Automated detection and classification of baleen whales using PAM-equipped Slocum gliders in the USVI and Puerto Rico

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Abstract

Whales play vital ecological, cultural, and economic roles in oceans worldwide, yet face increasing threats from human activities. Traditional monitoring methods, such as visual surveys and moored passive acoustics, have limitations, resulting in patchy global data. The U.S. Virgin Islands and Puerto Rico require enhanced foundational data on local whale populations. This master's thesis, conducted with the University of the Virgin Islands Ocean Glider Lab, uses PAM-capable Slocum G3 gliders to identify low-frequency-emitting whale species in the region. The goal is to fill baseline data gaps and assess the effectiveness of gliders as a consistent whale monitoring tool.

Introduction

Whales play critical ecological, cultural, and economic roles in marine ecosystems (Kiszka et al., 2015; Roman et al., 2014; Marine Mammal Commission, n.d.), yet face numerous threats, including pollution, vessel traffic, and bycatch (Avila et al., 2018). A comprehensive understanding of whales is limited by species diversity, wide-ranging habitats, and resource-intensive research methods. Traditional approaches such as visual surveys cover only small areas, leading to global data gaps (Kaschner et al., 2012).

In the U.S. Virgin Islands (USVI) and Puerto Rico (PR), data beyond humpback whales are sparse. This master's thesis aims to identify baleen whale species in these waters using PAM-capable autonomous underwater vehicles (AUVs, Figure 1) and two species detection algorithms—the low-frequency detection and classification system (LFDCS, Baumgartner & Mussoline, 2011) and MinkeNet (Mouy et al., 2025). An open-access citizen science database was also developed to enhance marine mammal data in the region (Figure 2). Funded by NOAA and NSF, this research contributes to baseline knowledge, informs conservation and management, supports NOAA's monitoring efforts, and guides responsible establishment of wind farms in the waters around these islands.

