The following Supplement accompanies the article

Bioacoustic measurements complement visual biodiversity surveys: preliminary evidence from four shallow marine habitats

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Table S1. Results from either one-way ANOVAs or Kruskal-Wallis tests, testing for differences within each biodiversity and environmental variable across habitat types and sites. Significant differences were followed by Tukey's HSD pairwise comparisons. DV= dependent variable; IV= independent variable; AN= ANOVA; K-W= Kruskal-Wallis; DF= degrees of freedom. Significant values are listed in bold.

DV	**IV**	**Test**	**DF**	**Test statistic**	**P-value**	**IV**	**DF**	**Test statistic**	**P-value**
Mobile Species Richness	Habitat	AN	3,8	F=4.19	**<0.05**	Site	2,9	F=0.21	0.81
Mobile ENS	Habitat	AN	3,8	F=1.5	0.29	Site	2,9	F=2.63	0.13
Mobile Simpson	Habitat	K-W	3	χ^2=3.31	0.35	Site	2	χ^2=4.89	0.09
Mobile biomass	Habitat	K-W	3	χ^2=6.59	0.09	Site	2	χ^2=0.27	0.87
Mobile abundance	Habitat	K-W	3	χ^2=3.56	0.31	Site	2	χ^2=3.97	0.14
Invert Species Richness	Habitat	AN	3,8	F=4.83	**<0.05**	Site	2,9	F=0.59	0.57
Invert ENS	Habitat	AN	3,8	F=10.4	**<0.01**	Site	2,9	F=0.28	0.76
Invert Simpson	Habitat	AN	3,8	F=4.32	**<0.05**	Site	2,9	F=0.31	0.74
Invert abundance	Habitat	K-W	3	χ^2=7.50	0.06	Site	2	χ^2=0.35	0.84
Cryptic Species Richness	Habitat	AN	3,8	F=5.48	**<0.05**	Site	2,9	F=0.30	0.75
Cryptic abundance	Habitat	K-W	3	χ^2=6.75	0.08	Site	2	χ^2=0.71	0.70
Temp	Habitat	AN	3,8	F=0.87	0.50	Site	2,9	F=4.24	0.05
Salinity	Habitat	AN	3,8	F=0.82	0.52	Site	2,9	F=0.95	0.42
pH	Habitat	AN	3,8	F=1.61	0.26	Site	2,9	F=0.75	0.50
Depth	Habitat	AN	3,8	F=5.22	**<0.05**	Site	2,9	F=0.62	0.56
Dissolved Oxygen	Habitat	K-W	3	χ^2=3.31	0.35	Site	2	χ^2=3.11	0.21
HAS score	Habitat	AN	3,8	F=24.5	**<0.01**	Site	2,9	F=0.06	0.94

Table S2. Results from one-way ANOVAs in the low band, testing for differences across habitat types or sites. Significant differences were followed by Tukey's HSD pairwise comparisons. DV= dependent variable; IV= independent variable; DF= degrees of freedom. Significant values listed in bold.

DV	IV	DF	F	P-value	IV	DF	F	P-value
LBL Dawn	Habitat	3,8	9.60	**<0.01**	Site	2,9	0.71	0.52
LBL Day	Habitat	3,8	11.96	**<0.01**	site	2,9	0.58	0.58
LBL Dusk	Habitat	3,8	5.38	**<0.05**	Site	2,9	0.68	0.53
LBL Night	Habitat	3,8	8.18	**<0.01**	Site	2,9	0.36	0.71
Dawn ACI	Habitat	3,8	0.93	0.47	Site	2,9	3.83	0.06
Daytime ACI	Habitat	3,8	1.01	0.43	Site	2,9	6.96	**0.01**
Dusk ACI	Habitat	3,8	0.33	0.81	Site	2,9	3.23	0.09
Night ACI	Habitat	3,8	0.79	0.54	Site	2,9	3.55	0.07
Dawn entropy	Habitat	3,8	13.4	**<0.01**	Site	2,9	0.21	0.81
Daytime entropy	Habitat	3,8	13.11	**<0.01**	Site	2,9	0.34	0.72
Dusk entropy	Habitat	3,8	3.0	0.10	Site	2,9	0.52	0.61
Night entropy	Habitat	3,8	5.22	**<0.05**	Site	2,9	0.64	0.55

Table S3. Results from one-way ANOVAs in the high band, testing for differences in each acoustic variable across habitat types or sites. DV= dependent variable; IV= independent variable; DF= degrees of freedom. Significant values listed in bold.

