# UNIVERSIDAD MICHOACANA DE SAN NICOLÁS DE HIDALGO

## Instituto de Investigaciones sobre los Recursos Naturales

## DIVERSIDAD Y ABUNDANCIA ECTOPARÁSITA EN ROEDORES SILVESTRES EN ZONAS DE COBERTURA VEGETAL CONTRASTANTE DE MARQUÉS DE COMILLAS, CHIAPAS

## TESIS

### Que presenta

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### Como requisito para obtener el título de
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# Agradecimientos

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El cambio del uso del suelo es uno de los principales factores que causan la pérdida y modificaciones en la composición y abundancia de la fauna silvestre de los bosques tropicales. Los roedores son un grupo de mamíferos que responden de diversas maneras a la perturbación, las especies de roedores generalistas e invasoras pueden aumentar sus poblaciones; mientras que las especies con hábitos especialistas pueden experimentar poblaciones fuertemente reducidas. Aún son pocos los estudios que abordan los efectos en cascada que derivan de los impactos directos que la pérdida de los bosques tiene sobre la fauna silvestre. Analizamos el impacto que la pérdida de la selva tiene sobre la abundancia, diversidad, y composición de roedores silvestres y su comunidad de ectoparásitos asociada en seis sitios de muestreo en la Región de Marqués de Comillas, en el estado de Chiapas del sureste de México. Encontramos que la deforestación del bosque asociada con el cambio del uso del suelo favorece el incremento en la abundancia de algunas especies locales de roedores, promoviendo una mayor abundancia de ectoparásitos hematófagos potenciales vectores de enfermedades zoonóticas.

**Palabras clave:** deforestación, bosques tropicales, ácaros, enfermedades zoonóticas.

II.	**General summary**

The land use change is the principal driver of the loss and the modification in the abundance and composition of tropical wildlife. Rodents are a group of mammals that can respond to disturbance in diferent ways. Generalist and invasive rodent species can increase their

population abundances, whereas, rodents species of specialized habits could suffer marked reductions in the abundance of its populations. There are few studies, yet, focused on analyzing the domino effects derived from the direct outcomes of tropical forest loss on wildlife. We analized the impact of tropical forest loss on the abundance, diversity and composition of wild rodents, and their associated ectoparasites in six sampling sites, in the Marques de Comillas Region in the state of Chiapas, southern Mexico. We found that forest deforestation promotes an increase in the abundance of generalist rodent species, increasing in turn that abundance of hematophagous ectoparasites, including some potential vectors of zoonotic diseases.

**Keywords:** deforestation, tropical forest, mites, zoonotic diseases.

## III.    Introducción general

El impacto que las actividades humanas ejercen sobre los bosques tropicales, ha generado una pérdida drástica de su cobertura (Wijaya et al., 2017; Weisse & Goldman, 2017; Edwards et al., 2019; Vargas et al., 2019). Se estima que, en los últimos cinco años los bosques tropicales del mundo perdieron en promedio un área de 9,28 millones de hectáreas por año debido principalmente al cambio de uso de suelo y la tala selectiva (Lewis et al., 2004; Gatti et al., 2015; Keenan et al., 2015; Bieng et al., 2021). La deforestación de los bosques se asocia con la extinción de especies (Pekin & Pijanowski, 2012), pero también con una pérdida de los servicios ambientales que provee, como el control de enfermedades zoonóticas (Allen et al., 2017).

Existe evidencia, de que la proliferación de reservorios naturales de enfermedades, como los roedores y sus patógenos asociados, está relacionada con la pérdida de biodiversidad (Young et al., 2014; Halliday et al., 2020; Keesing & Ostfeld, 2021). Estudios experimentales han demostrado que la remoción de la fauna de mamíferos de mayores tallas promueve un aumento en las poblaciones de roedores (Young et al., 2014; Young et al., 2015; Gibb et al., 2020). Se ha sugerido que hay factores como la competencia por recursos alimenticios entre mamíferos herbívoros grandes y pequeños que son una limitante para la propagación de roedores (Keesing & Young, 2014). El incremento en la prevalencia de ectoparásitos (p.ej., pulgas y garrapatas) parece seguir el mismo patrón. La reducción de fauna autóctona de ecosistemas naturales, y el incremento de las poblaciones de hospederos como roedores y algunas especies de ungulados (reconocidos por ser anfitriones preferidos para los ectoparásitos); favorece la proliferación de artrópodos parásitos incrementando las enfermedades zoonóticas (Kilpatrick et al., 2014; Young et al., 2014).

El éxito de los roedores como propagadores de agentes etiológicos, parece estar asociado a que estos organismos están provistos de sistemas inmunológicos muy eficientes que les dan una alta tolerancia a los patógenos (Luis et al., 2013; Rynkiewicz et al., 2013). Esto podría, a su vez, explicar la escasa cantidad de reportes de ectoparásitos afectando directamente la salud de los roedores (Romero, 1994). Sin embargo, se ha registrado que, cuando una gran cantidad de ectoparásitos llegan a infestar un solo organismo, pueden causar, infecciones en la piel, anemia y en algunos casos extremos, la muerte del hospedero (López & Jaime, 2006; Jofré et al., 2009).

El orden Rodentia, es uno de los grupos de mamíferos más diverso por sus aproximadamente 2277 especies descritas en el mundo (Pachaly et al., 2001; Tzab & Macswiney, 2014). Los roedores pueden jugar distintos roles en el ecosistema, son un recurso alimenticio de diversos carnívoros (Ceballos & Olivia, 2005) y algunas especies favorecen la dispersión de semillas (Carvajal & Adler, 2008; Vélez & Pérez, 2010). Inclusive, se ha documentado que especies como *Pseudomys oralis*, roedor dispersor de hongos micorrícicos, favorecen el mantenimiento de los bosques en Australia (Elliott et al., 2020). Cabe señalar que entre los roedores se encuentran especies nativas de bosques conservados con hábitos alimenticios muy especializados y que presenta de manera natural densidades poblacionales bajas (Jorge, 2008; Niu et al., 2021). Dos ejemplos de estas especies son: *Geomys tropicalis* y *Neotoma floridana,* que están siendo seriamente afectadas por la deforestación (Cove et al., 2017; Cervantes, 2021).

No obstante, cuando las condiciones del medio ambiente son favorables, algunas especies de roedores, sobre todo las invasoras y generalistas pueden llegar a convertirse en plagas (Mendoza et al., 2020). Esto se debe en gran medida a las características de la historia de vida de los roedores, como sus altas tasas reproductivas y periodos de gestación cortos (Kay & Hoeskstra, 2008). Además, el incremento de áreas dominadas por cultivos, proporcionan un recurso alimenticio que permite la proliferación de los roedores (Kay & Hoekstra, 2008; Lacher et al., 2021).

