Ecology of the Harris Mud Crab (*Rhithropanopeus harrisii*) in Lake Texoma

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Abstract: Harris mud crab, *Rhithropanopeus harrisii,* was first reported in Lake Texoma in 2008. Since that time, very little research regarding this population has been conducted. Goals of this study included determining reproductive periods, noting microhabitat preferences, and documenting the distribution of crabs in Lake Texoma. Six sampling sites were established on the Oklahoma side of Lake Texoma along a transect from the OU Biological Station to near the Denison Dam. Sites were sampled from August 2019 to August 2021. A total of 1,396 crabs were observed with 1,326 collected for analyses. Results indicated a significantly male-dominated sex ratio in the population. Abundance and distribution of crabs varied across the lake, likely due to salinity values and microhabitat availability of each site. Population densities in Lake Texoma were higher than those observed in other locations. Seasonal trends noted the difference in crab frequency during the warm and cool seasons. A rapid drop in lake level during late winter of 2020 provided evidence these crabs migrate to deeper water to take refuge from cold temperatures. The presence of larvae and gravid females suggests a reproductive period from June to October and confirms the successful establishment of Harris mud crab in Lake Texoma.

Introduction

Rhithropanopeus harrisii is a small decapod crustacean commonly known as the Harris mud crab. *R. harrisii* is native to the Atlantic coast, ranging from Miramichi Estuary, Canada to Veracruz, Mexico (Boyle Jr. et al. 2010). Today, *R. harrisii* is one of the most widely distributed brachyuran species worldwide (Grosholz & Ruiz 1996, Roche & Torchin 2007). *R. harrisii* has been introduced in over 22 countries, two oceans, ten seas, and several US freshwater reservoirs in Texas (Boyle Jr. et al. 2010).

In 2008, Patton et al. (2010) confirmed the furthest inland report of Harris mud crab to date from Lake Texoma. Lake Texoma is a 360.27 km^2 freshwater reservoir located on the Oklahoma-Texas border. Boating and fishing are popular sports on Lake Texoma and are thought to be the source of invasive species introduction. Historically, Harris mud crabs have been introduced by anglers through live-wells and bait buckets, transported through ship ballast water, and released during marine fish stocking of striped bass (*Morone saxatilis*) and red drum (*Sciaenops oscellatus*) (Boyle et al. 2010). According to genetic analyses, the founding individuals likely originated from Texas estuaries (Huebner et al. 2021) and could have been introduced to Lake Texoma through any of these human-initiated methods (Boyle et al. 2010).

The Oklahoma Department of Wildlife Conservation (ODWC) recognizes the Harris mud crab as a potentially destructive species due to its documented impacts including pipe fouling, economic loss, displacement of native species (i.e. crayfish and midges), and spread of disease (Payen & Bonami 1979 cited in Roche & Torchin 2007). Currently, only two studies have been conducted on the Lake Texoma population. This study describes several ecological aspects of the Lake Texoma population of Harris mud crab for the first time.

Methods

Based on preliminary studies, six collection sites were established along the Oklahoma side of Lake Texoma. Locations of these sites listed from upstream to downstream are 1) OU Biological Station, 2) Lark Sandy Beach, 3) Caney Creek Yacht Club, 4) Texoma State Park, 5) Willow Springs Marina, and 6) West Burns Run Campground (Fig. 1). Sites were sampled monthly during the warm season and every other month during the cool season, with the exception of site #6 which was not accessible from October 2019 to April 2020. Sampling occurred from August 2019 to August 2021.

At each site, a 13.5 cm x 18.0 cm scoop was used to dredge two 1m^2 plots of submerged shoreline sediments. The entire benthic sample of the plots was transferred into 0.5 mm sieve buckets and sorted. Harris mud crabs were then separated from the sample and counted. Searching for crabs outside the plots was conducted if fewer than 10 crabs were found in the plots. Specimens were preserved in 70% ethanol and returned to the laboratory at the University of Central Oklahoma. Water temperature, salinity, specimen counts, and general observations from each site were recorded. A dissection microscope was used to determine the sex of each crab. A two-proportion z-test was used to analyze the data and calculate sex ratio.

