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Rice's whales (*Balaenoptera ricei*) are one of the most endangered marine mammal species in the world. Their known distribution is restricted to the Gulf of Mexico (GoMx) and basic knowledge of their ecology is limited. In their core distribution area along the northeastern GoMx shelf break (Rosel & Garrison, 2021), their abundance was estimated at 51 individuals, 95% CI [20, 130], based on line transect surveys conducted during 2017 and 2018 (Garrison et al., 2020). Most Rice's whale sightings and acoustic detections during the last 30 years occur in this area off the northwestern coast of Florida (Rice et al., 2014; Rosel et al., 2021; Širović et al., 2014; Soldevilla et al., 2017; Soldevilla, Ternus, et al., 2022). While visual sightings are rare (e.g., Rosel et al., 2021), recent passive acoustic detections during one year of recordings (Soldevilla, Debich, et al., 2022) establish that they routinely occur along the shelf break of the northwestern GoMx off Louisiana as well. Currently, Rice's whales are only known to occur within U.S. waters of the northern GoMx, although whaling records (Reeves et al., 2011) suggest they were distributed more broadly across the GoMx historically. Understanding their range and distribution is important for evaluating the impacts of human activities, including climate change, that threaten their long-term survival. Considering the high levels of anthropogenic activity throughout the GoMx (e.g., oil and gas exploration and extraction, fisheries,

shipping, and oil spills), a comprehensive knowledge of the current distribution of Rice's whales is needed to understand the risk of these activities to the whales and to develop effective recovery and conservation strategies for this endangered species (Rosel et al., 2016).

Long-term autonomous passive acoustic monitoring (PAM) is a highly effective method for establishing the distribution of rare whale species, particularly in areas where they occur infrequently or were sighted by whalers historically (e.g., Mellinger et al., 2011; Munger et al., 2008). Rice's whales produce highly stereotyped call types, including long-moans, tonal-sequence calls, and pulsed downsweep sequences, which are readily identifiable in autonomous recordings (Rice et al., 2014; Širović et al., 2014; Soldevilla, Ternus, et al., 2022). Variants of the long-moan calls that have been described include one detected only in the northeastern GoMx and six detected primarily in the northwestern GoMx (Soldevilla, Debich, et al., 2022; Soldevilla, Ternus, et al., 2022). The northeastern long-moan call type is a long-duration frequency-downswept call with an average initial frequency of 150 Hz, center frequency of 107 Hz, and duration of 22 s (Rice et al., 2014). Northwestern long-moan call types also begin with a 2–3 s tone at 150 Hz, but rather than a continuous downsweep to a long lower frequency tonal tail, they have a more abrupt transition between the 150 Hz tone starting segment and a lower frequency tonal tail (Soldevilla, Debich, et al., 2022). The six northwestern variants each have a stereotyped frequency-modulation pattern to the transition component