Existe una gran diversidad de especies de ectoparásitos asociados a los roedores. Algunos de estos artrópodos mantienen relaciones benéficas o de tipo comensal con su hospedero (Kim, 1985) pero otros, como las garrapatas, ácaros hematófagos y pulgas son de alto riesgo por ser vectores de patógenos como: *Flavivirus*, *Rickettsiosis*, *Borreliosis* y

*Bartonelosis Rickettsiosis, Borreliosis, Bartonelosis*, y *Yersinia pestis* (Durden et al., 2004; Diarra et al., 2020; López et al., 2021). Estos ectoparásitos son capaces de utilizar una amplia gama de hospederos, por lo que incrementan el contagio por agentes etiológicos de origen zoonótico (Tretyakov et al., 2012). La cantidad de casos de padecimientos por zoonosis va en aumento (Arrivillaga & Caraballo, 2009; Han et al., 2015; Han et al., 2016), por lo que el mantenimiento de los ecosistemas naturales es necesario para el control de estas enfermedades zoonóticas.

Desafortunadamente, a pesar de los esfuerzos por conservar a los ecosistemas naturales, la deforestación de los bosques tropicales sigue incrementándose (Brancalion et al., 2020). Por esta razón, es de particular importancia monitorear a los vectores de enfermedades (Rubio et al., 2014; Reaser et al., 2021). Esto nos permitirá saber cómo influye la interacción de factores ecológicos en la proliferación de agentes etiológicos y, cuál es la gama de respuestas de las especies de roedores que son reservorios y vectores de patógenos a la deforestación y el cambio de uso de suelo (Guégan et al., 2020). En el presente estudio evaluamos los impactos de la deforestación y sus efectos sobre la riqueza y abundancia de roedores silvestres, así como, la respuesta en la composición y abundancia de especies de ectoparásitos asociados a estos pequeños mamíferos, con especial énfasis en documentar la presencia de ectoparásitos vectores de enfermedades.

## IV.    Referencias

Allen, T., Murray, K.A., Zambrana-Torrelio, C., Morse, S.S., Rondinini, C., Di Marco, M. & Daszak, P. (2017). Global hotspots and correlates of emerging zoonotic diseases. Nature communications, 8(1), 1-10.

Arrivillaga, J. & Caraballo, V. (2009). Medicina de la Conservación. Revista Biomédica, 20(1), 55-67.

Bieng, M., Oliveira, M.S., Roda, J.M., Boissière, M., Hérault, B., Guizol, P. & Sist, P. (2021). Relevance of the secondary tropical forest for landscape restoration. Ecology and Forest Management, 493, 119265.

Brancalion, P.H., Broadbent, E.N., de-Miguel, S., Cardil, A., Rosa, M.R., Almeida, C.T. & Almeyda, Z.A.M. (2020). Emerging threats linking tropical deforestation and the COVID-19 pandemic. Perspectives in Ecology and Conservation, 18 (4), 243246.

Carvajal, A. & Adler, G.H. (2008). Seed dispersal and predation by Proechimys semispinosus and Sciurus granatensis in breccias and understory in central Panama. Journal of Tropical Ecology, 24 (5), 485-492.

Ceballos, G. & Oliva, G. (2005). Los mamíferos silvestres de México (Vol. 986). México: Fondo de Cultura Económica.

Cervantes, F.A. (2021). The tropical pocket gopher (Geomys tropicalis) on the brink of extinction. Therya Notes, 2, 1-7.

Cove, M.V., Simons, T.R., Gardner, B., Maurer, A.S. & O'Connell, A.F. (2017). Evaluation of nest supplementation as a recovery strategy for endangered rodents in the Florida Keys. Restoration Ecology, 25 (2), 253-260.

Diarra, A.Z., Kone, A.K., Niare, S.D., Laroche, M., Diatta, G., Atteynine, SA. & Parola, P. (2020). Molecular detection of microorganisms associated with small mammals and their ectoparasites in Mali. The American Journal of Tropical Medicine and Hygiene, 103 (6), 2542-2551.

Durden, L.A., Polur, R.N., Nims, T., Banks, C.W. & Oliver Jr, J.H. (2004). Ectoparasites and other epifaunistic arthropods of sympatric cotton mice and golden mice: comparisons and implications for vector-borne zoonotic diseases. Journal of Parasitology, 90 (6), 1293-1297.

Edwards, D.P., Socolar, J.B., Mills, S.C., Burivalova, Z., Koh, L.P. & Wilcove, D.S. (2019). Conservation of tropical forests in the Anthropocene. Current Biology, 29 (19), R1008-R1020.

Elliott, T.F., Townley, S., Johnstone, C., Meek, P., Gynther, I. & Vernes, K. (2020). The endangered Hastings river mouse (Pseudomys oralis) as a dispersal of ectomycorrhizal fungi in eastern Australia. Mycology, 112 (6), 1075-1085.

Gatti, R.C., Castaldi, S., Lindsell, J.A., Coomes, D.A., Marchetti, M., Maesano, M. & Valentini, R. (2015). The impact of selective logging and tree felling on the forest structure, tree diversity, and aboveground biomass of African tropical forests. Ecological Research, 30 (1), 119-132.

Gibb, R., Redding, D.W., Chin, K.Q., Donnelly, C.A., Blackburn, T.M., Newbold, T. & Jones, K.E. (2020). The diversity of zoonotic hosts increases in human-dominated ecosystems. Nature, 584 (7821), 398-402.

Guégan, J.F., Ayouba, A., Cappelle, J. & De Thoisy, B. (2020). Forests and emerging infectious diseases: Unleashing the beast within. environmental research Letters, 15 (8), 083007.

Halliday, F.W., Rohr, J.R. & Laine, A.L. (2020). Biodiversity loss underlies the dilution effect of biodiversity. Ecology letters, 23(11), 1611-1622.

Han, B.A., Schmidt S.P., Bowden S.E.& Drake, J.M. (2015) Rodent reservoirs of future zoonotic diseases. Proc Natl Acad Sci U S A 112:22.

Han, B.A., Kramer, A.M. & Drake, J.M. (2016). Global patterns of zoonotic diseases in mammals. Trends in Parasitology, 32 (7), 565-577.

Jofré, L., Noemí, I., Neira, P., Saavedra, T. & Díaz, C. (2009). Acarosis y zoonosis relacionadas. Revista chilena de infectología, 26(3), 248-257.

Jorge, M.L.S. (2008). Effects of forest fragmentation in two sister genera of Amazonian rodents (Myoprocta acouchy and Dasyprocta leporina). Biological Conservation, 141 (3), 617-623.

