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Invasions of *Hylesia metabus* (Lepidoptera: Saturniidae, Hemileucinae) into Trinidad, West Indies

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ABSTRACT

Hylesia metabus (Cramer) is a saturniid moth of public health importance. Contact with the abdominal hairs of the adult females causes dermatitis, eye lesions and respiratory tract manifestations. It has been reported from the northern parts of South America, but not Trinidad. However, we have shown from specimen data that the moth is part of the natural fauna and widely distributed in Trinidad. On four occasions, between July, 2005 and May, 2006, *H. metabus* invaded the southwestern coastal communities of Trinidad. Since then, no invasions have been reported up to March, 2010. This paper reviews the published and grey literature on *H. metabus*, chronicles the movement of the moths and reports on its socio-economic impact on coastal communities in Trinidad. We postulate that the observed moths originated from South America rather than Trinidad and attempt to explain the frequency and timing based on biological, ecological and environmental factors. Possible management strategies are discussed.

Key words: Invasive species, mangrove, migration, lepidopterism, moth, Venezuela.

INTRODUCTION

Direct and indirect contact with insects, other arthropods, and their products can elicit a range of adverse reactions in humans, and lepidopterism, the ill effects that immature and adult butterflies and moths can have on humans, has been reported in several countries (Wirtz 1984). Contact with the abdominal setae (hairs) of adult female *Hylesia metabus* (Cramer) (Lepidoptera: Saturniidae, Hemileucinae) causes dermatitis (commonly known as "la palometa peluda", "la papillonite guyanaise" and "Carapito itch"), eye lesions and respiratory tract manifestations (Michel *et al*. 1980, Wirtz 1984, Rodríguez-Acosta *et al*. 1998, Lemaire 2002, Rodriguez-Morales *et al*. 2005).

Rodriguez *et al*. (2004) stated that the short barbed abdominal hairs contain a kallikrein-like substance which is associated with increased vascular permeability and the production of pain and irritation. These short hairs are associated with the ovipositor and are the most abundant type of hairs in egg nests where their main purpose is to conceal eggs from ants and to discourage avian and mammalian predators.

Other species of *Hylesia* cause similar problems elsewhere in the Neotropical Region, e.g. *Hylesia alinda* Druce in Mexico (Fernandez *et al*. 1992), and *H. nigricans* (Berg) in south-east Brazil (Specht *et al*. 2006). However, Lemaire (2002) considers *H. metabus* to be the most noxious because of the ease with which the urticating abdominal hairs disperse into the air and the high numbers of females during outbreaks.

Trinidad is the southernmost Caribbean island, close to, and zoogeographically part of, the mainland countries of Venezuela and Guyana. The south-west tip of Trinidad is approximately 14 km from the Venezuela coast. On four occasions, between July 2005 and May 2006, night flying *H. metabus* were reported at offshore oil facilities in the Gulf of Paria and in coastal communities in southwestern Trinidad causing skin irritations to oilfield workers and island residents. A brief account of this appeared in the

GISP newsletter (Polar 2006). This paper reviews the biology of the moth and reports on previous outbreaks. It also documents as far as possible the chronology of the incursions of *H. metabus* and their economic, social and medical impacts. Factors which may have influenced the invasions and management strategies are discussed.

Hylesia metabus

Life cycle

Hylesia metabus (Fig. 1a,b,c) has a three-month life cycle (approximately 109 days), and up to four generations per year although this is not always the case (Silvain and Vassal 1991). Eggs are laid in a single batch averaging 200 (Vassal *et al*. 1986) or more (Lemaire 2002) and covered with harmless long hairs and short urticating hairs from the end of the female's abdomen (Rodriguez *et al*. 2004). Eggs hatch in 24 to 26 days and produce caterpillars (Fig. 1d), which take 45-59 days to mature through seven instars (Vassal *et al*. 1986, Lemaire 2002). They feed gregariously on their food plants, in a similar manner to that described for *H. lineata* (Druce) in Costa Rica by Janzen (1984). Pupae take 15-21 days to eclose (Vassal *et al*. 1986, Lemaire 2002) and the adults, which do not feed, live for only 4-7 days (Vassal *et al*. 1986). Caterpillars are illustrated by Michel *et al*. (1980) and Vassal *et al*. (1986). However, the oldest illustration we have found dates back to the 18th century when Merian (1705, plate 43) illustrated the caterpillar (Fig. 1e). The associated food plant is *Duroia eriopila* L.f. (Rubiaceae) and the associated adult is a swallowtail butterfly, *Protesilaus protesilaus* (L.) (Basset *et al*. 2005). Unfortunately, Merian did not always correctly associate caterpillars, adults and food plants, so it is not safe to assume that either the caterpillar or adult are associated with this food plant (M.J.W. Cock unpublished). As far as we are aware, this is the first time that this caterpillar illustrated by Merian from Surinam has been named.