DV	IV	DF	F	P-value	IV	DF	F	P-value
HBL Day	Habitat	3,8	2.97	0.10	site	2,9	1.8	0.22
HBL Dusk	Habitat	3,8	1.33	0.33	Site	2,9	3.05	0.10
HBL Night	Habitat	3,8	1.77	0.23	Site	2,9	1.99	0.19
HBL Dawn	Habitat	3,8	2.55	0.13	Site	2,9	1.65	0.25
Daytime ACI	Habitat	3,8	0.18	0.91	Site	2,9	12.5	**<0.01**
Dusk ACI	Habitat	3,8	0.73	0.56	Site	2,9	2.55	0.13
Night ACI	Habitat	3,8	0.28	0.84	Site	2,9	4.72	**<0.05**
Dawn ACI	Habitat	3,8	0.41	0.75	Site	2,9	4.15	0.05
Daytime entropy	Habitat	3,8	1.04	0.43	Site	2,9	5.21	**<0.05**
Dusk entropy	Habitat	3,8	1.90	0.21	Site	2,9	2.16	0.17
Night entropy	Habitat	3,8	0.96	0.46	Site	2,9	3.15	0.09
Dawn entropy	Habitat	3,8	1.15	0.39	Site	2,9	3.22	0.09

Table S4. Raw data from biodiversity surveys conducted across Bocas del Toro, Panama between Jan 26-Feb 3, 2016. Species names are listed on the far left, and counts are listed for each habitat and each site in the columns.

	STRI Point	San Cristobal	Almirante		STRI Point	San Cristobal	Almirante		STRI Point	San Cristobal	Almirante		STRI Point	San Cristobal	Almirante
	Reef				Seagrass				Mangrove				Sand		
Ablennes hians	0	0	0		0	0	0		0	0	7		0	0	0
Abudefduf saxatilis	0	13	0		0	0	0		2	5	5		0	0	0
Acanthurus bahianus	0	0	0		0	0	1		0	0	0		0	0	0
Acanthurus chirurgus	0	0	0		0	0	0		1	0	0		0	0	0
Acanthurus coeruleus	0	0	0		0	0	0		1	0	0		0	0	0
Actinopyga agassizii	0	0	0		0	0	0		1	0	0		0	0	1
Alatina alata	0	0	0		0	0	0		0	2	0		0	0	0
Ancylomenes pedersoni	1	0	0		0	0	0		0	0	0		0	0	0
Anisotremus virginicus	0	0	0		0	0	1		6	0	0		0	0	0
Aulostomus maculatus	0	0	0		0	0	0		0	0	0		0	0	0
Bathygobius sp.	0	0	0		0	0	0		0	0	0		0	0	0
Canthigaster rostrata	5	2	0		1	0	0		0	0	0		0	0	0
Caranx latus	0	0	0		0	0	0		0	0	27		0	0	0
Caranx ruber	0	5	0		0	0	0		0	0	0		0	0	0
Cassiopea frondosa	0	0	0		4	0	0		0	0	0		0	0	1
Centropomus undecimalis	0	0	0		0	0	0		0	0	0		0	0	0
Cephalopholis cruentata	1	2	0		0	0	0		0	0	0		0	0	0
Cerithium litteratum	200	1	4		0	0	0		0	0	0		2	0	0
Cerithium spp.	0	0	0		0	0	0		0	0	0		0	0	0
Chaetodon capistratus	10	20	1		0	0	7		20	2	0		0	10	0
Chaetodon ocellatus	1	0	0		0	0	0		1	0	0		1	1	0
Chaetodon striatus	0	0	0		0	0	0		0	0	0		0	0	0

