Literature Search Report on AIS and Marine Mammals

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Objective: Literature search on research using AIS data to examine the relationship between ships and marine mammal populations/behavior, with emphasis on analytical techniques and data visualizations that may be applicable to SWFSC SAEL data. Here, I highlight the diversity of studies within AIS/marine mammal research and show notable visualizations.

Literature search details:

- Google Scholar search using keywords “AIS ships marine mammal population behavior” resulted in 7,480 hits
- Further cut down papers based on mention and use of AIS and marine mammals
- Total papers: 98
- Date range: 2008 - 2023 (many in 2021-2023)
- 4 theses, 2 conference papers, 3 reports, 3 review articles about applications of AIS in research (Fournier et al., 2018, Robards et al., 2016, Svanberg et al., 2019).

Overview

Within marine mammal studies, an Automatic Information System (AIS) can provide valuable vessel information to inform collision/shipstrike risk and noise pollution. Two broad approaches exist to examine each threat - an analytical-based approach that makes assumptions like marine mammal density and can translate to larger-scale projects; and an agent-based approach where individual marine mammals behaviors and vessel positions are tracked and analyzed (Barkaszi et al., 2021).

Collision/Shipstrike Risk

Analytical-Based Approach

This method uses vessel density to model shipstrike risk, areas of highest risk within a marine mammal habitat, and effectiveness of speed restrictions (Wiley et al., 2011, Crum et al., 2019) or Areas To Be Avoided (van der Hoop et al., 2012). Vessel density is typically depicted as raster cells of 1x1 km, though smaller and larger sizes have been used. Often, researchers used previously acquired whale abundance estimates rather than data collected as part of the study. Information such as vessel size, speed, number of transits, and position were commonly used as inputs. With this approach, it is not practical to model parameters like avoidance by a vessel or whale, so an encounter rate theory calculation or simulation approach can model their interactions. Three studies used animats, or artificial modeled animals, to predict how realistic subjects would interact with vessels (Cholewiak et al., 2018, Gabriele et al., 2018,). Further separating types of vessel pressure (Madon et al., 2022), whale groups like calves and non-calves (Smith et al., 2020), species (Olson et al., 2022), and seasons of the year (Silber et al., 2021) show interesting perspectives. In a couple of cases, AIS was more of a supplementary part of the study, showing average AIS density on a grid with survey effort tracks overlaid on top (Hazen et al., 2017) or alongside marine mammal density (Fais et al., 2016).

Papers: Williams and O'Hara, 2010, Wiley et al., 2011, Chion et al., 2012, van der Hoop et al., 2012, Conn and Silber, 2013, Redfern et al., 2013, Dransfield et al., 2014, Constantine et al., 2015, Fais et al., 2016, Martin et al., 2016, Priyadarshana et al., 2016, Hazen et al., 2017, Rockwood et al., 2017, Soldevilla et al., 2017, Chion et al., 2018, Crum et al., 2019, Blondin et al., 2020, Smith et al., 2020, Wilson et al., 2020, Barkaszi et al., 2021, Silber et al., 2021, Stepanuk et al., 2021, Awbery et al., 2022, Halliday et al., 2022, Madon et al., 2022, Olson et al., 2022, Portal et al., 2022

Example:
From Fais et al., 2016: acoustic tracks and detections overlaid onto vessel density (AIS/yr/km²).

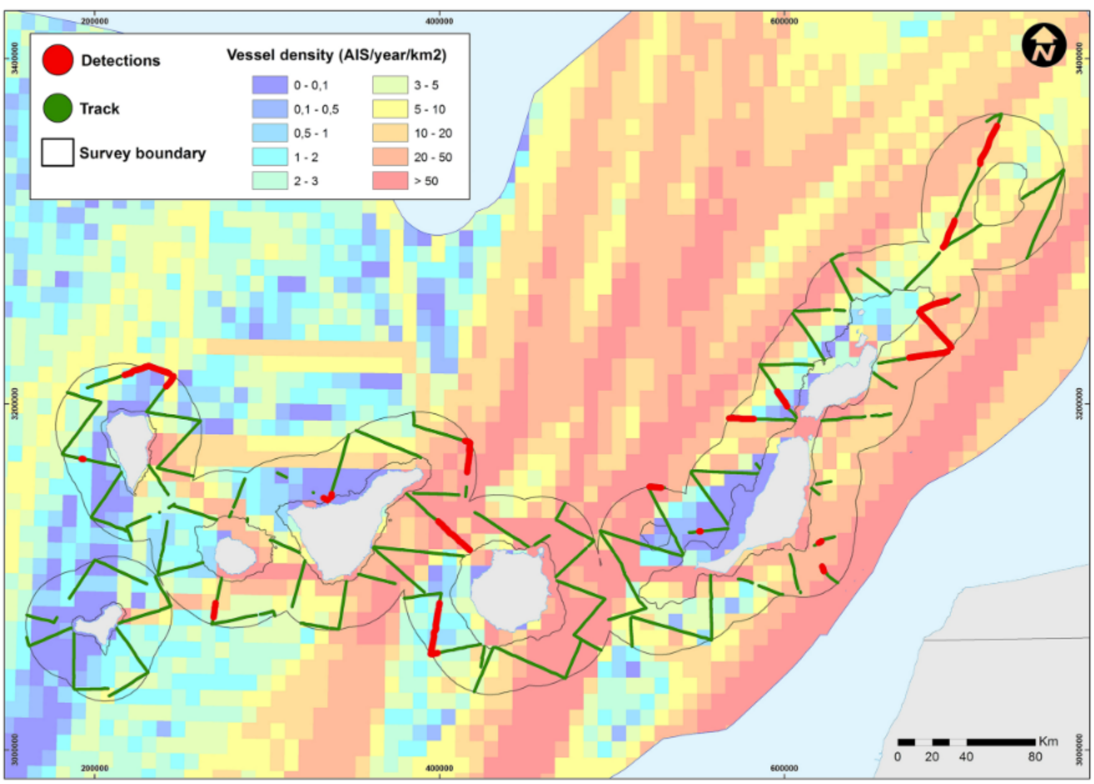

Fig 5. Sperm whale survey effort and detections overlaid on map of marine traffic density. Acoustically surveyed tracks are shown as green lines, while tracks in red show when sperm whales were acoustically detected. Marine traffic data were obtained from AIS data and coloured by traffic density (given as AIS signals/km^2/year).

