ASSESSING THE POTENTIAL FOR CHINESE MITTEN CRAB PREDATION
ON EGGS AND LARVAE OF SALMONIDS

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ABSTRACT

Ecological impacts of the invasive Chinese mitten crab, *Eriocheir sinensis*, in California remain virtually unstudied. Of specific concern are potential impacts of mitten crabs to the eggs and larvae of salmonids. When foraging, mitten crabs may consume, damage, or expose these prey. Under laboratory conditions, we assessed the consumption of exposed and buried eggs and larvae (sac fry) of steelhead (*Onchorhynchus mykiss*) and Chinook salmon (*Onchorhynchus tshawytscha*) by *E. sinensis*, as well as evaluated the ability of mitten crabs to locate these prey items. Mitten crabs readily consumed exposed salmonid eggs and larvae. On average, juvenile mitten crabs consumed approximately 3.25 steelhead eggs and 2.9 steelhead larvae, when the prey was exposed. Likewise, adult mitten crabs consumed an average of 3.9 exposed Chinook salmon eggs and 4.1 exposed Chinook salmon larvae. There was a significant difference in consumption of exposed and buried prey by both juvenile and adult mitten crabs. However, while none of the buried steelhead eggs and larvae was consumed by juvenile crabs, adult mitten crabs consumed an average of 1.0 and 2.1 buried Chinook salmon eggs and larvae respectively. Notably, adult mitten crabs readily foraged through all layers (approximately 7.5 cm depth) of the gravel substrate and exposed previously buried prey, while juvenile mitten crabs typically foraged in only the top portion (< 2.5 cm deep) of the substrate leaving buried prey undisturbed. Observations indicated that mitten crabs typically located these prey items through random contact, not through detection of chemical cues of the salmonid eggs and larvae, and that fish larvae may provide a tactile stimulus that increases the ability of the crabs to locate this prey type. These laboratory results suggest that *E. sinensis* may represent a significant threat to eggs and larvae of salmonids through direct consumption and by exposing the prey to other potential predators and unfavorable conditions, with the level of risk dependent on the size of the crab. An improved assessment of the actual level of risk to salmonids by this invasive species requires studies of crab foraging under natural conditions.

INTRODUCTION

The Chinese mitten crab, *Eriocheir sinensis*, was established in the San Francisco Estuary (SFE) over 10 years ago. By 1998, mitten crabs represented a significant proportion of the biomass in many areas of the SFE, raising concern about the realized and anticipated impacts associated with this invasive species (Anonymous, 2002). A catadromous species, this pest inhabits both brackish and freshwater habitats and has caused substantial economic impacts, particularly to federal/state water diversion plants, power plants and commercial and recreational fishermen (Veldhuizen & Stanish 1999). In addition, substantial bank erosion and slumping has been associated with the burrowing activities of the crab (Phillips & Kneeshaw 2002). With a distributional overlap with many threatened and endangered species (Wang 1986; Veldhuizen & Hieb 1998; Baxter et al. 1999; Veldhuizen and Stanish 1999), ecological impacts to these species by mitten crabs also may have occurred, but these impacts remain largely undocumented. Of particular concern, is the potential mortality of eggs and larvae of salmonids due to *E. sinensis* (Mitten Crab Control Committee, 2003).