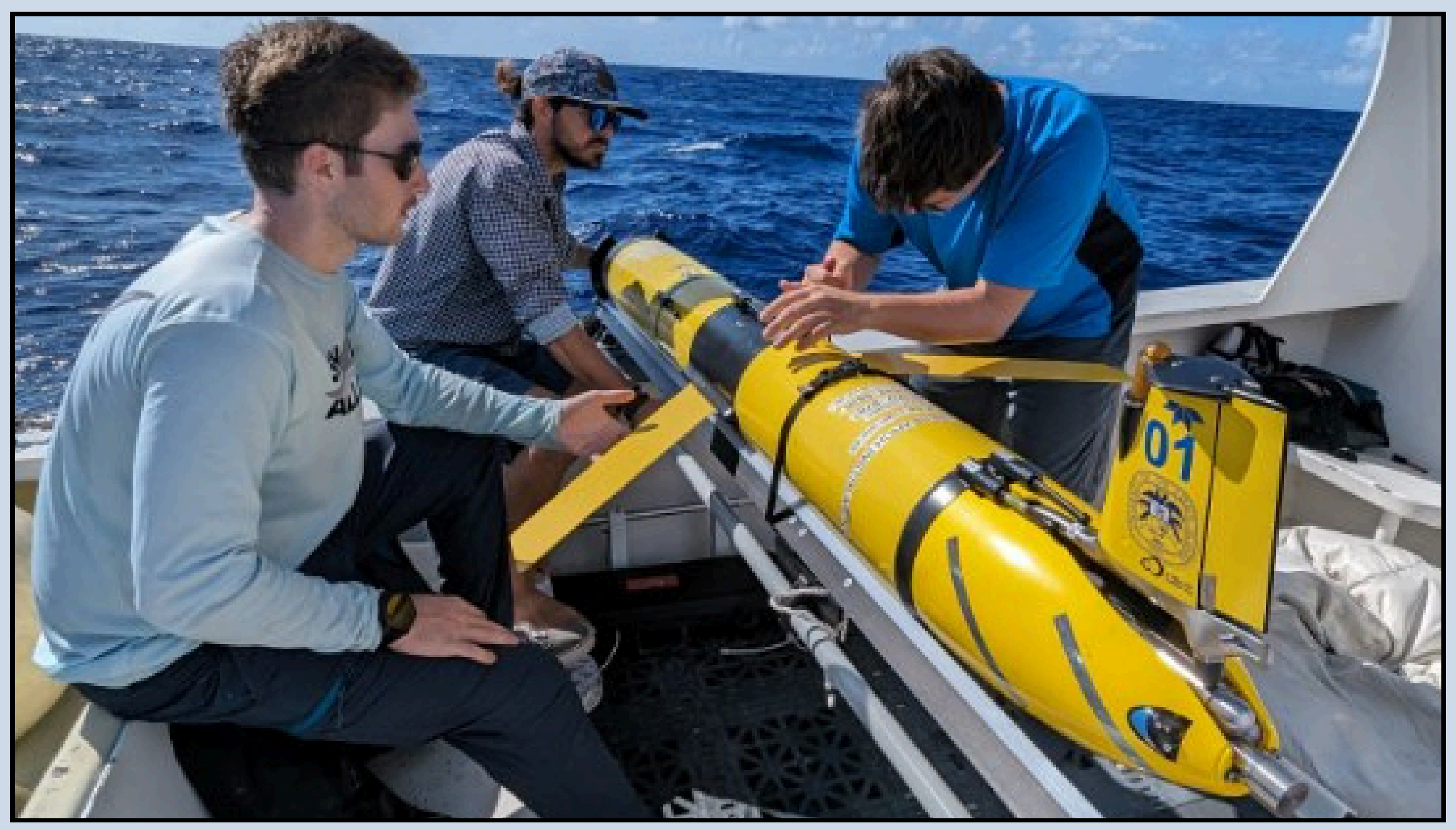

Figure 1. Members of the UVI Glider Lab preparing a Slocum glider for deployment.

MARINE MAMMAL ID

DATABASE INSTRUCTIONS

Figure 2. A QR code that links to instructions for use of the Marine Mammal ID database for the Virgin Islands and Puerto Rico.

Glider Deployments

Two Slocum gliders equipped with DMON2 PAM sensors completed eight missions between August 2024 and March 2025, covering multiple seasons to detect whale presence, including migratory species like *Megaptera novaeangliae* and *Balaenoptera acutorostrata* (Elwen et al., 2014; Risch et al., 2014; Mignucci-Giannoni, 1998). Missions spanned 18–33 days and 256 - 582 km along the north and south coasts of Puerto Rico and around the US Virgin Islands (Figure 3). Mission duration was limited by DMON2 storage capacity, with gliders following a vertical zigzag path from the surface to depths based on local bathymetry, reaching up to 900 meters.