Kay, E.H., & Hoekstra, H.E. (2008). Rodents. Current Biology, 18(10), R406-R410.

Keenan, R.J., Reams, G.A., Achard, F., de Freitas, J.V., Grainger, A. & Lindquist, E. (2015). Dynamics of global forest area: results of the 2015 FAO Global Forest Resources Assessment. Forest Ecology and Management, 352, 9-20.

Keesing, F., & Ostfeld, R.S. (2021). Impacts of biodiversity and biodiversity loss on zoonotic diseases. Proceedings of the National Academy of Sciences, 118(17).

Keesing, F. & Young, T.P. (2014). Cascading consequences of the loss of large mammals in an African savanna. Bioscience, 64 (6), 487-495.

Kilpatrick, H.J., Labonte, A.M. & Stafford III, K.C. (2014). The relationship between deer density, tick abundance, and human cases of Lyme disease in a residential community. Journal of Medical Entomology, 51 (4), 777-784.

Kim, K.C. (1985). Coevolution of parasitic arthropods and mammals. Wiley.

Lacher Jr, T.E., Kennerley, R., Long, B., McCay, S., Roach, N.S., Turvey, S.T. & Young, R.P. (2021). Support for rodent ecology and conservation to advance zoonotic disease research. Conservation Biology, 1, 2.

Lewis, S.L., Malhi, Y. & Phillips, O.L. (2004). Fingerprinting of the impacts of global change on tropical forests. Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences, 359 (1443), 437-462.

López, B.J.L. & Jaime D.H. (2006). Estudio epidemiólogico de la prevalencia e identificación de garrapatas en el ganado bovino del municipio de San Pedro de Lóvago-Chontales (Doctoral dissertation, Universidad Nacional Agraria, UNA).

López, P.A.M., Chaves, A., Sánchez, M.S., Foley, P., Uhart, M., Barrón, R.J. & Foley, J. (2021). Diversity of rickettsiae in domestic, synanthropic, and jungle mammals and their ectoparasites in a spotted fever epidemic on the western border of the United States and Mexico. Transboundary and emerging diseases.

Luis, A.D., Hayman, D.T., O'Shea, T.J., Cryan, P.M., Gilbert, A.T., Pulliam, J.R. & Webb, C.T. (2013). A comparison of bats and rodents as reservoirs of zoonotic viruses: are bats special? Proceedings of the Royal Society B: Biological Sciences, 280(1756), 20122753.

Mendoza, H., Rubio, A.V., García, P.G.E., Suzán, G. & Simonetti, J.A. (2020). Does land use change increase the abundance of zoonotic reservoirs? Rodents say yes.

European Journal of Wildlife Research, 66 (1), 1-5.

Niu, H., Wang, X., Wu, S., Xing, J., Peng, C., Chen, Z. & Zhang, H. (2021). The loss of granivorous rodents poses greater threats to oaks with large acorns than to those with small ones in urban forests. Urban forestry and urban greening, 62, 127185.

Pachaly, J.R., Acco, A., Lange, R.R., Nogueira, T.M.R., Nogueira, M.F. & Ciffoni, E.M.G. (2001). Order rodentia (rodents). South American Wild Animal Biology, Medicine and Surgery. State University Press, Iowa, 225-237.

Pekin, B.K. & Pijanowski, B.C. (2012). Global intensity of land use and endangered status of mammalian species. Diversity & Distributions, 18 (9), 909-918.

Reaser, J.K., Witt, A., Tabor, G.M., Hudson, P.J. & Plowright, R.K. (2021). Ecological countermeasures to prevent zoonotic disease outbreaks: when ecological restoration is an imperative for human health. Restoration ecology, e13357.

Romero, H.Q. (1994). Parasitología y enfermedades parasitarias de animales domésticos. Editorial Limusa.

Rubio, A.V., Ávila F.R. & Suzán, G. (2014). Responses of small mammals to habitat fragmentation: epidemiological considerations for rodent-borne hantaviruses in the Americas. EcoHealth, 11(4), 526-533.

Rynkiewicz, E.C., Hawlena, H., Durden, L.A., Hastriter, M.W., Demas, G.E. & Clay, K. (2013). Associations between innate immune function and ectoparasites in wild rodent hosts. Research in Parasitology, 112 (4), 1763-1770.

Tretyakov, K.A., Medvedev, S.G. & Apanaskevich, M.A. (2012). Ixodid ticks in St. Petersburg: a possible threat to public health. Estonian Journal of Ecology, 61 (3), 215.

Tzab, H.L.A. & Macswiney, G.M.C. (2014). Roedores ¿plagas indeseables o animales útiles? CONABIO. Biodiversitas, 115:12-16.

Vargas, C., Montalbán, J. & León, A.A. (2019). Early warning of tropical forest loss in Peru using Landsat. Environmental Research Communications, 1 (12), 121002.

Vélez, G.F. & Pérez, T.J. (2010). Remoción de semillas por roedores en un fragmento de bosque seco tropical (Risaralda-Colombia). Revista MVZ Córdoba, 15(3), 22232233.

Weisse, M. & Goldman, E. (2018). 2017 Was the second-worst year on record for tropical tree cover loss. World Resour. Inst. https://www.wri.org/blog/2018/06/2017wassecond-worst-year-record-tropical-tree-cover-loss Accessed 13 July 2021.

Wijaya, A., Juliane, R., Firmansyah, R., & Payne, O. (2017). 6 Years After Moratorium, Satellite Data Shows Indonesia's Tropical Forests Remain Threatened.

Young, H.S., Dirzo, R., Helgen, K.M., McCauley, D.J., Billeter, S.A., Kosoy, M.Y. & Dittmar, K. (2014). The decline in large wildlife increases the landscape-level prevalence of rodent-borne diseases in Africa. Proceedings of the National Academy of Sciences, 111 (19), 7036-7041.

Young, H.S., McCauley, D.J., Dirzo, R., Goheen, J.R., Agwanda, B., Brook, C. & Helgen, K.M. (2015). Context-dependent effects of large wildlife declines on small mammal communities in central Kenya. Ecological Applications, 25 (2), 348-360.

