Numerous species of invertebrate animals are found in rice fields. These species are adapted to utilize the short-term aquatic environments of a typical rice field. The quickly changing nature of a rice field, i.e., dry, followed by flooded, quickly developing plant material and finally drained with senescent plants, require specialized life histories in the invertebrates. Insects, spiders, crustaceans, and other groups comprise the invertebrates. Grigarick and co-workers (1990) sampled about 60 different species of arthropods in a survey of a California rice field.

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 also of crustaceans hinder seedling establishment. During the vegetative growth phase, a few species potentially can be problematic by feeding on foliage, but populations are generally low. Invertebrate pests in California are rare during the grain-filling period. Fortunately, the stink bug pests that severely impact grain quality of southern U.S. rice are absent in the California system. Similarly, leafhopper and planthopper species (and associated virus diseases they transmit) that severely impact Asian rice production as well as stem borers also do not occur in California.

Another segment of the invertebrate complex in rice fields 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 rice production practices can impact the mosquito populations and management. This area is gaining increased importance with the recent upswing in mosquito-vectored diseases.

A rice field is a definite “agroecosystem”. Management actions intended to facilitate seeding establishment, weed control, plant growth (fertilization), etc. have effects on populations of invertebrates. These effects could be positive or negative on levels of these invertebrates. 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.

### Seeding to 4-5 Leaf Stage

Tadpole shrimp, crayfish, seed midge, and rice leafminer all hinder rice seedling establishment and early-season growth. In addition, rice water weevil adults feed during this period; however, the primary damage is done later in the growing season by the rice water weevil larvae. Insecticidal management of this pest is targeted toward the adults so it is appropriate to consider this pest in this section.
Tadpole shrimp and crayfish reside in the field and quickly become a problem upon flooding. **Tadpole shrimp** persist during dry periods in the egg stage (surviving for several years) and hatch quickly with the addition of water. About 9 days after hatching from the egg stage, the reproductive stage occurs and the shrimp readily feed on rice seeds, germinating spikes, and uproot seedlings while digging in the soil. The occurrence of floating seedlings, caste skins (shed skins produced as the animals develop), muddy water, etc. are indicative of tadpole shrimp infestations. Cut leaves on the floating seedlings can distinguish them from seedlings which are floating due to high wind or other conditions. The muddy water can reduce light penetration and further inhibit seedling growth and establishment.

**Crayfish** inflict similar damage. They reside in tunnels which remain moist or water-laden. Crayfish feed on dead and decaying matter, insects, and plants. The plant-feeding can be a problem on seedling rice. Muddy water, uprooted seedlings, and reduced stands result from crayfish infestations. The tunneling activity of crayfish represent another type of damage. This can create seepage in levees which could allow illegal release of pesticides.
**Seed midge** also hinder seedling establishment; there are several species in this group. This insect, the adult of which is a small mosquito-like fly (they actually have no functional mouthparts so cannot bite like a mosquito), is extremely mobile. Upon flooding a field, thousands of these adults arrive at the field in a swarm and deposit eggs on the water surface. These swarms are often misidentified as mosquitoes. The eggs hatch in one to two days and the larvae feed on the soil surface of the flooded check. Larvae feed on seeds and seedlings as well as on algae, etc. They often destroy the seed before it can germinate in the water. Once the seedling is 3 to 4” long, it is not susceptible to midge damage.

Management of all these seedling pests is similar. Pesticides are of some use for these pests. At present, no soil or seed insecticide treatments are registered. These could be of use especially for seed midge. Copper sulfate can reduce numbers of tadpole shrimp. Cultural practices are quite useful; anything that can facilitate quick establishment of the rice stand can mitigate damage from these pests. Since these invertebrates only damage rice seeds and “spikes”, once these stages are past the potential for damage is nil. Quick flooding and timely seeding, warm water, shallow water, etc. all play a role. Crop rotation can help manage crayfish and field draining can assist in managing tadpole shrimp and seed midge.

The **rice leafminer** can be found in every field, can produce large swarms under certain conditions. The developing larvae will feed on the germinating seed, killing it. The Rice Seed Midge can produce large swarms under certain conditions. Leafminer can be an occasional pest. Leafminer larvae tunnel within the leaf eating the tissue. Large numbers can cause browning of the leaf and reduce photosynthesis.
but seldom if ever reaches damaging levels. The adult flies, similar to a small house fly, lay a single egg on leaves. The resulting larva mines between the epidermal layers of the leaf. This damage 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 insect 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 attack.

The rice water weevil is the most important invertebrate pest of California rice. Weevil adults overwinter in a diapause state. The overwintering sites include on levees and ditch banks, in the crop residue in the basins, in riparian areas, etc. As the temperatures increase, the adults feed on leaves of grasses and eventually break the diapause. This involves regenerating the flight muscles such that the adults can fly for several miles (hypothesized to be up to 20 miles). The spring flight (April to June) occurs during days characterized by warm, calm evenings. During these periods, the adults fly and prefer to infest newly flooded rice fields; those with rice plants emerging through the water are most susceptible to infestation. The adults feed on the leaves of rice plants, which result in characteristic longitudinal feeding scars. This feeding has no effects on rice growth or yield; however, coinciding with this the adults oviposit in the rice leaf sheaths found just below the water level. This oviposition occurs in plants with from 2 to 6 leaves. Eggs hatch in 5-7 days; the first instar larvae feed on the leaf tissue for a few days and then drop down through the water and soil to the roots. The remaining portion of the life cycle is spent in the flooded soil of rice fields. The larvae develop through four instars and feed on rice roots doing significant damage. Pupation occurs on the rice roots and the 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. The effects of RWW injury on rice plant growth, development, and yield have been intensively studied by my laboratory since 1992. Results support an economic threshold of about 1 larva per plant. A linear relationship exists between the percentage of plants with adult feeding scars and larval density. Quantification of adult feeding scars was used as a sampling tool to determine the necessity for a chemical control (e.g., post-flood application of Furadan® 5G, an insecticide that kills primarily larvae of this pest). However, the switch to an adult management program resulted in this method being useless. Grain losses from larval feeding of up to 45% have been recorded in studies.