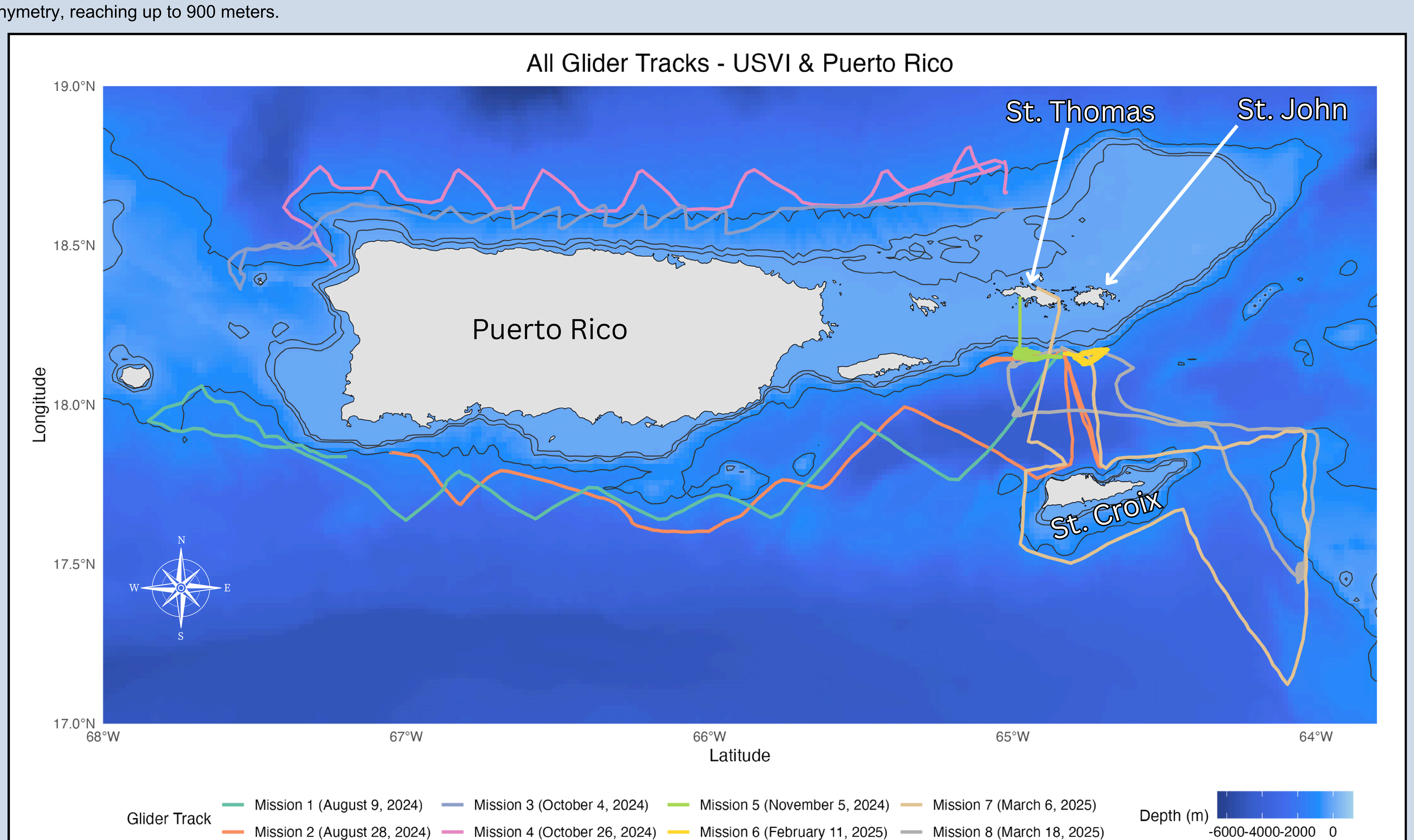

Figure 3. The glider tracks for all eight missions of this research. Each trackline, given a unique color, represents the horizontal path that a glider traveled while in mission.

Mobile PAM

These gliders are equipped with a DMON2 computer (Figure 4) programmed to capture both low- and high-frequency sounds. The DMON2 low frequency hydrophone (optimized to operate in the range 10 Hz–7.5 kHz; Figure 5), continuously sampled at 2 kHz throughout all eight missions to capture sounds from target whale species. Gliders surfaced approximately every three hours to transmit diagnostics via Iridium satellite, including .asc files confirming DMON2 recording status. Full acoustic datasets were downloaded after each mission for analysis.

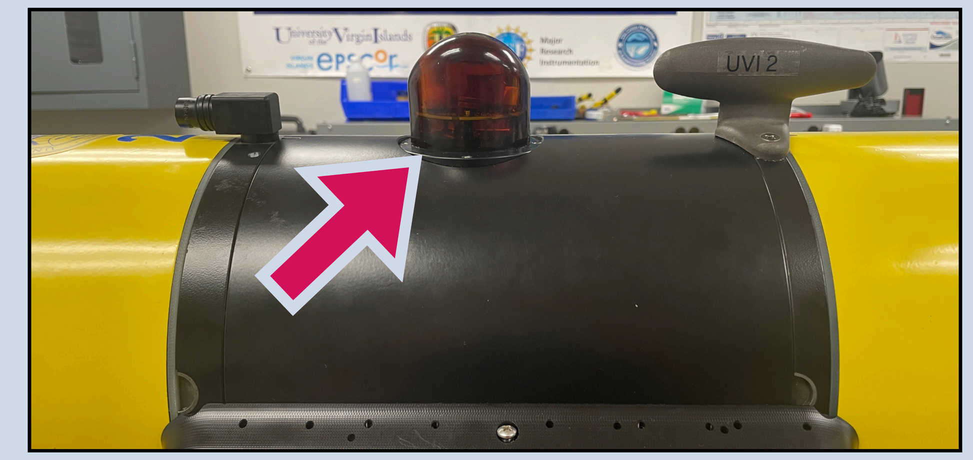

Figure 4. The external portion of the DMON2 system, attached to the science bay of a TWR G3 slocum glider. This epoxy dome encapsulates three hydrophones: low, medium, and high frequency recorders.