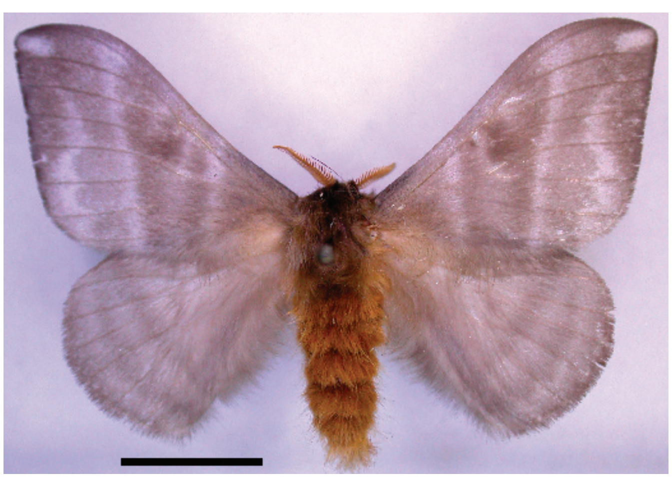
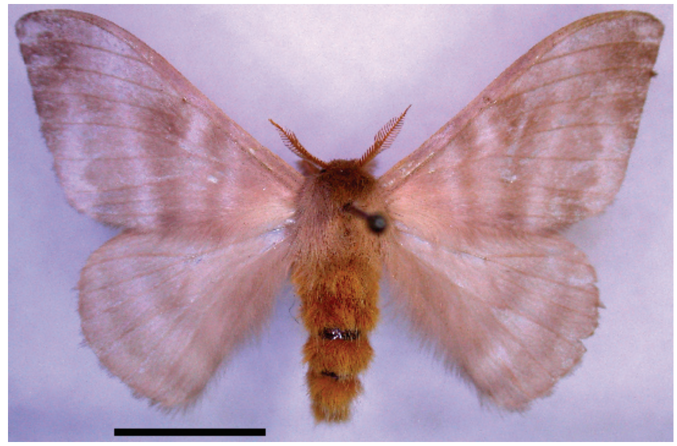
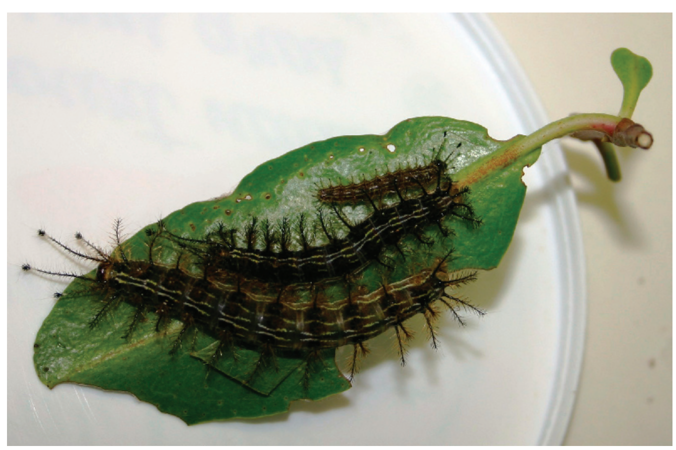


Fig. 1(a). Adult male *Hylesia metabus* dark coloured, Arima Valley, Simla, at MV light, 6.viii.1982, M.J.W. Cock (MJWC coll.).

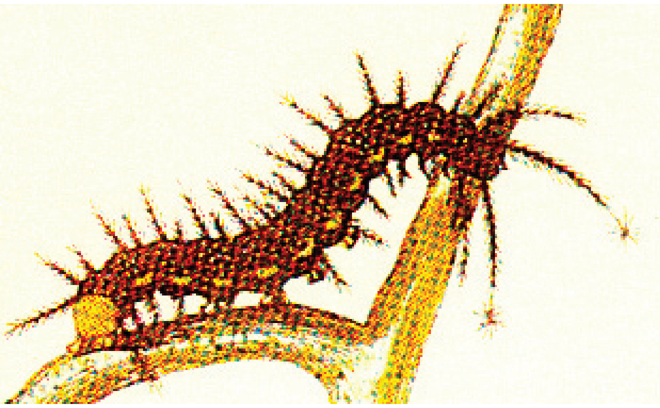


(b). Adult male *Hylesia metabus* light coloured, Nr. Chatham, at light, 1.iv.1981, M. Alkins (MJWC coll.).

(c). Adult female *Hylesia metabus*, Curepe, C.I.B.C. stn, 22.iii.[19]89, R.G. Brown (CABI coll.). Right forewing = 3cm



(d). Caterpillars of *H. metabus* of different ages, Columbia Road, Trinidad, 19 December, 2005, C. Fredrickson. Largest caterpillar approx. 3.5 cm



(e). Mature caterpillar of *Hylesia metabus* reproduced from Merian (1705, plate 43).

