INVERTEBRATES

Numerous species of invertebrate animals are found in rice fields. These species are able to utilize the short-term aquatic environments of a typical rice field and are often pre-adapted to this type of agricultural environment. The changing nature of a rice field limits use of this habitat to invertebrates with specific life histories. Rice fields go from dry soil to a flooded aquatic environment, followed by quickly developing plant material, and finally drained soil with senescent plants. Insects, spiders, crustaceans, and other groups constitute the invertebrates in rice fields. In a study conducted in 1990, researchers sampled and identified about 60 different species of arthropods in a survey of a California rice field. More recent efforts in the 2000's again found this level of diversity in California rice fields.

Most of these invertebrates inflict no damage to rice plants, whereas about ten species can hinder rice productivity and yield. Rice is most susceptible to damage during the first six weeks after seeding. A couple of species of insects and crustaceans decrease seedling establishment. During the vegetative growth phase, a few species can potentially be problematic by feeding on foliage, but populations are generally low and damage minimal. Invertebrate pests in California are uncommon during the grain-filling period. The rice stink bug, a pest that severely impacts grain quality of southern U.S. rice, is absent in the California system. Similarly, leafhopper and planthopper species (and associated virus diseases they transmit) that severely hamper Asian rice production do not occur in California rice. Stem borers also do not occur in California rice.

Another segment of the invertebrate complex in rice fields that is of interest is the mosquito population and the natural enemies that feed upon aquatic mosquito eggs, larvae, and pupae. These individuals have no direct impact on rice plant productivity but are important from a "good neighbor" standpoint. Rice production practices can affect mosquito populations and their management. Mosquito management is gaining increased importance with the increased prevalence of mosquito-vectored diseases, i.e., West Nile Virus.

A rice field is a definite "agroecosystem". Management actions intended to facilitate seedling establishment, weed control, plant growth (fertilization), etc. have effects on population levels of invertebrates. These effects could be positive or negative. Discussions of management of invertebrate pests will be divided into three portions of the growing season:

1. Seeding to 4-5 leaf stage (0 to ~30 days after seeding),
2. 5-leaf stage to heading and flowering stage (30 to ~90 days after seeding),
3. Heading to harvest.
4. Management actions... have effects on populations of invertebrates

Seeding to 4-5 leaf stage

Tadpole shrimp, crayfish, seed midge, and rice leafminer all have the capacity to hinder rice seedling establishment and early-season plant growth. In addition, rice water weevil adults feed during this period; however, the primary damage is inflicted later in the growing season by the rice water weevil larvae that develop on roots under the soil. Insecticidal management of this pest is targeted toward the adults so it is appropriate to consider this pest in this section.

Tadpole shrimp

Tadpole shrimp (fig. 1) persist during dry periods in the egg stage (surviving for several years at minimum) and hatch quickly in the spring with the addition of water and sufficiently high temperatures. Eggs in the surface layer of soil hatch primarily two to three days after the flood is initiated, although some eggs will continue to hatch. Just-hatched tadpole shrimp are extremely small, but young tadpole shrimp grow fast, with higher water temperatures leading to more rapid growth. Initially, they feed on algae and other small organisms. Very young shrimp resemble adult shrimp, although they have less pigmentation. When their carapace (primary shell) is about half the length of a rice seed, tadpole shrimp readily feed on germinating rice seeds, preferring the emerging radicle and coleoptile (fig 2, fig. 3). Large tadpole shrimp can cause further damage by uprooting seedlings while digging in the soil. The occurrence of floating seedlings, cast exoskeletons (shed skins produced as the tadpole shrimp molts), and muddy water (from shrimp digging) are indicative of tadpole shrimp infestations. Chewed and pruned roots on the floating seedlings can distinguish drifting seedlings due to tadpole shrimp from seedlings that are floating due to strong winds or other conditions.

Muddy water produced by the shrimp can reduce light penetration and further inhibit seedling growth and establishment. Once seedlings have a well-established root and the prophyll (spike) is emerged, they are less susceptible to tadpole shrimp injury. Mature tadpole shrimp lay eggs along the bottom.