# V.

# Capítulo I

**Forest loss increases the abundance of rodents and their associated ectoparasites in the Lacandon forest, southern Mexico**

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**Abstract**

One particularly important service that tropical forests provide is disease control. However, there are still few studies focused on analyzing how this service is affected by deforestation. We assessed the relationship between deforestation and rodent abundance and how this affects ectoparasite abundance and diversity in the Marques de Comillas region in the state of Chiapas, southern Mexico. Using Sherman traps we captured 70 rodents of five species: *Sigmodon toltecus, Heteromys desmarestianus, Ototylomys phyllotis, Peromyscus mexicanus,* and *Oryzomys couesi* in six sites differing in their percentage of forest cover. Rodent abundance increased with forest loss ($r^2=0.706$, $p=0.022$). The highest rodent species

richness occurred in sites with intermediate forest cover (40% and 78%). The most abundant species were *S. toltecus* (n=45) followed by *O. couesi* (n=9), these species dominated in sites with the lowest forest cover. The captured rodents were euthanized to search for ectoparasites in the laboratory. From a total of 23 different ectoparasites, we identified 15 to the species level and 8 to the genus level. The sites with the lowest forest coverage had the lowest ectoparasite species richness. The most abundant ectoparasites belonged to the family Listrophoridae (n=5870) and Trombiculidae (n=1853). We detected 3 ectoparasite species (*Amblyomma* sp*., Ornithonyssus bacoti,* and *Androlaelaps fahrenholzi)* which are known to be vectors of zoonotic diseases. We found that ongoing forest loss is promoting an increase in the proliferation of zoonotic disease vectors which in turn can result in an increased frequency of affectation among local people.

**Introduction**

Human activities are causing a drastic transformation of tropical landscapes characterized by a marked reduction and fragmentation of natural habitats and the proliferation of land dedicated to monocultures, commercial plantations, cattle pasture, or covered by secondary vegetation (Jacobson et al., 2019; Gayley and Sridith 2020). There is an increasing number of studies focused on analyzing the consequences of this transformation on tropical biodiversity (Dudley and Alexander 2017; Symes et al., 2018). However, most of these studies assess the direct impacts of this transformation on basic ecological variables such as population abundance and community diversity (Sayer et al., 2017; Thompson and Donnelly 2018; Cavada et al., 2019). In contrast, much fewer studies focus on assessing

cascade ecological impacts derived from tropical landscape transformation (Ostfeld and Holt 2004; Young et al., 2014; Morante et al., 2018; Portela and Dirzo 2020).

Rodents are of great relevance in tropical forests due to their abundance and the variety of ecological roles in which they are involved, such as seed dispersal and predation (Vélez and Pérez 2010). Some rodent species seem to withstand the effects of human perturbations most commonly affecting tropical forests and even, in some instances, result benefited from the conditions associated with anthropized landscapes (Morand et al., 2019; Mendoza et al., 2020; Prist et al., 2020). In contrast, some rodent species have reduced distribution ranges and specialized habits that make them more prone to be negatively impacted by tropical forests perturbation (Mendoza and Horváth 2013; Rubio et al., 2014).

Small rodents interact with an important number of arthropods in the orders Ixodida (ticks), Mesostigmata (facultative parasite mites), Trombidiformes (free-living mites, parasites in larval stage), Sarcoptiformes (commensal and parasite mites) as well as insects in the orders Siphonaptera (fleas), Phthiraptera (lice) and Heteroptera (bugs) (Reeves et al., 2007; Madinah et al., 2014; Guzmán et al., 2020). Despite the known role of these arthropods as ectoparasite which in turn act as reservoirs and vectors of pathogens, such as viruses and bacteria, information on how these invertebrates are affected by habitat perturbation is still sparse (Guzmán et al., 2020; Kiene et al., 2020; Ramalho and Gubler 2020).

Tropical forest perturbation can affect the prevalence of rodent ectoparasites trough different ways. First, impacts of forest perturbation on the abundance of rodent populations and the composition of their communities can in turn affect host availability (Johnstone et

al., 2014; Ladds 2015; Ssuuna et al., 2020). Second, habitat perturbation can affect the physiological condition of rodents (e.g., stress levels) making them more prone to be parasitized or can directly affect the species composition and population abundance of ectoparasites due to the associated changes in abiotic factors such as humidity and temperature (Moyer et al., 2002; Rynkiewicz et al., 2013; Hammond et al., 2019).

Studies, at the global level, evidence the existence of a relationship between the transformation of natural hábitats and the emergence of zoonotic diseases (Arrivillaga and Caraballo 2009; Egeru et al., 2020; Rahman et al., 2020). Moreover, these studies point out that countries having a high mammal diversity, but undergoing heavy perturbation of their natural vegetation cover, such as it occurs in tropical rain forests, are more likely to have a greater frequency and concentration of zoonosis (Allen et al., 2017; Lorenzo et al., 2017). It remains, therefore, an issue of prime relevance to document the impacts of tropical deforestation on rodent populations and the corresponding consequences for ectoparasite abundance and diversity. This will help to further our understanding of the ecosystem service tropical forests provided for disease control (McMurray et al., 2017).

In this we focused on: a) evaluating the relationship between tropical forest loss and rodent species richness and abundance, b) assessing the associate effects on the abundance of rodent ectoparasites and their species richness and composition and, c) documenting the presence of ectoparasites of zoonotic relevance such as ticks, fleas, lice, and hematophagous mites. We expect to find a reduction in rodent species diversity but an increase in their overall abundance as forest extent reduces. This will reflect on a greater abundance of the associated ectoparasites (Suzán et al., 2008; Morand et al., 2019; Kiene et al., 2020). Among the species

of ectoparasites increasing their abundance, we expect to find some species already identified as vectors of zoonotic diseases (Wells et al., 2007; Suzán et al., 2009; Young et al., 2014).

**Materials and methods**

*Study area*

This study was conducted in the Marques de Comillas (MC) region which is part of the Lacandon forest in the state of Chiapas, southern Mexico. The MC region has an extent of 942 66 km.² (INAFED 2010); limits to the west and north with the Lacantún river, to the south with the Guatemala border, and the east and north with the Salinas river (Carabias et al., 2000) (Fig.1). Towards the west is located the Montes Azules biosphere reserve which has an extent of 331,200.00 ha (CONANP 2019). The mean annual precipitation in the region is 3000 mm and the mean temperature 24 ° C (Martínez et al., 2009).