Mortality of salmonid eggs and larvae by mitten crabs may result from direct consumption of the prey by the crabs or from damage to the eggs and larvae when the substrate is disturbed by the foraging activities of the crab. Foraging activity could also result in indirect mortality of salmonid eggs and larvae by exposing the eggs and larvae to other predators and/or unfavorable conditions. The distributional overlap of *E. sinensis* and salmonids supports the hypothesis that
eggs and larvae of salmonids may be at risk to mortality by mitten crabs. Specifically, large numbers of mitten crabs have been sighted in Adobe and Coyote Creeks in areas with spawning pools of steelhead (*Onchorhynchus mykiss*) and Chinook salmon (*Onchorhynchus tshawytscha*) (T. Furrer, pers. obs.; D. Salsbery, pers. obs.). Further, during the crab breeding migration in 1999, over 11,000 crabs were collected at Coyote Creek (Culver & Walter 2003) in an area documented as a Chinook salmon spawning ground (Leidy et al. 2003). Mitten crabs likely occur in other salmonid spawning areas, although documentation is limited. In addition, limited laboratory observations indicate that mitten crabs readily eat ‘bait’ salmon eggs (C. Culver pers. obs.), albeit these commercial products likely had added attractants. Foraging and burrowing activity of mitten crabs further suggests that mitten crabs may disturb salmonid redds. More broadly, crayfishes, decapods that have a similar dietary regime and foraging behavior to that of mitten crabs, are known predators of eggs and larvae of various fishes, including rainbow and lake trout (Horns & Magnuson 1981; Savino & Miller 1991; Miller et al. 1992). Taken together, *E. sinensis* likely represents a threat to salmonid populations.

This study was designed as a first step toward assessing the potential risk of mitten crabs to salmonids. Direct consumption of exposed and buried salmonid eggs and larvae by mitten crabs was assessed in the laboratory. We addressed two specific questions: 1) are the eggs and larvae of salmonids palatable to mitten crabs? (i.e., do mitten crabs consume salmonid eggs and larvae if encountered?) and 2) do mitten crabs consume salmonid eggs and larvae when these prey are buried in gravel substrate? While laboratory investigations are not necessarily representative of predator/prey interactions in the field, they provide a tool for better understanding the abilities of the crab to consume, as well as to locate, the prey under controlled conditions. Given the sensitivity of these prey species and their natural habitats, this laboratory study represented a necessary initial step for evaluating the potential for impacts to the eggs and larvae of salmonids by *E. sinensis*.

**MATERIALS AND METHODS**

**Crab collections**

Juvenile mitten crabs were collected from several south bay creeks using passive “condo” traps and by excavation from burrows (Veldhuizen 2003; Rudnick 2003). Adult mitten crabs were provided by the U.S. Bureau of Reclamation, Tracy Fish Collection Facility in collaboration with Professor Dick Tullis at Hayward State University. These crabs were passively captured in the fish passage system at the Tracy facility during the fall when adult crabs were migrating through the area. Crabs were sexed and size measured as carapace width at the 4th anterolateral notch. Crabs with missing limbs were excluded from the trials.

**Prey item collections**

The prey items, eggs and larvae (sac fry) of Chinook salmon (*Onchorhynchus tshawytscha*) and steelhead (*O. mykiss*), were obtained from the California Department of Fish and Game state fish hatcheries, including the Nimbus, Warm Springs and Feather River hatcheries. Salmonid eggs were wrapped in damp cheesecloth and transported in a cooler with ice. Care was taken to keep the eggs off the bottom of the cooler, out of static water. Once in the laboratory, we assessed the temperature of the eggs by placing a thermometer in the middle of the batch of eggs. Freshwater was chilled to a temperature similar to the eggs, and then the eggs were placed in a container with the chilled freshwater and an aerator to minimize stress to the eggs. The eggs slowly reached room temperature in these containers, with the water then changed and debris and
dead material removed daily. Larvae were handled in a similar manner, except that they were transported in chilled freshwater from the state hatcheries in a cooler containing a battery operated aerator.

Experimental Set-up

To assess the potential for consumption of the prey items when encountered by a mitten crab, we placed the prey items on top of gravel (substrate) that was approximately 7.5 cm deep in a rectangular (30.5 cm x 19.5 cm x 26.5 cm; l,w,h) plastic aquaria filled with 5 liters of freshwater. Five individual prey items of the same type were added to each tank, initially with one item near each corner section and the fifth near the center of the tank. This configuration was used to increase the likelihood of an encounter by the crab with at least a single prey item. While placing a crab and a prey item in a small aquaria lacking substrate would inherently increase the likelihood of an encounter, preliminary trials indicated that crab behavior was altered when there was no substrate in the tank. Thus, to enhance the likelihood that the crab would encounter the prey item we included gravel in our trials. A single crab was added to each tank and left to forage for approximately 24 hours.