Management of all seedling pests is generally similar. For tadpole shrimp, application of insecticides pre-plant or soon after seeding is typically most effective due to the quick developing nature of the infestations after flooding. Scouting for tadpole shrimp while small followed by rapid applications can still avoid damaging populations however. Actions that facilitate quick establishment of rice seedlings can also mitigate damage from tadpole shrimp. Since they only damage rice seeds and young seedlings, once these stages are past, the potential for damage is low. Quick flooding and timely seeding reduces the risk of injury. Field draining soon after seeding until there is no standing water can assist in managing tadpole shrimp.

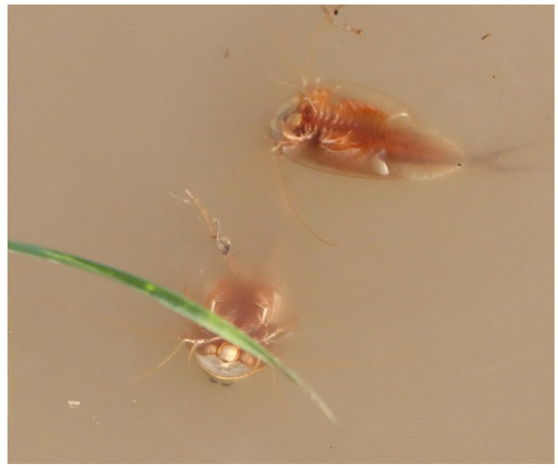

Figure 1. Tadpole shrimp can feed on germinating seeds, uproot seedlings, and muddy water, reducing the amount of light seedlings growing underwater can get.

Figure 2. Small tadpole shrimp look very similar to large shrimp, with a rice grain shown for scale here.

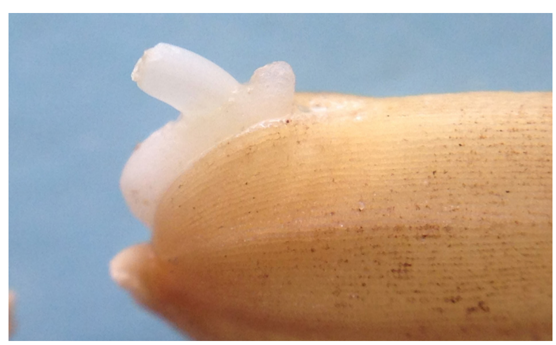

Figure 3. Tadpole shrimp injury to the emerging coleoptile.

Crayfish

Crayfish (fig. 4) make burrows and tunnels in levees near water boxes, compromising the structure of the levee (fig. 5). Crayfish's tunneling activity can cause seepage in levees, which could result in the illegal release of pesticide-treated water. Crayfish feed on dead and decaying matter, insects, and plants.

Their feeding on plants can also be a problem on seedling rice. Muddy water, uprooted seedlings, and reduced stands result from crayfish infestations as they feed on rice and forage along the bottom.

Similar to preventing damage by tadpole shrimp, quick flooding and seeding can prevent damage to seedlings by crayfish. Crop rotation can also help manage crayfish. No insecticides are labelled for crayfish.

Rice seed midge

Rice seed midge also hinders seedling establishment and can damage newly planted rice as larvae. There are several midge species in this pest grouping (Cricotopus sylvestris, Paralauterborniella subcincta, Paratanytarsus spp.). The adults are a small, somewhat mosquito-like fly, although they cannot bite like a mosquito (fig. 6). Adults are extremely mobile. Upon flooding a field, thousands of these adults fly to the field and deposit eggs on the water surface. Swarms of adult midges near fields are often misidentified as mosquitoes. The eggs hatch in one to two days and the larvae feed on the soil surface of the flooded field (fig. 7). Larvae feed on seeds and seedlings as well as on algae. They often destroy the seed before it can germinate in the water (Fig. 8). Once the seedling is 3 to 4" long, it is not susceptible to midge damage.