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Agent-Based Approach

Fewer studies adopted an agent-based approach whereby individual marine mammals were tagged to assess behavioral changes when approached by a vessel. This method places greater emphasis on the spatiotemporal nature of AIS data (lines), rather than yearly or seasonal vessel traffic density (cells). All studies using this method placed digital acoustic recording tags (DTAGs) on their study species and measured the horizontal distances from individual to nearest vessel at the closest point of approach (CPA). All had similar maps and visualizations showing whale tracks and vessel tracks as lines, and CPA as a single point. The trade-off with a more focused behavior assessment is a smaller sample size and typically smaller spatial and temporal scope of study.

Papers: Szesciorka et al., 2019, McKenna et al., 2015, Martin et al., 2023, Guzman et al., 2013

Example: From Guzman et al., 2013: tagged whales showed close encounters with vessels

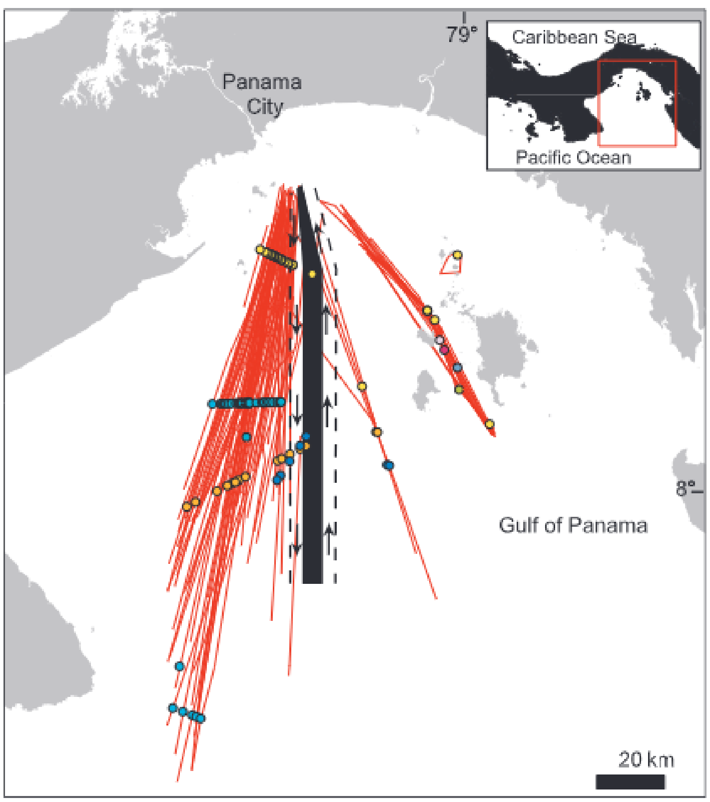

Figure 2. Tracks of 81 vessels and the spatial distribution of the 97 interactions with eight different whales (see Table 3) plotted over the suggested two-way Traffic Separation Scheme for ship routing of *ca*. 120 km (65 nmi) between parallels 8.8°N and 7.0°N in the Gulf of Panama, Panama. Each dot represent an interaction and each color an individual whale.

Noise Pollution

Analytical-Based Approach

Several papers used vessel traffic density to model sound or risk of exposure with a receiver. This was typically achieved by displaying vessel traffic density onto grid cells (min size: 100x100 m, max size: 10x10 km). Each grid cell models a sound level as a function of vessel speed, vessel hours, or number of vessel transits given a known vessel type. Often, an additional map was created from a shipping noise model to show relative loss of communication space, human activity/marine mammal habitat overlap, relative noise exposure risk, or number of times a certain acoustic threshold was exceeded. For this approach, AIS is generally used in conjunction with a sound model or equation to understand and visualize sound emission.

Papers: Azzara, 2012, Erbe et al., 2014, Ryan et al., 2014, Redfern et al., 2017, Cominelli et al., 2018, Gabriele et al., 2018, Cominelli et al., 2020, Cope et al., 2021a, Drackett and Dragićević, 2021, Halliday et al., 2021, Kochanowicz et al., 2021, Verling et al., 2021, Thornton et al., 2022

Examples: From Redfern et al. 2017:

