This is a pre-print of a manuscript submitted to the Journal of Foraminiferal Research *and posted to BioArXiv. It has not yet undergone peer review and will likely change before it is finalized. Comments are very welcome, and should be sent to the corresponding author (cmlowery@utexas.edu)*

DISTRIBUTION OF LIVING (ROSE BENGAL STAINED) BENTHIC FORAMINIFERA IN COPANO, ARANSAS, AND REDFISH BAYS, CENTRAL TEXAS COAST

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ABSTRACT

Benthic foraminifera are sensitive indicators of environmental conditions in estuary environments. Here, we report populations for living (Rose Bengal stained) benthic foraminifera from three bays in the Texas Coastal Bend, along the northwestern Gulf of Mexico: Copano Bay, Aransas Bay, and Redfish Bay. We sampled 11 stations in May 2023 and 2024, and found populations dominated by *Ammonia parkinsoniana* in Copano Bay and central and northeastern Aransas Bay. Southwestern Aransas Bay, more proximal to the Aransas Pass inlet, contained a much higher abundance *Elphidium* spp. Redfish Bay was also dominated by *A. parkinsoniana*, although a single sample taken from a seagrass bed was dominated by *Buliminella gracilis*. These predominance facies represent a shift from the last complete census of Aransas and Copano bays, carried out by Frances Parker and colleagues in 1951. That year, in the midst of a shattering drought that raised salinity in the bays to such an extent that brackish oysters died and corals invaded as far as Rockport, was characterized by a much higher proportion of *Elphidium* spp. than we found in 2023-24 or was observed by others in samples from Aransas Bay in 1954 or Copano Bay in 2006. We attribute this to the reduced salinity in the bays in the years since. We see no direct correlation between predominance facies and salinity in our samples, although we only record a salinity range of 25-30‰, a small fraction of the possible range of ~10-40‰ in these bays. We do observe a relationship between sediment grain size and predominance facies, with *Ammonia* more common in finer grained environments. In the face of continuing anthropogenic impacts in these waters, continued monitoring of the living population is important to understand the environmental parameters that control species distribution and establish a baseline against which to measure future change.

INTRODUCTION

Estuarine ecosystems in the Gulf of Mexico are being impacted by a suite of changes related to human activity and climate change, including sea level rise, warming temperatures, changing salinity, and degraded water quality. Anthropogenic developments in and around the Texas Coastal Bend add external stress through urban run-off, dredging, increasing salinity, and temperature rise. This area has always been prone to large swings in salinity due changing hydroclimate conditions (Evans et al., 2012), with major implications for salinity-sensitive estuarine species (Parker, 1955; Buzas-Stephens, 2011). Increasing hydrologic extremes are an expected part of climate change (Senevirante et al., 2021) and will in turn make the swings in salinity more extreme. Engineering projects are also altering the salinity of these bays. The dredging of Aransas Pass, which was recently deepened to allow and the passage of very large liquefied natural gas carriers to the terminals in the Port of Corpus Christi, has increased the volume of water that passes through the inlet with each tide, with impacts on a number of estuarine species (Brown, et al., 2004; Valseth, 2021). Additionally, to meet increasing needs for freshwater, stakeholders in Corpus Christi (including the city, the port, and private industry) are planning to build up to five desalination plants, which would release brine directly back into bay waters (City of Corpus Christi, 2022). The contract for the first of these plants, in the Corpus Christi Inner Harbor, was just awarded to a contractor in October 2024 (City of Corpus Christi, 2024). Although the modelled salinity increase in the bays from the brine is less than the annual salinity range, this effluent is typically warmer than surrounding water and contains a greater concentration of toxic chemicals than typical seawater (Soliman, et al., 2021).

Tracking ecosystem changes caused by these anthropogenic stressors is urgently important, because such data are necessary to plan interventions and policy changes to preserve

these important ecosystems. Our knowledge of the effect of climate change and other human activities on coastal ecosystems often only extends as far back as the date of the first observational study at a particular place, limiting our understanding of the extent and duration of change, and of the natural variability of these ecosystems. Benthic foraminifera are sensitive to environmental parameters like salinity, pollution, dissolved oxygen, and nutrient flux, and are commonly used in environmental monitoring studies (e.g., Frontalini and Coccioni, 2011; Martins et al., 2016, 2019; Soukhrie et a., 2017, Sousa et al., 2020). They offer an advantage in paleoecological studies over other larger organisms (e.g., oysters, fish, etc.) because they are ubiquitous in marine environments and can be found in high abundance in small volumes of sediment, making it easy to reconstruct a statistically significant species-level population. Thus, while they are not necessarily ecologically important organisms themselves, benthic foraminifera serve as useful proxies for the overall health of an ecosystem.