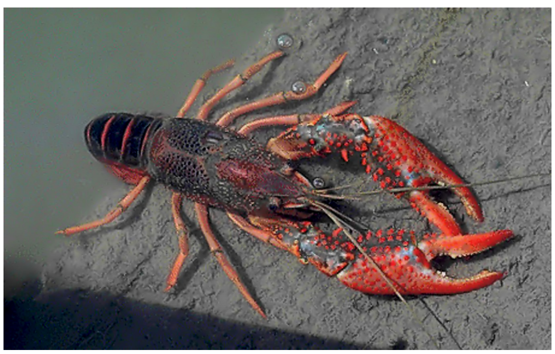

Figure 4. Crayfish can directly affect rice by feeding on the germinating seed

Figure 6. The rice seed midge can produce large swarms under certain conditions.

Figure 5. Holes dug by crayfish may cause unwanted seepage.

Figure 7. Rice seed midge form tubes in sediment.

Management of all these seedling pests is similar. Application of insecticides pre-plant or soon after seeding is most effective due to the quick developing nature of the infestations after flooding. Scouting for tadpole shrimp while small followed by rapid applications can still avoid damaging populations. Actions that facilitate quick establishment of rice seedlings can also mitigate damage from these pests. Since these invertebrates only damage rice seeds and young seedlings, once these stages are past, the potential for damage is low. Quick flooding and timely seeding reduces the risk of injury by these pests. Crop rotation can help manage crayfish, and field draining soon after seeding can assist in managing tadpole shrimp and seed midge.

Figure 8. Developing rice seed midge larvae will feed on germinating seeds, killing them.

Rice leafminer

The rice leafminer was a significant pest of rice in California through the 1970's. During the 1990's, this pest could be found at low levels in most fields. Today, populations of rice leafminer are very low or absent. The adult fly is small, bristly, and brown-grey. Female flies lay single eggs on leaves. The resulting larva (fig. 9) mines between the epidermal layers of the leaf (fig. 10). This injury can resemble that of rice water weevil adults with the difference being that the leafminer larva can be seen in the leaf when it is held up to the sunlight. There are multiple generations of rice leafminers per year (up to 11), but this pest only damages rice before the plants start to grow upright. Leaves laying on the water surface are susceptible to attack. Therefore, slow-growing rice (cool weather and/or deep water) is most susceptible to damage. Biological control by parasitic wasps does aid in managing this pest.

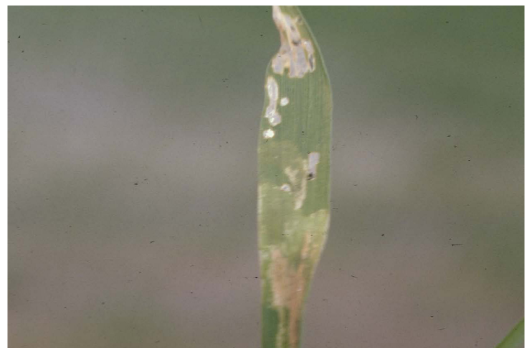

Figure 9. Rice leafminer larvae tunnel within the leaf eating the tissue.

Figure 10. Large rice leafminer numbers can cause browning of the leaf and reduce photosynthesis

Rice water weevil

The rice water weevil (fig. 11) was one of the most damaging insect pests of rice in California after its discovery in the Sacramento Valley in the late 1950s. Currently, noticeable damage by rice water weevil is unusual and limited to areas with a history of rice water weevil pressure. Most likely, the decline in issues with rice water weevil can be explained by the use of new, more vigorous varieties and the intensive use of insecticides to manage tadpole shrimp.

Adult rice water weevils overwinter in a diapause (reduced activity) state in ditch banks, crop residue, and riparian areas. As temperatures increase, adults feed on leaves of grasses and break diapause. Through this, they regenerate their flight muscles such that adults can fly for several miles (hypothesized to up to 20 miles). The spring flight (Apr.-June) occurs days with warm, calm evenings. Adults prefer to infest newly flooded rice fields. Fields with rice plants emerging through the water are most susceptible to infestation. Adults feed on the leaves of rice plants, which result in characteristic longitudinal feeding scars (fig. 12). This feeding has no effects on spring rice growth or yield.