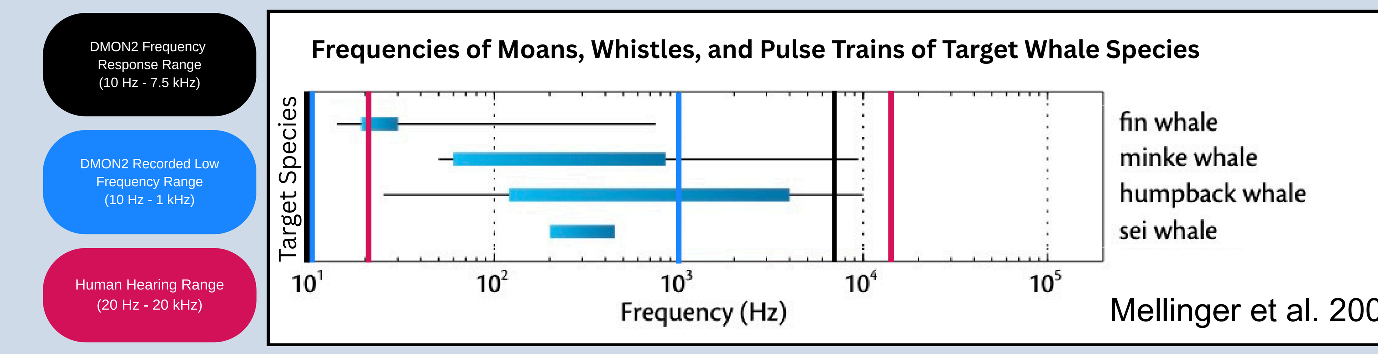

Figure 5. A plot of the known frequency ranges of target cetacean moans, whistles, and pulse trains. The thick blue horizontal lines represent the most common call frequency ranges known for these species, and if present, the thin black horizontal lines represent the recorded frequency extremes of the associated species. The vertical black lines represent the DMON2 frequency response range, the vertical blue lines represent the boundaries of the DMON2 low-frequency hydrophone recorded frequency range and the vertical pink lines represent the range of human hearing. Adapted from: Mellinger, D., Stafford, K., Moore, S., Dziak, R., & Matsumoto, H. (2007). An Overview of Fixed Passive Acoustic Observation Methods for Cetaceans. Oceanography, 20(4), 36–45.

Whale Detection

This study used two baleen whale detectors: the Low-Frequency Detection and Classification System (LFDCS; Baumgartner & Mussoline, 2011) and MinkeNet (Mouy et al., 2025). LFDCS, developed in IDL, detects humpback, sei, and fin whale calls by pitch tracking sounds 12 dB above background within 2 kHz, then classifies them using discriminant function analysis based on spectral features. MinkeNet, a ResNet18-based neural network trained on diverse marine and anthropogenic sounds, identifies minke whale pulse trains from spectrograms.

All detections were manually reviewed. LFDCS detections were analyzed using an adapted NOAA NEFSC protocol (Davis et al., 2017, 2020; Wilder et al., 2023) in hourly bins, scored as "detected," "possibly detected," or "not detected" per species. The criteria to fulfil the requirements for one of these three options for an hour varies slightly by species, but generally, at least one pitch tracked vocalization of that species needed to be present and manually confirmed to mark an hour bin as "possibly detected". To mark an hour bin as "detected", an hour bin needed at least one pitch tracked and manually confirmed vocalization of that species and additional pitch tracked or non-pitch-tracked vocalizations. A similar protocol was applied for minke whales, where a single clear pulse train from a minke whale in a day was marked as "detected". MinkeNet detections followed a similar protocol, using daily bins. Summary statistics of whale presence were generated, with further analyses—such as diel calling patterns and detector performance—planned for future work.

Initial Results

In the months of August, October, and November of 2024 and February and March of 2025, the gliders spent 180 days at sea, collecting 128 days of continuous low-frequency data. The gap was due to DMON2 storage limits and one recorder failure during a 28-day mission. No target species were detected in the 87 days of data from August–November 2024. However, in February–March 2025, humpback, sei, and minke whales were identified in 41 days (1016 hours) of recordings. Humpbacks were detected in 403 hours, sei whales had three possible detection hours, and minke whales were detected on 31 of the 41 days. Figure 6 depicts samples of humpback, sei, and minke whale calls from the two missions where these whales were detected or possibly detected.