To assess the potential for mitten crabs to locate salmonid prey items under more realistic conditions, we placed the prey items on the bottom of the aquaria amongst a single layer of gravel in a configuration similar to that described above. Once the prey items had settled, we added approximately 7.5 cm of gravel to bury the prey items in a manner more similar to natural conditions. Although salmonid redds can be at depths greater than 7.5 cm, we chose this depth as a starting point because it was representative of the shallower redds that occur in the SFE (B. Burkes, pers. comm.). An individual crab was added to each tank for 24 hours. At the end of the trial, crabs were removed from the aquaria and the water was drained off into a colander lined with fine mesh (i.e., paint strainer bag) to catch any prey items that might be in the water column. The gravel was then rinsed in a container of water using a mesh basket that allowed the remaining prey items to fall through the basket into the container of water while the gravel remained within the basket. The remaining prey items were enumerated and their condition (alive/dead) was noted. Random observations of crab behavior were also recorded, particularly during the first hour of each trial.

We conducted two trials (buried and exposed) for each of the four prey types (Chinook salmon eggs, Chinook salmon larvae, steelhead eggs and steelhead larvae). Due to low crab abundance, we used the same crabs for both trials of each prey type. We began the trials with the prey items buried, as we expected few, if any, of the crabs to reach these items thereby minimizing the potential for “learned” behavior between trials. To determine whether the crabs were satiated at the end of the trials, thus influencing the consumption rates, we placed each crab in separate aquaria with a small artificial food pellet that they typically consumed in the laboratory. Consumption of the pellet was recorded after 24 hours.

Data analyses

Statistical analyses were done using the SAS 9.1 statistical package (SAS Institute 2002). We used the Student’s t test to analyze for differences in consumption of exposed and buried prey items. Animals that subsequently molted shortly after the experiment (less than 48 hours) or did not consume the artificial food following the trials were removed from the analyses.
RESULTS

Mean crab size varied among trials, with crabs in the spring steelhead trials significantly smaller than crabs in the fall Chinook salmon trials (Table 1) \( t = 28.7; p < 0.0001 \). Overall, the mean crab size for the combined steelhead egg and larva trials was 26.5 ± 0.76 mm carapace width (CW), ranging from 19.0 – 36.4 mm CW. In contrast, mean crab size was 69.7 ± 1.3 mm, ranging from 60.4 – 80.2 mm CW, for the combined salmon egg and larva trials.

At least one steelhead egg and larva were consumed by all crabs when the prey items were exposed, with the exception of the few crabs \( n=6 \) that molted following the experiment (Figure 1a, b). Consumption of exposed eggs was not significantly different than consumption of exposed larvae \( t = 0.74; p = 0.467 \), with an average of 3.25 eggs and 2.9 larvae consumed in these trials. In contrast, none of the crabs consumed any of the buried steelhead eggs and larvae (Fig. 1a, b). Overall, significantly more eggs and larvae were consumed when the prey items were exposed as compared to buried (eggs: \( t = (-) 9.08; p < 0.0001 \); larvae: \( t = (-) 10.58, p < 0.0001 \)). Crabs were observed digging and moving the gravel in all trials, picking up individual pieces of gravel as well as pushing larger gravel with the sides of their claws. The crabs were also found frequently buried under the gravel. However, only the top layer of gravel was affected, down to a maximum of 2.5 cm. All crabs consumed the artificial food pellet at the end of the trials, with the exception of those that subsequently molted following the experiment.