Adults oviposit in rice leaf sheaths just below the water level in plants with 2 to 6 leaves. Eggs hatch in 5-7 days. The first instar larvae feed on leaves for a few days and then drop down through the water and soil to the roots (fig. 13). The remainder of the life cycle is spent in the flooded soil of rice fields. The larvae develop through four instars and feed on rice roots. Rice water weevil larvae root feeding causes reduced plant growth, chlorosis, and reduced tillering. These symptoms become noticeable four to six weeks after seeding. Pupation occurs on rice roots (fig. 14) and new adults emerge in late July. These adults feed to a limited extent on rice leaves and then leave the rice fields for overwintering sites. In California, damaging infestations of rice water weevil larvae are limited to areas up to 50 feet next to borders of fields and levees (fig. 15). Grain losses from larval feeding of up to 45% have been recorded. In California, research results support an economic threshold of about 1 larva per plant.

Management of rice water weevil in California relies on chemical and cultural controls. Biological control of this pest is nonexistent. For cultural controls, removal of levee vegetation in the spring helps reduce rice water weevil den-

Figure 11. The rice water weevil is the most important pest of rice in the US. In California, it only affects areas near borders and levees.

Figure 12. Overwintering adults emerge in the spring to feed on rice leaves

Figure 13. The small, legless larva drop to soil where they feed on the roots.

sities. The additional herbicides required for this and the loss of wildlife habitat on levees are substantial drawbacks of this tactic. Two additional cultural methods assist in reducing rice water weevil densities, but may not fit all production schemes. They include dry seeding rice and delaying seeding dates. The reduced yields that can result from these techniques make them undesirable to growers.

Currently, the need for insecticide applications against rice water weevil rely on grower experience and the history of the field. Several insecticides are available for rice water weevil. In 1999, diflubenzuron (Dimilin) and lambda-cyhalothrin (Warrior) were registered, followed by another pyrethroid, zeta-cypermethrin (Mustang), in 2002. Generic formulations of lambda-cyhalothrin are also available. These insecticides are effective for RWW management in California, although they have limitations. They target adults, and have limited effects on larvae, which is the damaging stage. Dimilin sterilizes adults (i.e., females produce no viable eggs) and the pyrethroid products kill adults, limiting egg laying. Application timing is of utmost importance since control with these products is not possible after a few days following oviposition. These insecticides are recommended to be sprayed at the 2-4 rice leaf stage. Additionally, lambda-cyhalothrin can be applied preflood up to five days before the field is flooded. Applications can be made to field borders and only 50 feet adjacent to the levee. Clothianidin (Belay), a third generation neonicotinoid, was registered in 2014. A post-flood application timing (~2-3 leaf stage) appears to be the optimal timing or this product, although clothianidin can be used as a rescue treatment when larvae are present and feeding on roots at the 5 to 6 leaf stage of rice.

Figure 14. Feeding from the larvae will prune the root system and retard the growth of the plant, resulting in costly yield reductions.

Figure 15. Injury by rice water weevil is observed as a reduction of plant growth, reduction in tillering, and chlorosis. Damage is limited to areas near borders and levees.

5-leaf Stage to Heading and Flowering Stage

Two species of armyworms, true armyworm and western yellowstriped armyworm, are found in rice fields during the summer, although true armyworm is the species most often associated with damage (fig. 16). In recent years, damage from these pests has been more severe than it has been historically.

The armyworm moth lays its eggs in linear masses with the leaf tied around the eggs in a roll on rice or other grass species in and around rice fields. Larvae of both species are striped and vary in body color. Larvae feed predominantly at night or during cloudy days. They grow to full size and pupate in about 3 to 4 weeks in the summer. Pupation normally takes place in the upper surface of the soil or in debris, so many

Figure 16. Armyworm larva with true armyworm on the left and yellowstriped armyworm on the right.

Figure 17. Adult true armyworm.

mature larvae drown in flooded paddies before reaching a suitable pupation site. However, some are able to pupate lodged between leaves or tillers. Adult moths of both species have a wing span of about 1.5 inches and are predominantly silver and gray (western yellowstriped armyworm) or buff colored (true armyworm) (fig. 17).