A plankton net was used to sample Harris mud crab larvae during darkness. Ten tows of approximately 10 m in length were performed two to three hours after sunset. The samples were preserved in 70% ethanol and returned to the laboratory. Examination with a dissection microscope confirmed the presence or absence of zoea larvae during each sampling period. Larval presence-absence data and the collection of gravid females were used to determine reproductive period of Harris mud crab in Lake Texoma.

Results and Discussion

Sex ratio

A total of 1,396 crabs were collected during 18 sampling trips. Of the 1,326 crabs analyzed, 420 (31.7% were female, 524 (39.5%) were male,

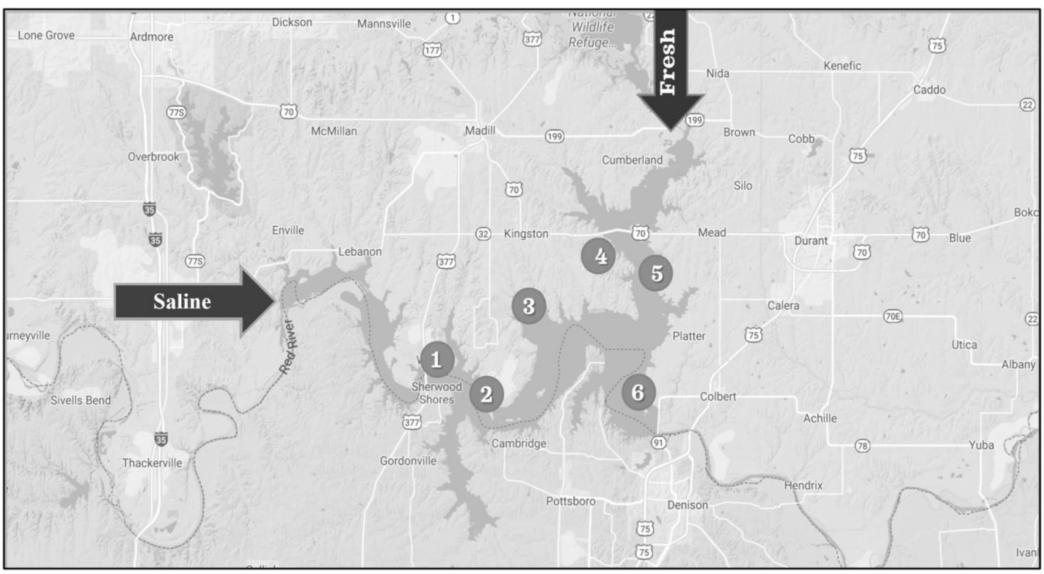

Figure 1. Map showing the Red River, Oklahoma-Texas border, and Lake Texoma. Study sites are 1) OU Biological Station, 2) Lark Sandy Beach, 3) Caney Creek Yacht Club, 4) Texoma State Park, 5) Willow Springs Marina, and 6) West Burns Run Campground. Arrows indicate the direction of flow and input of salts by the Red River and freshwater by the Washita River.

341 (25.7%) were immature, and 41 (3.1%) were too damaged to determine sex. Findings from a two-proportion z-test indicated that the number of males and females differed from an expected 1 male:1 female ratio, favoring males ($p<0.001$) and resulted in a 1.26:1 (male:female) sex ratio in this Lake Texoma population. Male-dominated sex ratios have been observed in other populations of Harris mud crab, including a 1.3:1 in the Dead Vistula River (Normant et al. 2004) and 2.4:1 in Vistula Lagoon (Rychter 1999 as cited in Normant et al. 2004).