Mating behaviour

Fornés and Hernández (2000) described the mating behaviour of *H. metabus*. Adults emerge between 0700 h and 1200 h. The first flight of males occurs between 1800 h and 1900 h and is related to dispersal. The second flight, smaller in number, is between 2030 h and 2400 h and is related to sexual activity. The females have a single flight which coincides with the first flight of the males. In contrast, Lemaire (2002) gives the flight period as very short, from 15 minutes after dusk until 1900 - 2130 h.

The pheromone call behaviour of the females lasts from 2030 h until 0200 h, i.e. during the second flight period of the males. Mating was observed to occur between 2137 and 0052 h and may last on average 9.5 h. Oviposition takes place the following night between 1900 h and 2200 h.

Geographic distribution

Lemaire (2002) in his seminal work on the Hemileucinae, stated that *H. metabus* is widespread at low elevations in tropical South America, except the Pacific Coast and arid and semi-arid areas. Countries reported are: the Guyanas, Venezuela, Ecuador, Peru, Bolivia and Brazil. In Venezuela, outbreaks of *H. metabus* occur primarily in the north-east, in the states of Monagas, Sucre and Delta Amacuro (Fornés and Hernández 2001) while in French Guiana outbreaks occur in coastal areas (Vassal *et al*. 1986).

History of outbreaks

Hylesia metabus has been a persistent pest to residents and workers in coastal communities, oil rigs and ships in Venezuela, Guyana and French Guiana for 100 years or more (Michel *et al*. 1980, Fornés and Hernández 2001, Lemaire 2002). Outbreaks last 2-3 generations (Silvain and Vassal 1991). In French Guiana, between 1968 and 1985, there were five outbreaks separated from each other by a period of six months to four years (Vassal *et al*. 1986). In Irapa, Venezuela, Fornés and Hernández (2001) cited literature which indicated that the moths have been present annually since 1942 until the 1960s and 1970s followed by an absence and re-emergence in the early 1980s. Silvain and Vassal (1991) reported that between outbreaks, naturally occurring *Bacillus thuringiensis* v. *israelensis* is the main cause of mortality, but during outbreaks, a nuclear polyhedrosis virus is common. It seems likely that the combination of the two pathogens terminates the outbreaks.

Factors influencing outbreaks

Outbreaks of *H. metabus* are associated with mangroves. The principal mangrove hostplants for *H. metabus* are *Rhizophora mangle* L. (red mangrove, Rhizopheraceae), *Avicennia germinans* (L.) (black mangrove, Verbenaceae) and *Laguncularia racemosa* (L.) C.F. Gaertn. (white mangrove, Combretaceae) (Michel *et al*. 1980, Osborn *et al*. 2001). *Hylesia metabus* is known to be polyphagous, attacking species of more than 16 families including *Psidium guajava* L. (guava, Myrtaceae), *Hura crepitans* L. (sandbox, Euphorbiaceae), *Anacardium occidentale* L. (cashew, Anacardiaceae), *Syzygium malaccense* (L.) Merr. & L.M. Perry (pomerac, Myrtaceae), *S. cumini* L. (gulopjamoon) and *Erythrina poeppigiana* (Walp.) O.F. Cook (mountain immortelle, Fabaceae) (Osborn *et al*. 2001).

Hylesia metabus is known to be attracted to the lights in rural communities, boats and petroleum tankers in Venezuela (Fornés and Hernández 2001). A variety of physiological, behavioural and environmental factors determine which moths fly to light and when, as reviewed by Frank (1988). Although moths are sensitive in the region of 598 nm, like humans, they exhibit maximum sensitivity in the green part of the spectrum (500 - 550 nm). Light from low pressure sodium lamps is spectrally narrow near 598 nm and does not elicit the flight to light behaviour. However, high pressure sodium, metal halide and mercury vapour fluorescent lights produce significant energy in the green spectrum leading to the attraction of moths. Mercury vapour fluorescent lights provide a bright white light and have hitherto been used quite extensively on offshore oil platforms around Trinidad. Low and high pressure sodium lights have mostly been used for lighting urban areas in Trinidad (Powergen, pers. comm.).

Observations of moths

Chronology of moth invasion

Hosein (2006) describes the movements and impacts of the moths offshore. In the first invasion, moths were observed on offshore oil facilities in the Gulf of Paria north-west of the southern peninsular of Trinidad. The offshore installations of the Soldado Block are divided into four areas – South West Soldado, Main, North and East Fields. The moths first appeared in the South West Soldado Field (which also extends southwards to the edge of Venezuelan territorial waters and where Venezuelan mangroves are visible from oil facilities) on 1 July, 2005 (1830 h). By 7 July, 2005, moths had appeared throughout the entire offshore operation and were observed approximately every two nights until 14 July, 2005. Moths were reported on land between 5 and 12 July, 2005 in the communities of Icacos, Fullerton, Bonasse, Bois Bourge, and Coromandel Village, all located near the shoreline of the southwestern peninsular of Trinidad (Fig. 2).