For Chinook salmon prey items, all crabs consumed at least one egg and larva when the prey items were exposed (Figure 2a, b). Consumption of exposed eggs was not significantly different from consumption of exposed larvae \( t = (-) 0.58, p = 0.563 \), with an average of 3.9 eggs and 4.1 larvae consumed by the crabs. Likewise, all crabs consumed at least one egg and larva when the prey items were buried. Significantly more buried larvae were consumed as compared to buried eggs \( t = (-) 2.84; p = 0.008 \), with an average of 2.1 larvae and 1.0 eggs consumed by the crabs. Overall, consumption of exposed prey items was significantly greater than consumption of buried prey items (eggs: \( t = (-) 8.77, p < 0.0001 \); larvae: \( t = (-) 5.20, p < 0.0001 \)). We observed substantial foraging and digging activity among these crabs, with the crabs often redistributing the gravel and clearing sections all the way down to the bottom of the tank. Crabs picked up individual pieces of gravel and used all limbs to move the gravel. All crabs consumed the artificial food pellet at the end of the trials.

In all trials, we observed crabs in close proximity to the prey items. Foraging behavior did not appear to change when prey was nearby. However, on several occasions we observed the larval prey swim into the limbs and body of the crabs, and this resulted in increased foraging activity (digging & movement) by the crabs.

Overall, there was little damage to the prey items, with live, undamaged eggs and sac fry recovered from all aquaria. On a few occasions \( n=6 \), dead, damaged prey items were recovered. All of these events occurred during the Chinook salmon larval trials, including three events involving exposed larvae and three events involving buried larva. During the buried larval trials, we observed a live sac fry close to the side of the aquarium. At the end of the trial, this larva was observed dead, pushed against the side of the aquarium.

DISCUSSION

Eggs and larvae of both steelhead and Chinook salmon may be at risk to predation by Chinese mitten crabs. Both juvenile and adult mitten crabs consumed these prey types, with many of the mitten crabs consuming several, if not all, of the prey that were available. Further,
all of the crabs (with the exception of those that later molted) consumed additional food following the trials, indicating that they were not satiated and consumption rates could have been higher. Unfortunately, crab abundance was extremely low at the time of our study making it difficult to collect desirable numbers and sizes of crabs for our trials. This problem was further exacerbated by the fact that we needed to collect crabs when the hatchery produced prey items were available. As a consequence, there may have been “learned” behavior by adult crabs, as we used the same crabs for the exposed and buried trials for each prey type. While the same crabs were also used in the trials using juvenile crabs, none of the juveniles consumed any prey in the first (buried) treatment. Thus, no learned behavior could have been transferred during those trials. These data, and the fact that all crabs consumed all prey types, support the hypothesis that mitten crabs represent a potential threat to eggs and larvae of salmonids.

While salmonid eggs and larvae may be palatable to *E. sinensis*, several factors may influence the actual level of risk that mitten crabs pose to these prey under natural conditions. In particular, the depth of the redd may provide a refuge for the prey, as consumption of buried prey was significantly lower than consumption of exposed prey. In fact, none of the prey that was buried (7.5 cm) under gravel was consumed by juvenile mitten crabs. These small crabs appeared to forage in only the top 2.5 cm of substrate. In contrast, adult crabs readily foraged through gravel 7.5 cm in depth, and consumed some buried prey items. Further, the foraging activity of these large crabs typically resulted in exposure of the prey. Taken together, these results indicate that prey in shallow or exposed redds, such as frequently occurs in certain water years, are likely at risk to predation by juvenile and adult mitten crabs. In addition, deeper redds may be at risk to predation by adult (large) mitten crabs, as well as to increased vulnerability to other predators and/or unfavorable conditions due to the foraging activity of these crabs.

Understanding crab foraging behavior under natural conditions, particularly spatial patterns of foraging (e.g., area covered, depths reached), is critical for improving our assessment of the actual level of risk posed by mitten crabs to salmonids.