One explanation for a male-dominated population is competition for limited space or resources. For instance, the crab's preferred microhabitat of rock/gravel was a limited resource at several of the sampling sites in Lake Texoma. The abundance of this microhabitat also fluctuated depending on lake level and the presence of inhabitable debris on the shoreline (i.e. burlap, trash, recreational equipment). It is possible that with limited space, the larger males outcompeted smaller females. Additionally, males are more motile and better able to obtain food, which is advantageous when resources are scarce (Czerniejewski 2009). However, based on the crab's opportunistic omnivorous nature, food is perhaps the least probable reason for a male-dominated population in Lake Texoma.

Another explanation for unequal sex ratio is sampling methods. Normant et al. (2004) states that sex ratios are largely dependent on the technique used to capture the crabs. For example, Normant et al. (2004) and Janta (1996) reported opposite sex ratios from the same area, and determined the results were likely due to a difference in sampling methodology. In similar studies, Krzywosz et al. (1995) concluded that the number of males is a characteristic feature of the collection method when sampling other decapod crustaceans, such as crayfish (cited in Normant et al. 2004). Method-dependent sex ratios are expected because males are more mobile, especially in warmer months. The sampling methods used in this study were most similar to those employed by Janta (1996), which yielded a sex ratio skewed towards female. Therefore, it is reasonable to assume this study was equally effective at capturing males and females because our results actually yielded a greater number of males.

Lastly, Tesch (1913) found that the sex ratio of *R. harrisii* favored males as the salinity of the water decreased (as cited in Turoboyski 1973). This concept seems to apply with the low salinity conditions of Lake Texoma, so it may partly explain the higher proportion of males.

Site Trends

The number of crabs varied greatly between sites. Figure 2. illustrates the relative abundance of crabs at each site and the frequency of male, female, and immature crabs in each collection. Sites #2 and #3 accounted for more than half of the total crabs collected (95% CI, 391.3, 473.7) and (95% CI, 414.1, 498.8), respectively (Fig. 2). Site #5 had the fewest number of crabs during the sampling period (2.9%) (Fig. 2e). One explanation for this distribution is the range in salinity. The Red River flows through 250-million-year-old salt beds in western Oklahoma and Texas, leaching up to 3,450 tons of sodium chloride per day (Malewitz 2013). Salinity in Lake Texoma generally decreases in the downstream direction, with a specific conductance of 3,740 µS/cm above Lake Texoma, closest to site #1, and 1,795 µS/cm at the outflow of Denison Dam near site #6 (USGS 2003) (Fig. 1). Additionally, there are inputs of freshwater from the Washita River between sites #4 and #5 in the north-east arm of the reservoir. Because these crabs are a marine species, it is possible that their distribution is influenced by the salinity gradient, resulting in a higher number of crabs in the west and fewer in the east (Fig. 2).

Another explanation could be habitat availability. Results from an unpublished independent study using a limited number of crabs, indicate that 94% of Harris mud crabs from Lake Texoma select gravel/cobble as a microhabitat over vegetation and sediments. This was reflected by results from the primary study. For example, site #4 contained primarily clay substrate, while site #5 was mostly sand. Neither site offered the cover or protection