The Lacandon forest in southern Mexico, together with its natural prolongation in Belize and Guatemala, constitutes one of the largest remnants of tropical rain forest in Mesoamerica (Cruz et al., 2004). Unfortunately, this region has suffered a heavy impact due to deforestation caused by the opening of new land for agriculture, cattle pasture and, commercial plantations (Mendoza and Dirzo 1999; Soto et al., 2012). Over a period no longer than 12 years, the Lacandon forest lost approximately 142 000 ha, accumulating a total loss of nearly 70% of its original extent (de la Torre and Medellín 2011; Carabias et al., 2015). Therefore, this region formerly covered with rain forest currently supports a mosaic of different types of vegetation and land uses which include secondary forest, cattle pasture, and African palm plantations (Muench and Martínez 2016).
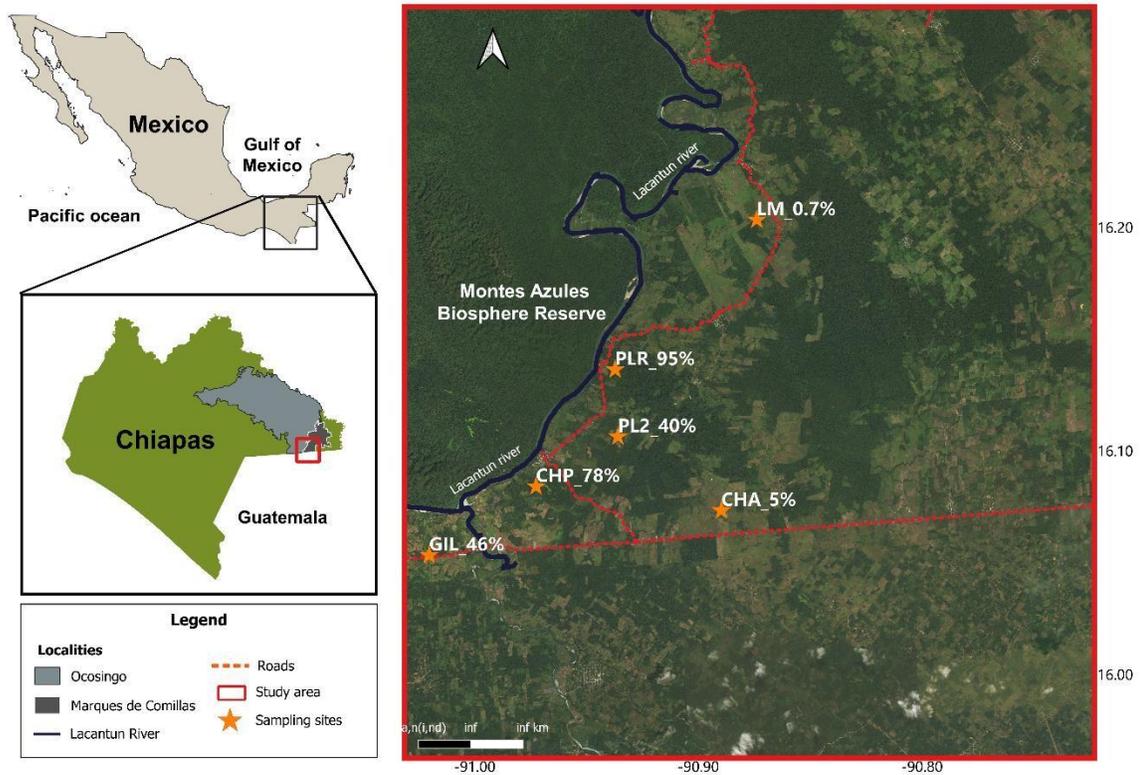
**Figure 1** Location of the study in the Marques de Comillas region in the state of Chiapas, southern Mexico. The stars indicate the location of sampling sites (Map data: own elaboration, sources of Bing Satellital and INEGI 2018).

*Selection of sampling sites*

For the selection of sampling sites, we used as a guide a previous study by Wies et al., (2021). In such a study 18 landscape units of 1km² were delimited within the MC. The percentage of forest cover in each one of these units was estimated using Sentinel-2 satellite images, with a 10 m spatial resolution, and ground-truthing. Base on this information we selected six sampling sites which different percentages of forest cover (Table 1).

**Table 1** Percentage of tropical forest in each sampling unit, main vegetation covers and land uses, and location. The percentage of forest cover was calculated based on an area of 1km² (Wies et al., 2021).

| Site | Main vegetation cover/land use | Forest cover (%) | Coordinates | |
|---|---|---|---|---|
| | | | Lat. | Long. |
| LM_0.7% | Cattle pasture-crops/ abandon cattle pasture | 0.7 | 16.1968 | -90.8382 |
| CHA_5% | Cattle pasture / crops | 5.0 | 16.0917 | -90.8602 |
| PL2_40% | Cattle pasture-crops/ Old forest | 40.8 | 16.1215 | -90.8970 |
| GIL_46% | Cattle pasture-crops/ Secondary forest | 46.0 | 16.0836 | -90.9717 |
| CHP_78% | Secondary forest/ abandon cattle pasture | 78.0 | 16.1057 | -90.9294 |
| PLR_95% | Old forest/ secundary forest | 95.8 | 16.1461 | -90.8961 |

*Rodent capture*

Fieldwork consisted of two sampling periods, the first one was conducted in October 2019 (18 days) and the second in September 2020 (24 days). Both sampling periods occurred during the rainy season when rodent abundance tend to be higher in tropical forests (Cruz et al., 2010; Pérez et al., 2011). In each of the six sites, we set 90 Sherman traps. These traps were set along two parallel lines, the separation between these lines was 20m and between consecutive traps in a line was 10m. The traps were baited daily with a mixture of liquid

vanilla and oat flakes. The traps were checked early every morning and were active during the day and night.

The captured rodents were euthanized by applying them an overdose injection of pentobarbital sodic in the intraperitoneal zone. This procedure followed the guidelines of ethic treatment to animals from the American Society of Mammalogists (Gordon 1998). To limit the number of rodents to be sacrificed we reduced our sample size to the minimum number of six sites as indicated above. The sacrificed individuals belonged to species not listed as threatened at the national o global level.

*Ectoparasite sampling*

In the laboratory, we practiced repetitive abrasive combing of the whole body of each one of the sacrificed rodents with the help of a toothbrush. This technique has been applied in several studies with great success to remove mites from the fur of small rodents (Kamani et al., 2013; Lareschi et al., 2019). Moreover, we conducted a visual search of ectoparasites attached to the skin of each rodent. All the collected arthropods were deposited in a solution of Kono's liquid for 7 to 30 days to disintegrate their internal organs and stomach content. This left only the organism's exoskeleton which was mounted on a slide with a drop of Hoyer's solution to conduct the corresponding taxonomic identification (Palacios and Mejía 2007). The taxonomic determination of the ectoparasites was conducted with the help of specialized taxonomic keys (Stojanovich and Pratt 1961; Bassols 1975; Fain and Lukoschus 1984; Guzmán et al., 2011).

*Data analyses*

We conducted regression analyses to assess the relationship between forest cover (%) and rodent abundance. We assessed this relationship using as explicative variable the percentage of forest cover at 1km², 2km² y 3 km² areas including our trapping sites. Forest cover in these areas was obtained from Wies et al., (2021).

