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Dynamis borassi (Coleoptera: Curculionidae), a new potential pest to the palms (Arecaceae): an early warning for the palm producers

Jackeline Gaviria^{1,*}, James Montoya-Lerma², Inge Armbrecht², Bernhard Löhr¹, and Aymer Andrés Vásquez-Ordóñez²

Abstract

Emergent and potentially invasive weevils are a permanent threat to the survival of palm plantations. Hence, understanding the role of emergent pests may be key for preventing future phytosanitary emergencies. In the present study, the role of *Rhynchophorus palmarum* L. and *Dynamis borassi* F. (both Coleoptera: Curculionidae) as main causative agents of the peach palm (*Bactris gasipaes* Kunth; Arecaceae) crown toppling problem were investigated, and the damage was described in 36 farms in the principal production areas of Colombia. A management strategy with the use of 2 pheromones (Rhynchophorol and Ferrolure) in 2 production areas also was evaluated. In total, 4,098 palms were examined from Nov 2017 to Feb 2019. Visible damage oscillated between 0 to 70% of palms affected and was highest on the Pacific coast. Larvae of *D. borassi* were found exclusively in the inflorescences suggesting that it initiates the damage. Meanwhile, adults of *D. borassi* and all stages of *R. palmarum* were recovered from stem damages. Also, new reports of damage were confirmed at the southern Pacific coast, the Andes, and the Amazon region. A total of 8,239 *D. borassi* and 2,886 *R. palmarum* were captured in pheromone traps for 14 mo on the Pacific coast. The traps baited with Ferrolure + Rhynchophorol captured a greater number of *D. borassi* specimens. The data strongly confirm the central role of *D. borassi* in peach palm damage. Therefore, it is recommended strongly that pheromones be used to prevent further spread of this pest in other countries of this region and to protect palm industries.

Key Words: American palm weevil; economic damage; pheromone traps; Neotropical palm weevil

Resumen

Los picudos emergentes y potencialmente invasivos son una amenaza constante para la supervivencia de las plantaciones de palmas. Por lo tanto, el comprender el papel de las plagas emergentes puede ser clave para prevenir futuras emergencias fitosanitarias. En el presente estudio se investigó el papel de *Rhynchophorus palmarum* L. y *Dynamis borassi* F. (ambos Coleoptera: Curculionidae) como principales causantes del problema de derribo de la corona de la palma de chontaduro (*Bactris gasipaes* Kunth; Arecaceae) y se describieron los daños en 36 fincas de las principales zonas de producción de Colombia. Además, se evaluó una estrategia de manejo con el uso de dos feromonas (Rhynchophorol y Ferrolure) en dos zonas de producción. En total, se examinaron 4,098 palmas entre noviembre de 2017 y febrero de 2019. Los daños visibles oscilaron entre el 0 a 70% de las palmas afectadas y fueron mayores en la costa del Pacífico. Las larvas de *D. borassi* se encontraron exclusivamente en las inflorescencias, lo que sugiere que es la causa del daño. Mientras tanto, los adultos de *D. borassi* y todos los estadios de *R. palmarum* se recuperaron de daños en los tallos. Se confirmaron nuevos reportes de presencia y daños en las regiones de la costa sur del Pacífico, los Andes, y del Amazonas. Un total de 8,239 *D. borassi* y 2,886 *R. palmarum* fueron capturados en trampas de feromonas durante 14 meses en la costa del Pacífico. Las trampas cebadas con Ferrolure + Rhynchophorol capturaron un mayor número de especímenes de *D. borassi*. Los datos confirman firmemente el papel central de *D. borassi* en el daño de las palmas del chontaduro. Se recomienda el uso de feromonas como una intervención temprana para prevenir la distribución de esta plaga a otros países de la región y proteger así las diferentes industrias asociadas a las palmas.

Palabras Claves: picudo americano de las palmas; daño económico; trampas de feromonas; picudo de las palmeras neotropicales

Palms represent one of the largest families of commercially important plants of the tropics and subtropics. Species such as coconut, *Cocos nucifera* L., African oil palm, *Elaeis guineensis* Jacquin, and date palm, *Phoenix dactylifera* L. (Arecaceae) are cultivated widely (Howard et al. 2001). Other palm species of regional or local importance have great potential for development due to their food and ornamental products. However, over the past few decades, an increasing number

of serious pests have been threatening palm production and international commerce. Two examples where exotic palm pests have become serious economic problems are the red palm weevil, *Rhynchophorus ferrugineus* F. (Coleoptera: Curculionidae) (Fiaboe et al. 2012), and the red coconut mite, *Raoiella indica* Hirst (Acari: Tenuipalpidae) (Amaro & de Moraes 2013), both of which have shown the ability to adapt to new host species and produce heavy damage (Faleiro et al. 2016;

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Milosavljević et al. 2019). Palm pests in their native range also may become a serious economic problem, such as the case of *Rhynchophorus palmarum* L. (Coleoptera: Curculionidae). This species has been shown to have high potential for invasiveness (Giblin-Davis et al. 2013) and the ability to adapt to new host species (Milosavljević et al. 2019, 2020a). This has been confirmed by recent reports of expansion into southern California and northwestern Mexico (García-Hernández et al. 2003; Aguilar 2017; Hoddle et al. 2020). Early alerts on such potentially serious invasive pests constitutes valuable information to prevent their spread, and to limit damage to other palm cultivation (Howard et al. 2001).

Dynamis borassi F. (Coleoptera: Curculionidae) is a native South America palm weevil of wide distribution that has been reported in the past principally on native, non-commercial palm species, mainly of the genera *Oenocarpus* (Couturier et al. 2000; Bautista-Giraldo et al. 2020) and *Astrocaryum* (both *Arecaceae*) (Couturier et al. 1998). However, here we present evidence of a host range expansion of this serious pest to peach palm, *Bactris gasipaes* Kunth (*Araceae*), the only domesticated native palm species of South America (Clement et al. 2010), widely used by indigenous and African-American populations in the humid tropical lowlands of the Amazon and Pacific coast for subsistence and local commerce (Mora-Urpí et al. 1997; Graefe et al. 2013).

Recently, in the Colombian Pacific coast area, this crop has been affected by 2 phytosanitary problems which have caused a drastic reduction in production, area, and yield (Agronet 2019). First, fruit abortion due to attack by the weevil *Palmelampus heinrichi* O'Brien & Kovarik (Coleoptera: Curculionidae), which causes losses of up to 100% of the fruits in the principal areas of production (Clement et al. 2004). More recently, the toppling of the crown, locally known as "desnucamiento" (broken neck), has led to a 75% reduction in the country's production (Agronet 2019).

