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on Lygodium microphyllum (Polypodiales: Lygodiaceae)
in Florida**

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CURRENT STATUS OF THE BIOLOGICAL CONTROL AGENT *NEOMUSOTIMA CONSPURCATALIS* (LEPIDOPTERA: CRAMBIDAE), ON *LYGODIUM MICROPHYLLUM* (POLYPODIALES: LYGODIACEAE) IN FLORIDA

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Old World climbing fern, *Lygodium microphyllum* (Cav.) R. Br (Polypodiales: Lygodiaceae), is an invasive weed that is widespread throughout wetland and mesic habitats in south Florida, and degrades critical ecosystem services and habitats of rare and endangered species (Pemberton & Ferriter 1998; Volin et al. 2004). Old World climbing fern likely arrived in Florida through the ornamental plant trade and was first reported naturalized in Florida in 1968 (Beckner 1968). By 1978 it was found commonly throughout Martin County and has now spread to many parts of the sensitive Everglades ecosystem including the Arthur R. Marshall Loxahatchee National Wildlife Refuge, Everglades National Park and Big Cypress National Preserve (Nauman & Austin 1978; Ferriter & Pernas 2006, www.eddMaps.org, accessed 13-IX-2013). Though various state, regional and federal agencies have sought for years to curb the spread of *L. microphyllum*, it continues to rapidly expand its range, which now includes much of south and central Florida and isolated points in northern Florida (e.g. Jacksonville, Daytona [www.eddmaps.org, accessed 14-I-2014], Ferriter & Pernas 2006).

An indeterminate rachis and extensive rhizomatous growth smother native understory vegetation and act as a fire ladder carrying low-intensity fires into the canopy, which causes extensive tree death (Pemberton & Ferriter 1998). Compounding the challenge to control *L. microphyllum* is the strong propagule pressure from spores that travel via wind currents and arrive at isolated sites. No native herbivores exert control over the fern's growth and herbicides are difficult to apply in habitats in which *L. microphyllum* invades. Although herbicides and fire kill above-ground biomass, new fiddleheads rapidly regrow from the underground rhizome (Stocker et al. 2008).

In 1997, scientists from the U.S. and Australia conducted foreign exploration for biological control agents of *L. microphyllum* in Asia and Australia. These surveys yielded several insects and one mite that negatively impact *L. microphyllum* in the native range (Pemberton 1998; Goolsby et al. 2003). Of these candidates, 2 moths (*Austromusotima*

camptozonale Yen and *Neomusotima conspurcatalis* Warren, Lepidoptera: Crambidae) and one leaf-galling mite (*Floracarus perrepae* Knihinicki & Boczek, Acariformes: Eriophyidae) were approved for release by the USDA-APHIS Technical Advisory Group (APHIS-TAG). *Austromusotima camptozonale* was released from 2004 until 2007 and then again from 2010 to 2012, but failed to establish despite the release of more than 160,000 adults and larvae into the field (Boughton & Pemberton 2008). *Floracarus perrepae* was released from 2008 until 2010 and has established within isolated patches in Martin County and Everglades National Park (Lake et al. in press).

Neomusotima conspurcatalis Warren (Lepidoptera: Crambidae) is a *Lygodium* specialist native to Southeast Asia and Australia. This agent readily established populations in Old World climbing fern stands after its introduction in early 2008. By Dec 2008, large larval populations were present in Jonathan Dickinson State Park and caused measurable impacts on *L. microphyllum* (Boughton & Pemberton 2009; Boughton unpublished data). However, two consecutive cold winters followed in 2010 and 2011 and moth populations decreased or were reportedly extirpated from previously established sites (Boughton et al. 2012a; Boughton & Pemberton 2012).

In late 2012, land managers once again began to report large larval feeding events, known as brown outs, in areas of Loxahatchee National Wildlife Refuge, Jonathan Dickinson State Park, and Barley Barber Swamp Conservation Area (pers. com). To verify these reports and determine the current status of *N. conspurcatalis* populations, we resurveyed all original release sites ($N = 18$) from Oct 2012 to Mar 2013. Each site was searched by 2 investigators for approximately 30 min and then assigned an infestation score (0–5), according to the frequency of occurrence of characteristic leaf feeding damage and abundance of *N. conspurcatalis*. Sites where *N. conspurcatalis* was absent were assigned a score of 0; old signs of feeding, but no insects = 1; low densities, but insects present = 2; moderate infestation, insects present and patchy throughout the site = 3; feed-

TABLE 1. RELEASE HISTORY, FEEDING SCORE AND DATE OF LAST ASSESSMENT FOR *N. CONSPURCATA*LIS. SITES WITH (*) DENOTE THAT THEY WERE SPRAYED WITH HERBICIDE AND WERE NOT USED IN THE REGRESSION ANALYSIS. FEEDING LEVELS ARE SCORED AS FOLLOWS: 0, NO FEEDING SIGNS; 1, SIGNS OF OLD FEEDING; 2, LOW DENSITIES, BUT INSECTS PRESENT; 3, INSECTS PRESENT, BUT PATCHY THROUGHOUT THE SITE; 4, FEEDING DAMAGE FREQUENT WITH HIGH MOTH PRESENCE; AND 5, EXTENSIVE FEEDING DAMAGE AND POPULATION EXPLOSIONS (BROWN OUTS), WITH THE EXCEPTION OF RODGER'S RIVER IN EVERGLADES NATIONAL PARK AND TWO ISOLATED TREE ISLANDS IN LNWR, *N. CONSPURCATA*LIS ESTABLISHED POPULATIONS AT ALL SITES.