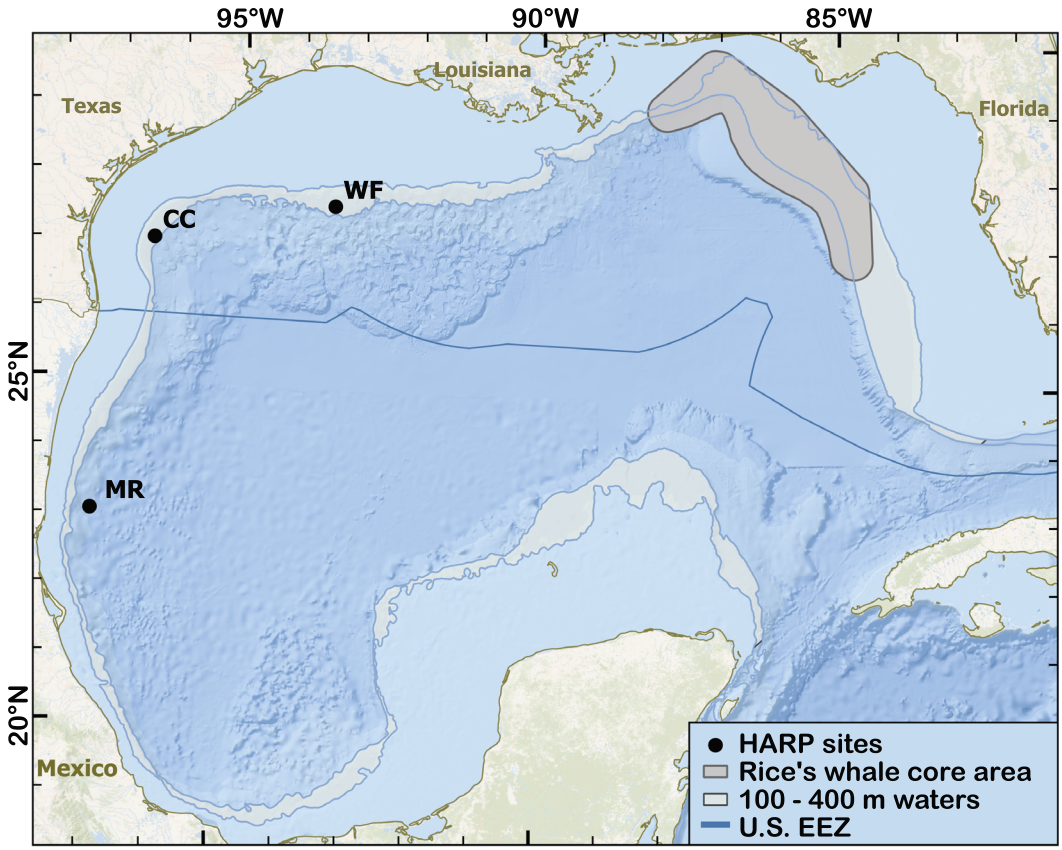

FIGURE 1 Locations of three High-frequency Acoustic Recording Packages (HARPs, represented by black dots) deployed near the western Gulf of Mexico (GoMx) shelf break from September 2019 to August 2020 (CC and WF) and from September 2020 to July 2022 (MR). Rice's whale core distribution area (as of June 2019; medium gray polygon), the region with 100–400 m water depths (light gray polygon), and the U.S. EEZ (blue line) are shown. Site names: CC = Corpus Christi; MR = Mexican Ridges; WF = Flower Garden West.

that distinguishes them. Additionally, frequently reported calls consisting of only the 150 Hz tone were proposed to be partial northwestern long-moan calls in which the transition and tail components are masked by increased low-frequency (below 125 Hz) noise levels common in the western Gulf (Soldevilla, Debich, et al., 2022).

As a component of several projects monitoring cetaceans in oceanic GoMx waters, we deployed long-term passive acoustic recorders offshore of Louisiana and Texas, and in Mexican waters of the southern GoMx (Figure 1). Between September 7, 2019, and August 29, 2020, autonomous passive acoustic recorders were deployed to monitor for Rice's whales at two shelf-break sites (Table 1), including the previously studied Flower Garden West site (WF), offshore of the Flower Garden Banks located off Louisiana (Soldevilla, Debich, et al., 2022), and a new site offshore of Corpus Christi, Texas (CC) near where a Rice's whale was sighted in 2017 (Rosel et al., 2021). These recorders yielded continuous recordings over 356 days at each site. Autonomous passive acoustic recorders were also deployed to monitor for cetaceans from September 7, 2020, to July 19, 2022, at a new site in Mexican continental slope waters northeast of Tampico, near the Mexican Ridges (MR). These recorders yielded continuous acoustic recordings over 680 days (Table 1). Our objective in this study was to find whether Rice's whales occur in Mexican waters of the western GoMx and to evaluate how frequently they occur at all three western Gulf sites. With this aim, we conducted manual spectrogram reviews and ran automated long-moan call and downsweep-sequence detectors on the combined four instrument-years of acoustic recordings.

The acoustic recorders used in this study were High-frequency Acoustic Recording Packages (HARPs), which were moored to the seafloor and consisted of a calibrated hydrophone tethered ~10 m above a packaged data logger, batteries, flotation, acoustic release, and ballast weight system (Wiggins & Hildebrand, 2007). To improve processing efficiency, recordings originally sampled at 200 kHz were decimated to a sample rate of 2 kHz, yielding an effective frequency bandwidth from 10 to 1,000 Hz. This bandwidth is sufficient for recording Rice's whale calls, which fall within 60–160 Hz. In recordings from sites CC and WF, Rice's whale calls were manually detected in long-term spectral averages (LTSA's) by trained acoustic analysts (S.J., I.C.) and verified by a Rice's whale acoustic expert (A.J.D.) following previously established methods (Soldevilla, Debich, et al., 2022). In recordings at site MR, Rice's whale calls were automatically detected using long-moan call and downsweep sequence spectrogram correlation detectors (Soldevilla, Debich, et al., 2022). Detector thresholds were set to minimize missed calls at the cost of higher false positives. However, the GoMx soundscape is heavily influenced by anthropogenic noise from seismic airgun surveys and shipping (Wiggins et al., 2016), resulting in high numbers of false positive detections. To ensure only true calls were retained for further analysis, all call detections were manually validated by an experienced acoustic analyst (A.J.D.) and false detections were removed.

