The Effects of Substrate on the Burrow Morphology of the Chinese Mitten Crab

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Abstract High densities of burrows created by the Chinese mitten crab, *Eriocheir sinensis*, an invasive species in the San Francisco Bay, have been implicated in bank slumping along stream banks. Past studies of crustaceans have shown that substrate composition can influence burrow morphology and, in turn, the types of sediment in which burrows can be constructed. This study examined differences in burrow morphology of the Chinese mitten crab in various types of substrate (gravel, clay and composites) that were categorized based on sediment size, which was measured using sieves with three mesh sizes. Burrow casts were made using fiberglass resin; casts were measured for surface area, volume, number of bifurcations and number of end chambers. Burrows were highly variable in morphology and did not correlate with any specific substrate types. However, volume, surface area, number of bifurcations and number of chambers were all positively correlated with each other. Where silt overlay gravel, burrows did not extend into the gravel. Up to seven mitten crabs were found sharing a single burrow. Burrow morphology may be affected by the number of crabs inhabiting a burrow, which has implications for population estimates based on surface burrow counts. Although, substrate composition was not found to significantly affect burrow morphology, other factors (e.g. the number of crabs inhabiting a burrow) may have a larger influence on burrow morphology.

Introduction

The Chinese mitten crab, *Eriocheir sinensis*, is native to Asia and invasive worldwide. The native range of the crab extends along the West Coast of North Korea to Hong Kong and throughout the tributaries of the rivers draining into this region (Panning 1938). This species was first discovered outside of Asia in 1912, in the river Elbe in Germany (Peters & Panning 1933). The German population of the crab became abundant in the 1920's and has since fluctuated (Panning 1938, Gollasch 1999). It has subsequently spread to other European nations including England (Ingle 1986, Clark et al, 1998), Belgium, Netherlands (Adema 1991), France (Hoestlandt 1959), Austria, Spain and Portugal (Cabral & Costa 1999). The mitten crab is believed to have been introduced to Europe via ballast water (Panning 1938).

The crab was first discovered in San Francisco Bay, California in 1992 (Cohen & Carlton 1997) and has since become abundant and broadly distributed (Rudnick et al. 2000). There have been many theories as to how the mitten crab was introduced into San Francisco Bay, including ballast water and intentional release (Cohen and Carlton 1998).

Outside of their native range, mitten crabs may have both economic and ecological impacts. In Germany, mitten crabs have been found to have detrimental effects on the fishing industry from damage to nets and catches (Panning 1938). The mitten crabs may be an intermediate host for the Oriental lung fluke, a parasite, which if ingested by humans can cause severe bronchial and neurological illnesses (US Fish and Wildlife Service 1989; Cohen & Carlton 1995). Concerns over potential harm to fisheries, stream banks and public health led to the banning of the live importation and sales of the mitten crab in California in 1987 (Parnell 1986). The crab was later added to the list of "injurious species" under federal law and the ban was extended to include the whole of the United States in 1989 (US Fish and Wildlife Service 1989).

Mitten crabs are extensive burrowers and their burrows were observed to undermine stream banks in Germany, causing banks to collapse (Panning 1938). Since their introduction into San Francisco Bay, there have been many concerns about the crabs' impacts on the Bay and Delta notably on stream banks, especially those used for flood control (Cohen & Carlton 1995, Rudnick et al. 2000). Mitten crab burrows could also potentially damage the levees in the Sacramento - San Joaquin Delta and the rice fields of the Central Valley (Cohen & Carlton 1995), though thus far there have been low numbers of burrow found along the banks of the North Bay (Rudnick, pers. com.).

Mitten crab burrows are quite evident along the banks of rivers in the South Bay (Figure 1). However, little research has been conducted to examine mitten crab burrows and their impacts, and present knowledge is based on simple, external observations (Peters and Panning 1933; Panning 1938). Peters and Panning (1933) describe the burrows as simple, cylindrical tubes positioned between the high and low tide level of stream banks. Rudnick et al. (2000) noted that burrows are built at a downward sloping angle and that they retain water when the tide recedes.

Mitten crab burrows were originally thought to be found only in areas of fine sediment (Rudnick et al. 2000), but burrows have since been observed in areas of coarse sediment (Phillips, pers. com). In several South Bay streams, fine sediment is the dominant sediment type, but gravelly banks and bars can be found especially upstream

Researchers have theorized that high densities of burrows lead to slumping in stream banks and increased erosion (Panning 1938, Rudnick et al. 2000). However, actual effects have never been clearly demonstrated. Studying sediment type is crucial to determining rates of desedimentation and bank destabilization. Finer sediment is more rapidly eroded over coarser sediment, but banks composed of fine sediment are more stable than banks composed of coarser sediment.