Here, we report living (Rose Bengal stained) benthic foraminifera collected in May 2023 and 2024 in Redfish, Aransas, and Copano Bays (Figure 1), all within the Mission-Aransas National Estuarine Research Reserve (NERR). These bays have fewer direct human impacts than adjacent Corpus Christi Bay (especially in terms of dredging), making them ideal for understanding the benthic foraminiferal response to environmental change. Benthic foraminifera were previously collected in Aransas Bay in 1951 by Parker et al. (1953) and in 1954 by Phleger (1956), and in Copano Bay in 1951 by Parker et al., (1953) and 2006 by Buzas-Stephens et al. (2018); as far as we are aware our paper is the first quantitative report on living benthic foraminifera in Redfish Bay, although Ladd et al. (1957) reports qualitative abundances of benthic foraminifera from Redfish Bay based on observations in 1940. These populations thus provide a modern baseline against which to measure future change and an opportunity to

determine how the community has changed in the past decades. Interestingly, we found large shifts in dominant species in Aransas Bay compared to those reported by Parker et al. (1953). In 1951, Aransas Bay assemblages were characterized by a roughly even split of *Ammonia* and *Elphidium* species, with small numbers of other taxa rounding out the assemblage. In 2023 and 2024, Aransas Bay assemblages were nearly entirely *Ammonia*.