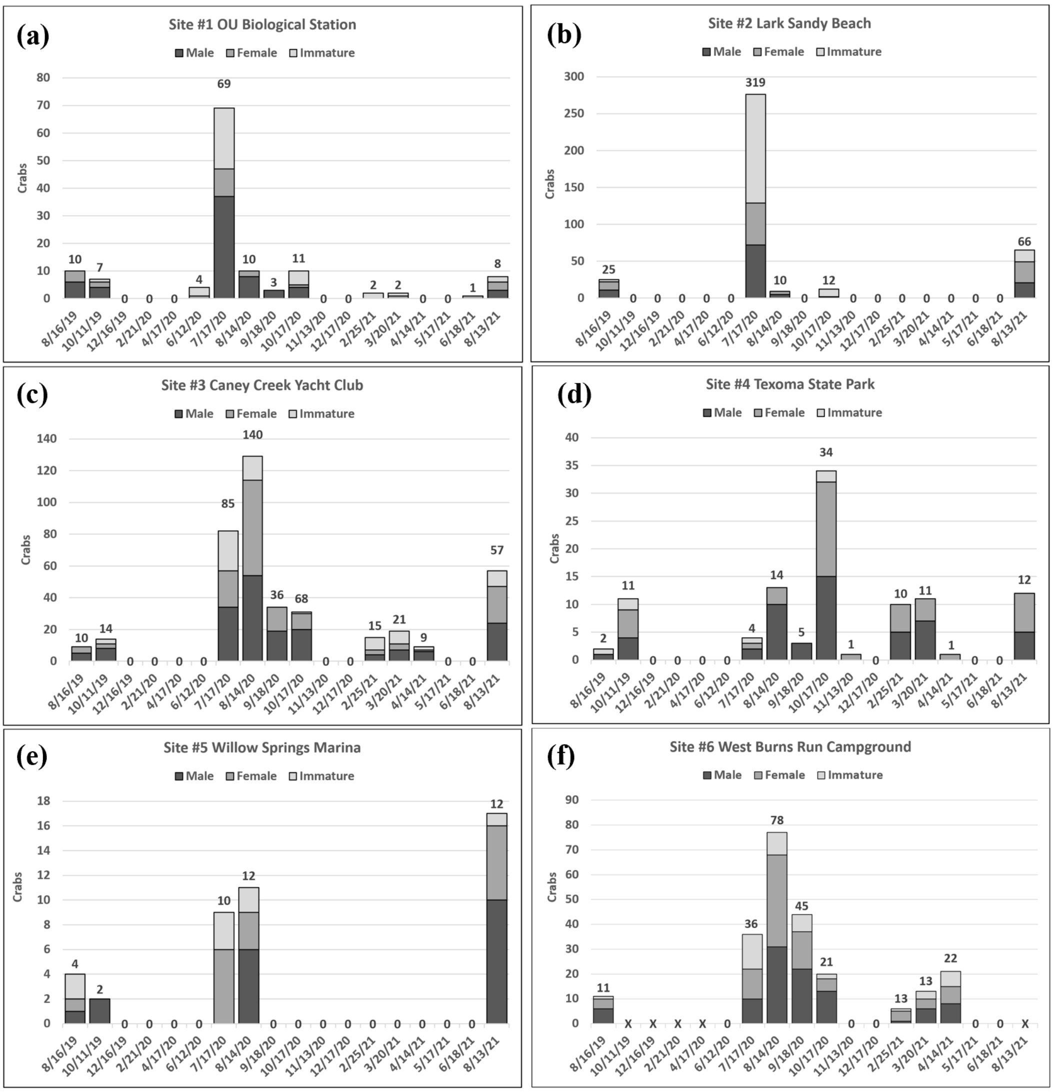

Figure 2. Number of male, female, and immature crabs collected at six collecting sites from August 2019 to August 2021. The y-axes are individually scaled. Data labels are based on the number of crabs observed, including those collected. The "X" indicates samples that did not occur due to site inaccessibility.

these crabs require (Nurkse et al. 2015), possibly explaining the lower numbers usually occurring at those sites. Sites #3 and #6 had rocky shorelines that made suitable habitats for Harris mud crabs resulting in higher population densities. Rocks and gravel at sites #1 and #2 were submerged only during periods of higher lake levels. Low lake levels left the gravel/ rock exposed, and the submerged portion of the sampling areas were mostly sand and mud. Figure 2b illustrates the majority of the crabs collected at site #2 were from one sample when the lake level was elevated. The same site had considerably fewer crabs during the rest of the sampling period when lake water levels receded. This resulted in site #2 appearing to have a higher population than actually survived (Fig. 2b). Overall, the data suggests a combination of salinity and microhabitat availability influence the distribution pattern of Harris mud crabs in Lake Texoma.