The level of risk of mitten crab predation to salmonids may also be influenced by the life history stage of the prey. Mitten crabs forage in benthic habitats on sessile prey that have limited mobility (e.g., vegetation, polychaetes, clams, gastropods) (Panning 1938). Thus, demersal eggs and larvae (sac fry) are at potential risk, while non-benthic, swimming stages (juveniles and adults) of salmonids are presumably at little or no risk to mitten crab predation. Intuitively, eggs would seem to be at more risk to mitten crab predation than larvae due to the mobility and escape response of the larval stage. However, our results indicate otherwise, as equal or higher numbers of larvae were consumed as compared to eggs. Notably, twice as many buried Chinook salmon larvae were consumed than buried salmon eggs. Variation in detection of chemical signatures of the two prey items by the crabs could explain our results, if larvae were more readily detected than eggs. Our observations, however, suggest that neither the eggs nor larvae released any chemical signature that provided an olfactory stimulus for the crabs. Crabs were often within close proximity of the prey, but foraging activity was not directed toward the prey. Given the static condition, small size and minimal water volume of the aquaria, a chemical signature would have presumably been readily detectable by the crabs. Further, as the eggs and larvae were recovered in good condition following the experiment, experimental conditions, including the artificial burial of the prey, were suitable for maintaining the eggs and larvae allowing production of any such chemical signatures.

Instead, observations indicated that a tactile stimulus may cause larvae to be more readily detected by the crabs. That is, the sac fry often swam into the limbs and body of the crab, eliciting increased foraging activity by the crab that was directed toward the prey. Thus, instead of mobility increasing survivorship as an escape response, it decreased survivorship because it...
provided a tactile stimulus for the predator. Obviously, movement of the larvae was restricted within the small aquaria, and this could have decreased the ability of the larvae to escape. However, sac fry typically exhibit only short bursts of swimming activity, suggesting that once they have swam into the limbs/body of the crab and provided a tactile stimulus, they may be limited in their ability to swim far enough away from the crab. Further evaluations of sac fry movements in the presence of mitten crabs would clarify whether such a stimulus could increase mitten crab predation of salmonid larvae under natural conditions.

The lack of directed foraging by mitten crabs toward salmonid eggs and larvae (prior to any potential tactile stimulus), indicates that encounters occur primarily as a result of random contact. This type of foraging suggests that the risk of predation to salmonid eggs and larvae by mitten crabs may be minimal, as encounters would likely be infrequent. Further, if mitten crabs forage in an opportunistic manner, with a lack of preference for any particular prey type, they may feed on other prey that is more readily available. However, while the risk of predation to salmonid eggs and larvae by mitten crabs could be low, the haphazard foraging exhibited by the mitten crabs could expose the prey to other predators or unfavorable conditions. Indeed, this impact may be more significant on salmonid populations than predation specifically by mitten crabs.

Apparent differences between mitten crab consumption of eggs and larvae of the two salmonid species in our trials suggests that some species of salmonid may be at more risk to predation by mitten crabs. However, a direct comparison of these trials is not valid, as they were conducted at different times of the year, with crabs of different sizes. Thus, the apparent trend toward a higher risk of mitten crab predation on eggs and larvae of Chinook salmon as compared to steelhead was likely an artifact of the trials. For example, size or ontogeny of mitten crabs may influence the level of risk of predation to the prey. While mitten crabs are omnivorous, they become more carnivorous as they grow. In addition, crabs cease to feed for several days before and after molting, and molting becomes less frequent as a crab grows. The change in feeding behavior in association with molting likely explains the greater variability in consumption of prey by juvenile crabs. Further, our observations indicated that foraging behavior was dramatically different between the smaller juvenile crabs in the steelhead trials and the larger adult crabs in the salmon trials, with substantially more mining and moving of gravel by large, adult crabs. While these characteristics support the hypothesis that large, adult mitten crabs may represent a greater risk to salmonid eggs and larvae, appropriately designed studies are needed to validate this hypothesis.