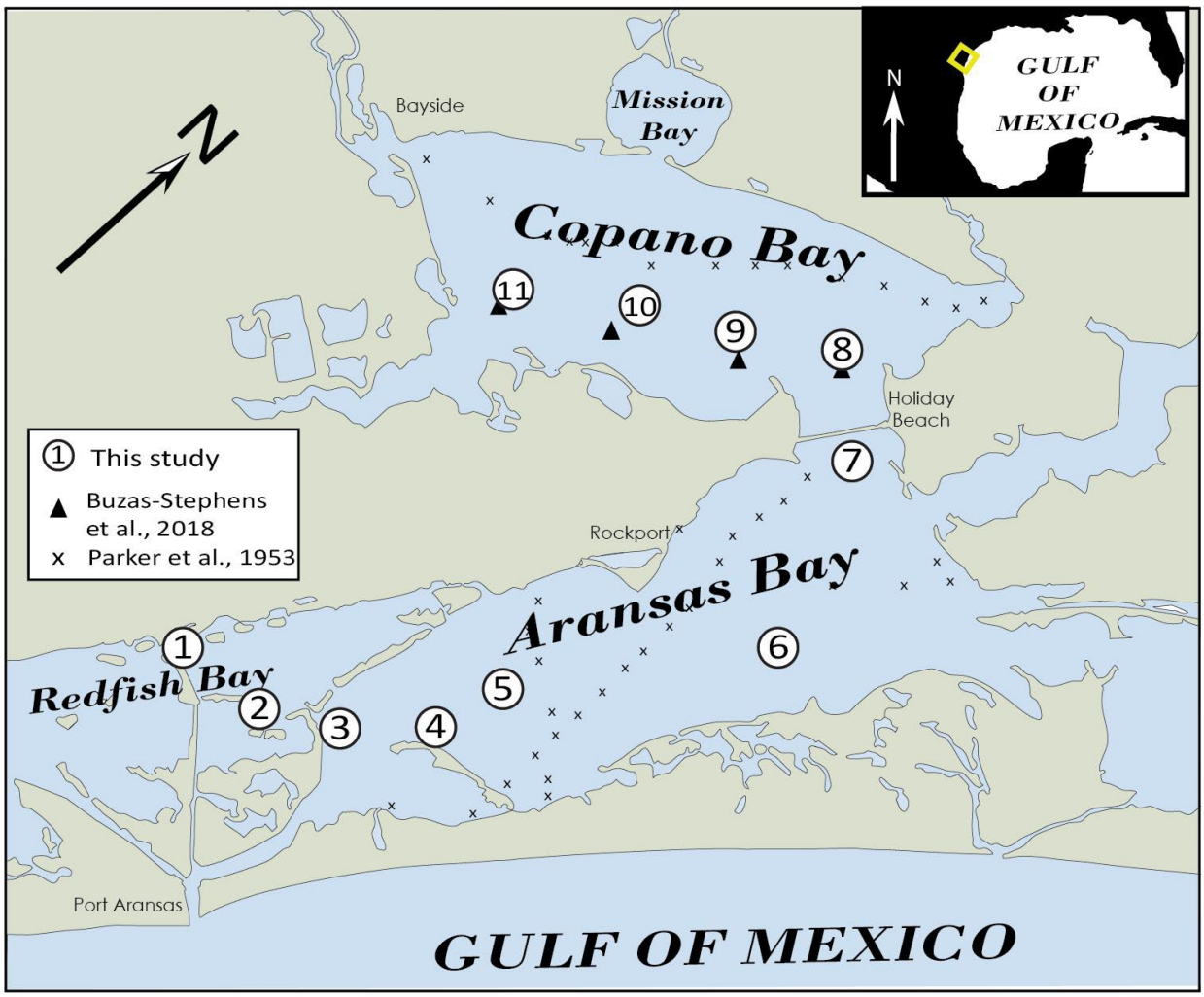

Figure 1. Location map showing the three bays studied and sample locations. Map traced from the "Oceans" basemap on the NOAA arcgis map viewer (NOAA 2024).

METHODS

SAMPLE COLLECTION

Samples analyzed here were collected during two consecutive years of the University of Texas at Austin's Marine Geology and Geophysics Field Course, an upper level course taught each May, with the field component based in Port Aransas, TX. Samples were collected using a Ponar Grab Sampler deployed from the R/V *Curt Johnson*, a shallow-draft vessel that allows access to very shallow and restricted environments. A total of seventeen samples were collected from the eleven stations, including nine in 2023 and eight in 2024 (one station in Copano Bay which returned mud in 2023 was covered with oyster shells in 2024). At each station, surface salinity was measured with an optical refractometer and recorded. The optical refractometer displays salinity in units of per mille (‰), and so this is how we report it here.

SAMPLE PROCESSING AND ANALYSIS

Immediately after retrieval, the upper centimeter of sediment was scraped off the top of the retrieved grab sample, placed in a Nalgene bottle, and covered with a solution of 2% Rose Bengal, 4% formalin (a fixant), and sodium hexametaphosphate (a buffer). This mixture of sample and solution was given a good swirl to break up the mud, and then placed in a cooler for at least 24 hours. The sample then was washed over a 63 micron sieve and dried in an oven. Back in the lab, the sample was split in a microsplitter to obtain a manageable amount, and stained foraminifera were identified and picked under a Zeiss Stemi binocular microscope. We aimed for at least 300 specimens per sample but many samples did not yield this many stained specimens. All samples except for one contained more than 100 specimens. "Stained" specimens were defined as specimens in which at least one chamber was fully stained pink; specimens with

surface staining, speckled staining inside one or more chambers, or which were lightly tinted pink were not included in the counts. Since we were picking samples dry, it was necessary to wet opaque tests (miliolids and agglutinated taxa) with the brush to determine staining.

Specimens were identified using species lists from Parker et al., 1953 updated to modern species concepts based on the work of Poag (2015). Many estuarine taxa, *Ammonia* in particular, have a rich history of species concepts that have been synonymized, split, relegated to subspecies, and then resurrected by different workers (Haynes, 1992, lamented "nomenclatural chaos" when writing about *Ammonia*). Acknowledging this, we follow the lead of Poag (2015), whose book on Gulf Coast foraminiferal assemblages names the common species of this genus *Ammonia parkinsoniana*, and recognizes two ecophenotypes as subspecies, a large, thick-walled "forma *typica*" and a small, thin walled "forma *tepida*." In our data, we do not differentiate between these ecophenotypes and simply report *A. parkinsoniana*. To account for sampling error, confidence intervals for each genus were calculated using the method of Patterson and Fishbein (1989). Predominance Facies were defined by identifying the dominant genus in each sample.