Seasonal trends

The greatest number of crabs were observed on July 17, 2020. Crabs were most abundant throughout the study period when water temperatures were above 30°C (Fig. 3). This is likely due to the crab's increased locomotor activity during the warm season. Because they are ectotherms, crabs experience an increased demand for food as their metabolism responds to warming temperatures (Mat et al. 2017). Additionally, elevated water temperature induces breeding activity in Harris mud crabs. This not only means the crabs were more likely to be captured in samples because they are active and searching for mates, but the population totals also included the addition of new juveniles. During this time, large numbers of juveniles may be present in the population, but only a small percentage survive long-term (Gothland et al. 2014). The July 17, 2020 a peak in the number of crabs collected (488) included 212 (43%) juveniles. The following months showed a sharp decrease in the population as many crabs were likely consumed by predators or outcompeted for limited resources and/or space, a pattern typical of crabs and other r-selected species (Gothland et al. 2014).

Alternatively, very few crabs were observed during periods of cool water temperature and no crabs were collected in 6 of the 18 sampling periods when water temperatures were below 23°C (Fig. 3). The disappearance of crabs from the sampling plots may be explained by seasonal migration. Turoboyski (1973) suggests that Harris mud crabs migrate to deeper water during the cool months to take refuge from the cold intertidal conditions. To date, there are no studies describing this behavior in reservoir populations. However, seasonal migration was suspected during February 2021 when crabs were found despite the water temperatures being below 23°C (Fig. 3). Leading up to the February collection, the lake level dropped to 614 ft, which shifted the sampling area further into the lakebed (Fig. 4). It appeared crabs had remained in place from their earlier seasonal migration and 40 individuals were found. Crabs continued to be collected in samples until the lake level rose in April 2021 (Fig. 4). This indicates Harris mud crabs migrate to deeper water in Lake Texoma during the cool months, presumably seeking

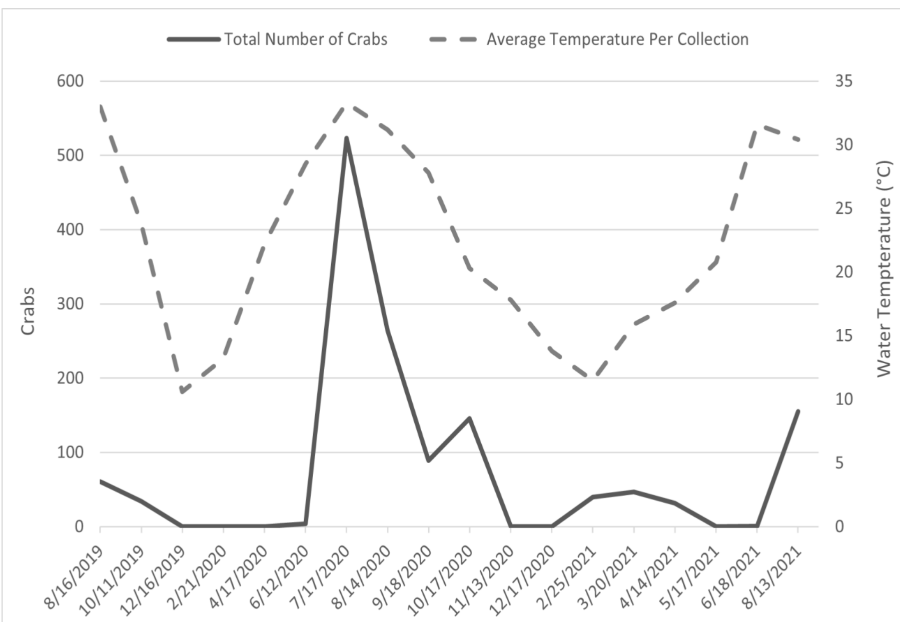

Figure 3. Line graph illustrating the total number of crabs observed and the average water temperature (°C) per collection from August 2019 to August 2021.