Rice's whale calls were frequently detected at site CC, providing the first evidence of their regular occurrence in waters offshore of Texas. A total of 1,694 long-moan calls were detected in the one year of recordings at CC, and 4,323 long-moan calls were detected at WF (Table 2). Of these, 1,102 and 2,115 calls from CC and WF, respectively, could be definitively identified as western long-moan calls (including the 150 Hz tone, transition, and tail), while only the 150 Hz tone could be identified for the remaining 592 (34% of total) and 2,208 (51% of total) calls at each of the

TABLE 1 GoMx HARP mooring deployment details.

ID	Latitude	Longitude	Depth (m)	Start date, time	End date, time	Duration (day)
CC01	27.1097°N	96.3245°W	251	September 8, 2019, 6:00	August 29, 2020, 18:50	356.1
WF02[a]	27.7019°N	93.3936°W	180	September 7, 2019, 18:00	August 28, 2020, 20:15	356.5
MR01	23.1062°N	97.0911°W	1,245	September 7, 2020, 7:00	September 4, 2021, 13:46	362.4
MR02	23.1061°N	97.0901°W	1,133	September 4, 2021, 15:00	July 19, 2022, 18:27	318.1

[a]WF site is located 5 km north of previous deployment location in 2016–2017.

TABLE 2 Availability of recordings and number of calls detected on three HARPs located in the western GoMx. CC = Corpus Christi; MR = Mexican Ridges; WF = Flower Garden West.

	CC	WF	MR
Recordings available			
Days	356	356	680
Hours	8,547	8,557	16,333
Long-moan calls			
No. of calls	1,694	4,323	579
Days present (%)	88 (24.7)	119 (33.4)	101 (14.9)
Hours present (%)	384 (4.5)	868 (10.1)	317 (1.9)

TABLE 3 Call detections by call type for the GoMx HARP deployments.

ID	Western long-moan	150 Hz tones
CC01	1,102	592
WF02	2,115	2,208
MR01	0	226
MR02	6	347

sites, respectively (Table 3). Western long-moan calls and 150 Hz tones cooccurred on 77% of days and 88% of days at CC and WF, respectively, adding further support that the 150 Hz tones are partial western long-moan calls. Compared to previous recordings from 2016 to 2017, there were more than twice as many calls detected at WF in 2019–2020 recordings, and 150 Hz tones were more common, representing 51% of total calls at WF compared to 20% of calls in 2016 to 2017 (Soldevilla, Debich, et al., 2022).

Rice's whale long-moan calls were present throughout the year at sites CC and WF (Figure 2), with calls detected on 24.7% of days (4.5% of hours) at CC and 33.4% of days (10.1% of hours) at WF (Table 2). While call detections occurred year-round, with no strong seasonal cycle, there was a peak in call detections from November to January at site WF and from June to August at sites WF and CC during the September 2019 to August 2020 deployment year (Figure 2, Table 4). Winter and summer peaks in call detections were also seen during the previous 2016 to 2017 deployment at WF, when call detections were highest in December and August (Soldevilla, Debich, et al., 2022). It is notable that Rice's whale calls were present at WF on one third of all days in 2019–2020, which was twice as often as in 2016–2017 (Soldevilla, Debich, et al., 2022). This highlights both their persistence at this site over multiple years, as well as the variability among years. The interannual variability may be due to the slight 5 km north shift in site location, differences in detectability across years, or a response to oceanographic conditions.

Rice's whale calls were also detected at site MR, providing the first evidence of their occurrence in Mexican waters, and demonstrating that Rice's whales have a transboundary range including both U.S. and Mexican waters of the GoMx. In each of the two deployment years, a total of 226 and 353 Rice's whale western long-moan calls were detected, respectively (Table 3). Although the majority (99%) of these calls consisted of the 150 Hz tone only, six calls from the MR02 deployment definitively exhibited both the 150 Hz tone and a transition or tail portion of the call. These six western long-moan variants were detected over three separate days (October 1, 2021, October 3, 2021, and December 27, 2021), and the five from October were each followed by a 150-Hz-tone-only call.

