I.2 *Nosema locustae*

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Introduction

Grasshoppers are the most economically important insect pests on rangeland in the Western United States (Hewitt and Onsager 1982). A conservative estimate for the average value of rangeland forage loss to grasshoppers in the West each year is about $393 million (Hewitt and Onsager 1983). Since the late 1960's, controlling major infestations of grasshoppers on rangeland has involved the use of chemical insecticides, primarily malathion and carbaryl. However, increasing awareness of the environmental risk associated with the exclusive use of chemical insecticides led to the establishment of the Grasshopper Integrated Pest Management (GHIPM) Project.

Disease-causing micro-organisms have been investigated as potential biological control agents of grasshoppers for many years. Probably the most well-known case has been the parasite *Nosema locustae*, a pathogen that was selected in the early 1960's for development as a microbial control agent for use in long-term suppression of grasshoppers (Henry 1978, Onsager 1988). *Nosema locustae* is the only registered microbial agent that is commercially available for control of rangeland grasshoppers.

Nosema has been studied more than any other microbial control agent for the suppression of grasshopper populations. Applications of *Nosema* formulated on a wheat bran bait have resulted in numerous successful introductions of the pathogen into field populations. However, while this parasite has proven a potentially effective tool in grasshopper management, several questions have been raised regarding the effectiveness of *Nosema* in the field.

Unpredictability of *Nosema*

Vaughn et al. (I.4) attributed the apparent failures of *Nosema* to low-quality material, equipment failure, poor formulation, inappropriate target species, and unreasonable expectations by users. Onsager (1988) also discussed some of the reasons for this lack of confidence in *Nosema* for controlling grasshopper populations. He noted that the traditional sampling approach used to estimate grasshopper reductions in field trials with chemical insecticides may not be appropriate to assess the effectiveness of *Nosema*. Typically *Nosema* requires much longer to kill a grasshopper than chemicals. Grasshoppers are then able to disperse and conceal differences between treated and control plots.

Reuter et al. (1990) suggested that the standard application rate of *Nosema* (1×10^9 spores/acre) was too low to induce immediate grasshopper population suppression. In a field evaluation, an untreated control plot was compared to plots receiving either the standard rate (1×10^9 spores/acre) or a higher ($100\times$) rate (1×10^{11} spores/acre) of *Nosema*. Density estimates were taken weekly, and bottomless field cages and small rearing cages were used to estimate mortality. The lack of treatment replication, the small plot size, and the close proximity of plots made it impossible to draw firm conclusions about the grasshopper densities or relative rates of suppression after treatment. However, significant mortality was observed at the higher application rate for *Melanoplus sanguinipes* in the small rearing cages 7 weeks after application (Reuter et al. 1990). These preliminary mortality results lend support to Henry's (1981) contention that applying higher dosages of Nosema will not necessarily produce a commensurate gain in density reduction.

A more immediate density reduction has been demonstrated in field studies using wheat bran bait formulations of *Nosema* and carbaryl in which significant short-term response to carbaryl was followed by a later response to *N. locustae* (Onsager et al. 1981). Further studies on the response of grasshoppers to higher application rates of *Nosema* may be warranted.

A review of the literature on the effectiveness of *Nosema* in the field identifies dispersal as a common problem. Movement between plots was cited as affecting results in six of eight studies that evaluated the effects of Nosema in the field (Henry 1971; Henry and Oma 1974, 1981; Henry and Onsager 1982; Henry et al. 1973, 1978). Only Johnson and Henry (1987) suggested that there was little movement of infected individuals into control plots within 31 days of application.

Detection of *Nosema locustae*

In the past, visual examinations with phase contrast microscopy for spores have been required to detect *Nosema* infection in grasshoppers. Generally, *Nosema*

spores are detectable about 21 days after application (Henry and Oma 1974). Most protocols recommend microscopic examinations at 28 days following application (Henry 1978). Thus, it has not been possible to assess some of the earlier events in a *Nosema* treatment program.

Dispersal and death that occur prior to the detection of Nosema reduce estimates of its presence in the field. Early detection of *Nosema* infections is therefore necessary to obtain unbiased estimates of initial prevalence. Scientists have developed a sensitive nucleic acid probe for the detection of *Nosema* in grasshoppers. Data indicate that the probe can reliably detect *Nosema* in grasshoppers within 7–10 days after infection. Use of a probe to estimate infection rates should eliminate much of the inherent bias associated with visual examination.

Nosema Transmission

A recent laboratory study by Raina et al. (1995) has reported transovarial transmission of *N. locustae* in *Locusta migratoria migratorioides* with the incidence of infection ranging from 72 percent to 92 percent among progeny up to the F7 generation. *N. locustae* spores also were found in all nymphal instars for the F1 and F2 generations.

The mechanisms and rates of *Nosema* transmission in the field have not been addressed adequately. Spores have been observed in feces (Henry 1969 unpubl.), but the scavenging of *Nosema*-infected cadavers by healthy grasshoppers may represent the greatest potential for transmission to uninfected grasshoppers of the same generation. Scavenging of cadavers is common in many species of grasshoppers (Lavigne and Pfadt 1964, Lockwood 1988). Henry (1969 unpubl.) observed feeding on *Nosema*-infected cadavers in the field. Scavenging may offer a very efficient means for transmission of *Nosema* during the year of treatment and possibly into later generations (O'Neill et al. 1994).

Spores of *Nosema* have been observed in ovaries from and in eggs produced by infected females (Henry 1969 unpubl.). Although Ewen and Mukerji (1980) were unable to find spores in eggs collected from *Nosema*-treated plots, they did observe *Nosema* infection among nymphs raised from field-collected eggs. Henry and Onsager (1982) also reported infection in grasshopper populations during the year after treatment. These observations indicate that transmission to subsequent generations is indeed likely, but the details of *Nosema* transmission in field populations of grasshoppers have never been fully explained.

Effect on Grasshopper Egg Production

Nosema-infected females produce fewer eggs than healthy females (Henry and Oma 1981). Henry (1969, 1971) reported detecting little ovarial or egg debris in infected grasshoppers that were ground up, which suggests that infected females fail to develop reproductively. Ewen and Mukerji (1980) reported substantially lower rates of egg laying after applications of *Nosema* in the field. Henry and Oma (1981) suggested the need to measure the effects of *Nosema* on egg numbers and egg viability. Lockwood and Debrey (1990) also observed some evidence of lower egg production in higher populations (greater than 11.5 grasshoppers/yd^2 or 9.6 grasshoppers/m^2) of grasshoppers treated with *Nosema.*

Conclusions

Until the reasons for the inconsistent response of *Nosema* to grasshoppers are better understood, its effectiveness will probably continue to be disputed (*See* I.4.). The grasshopper species complex, the age of the grasshoppers, and population density can affect the response to a *Nosema* application. Therefore, a more comprehensive approach is needed to adequately assess *Nosema* against grasshoppers. This approach must include a better understanding of the major disease processes of *Nosema.* Vaughn's team (I.4) recommends that *Nosema* be used to suppress rangeland grasshoppers in environmentally sensitive areas where cost and acute insecticide control are not primary concerns and proposes the use of higher rates and/or multiple applications when environmental issues outweigh the economic issues.

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