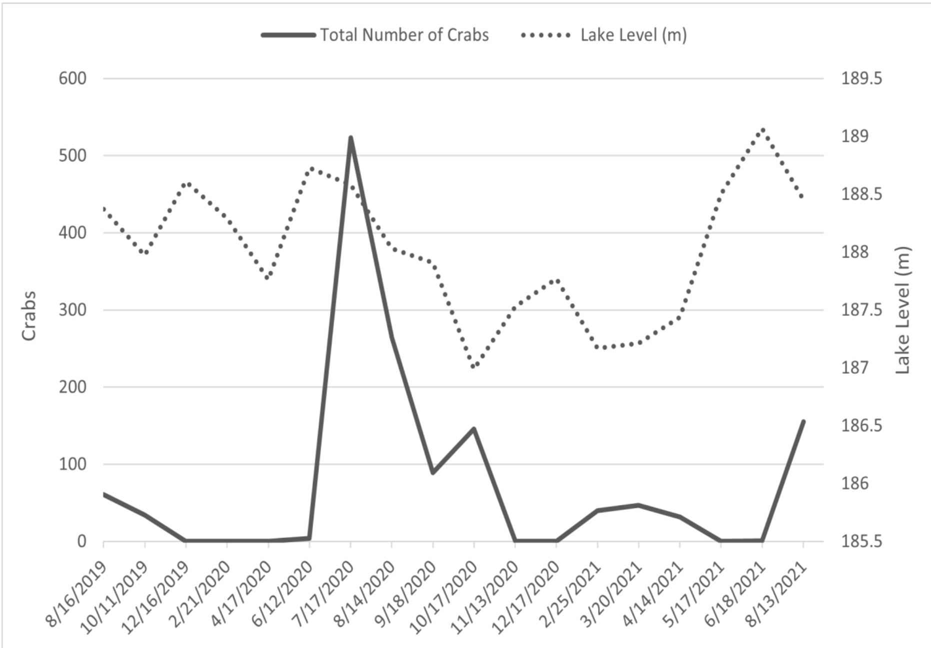

Figure 4. Line graph illustrating the total number of crabs observed and the lake level (m) at each collection from August 2019 to August 2021.

greater temperature stability.

Population trends for Harris mud crabs in Lake Texoma are best described as seasonal. The number of crabs present in the shoreline habitat is largely dependent on the water temperature and lake level. Additional studies are needed to accurately assess the frequency and distribution of crabs in the deeper water during the cool months.

Population density

The overall densities of Harris mud crab ranged from 0 individuals/m^2 to 186 individuals/m^2. When crabs were present, the lowest average population density was observed at site #5 (2.00 individuals/m^2 ± 1.00, $\bar{x}$ ± s.d.) while the highest was at site #2 (87.5 individuals/m^2 ± 85.92). The average density observed from all sites was 23.4 individuals/m^2 (± 38.62) when crabs were present. Population densities of crabs in Lake Texoma surpass densities reported from other locations. Hegele-Drywa et al. (2014) reported 19 individuals/100m^2 in the Gulf of Gdansk. Despite high crab densities in several of the quadrats in this Lake Texoma population, crabs were present in only 57 (26.4%) of the 216 total quadrats sampled during the collections, indicating an extremely patchy distribution. To avoid overestimating the population densities, quadrats were randomly selected rather than intentionally sampled where crabs would most likely occur. This often meant that few or no crabs were found in the plots, even if crabs were present elsewhere. Also, it should be noted that the population densities during the cooler months are most likely underestimated when crabs moved to deeper waters as described earlier.

