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Cost effectiveness of biological control of invasive mole crickets in Florida pastures

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HIGHLIGHTS

- Mole cricket biological control minimized Florida pasture losses due to this pest.
- The perpetual economic benefit had a benefit-cost ratio of 52:1.
- The highly successful mole cricket biological control required 34 years to complete.
- Mole cricket biological control is part of ongoing integrated pest management.
- Publicly funded mole cricket biological control was a prudent investment.

GRAPHICAL ABSTRACT

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ABSTRACT

The Mole Cricket Biological Control Program (MCBCP) is a compelling example of successfully managing alien invasive pests that warrants formal analysis and documentation of its effectiveness and benefits relative to costs for cattlemen in the southeastern U.S. Three biological control agents that parasitize the short-winged mole cricket, *Neoscapteriscus abbreviatus* (Scudder); tawny mole cricket, *Neoscapteriscus vicinus* (Scudder); and southern mole cricket, *Neoscapteriscus borellii* (Giglio-Tos) (Orthoptera: Gryllotalpidae) were imported from the origin of the pests in South America, tested for non-target affects, and distributed widely in Florida. *Larra bicolor* F. (Hymenoptera: Crabronidae), a parasitoid of large nymph and adult mole crickets, was collected in Bolivia and established in Florida in 1988–89, and later in Georgia, Alabama, and Mississippi. Another parasitoid of large mole crickets, *Ormia depleta* (Wiedemann) (Diptera: Tachinidae), was introduced several times from Brazil during the early 1980s and released extensively. An entomopathogenic nematode discovered in Uruguay, *Steinernema scapterisci* (Nematoda: Rhabditida: Steinernematidae) reproduces within adult mole crickets, building up large populations that infect additional mole crickets and ultimately creates an epidemic. This very effective biological control agent was applied to pastures, turf farms, golf courses, athletic fields, and other mole cricket habitats across Florida after *in vitro* culture was developed and a commercial product, "Nematac® S," became available. During the 34 years of the MCBCP (1979–2012), about $8.7 million was spent on faculty salaries and operating costs and the overall annual savings in control costs was estimated to be $13.6 million; a first year benefit-cost ratio of 1.6:1. Applying a 3% social discount rate (perpetual benefit), the MCBCP will save cattle producers $453 million for a long-term benefit-cost ratio of 52:1.

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1. Introduction

The Mole Cricket Biological Control Program (MCBCP) was established in 1979 within the University of Florida, Institute of Food and Agricultural Sciences (UF/IFAS), Entomology and Nematology Department to conduct research on controlling three species of alien invasive mole crickets that had been problem pests since about 1899–1925 (Frank and Leppla, 2009): the short-winged mole cricket, *Neoscapteriscus abbreviatus* (Scudder); tawny mole cricket, *Neoscapteriscus vicinus* (Scudder); and southern mole cricket, *Neoscapteriscus borellii* (Giglio-Tos) (Orthoptera: Gryllotalpidae) (Frank and Walker, 2006; Cadena-Castaneda, 2015). These pest mole crickets from South America became established in the southeastern U.S., the tawny and southern mole crickets becoming particularly widespread and occurring across the southern coastal plains from North Carolina west to Texas (Frank and Parkman, 1999) where they began to cause significant agricultural losses by mid-1900. Mole crickets severely damage pastures, other grassy areas, and vegetable crops by feeding primarily on roots and stems at night as they burrow underground. The MCBCP became necessary in 1979 because the U.S. Environmental Protection Agency withdrew registration of chlordane that had effectively controlled mole crickets in pastures. Other insecticides were tested in various formulations but all were less effective and more expensive. Consequently, UF/IFAS researchers conducted a classical biological control program involving foreign exploration for mole cricket natural enemies in South America. They also investigated mole cricket systematics, ecology, behavior, physiology, toxicology and pathology in an effort to discover alternative ways to control these pests (Frank and Parkman, 1999).

The MCBCP provided an opportunity to analyze the costs and benefits of using a combination of classical and augmentation biological control to successfully manage alien invasive pests (Frank and Parkman, 1999; Frank and Walker, 2006). Eventually, three biological control agents that parasitize *Neoscapteriscus* spp. mole crickets were imported, tested for non-target affects, and distributed widely in Florida (Frank and Walker, 2006). *Larra bicolor* F. (Hymenoptera: Crabronidae), a parasitoid of large nymph and adult mole crickets, was collected in Bolivia and established in Florida, Georgia, Alabama and Mississippi during the late 1980s (Frank et al., 2009). Another parasitoid of large mole crickets, *Ormia depleta* (Wiedemann) (Diptera: Tachinidae), was imported several times from Brazil during the early 1980s (Frank et al., 1996) and released extensively after rearing methods were developed (Wineriter and Walker, 1990). An entomopathogenic nematode discovered in Uruguay, *Steinernema scapterisci* Nguyen & Smart (Nematoda: Rhabditida: Steinernematidae), reproduces within adult mole crickets and builds up large populations that infect additional mole crickets (Georgis et al., 2006), ultimately creating an epidemic (Nguyen and Smart, 1990). This very effective biological control agent was applied to pastures, turf farms, golf courses, athletic fields, and other mole cricket habitats across Florida after *in vitro* culture was developed and Becker Underwood marketed the product, Nematac® S (Leppla et al., 2007). Establishment of these agents was verified and attempts were made to quantify their impacts on different mole cricket populations; however, the only long-term study was conducted in Gainesville, Florida (Frank and Walker, 2006) where >95% reduction occurred for both *N. vicinus* and *N. borellii*. In Central Florida pastures, applications of the nematode reduced mole cricket populations by 85% within three years (Leppla et al., 2007).