To compare ectoparasite species richness among the trapping sites we built accumulation curves using Hill number q=0. These curves were extrapolated to the largest sample size, using as a sampling unit the corresponding number of trapped rodents. We calculated the corresponding 95% confidence intervals for each curve (Chao et al., 2014). To do this we used the iNEXT package (Hsieh et al., 2019).

We generated a dendrogram to explore the relationship among trapping sites based on the richness and abundance of the ectoparasite species recorded in the rodents. To do this we followed the procedure described in Borcard et al., (2018). We produced a matrix of Euclidean distances among sites based on the standardized abundance (option "normalized") of their ectoparasites. We generated four dendrograms using the following algorithms: single linkage, complete linkage, UPGMA, centroid, and Ward´s minimum distance. We conducted cophenetic correlations and calculated Gower distances to assess the performance of these algorithms to describe the relationship among sites. Gower's distance is a statistic used to assess the comparative performance of data grouping methods. It is calculated as the sum of squared differences of original and cophenetic distances. The grouping method having the lowest Gower value is taken as the one having the best performance (Borcard et al., 2018). To conduct this analysis, we used the package Vegan (Oksanen et al., 2020). We excluded from this analysis the rodent species *Ototylomys phyllotis* due to the fact it was represented only by one individual and in contrast with the other species recorded is highly arboreal.

To examine for the existence of differences in the number of ectoparasites recorded on *Sigmodon toltecus* (the species most commonly trapped overall) among the different trapping sites we applied a Kruskal-Wallis test (Zar 2010). Afterward, we applied a Dunn test with Bonferroni's adjusted probabilities to identify which pairs of sites were statistically different. The use of this test is recommended in cases in which replication is not balanced among treatment levels (Zar 2010). To conduct these analyses, we used the package FSA (Ogle et al., 2021). All the above analyses were conducted using the software R ver. 3.6.3 (R Core Team 2020).

**Results**

With a sampling effort of 3 780 trap days, we captured a total of 70 rodents (overall 43 males and 23 females) belonging to five species. The most abundant species was *Sigmodon toltecus (*n=45)*, followed by *Heteromys desmarestianus* (n=9) and, *Oryzomys couesi* (n=9)*, Peromyscus mexicanus* (n=6) and *Ototylomys phyllotis* (n=1). In the sites where the forest coverage was the lowest, the abundance of *S. toltecus* and *O. couesi* was the highest. In contrast, the species *P. mexicanus* and *H. desmarestianus* occurred only in the sites with greater forest coverage (Fig. 2). None of the five rodent species occurred in the six trapping sites.
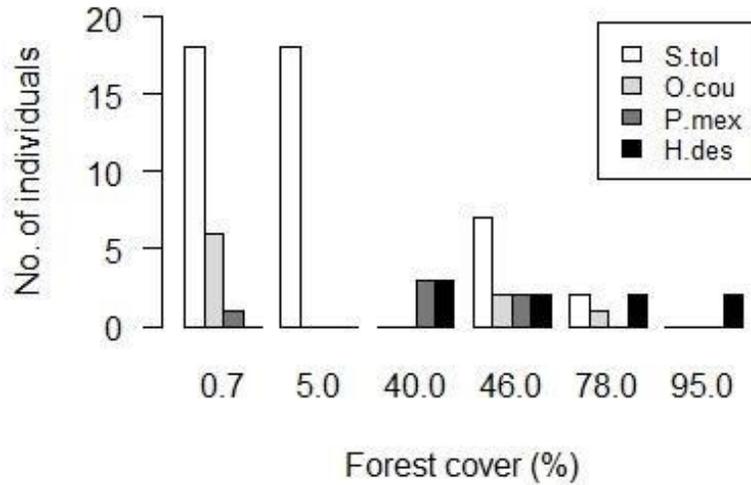
**Figure 2** Rodent abundance in six sites differing in their forest cover in the Marques de Comillas region in the state of Chiapas, southern Mexico.

We found that the overall abundance of rodents was inversely proportional to the percentage of forest cover ($r^2$=0.706, df =8, p=0.022). Thus, the sites with less forest cover (LM_0.7% and CHA_5%) concentrated the greatest number of rodents (25 and 17, respectively) whereas in the sites with the greatest forest coverage (CHP_78% and PLR_95%) only occurred 5 and 3 rodents (Fig. 3). The results were very similar when using forest coverage estimated at 2 km² and 3km² was used for regressions.
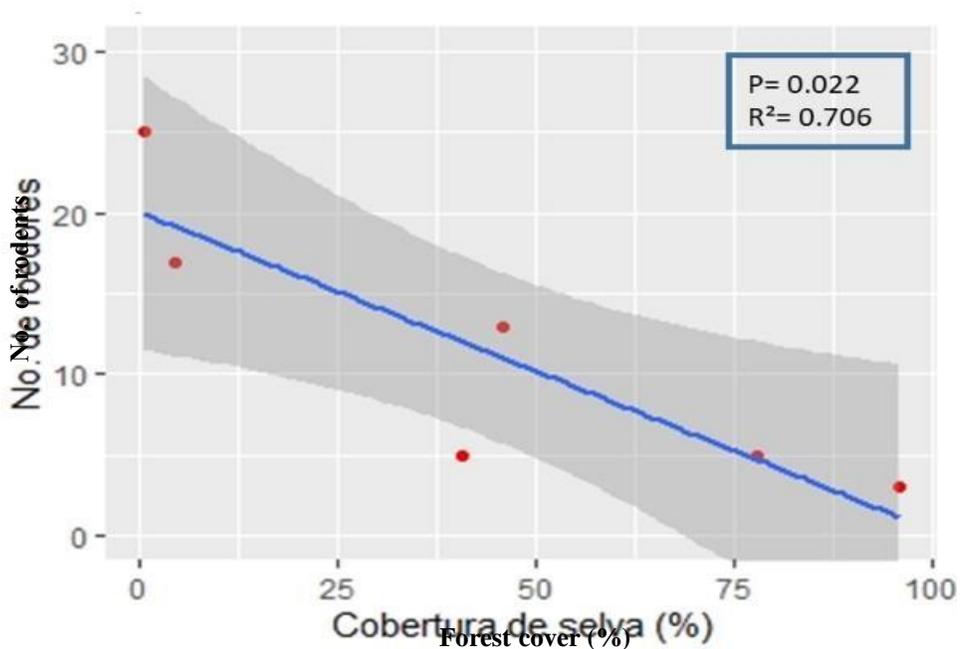
**Figure 3** Relationship between forest coverage and overall rodent abundance. The shaded area corresponds to the 95% confidence interval for the regression.