The latter initially was attributed to *R. palmarum*, and a general pest alert was published by the Colombian phytosanitary authority (ICA 2015). However, Pardo-Locarno et al. (2016) and later Vásquez-Ordóñez et al. (2020) associated the problem with the Neotropical palm weevil, *D. borassi*. Both weevil species share similar morphological characteristics that make diagnosis difficult, particularly in the larval stage, where the damage occurs (Vásquez-Ordóñez et al. 2020).

Control measures suggested by the phytosanitary authority integrated mechanical, chemical, and ethological strategies. The last 2 focused on the use of the synthetic aggregation pheromone Rhynchophorol (2-methyl 5-hepten-4-ol), which is specific to *R. palmarum* (Giblin-Davis et al. 2013). However, this did not lead to a recovery of production (B. Löhr, unpublished), probably because *D. borassi* was not covered by the control strategy. A worrisome observation is that *D. borassi* has been reported as a vector of *Bursaphelenchus cocophilus* (Cobb) Baujard (Nematoda: Aphelenchoididae), a nematode causing the lethal disease known as red ring on coconut (Gerber et al. 1990; Giblin-Davis et al. 1997; Claro et al. 2009) and oil palm (Guerrero et al. 1995; Boari et al. 2016). At present, both are crops with huge commercial importance, the latter with great potential for further expansion into Colombia and other countries in Latin America (Mariau 2001; FAO 2009). Hence, *D. borassi* could develop into a considerable problem for the oil palm industry and for other palm species in many countries.

The principal purposes of this study were to: (1) properly identify the causative agent and document the process leading to the toppling of the palm crown; (2) to describe and quantify the extent of damage in the main production areas of Colombia; and (3) to propose a potential control with the use of 2 pheromones (Rhynchophorol and Ferrolure).

Materials and Methods

STUDY SITES

A total of 36 peach palm production sites in the Amazon, Andes, and Pacific regions of Colombia (Fig. 1) were included in this study. These regions are different slightly in altitude, topography, and climate, but it is not our aim to compare them. The Amazon and Pacific regions are at low altitude and of variable topography, but present high levels of precipitation and temperature compared to the Andes (Rangel-CH & Aguilar-P 2011). In the Pacific region, 2 locations were selected for the evaluation of the pheromone traps (Fig. 1). Both sites are accessible and are representative of the environmental conditions of this region; additionally, these were severely affected by crown toppling. In all areas, the peach palms were planted in small agroforestry plots requiring relatively low maintenance costs (low or no external inputs) and associated with other crops, such as plantain (*Musa × paradisiaca* L.; *Musaceae*), coffee (*Coffea arabica* L.; *Rubiaceae*), and cocoa (*Theobroma cacao* L.; *Malvaceae*). Basically, the plots were not intensively managed (except for eventual application of lime, insecticides, and fertilizers).

SAMPLING METHODS

For all sites (Supplementary Material 1), the crops were inspected, and weevil samples were taken. During Mar 2018 to Jul 2018 and Dec 2018 to Feb 2019, a variable area transect was delimited following, with modifications, the method described by Sheil et al. (2002). Specifically, a central transect line of maximum 80 m in length was established according to the size of the inspected field. Four rectangles, 20 m wide (perpendicular to the transect) were marked all along the transect from both the right and left of the central line. The length of each rectangle was determined by measuring the distance from the central line to the sixth palm with signs of damage. When 6 damaged palms were not found, the search was stopped at 50 m (Fig. 2). Healthy and damaged palms present in each rectangle were counted, and the proportion of affected palms was calculated for the entire transect.

DESCRIPTION OF PALM DAMAGE AND WEEVIL INFESTATIONS

In all sites, the types of damage attributable to weevils were described and, for each type, up to 6 palms per site were selected randomly for dissection. The infested palm was cut down after which the internal and external damage was recorded. All adults, pupae, and larvae belonging to any weevil species were collected. Larvae were boiled in water for 5 min (Stehr 1987); adults and larvae were preserved in 96% ethanol. The pupae were kept in 1.5 L multi plastic storage boxes (Home Collection, Cali, Colombia) until adults emerged, which were then stored in 96% ethanol. Both the adults collected from the stems and larvae collected in inflorescences were identified to species level following the keys of Wattanapongsiri (1966), Chamorro (2019), and direct examination of specimens as documented in Vásquez-Ordóñez et al. (2020).

PHEROMONE TRAPPING

The trapping system for both *R. palmarum* and *D. borassi* was established in 2 peach palm production sites, Bajo Calima (3.9536°N, 76.9764°W) and Sabaletas (3.7629°N, 76.9632°W), municipality of Buenaventura, Valle del Cauca, Colombia. During the 14 mo of the sampling period, 3 precipitation variables, i.e., mean daily rainfall, the proportion of d with rain, and maximum rainfall were analyzed. The mean daily rainfall corresponds to the monthly average of rainfall val-