Grain size analysis was conducted by the field course students immediately after sampling using the pipette-sieve method, where the gravel (>2000 microns) and sand (2000-63 microns) size fractions were measured directly over sieves, and the silt (63-4 microns) and clay (<4 microns) size fractions were calculated from aliquots taken from the <63 micron fraction after settling in a 1000 ml graduated cylinder for 57 second (silt+clay fraction) and 2 hours and 3 minutes (clay fraction).

Table 1. Sample names, sample locations, measured salinity, and percentage abundance of common living (stained) foraminifera found in each. Individual samples are labelled by campaign, year, sampler type (GB = grab sampler), individual sample number. Station were numbers assigned post-hoc based on the samples selected for this study. See supplemental data for the full population table.

Bay	**Station** & Sample #	Latitude	Longitude	Salinity (‰)	%*Ammonia*	%*Elphidium*	%Mililoids	%*Ammotium*	%*Buliminella*	%Other
Redfish Bay	**STATION 1**									
	PortA2023 GB-14	27.897924	-97.137403	29	70	26	0	1.8	0	1.7
	PortA2024 GB-16	27.897577	-97.131305	25	67	32	0	0	0.3	1.6
	STATION 2									
	PortA2023 GB-12	27.899141	-97.094839	30	29	1.3	4	0	51	15
	PortA2024 GB-13	27.89914	-97.094725	25	64	5.3	0	0	19	12
Aransas Bay	**STATION 3**									
	PortA2023 GB-10	27.914018	-97.061593	30	48	43	1.8	0	4.2	3.5
	STATION 4									
	PortA2023 GB-9	27.942425	-97.040161	30	27	71	0	0	0.5	1.1
	PortA2024 GB-7	27.942517	-97.040327	25	27	69	1.7	0	0	1.7
	STATION 5									
	PortA2023 GB-8	27.974705	-97.023859	30	92	7.7	0	0	0	0
	PortA2024 GB-8	27.974682	-97.023898	24	70	5	0	0	21	4
	STATION 6									
	PortA2023 GB-7			30	90	4.5	0	0	0	5.7
	PortA2024 GB-9	28.037452	-96.982728	27						
	STATION 7									
	PortA2024 GB-21	28.1155	-97.0143	27	94	5.3	0	0	0	0.9
Copano Bay	**STATION 8**									
	PortA2023 GB-5	28.141447	-97.041838	30	67	16	0	0	0	17
	PortA2024 GB-22	28.1415	-97.042	28	60	13	0	0	1.9	25
	STATION 9									
	PortA2023 GB-4	28.114914	-97.068549	30	93	6.6	0	0	0	0.3
	PortA2024 GB-23	28.115	97.0685	27	89	10	0	0	0	0.8
	STATION 10									
	PortA2024 GB-24	28.0993	97.1016	27	87	5.2	0	2.3	0	5.8
	STATION 11									
	PortA2023 GB-2	28.074257	-97.137114	28	93	5.6	0	0.7	0	0.7