	STRI Point	San Cristobal	Almirante		STRI Point	San Cristobal	Almirante		STRI Point	San Cristobal	Almirante		STRI Point	San Cristobal	Almirante
	Reef				Seagrass				Mangrove				Sand		
Clupeidae	0	0	0		0	0	0		0	0	0		0	0	0
Copidaster lymani	0	0	0		0	0	1		0	0	9		0	0	0
Coryphopterus eidolon	10	21	1		0	8	0		0	0	0		68	232	0
Coryphopterus glaucofraenum	2	4	46		16	14	45		3	1	1		35	7	2
Coryphopterus personatus	2520	910	173		0	0	188		124	0	0		900	0	0
Cyphoma spp.	0	0	0		0	0	0		1	0	0		0	0	0
Diadema antillarum	0	8	0		0	0	0		0	0	0		0	0	0
Diapterus auratus	0	0	0		0	0	0		0	0	0		0	0	0
Echinaster echinophorus	0	0	0		0	0	0		0	0	5		0	0	0
Echinometra viridis	520	114	1818		0	0	0		1	0	3		4	25	0
Elacatinus spp.	0	0	1		0	0	0		0	0	0		0	0	0
Elacatinus xanthiprora	0	0	0		0	0	1		0	0	0		0	1	0
Eucinostomus melanopterus	0	0	0		8	0	0		0	1	56		0	0	14
Gerres cinereus	0	0	0		0	0	0		0	0	0		0	1	0
Haemulon carbonarium	0	1	0		0	0	0		2	0	0		0	0	0
Haemulon flavolineatum	2	2	2		5	0	3		0	18	39		0	0	0
Haemulon macrostomum	0	0	4		0	0	0		0	0	0		0	0	0
Haemulon plumierii	6	806	4		3	0	4		0	1	1		0	0	0
Halichoeres bivittatus	7	78	63		7	172	95		0	9	9		194	244	1
Hermodice carunculata	1	0	0		0	0	0		0	0	0		0	0	0
Holocentrus rufus	1	0	0		0	0	0		0	0	0		0	0	0
Holothuria mexicana	2	0	0		1	3	1		0	0	0		1	0	0
Hypoplectrus nigricans	3	3	3		0	0	0		0	0	0		2	0	0
Hypoplectrus puella	15	8	12		1	0	3		0	0	1		0	0	0
Hypoplectrus unicolor	2	2	0		5	0	0		0	0	0		0	0	0
Isostichopus badionotus	0	0	0		0	0	0		0	0	0		0	0	0

	STRI Point	San Cristobal	Almirante		STRI Point	San Cristobal	Almirante		STRI Point	San Cristobal	Almirante		STRI Point	San Cristobal	Almirante
	Reef				Seagrass				Mangrove				Sand		
Isostichopus fuscus	0	0	0		0	0	0		0	1	0		0	0	0
Jenkinsia lamprotaenia	0	0	0		3600	0	0		450	0	0		0	0	0
Lutjanus apodus	0	0	0		0	0	0		12	9	5		0	0	0
Lutjanus griseus	0	0	0		0	0	0		0	0	0		0	0	0
Lutjanus jocu	0	30	0		0	0	0		6	1	15		0	0	2
Lutjanus synagris	0	0	0		0	0	0		0	0	0		1	0	0
Lytechinus williamsi	1	0	0		0	0	0		0	0	1		0	18	0
Malacoctenus triangulatus	0	0	0		3	0	0		0	0	0		1	0	0
Microgobius meeki	0	0	0		0	0	0		0	0	0		0	0	6
Mithrax forceps	0	0	0		0	0	0		0	0	0		0	0	0
Mithrax spinosissimus	0	0	0		0	0	0		0	1	0		0	0	0
Mugil cephalus	0	0	0		0	0	0		0	0	0		0	0	0
Ocyurus chrysurus	0	0	0		0	0	0		0	0	1		0	0	0
Odontoscion dentex	0	1	0		0	0	0		0	0	0		0	0	0
Ophionereis reticulata	0	0	2		0	0	0		0	0	0		0	0	0
Ophioroid	0	0	2		0	0	0		0	0	0		0	0	0
Ophiothrix suensoni	1	151	86		0	0	0		5	0	0		0	0	0
Opistognathus aurifrons	0	0	0		0	0	0		0	0	0		100	17	0
Oreaster reticulatus	0	0	0		0	0	0		0	1	0		0	0	0
Paguroidea spp.	0	0	0		2	0	0		0	0	0		0	3	0
Parablennius marmoreus	0	0	0		0	0	0		0	0	0		0	0	0
Pomacanthus arcuatus	1	0	0		0	0	0		0	0	0		0	0	0
Pseudupeneus maculatus	1	0	0		0	0	0		0	0	0		0	0	0
Pterois volitans	0	0	0		0	0	0		0	0	0		0	0	0
Scarus iseri	300	334	263		16	0	136		5	1	0		9	104	0
Scyphozoa	0	0	0		0	0	0		0	0	0		0	0	0