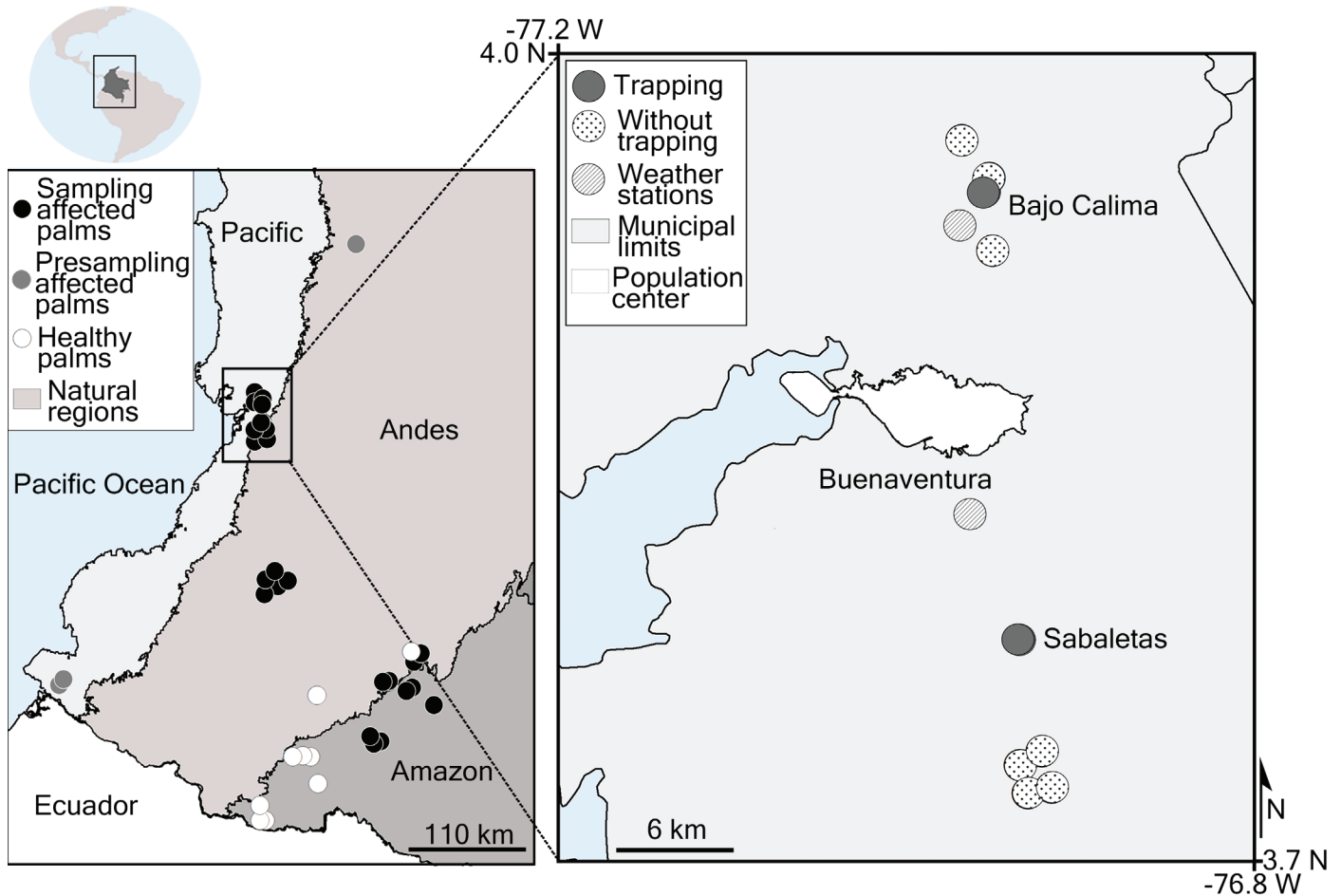


Fig. 1. Geographical location of the 36 peach palm production sites (circles) visited during the survey for palm weevil damage and pheromone trapping.

ues for every d and maximum rainfall at the highest daily rainfall value. This information was obtained from Bajo Calima (3.954°N, 76.990°W) and Buenaventura Airport (3.820°N, 76.992°W) meteorological stations, Valle del Cauca, Colombia (Institute of Hydrology, Meteorology and Environmental Studies, Bogotá, Colombia). Both stations are the closest to the 2 farms where the trapping was conducted.

At each site, 20 pheromone traps as described by Löhr and Parra (2014) were installed, 10 containing 0.5 mL of Rhynchophorol (2 methyl 5 hepten 4 ol, the synthetic aggregation pheromone of *R. palmarum*) (Cenipalma, Bogotá, Colombia) whereas the other 10 traps contained 0.5 mL of Rhynchophorol added with 700 mg of Ferrolure™ (4-methyl-5-nonanol) (Chemtica, San Jose, Costa Rica), the latter being the synthetic aggregation pheromone for *R. ferrugineus* and also for *D. borassi* (Giblin-Davis et al. 1997). As an attractive synergist, 4.5 mL of ethyl acetate was dispensed in each trap from Eppendorf tubes (Merk, Bogotá, Colombia). Freshly cut pineapple peel was used as food bait. To prevent weevil escape from the traps, deltamethrin insecticide $1 \text{ cm}^3 \text{ L}^{-1}$ (C22H-19Br2NO3) (Decis® Bayer, Leverkusen, North Rhine-Westphalia, Germany) was mixed with the food bait. The distance between traps was 120 m, selected due to the high infestation of weevils in the area. All traps were examined at weekly intervals from Sep 2018 to Oct 2019 to change (as necessary) the pheromones, pineapple peels, and addition of ethyl acetate. The captures for each trap were separated into their respective 1.5 L multi plastic storage box (Home Collection, Cali, Colombia), and later were sexed and counted by species (*R. palmarum* or *D. borassi*) according to morphological characteristics (Vásquez-Ordóñez et al. 2020).

The number of inflorescences was recorded monthly (Oct 2018 to Oct 2019) by selecting 3 palms near the position where traps were installed (60 palms for each site). In each review, the number of mature stems per palm and the number of damaged and healthy inflorescences were recorded.

STATISTICAL ANALYSES

A generalized linear mixed model was used to compare the effect of the 2 pheromone treatments on the abundance of the 2 weevil species throughout 14 mo at both sites. The generalized linear mixed model used Poisson error due to the discrete nature of data (counts) and because of the repeated measures throughout time in the same traps. Different models were adjusted according to the interactions among the explained factors with different random effects, and further selecting the best model according to the Akaike's Information Criterion and the Bayesian Information Criterion, and additionally evaluating the possible model overdispersion.

To detect the possible effects of pheromone type, weevil abundance, weevil species, and location of the traps on the average of healthy and damaged inflorescence (calculated from bimonthly data, thus avoiding re-counting of inflorescences), a generalized linear mixed model with different interactions between the factors, as well as tests of structures of different variance (homogeneous or heterogeneous) and a temporal correction was used. The best model was selected by penalized plausibility (Akaike's Information Criterion and Bayesian In-