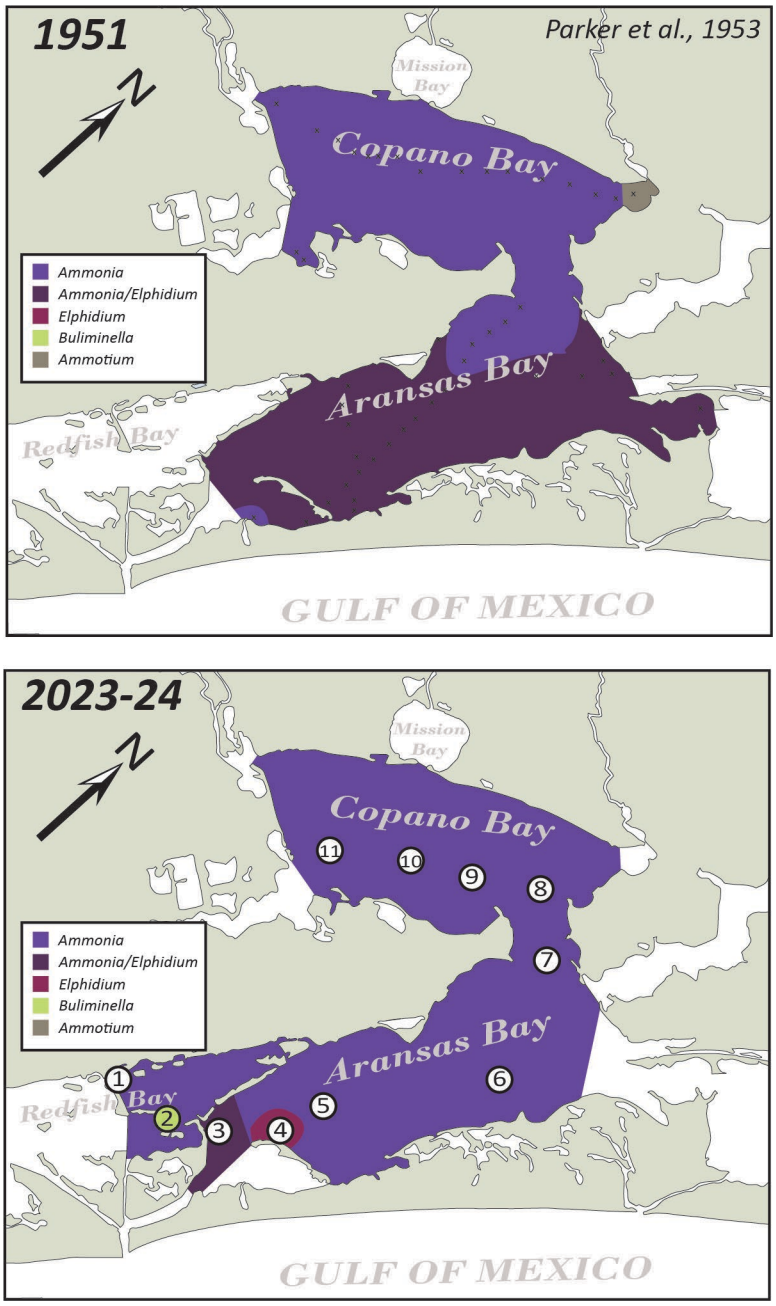

Figure 2. Predominance Facies maps showing the dominant genus or genera at a sample in 1951 (Parker et al., 1953) and 2023-2024 (this study). Predominance facies did not change from 2023 to 2024, with the exception of station 2 (taken in a seagrass bed), which was dominated by *Buliminella gracilis* in 2023 (when the sample contained numerous blades of seagrass) and *Ammonia parkinsoniana* in 2024 (when the sample contained no seagrass).

RESULTS

SALINITY

Average salinity across all stations was about 4‰ higher in 2024 than 2023. In 2023, salinity averaged of 25.0‰ in Redfish Bay, 25.3‰ in Aransas Bay, and 27.2‰ in Copano Bay. In 2024, salinity averaged 29.6‰ in Redfish Bay, 30.0‰ in Aransas Bay, and 29.3‰ in Copano Bay. The Aransas River is the main source of freshwater into the studied bays, along with the smaller Mission River, which covers an adjacent catchment. For the month prior to sample collection in 2023, discharge of the Aransas River at the USGS stream gauge near Skidmore, TX averaged 0.12 cubic meters per second. In 2024, it averaged 0.08 cubic meters per second.

GRAIN SIZE

Grain size varied throughout the study area, with samples dominated by either sand or silt. Clay seldom made up as much as a double-digit percentage of the bay floor, and gravel fraction was represented only by the occasional macroinvertebrate shell. Sand was the dominant sediment type in the southwestern Aransas Bay and in Redfish Bay, both near the tidally-dominated Lydia Anne Channel. Middle and upper Aransas Bay and Copano Bay were muddier, except for Station 8 just inside the entrance to Copano Bay, which was sandy, perhaps reflective of a concentration of tidal energy in that area.

FORAMINIFERA

The nine samples collected in 2023 contain a range of 26 to 305 individuals per sample and 14 genera total. The eight samples collected in 2024 contain a range of 103 to 310 individuals per sample and 13 genera were identified. Simplified count data are shown in Table 1; full counts including rare taxa are included as a supplemental table. Overall, all three bays

were dominated by *Ammonia*, with *Elphidium* becoming more common in the southwestern part of Aransas Bay, near Lydia Anne Channel (which leads directly to the Aransas Pass inlet), and a single sample in a seagrass bed in Redfish Bay dominated by *Buliminella gracilis*.