The objective of this study is to examine whether sediment composition affects the burrow morphology of mitten crabs. Finer grain sediments are very malleable and thus it should be easier for crabs to build burrows in fine grain sediments such as clay and silt. Coarser grain sediments such as gravel and sand are not very malleable making it more energy intensive for crabs to construct burrows within them.

Studies have been conducted on the relationship of burrows with substrate in other crustaceans. Grow (1982) found that soil composition affected burrowing in crayfish, as shallow depressions were only created in coarse grained sediments while three-chambered burrows were created in fine-grained sediments. Correia & Ferreira (1995) found a positive relationship between burrow density, the number of burrows per area, and the amount of fine sediment in the soil. Griffis & Chavez (1988) found that shrimp burrows made in muddy sediments were larger and possessed more openings than those created in the sand. These studies support the idea that crustacean burrows in finer grained sediments are larger and more intricate in structure relative to burrows constructed in coarser grained sediments.

Figure 1 – Mitten crab burrows in a gravel bar on Coyote Creek

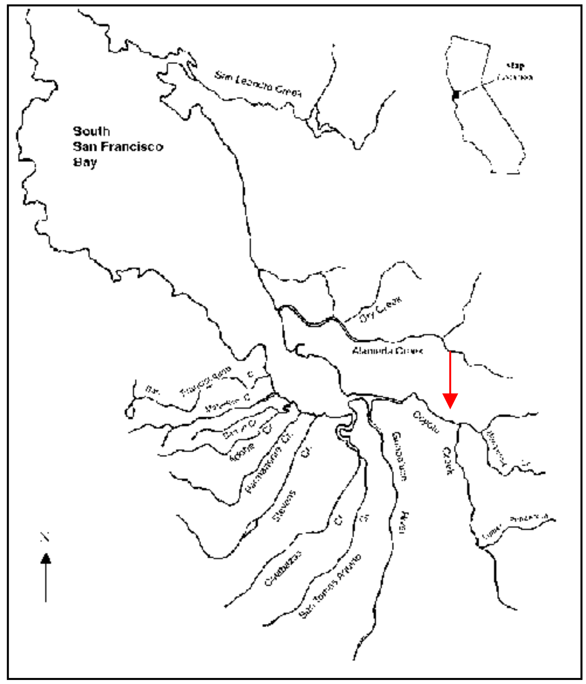

Figure 2 – Map of the study area. The arrow points out the study site. Map from Rudnick et al. 2000

This project is important because relatively little is known about the impacts of burrowing by mitten crabs, especially in San Francisco Bay. A few studies on mitten crabs have been conducted in the Bay and Delta (Rudnick et al. 2000), but most studies have occurred in Europe (Ingle 1986, Cabral & Costa 1999, Clark et al. 1998). If sediment composition does affect burrow morphology, then this knowledge can be used to predict where effects of intense burrowing may be highest based on sediment composition. The results from this project may help in further understanding how mitten crab burrow morphology changes with varying sediment type and potential effects for the surrounding environment.

Methods

The study was conducted between February 1-4, 2002 in a tidally influenced area (37°27'12" N, 121°55'24" W) of lower Coyote Creek in San Jose, California (Figure 2). A 100m section of creek was used in this study. A site visit was also made on November 4, 2001 to map the area.

The site was divided into 3 areas based on a visual assessment of sediment composition. The three areas of sediment composition were sediment mainly composed of gravel, sediment mainly composed of clay/mud and sediment composed of both gravel and clay/mud. The area of sediment composed mainly of gravel was a gravel bar in the middle of the creek. The area of sediment composed of clay/mud was on the right stream bank while the area of sediment composed of a mixture of both gravel and clay/mud was on the left stream bank. Notation for the areas is as follows; GB for gravel bar, RB for right bank, and LB for left bank.

In each of the three areas, five burrows were randomly selected to cast with resin. Fiberglass boatyard resin manufactured by Evercoat (model #516237) was poured into the burrows and then allowed to set overnight. Additional resin was added the following day if the resin was found to have subsided in the burrow overnight. The resin casts were recovered by excavation. 10-30 cm^3 of sediment within 0.5 m adjacent to the surface of the burrow was collected using a 30 cm^3 syringe. 10-30 cm^3 of sediment was also collected from underneath the lowest part of the burrow. If the sediment composition appeared to be primarily coarse materials, 1 liter of sediment was collected to allow for an adequate sampling of the larger coarse sediment.