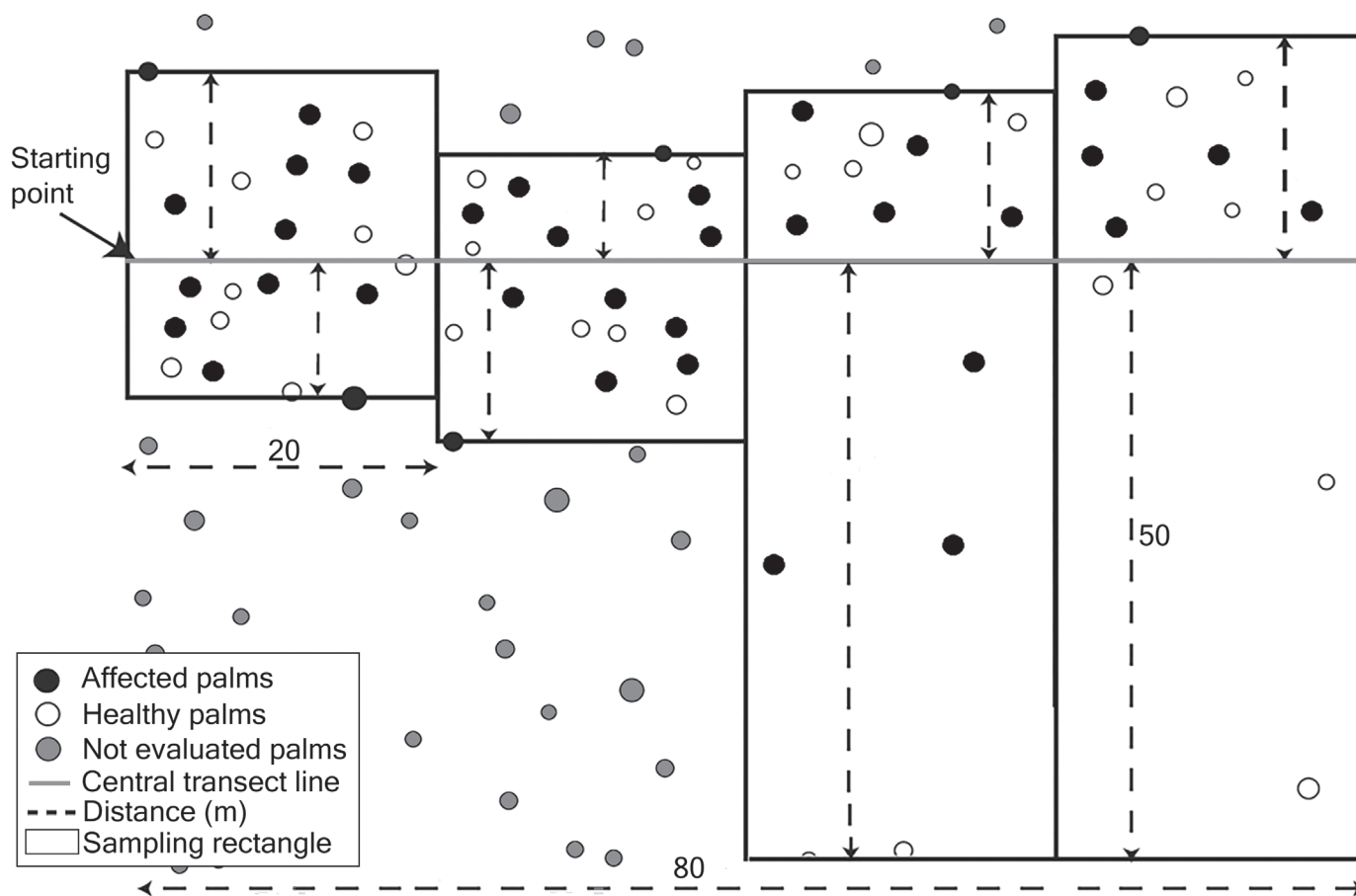


Fig. 2. Variable area transects used in the evaluation of the peach palm infestation by *Dynamis borassi* and *Rhynchophorus palmarum* in 33 production sites in Colombia. The size of each sampling rectangle is determined for the number of affected palms, as illustrated.

formation Criterion) and by plausibility ratio. Due to the absence of data for daily reports in some mo, the mean daily rainfall per mo was used instead of the use of the sum (WMO 2018). Other variables used were the maximum rainfall and the proportion of d with rain. All the statistical analyses were carried out using the free distribution program R version 3.6.2 (R Development Core Team 2019) with a significance level of 5%.

Results

DESCRIPTION OF PALM DAMAGE AND WEEVIL INFESTATIONS

In total, 4,098 peach palms in 36 production sites of the Amazon (Caquetá and Putumayo), Andes (Cauca), and Pacific (Nariño, Risaralda, and Valle del Cauca) region were examined between Nov 2017 and Feb 2019. We identified 4 stages of damage. First, the presence of holes in different parts of unopened inflorescences (also the distal section), where the larva consumes the flowers and rachis (Fig. 3a). Second, holes about 2 cm in diam in the upper part of the palm near the crown at the point of attachment of the inflorescence to the stem (Fig. 3a). Third, the presence of large longitudinal galleries inside the stem in the upper and middle parts of the palm, with elongated or irregular shapes (Fig. 3b, c). Fourth, the presence of a tilted or completely toppled crown palm (Fig. 3d).

The infestation was variable in all sites but always highest in the Pacific region followed by the Andes and Amazon (Figs. 1, 3e; Table 1).

Noteworthy, damage level 4 was higher in the Pacific compared with the other 2 zones. However, damage level 3 was significantly higher in the Amazon area, and 1 and 2 were higher in the Andes (Table 1).

Of the 378 damaged palms, 87 were dissected in 14 farms from all regions. Six samples of inflorescences were taken from 2 sites in Nariño and 1 from Risaralda. A total of 686 weevils in different stages of development were found: 321 in different larval stages, 20 as adults, and 345 as pupae. From these, 30 larvae were identified as *D. borassi* and 291 as *R. palmarum*. Further, 78 adults emerged from pupae, totaling 98 adults (21 *D. borassi* and 77 *R. palmarum*). Larvae of *D. borassi* were found exclusively in the inflorescences. In contrast, adults of *D. borassi* and all stages of *R. palmarum* were recovered from stems.

PHEROMONE TRAPPING

The abundance of weevils captured showed significant differences ($\chi^2 = 1448.99$; $df = 1$; $P < 0.001$) with a total of 8,239 *D. borassi* and 2,886 *R. palmarum* captured during the 14 mo of evaluation (Sep 2018 to Oct 2019) in the 2 production sites of Bajo Calima and Sabaletas. A higher number of weevils was trapped in the Bajo Calima with respect to Sabaletas (Table 2) ($\chi^2 = 5.27$; $df = 1$; $P = 0.022$) (Supplementary Material 2).