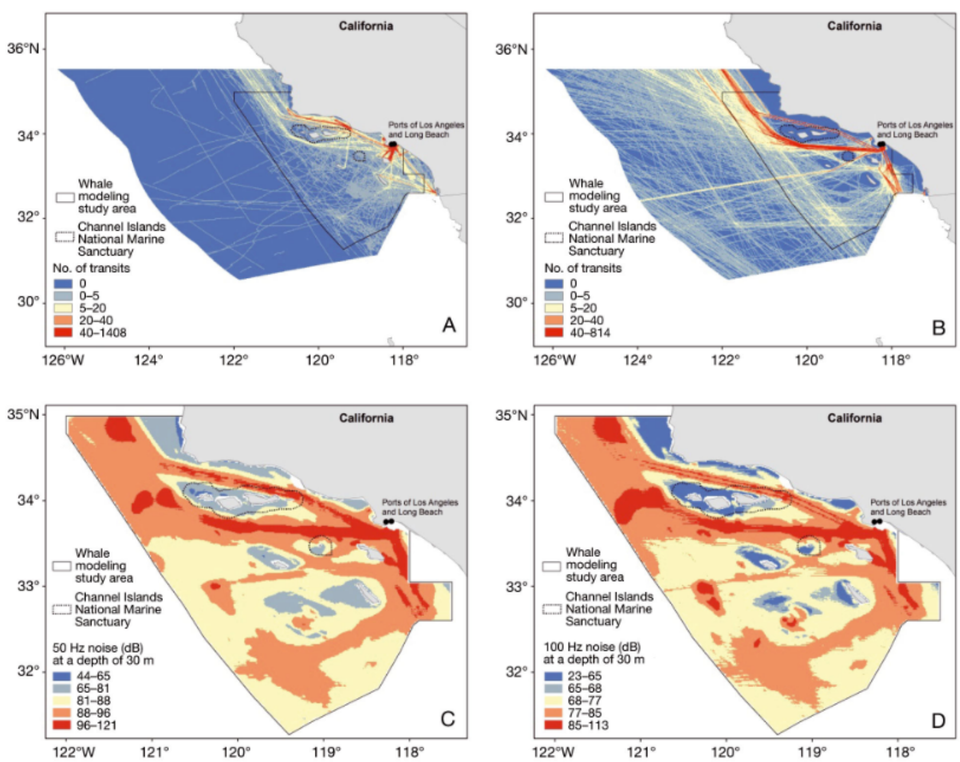

Fig. 3. Number of transits by ships (A) ≥18 and ≤120 m in length and (B) >200 and ≤320 m in length between August and November in 2009 was calculated in an area larger than the whale modeling study area to capture the influence of ships in surrounding waters in the noise predictions. Maps for the 2 other ship length categories (>120 and ≤200 m in length and >320 m in length; see 'Marterials and methods: Characterization of noise from commercial shipping' for details) are not shown because their traffic patterns are similar to the patterns seen for ships >200 and ≤320 m in length. Predicted (C) 50 and (D) 100 Hz noise levels at 30 m depth between August and November 2009. Noise predictions at both frequencies were categorized using an estimate of pre-industrial noise conditions (65 dB) and the 10^{th}, 50^{th}, and 90^{th} percentiles of the predictions. Noise predictions generally correspond to the traffic patterns for larger ships, although some influence from smaller ships can also be seen

Agent-Based Approach
Just as with studies assessing shipstrike risk using this approach, individual AIS vessel positions were tracked as lines to determine sound levels. These were then compared to the behavior change of a marine mammal during co-occurrence. Studies either noted an animal's change in depth or acceleration using DTAGs or noted a change in vocalizations. This approach highlights an individual's exposure to noise at a certain point in space and time, though the sample size of individuals with this method is inherently limited. Because seasonality influences the propagation of vessel noise, dynamic oceanographic features like temperature or salinity can be monitored at high resolution with this approach.

Papers: Azzara, 2012, Broker et al., 2015, Ahonen et al., 2017, Chen et al., 2017, Pedersen et al., 2017, Gabriele et al., 2018, Wisniewska et al., 2018, Halliday et al., 2019, Mikkelsen et al., 2019, Benhemma-Le Gall et al., 2021, Williams et al., 2021, Nachtsheim et al., 2023, Taylor et al., 2023

Examples:
From Mikkelsen et al., 2019: A harbor seal's DTAG overlaid with AIS tracks, colored by TOL 1kHz sound level exposure during its trip.

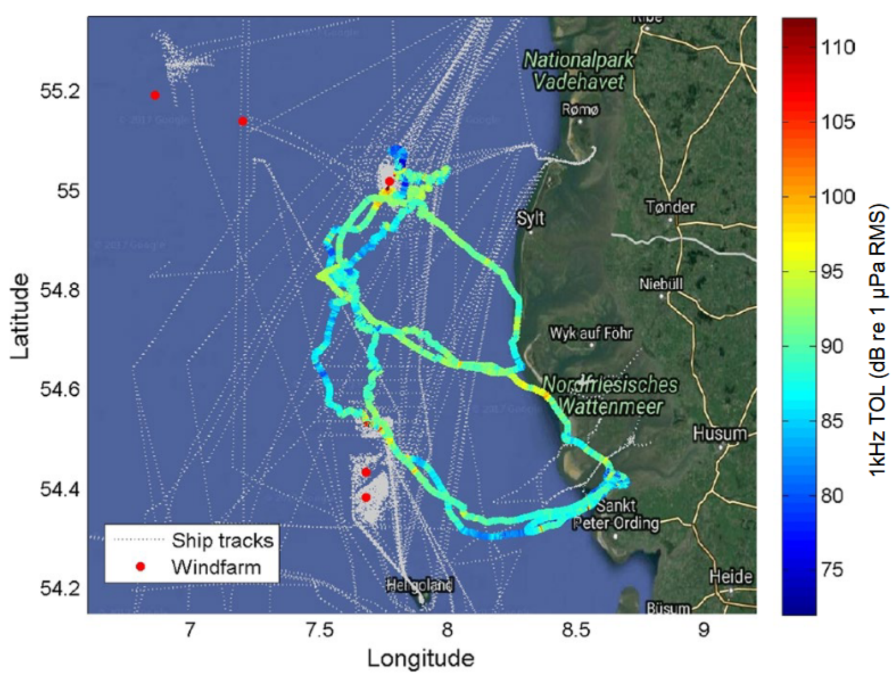

FIGURE 3 Track of harbor seal hs16_265c, color-coded with 30-s averages of third-octave levels (TOL) in the 1-kHz-centered band (see Materials and Methods). Gray dotted lines indicate Automatic Identification System (AIS) tracks of ships that at some point pass within 5 km of the seal (roughly corresponding to the expected range of audibility) and red dots mark the positions of wind farms

From Nachtsheim et al., 2023: Harbor seal tracks and points of co-occurrence. In only 31.8% of recorded vessel noise exposures could an AIS registered vessel be attributed to the actual source of noise.