Rice's whale calls were detected sporadically throughout the year at site MR (Figure 2), with calls detected on 14.9% of days (1.9% of hours) across the 2 years (Table 2). A peak in call detections occurred from August 2021 to January 2022 (Figure 2, Table 4). Nevertheless, seasonality is not evident at this site as there was no concordant peak in detections during August 2020 to January 2021. The MR HARP site occurs in deeper water (1,200 m) than

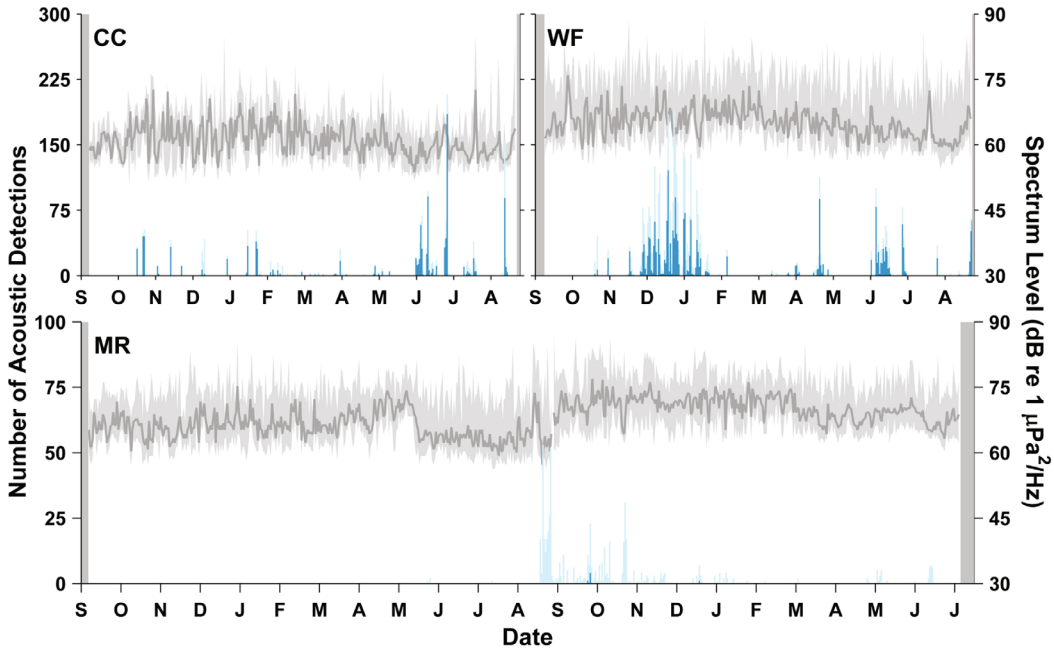

FIGURE 2 Daily detections of Rice's whale calls (western long-moans: dark blue bars; 150 Hz tones: light blue bars; bars are stacked to indicate total calls per day) and sound pressure spectrum levels at 150 Hz (average: thick line, standard deviation: shading). Dark gray shaded periods at start or end indicate no recording effort. Note: Acoustic detections on the *y*-axes are on different scales for site MR compared to sites CC and WF. Site names: CC = Corpus Christi; MR = Mexican Ridges; WF = Flower Garden West.

Rice's whales have typically been found in; however, it is only 28 km from the 400 m isobath and Rice's whale calls have been detected as far as 75 km away (Rice et al., 2014). With only a single acoustic sensor on the HARP, it cannot be determined whether the whales occur in deeper waters or if the whales producing the calls detected at MR were located in the typical 100–400 m water depths. The high proportion of call detections at this site containing only the 150 Hz tone suggests the whales may be farther away.

The discovery that Rice's whales regularly occur in waters off Texas and in Mexican waters of the western GoMx has numerous implications for the management and conservation of this critically endangered species. The Gulf's extensive industrialization poses multiple threats to Rice's whales. These threats include injury or mortality due to vessel strikes, oil and gas exposure, entanglement in fishery gear, and exposure to marine debris, and habitat degradation due to noise from shipping traffic and seismic airgun surveys (Rosel et al., 2021). The levels of these threats are highest in the northwestern GoMx offshore of Texas and Louisiana, where numerous major shipping ports and high levels of oil and gas exploration and extraction occur near Rice's whale habitat (Garrison et al., 2023; Soldevilla, Debich, et al., 2022). Moreover, new aquaculture and wind energy industries have areas under consideration for development on the nearby GoMx shelf (Farmer et al., 2022, 2023), and oil and gas leasing opportunities are being considered along the northwestern and northcentral shelf-break where Rice's whales are found. Further, effects of warming waters due to climate change on the GoMx ecosystem may impact their distribution and population health. Until now, efforts for the management and conservation planning for the recovery of Rice's whales have been limited to U.S. management agencies as there was only evidence for their occurrence in U.S. waters. Similar industries are active in Mexican waters of the GoMx (Benitez et al., 2014). Two major shipping ports, Puerto Industrial Altamira and Puerto de Tampico, occur within 125 km of the MR HARP site, oil and gas exploration and extraction occur within Campeche Bay to the south (Murawski et al., 2020), and a gas pipeline installation is planned near the 200 m isobath from Tuxpan to Tabasco. This suggests whales in Mexican waters are similarly at risk of injury or mortality

TABLE 4 Western long-moan variant call detections and percent of days present per month per HARP deployment year. CC = Corpus Christi September 2019 to August 2020; MR-Y1 = Mexican Ridges September 2020 to August 2021; MR-Y2 = Mexican Ridges September 2021 to July 2022; WF = Flower Garden West September 2019 to August 2020.