Many economic analyses have been completed for weed biological control projects (Culliney, 2005; McFadyen, 2008) but there are considerably fewer for insects (Voegele, 1989; Alvarez et al., 2016; Naranjo et al., 2015). Hill and Greathead (2000) included both weed and insect biological control in their analysis of 27 classical biological control programs worldwide that were conducted for 30–40 years and all but one had a benefit-cost ratio (BCR) greater than 1:1, indicating that successful programs are cost effective. Habeck et al. (1993) calculated the potential benefits of research on classical biological control using entomophagous insects and suggested that for projects costing $293,000 or $461,000 and lasting 4–7 years a return on investment of $62,000 or $97,000 per year, respectively, would assure a favorable BCR. This return was considered so low that many economically important pests would meet the necessary economic criterion for investing in classical biological control projects. Moreover, research on biological control reportedly is more cost effective than investments in chemical control (30:1 versus 5:1) and the overall BCR for classical biological control was estimated at 250:1 (Bale et al., 2008; Tisdell, 1990; van Driesche and Bellows, 1996). Biological control in general, including augmentation, has been highly cost effective with BCRs ranging from 3:1 to more than 100:1 (Van Driesche and Bellows, 1996).

Economic evaluation methods for insect biological control programs have lacked consistent methodology and often relied on cost approximations and producer interviews, resulting in highly variable BCRs, e.g., two-spotted spider mite, *Tetranychus urticae* (Koch) (24.4:1); wood wasp, *Sirex noctilio* (F.) (2.5:1); and white wax scale, *Ceroplastes destructor* Newstead (1.4:1). Comparing the geographical distribution of maize yields with release rates of *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) over 20 years in Kenya, Africa, Kipkoech et al. (2006) estimated a BCR of 19:1 due to parasitism of the stem borer, *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae). In this study, reductions in yield were estimated using established pest density-yield loss functions rather than actual on-farm data. An analysis of the economic impact of *Diadegma semiclausum* (Hellen) introduced into Kenya for biological control of the diamondback moth, *Plutella xylostella* L., was conducted using both farmer interviews and measurements from farmer-managed fields (Macharia et al., 2005). The two sources of information yielded similar data. Variables analyzed included annual cabbage production and price, supply and demand, increased consumption, and economic surplus produced. Over 25 years, the gain was $28.3 million for a BCR of about 24:1. Mango producers in Benin, Africa were interviewed to determine plant production losses and positive impacts after the parasitic wasp *Gyranusoidea tebygi* Noyes (Hymenoptera: Encyrtidae) was introduced from India for biological control of the mango mealybug, *Rastrococcus invadens* Williams (Homoptera: Pseudococcidae). Interviewed mango producers gained an average of $328 per year, so by extrapolation the biological control program produced a yearly gain of $50 million for producers at all levels of mango production, estimated at $531 million over a period of 20 years. The total cost of the biological control program was estimated at $3.66 million, resulting in a BCR of 145:1 (Bokonon-Ganta et al., 2002).

Economic analyses of insect biological control projects are infrequently based on quantitative information. An exception is a detailed economic analysis of a 40-year effort to control the cassava mealybug, *Phenacoccus manihoti* Mat.-Ferr. (Homoptera: Pseudococcidae) in 27 African countries with its parasitoid *Apoanagyrus* (*Epidinocarsis*) *lopezi* De Santis (Hymenoptera: Encyrtidae) that indicated a combined annual loss reduction of $26 per hectare and the BCR of 199:1 to 297:1, depending on the situation in each country (Zeddies et al., 2000). A previous more conservative estimate for this ground-breaking biological control program yielded a BCR of 149:1 (Norgaard, 1988). In the U.S., growers of baby blue gum, *Eucalyptus pulverulenta* Sims, achieved BCRs ranging from 9:1 to 24:1 for biological control of the blue gum psyllid, *Ctenarytaina eucalypti* (Maskell) (Homoptera: Aphalaridae), with the parasitoid, *Psyllaephagus pilosus* Noyes (Hymenoptera: Encyrtidae)