We identified 23 different ectoparasites, 15 of them to species level and 8 to the genus level (Table 2). The more abundant groups were mites in the families Listrophoridae (*Geomylichus nectomys, Prolistrophorus* sp*., Prolistrophorus bakery* and, *Prolistrophorus grassi*) and Trombiculidae (*Cordiseta mexicana, Pseudoschoengastia brennani, Parasecia kansasensis, Dermadelema mojavense* and*, Eutrombicula batatas).* The less abundant species was *Gigantolaelaps boneti* which belongs to the Laelapidae family.

In most of the sites ectoparasite, species accumulation curves (and their extrapolation) showed a trend towards stabilization with the clear exception of site PLR_95%. The sites with less forest cover (LM_0.7%, CHA_5%, and PL2_40%) had the lowest ectoparasite species richness and showed a large overlap in their 95% confidence intervals. The sites with intermediate forest coverage (GIL_46% and CHP_78%) had, in turn, a greater species

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richness than sites with low forest coverage, and the corresponding 95% confidence intervals had only a slight overlap. Finally, the site with the greatest forest coverage PLR_95%) had the highest species richness when it was compared to the other sites at the same sampling effort; however, since this site had the smallest number of rodents captured comparisons are not greatly supported (Fig. 4).
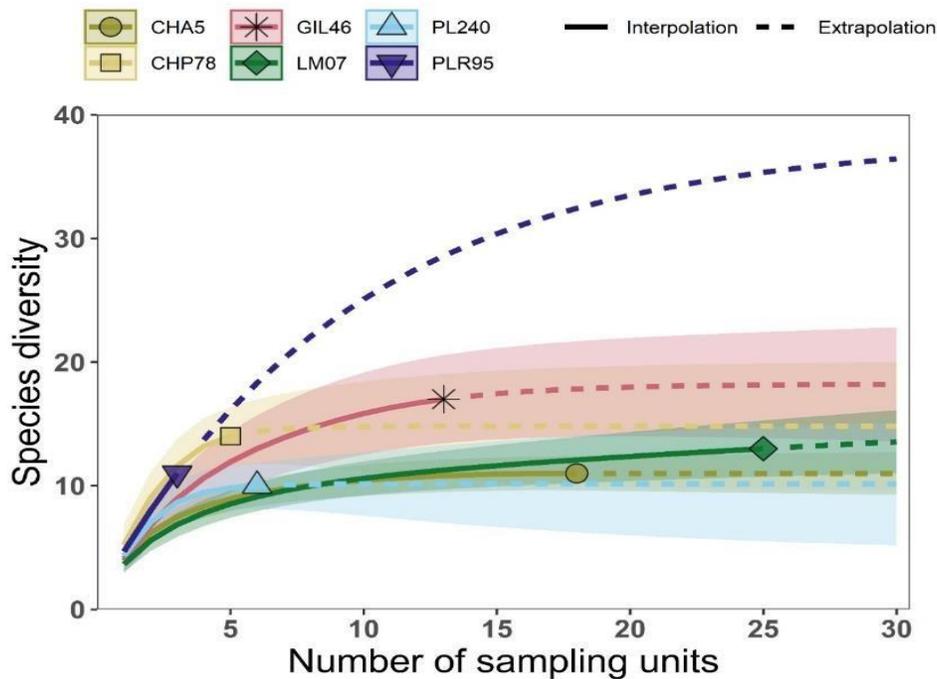


**Figure 4** Accumulation curves of ectoparasite species in six sites with different percentages of forest coverage in the Marques de Comillas in the state of Chiapas, southern Mexico. The shaded areas correspond to 95% confidence intervals and dashed lines to extrapolations.

The dendrogram using the UPGMA algorithm had the highest cophenetic correlation (0.846 vs. 0.840, 0.830, 0.782) and the lowest Gower distance (0.401 vs. 1.036, 1.390, 3.037).

Therefore, we used such a dendrogram to represent the relationship among sites based on their ectoparasite fauna. Sites were segregated into two main clusters. The first one of them was constituted by the sites with the lowest forest coverage. The second main cluster was, in turn, divided into two smaller clusters. The first one of these sub-clusters included sites GIL_46% and CHP_78%, which had a relatively high species richness of ectoparasites whereas the second included sites PL2_40% and PLR_95% (Fig. 5).
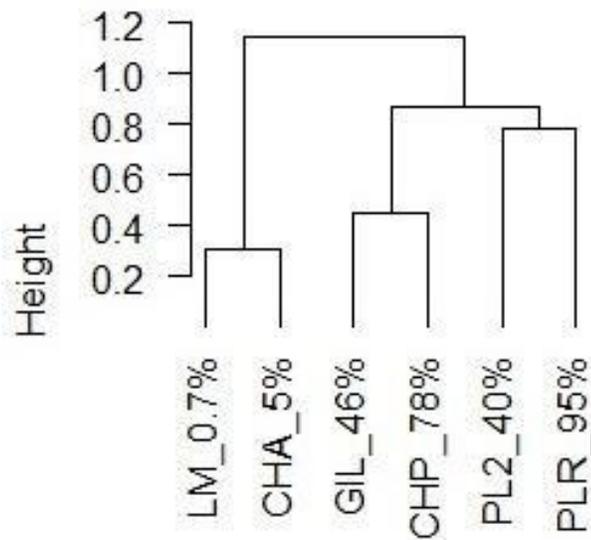


**Figure 5** Relationships among rodent trapping sites in the Marques de Comillas, state of Chiapas, based on the composition of the recorded ectoparasite fauna.

There was a significative variation in the number of ectoparasites among individuals of *S. toltecus* captured (Chi²=13.2, df=3, p=0.004; Fig. 6). Two sites were different LM_0.7% and GIL_46% (Dunn test, p= 0.0044).
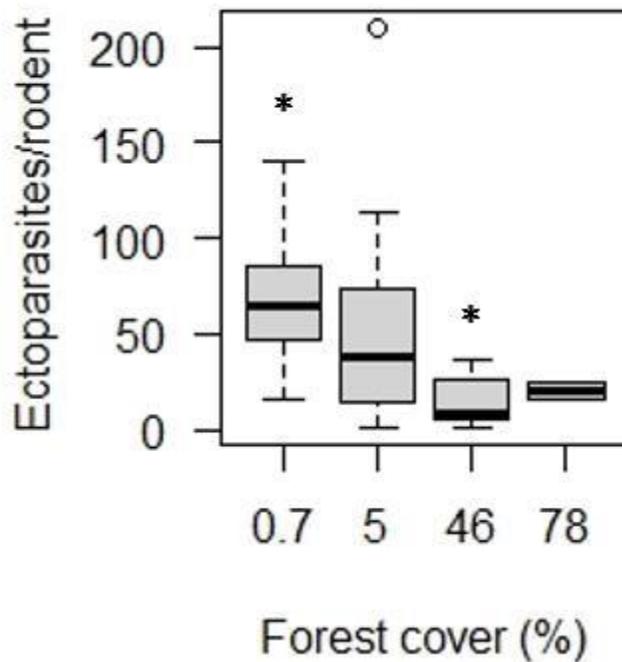
**Figure 6** Comparison of the abundance of ectoparasites recorded in individuals of *Sigmodon toltecus* captured

in sites with different levels of forest coverage in the region of Marques de Comillas in the state of Chiapas,

southern Mexico. * Sites statistically different based on Dunn test (P< 0.05)**.**

