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Acoustic influence of underwater mobile survey vehicles on the soundscape of Pacific rockfish habitat

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Abstract: Noise produced by scientific equipment during fisheries surveys is largely unstudied, though these sound sources may have an effect on the organisms of interest and on their resultant stock assessments. This paper describes acoustic signatures of two underwater mobile vehicles and accompanying research ships used to survey demersal fishes, and discusses the acoustic contributions of the survey equipment to rockfish habitat. Increases in noise over ambient levels were high, but the majority of sound energy was generated by communication and navigation instrumentation on the ships and survey vehicles, and was out of the expected sensitivity range for fish hearing.

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1. Introduction

Increasing awareness of anthropogenic noise in our environment has prompted a surge in research on potential impacts of sound on wildlife. A recent review (Shannon *et al.*, 2016) documented 242 empirical peer-reviewed studies on this topic between 1990 and 2013, for both terrestrial and marine species. Most of these papers described effects of urban/ambient, industrial, military, or transportation noise sources, and though many more papers have been published since then, the focus within the marine environment has remained on non-scientific sound sources (for exceptions, see De Robertis and Handegard, 2013; Quick *et al.*, 2016; Cholewiak *et al.*, 2017). However, scientific researchers use several types of marine equipment that emit sound of various frequencies and intensities, including small seismic airgun or plasma sound source arrays to conduct geological surveys, echo-sounding devices to map ocean bathymetry and measure densities of fish schools, and Acoustic Doppler Current Profilers (ADCPs) to estimate oceanographic conditions. Sounds from these types of equipment are emitted in addition to noise of the accompanying research vessels, which are in relatively close proximity to the animals of interest.

Direct observation surveys of demersal fishes are often complex operations, combining a variety of noise-generating equipment types to estimate population size and describe fish behavior at depth. Some of these equipment types include autonomous underwater vehicles (AUV), human-occupied submersibles (HOV), and remotely operated vehicles (ROV), which are used to survey fishes along predetermined tracklines in high relief rocky habitats (Yoklavich *et al.*, 2015). Stoner *et al.* (2008) reviewed the behavioral response of demersal fishes to underwater survey vehicles, and Laidig *et al.* (2013) described specific reactions of rockfishes (*Sebastes* spp.) to two mobile tools (an ROV and HOV). Responses varied by vehicle and life history of the fishes,

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included both attraction and repulsion, and had the potential to bias visual assessments of fish population densities. The mechanism for these responses, however, is not fully understood. Several stimuli prompting these reactions have been suggested, including noise, but there is little information on acoustic signatures of these underwater vehicles (Stoner *et al.*, 2008) and associated instrumentation. Identifying the acoustic signatures of survey vehicles is therefore important in understanding potential biases of the methods we use to count fishes.

In this study, we deployed a continuously recording passive acoustic monitor attached to a stationary surveillance platform in deep rocky habitat off southern California. We quantified acoustic signatures of mobile vehicles and accompanying research vessels used to survey rockfishes and assessed the acoustic contribution of these vehicles to the rockfish habitat and the soundscape in general.

2. Methods

Data were collected over six days in October of 2016 on a rocky bank off the Channel Islands [Footprint Bank; Fig. 1(a)]. Scientists deployed a stationary surveillance platform (width: 1 m; depth: 1 m; height: 2 m) in rocks on the seafloor at approximately 120 m water depth. The platform was equipped with stereo cameras, ultrasonic imaging sonars (DIDSON), a passive acoustic recording system [digital acoustic monitor (DMON)], a long baseline (LBL) tracking transponder, and other environmental sensors [Fig. 1(b)]. Of note is a flotation pack constructed of rigid polymer foam located at the top of the surveillance platform [Fig. 1(b)], which was used to offset the weight of the platform during deployment but may have attenuated sounds produced above the DMON.