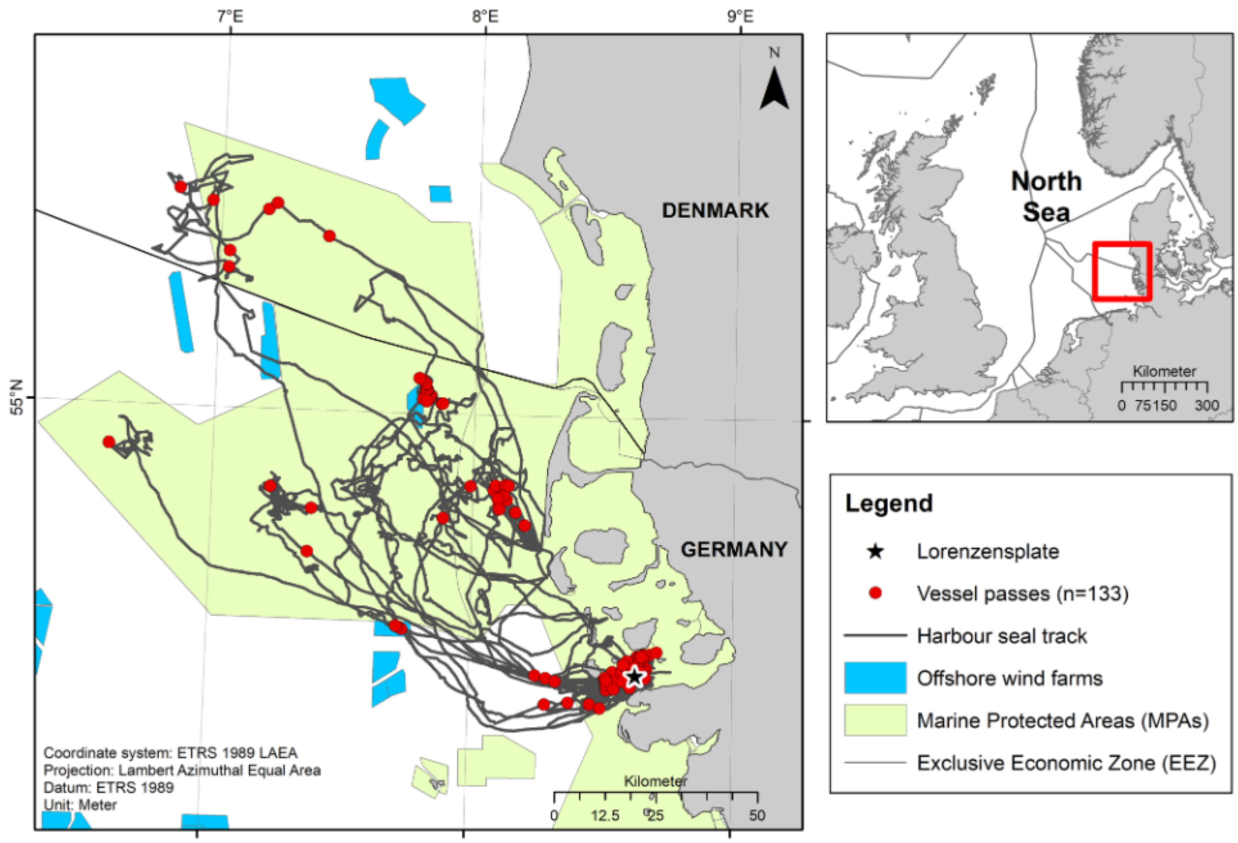

Figure 2. Tracks of harbour seals (n = 9) in the North Sea. The red dots illustrate the locations of high level vessel passes during on-effort periods (n = 133). The tagging site Lorenzensplate is indicated by a black star. Harbour seals were tagged in three catches over two consecutive years. The map was created using ESRI ArcGIS, version 10.5.

From (Chen et al., 2017): A grey seal's distance from a vessel alongside sound levels in summer and (simulated) winter ocean conditions.