Damage by armyworms typically occurs during periods of stem elongation (early summer) and grain formation (late summer). Larvae defoliate plants, typically by chewing angular pieces off

Figure 18. Leaf damage is the most obvious sign of the presence of caterpillars. Even large caterpillars can be hard to find, as evidenced by the two caterpillars hiding in the photo on the right.

Figure 19. Severe defoliation can occur when armyworms reach high population levels.

leaves (fig. 18). During outbreaks, defoliation to the water level can occur (fig. 19). Armyworm larvae may also feed on the panicle, specifically on the rachis near the developing kernels causing these kernels to dry before filling. This feeding causes all or parts of the panicle to turn white (fig. 20). The seriousness of armyworm injury depends on the maturity of the plant and the amount of tissue consumed. Significant yield reduction can occur if defoliation is greater than 25% during the early summer infestation or if panicle injury is higher than 10% later in the summer

True armyworm outbreaks occurred in 2015, 2016 and 2017. Pheromone moth trapping is being used to predict activity of armyworm larvae and improve timing of field monitoring (fig. 21). Various natural factors cause mortality of armyworms. Many caterpillars drown or are killed by natural enemies, including predators,

Figure 20. Armyworm injury during heading results in broken panicle branches and empty kernels.

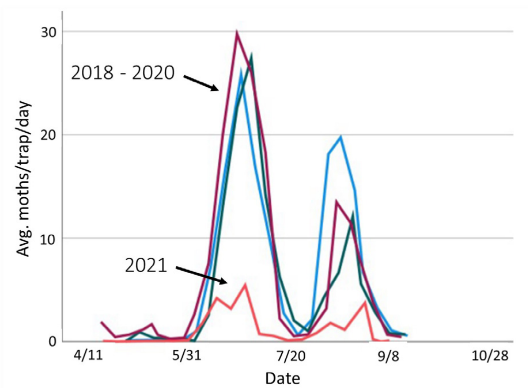

Figure 21. Average number of true armyworm moths trapped across the Sacramento Valley in pheromone traps, 2018-2021. There are typically two peaks in adult moth captures.

pathogenic microorganisms, and parasitoids. Insecticide treatments are justified if, from late June through early July, more than 25% defoliation occurs and armyworms are present on the plants. Treatment for panicle loss is justified if 10% of the panicles in the area sampled are damaged and armyworms are observed.

The pyrethroid insecticides (lambda-cyhalothrin and zeta-cypermethrin) are ineffective for controlling armyworms. The insect growth regulator diflubenzuron (Dimilin) is effective; however, it has an 80 day pre-harvest interval which prevents its use during the heading stage. The biological insecticide Bacillus thuringensis is effective when applied against small armyworms, which can be difficult to find timely in the field. The insect growth regulator methoxyfenozide (Intrepid) has received a Section 18 registration, allowing its use on rice on a yearly basis. Other alternative insecticides are still being evaluated.

Heading to Harvest

A few instances of pecky rice (fig. 22) have occurred in California in recent years. Pecky rice refers to kernels that exhibit a discoloration after hulling and milling. This discoloration can be caused by insects, but can also be caused by pathogens developing on the kernel due to excess moisture from rain or lodged rice. In fields that produced some pecky rice and quality downgrades the previous year, a native stink bug called the redshouldered stink bug (fig. 23) (Thyanta pallidovirens [= T. accerra]) was collected the following year in early September.

Figure 22. Pecky Rice

Figure 23. Redshouldered stink bug

Cage studies showed that this and other common stink bug species have the potential to feed on developing kernels and cause peck. Stink bugs can be common in rice fields with higher levels of weeds, fields near natural/riparian areas, and rice fields interspersed with other crops. Nevertheless, in most fields, stink bugs are present at very low levels and do not constitute a problem.

Additional Information:

The UC Pest Management Guidelines for Rice maintains up-to-date information on management of key invertebrate pests of rice (UC IPM Pest Management Guidelines: Rice, UC ANR Publication 3465; http:// www.ipm.ucdavis.edu/PMG/selectnewpest.rice.html). In addition, the publication entitled, Integrated Pest Management for Rice, 3rd Edition (UC ANR Publication 3280) is a good resource for rice IPM.