Reproductive Periods

Harris mud crab larvae were found in plankton tows from July through October 2020 and in June and July 2021. Larvae were encountered only when water temperature was above 20°C. This larvae data is consistent with the spike in juvenile crabs found in July 2020. Furthermore, twelve gravid females were collected from quadrats in samples from October 2019, August 2020, September 2020, and August 2021. Based on these results, the reproductive period for Harris mud crabs in Lake Texoma is likely June through October.

The presence of larvae and gravid females confirms Harris mud crabs are established and reproducing in Lake Texoma. However, prior studies found that the larvae could not hatch in salinities less than 5.0‰ (Costlow et al. 1966) and physiological problems occurred in adults exposed to freshwater for extended time (Turoboyski 1973). The salinity of Lake Texoma consistently ranged from <1‰ to 1‰ during the study, suggesting this population of crabs is adapted to freshwater conditions. This is noteworthy because Harris mud crabs from Lake Texoma exhibit potential to spread and colonize a greater range of habitats across North America.

Summary and Conclusion

The abundance of Harris mud crabs in Lake Texoma was considerably higher than the previous observations in 2008 by Patton et al. (2010). Since that time, Harris mud crabs have multiplied and spread to many available areas of the reservoir and now exist at densities of up to 186 individuals/m^2. Salinity and microhabitat availability appear to be the predominant factors determining the distribution and abundance of crabs at each site. Seasonal trends were observed, most notably a large increase in the population as water temperature rises at the beginning of breeding season and a disappearance of crabs during the cool months. A rapid drop in lake level provided evidence the crabs migrate to deeper water to take refuge from cold temperatures. The presence of Harris mud crab larvae and gravid females indicate a reproductive season from June to October in Lake Texoma. All life stages of the Harris mud crab are thriving despite Lake Texoma's low salinity and this oligohalene tolerance should raise concern for other areas susceptible to invasion. Future studies are needed to access the ecological consequences, if any, of Harris mud crabs in Lake Texoma. The crabs are known to cause economic loss (Zaitsev & Ozturk 2001), decrease in biodiversity (Jormalainen et al. 2016), and displacement of native species like crayfish in other areas of introduction (Richey 2004). Additional studies would benefit the current and potential areas of invasion, as well as provide a better understanding of Harris mud crabs.

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References

Boyle, Jr. T, Keith D, Pfau R. 2010. Occurrence, reproduction, and population genetics of the estuarine mud crab *Rhithropanopeus harrisii* (Gould) (Decapoda, Panopidae) in Texas freshwater reservoirs. Crustaceana 83:493-505.

Costlow Jr. JD, Bookhout CG, Monroe RJ. 1966. Studies on the larval development of the crab, *Rhithropanopeus harrisii* (Gould). I. The effect of salinity and temperature on larval development. Physiol Zool 39:81-100.

Czerniejewski P. 2009. Some aspects of population biology of the mud crab, *Rhithropanopeus harrisii* (Gould, 1841) in the Odra Estuary, Poland. Oceanol Hydrobiol Stud 38:49-62.

Gothland M, Dauvin JC, Dennis L, Dufossè F, Jobert S, Ovaert J, Pezy JP, Tous Rius A, Spilmont N. 2014. Biological traits explain the distribution and colonization ability of the invasive shore crab *Hemigrapsus takanoi*. Estuar Coast Shelf Sci 142:41-49.

Grosholz, ED, Ruiz GM. 1996. Predicting the impact of introduced marine species: lessons from the multiple invasions of the European green crab (*Carcinus maenas*). Biol Conserv 78:59-66.

Hegele-Drywa J, Normant M, Szwarc B, Podluska A. 2014. Population structure, morphometry, and individual condition of the non-native crab *Rhithropanopeus harrisii* (Gould, 1841), a recent coloniser of the Gulf of Gdańsk (southern Baltic Sea). Oceanologia 56:805-824.

Huebner,TS, Boyle TM, Pfau RS. 2021. Population genetics of estuary and reservoir populations of Harris mud crabs, *Rhithropanopeus harrisii*, in Texas and Oklahoma. Biol Invasions 23:3369-3382.