Subsequent invasions followed a similar pattern. The second invasion consisted of two main masses, which arrived between 7 and 17 October, 2005 and again from 21 October, 2005 to 6 November, 2005 where they were also observed approximately every two nights. On both occasions, moths were observed first in the South West Soldado Field followed sequentially by the Main, North and East Fields in a single night. The extent of the invasion on land was greater than the previous invasion with Icacos, Fullerton, Bonasse, Bois Bourge, Coromandel Village and Granville affected on 11 October, 2005 (1930 - 2100 h) and Point Fortin the following evening.

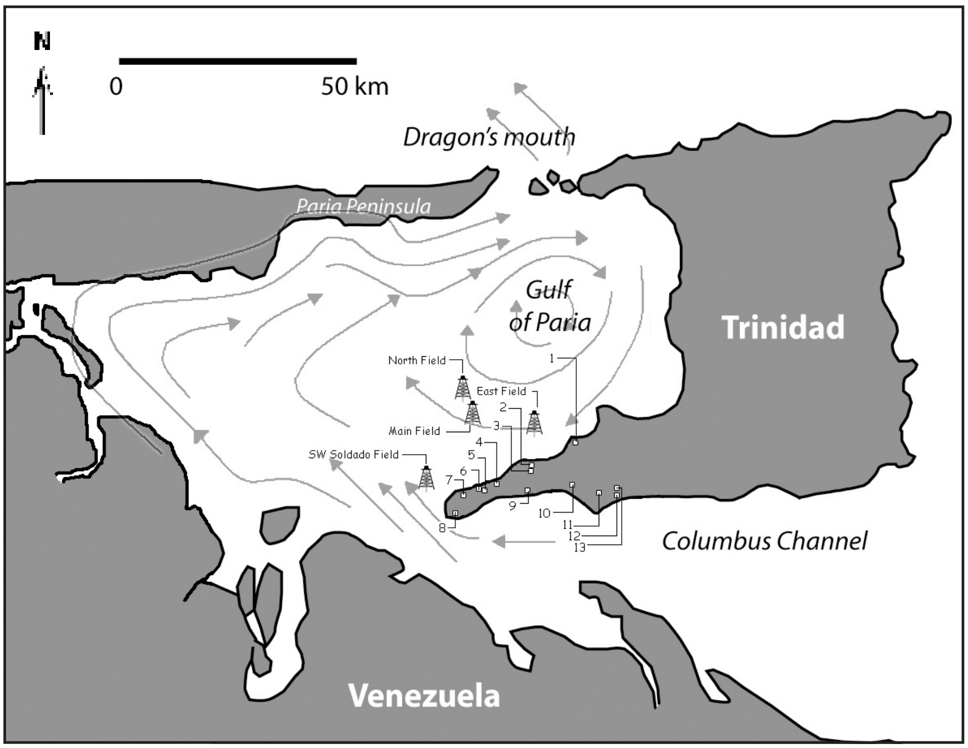


Fig. 2. Map of Trinidad showing wind patterns, location of oil platforms and towns affected by *Hylesia metabus*.

Key to locations: 1. Point Fortin; 2. Granville; 3. Coromandel; 4. Bamboo; 5. Bonasse; 6. Cedros; 7. Fullerton; 8. Icacos; 9. Erin; 10. Buenos Ayres; 11. Rancho Quemado; 12. Beach Camp; 13. Palo Seco.

The third invasion consisted of two main masses, the first on 15 January, 2006 and the second between 21 to 22 January but moths lingered until 30 January, 2006. The offshore oilfields were affected in the same sequence as before, but the number of moths reported was lower. On land, many moths were present at Fullerton, Bonasse and Bois Bourge on 15 January, 2006 while Icacos was affected on 17 January, 2006. The second land invasion during this period was heavy and similarly affected Fullerton, Bonasse and Bois Bourge on 21 January, 2006 and Icacos on 22 January, 2006. Moths were observed laying egg masses indiscriminately on vegetation and solid substrates in affected communities.

The fourth invasion consisted of two swarms of limited size. Relatively few moths (< 20 per location) were observed intermittently in the offshore oilfields between 13 April and 29 May, 2006. On 30 April, 2006, moths were observed in Icacos, Bamboo, Bois Bourge and Palo Seco. On 10 May, 2006, moths were observed further to the east in Rancho Quemado, Beach Camp (Palo Seco), Buenos Ayres and Erin. Moths in the fourth invasion were observed onshore for approximately seven weeks in contrast to previous invasions which lasted only three weeks. As of March, 2010, there have been no further reports of *H. metabus* invasions.

In surveys conducted on 19 December, 2005 (after the second invasion), 7 and 28 March, 2006 (after the third invasion), caterpillars were observed feeding on *R. mangle*, *R. x. harissonii* Leechm. and *L. racemosa* in the mangroves of Los Blanquizales and Icacos. Although present on *Conocarpus erectus* L. (button mangrove, Combretaceae), these caterpillars were pupating but not feeding. Caterpillars were also seen in the coastal communities and the surrounding disturbed forest on the following economic and ornamental plants: *Delonix regia* (Bojer ex Hook.) Raf. (flamboyant, Fabaceae), *Andira inermis* (W. Wright) Kunth ex DC. (angelin, Fabaceae), *P. guajava*, *Terminalia cattapa* L. (tropical almond, Combretaceae), *Persea americana* Mill. (avocado, Lauraceae), *S. malaccense* and *S. cumini*.