Sediment composition was measured through fractionation of the sediments. 10-15 cm^3 of sediment was sieved using 2mm and 0.063 mm sieves (Folk 1980). If the sediment composition was primarily coarse then 50 cm^3 of sediment was sieved to better represent the larger coarse sediment (Phillips, pers. com.). The gravel fraction was defined as all sediments greater than 2mm in size, while the sand fraction was defined as all sediments between 0.063mm and 2 mm, and the clay/mud fraction was defined as all sediment less than 0.063 mm. The clay/mud fraction was filtered through pre-weighed Whatman 541 filter paper. All sediments were dried at 80°C in an oven for 24 hours and then weighed. The weights of the gravel, sand and mud fractions were combined to find the total weight of the sample and percentage weights of gravel, sand and mud were calculated.

Data collected from the resin casts included volume, surface area, shape and tunnel length. The density of the resin was found using volumetric displacement of water with a small piece of a cast. The mass of the resin cast was divided by the volume of water displaced to find the density. Volumetric displacement of water was not utilized for all the casts due to their large size. Burrow volume was found by dividing the mass of the casts by the calculated resin density of 1.17g/ml. Density was assumed to be uniform across all the casts. The remainder of the burrows were weighed on a 25 lb. scale, and volume was calculated by dividing mass by density. Burrow surface area was found by covering the casts with aluminum foil, then removing the foil and weighing the foil. The ratio area of aluminum foil to weight of aluminum foil, 0.022 g/m^2, was applied to find the surface area for each cast. Burrow morphology was characterized by the number of bifurcations or splits in the burrow and counting the number of terminal chambers.

One way ANOVAs were used to test for differences in burrow size and morphology and sediment composition among areas. Paired t-tests were used to compare the sediment composition from the top and bottom of the burrows. Regressions were also used to test for correlations between burrow size and morphology.

Results

The three sites selected for casting burrows were found to be different in sediment composition for percentage of gravel (p=0.038, F=4.31, df=2) while the percent sand (p=0.067, F=3.39, df=2) and the percent silt (p=0.059, F= 3.61, df=2) were approaching significant.

The sediment composition within the sites varied from top to bottom for the burrows cast in the gravel bar, but not in the mixed bank or the clay/silt bank. The percentage of gravel (p=0.0003) and percentage of silt (p=0.0002) found at the top of the gravel bar was significantly less than the sediment found at the base of the burrows. There was a significant difference seen in the percentage of silt between the sediment composition between the top and bottom of the burrows in the mixed bank (p=0.009). There were no differences between the percentage of sand (p=0.602) and the percentage of gravel (p=0.149). Paired t-tests of the sediment composition between the surface and base of the burrows in the clay/silt bank did not show a significant difference in the sediments.

Burrow volume (p=0.84, F=0.39, df=2), Surface Area (p=0.91, F=0.09, df=2), and bifurcations (p=0.68, F=0.39, df=2) did not differ significantly among the sediment types. Average burrow measurements from the gravel bar, mixed bank and clay/mud bank can be seen in Table 1.

	Surface Area (m^2)	**Volume (cm^3)**	**Number of Bifurcations**	**Number of End Chambers**
Gravel Bar (n=5)	0.2336 (0.098)	864 (316.75)	4.2 (2.5)	3.4 (1.69)
Right Bank (n=5)	0.1984 (0.018)	890.8 (61.7)	2.6 (.39)	3.4 (0.245)
Left Bank (n=5)	0.202 (0.049)	732.4 (151.69)	2.4 (1.02)	2 (0.89)

Table 1-The average surface area, volume, number of bifurcations and end chambers for the burrows in the gravel bar, right bank and left bank. The values in parenthesis represent the standard error.

Figure 3 – Resin cast of GB 5, the smallest burrow cast in the study. Each block on the scale represents 10 cm.

Figure 4 – Resin cast of GB 3, the largest and most intricate burrow cast in this study.

Variability in shape and size was the greatest in the burrows in the gravel bar. Gravel Bar 5 was the smallest burrow cast of all the burrows sampled with a surface area of 0.082 m^2 and a volume of 199 cm^3 (Figure 3). Gravel Bar 5 had two bifurcations and 1 end chamber. In contrast, Gravel bar 3 was the largest burrow cast of all the casts sampled (Figure 4). Its surface area was 0.614 m^2 and its volume was 1,994 cm^3. GB 3 had 14 bifurcations and 10 end chambers.