Management of rice water weevil in California relies on chemical and cultural controls. Biological control of this pest is nonexistent. The adult weevils infest rice fields a few days after flooding and before the establishment of a plant canopy or the aquatic arthropod community. The larval and pupal stages are in the flooded soils and protected from the activity of most arthropods. Some moderate host plant resistance has been identified to RWW and is being incorporated into commercial varieties, but this does not appear to be a stand-alone management tool. Cultural controls are useful for management of rice water weevil in California. Removal of levee vegetation in the spring helps reduce rice water weevil densities in the adjacent rice basins. The additional herbicides required for this and the loss of wildlife habitat on the levees are substantial drawbacks of this management technique. Two additional cultural methods assist in reducing rice water weevil densities, but inherently result in lower rice yields. They include dry seeding rice and delayed seeding dates. The reduced yields that can result from these techniques make them undesirable to growers. Research has shown that winter-flooding reduces RWW populations the
Chemical control of RWW relied on carbofuran (Furadan® 5G) since the late 1970’s. The granular insecticide was applied before flooding and was incorporated into the soil to about 35-40% of the rice acreage. Since higher rice water weevil densities occur near the field edges, border applications of Furadan were commonplace, resulting in significant savings to growers and greatly reducing the amount of insecticide going into the rice agroecosystem. Furadan 5G registration was cancelled after the 2000 season. In 1999, two new insecticides were registered as alternatives to Furadan. These insecticides were proven effective for RWW management in California; however, they have some limitations and required changes in management practices. These two insecticides are diflubenzuron (Dimilin®) and lambda-cyhalothrin (Warrior®). The most important change is that diflubenzuron and lambda-cyhalothrin have to be applied after flooding and seedling emergence. These insecticides have limited effects on RWW larvae, which is the damaging stage. They manage this pest by targeting the adults and minimizing the deposition of viable rice water weevil eggs. Dimilin sterilizes the RWW adults (i.e., females produce no viable eggs) and Warrior kills the adults. Application timing is of utmost importance since no control is possible with these products after a few days following oviposition. These insecticides are recommended to be sprayed at the 2-4 rice leaf stage.

The post-flood application nature of these new insecticides introduced two other questions in terms of RWW management, 1.) how long is control of this insect pest needed, and 2.) what threshold is applicable to use to assess the need for treatment. Studies were conducted for two years to examine yield losses from RWW at various plant growth stages. In one year, no yield losses occurred with infestations occurring on ~4-leaf stage or greater rice, whereas in the second year the yield losses extended much later into the season, (~7-leaf stage rice). It makes sense that the plant is more tolerant of root damage as it becomes more established, but the exact timing is still being examined. Secondly, threshold values developed for Furadan use are inadequate now. A floating barrier trap has been developed in Arkansas for sampling adult populations. This tool shows promise in California but no exact recommendations for use are available yet. The best recommendation presently is to base the need for treatments on past field history and observations. Applications can be made only to field borders in the same fashion Furadan was used.
5-leaf Stage to Heading and Flowering Stage

Two species of armyworms may occasionally be found in rice fields in mid-summer. In recent years, damage from these pests appears to be on the upswing. The armyworm moth lays its eggs in linear masses with the leaf tied around the eggs in a roll on either rice or on other grass species in the paddy. Larvae of both species (true armyworm and western yellowstriped armyworm) are striped and vary in body color. Larvae feed predominantly at night or during cloudy days. They develop 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, consequently many mature larvae drown in flooded paddies before reaching a suitable pupation site. Usually only one generation a year will be spent on rice. 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).

Damage by armyworms is most serious during periods of stem elongation and grain formation. Larvae defoliate plants, typically by chewing angular pieces off leaves. They may also feed on the panicle near the developing kernels causing these kernels to dry before filling. This feeding causes all or parts of the panicle to turn white. 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% at 2 to 3 weeks before heading.

Various natural factors cause mortality of armyworms in the rice paddy. Many caterpillars drown or are killed by natural enemies including predators, pathogenic microorganisms, and parasites. Insecticide treatments are justified if more than 25% defoliation occurs and armyworms are present on the plants from August through early September. Treat for panicle loss if 10% of the panicles in the area sampled are damaged and armyworms are observed. Warrior and Bt products are effective.
Heading to Harvest

Armyworms can also damage panicles during this part of the season. They are the only invertebrate pest which commonly damages rice in this stage. A few instances of “peck” rice have occurred in California. However, the exact identification of the insect involved (or even if an insect was involved) has not been done yet.

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, 2nd Edition (UC ANR Publication 3280) is a good resource for rice IPM.