The DMON recording system was used to record sound that is typically generated during surveys of demersal fishes. The DMON low-frequency channel had a raw sampling rate of 80 kHz, decimated in firmware to 16 kHz to improve signal-to-noise ratio and reduce size on flash (analog high- and low-pass filters at 8 Hz and 7.5 kHz, respectively). The mid-frequency channel had a raw sampling rate of 240 kHz, decimated in firmware to 120 kHz (analog high- and low-pass filters at 100 Hz and 60 kHz, respectively). The system therefore had a functional recording bandwidth of 8 Hz–60 kHz across the three acoustic channels. The individual DMON unit used in this project was not calibrated, but calibrated electronics gain was combined with ceramic manufacturer's sensitivity to specify the system sensitivities. The system contained three custom-made and nominally omnidirectional hydrophones, two of which were mid-frequency channels [-167 dB re: 1 V/μPa nominal system sensitivity +/$-$3 dB from 1 to 55 kHz, but see calibrations of similar units by Gray (2018); Mooney and Gray (2018)] and one of which was a low-frequency channel (-170 dB re: 1 V/μPa nominal system sensitivity, +/$-$4 dB from 0.1 to 1.4 kHz). These system sensitivities include 20 dB hydrophone gain and 13.2 dB audio board gain.

We used the DMON to record sound generated by two untethered mobile survey vehicles, each making multiple passes in front of or above the surveillance platform. The *DeepWorker* HOV (Nuytco Research Ltd.) was operated at 0.5 kn about 1 m above the seafloor by one experienced submersible pilot from inside the submersible. Passes were made 1–3 m directly in front of the DMON. The *Seabed* AUV (Seabed Technologies Inc.) was programmed to operate at 0.25 m/s ($\sim$0.5 kn) and 3 m above the seafloor. AUV passes were made about 1 m above the surveillance platform and about 1.5 m above the DMON hydrophone, however, horizontal distance from the platform was rarely closer than 20 m. While reliable source level estimates were not possible with these data, acoustic levels of the AUV transmissions were compared based on two AUV distances from the

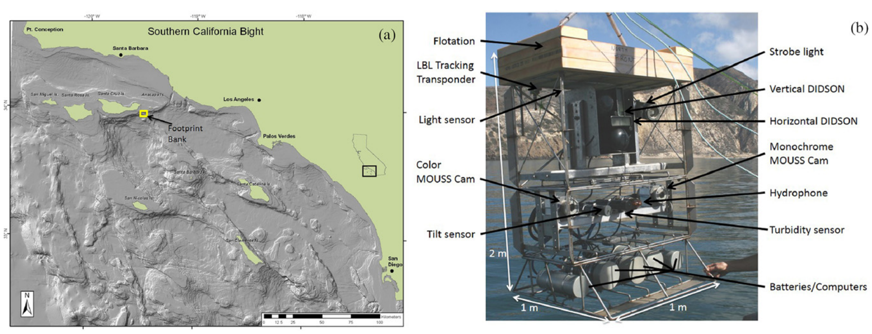

Fig. 1. (Color online) (a) Study area (with Footprint Bank marked by yellow box) in geographic context of the Southern California Bight. (b) Surveillance platform, indicating location of the DMON hydrophone, other survey instruments, and flotation material.

surveillance platform. Range from the AUV to the platform was estimated using interpolated navigation data from an ADCP and fiber optic gyroscope.

The mobile vehicles were supported by two research vessels. The AUV was deployed from NOAA Ship *Reuben Lasker*, a 209-ft Oscar Dyson-class fisheries survey vessel that has a low sound signature and meets the modified ICES (International Council for Exploration of the Sea) criteria for diesel generators when operating at 11 kn and below (Mitson, 1995). The *Reuben Lasker* typically operated at <1 kn while tracking the AUV, remaining within 1 km proximity but limiting noise signatures and turning off echosounders when possible. The HOV was deployed from the *R/V Velero IV*, a 110-ft, single engine fisheries research vessel. This ship typically operated at <1 kn while tracking the HOV, remaining in close proximity (directly overhead, $\sim$120 m) to the surveillance platform and the HOV.

Sound sources and acoustic frequencies associated with the HOV, AUV, and these two support vessels are listed in Table S1 of the supplementary material.[1] Notably the HOV contained an ultra short baseline (USBL) tracking transponder, UQC transducer/telephone, and scanning sonar. The UQC is used to communicate between the submarine and the support vessel. UQC is designated shorthand for electronic equipment based on the Joint Electronics Type Designation System (U: General Utility, Q: Sonar and Underwater Sound, C: Communications, Two-Way). The AUV also held a USBL transponder, as well as an ADCP and acoustic micromodem (WHOI AUV 0.92). Scientific echosounders also were active on the ships, but some frequencies were outside the recording bandwidth of the DMON.