	STRI Point	San Cristobal	Almirante		STRI Point	San Cristobal	Almirante		STRI Point	San Cristobal	Almirante		STRI Point	San Cristobal	Almirante
	Reef				Seagrass				Mangrove				Sand		
Sepioteuthis sepioidea	0	0	0		0	1	0		0	0	0		0	0	0
Serranus tigrinus	6	6	1		0	0	0		0	0	0		0	6	0
Serranus tortugarum	57	137	0		0	0	0		0	0	0		4	45	0
Sparisoma aurofrenatum	0	2	0		0	0	0		0	0	0		0	0	0
Sparisoma viride	1	0	0		0	0	0		0	0	0		0	0	0
Sphoeroides spengleri	0	0	0		0	0	0		0	0	0		0	1	0
Sphyraena barracuda	0	0	0		0	0	0		5	0	2		0	0	0
Stegastes adustus	1	0	0		0	0	0		2	0	2		0	0	0
Stegastes diencaeus	0	0	1		0	0	0		0	0	1		0	0	0
Stegastes partitus	9	49	0		0	0	3		0	0	0		0	3	0
Stegastes planifrons	233	100	78		0	0	2		1	0	0		0	4	0
Stegastes variabilis	0	0	1		0	0	0		0	0	0		0	0	0
Stenopus hispidus	0	0	0		0	0	0		0	0	0		0	0	0
Stenorhynchus seticornis	1	0	0		0	0	0		7	0	0		0	0	0
Synodus intermedius	2	1	0		0	0	0		0	0	0		0	0	0
Thalassoma bifasciatum	4	0	0		0	0	0		0	0	0		0	0	0
Tripneustes ventricosus	0	0	0		0	0	0		0	0	0		0	15	1
Urobatis jamaicensis	0	0	0		0	0	0		0	0	0		0	0	0
Vasum spp.	0	0	0		0	0	0		0	1	0		0	0	0