There was no significant correlation between the volume, surface area, bifurcations or end chambers with sediment composition. For example, correlations with percentage of gravel to the volume (r^2=0.022), surface area (r^2= 0.019), bifurcations (r^2 = 0.011) were insignificant.

Positive correlations were found between volume, surface area, number of bifurcations and number of end chambers (Figure 5-8). Overall larger burrows have a greater surface area, more bifurcations and more chambers.

Several crabs were found encased (Table 2). Some of the crabs were difficult to measure and identify since they were encased in the cast. A few crabs were unfortunately eaten out of the casts by vermin before they could be measured. Thus, measurements were taken as best as possible.

Figure 5

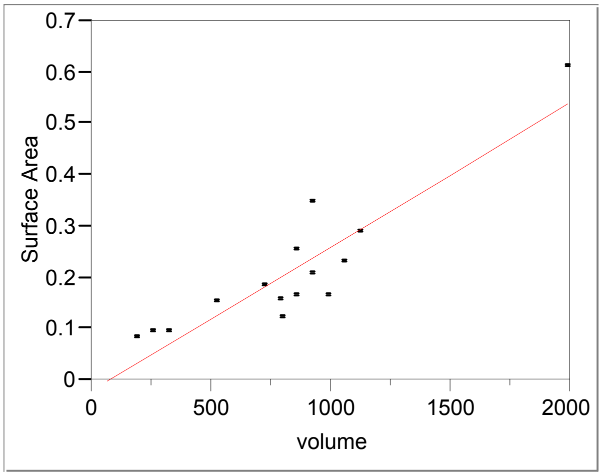

Figure 6

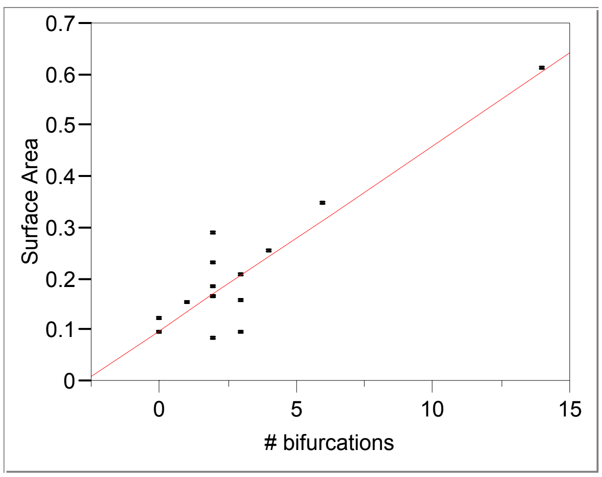

Figure 7

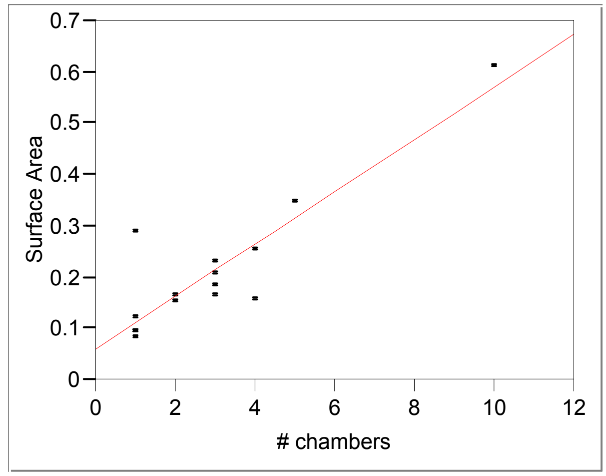

Figure 8

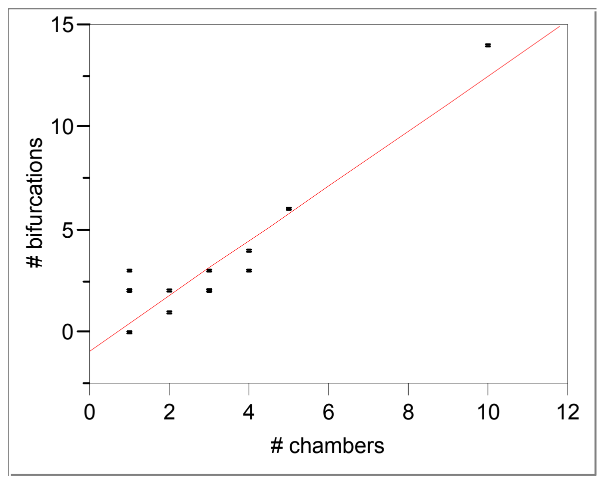

Figure 5-8 –Correlations between surface area (m^2), volume (m^3), number of bifurcations, and number of tunnels. The red lines are regression lines. R^2s, slopes and errors are as follows: Figure 5: r^2= 0.81 slope = 0.0003, error = 0.06; Figure 6: r^2= 0.79, slope = 0.05, error = 0.06; Figure 7: r^2= 0.83, slope = 0.04, error = 0.06; Figure 8: r^2= 0.86, slope = 1.34, error = 1.27.