DMON recordings were manually scanned in Adobe Audition to identify occurrences of various acoustic sources, and representative examples were used to illustrate their acoustic signatures. Selected clips were analyzed using custom programs in MATLAB 2014a (The MathWorks, Inc.) to calculate variations in root-mean-square (RMS) received level of sound in three nominal frequency bands: low (50–500 Hz), middle (500 Hz–25 kHz), and high ($>$25 kHz) (Hildebrand, 2009). The DMON low frequency channel was used for the low frequency band, and mid-frequency channels were used for the middle and high bands. Ambient noise was estimated as the noise level in the low frequency band during the 10 min prior to and after a period of maneuvering of the *R/V Velero IV* near the surveillance platform [as in Fig. 4(b)], during a time when the AUV was not in the water and the HOV was not on station.

3. Results

The DMON recorded for a total of 32:35:51 (h:m:s). We identified acoustic signatures of the two underwater mobile survey vehicles and their support vessels, which included several distinctive communication signals as well as lower frequency thruster noise. Baseline ambient noise in the area during the time of the experiment was estimated at 99 $+/-3$ dB re 1 μPa RMS (50–500 Hz). Local sea conditions were generally calm, ranging from 0 to 1 m swell and with winds less than 5 kn over the duration of the experiment.

The AUV's overall acoustic signature was comprised of several components, including sound from the LBL transponder used for vehicle tracking (located on the surveillance platform), from an acoustic micromodem used for telemetry data transmission between ship and vehicle (located on the AUV), and from the thrusters used to maneuver the vehicle along the trackline. Most prominently, the AUV LBL and acoustic modem transmissions produced a distinct, non-continuous signal around 10 kHz [detail shown in Fig. 2(a), Mm. 1]. This signal registered on the DMON approximately every 20 s whenever the AUV was operating under water, regardless of its distance from the hydrophone. In the low frequency band this signal was not detectable over ambient background levels during transmission, but in the mid-frequency band it resulted in increases of up to 40 dB over ambient levels [Fig. 2(b)]. Though the signal was easily detectable at any time during the survey, RMS received levels at the DMON were $\sim$20 dB lower when the AUV was far away (423 m) than during periods when the AUV was closer (29 m) to the hydrophone [Fig. 2(c)].

Mm. 1. Example acoustic clip of AUV. This is a file of type "wav" (7 Mb).

The spectrogram of the HOV passing 1–3 m in front of the platform showed several components of the vehicle's acoustic signature (Fig. 3, Mm. 2), including a 10–20 dB increase in general noise in the low and mid-frequency bands during the 60–120 s pass [Figs. 3(a) and 3(b)], transmissions of the UQC telephone at 27 kHz before and after the closest point of approach, and transmissions of the USBL tracking transponder at 30–40 kHz.

Mm. 2. Example acoustic clip of HOV. This is a file of type "wav" (7 Mb).

Low frequency sound in the range of rockfish hearing (e.g., < 1 kHz) was generated at varying intensities by both vehicles and their support vessels depending on their mode of operations. For example, low frequency sound from the *Reuben Lasker* was minimal (levels ranging from 105 to 112 dB re 1 μPa RMS) during a period when the ship was surveying at a constant speed within 500 m of the hydrophone and neither the HOV or AUV were in the water [Fig. 4(a)]. Sound levels produced by the R/V *Velero IV* while maneuvering to remain on station and in communication with the HOV reached much higher levels [up to 121 dB re 1 μPa RMS, Fig. 4(b)]. AUV thrusters were occasionally, but not always, audible as humming with harmonics visible in the low frequencies [<0.3 kHz; Fig. 4(c), Mm. 3], and were 10–15 dB lower than those of the HOV. HOV thrusters exhibited audible oscillations (a whining sound) in the low frequencies during passes in front of the surveillance platform [Fig. 4(d), Mm. 2].

Mm. 3. Example acoustic clip of AUV, low frequency thrusters audible. This is a file of type "wav" (0.8 Mb).

4. Discussion

The research presented here describes the acoustic contributions of underwater (an HOV and AUV) and surface (research vessels) survey equipment to the soundscape of demersal fishes living in deep rocky habitats off Southern California. In general, the communication and navigation instrumentation on the ships and survey vehicles produced more intense sound than the vehicles themselves. Acoustic levels of these communication systems were sometimes high enough to saturate recordings beyond the maximum recordable level of the DMON, despite potential attenuation from the foam flotation pack on top of the surveillance platform if it were in the line of sight between the hydrophone and the vehicle. The peak frequencies of this instrumentation were well above presumed fish hearing ranges (which is generally best below 2 kHz, Tavolga, 1980), but at close ranges we saw evidence of transducer low frequency rolloff, and general vehicle noise (engines, thrusters, mechanical noise, etc.) was present in these lower frequencies as well.