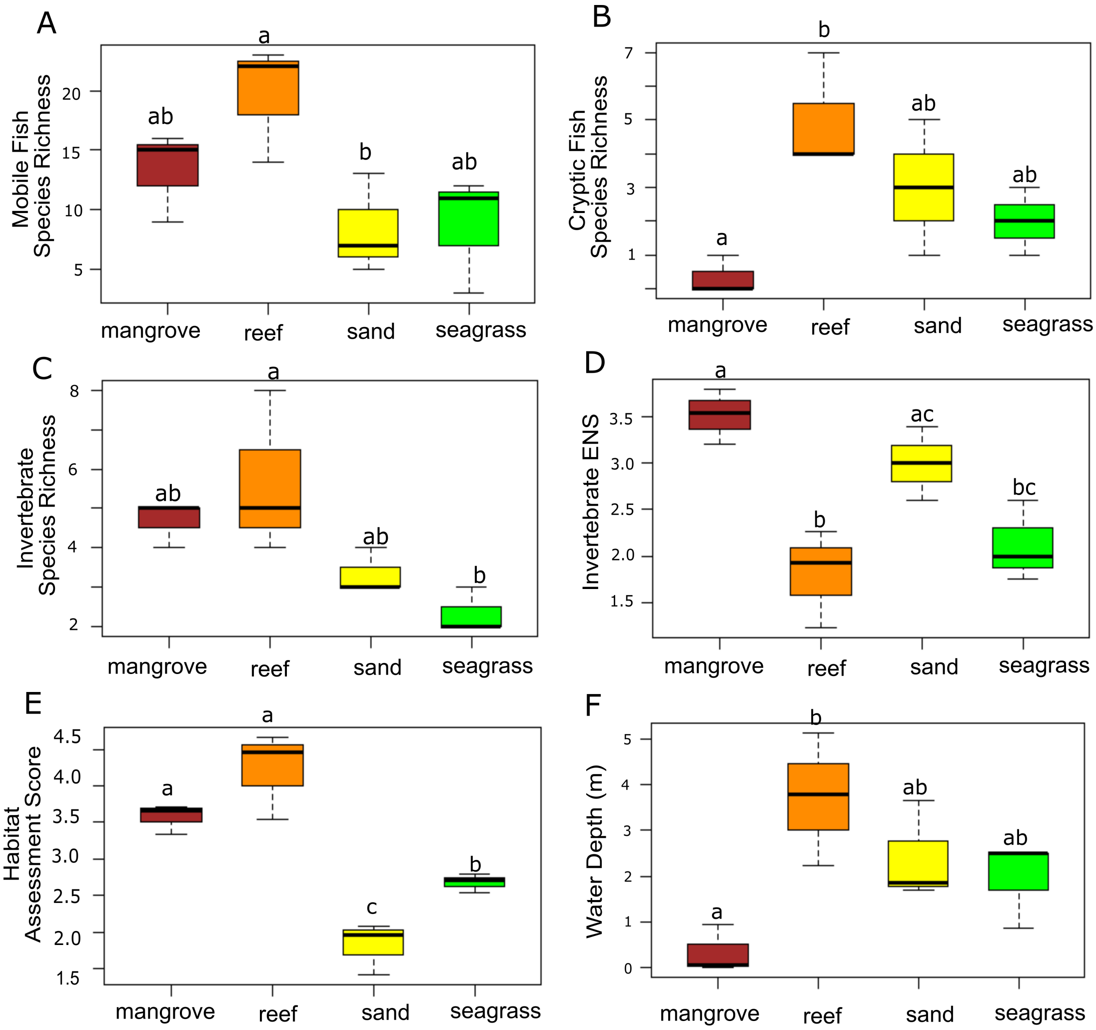

Figure S1. Box plots of several diversity and environmental variables that were significantly different between habitat types (Table S1). Horizontal bars represent medians, box edges represent inter-quartile range, and whiskers represent the most extreme ranges of the data. Results from pairwise comparisons are shown here; different letters depict significant differences (Tukey's HSD, adjusted p-value<0.05). Reefs had the highest habitat complexity, greatest water depth, and had the highest species richness for the three organism types. Although not significant, invertebrate abundance was highest on reefs (p=0.06), but this was primarily driven by the high abundance of a single urchin species, *Echinometra viridis*. This led to lower values for the Effective Number of Species for invertebrates on reefs.