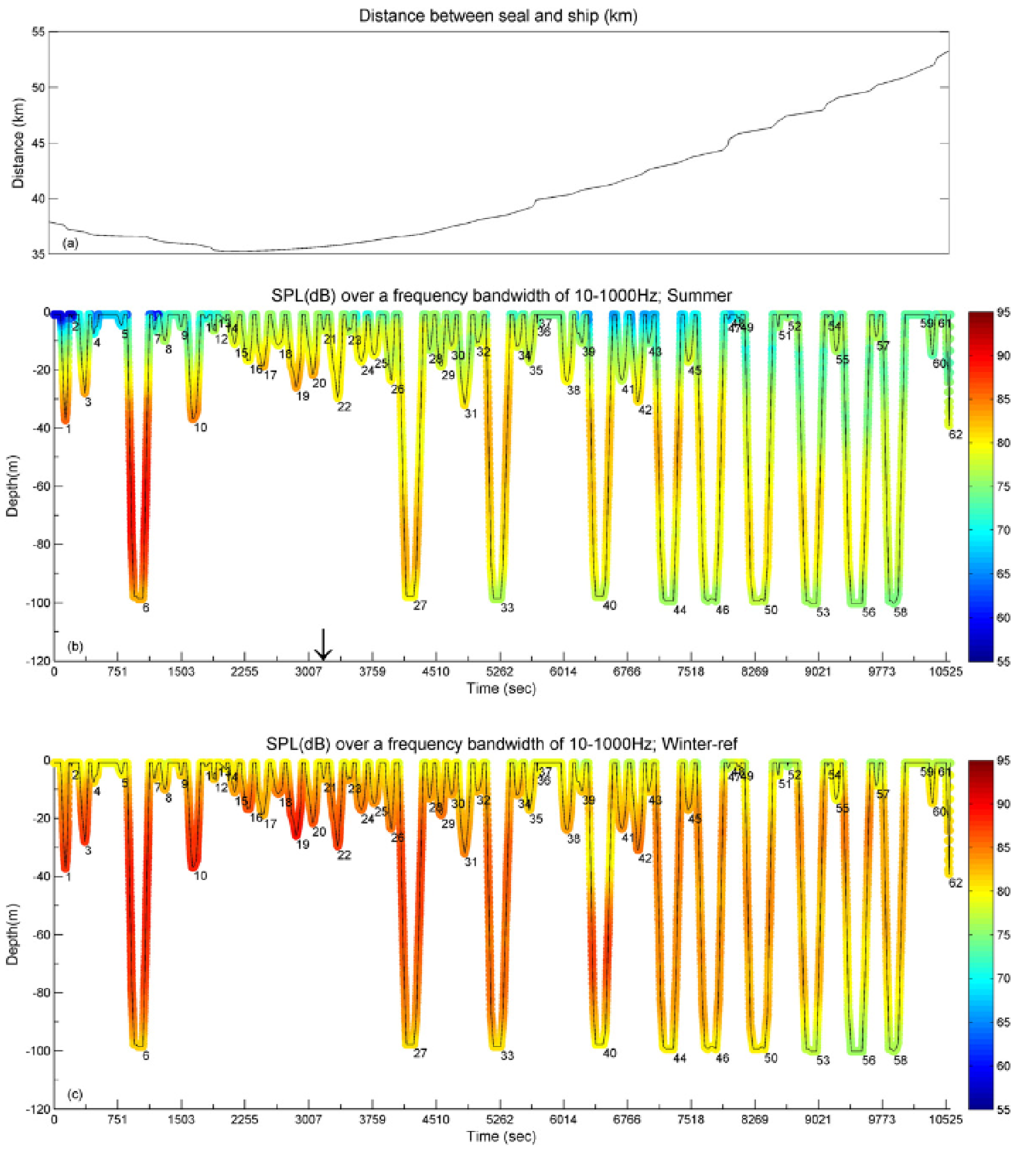

Fig. 5. Sound exposure for Seal1 (see Fig. 1) in summer. (a): relative distance between Seal1 and ship (MMSI: 563483000); (b): SPL (dB) over a frequency bandwidth of 10–1000 Hz for Seal1 over its diving path. The black arrow in the figure marks the time point when the ship crosses the bottom front from onshore to offshore while the numbers are indices of diving profiles; (c): same as (b) with the water column data replaced by winter temperature and salinity for noise calculation.

Contribution to Soundscape

Many papers studied the contribution of vessels to the soundscape, but without the inclusion or collection of marine mammal data. As marine mammals are still considered one of the affected parties from ship noise, some known value from previous studies (hearing threshold, frequency range of hearing sensitivity, distribution, or BIA) can guide implications for certain vessel types. To characterize the soundscape, AIS was commonly used to ground-truth ship noise detections, then compare it with the associated vessel type.

Papers: Hatch et al., 2008, McKenna, 2009, Willems et al., 2009, Lagueux et al., 2011, Bassett et al., 2012, Erbe et al., 2012, McKenna et al., 2012, Merchant et al., 2012, Hermannsen et al., 2014, Jensen et al., 2015, Magilo et al., 2015, Webb and Gende, 2015, Aulanier et al., 2016, Veirs et al., 2016, Halliday et al., 2017, Karasalo et al., 2017, Allen et al., 2018, Putland et al., 2018, Hermannsen et al., 2019, Greig et al., 2020, Almunia et al., 2021, Cope et al., 2021a,Cope et al., 2021b, McKenna et al., 2021, McWhinnie et al., 2021, Nesdoly, 2021, HDR (Athens, AL), 2022, Lo et al., 2022, Rutenko et al., 2022, Escajeda et al., 2023

Example:
Escajeda et al., 2023: Characterization of sound levels and distance heard by vessel type