Rockfishes, a diverse group of demersal fishes being surveyed by underwater vehicles, are a soniferous genus that produce low level sounds below 800 Hz (Širović *et al.*, 2009). One northwestern Pacific Ocean species (black rockfish, *Sebastes inermis*) has been estimated to hear between 80 and 800 Hz with a peak sensitivity at 300 Hz and auditory thresholds close to 100 dB re 1 μPa (Lee and Seo, 2000). This genus is therefore likely to hear the frequencies of the survey vehicle noise, which could mask acoustic communication of the fishes or impact their ability to perceive the auditory scene (Fay and Popper, 2012). The temporal components of sound are also important in fish hearing, and may particularly affect the way fish respond to a sound. Sounds

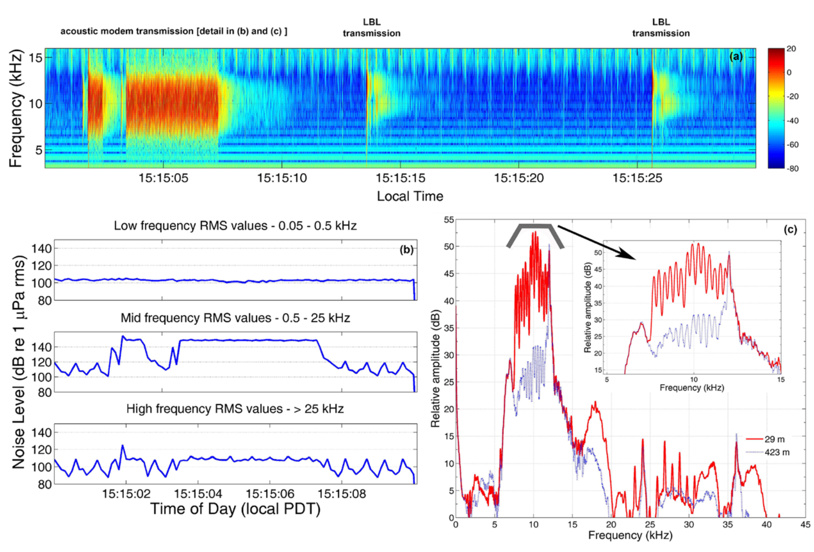

Fig. 2. (Color online) Typical noise signature of the SeaBED-class AUV. (a) Spectrogram (FFTsize 512, 75% overlap) of communications from the AUV during a relatively close pass (< 50 m from surveillance platform), showing one modem transmission containing vehicle telemetry information and two transmissions from a LBL tracking transponder. Transmissions from ship scientific echosounder at 18 kHz are visible at top of spectrogram. (b) RMS received levels during one acoustic modem transmission as calculated from the passive acoustic recorder over low, mid, and high frequency bands. (c) Savitzky-Golay filtered frequency spectrum of an acoustic modem transmission at close (29 m) and far (423 m) range from the surveillance platform. Distance from AUV to platform is estimated by integrating data from onboard navigational sensors (see Sec. 2).