In Redfish Bay in 2023, the predominant genus was *Ammonia*, which made up 70.2% of at assemblage at Station 1 and 29.3% at Station 2. (Table 2). The second most common genus was overall was *Buliminella*, which dominated Station 2 with 50.7%. This station was in a seagrass bed near Hog Island, and the grab sample came up with numerous blades of grass in its jaws. *Elphidium* made up 26.3% of Station 1 and just 1.3% at Station 2. Samples from 2024 in Redfish Bay were similar overall, although Station 2 had far less *Buliminella* (18.8%) and did not contain any seagrass (this more likely reflects the spotty nature of seagrass cover than any major shift in the ecosystem). Instead, *Ammonia* made up 64.3% of Station 2, similar to the 66.5% of Station 1.

In central and northern Aransas Bay, *Ammonia* was the dominant genus in both 2023 and 2024, comprising up to 93.8% of the assemblage (Figure 2). Most of the rest of these samples is rounded out with single digit percent abundances of *Elphidium*, with a few *Haynesina* present in low abundance and a significant assemblage of *Buliminella* (21%) at Station 5 in 2024 (this taxon was completely absent there in 2023). However, *Elphidium* becomes increasingly abundant in the southwestern part of Aransas Bay, dominating Station 4 near Mud Island with ~70% both years and comprising about equal parts, along with *Ammonia* (42.8% and 47.7%, respectively), of Station 3 north of the tidally dominated Lydia Anne Channel, which connects directly to the Aransas Pass inlet. It is interesting to note that at the time of sampling these two stations had nearly identical salinities to the other stations in Aransas Bay (and in Copano Bay, for that matter).

Copano Bay was also dominated by *Ammonia* both years (Figure 2), although the degree of its dominance varied from east to west. At the eastern most Copano Bay Station, Station 8, *Ammonia* comprised 67.3% of the population in 2023 and 60.2% in 2024. Other common taxa included *Elphidium* (15.7% and 12.6%, respectively), followed by *Bolivina* (10.6% and 10.7%) and various agglutinated taxa. Further west, in Stations 9-11, *Ammonia* was present at similar levels to Aransas Bay, representing 86.7 to 93.1% of the assemblage.

DISCUSSION

DIFFERENCE IN ASSEMBLAGES SINCE THE 1950S

The most striking feature of the benthic foraminiferal population in 2023 and 2024 is how different it is from the last census of living benthic foraminifera in these bays in 1951 (Parker et al., 1953) (Figure 2). In August 1951 Frances Parker, Fred Phleger, and Jean Pierson took 37 samples in Aransas Bay and 16 samples in Copano Bay using a small coring tube and examined the upper 1 cm of sediment for foraminifera. In both Aransas and Copano Bays they found assemblages with a much higher proportion of *Elphidium* than was observed in 2023 and 2024. In Copano Bay, although *Ammonia* still dominated the assemblage, *Elphidium* averaged 19% of the population (compared to 9% in 2023-24) (Figure 2). In Aransas Bay, *Ammonia* and *Elphidium* were roughly equal, representing 45% and 38% of the mean assemblage, respectively. Today, *Elphidium* is common in the far southwestern part of Aransas Bay, but is only present in single digit percent abundances through most of the bay (Figure 2).

In 2006, Pamela Buzas-Stephens and colleagues sampled four stations in Copano Bay, and found assemblages that are distinctly similar to ours, with three of the four stations similarly

dominated by *Ammonia* (average 78% of the population) and the fourth nearly evenly split between *Ammonia* and the agglutinated genus *Ammotium* (Buzas-Stephens et al., 2018), which is a common component of populations proximal to fresh water inputs (Poag, 2015).

Why is there such a large difference between populations in 1951 and 2006/2023-24? The most likely cause is salinity. Salinity varies from ~10 ‰ to ~40‰ on multiyear scales in Aransas and Copano Bays (Evans et al., 2012). Sampling in 1951 occurred in the middle of an extended drought that lasted from 1948 to 1953 (Parker, 1955). Salinity at the time of sampling was very high in the bays, ranging up to 42‰ (compared to 36‰ in the open Gulf of Mexico at the time; Parker et al., 1953). This extended drought is associated with major changes in the macroinvertebrate community of the Coastal Bend estuaries and lagoons as open ocean taxa, better adapted to higher salinities, displaced estuarine species which were not (Parker et al., 1955). Echinoderms and corals invaded Aransas Bay as far north as Rockport, and Gulf Crabs became more common in the bays (Parker, 1955). The shrimp catch dropped from 1949 to 1951 (Hildebrand and Gunter, 1953) and production of the common oyster (*Crassotrea virginica*) was reduced (Parker, 1955). Parker (1955) reports that oysters from 1948-1950 were "thin, flabby, and tasteless" and by 1952 oysters were dying in large numbers in Copano Bay. Oyster reefs became dominated by the more salinity-tolerant small oyster *Ostrea equistris* (Parker, 1955).