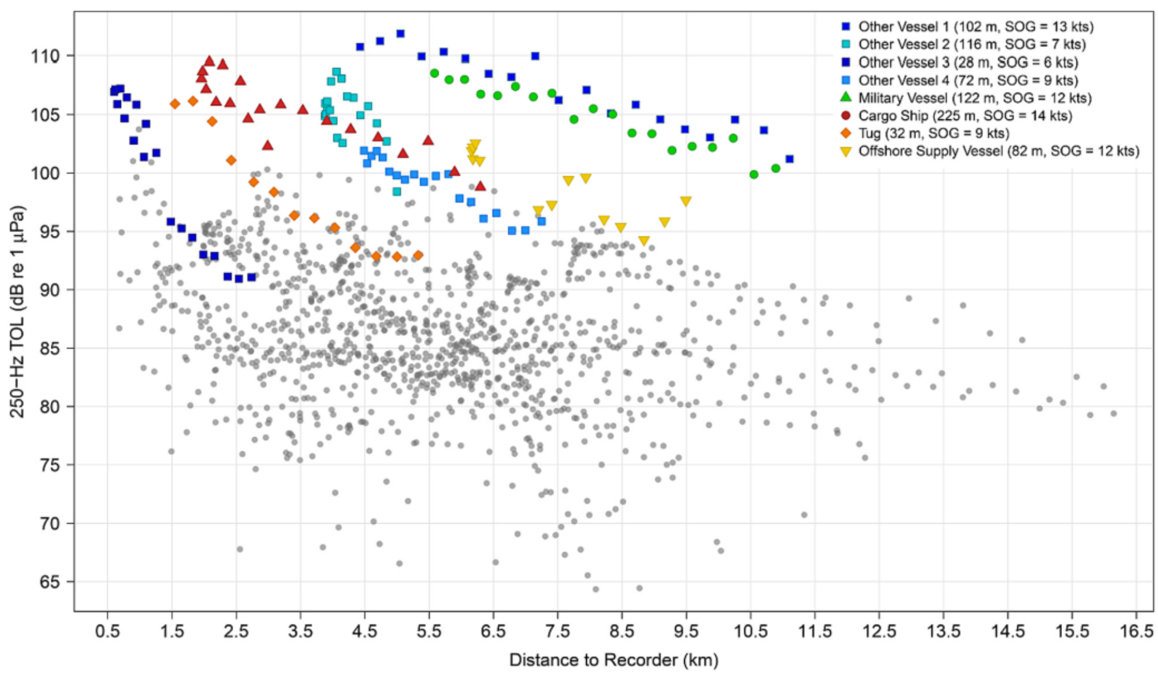

Fig. 6. (Color online) Received levels (RL) for the 250-Hz third-octave frequency band (TOL) vs. slant range to the recorder (km) for the loudest vessels from the select dataset of unique ship events ($n = 8$; color points) plotted against the RLs for all select ship events (total $n = 73$; gray points). A 'ship event' is a ship recording matched with the AIS tracks of a single vessel that was traveling at speeds >5 knots and passed within 10 km of the mooring (see Section 2.5). Vessel type is listed for each of the loudest vessels along with the ship's length and mean speed over ground (SOG) in knots (kts). Each point represents the RL measured over each minute of the ship event recording and corresponds to an AIS transmission.

Additional notes for AIS use

- A large portion of AIS data is problematic and omitted (McGillivary et al., 2009) due to missing or incomplete messages (Lo et al., 2022). Often, non-AIS vessels are not counted. In most studies, these are explicitly mentioned as limitations.

- To fill these gaps, several studies used vessel tracking methods other than AIS, including radar (Cope et al., 2021a), aerial survey (Thornton et al., 2022), land-based observational survey (Oakley et al., 2017), theodolite tracking for non-AIS vessels (Hermannsen et al., 2019, Williams et al., 2021), or satellite AIS (Greig et al., 2020, McWhinnie et al., 2021). Using alternative vessel tracking sources can ultimately improve noise impact assessments, sound propagation models, or traffic density assessments that only use AIS.
- AIS sometimes requires interpolation to achieve correct temporal resolution, but otherwise is sourced pre-processed and ready to use.

Notable visualizations

Jones, 2021: Sound levels before/during/after moment of CPA of vessel

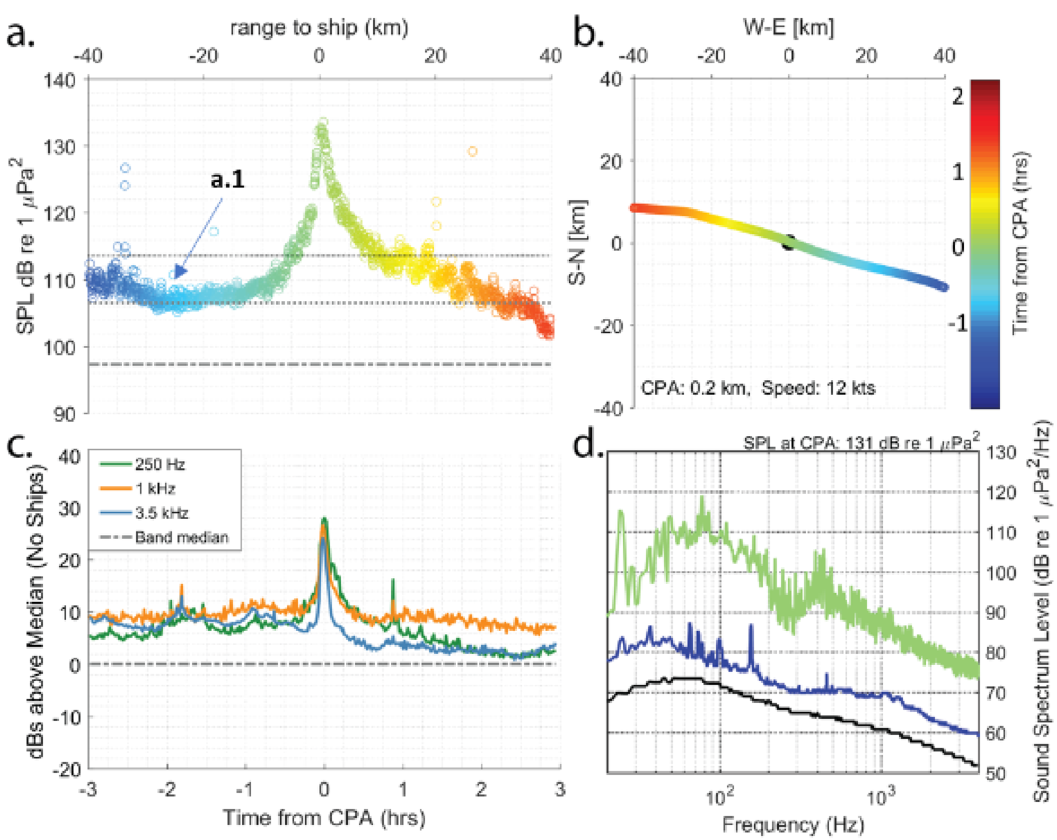

Figure 4.24: Transit of general cargo ship *Sedna Desgagnes* (MMSI 316015251) August 24, 2019. SPL_{BB} (a; open circles) averaged every 5s increases above pre-transit background level (a.1) starting at 10 km range to ship pre-CPA and ending 30 km post-CPA. SPL_{BB} was 131 dB at CPA range 0.2 km. Colors in SPL scatter plot (a) and map showing ship track (b) represent time from CPA. One minute average 250 Hz (c; green line), 1 kHz (orange line), and 3.5 kHz (blue line) $1/3^{rd}$ octave band levels during ship transit plotted relative to median for the frequency band excluding ship transits (dash-dot line). SPSL (d) of CPA period (green line) with median SPSL of the first 30 min of transit plot (blue line) and shipping season median levels during periods excluding ship transits (black line).