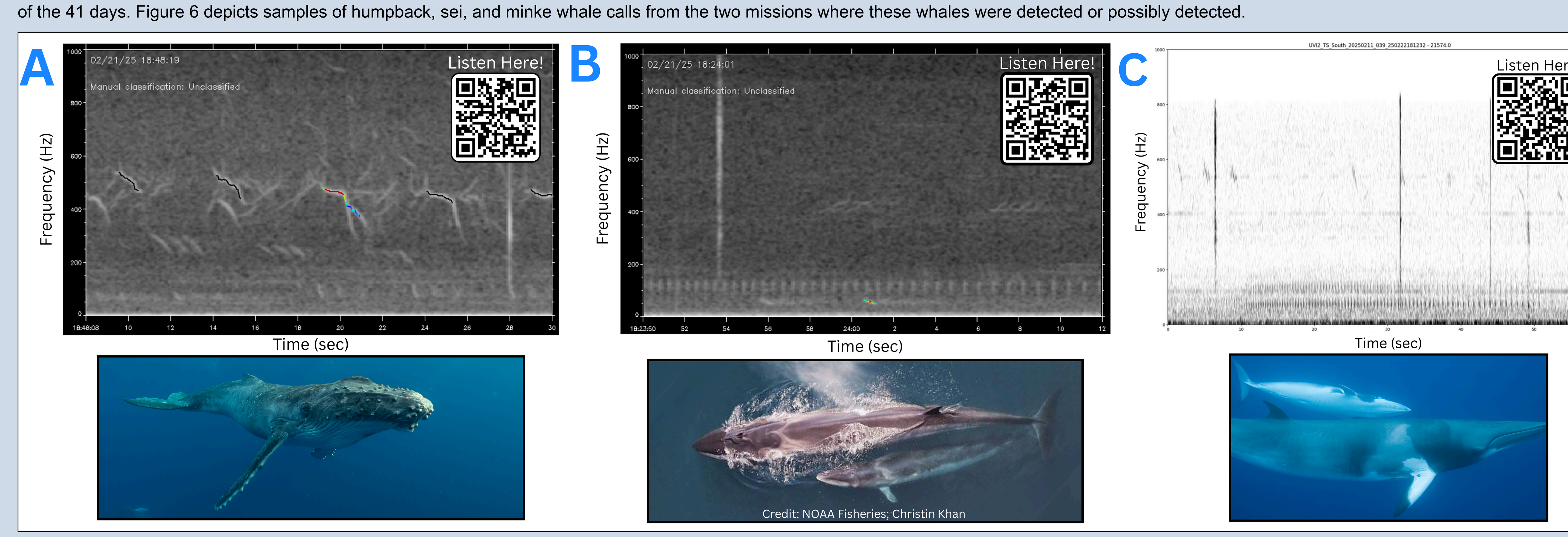

Figure 6. An example spectrogram of each detected or possibly detected species. Spectrogram A is of a humpback whale detection, B is of a sei whale possible detection, and C is of a minke whale detection. A and B are spectrograms created through the LFDCS. Sounds that the LFDCS considered whale calls are pitch tracked (annotated). The colored line represents the user's current selection. The color of the pitch track represents the amplitude, where red is the loudest and violet is the quietest. The black pitch tracks are other detections not currently selected. Only one pitch track can be selected at a time. Spectrogram A depicts a variety of humpback calls, but the pitch tracked calls are a variation of downsweeps. A single pitch track is present for the possible sei whale call at ~50 Hz. This sound and the similar sound at the 56 second mark may be sei whale singlet downsweeps. Spectrogram C was created through MinkeNet. In the center of this spectrogram from ~50-175 Hz is a minke whale pulse train, which is a series of repeated pulses that appear as vertical lines on the spectrogram.

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Acknowledgements

I would like to thank my mentors Doug Wilson, Travis Hamlin, Dr. Héloïse Frouin-Mouy, Dr. Melissa Soldevilla, Dr. Kayla Blincow, Julianne Wilder, Dr. Genevieve Davis, and Lindsey Transue for providing their expertise and support in this research, Dr. Mark Baumgartner for allowing me access to the LFDCS, Dr. Xavier Mouy for allowing me access to MinkeNet, NSF and NOAA for funding this research, and everyone else who assisted in this project along the way.