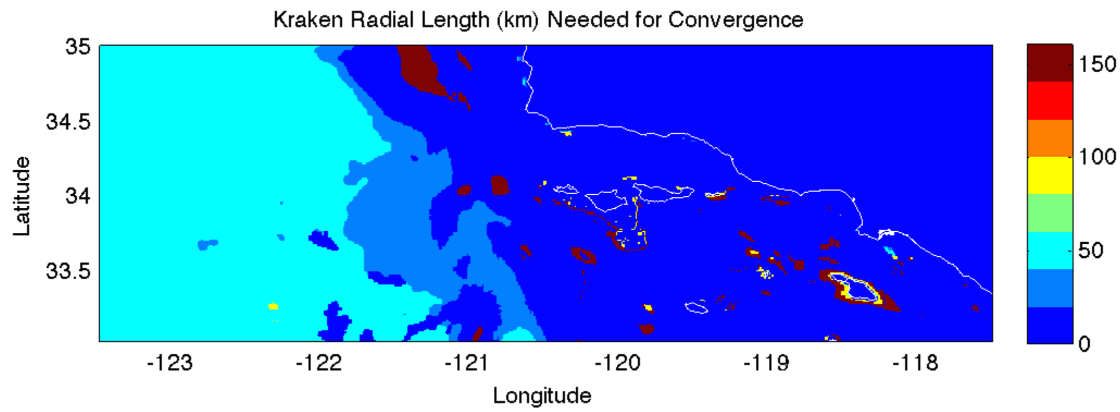

Figure 5. *Map of the noise footprint characterized in terms of the radius in km of the noise disc that is required to obtain a convergent noise level.*

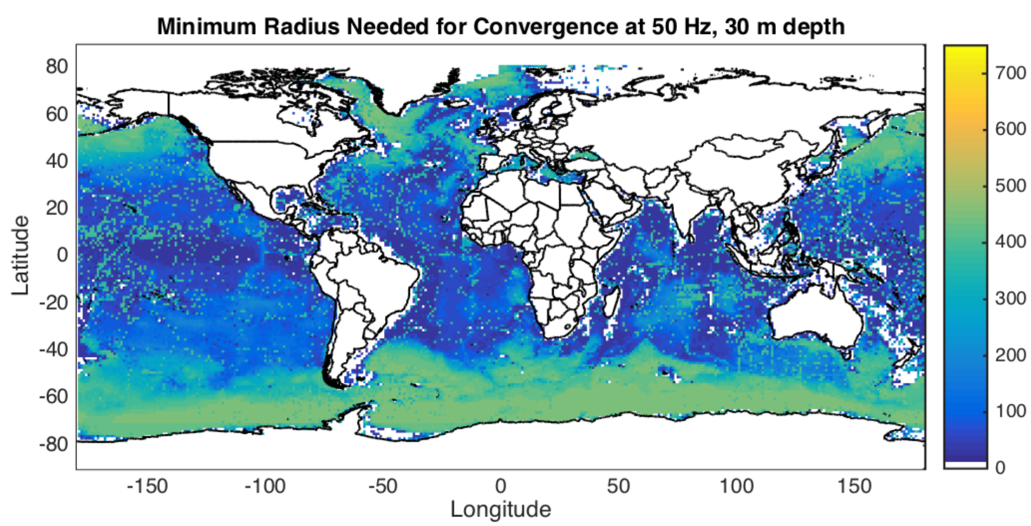

Figure 6. *Global map of the noise footprint characterized in terms of the radius in km of the noise disc that is required to obtain a convergent noise level.*

IMPACT/APPLICATIONS

The importance of this work is that it provides information on the ambient noise field, which is a key part of the marine mammal habitat, and in turn can inform regulatory decisions by conservationists. For instance, one may assess the value of ship quieting and the role of acidification. In addition, the ambient noise provides the background field against which new sound sources such as pile drivers are heard. It also facilitates the studies of masking effects on marine mammals.

We have continued to be active in presenting this work to the broader community. I participated as an invited speaker at a Workshop in D.C. on Sound Exposure Modeling (January 7-9) organized by the *American Petroleum Institute*, the *International Association of Geophysical Contractors*, and the *Bureau of Ocean Energy Management*, the *National Marine Fisheries Service*.

I also was invited to participate in a workshop in Leiden (April 14-17), The Netherlands, on Predicting Sound Fields - Global Soundscape Modeling to Inform Management of Cetaceans and Anthropogenic Noise, sponsored by the *International Whaling Commission*, the *Scientific Committee on Oceanic Research*, *NOAA*, and the Dutch *Ministry of Infrastructure and the Environment.* A key result of this Workshop was a joint report with recommendations directed to sponsoring international organizations or their advisory groups on soundscape modeling and mapping tools.

RELATED PROJECTS

We have entered into a contract with the Comprehensive Test Ban Treaty Organization that provides us access to their network of hydrophones. We are also working on an Workshop on global soundscape modeling that is supported by the International Whaling Commission and the Scientific Committee on Oceanic Research. The technique permitting us to model steep angle paths in a normal mode framework was developed with the support of the ONR Ocean Acoustics program. Lastly, we are partnering with the NATO Centre for Maritime Exploration in REP-14 which will provide extensive ship noise data.

PUBLICATIONS

Michael B. Porter and Laurel J. Henderson, “Global Ocean Soundscapes”, *Proceedings of the International Congress on Acoustics* 2013, Vol. 19, 010050 (Proceedings of Meetings on Acoustics), Montreal, Canada (2013) [published].

J. Gedamke, et al., “Predicting Anthropogenic Noise Contributions to U.S. Waters in The Effects of Noise on Aquatic Life,” Eds. A. Popper and A. Hawkins (Conference Proceedings), 2013 [published].

HONORS/AWARDS/PRIZES

Pioneers Medal, *Acoustical Society of America*
(to be awarded at the Indianapolis Meeting, October 2014).