Broker et al., 2015: Sound levels in color as it moves on grey whale

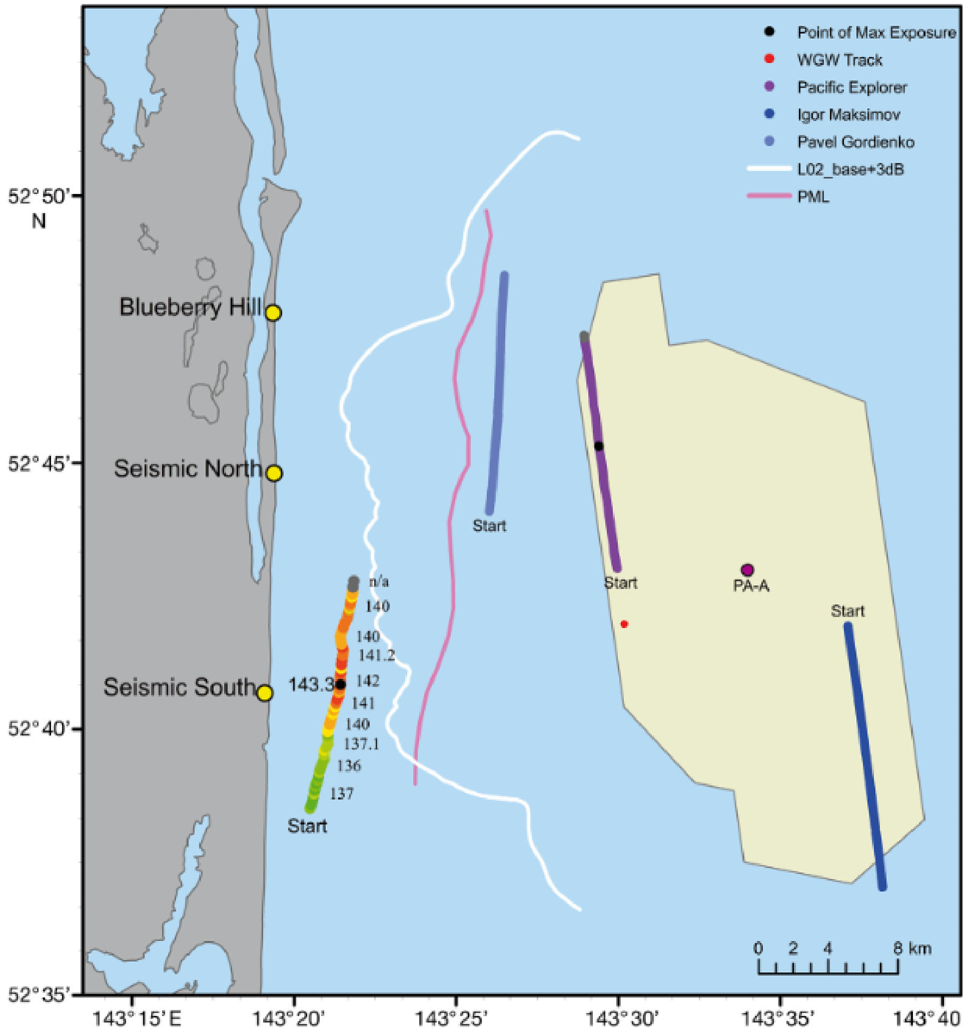

Fig. 6. Gray whale path annotated with estimated received sound levels (per-pulse SEL) from the seismic source acquiring a survey line. The track of the source vessel 'Pacific Explorer' for the same time period is shown in purple at the nearshore edge of the seismic survey area (yellow). The corresponding track of the monitoring vessel 'Pavel Gordienko' is shown in lighter blue near the perimeter monitoring line (PML), and that of the scout vessel 'Igor Maksimov' in darker blue near the offshore edge of the survey region. The simultaneous start points of the tracks are labelled, and black dots indicate the relative locations of source and whale at time of maximum exposure. Shown on shore are 3 behavioural monitoring stations

Rutenko et al., 2022: Software displays real-time grey whale locations and AIS vessel information.