In the first and second survey, the number of caterpillars observed was low; however, a larger number was observed in the third survey. Caterpillars of instars 3-5 (433) were collected after the third invasion and reared for parasitoids; however none were obtained. A range of parasitoids have been recorded from *H. metabus* (Silvain and Vassal 1991, Hernández *et al*. 2005) and *Conura maria* Riley (Hymenoptera: Chalcididae) has been reported from *Hylesia* spp. from Trinidad (Peigler 1994).

Socio-economic and medical impacts

During the first invasion, offshore oil platforms in the four fields, all belonging to the Petrotrin Trinmar Operations, were closed for at least one week. The company's medical team examined 510 workers during the first invasion. No medical data from health centres was available for this period, but newspaper reports indicated that 145 workers on the oil platforms were treated for dermatitis (Fig. 3) at the company's medical facility and fishing activities ceased for one week (Kissoon 2005).

For the second invasion, the offshore oil platforms in the four fields were closed for two days; however, this was primarily due to the invasion of the base operations of Petrotrin Trinmar Operations and Atlantic LNG Limited (Danny-Maharaj 2005). Several businesses and schools, including Cedros Government Primary, Cedros Anglican Primary, Cedros Composite and Lochmaben Roman Catholic, were also closed (Danny-Maharaj 2005). Data collected from the Cedros/Icacos Health Centre indicated that 191 residents were treated for dermatitis while there was one reported case of eye irritation.

Fig. 3. Dermatitis resulting from hairs of *Hylesia metabus* on resident of Icacos Village, Cedros, 9 July, 2005. Trinidad Express.

Offshore operations at Petrotrin Trinmar Operations were again temporarily closed during the third and fourth invasions. Schools, including Cedros Composite, Cedros Government and Cedros Government Primary, were closed (Ragoonath 2006). Data from the Cedros/Icacos Health Centre indicated that 109 residents in the affected areas were treated for dermatitis. The fourth invasion was limited and had little social or economic impact. Data from the Cedros/Icacos Health Centre indicated that only 12 residents in the affected areas required treatment for dermatitis.

The change from fluorescent lights to low pressure sodium lighting on the offshore oil platforms in Trinidad after the second invasion (Hosein 2006) may have been responsible for the reduced incidence of moths on oil platforms in subsequent invasions. The use of light traps in Petrotrin Trinmar Operations during the second and third invasion as a mitigation measure was considered ineffective (Hosein 2006) and was discontinued by the time of the fourth invasion. This may be due to the fact that the flight to light behaviour of moths is only effective over small distances, for example, a 125 watt mercury vapour fluorescent bulb is only estimated to attract moths over a 3 m radius (Frank 1988).

Museum records

Adult moths collected at the time of the first invasion in Trinidad were identified as *H. metabus* by F. Osborn of the Instituto de Investigaciones en Biomedicina y Ciencias Aplicadas, Venezuela. Caterpillars collected after the invasions were reared on leaves of *P. guajava* and the adult moths were confirmed as *H. metabus* by the second author, based on comparison with museum collections and Lemaire (2002).

Based on the catalogue of moths of Trinidad (Kaye and Lamont 1927) and its supplement (Lamont and Callan 1950), *H. metabus* is not a known Trinidadian species. Similarly, it is not recorded from Trinidad by Lemaire (2002) in his authoritative work on the Hemileucinae. Hence, there was concern that this was an invasion by an alien species that could become established in Trinidad, with probable ecological, economic and social impacts. However, other *Hylesia* spp. do occur in Trinidad, and this is a genus that includes many similar grey species with indistinct markings (Lemaire 2002), at least four of which occur in Trinidad (M.J.W. Cock unpublished), so the earlier records merit re-evaluation.

Kaye and Lamont (1927) recorded *Hylesia inficita* (Walker) (as *Batataria inficita*), based on specimens collected at "Palmiste, April, 1913; Guaico, 18 April, 1915; San Fernando, Jan., 1922 (N.L.); St. Joseph, March, 1922 (F.W. Jackson)." N.L. refers to Sir Norman Lamont, whose collection is now divided between The National Museums of Scotland (Edinburgh) and the University of the West Indies (UWI), St. Augustine, Trinidad and Tobago. F.W. Jackson's moths are mostly in the Natural History Museum (London) and the Hope Entomological Collections (Oxford University Museum). Of these recorded specimens, only one of Lamont's could be located in these collections. Lamont's specimen from Guaico is now in the National

Museums of Scotland, and bears a label from Lamont's collection *"Batataria inficita"*; it is a male *H. metabus*. However, Lamont's collection in UWI includes four specimens curated by Lamont as *Batataria inficita*; they are male specimens of *H. metabus* collected at Palmiste between 1934 and 1948. There seems little doubt, therefore, that the species reported from Trinidad as *H. inficita* by Kaye and Lamont (1927) is actually *H. metabus*.