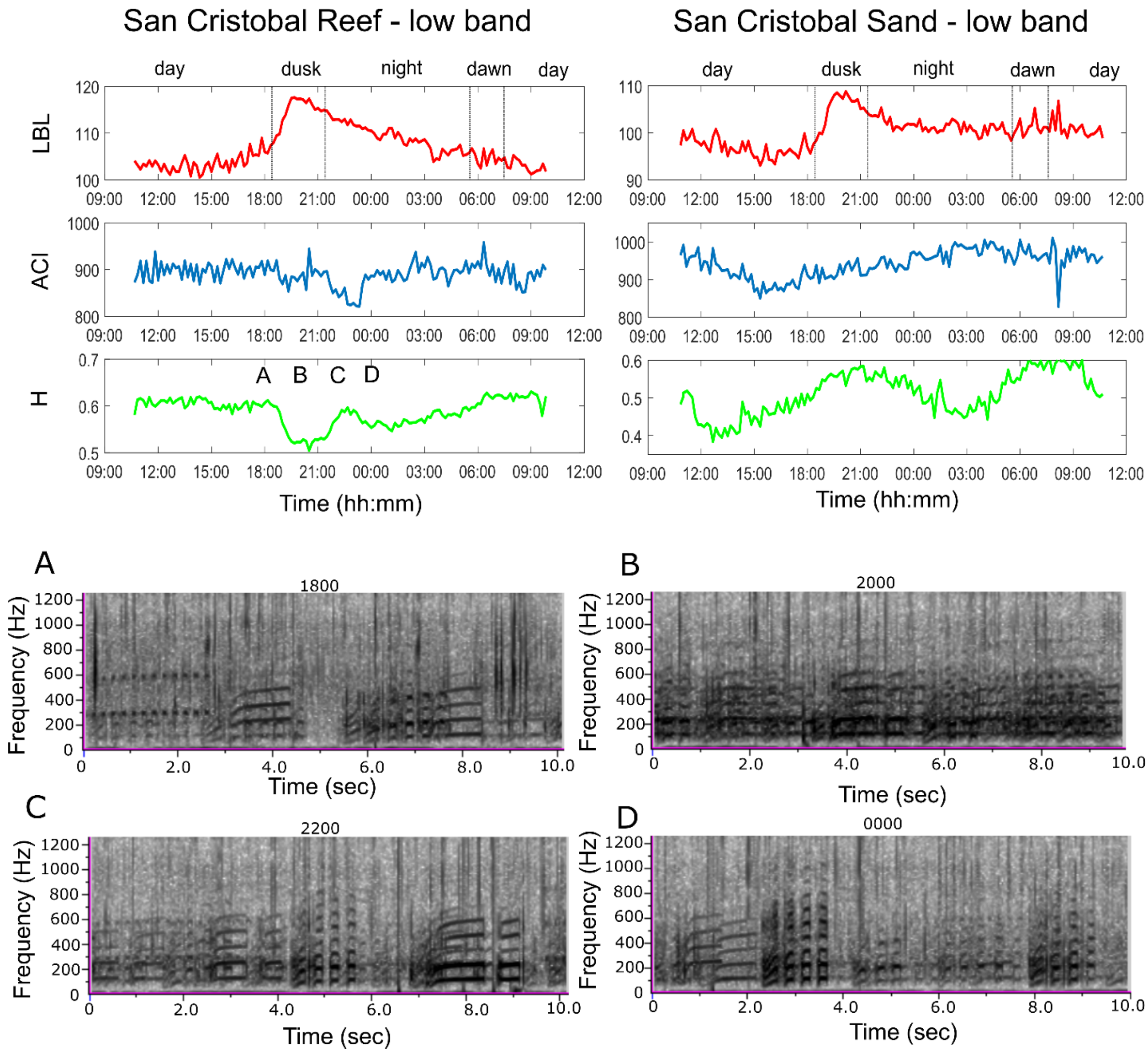

Figure S2. Example of acoustic data collected at the San Cristobal reef and sand sites. Top plots: Low Band Level (LBL, in dB re: 1 µPa), Acoustic Complexity (ACI), and Acoustic Entropy (H) plotted over the 24-hour recording period at the two locations. Vertical lines depict time-of-day designations used in other data analysis. Points A-D on the entropy plot correspond to spectrograms in panels A-D. Panel A: at 18:00 h on San Cristobal reef, several types of fish sounds were audible: in the first 2.5 seconds, an 11-pulse signal is evident; at 3-4.5 seconds and 6-9 seconds, different toadfish calls are present. Panel B: at 20:00 h, only toadfish calls are audible and because the calling overlap one another, the soundscape becomes more monotonous. This led to a decrease in ACI and H, since these metrics depend upon the evenness of the signal. In panels C and D, toadfish calls are still present, but do not overlap in time, resulting in an increase in ACI and H. A different pattern occurred at the sand site, where chorusing was less intense, with less overlap between individual animal calls, so entropy increased during chorusing. These examples illustrate the fact that these two acoustic metrics may lead to counter-intuitive results during intense animal chorusing in which individual calls overlap.