Several factors such as the kind of pheromone, climate, and production sites significantly affected the abundance of *D. borassi*, but the kind of pheromone did not affect the abundance of *R. palmarum* (Supplementary Material 3; Table 3). The use of the combined pheromones Ferrolure + Rhynchophorol resulted in a significant effect on the

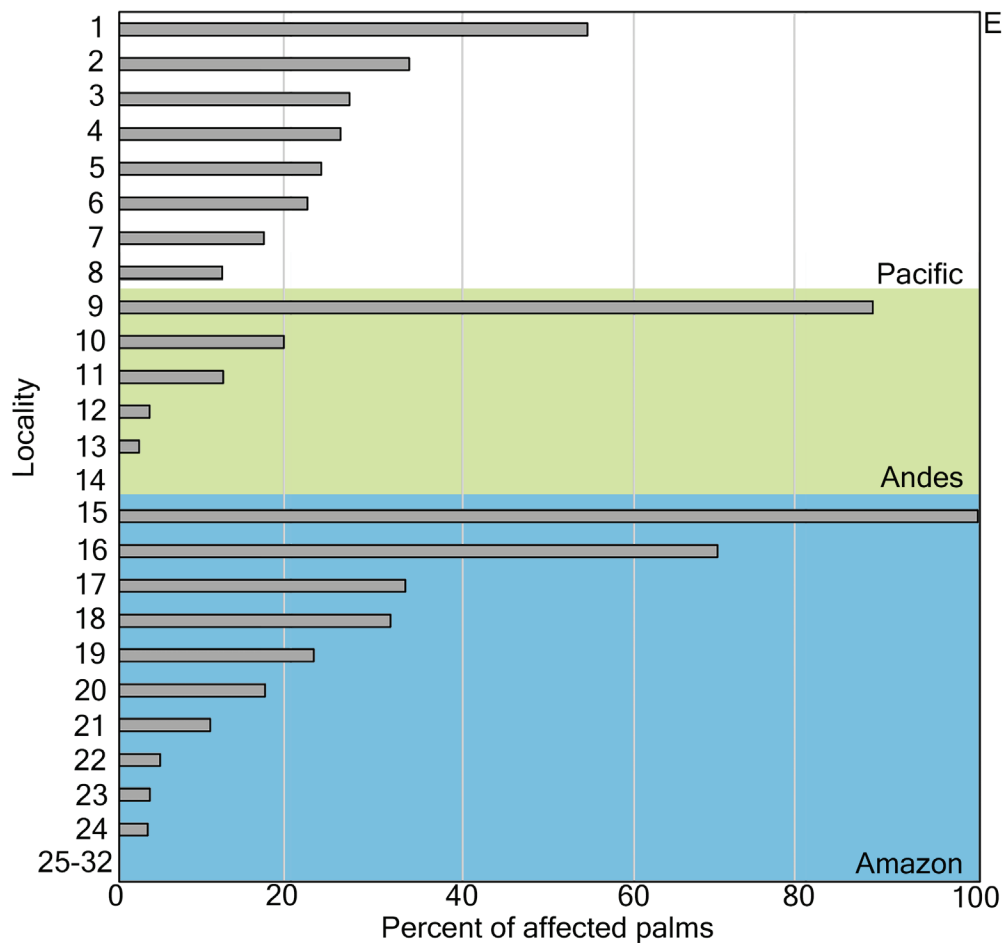
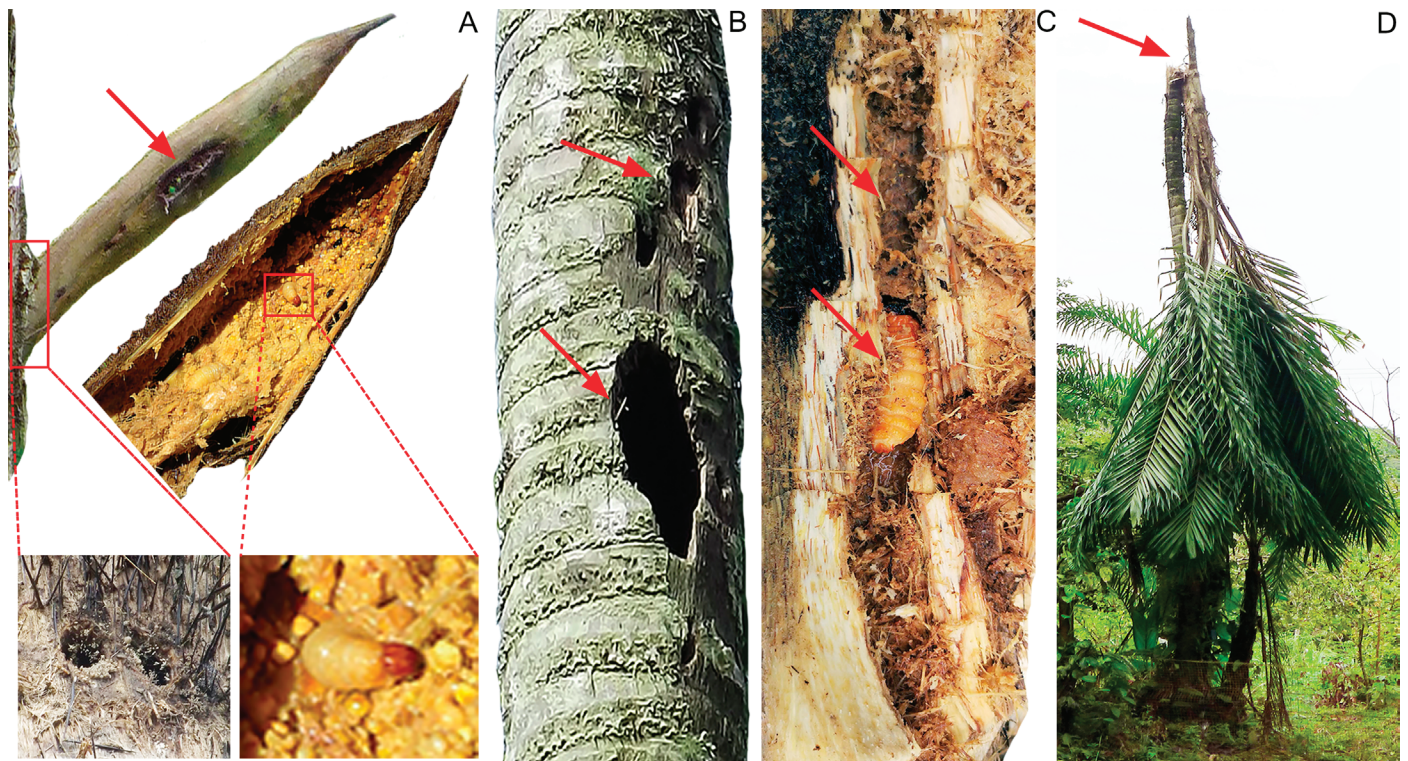


Fig. 3. Types of damages of weevil-damaged peach palms in 32 localities of Colombia. Inflorescence with perforation (arrow), circular hole at the insertion points and weevil larva inside (squares) (a); external view of trunk perforated by larvae, with round perforation exactly at the spot where the inflorescence is attached to the stem (arrow) (b); internal feeding galleries with larvae (arrow) (c); toppled crown (d); percent of affected palms by locality (e).

Table 1. Number of palms examined and affected by attack of *Dynamis borassi* and *Rhynchophorus palmarum* weevils in 3 Colombian regions. Damage was categorized according the physical characteristics.