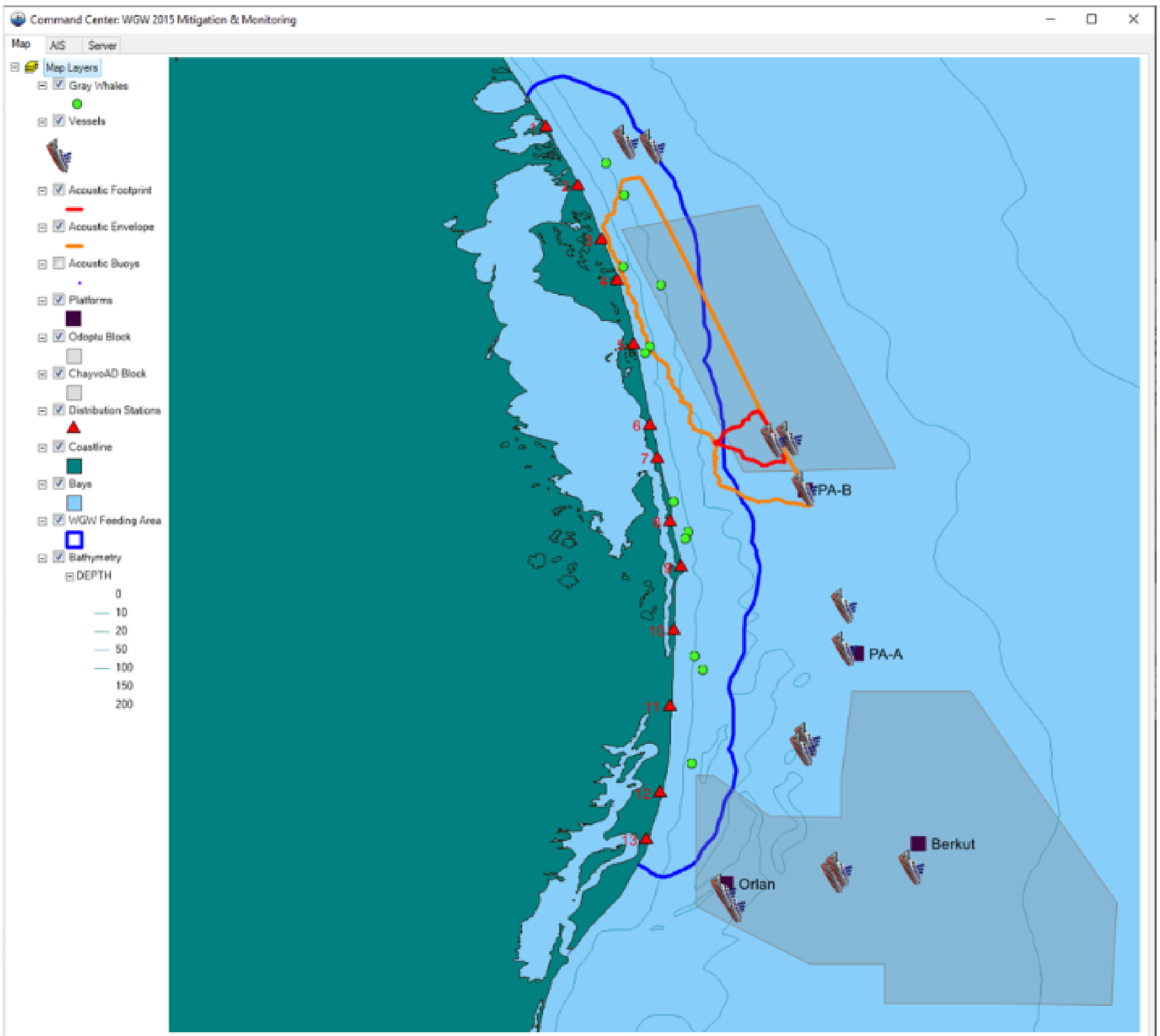

Fig. 9 Information display generated with Pythagoras™ software showing AIS vessel information, real time gray whale locations (colored dots), shore-based whale tracking stations (red triangles), outline of nearshore feeding area (blue contour), and 163 dB re 1 μPa² SPL footprint for the active seismic vessel (instantaneous: red contour; full-line envelope: orange contour)

From Allen et al., 2018:

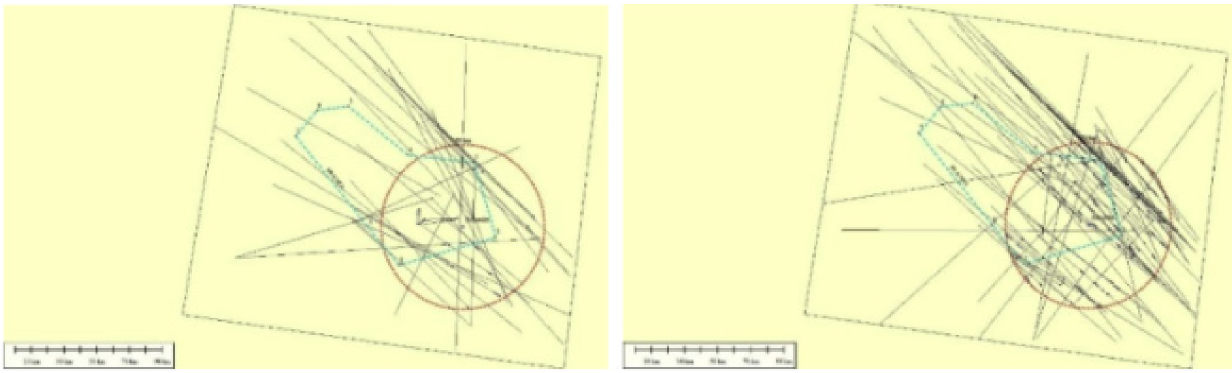

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Fig. 6. Satellite AIS vessel tracks within 50 km of the acoustic recorder and hydrophone at SK-B MPA for August 2011 (n = 18, left) and February 2012 (n = 52, right).

Implications for SAEL

Drifting buoys are a preferred passive acoustic monitoring tool because they cover a wide spatial area with a heavy temporal element. This best aligns with the agent-based approach as the buoy traverses specific soundscapes and has close encounters with vessels. Though no studies here used drifting buoys, those with DTAGs best resemble the movements of a drifting buoy since the receiver (marine mammal with tag) is also mobile. Most acoustic monitoring was done with a stationary hydrophone. Important information can be captured during the CPA of a vessel of a drifting buoy, something that cannot be captured with the analytical approach mentioned earlier. Many studies manually identify CPA, or use proprietary software to achieve their goals; only McWhinnie et al., 2021 appear to have links to openly available scripts that show pre-processing code. This leaves opportunities for the SAEL team to utilize AIS data alongside drifting buoy GPS tracks and whale detections.

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