Location	Site Name	Release Date(s)	Total	Feeding Score	Date last assessed
Everglades National Park	Rodger's River, Cape Sable	13-May-09	4050	0	13-Dec-12
Jonathan Dickinson State Park	JD24	22 May 2008 - 21 July 2010	17100	3	31-Jan-13
Jonathan Dickinson State Park	JD25	31 March 2008 - 7 May 2008	14791	3	29-Jan-13
Jonathan Dickinson State Park	JD44	31 Jan 2008 - 23 Aug 2010	2750	2	31-Jan-13
JW Corbett National Wildlife Refuge*	Corbett55	15-May-09	4250	sprayed	26-Mar-13
Lennar County Preserve	Lennar2	24 July 2008 - 28 Aug 2008	13358	2	31-Jan-13
Loxahatchee National Wildlife Refuge*	Lox kiosk	28-Oct-09	2000	sprayed	13-Feb-13
Loxahatchee National Wildlife Refuge *	Lox12 New	28-Oct-09	2000	sprayed	13-Feb-13
Loxahatchee National Wildlife Refuge	Lox32 Straznulla	29 Feb 2008 - 5 Dec 2008	19289	2	13-Feb-13
Loxahatchee National Wildlife Refuge	Lox41	27-Mar-09	2200	2	10-Oct-12
Loxahatchee National Wildlife Refuge	Lox42	27-Mar-09	2200	2	10-Oct-12
Loxahatchee National Wildlife Refuge	Lox43	27-Mar-09	2200	0	10-Oct-12
Loxahatchee National Wildlife Refuge	Lox44	27-Mar-09	2200	0	10-Oct-12
Loxahatchee National Wildlife Refuge	Lox5	10-Oct-08	4400	2	13-Feb-13
Cypress Creek Preserve - SFWMD	Cypress Creek	2 April 2009 - 10 Nov 2010	59209	3	5-Feb-13
Kissimmee River - SFWMD	Kissimmee River 1	2-Apr-09	14821	4	23-Oct-12
Flatword Swamp - SFWMD	Flatford Swamp 1	31 Aug 2009 - 11 Aug 2010	12000	2	6-Mar-13
Flatword Swamp - SFWMD	Flatford Swamp 3	32 Aug 2009 - 11 Aug 2010	12000	2	6-Mar-13

ing damage frequent with high moth presence = 4; and abundant populations and damage (brown outs) = 5. We then used a linear regression analysis to evaluate the relationship between release size and infestation score.

We recovered *N. conspurcatalis* in or adjacent to the site at all release points except Everglades National Park (Table 1). The single release made at Everglades National Park was conducted hurriedly due to thunderstorm activity during the release (H. Cooley, pers. com). An additional release made at Corbett National Wildlife Refuge was omitted from the analysis because the *L. microphyllum* in the release site was treated with herbicide. We found no significant linear relationship between release size and infestation score ($P = 0.06$). However all releases of 4,000 or more larvae successfully established populations that persisted for at least 5 years, and at many sites, releases of 2,200 larvae were adequate to establish persistent populations.

Neomusotima conspurcatalis occupies isolated, though large, areas within the Old World climbing fern range in Florida. Currently *N. conspurcatalis* does not extend beyond Central Florida, but warming temperatures and fewer frost events may facilitate a northward range expansion. Notwithstanding extenuating circumstances, all populations have persisted for at least 5 years. Despite cold temperatures and the acquisition of parasitoids (Boughton et al. 2012b), our findings indicate that *N. conspurcatalis* and the Lygodium galling mite, *Floracarus perrepae*, are more widely distributed in greater abundances than previously understood (Boughton & Pemberton 2011, Lake et al. *in press*). Further investigations will evaluate the impact of *N. conspurcatalis* on *L. microphyllum* as well as determine the northern limits for *N. conspurcatalis* and future *L. microphyllum* control candidates.

SUMMARY

The brown Lygodium defoliating moth, *Neomusotima conspurcatalis* Warren (Lepidoptera: Crambidae), was released beginning in 2008 to control Old World climbing fern, *Lygodium microphyllum* (Cav.) R. Br (Polypodiales: Lygodiaceae). The moth readily established in Jonathan Dickinson State Park, but at other sites populations remained at low densities or were locally extirpated. In 2012 and 2013, we recovered *N. conspurcatalis* populations at all original release sites except Everglades National Park and those treated with herbicide. The original releases of 4,000 or more individuals per site were entirely successful, pointing to a strategy that focuses on numbers at this target level or beyond for future releases in Florida.

Key Words: *Lygodium microphyllum*, *Neomusotima conspurcatalis*, Jonathan Dickinson State Park, establishment

RESUMEN

La polilla marrón defoliadora del Lygodium, *Neomusotima conspurcatalis* Warren (Lepidoptera: Crambidae), fue liberada a partir del 2008 para controlar el helecho trepador del Mundo Antiguo, *Lygodium microphyllum* (Cav.) R. Br. (Polypodiales: Lygodiaceae). La polilla se estableció fácilmente en el Parque Estatal de Jonathan Dickinson, pero en otros lugares la población se mantuvo en baja densidad o fue extinguida localmente. En 2012 y 2013, recuperamos poblaciones de *N. conspurcatalis* en todos los sitios donde fueron liberadas inicialmente, excepto el Parque Nacional de los Everglades y los lugares tratados con herbicida. Las liberaciones iniciales de 4000 o más individuos por sitio fueron completamente exitosas, que apunta a una estrategia que se centra en liberar números en este nivel o más para futuras liberaciones en la Florida.

Palabras Clave: *Lygodium microphyllum*, *Neomusotima conspurcatalis*, Parque Estatal de Jonathan Dickinson, establecimiento

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