Laurence (1973) records "*Hylesia* sp. (probably *canitia* Stoll.)" as a leaf feeder on guava collected at Centeno, Trinidad, and notes that "specimens of these insects will be deposited in the insect museum of the University of the West Indies, St. Augustine." There are two un-named and undated specimens of *Hylesia* added to Lamont's collection in UWI, which were reared on guava at Centeno by "G. Lawrence". Despite the mis-spelling of Laurence, and the lack of an identification label, these are almost certainly the specimens on which Laurence based his record. The specimens are female *H. metabus*.

Additional specimens of *H. metabus* in the collections mentioned above and those of CABI (Curepe, Trinidad) and M.J.W. Cock (Switzerland) are from Arima Valley, Brigand Hill, Centeno (larva on citrus, E.J. Rankin), near Chatham, Cumaca Road, Erin, Inniss Field, Morne Bleu Textel Installation, Parrylands Oilfield, Caigual (near Sangre Grande), St. Benedict's, and Valencia Forest.

Discussion

Alien or indigenous species?

Alien species are a cause for concern, as many have become invasive in natural ecosystems, and others have affected human livelihoods, through agriculture, forestry, trade and human health (Wittenberg and Cock 2001). Reports of the establishment of alien species are often met with great public concern, and in recent years several economically important species have become established in Trinidad: pink hibiscus mealybug, *Maconellicoccus hirsutus* (Green) (August, 1995), black sikatoga disease of bananas, *Mycosphaerella fijiensis* Morelet (October, 2003), red palm mite, *Raoiella indica* Hirst (March, 2006), and coconut moth, *Batrachedra nuciferae* Hodges (April, 2006) (McComie 2006). Hence, public concern over the invasiveness of an apparently alien species, with the potential to affect human health, economic plants and mangrove swamps, was significant.

Through a review of existing collections, we concluded that *H. metabus* was misidentified from Trinidad as *H. inficita* (Kaye and Lamont 1927) and *H.* sp. probably *canitia* (Laurence 1973), and it is an indigenous, common and widespread species in Trinidad, with specimens dating back to 1915 and therefore not an alien invasive species. The importance of taxonomy and maintaining collections is thus demonstrated, even for a family of such large and well studied moths as the Saturniidae.

Trinidad or Venezuelan origin?

Two options should be considered for the origin of these invasions: Trinidad or Venezuela. Trinidad has no previously recorded history of outbreaks of *H. metabus*, although MJWC recalls at least one occasion when adult moths were the commonest species at the lights of the Morne Bleu Textel Installation in 1978 or 1979. There are no recorded outbreaks in Trinidad mangroves. No encounters have been described by a long standing tour operator in the Caroni Swamp (W. Nanan, pers. comm.) nor have there been reports from Nariva Swamp during the period that the Trinidad Regional Virus Laboratory operated at Bush Bush Island. However, in support of the case for local origin, large moths would have difficulty in crossing the distance over sea between Trinidad and Tobago. Saturniidae are generally considered to be sedentary moths, with no migratory tendencies and poor colonizers. Even amongst the Saturniidae, *Hylesia* spp. are noteworthy as appearing to be weak fliers. For example, Janzen (1984) reports that female *H. lineata* are very reluctant to fly, but will do so. *Hylesia metabus* emerges with its full complement of eggs (200-300) fully formed, has a very high body mass to wing area ratio (Dudley 2000) and is one of the least flight efficient moths. While male *H. metabus* come readily to lights, females are almost never attracted to light (M.J.W. Cock unpublished), except in outbreak conditions. Therefore, extrapolating from other *Hylesia* spp., females mate, fly at most a short distance to find a suitable site for oviposition and then lay all their eggs.

We are more inclined to support the hypothesis that the moth invasions were from Venezuela. Venezuela has a long history of outbreaks. More importantly, a large food supply would be required to sustain a population of moths capable of achieving severe outbreak conditions. The seven main plant species in wetlands of Venezuela and Trinidad are the same: *R. mangle, R. x harissonii, A. germinans, A. schaueriana* Stapf & Leechm. ex Moldenke, *L. racemosa* and *C. erectus* (Bacon 1993, Conde and Alarcón 1993) and these include the main hostplants of *H. metabus*. However, the main island of Trinidad has only slightly more than 7000 ha of mangrove in 36 locations (Fig. 4) with the largest in the south-west being Los Blanquizales (840 ha).

In contrast, the total area of mangrove in Venezuela is approximately 650,000 ha and the three largest expanses are Orinoco Delta, Delta Amacurio, (46, 802 ha), Gulf of Paria, Sucre (45,150 ha) and San Juan River, Monagas (41, 314 ha) (Conde and Alarćon 1993) which are all in northeastern Venezuela, not far from Trinidad. Fornés and

Hernández (2001) reported migration of *H. metabus* in 1999 from the Venezuelan states of Monagas and Delta Amacurio to mangroves on the coast of Paria. Information on emerging adult populations from Paria in Venezuela by the Instituto de Investigaciones en Biomedicina y Ciencias Aplicadas also corresponded with invasions observed in Trinidad.