Region	Number of palms examined	Number of palms affected (%)	Damage type (%)			
			1	2	3	4
Andes	713	83 (11.6)	28 (33.7)	24 (28.9)	13 (15.7)	18 (21.7)
Amazon	2,503	94 (3.8)	1 (1.1)	5 (5.3)	84 (89.4)	4 (4.3)
Pacific	882	201 (22.8)	4 (2.0)	15 (7.5)	130 (64.7)	52 (25.9)
Total	4,098	378 (9.3)	33 (8.7)	44 (11.6)	227 (60.1)	74 (19.6)

capture of *D. borassi* versus the use of the Rhynchophorol pheromone. *Rhynchophorus palmarum* capture numbers, as expected, were not affected by the pheromones (Tables 2, 3). The production site also played an important role in the abundance of *D. borassi*; the capture in Bajo Calima was significantly higher than the capture of this same species at Sabaletas (Table 2). The temporal variability was evident principally during 2019 for *D. borassi*, which had high abundance from Mar to Aug in Bajo Calima and Jan to Apr in Sabaletas (Fig. 4).

Between Oct 2018 and Oct 2019, a total of 291 damaged inflorescences and 110 healthy inflorescences were found in Bajo Calima, and 177 damaged inflorescences and 51 healthy inflorescences in Sabaletas. The highest damage figures were recorded in Feb and Sep of 2019 in Bajo Calima, and a higher value was reported only in Jan of 2019 in Sabaletas (Fig. 4). The best generalized linear mixed model (Akaike's Information Criterion = 109.4; Bayesian Information Criterion = 173.7; Log-likelihood = -39.7) showed a significant effect of the collecting mo, which suggests that the change in the average number of healthy and damaged inflorescences varies throughout the evaluated mo (Supplementary Material 4). On the other hand, a relationship between the average of damaged inflorescences and the total of weevils per mo for *D. borassi* in Sabaletas was found (Spearman = 0.82; df = 6; $P = 0.02$) (Fig. 5; Supplementary Material 5a).

Finally, we detected a clear effect of mo in the response variables. In Sabaletas, the mean daily rainfall and proportion of d with rain was correlated with *D. borassi* abundance (Spearman = -0.86; df = 6; $P = 0.01$; Spearman = -0.77; df = 6; $P = 0.04$, respectively) (Fig. 5e, f; Supplementary Material 5). The proportion of d with rain also was correlated with the average of damaged inflorescences (Spearman = -0.81; df = 6; $P = 0.03$). In Bajo Calima, the mean daily rainfall was correlated significantly with the average number of the total and healthy inflorescences (Spearman = -0.89; df = 6; $P = 0.01$; Spearman = -0.86; df = 6; $P = 0.01$, respectively) (Fig. 5c).

Discussion

The toppling of the crown appeared as a new problem in peach palm production around 2010 in the Pacific lowland of Colombia. The

initial diagnosis attributed the damage solely to *R. palmarum*. However, the fact that crown toppling damage always was associated with dead or aborted developing inflorescences and with the migration of larvae through the stalk of the inflorescence to the stem of the palm (damage not typical for *R. palmarum*) suggested the presence of an additional species. This type of attack (reported in this study) in the palm inflorescence also has been documented for *D. borassi* in other native palms (Couturier et al. 2000; Beserra et al. 2006; Bautista-Giraldo et al. 2020). *Dynamis borassi* larvae were the only species collected inside inflorescences during our studies, whereas *R. palmarum* larvae were found exclusively within the stems. This confirms the idea that the latter species is opportunistic, as observed previously by Alpizar et al. (2002), and likely uses the damage caused by *D. borassi* as its entry point. It is likely that the joint attack of these 2 weevil species causes extensive structural damage until the crown of the palm finally drops (Pardo-Lorcana et al. 2016; Vásquez-Ordóñez et al. 2020). Early symptoms are negligible and quite difficult to detect. This may explain why the extensive and costly control efforts directed at *R. palmarum* did not contain the problem, and over time more and more areas in Colombia have been affected negatively.

Although both weevils are sympatric and have been around for yr, the known host range for *R. palmarum* is wider significantly than that for *D. borassi* (EPPO 2005; Bautista-Giraldo et al. 2020; Vásquez-Ordóñez et al. 2020). This makes the latter more vulnerable to changes in the environment, especially deforestation or selective harvesting of its host palms, and may have triggered a change in its host selection and acceptance behavior. Therefore, a former economically unimportant species may be developing into a potential key pest for palms. The problem may become more widespread if *D. borassi* is reported in oil palm (Guerrero et al. 1995; Boari et al. 2016), for which Colombia is one of the main world producers (Potter 2020).

In the present study, the Pacific was the region that presented damage in all sampled localities. This situation may be a consequence of the continuous weevil attacks reported since 2010 (ICA 2015; Pardo-Lorcana et al. 2016).

As the traps baited with Ferrolure + Rhynchophorol captured a greater number of *D. borassi* specimens, it is evident that there is no significant repellency or inhibition effect when these semiochemicals

Table 2. Number of males and females of *Rhynchophorus palmarum* and *Dynamis borassi* captured in 2 peach palm production sites, Bajo Calima and Sabaletas, municipality of Buenaventura, Valle del Cauca, Colombia, during a 14 mo period, using 2 aggregation pheromones (Ferrolure and Rhynchophorol).

Locality	Pheromone	<i>Dynamis borassi</i>		<i>Rhynchophorus palmarum</i>		Total
		males	females	males	females	
Sabaletas	Ferrolure + Rhynchophorol	524	690	385	445	2,044
	Rhynchophorol	252	333	328	432	1,345
Bajo Calima	Ferrolure + Rhynchophorol	1722	2,062	236	449	4,469
	Rhynchophorol	1247	1,409	220	391	3,267
	Total	3,745	4,494	1,169	1,717	11,125

Table 3. Analysis of variance of the best mixed generalized linear model of relationship between *Dynamis borassi* and *Rhynchophorus palmarum* abundances in traps with respect to pheromones, sampling mo, and locality. Details of selection of model in Supplementary Material 3.