Janta A. 1996. Recovery of the crab *Rhithropanopeus harrisii* (Gould) *tridentatus* (Maitland) population in the Dead Vistula Estuary (Baltic Sea, Poland). Crangon - Issues of the Marine Biology Centre in Gdynia, Proceedings of the 2nd Estuary Symposium in Gdansk, October, 1993. 37-41.

Jormalainen V, Gagnon K, Sjöroos J, Rothäusler E. 2016. The invasive mud crab enforces a major shift in a rocky littoral invertebrate community of the Baltic Sea. Biol Invasions 18:1409-1419.

Krzywosz, T, Bialkoz W, Chybowski L. 1995. The American crayfish in the waters of Suwalskie Province. Komunikaty Rybackie 2:7-59.

Malewitz, J. 2013. Communities along Red River seek feds' help. The Texas Tribune [online]. Available from: https://www.texastribune.org/2013/11/21/along-salty-red-river-communities-seekfedshelp/ (Accessed February 19, 2022).

Mat, AM, Dunster, GP Sbragaglia Aguzzi VJ, de la Iglesia HO. 2017. Influence of temperature on daily locomotor activity in the crab *Uca pugilator*. PLoS One 12:1-11.

Normant, M, Miernik J, Szaniawska A. 2004. Remarks on the morphology and life cycle of *Rhithropanopeus harrisii* ssp. *Tridentatus* (Maitland) from the Dead Vistula River. Oceanol Hydrobiol Stud. 33:93-102.

Nurkse, K, Kotta J, Orav-Kotta H, Pärnoja M, Kuprijanov I. 2015. Laboratory analysis of the habitat occupancy of the crab *Rhithropanopeus harrisii* (Gould) in an invaded ecosystem: The north-eastern Baltic Sea. Estuar Coast Shelf Sci. 154:152-157.

Patton T, Newman C, Sager C, Mauck M. 2010. Occurrence of Harris mud crab *Rhithropanopeus harrisii* in Oklahoma (Lake Texoma), the furthest inland report to date. Proc Okla Acad Sci. 90:75-82.

Payen GG, Bonami JR. 1979. Mise en évidence de particules d'allure virale associées aux noyaux des cellules mésodermiques de la zone germinative testiculaire du crabe *Rhithropanopeus harrisii* (Gould)(Brachyura, Xanthidae). Revue des Travaux del'Institut des Peches Maritimes. 43:361-365.

Richey H. 2004. Reproduction of the exotic estuarine mud crab *Rhithropanopeus harrisii* Texas impoundments: [MSc Thesis], Stephenville (TX): Tarleton State University. 30 p.

Roche DG, Torchin M. E. 2007. Established population of the North American Harris mud crab, *Rhithropanoeus harrisii* (Gould 1841) (Crustacea: Brachyura: Xanthidae), in the Panama Canal. Aquat Invasion. 2:155-161.

Rychter A. 1999. Energy value and metabolism of the mud crab *Rhithropanopeus harrisii tridentatus* (Crustacea, Decapoda) in relation to ecological conditions. [Ph.D. thesis], Gdynia. (Poland): Uniwersytet Gdański, 108 p.

Tesch JJ. 1912. Over twee merkwardige Zuiderzee-bewoners. De Lavende Natuur. 17: 113-115.

Turoboyski,K. 1973. Biology and ecology of the crab *Rhithropanopeus harrisii* ssp. *Trigentatus*. Mar Biol. 23:303-313.

United States Geological Survey (USGS). 2003. USGS Fact Sheet 106-03. https://pubs.usgs.gov/fs/fs10603/FS_106-03.htm Access date: 2/23/22.

Zaitsev Y, Ozturk B. 2001. Exotic species in the Aegean, Marmara, Black, Azov, and Caspian Seas. Istanbul (Turkey): Turkish Marine Research Foundation. 265 p.

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