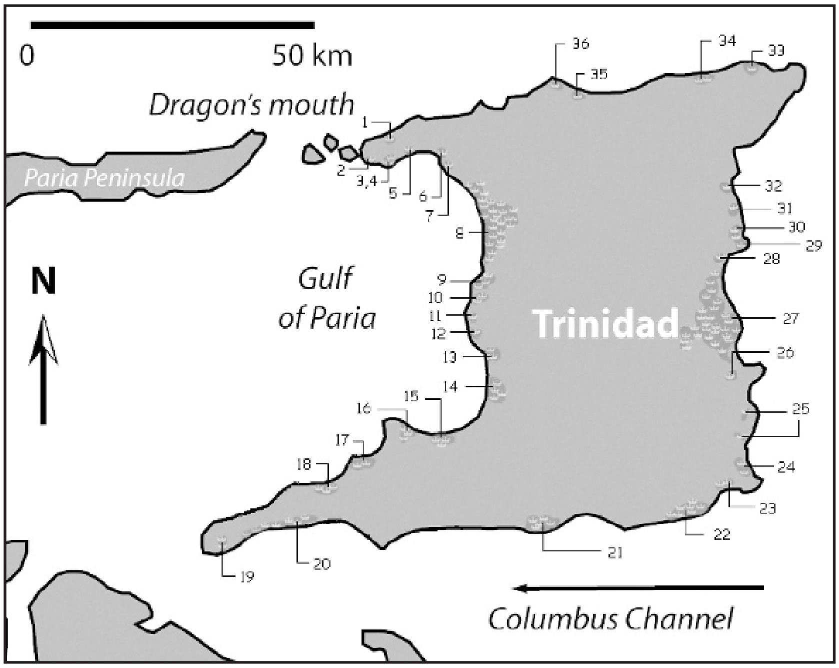


Fig. 4. Wetlands of Trinidad redrawn from Bacon (1993).

Key to localities: 1. Scotland Bay; 2. Chaguaramas Bay; 3. Hart's Cut; 4. Cuesto River; 5. Bayshore; 6. Mucurapo; 7. Sealots; 8. Caroni Swamp; 9. Waterloo; 10. Orange Valley; 11. Couva River; 12. Pt. Lisas Bay; 13. Claxton Bay; 14. Marabella; 15. Godineau; 16. Rousillac Swamp; 17. Point Fortin; 18. Irois Bay; 19. Icacos; 20. Los Blanquizales; 21. Moruga River; 22. Rustville; 23. Guayaguayare; 24. Mouville; 25. Mayaro Bay; 26. Ortoire River; 27. Nariva/ Cocos Bay; 28. L'Ebranche River; 29. North Manzanilla; 30. Manzanilla Windbelt; 31. North Oropouche; 32. Matura River; 33. San Souci; 34. Grande Riviere; 35. Marianne River; 36. Yarra River.

The mass movement of *H. metabus* from Venezuela to Trinidad is not normal. We suggest that there must have been a mass emergence of moths in Venezuelan mangroves (possibly the San Juan River), a change in behaviour causing the adults to fly for an extended period, a wind pattern to bring them to Trinidad and the presence of lights to attract moths in the sequence observed. This is not inconsistent with the definitions of adaptive dispersal or migration established by Johnson (1969). The moths fly from their habitat and are carried on the wind for a "sufficiently prolonged and undistracted" flight to enable at least some of the moths to reach new suitable breeding sites.

If moths emerge in an area with a plentiful supply of food plants, there is little adaptive advantage to dispersing, perhaps to areas where there are no food plants. Certainly, Janzen (1984) observed only short flights by the females of *H. lineata*. In an outbreak situation, the feeding of the gregarious caterpillars cause extensive defoliation of the mangrove food plants, so that final instar caterpillars could be forced to pupate without having been able to feed to complete maturity. This stimulus could trigger a physiological change (Angelo and Slansky 1984) or behaviour change in the emerging moths to fly for an extended time, thus facilitating their dispersal on the wind with the possibility of finding new breeding sites, where the food plants are in better condition and not recently defoliated. If this were correct, it is possible that the moths of the invasion would be smaller and with smaller egg complements than normal non-outbreak populations. Unfortunately, no observations were made to test this possibility, but in any future invasion, the size, weight and egg complement of females should be measured and compared with normal populations.

If enormous numbers of moths emerge, and a proportion of these inadvertently fly out over the sea at night, then they have no option but to keep flying until they fall into the sea, or encounter land again. With no lights to initially guide them, it can be assumed they will fly at random and be carried with the wind until they perish or eventually make landfall again.