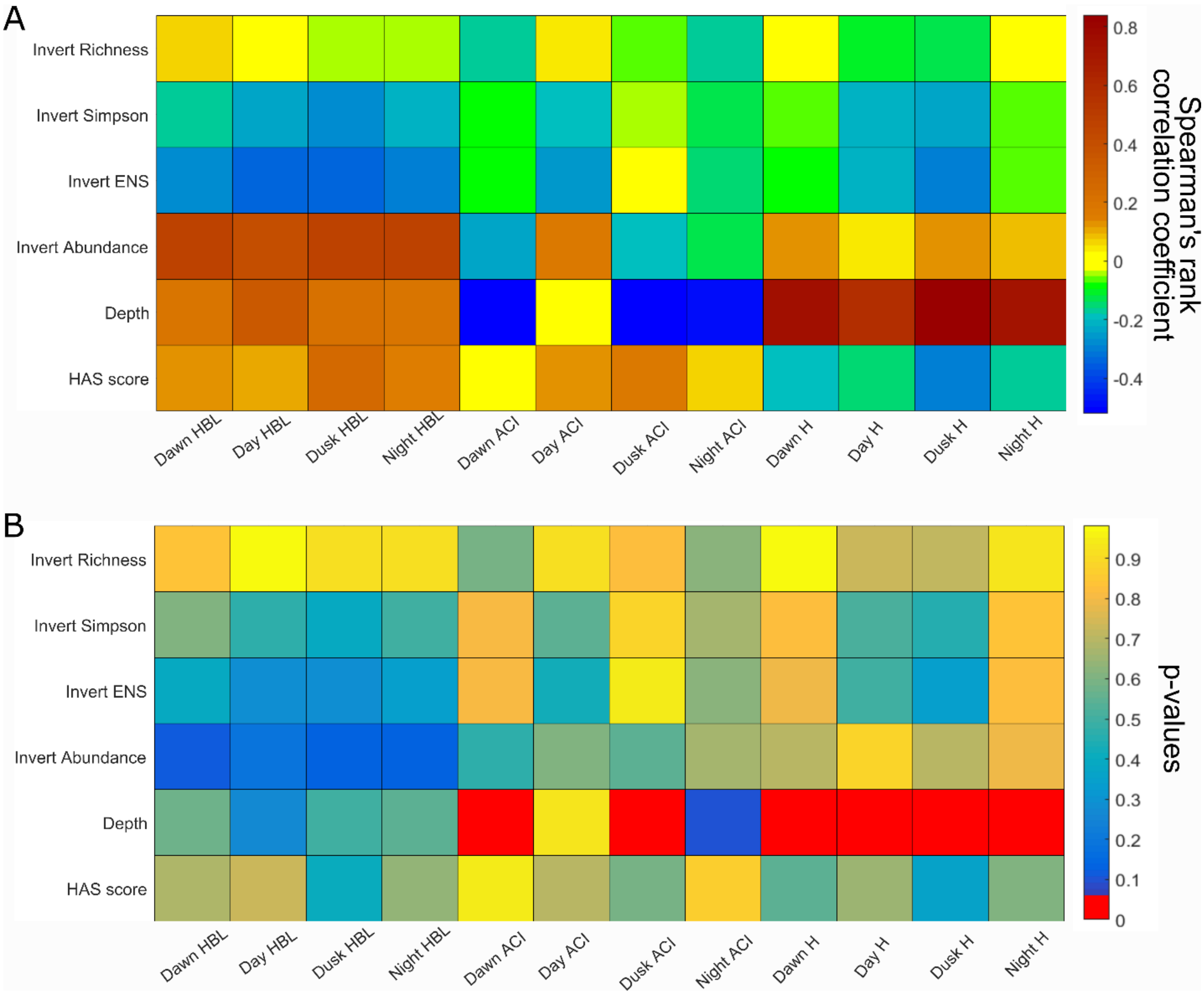

Figure S3. Spearman's rank coefficients (cool colors: negative correlation, warm colors: positive) and corresponding p-values (red=p<0.05) for invertebrate diversity variables, depth, and HAS scores and the high acoustic band (3,000-10,000 Hz). It was relevant to compare acoustic conditions in the high band to invertebrate diversity because some invertebrates (*Alpheidae spp*.) produce high-frequency sounds and tend to dominate this part of the frequency spectrum (Wenz 1962, Hildebrand 2009). However, we did not count a single snapping shrimp in our diver surveys, which explains the non-significant relationships. This mis-match provides an example of the utility of acoustic surveys for cryptic organisms.

LITERATURE CITED

<jrn>Hildebrand JA (2009) Anthropogenic and natural sources of ambient noise in the ocean. Mar Ecol Prog Ser 395:5–20 doi:10.3354/meps08353</jrn>

<jrn>Wenz GM (1962) Acoustic ambient noise in the ocean: spectra and sources. J Acoust Soc Am 34:1936–1956 doi:10.1121/1.1909155</jrn>