Against this backdrop of major changes in ecologically and economically important macroinvertebrate species, Parker et al. (1953) found a high occurrence of *Elphidium*, a higher-salinity tolerant taxon (e.g., Debenay and Guillou, 2002) which, along with the more broadly tolerant *Ammonia*, is commonly found in the open gulf and, in other Texas bays, dominants the most distal bay waters, near the inlet (Poag, 2015 and references therein). It is thus reasonable to assume that a long period of drought and increased salinity caused an increase in the number of

Elphidium in Aransas and Copano Bays in the 1950s, whereas more normal precipitation and lower salinities in 2006 and 2023-24 resulted in a higher dominance of the more brackish-tolerant *Ammonia.*

Fred Phelger collected living (Rose Bengal stained) foraminifera in Aransas Bay in June 1954, immediately following the drought (Phleger, 1956). Salinities Aransas Bay ranged from (31-36‰), roughly intermediate between those of the drought (~40‰) and those recorded during our sampling in 2024 (~30‰). Of the 10 samples he collected, five contained fewer than 100 specimens. The other five contained assemblages dominated by *Ammonia* but with a larger proportion of *Elphidium* (up to 30%) than we see in our samples today (Phleger, 1956). The sample with the highest proportion of *Elphidium* was directly adjacent to Mud Island, near our station 4 (which also contained the maximum *Elphidium* we observed). Overall, these samples seem to represent an intermediate stage between the high-salinity drought conditions sampled by Parker et al. (1953) and the moderate salinity conditions we observed in 2023-24.

CONTROLS ON MODERN SPECIES DISTRIBUTION

While a major sustained shift in salinity is an intuitive explanation for the differences from the 1950s to 2000s, the direct impact of fluctuating salinity conditions below the level of a severe multi-year drought is not clear. In our dataset we see an increased percentage of *Elphidium* in the southwestern part of Aransas Bay, near the connection to Lydia Anne Channel, Aransas Pass, and the open Gulf of Mexico, suggesting a more marine affinity for this genus, as we might expect if its distribution is driven by salinity. However, when we compare the percentage of *Elphidium* in our samples with the seawater salinity measured at the time of collection, we see absolutely no correlation (Figure 3; the R^2 value for that line is 0.0004). Salinity can fluctuate in these bays on a daily basis, and it is possible that these short term

fluctuations obscure longer salinity trends related to distance from the inlet or from freshwater input that control these distributions. Or, there could be some other physiographic parameter or set of parameters (nutrient supply, seafloor oxygen content, turbidity, temperature, pH, etc.) that we did not measure that may play a role.