Overall, encounter rates between *E. sinensis* and salmonid eggs and larvae are dependent on the distribution and abundance of both the predator and prey. Mitten crab distribution is affected by crab size, time of year, and crab abundance. Typically, mitten crabs are distributed along a size gradient, with small crabs (< 20 mm) occurring furthest downstream and large crabs occurring in upstream habitats (Veldhuizen & Stanish 1999). Such a distribution may put certain salmonid redds at more risk if predation by mitten crabs is associated with crab size. For example, if large (adult) crabs represent the greatest risk to salmonid eggs and larvae, upstream spawning grounds may be more readily impacted because these areas contain large crabs. In contrast, downstream spawning grounds, such as those that occur in the south bay, may be at limited risk to mitten crabs because these areas are typically inhabited by small crabs.

Of notable exception to the size gradient distribution of mitten crabs is when adult crabs undergo the breeding migration. While Chinese mitten crabs spend the majority of their lives in freshwater areas, they require estuarine conditions to reproduce (Panning 1938). Thus, adult mitten crabs undergo extensive migrations from freshwater habitats to estuarine areas to breed. This breeding migration occurs in the fall, peaking in September and October (Siegfried 1999;
White et al. 2000; Culver & Walter 2003). Given the timing of this adult migration, and the fact that the adults presumably die after one breeding season, redds developed in the late fall, winter and early spring are likely at less risk than those occurring in the late spring, summer and early fall based on the distribution of large, adult crabs. In fact, we could not obtain adult crabs from freshwater habitats for our spring steelhead trials because they had already moved down into estuarine areas. Importantly, while this breeding migration may reduce potential impacts to redds in upstream areas when the adult crabs leave, downstream spawning grounds could experience greater impacts in the fall as the adult crabs traverse through these habitats. Studies examining foraging behavior of adult crabs undergoing the breeding migration are needed to determine how much time the adults spend foraging in specific areas during their migration.

Assessing potential impacts to salmonid populations by *E. sinensis* is further complicated by extreme fluctuations in mitten crab abundance, with populations exploding and then dramatically declining over time. This “boom and bust” phenomenon has occurred in California, with mitten crab abundance peaking in the late 1990’s and then rapidly declining in the early 2000’s. Such cyclic changes in abundance have impacted the distribution of mitten crabs in other countries, with crabs remaining further downstream when crab abundance is low (Panning 1938; Ingle 1986). If true in California, during years of low crab abundance, many of the upstream salmonid spawning grounds may be at limited, if any, risk from mitten crabs, whereas downstream spawning areas may be at a higher risk from mitten crabs. However, years of little or no impact to salmonids from mitten crabs will undoubtedly be followed by years of potentially severe impacts, as the abundance of mitten crabs increases (“boom”) and returns to extremely high levels throughout the area.

**CONCLUSIONS**

This study provides the first step towards assessing the potential risk of *E. sinensis* to eggs and larvae of salmonids. Being a laboratory study, there are inherent limitations with extrapolating the results to natural conditions. Regardless, this study has provided important information about the palatability of steelhead and Chinook salmon eggs and larvae to mitten crabs, as well as the ability of these crabs to locate these prey types when exposed and buried. Further, our results illustrate a critical need for understanding foraging activities of *E. sinensis* in the natural environment. In particular, there is a need for studies that examine the spatial and temporal patterns of crab foraging, including the amount of area (size and depth) and substrates (types and sizes) explored, and the time spent foraging daily and seasonally by various sized crabs. In addition, studies on shifts in diet and prey preferences and how such may alter foraging by the mitten crabs are needed. At a minimum, a map illustrating salmonid redd sites, including information on the typical depths and substrates of the redds, overlaid with the distribution of mitten crabs should be developed. This map would help identify specific sites where salmonids may be impacted by mitten crabs, indicating locations for future field studies on the interactions of *E. sinensis* with salmonid eggs and larvae.

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REFERENCES


TABLE 1.

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FIGURE 1. A. Consumption of steelhead eggs by juvenile mitten crabs (n=19). Exposed eggs denoted by blue bars, with hatched blue bar representing exposed eggs consumed by crabs that subsequently molted. Buried eggs denoted by purple bar. B. Consumption of steelhead larvae by juvenile mitten crabs (n=22). Exposed larvae denoted by blue bars. Buried larvae denoted by purple bars.