	<i>Dynamis borassi</i> (NPW)			<i>Rhynchophorus palmarum</i> (APW)		
	χ^2	DF	P-value	χ^2	DF	P-value
Pheromone	4.196	1	0.04052	0.54	1	0.4634
Mo	623.32	13	< 2.2e-16	82.13	13	4.4E-12
Sites	15.34	1	9.0E-05	20.14	1	7.2E-06
Pheromone: mo	97.0564	13	6.16E-15	45.64	13	1.6E-05
Pheromone: sites	0.02	1	0.8834	2.82	1	0.0934
Mo: sites	417.18	13	< 2.2e-16	61.59	13	2.7E-08
Pheromone: mo: sites	41.0255	13	9.44E-05	19.59	13	0.1059

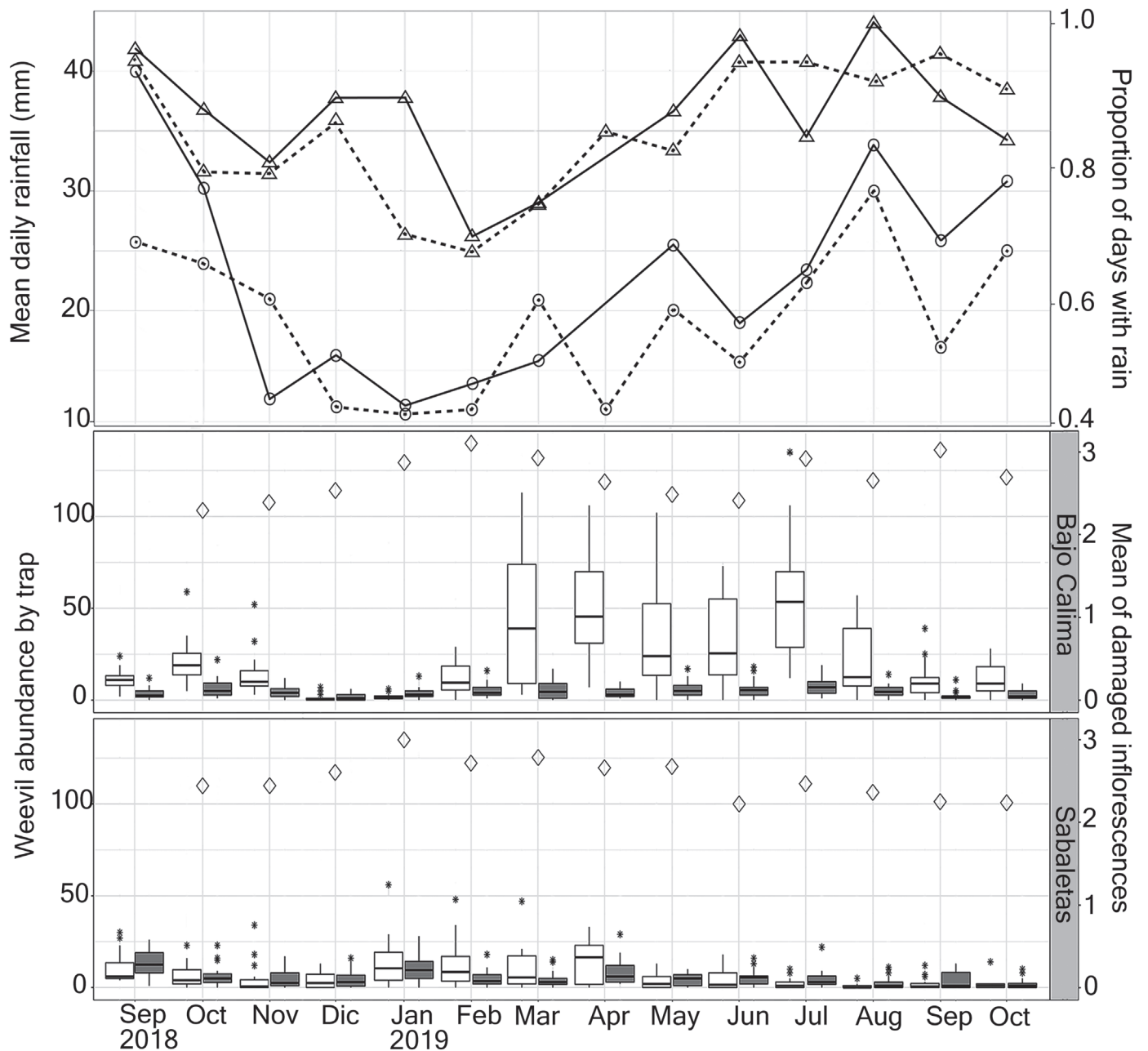


Fig. 4. Precipitation, weevil abundance, and mean of damaged inflorescences between Sep 2018 and Oct 2019. The precipitations (top panel) corresponding to mean daily rainfall (circle) and proportion of d with rain (triangles) were documented for Bajo Calima (solid line) and Sabaletas (dashed line). The abundance was represented with whiskers diagram for *Dynamis borassi* (white boxes) and *Rhynchophorus palmarum* (gray boxes). The asterisks are outliers. The damaged inflorescences were reported with rhombus.