	Calls detected				Percent days present			
	CC	WF	MR-Y1	MR-Y2	CC	WF	MR-Y1	MR-Y2
September[a,b]	0	0	0	133	0	0	0	67
October	135	99	0	182	10	13	0	74
November	65	239	0	39	13	30	0	60
December	111	1,899	0	16	16	97	0	16
January	151	929	0	19	23	68	0	26
February[c]	61	32	0	3	31	7	0	11
March	26	26	0	2	32	32	0	3
April	43	238	0	0	27	43	0	0
May	35	9	3	19	19	6	6	26
June	535	497	0	22	60	50	0	17
July[b]	346	177	1	0	42	16	3	0
August[a]	186	178	140	n/a	18	28	23	n/a

[a]September 2019 and August 2020 were partial months for CC and WF days with recordings present, with 24 and 23 days in September and 28 and 29 days in August, respectively.
[b]September 2020 and July 2022 were partial months for MR, with 24 and 19 days with recordings present, respectively. In September 2021, MR01 was recovered and MR02 deployed on September 4; September MR-Y2 includes all 4 days with 82 call detections present from MR01and 16 of 26 days with 51 call detections present from MR02.
[c]February 2020 had 29 days with recordings present at sites CC and WF.

from vessel strike and oil and gas exposure, as well as habitat degradation from shipping and seismic airgun surveys, and impacts of climate change. This new evidence demonstrating Rice's whales' transboundary distribution underscores the imperative for a collaborative approach to management actions to recover Rice's whales across U.S. and Mexican environmental and marine resource agencies.

Furthermore, these results have implications for the population monitoring of these endangered whales. To discern whether the population is declining, steady, or recovering, it is crucial to determine the full extent of their distribution throughout the GoMx and to conduct regular abundance monitoring throughout their entire range. The findings presented here, in combination with those of Soldevilla, Debich, et al. (2022), support the hypothesis that the Rice's whale habitat might encompass all 100–400 m depth waters encircling the entire GoMx along the shelf break (Garrison et al., 2023). The latest population estimate indicates there are fewer than 100 individuals in the northeastern core distribution area (Garrison et al., 2020), and this small population size is considered dangerously small, posing a significant extinction risk (Rosel et al., 2016). The IUCN categorizes Rice's whales as Critically Endangered due to this small population size (Rosel et al., 2016). The new acoustic recordings in the western GoMx support that appropriate habitat is present and being utilized outside the northeastern GoMx. This could imply the population size is somewhat larger than the current estimate of 51 individuals, which would be welcome news. Alternatively, it could be that whales simply have a broader distribution than just the northeastern GoMx. Differences in Rice's whale call types recorded in the eastern GoMx and those recorded in the western GoMx provide some support for the former. Further research to determine the full extent of the Rice's whale range, to understand their spatial density throughout U.S. and Mexican waters and how it may be changing over time, and to estimate a GoMx-wide population abundance is needed to better assess and mitigate the risks these whales face.

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The scientific results and conclusions, as well as any views or opinions expressed herein, are those of the author(s) and do not necessarily reflect those of NOAA or the Department of Commerce.

AUTHOR CONTRIBUTIONS

Melissa Soldevilla: Conceptualization; formal analysis; funding acquisition; investigation; methodology; project administration; software; visualization; writing – original draft; writing – review and editing. **Amanda Debich:** Data curation; investigation; validation; writing – review and editing. **Itzel Perez-Carballo:** Investigation; writing – review and editing. **Sierra Jarriel:** Investigation; writing – review and editing. **Kaitlin Frasier:** Funding acquisition; methodology; project administration; writing – review and editing. **Lance Garrison:** Conceptualization; funding acquisition; writing – review and editing. **Adolfo Gracia:** Funding acquisition; writing – review and editing. **John A. Hildebrand:** Conceptualization; funding acquisition; methodology; resources; writing – review and editing. **Patricia Rosel:** Funding acquisition; writing – review and editing. **Arturo Serrano:** Funding acquisition; writing – review and editing.

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