Unusual wind patterns were recorded by the Trinidad and Tobago Meteorological Office off the south-west of Trinidad a few days before the passing of Tropical Storm Emily on 7 July, 2005 and this may have assisted in the first invasion (Hosein 2006). The presence of mercury vapour fluorescent lights on offshore oil platforms in the Gulf of Paria dates back to the 1960s or 1970s (Hosein 2006) and may have also acted as an attractant resulting in their dispersion to the other oil facilities prior to making landfall and affecting villages on the northern side of the southern peninsular.

The ability of *H. metabus* to oviposit immediately upon arrival in a new breeding ground offers selective advantage (Rankin and Burchsted 1992), which may at least partially compensate for the high cost of maintaining an extended flight, and the risk of high mortality when flying over water. In the second part of the fourth invasion on 10 May, 2006, where the southeastern villages were affected was unusual and may represent just a greater spread of Venezuelan moths or possibly a F1 generation of the Venezuelan moths which may have established in local mangroves.

Davis and Thompson (2000) developed a nomenclature scheme based on dispersal distance (short or long), origin of colonizers (novel or common) and impact on the new environment (small or great) in order to clarify communication in the field of invasion ecology. In this scheme, in the context of its flight capability, *H. metabus* travelled a long distance (many times its normal dispersal distance) between two environments separated by the sea. It can be considered common to the new regions since there is no species range expansion. Although this mass arrival had immediate social and economic impacts, ecological impacts were limited. Hence, based on Davis and Thompson (2000) classification, this would be a type 5 colonizer (long distance, present in region, small environmental impact) and not an alien invasive species.

Recommendations

Although *H. metabus* invasions into Trinidad have ceased since 2006, outbreaks continue to occur in South America with the most recent being reported in French Guiana in August, 2007 (Renner, pers. comm.). If invasions into Trinidad resume and become commonplace, a range of management options may be considered.

Early warning system

Liaising with Venezuelan authorities to know when moths become adults, and in what numbers, can assist in defining an "at risk" period for Trinidad. This can ensure that the local authorities put in place measures to minimize impacts on the community.

Light management

The conversion of mercury vapour fluorescent light and metal halide streetlights to low pressure sodium has reduced flight to streetlights in many urban areas (Frank 1988) and this is likely to be the most effective strategy to reduce the impacts of *H. metabus* on communities. In Trinidad, high pressure sodium streetlights are being used and some parks are lit by large metal halide lighting which may be an attractant for *H. metabus* within communities. Changing to light frequencies that are less attractive to moths would have the added advantage of reducing the general impact on the indigenous moth fauna.

In Venezuela, light traps are used for both quantitative assessments of adult moth populations and to intercept moths before they reach communities. However, the efficacy of this strategy to control moth populations is debatable; as Frank (1988) states that the use of light trapping has not been effective even in small islands. As mentioned, this was also proven to be unsuccessful against *H. metabus* in Trinidad (Hosein 2006).

Chemical control

The use of water with detergent was adequate to kill caterpillars of *H. metabus* in residential areas in Trinidad and Venezuela. The use of chemical insecticides to control populations in mangroves and forest is not recommended due to the ecological sensitivity of these areas. Furthermore, chemical pesticides may affect predator and parasitoid populations which may subsequently result in larger local populations. Given the short longevity of the adults, those adults that do manage to cross will die within days and the insect control activities within the communities such as ULV fogging with malathion are likely to have a limited impact on the population. Diverting moths from residences is more practical than chemical control.

Classical biological control

Careful studies on local predators and parasitoids would be required in order to determine the local natural enemy complex for *Hylesia* spp. Introduction of non-resident parasitoids or predators should only be considered if outbreaks became routine and there were no or few natural enemies present in local ecosystems. Even then, the risk of impact on non-target Saturniidae is significant and would need careful evaluation.

Biological pesticides

Bacillus thuringiensis is widely used for the control of Lepidoptera pests sometimes including those in forest ecosystems (Nowak *et al*. 2000, Rosenberg and Weslien 2005). Control measures for *H. metabus* in Venezuela focus on the spraying of forest and mangroves with a commercial formulation of *Bacillus thuringiensis* var *kurstaki* (Dipel™) (Osborn *et al*. 2002). Although this method has been effective, preliminary data suggest that it has also reduced the populations of non-target Lepidoptera (Herrera *et al*. 2005).

In order to reduce non-target effects, development of a biological pesticide from organisms naturally infecting *H. metabus* is an option as pathogens isolated from a host are likely to be more pathogenic to the host than other non-targets under field conditions (Goettel *et al*. 1990). Other potential organisms which have been isolated from *H. metabus* which might have potential for development into biological pesticides include fungi, bacteria and a microsporidian (Gajardo *et al*. 2005, Vassal *et al*. 1993, Osborn *et al*. 2002). The nuclear polyhedrosis viral disease reported to be involved in ending outbreaks in French Guiana (Silvain and Vassal 1991) might also be considered.

Apart from changing the type of light source in affected locations and simple control options for caterpillar groups, these are all longer term options, which would require evidence of an established threat to Trinidad ecosystems, to justify investment to evaluate their potential.

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