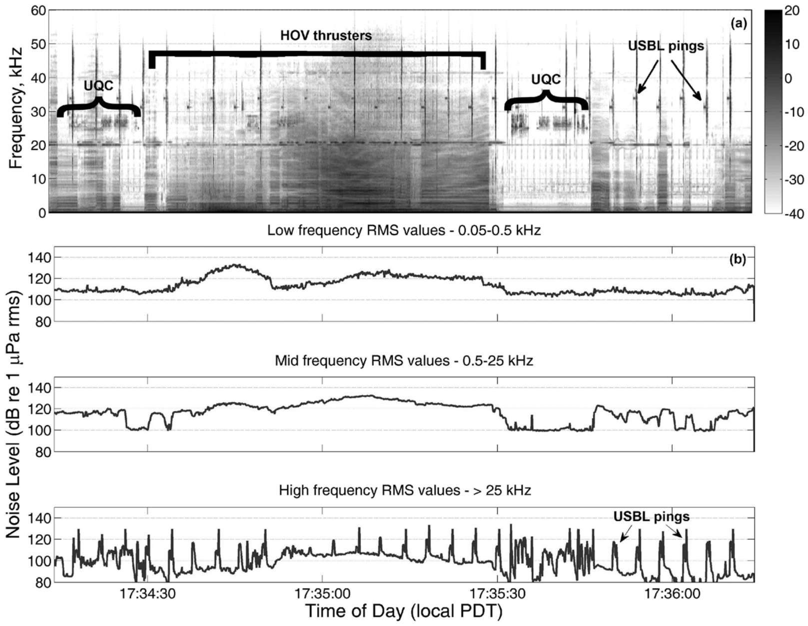

Fig. 3. Acoustic signature of HOV, including USBL navigation system and UQC underwater radio communication. (a) Spectrogram (FFTsize 512, 75% overlap) during a close pass (∼2 m from the surveillance platform). (b) RMS received levels of the generated noise calculated from the passive acoustic recorder over low, mid, and high frequency bands.

with a sharp and sudden onset (in mammals, 80–90 dB over a hearing threshold and ∼5 ms rise time, Götz and Janik, 2011) can elicit a startle response, which has been demonstrated in fish responding to impulsive sounds like seismic airguns (100–120 dB over hearing thresholds and 3 ms rise time, Wardle *et al.*, 2001). We do not expect that the sounds from survey vehicles in our study would elicit a classic startle response because the HOV acoustic signature increases in level relatively slowly over the duration of its 1–2 min pass (∼30 s rise time), and while the communication transmissions of the AUV have a much faster rise time (4–7 ms), the frequencies of these transmissions are well above the hearing ranges of most fish (Tavolga, 1980). The complex acoustic signature of the HOV does contain modulating thrusters, which could contribute to masking release or enhanced behavioral response (Fay, 2011; Neo *et al.*, 2014), but this sound is combined with several other acoustic components with varying spectral and temporal characteristics that ultimately complicate our predictions of how fish may perceive or respond to the sounds. Figure S1 of the supplementary material[1] shows the temporal envelope of an HOV passby, low-pass filtered at 5 kHz to focus on fish hearing range.

Captive rockfish have responded behaviorally to broadband seismic sounds at levels as low as 161 dB re 1 μPa (Pearson *et al.*, 1992), and similar sounds at ∼186 dB re 1 μPa peak have reduced catch-per-unit-effort values by over 50% in a commercial hook-and-line rockfish fishery (Skalski *et al.*, 1992). Sounds recorded in our study were usually well below these levels (the maximum HOV vehicle noise at low frequencies was ∼130 dB re 1 μPa RMS, which is well below the captive behavioral response threshold mentioned above), and we assume that received levels at the DMON are comparable to what fish occurring along a survey trackline would experience. Also generally, the behavioral response of rockfish species to underwater survey vehicles has been reported as minor compared to response from other fishes (Carlson and Straty, 1981; Yoklavich *et al.*, 2007).

Describing acoustic signatures of survey vehicles helps understand potential biases of the methods we use to count fishes. It is clear that some fish species respond to some survey vehicles operating at distances beyond the visual range of observers and cameras (Stoner *et al.*, 2008; De Robertis and Handegard, 2013), but the mechanism for this response is unknown. Laidig *et al.* (2013) found that fewer fishes reacted to an HOV than to a ROV. While sources of vehicle disturbance were not studied by Laidig *et al.* (2013), the ROV is operated from a tether attached to the ship while the HOV is untethered; along with difference in noise generation, movement of the tether could influence fish behavior. In our study, the HOV had a broader band acoustic signature and more intense energy in the lower frequencies than did the AUV, perhaps at least partially because of its closer range to the surveillance platform, but it remains to be seen whether fish responded more