Burrow	# of crabs	Notes
GB 2	2	19 cm female, 25.8 cm male
GB 3	7	7 unidentified crabs
GB 4	2	23 cm male, 1 unidentified crab
LB 1	1	21.1 cm female
LB 3	3	11.9 cm male crab, 12 cm female, 17 cm unidentified crab
LB 5	1	1 unidentified
LB 6	2	20 cm male, 1 unidentified
RB 2	3	3 unidentified
RB 3	2	21.9 cm female, 20 cm male
RB 5	1	20 cm unidentified

Table 2 List of all the crabs found in the burrows.

Discussion

Several correlations were seen in this study including that burrow volume, surface area, number of end chambers and number of bifurcations were all positively correlated with each other. The positive correlation between volume and surface area appears to indicate that the burrows do not have large chambers, but are mostly made up of tunnels. This may be explained by comparing the surface area to volume ratios of a sphere to a cylinder. For a sphere, the surface area to volume ratio equals 3/r and is not linear so that as the sphere enlarges, the slope would become shallower. In contrast, the surface area to volume ratio for a cylinder is approximately linear ($\sim r^2/r^2$) regardless of the size of the cylinder. The linear positive correlation corresponds with what is expected in burrows primarily composed of burrows rather than chambers. The positive correlation between number of end chambers and bifurcations indicates that splits made in the burrows tend to lead to an end chamber and do not tend to interconnect with one another.

The position of the burrows in the gravel bar was unexpected. From casts that had been previously taken in other gravel bars (Phillips, pers. com.), I assumed that the crabs in Coyote Creek would also burrow directly down into the gravel part of the gravel bar. However, the casts did not follow this behavior. Instead, the crabs burrowed into the thin layer of silt covering the gravel bar and then burrowed horizontally within the silt. This morphology may illustrate a preference of the crabs to burrow into the fine sediment instead of coarse sediment.

Previous studies have not addressed the number of crabs inhabiting a single burrow. In studies of other crustaceans, most species tended to follow the assumption of one animal per burrow (Coelho et al. 2000, Griffis & Chavez 1988, Grow 1982). For mitten crabs, there is little mention in the literature concerning the number of crabs per burrow. Rudnick et al. (2000) originally assumed that each burrow was inhabited by one crab, but later reported that this might not be the case. Results from this study show that multiple crabs may inhabit one burrow. The number of crabs caught in the casts varied greatly, but many contained several crabs.

The findings of multiple crabs in a burrow questions the validity of using burrow density to estimate population counts of crabs. Burrow density has been used to indirectly measure the population of crabs (Rudnick et al. 2000). However, this may not be an accurate way of measuring the population since many of the burrows have multiple entrances. Timing of burrowing activity may also influence the size of the burrows and number of burrows seen in an area. It is believed that crabs burrow year-round, but that more active burrowing is done in the spring to early summer (Rudnick et al. 2000).

Other crustacean burrows showed morphological effects from substrate type. This was not seen in mitten crab burrows, but there may be several factors that could confound any patterns from being recognized such as limited sample size, multiple crabs per burrow and no known burrow pattern. The small sample size limited the statistical power of the ANOVA. Grow's (1982) study of crayfish was looking at burrows created by single crayfish. Thus, multiple crabs could have significant effects on the size and shape of the burrow. Also, other studies looked at burrows in which the shapes and sequence of burrow construction were already previously known (Grow 1982) allowing for easy identification of the stage of burrow construction.

Though this study was unable to clearly show a link between burrow morphology and sediment type, other studies may be able to better understand mitten crab burrows and their burrowing habits. Substrate preference tests in a lab might show whether mitten crabs prefer burrowing in a certain substrate. The results seen in this study from the gravel bar seem to indicate that mitten crabs prefer to burrow in finer substrate versus coarser substrate since none of the burrows penetrated the coarser layer. A laboratory study of mitten crab burrows could control for sediment type, number of crabs and time of burrow construction.

In conclusion, sediment type alone does not influence the burrow morphology of the Chinese Mitten crab. Burrow morphology is likely affected by a combination of sediment type, time of construction and number of inhabitants.

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