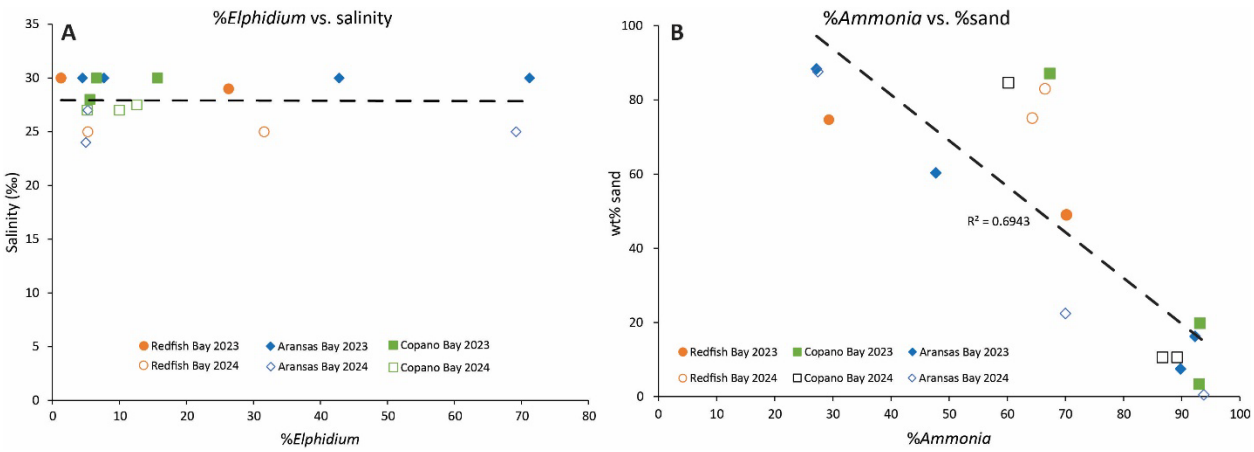

Figure 3. A) Crossplot showing complete lack of correlation between %*Elphidium* and salinity in all three bays in 2023 and 2024. B) Crossplot showing negative correlation between %*Ammonia* and %sand in all three bays in 2023 and 2024.

There is one other parameter important that we did measure during the field course, and that is grain size. In non-polluted coastal environments, sediment type is the main controlling factor in the distribution of foraminiferal biofacies (e.g., Armynot du Châtelet et al., 2009; Celia Magno et al., 2012). In stark contrast to salinity, the percentage of sand in each sample negatively correlates with the relative abundance of *Ammonia* (Figure 4; the R^2 value of that line is 0.69). *Ammonia parkinsoniana* is commonly associated with soft, muddy substrates (Armynot du Châtelet, 2009; Suokhrie et al., 2017). Because of this, it is also commonly found at polluted sites (as pollutants tend to settle on the bottom in lower energy, muddier areas) and sites with high sedimentary organic carbon content (TOC) (e.g., Armynot du Châtelet et al., 2009; Suokhrie et al., 2017). We do not have trace metal or TOC data for these sites, and unfortunately the NERR water quality monitoring stations in Copano Bay and Aransas Bay stopped recording

nutrient and chlorophyll data at the end of 2022. But we expect that the muddier sediments (which often had the distinct smell of decaying organic matter) are elevated in TOC.

We have only taken samples across a small portion of the known salinity range in these bays, which ranges from <10 to >40 PSU, and it is possible that a relationship between salinity and dominate taxa may become clear with greater differences in salinity. Moreover, these data highlight the need to measure a wide number of environmental variables when collecting living foraminifera.

Determining the relationship between benthic foraminifera and salinity and other environmental variables in the modern bays will provide a tool to investigate Holocene sediments and identify high salinity and high nutrient flux intervals in the past. This will allow us to determine the recurrence interval for natural intense droughts impacting estuarine salinity in the Coastal Bend like that of 1948-1953, and understand the natural variability in these ecosystems, in order to determine if anthropogenic impacts are pushing these bays outside their natural range. Ongoing modern observations at different parts of the salinity cycle are an essential pre-requisite for this.

CONCLUSIONS

Living benthic foraminifera collected in 2023 and 2024 from Copano, Aransas, and Redfish Bays reveal a foraminiferal ecosystem dominated by *Ammonia*, with increased *Elphidium* in southwestern Aransas Bay, closest to Lydia Anne Channel and the open Gulf of Mexico, and a dominance of *Buliminella gracilis* in a single sample from a seagrass patch in Redfish Bay. This is different than the population found in these same waters during an extreme drought by Parker et al. (1953), which had a much higher proportion of the more marine-affinity

genus *Elphidium,* which those authors attributed to the high salinity conditions in the bays at the time of sampling. Our work here demonstrates that the benthic foraminiferal population of these bays is not stable, and can change significantly over time periods of at least several decades, if not faster. Predominance facies defined in the literature for particular bodies of water, such as those presented by Poag (2015), are likely more ephemeral snapshots of conditions at the time of collection than stable environments which can be used to guide paleoecological interpretation. Similarly, it is not entirely clear that salinity is the cause of the change observed since the mid-century, although we suspect it is the most likely. All the published foraminiferal data come from the saltier part of the total possible salinity range of these bays, and more samples must be taken across lower salinities to gain the whole picture. Given ongoing anthropogenic threats to these habitats, a regular census of the benthic foraminiferal population would provide an important way to monitor ecosystem health.

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