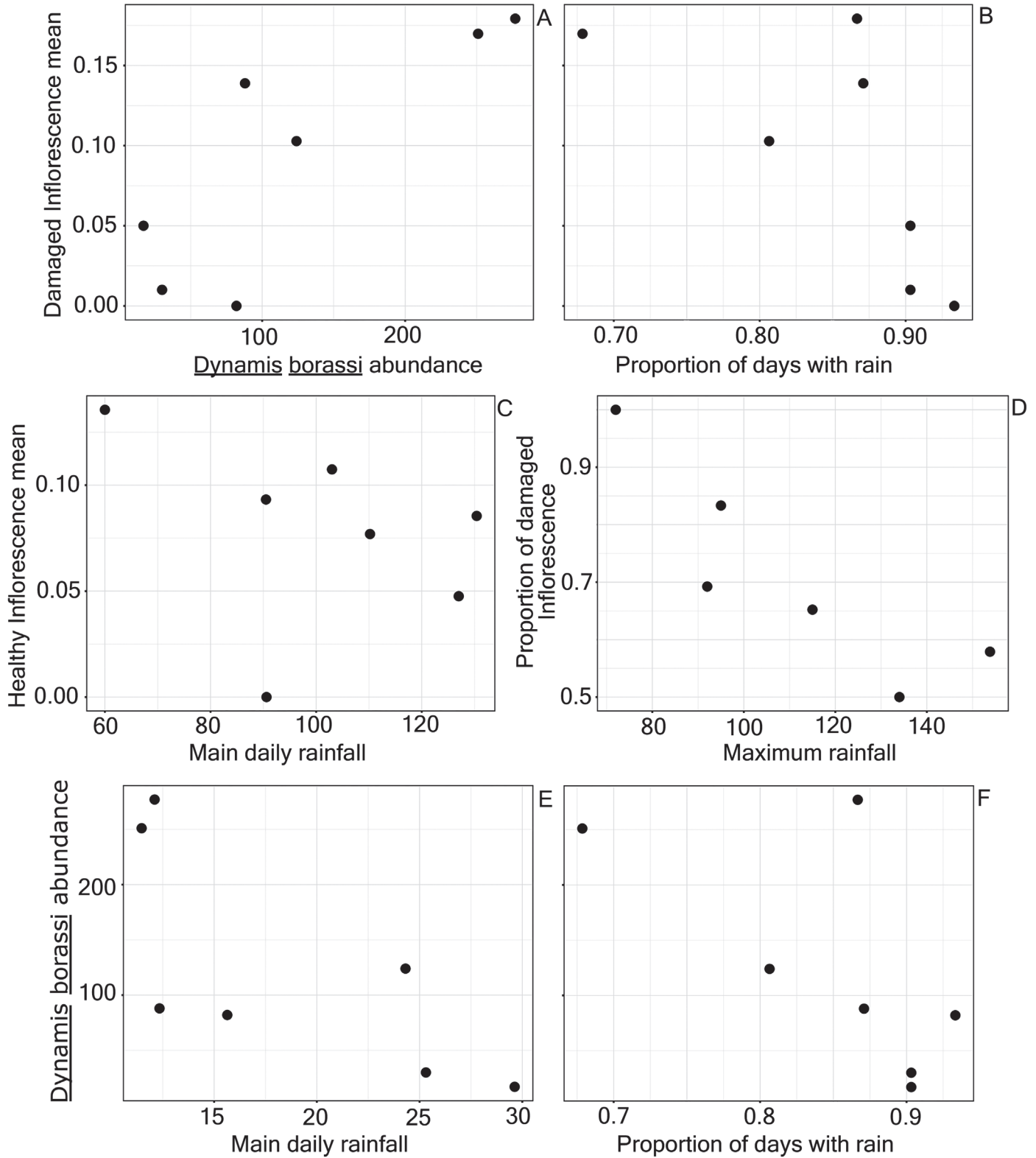


Fig. 5. Relationship between damaged inflorescence average with respect to the *Dynamis borassi* abundance (A) and proportion of d with rain (B); the proportion of healthy and main daily rainfall (C) damaged inflorescences; proportion of damaged inflorescence and maximum rainfall (D); the *D. borassi* abundance with respect main daily rainfall (E) and proportion of d with rain (F). Data was obtained in Sabaletas (A, B, D–F) and Bajo Calima (C), Valle del Cauca, Colombia.

are combined; similar results were reported by Milosavljević et al. (2019). This may represent a useful tool for pest control in palm plantations (Giblin-Davis et al. 1997). Ferrolure (4-methyl-5-nonanol) is a pheromone specific to the capture of *D. borassi*; however, Giblin-Davis

et al. (1997) and Rochat et al. (2000) also found attraction of this species to the specific pheromone for *R. palmarum*, i.e., Rhynchophorol (6-methyl-2-hepten-4-ol). Pineapple peel used as food bait in this work also could have played an important role in the number of catches,

as suggested by Rochat et al. (2000). The effectiveness of this bait to attract large numbers of weevils on its own also have been observed in other studies (Wahizatul & Haris-Hussain 2014; Murguía-González et al. 2018). The use of different types of traps and other food baits may render better results (Abdel-Azim et al. 2017; Milosavljević et al. 2020a, b); however, this specific subject was not our purpose.

The differential response in the abundance of weevils and damaged inflorescences in Bajo Calima and Sabaletas demonstrates that there are local particularities in different localities despite their proximity (24.3 km), even with similarity in the evaluated precipitation variables (Fig. 1). The larger *D. borassi* catch in Bajo Calima should be related to the landscape component of the area: *D. borassi* has been reported in native palms such as “naidi” (*Euterpe oleracea* Mart), “guérregue” (*Astrocaryum standleyanum* L. H. Bailey), but principally associated with “milpesos” (*Oenocarpus bataua* Mart) (all Areaceae) (Couturier et al. 2000), a palm species widely distributed in the Bajo Calima landscape (Bautista-Giraldo et al. 2020).

As expected, damage to inflorescence was correlated significantly with the abundance of *D. borassi*, corroborating the fact that this species initiates damage to the palm with an attack on the inflorescence, as indicated above. This factor must be considered when planning pest control campaigns in peach palm, i.e., whenever increases in *D. borassi* numbers are detected on time and taken care of, further damage by both weevils can be prevented.

For both species, the capture of females always was higher than that of males. This result coincides with that reported by several authors (Ramírez et al. 2000; Ferreira et al. 2003; Sumano et al. 2012; Moya-Murillo et al. 2015; Milosavljević et al. 2020a), who obtained a higher capture of females in traps baited with aggregation pheromone. According to Sánchez et al. (1993), the biotic potential or fertility of a female of *R. palmarum* is high with an oviposition capacity between 697 and 924 eggs throughout her life. A study on the life cycle of *D. borassi* showed that a female can lay hundreds of eggs (around 300 per female in laboratory conditions), and it takes about 201 d to develop to the adult stage (Cuéllar-Palacios et al. 2020). We suggest that an efficient management strategy for *D. borassi* in peach palm would be based on an integrated approach. First, it would be essential to determine the areas with low and high infestation levels in order to establish the number of pheromone-baited traps to deploy in each area. It is expected that pheromone-baited traps would reduce populations of both *D. borassi* and *R. palmarum*. This strategy could be complemented by removal of seriously damaged palms to reduce reproduction. In addition, we are studying the possibilities to collect and introduce a tachinid parasitoid from Brazil that may provide durable relief from damage by the palm weevil (Löhr et al. 2019).

In conclusion, the peach palm in Colombia has a new serious weevil pest that causes considerable economic losses and attacks other palms. The relatively recent appearance of this problem on the southern Pacific coast of Colombia, the invasion of an inter-Andean area during our study (A. Vasquez, unpublished), and the first report in the Colombian Amazon demonstrated its potential for further expansion. A genetic study of the natural and invasive populations should be able to demonstrate a possible selection process for adaptation of this weevil species to peach palm and help in diagnostics should neighboring countries be affected.

The confirmation of the central role of *D. borassi* in the toppling of the crown of the peach palm is the main contribution of this study and should lead to the redirection of pest management plans. It also should alert managers about the potential of this pest to expand to other economically important palms. As for control methods, the *D. borassi* pheromone was shown to be very effective in capturing high numbers of individuals. As *D. borassi* is the agent that initiates the problem, the use of pheromones could prevent further outbreaks as discussed above.

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