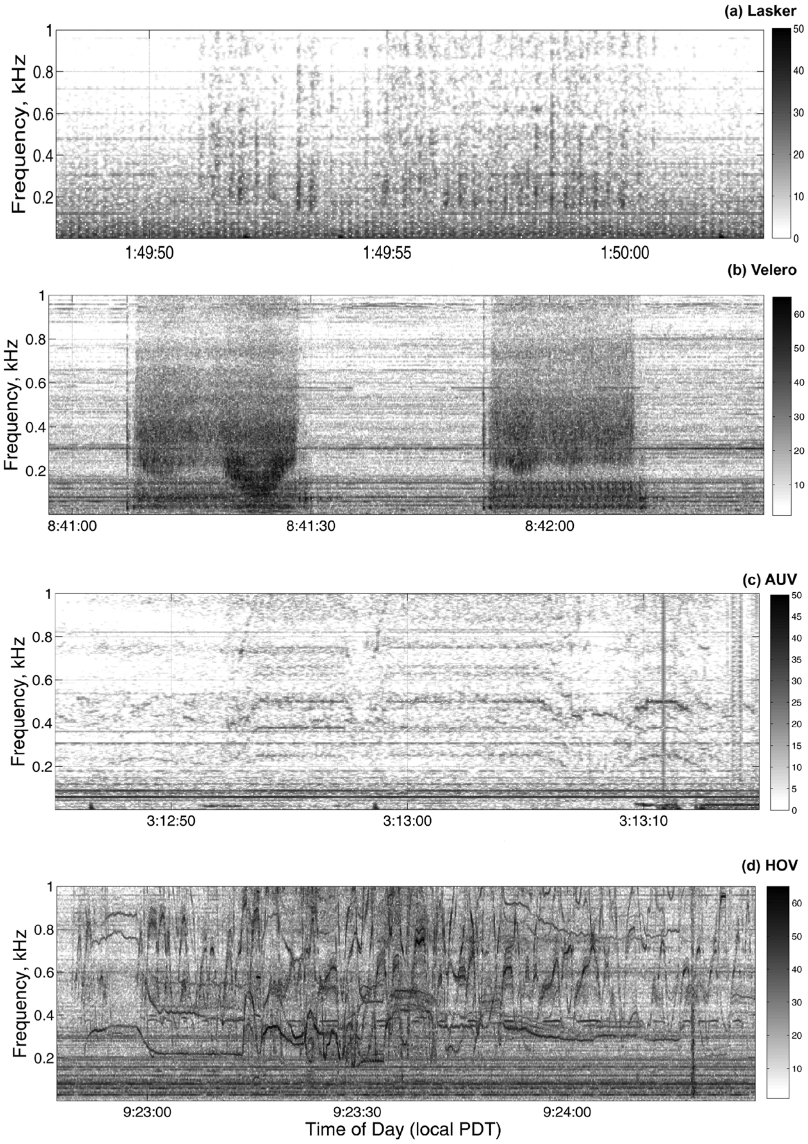

Fig. 4. Acoustic signatures of vehicles and support vessels within low frequency range of rockfish hearing (<1 kHz). (a) Support vessel *Reuben Lasker* engines during a survey when R/V *Velero IV* was not present and the AUV and HOV were not in the water (FFTsize 512, 75% overlap). Ship distance from hydrophone ranged from 380 to 500 m. (b) Support vessel R/V *Velero IV* during periods of maneuvering while tending the HOV (~120 m directly over the hydrophone). (c) AUV thrusters during periods of maneuvering close to the surveillance platform (~30 m distance) (FFTsize 1024, 75% overlap). (d) HOV thrusters during a pass in front of the surveillance platform (~2 m distance, FFTsize 1024, 75% overlap).

strongly to the HOV than to the AUV. Though ours is a pilot study to initially characterize acoustic signatures of underwater mobile survey vehicles and accompanying support ships, more comprehensive analysis is planned in the future to address these issues.

Evaluating the acoustic signatures of underwater survey vehicles and their support vessels also helps resource managers assess the overall contribution of these methods to the soundscape of what is often considered sensitive marine habitat. As mentioned above, the sound produced by survey vehicle instrumentation in this study was largely above the presumed hearing range of most demersal fishes, but many of these sounds are within the auditory range of most marine mammals and depending on propagation conditions, could influence behavior of these protected species. We have also confirmed that vehicle noise in the range of fish hearing was present, and this sound could at minimum serve as a cue of an oncoming survey vessel. Further research is needed to tease apart the drivers of fish behavioral responses amongst different stimuli including spectral and temporal components of noise, lights, and, in particular, particle motion (Popper and Fay, 1993; De Robertis and Handegard, 2013). Research efforts should include isolation of various stimuli, as well as more comprehensive description of how stimuli vary based on operating parameters of survey vehicles (such as possible increases of sound level or modulation rate with speed of the vehicle). We hope that this work will serve as a baseline for studies attempting to couple the sound signatures of scientific equipment to potential behavioral responses of fishes during surveys.

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References and links

[1]See supplementary material at https://doi.org/10.1121/1.5109914 for sound sources and acoustic frequencies associated with the HOV, AUV, and the two support vessels, as well as an image of the temporal envelope and fine structure of a pass of the HOV by the surveillance platform.

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