**Table 2** Ectoparasite species recorded in the rodent species captured in the Marques de Comillas region in the state of Chiapas, southern Mexico. The black dots indicate that the ectoparasite was present.

| Order | Ectoparasites | Host | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| | | *S. toltecus* | *H. desmarestianus* | *O. phyllotis* | *O. couesi* | *P. mexicanus* |
| Mesostigmata | *Androlaelaps fahrenholzi* (Berlese 1911) | ● | | | ● | |
| | *Echinonyssus* sp.[1] | | ● | | | |
| | *Echinonyssus* sp.[2] (C.a. *E. liomys*) | | ● | ● | | |

| Order | Species | | | | | |
|---|---|---|---|---|---|---|
| | *Echinonyssus* sp.³ (C.a. *E. isabela and E. teresa*) | | ● | | | |
| | *Echinonyssus* sp.⁴ | | ● | | ● | |
| | *Echinonyssus* sp.⁵ | ● | | | ● | |
| | *Laelaps manguinhosi* (Fonseca 1935) | ● | ● | | ● | ● |
| | *Steptolaelaps heteromys* (Bassols 1975) | | ● | ● | ● | ● |
| | *Gigantolaelaps boneti* (Bassols de Barrera 1970) | | | | | ● |
| | *Ornithonyssus bacoti* (Hirst 1913) | ● | | | | |
| Sarcoptiformes | *Prolistrophorus* sp. (C.a. *P. monilistriatus*) | | | | ● | |
| | *Prolistrophorus grassii* (Radford 1954) | ● | | | ● | |
| | *Prolistrophorus bakeri* (Radford 1949) | ● | | | ● | |
| | *Geomylichus nectomys* (Fain 1978) | | ● | | | |
| | *Dermacarus* sp. | | ● | | | |
| Phthiraptera | *Hoplopleura hirsuta* (Ferris 1916) | ● | | | ● | ● |
| | *Fahrenholzia ferrisi* (Werneck 1952) | | ● | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Trombidiformes | *Cordiseta mexicana* (Hoffmann 1954) | | | ● | | |
| | *Pseudoschoengastia brennani* (Hoffmann 1960) | | | ● | | |
| | *Parasecia kansasensis* (Loomis 1955) | ● | | | | |
| | *Dermadelema mojavense* (Pomeroy and Loomis 1984) | | | ● | | |
| | *Eutrombicula batatas* (Linnaeus 1758) | | | | ● | |
| Ixodida | *Amblyomma* sp. | ● | ● | | ● | ● |

**Discussion**

In agreement with our predictions, we found that rodent abundance decreases, and ectoparasite abundance increases with forest loss. The rodent species we recorded constitutes approximately 50% of the total number of species recorded in the Lacandon forest (Cruz et al., 2004). However, the species *S. toltecus*, *O. couesi*, *H. desmarestianus,* and *P. mexicanus,* were those more likely to be captured, with our sampling design, due to their abundance and ground-dwelling habits (Cruz et al., 2004; San José et al., 2014). This is illustrated by the fact that we only captured one individual of *O. phyllotis,* a species with arboreal habits (Hernández et al., 2008). It would be highly desirable to include surveys of the canopy fauna

in future studies to have a more complete view of the impact forest loss is having on the rodents and their associated ectoparasites. We recorded the greatest species richness of rodents in sites with intermediate levels of forest coverage (GIL_46% y CHP_78%). This likely relates to the presence in these sites of greater habitat heterogeneity associated with the mixture of vegetation in different levels of secondary succession, forest fragments, crop, commercial plantations, and cattle pasture (e.g., Ssuuna et al., 2020).

Our results indicate that species such as *S. toltecus* and *O. couesi* would likely result benefited from the extensive transformation of the landscape in our study region. These species are omnivorous and include a variety of grasses and seeds in their diets. This can help them to thrive in areas dominated by cattle pasture and monocultures (Peña et al., 2009). Moreover, these species have reduced gestation periods (no longer than one month) and produce on average 8 individuals per litter (Ceballos and Oliva 2005). Other studies have similarly found that these species thrive in modified landscapes (Howe and Davlantes 2017). On the other hand, species such as *H. desmarestianus* and *P. mexicanus* are known to have the capacity to move across areas with pasture or crops but their presence tends to be more associated with mature forests (Ceballos and Olivia 2005).

The observed impacts on the rodent fauna impacted, in turn, the abundance and composition of the associated ectoparasites. We obtained some evidence that the ecoparasite load increases with forest loss. A similar effect was reported by Froeschke et al., (2013) in fragmented forests in South Africa. These authors suggest that this effect relates to the fact that the conditions in the transformed habitats offer greater availability of resources such as water and a lower presence of predators. These conditions can in turn favor peridomestic rodents to reach a larger body size and therefore to have greater to carry a larger number of

ectoparasites. In contrast, other studies have suggested that the conditions prevailing on forest fragments and their edges negatively affect the presence of ectoparasites in comparison with those prevailing within forests (Rubio and Simonetti 2009; Kiene et al., 2020). This would emerge as a result of the associated changes in temperature, humidity, and solar incidence. Therefore, more research is needed to shed light on the mechanisms involved in the changes of ectoparasite load in rodents.

Studies conducted in Mexico have detected pathogens causing diseases such as leishmaniasis, Chagas, rickettsiosis, and hemorrhagic fever in all the rodent species we recorded in this study (Van et al., 2009; Cajimat et al., 2012; Milazzo et al., 2012; Lorenzo et al., 2017; Rengifo et al., 2017; Panti et al., 2021). It is of great importance to continuously monitor the abundance of rodent species to timely detect disease emergence. For instance, it has been shown that the incidence of Lyme disease increases with changes in vegetation cover and the loss of natural predators controlling the population size of animal species that are the host for vectors of zoonotic diseases such as ticks (Jongejan and Uilenberg 2004; Racelis et al., 2012; Ostfeld and Keesing 2013; Mysterud et al., 2015). Ticks are very dangerous vectors due to their hematophagous diet and need to have several hosts to complete their life cycles (Stafford et al., 1995; Main and Bull 2000). Moreover, other arthropod species we detected such as *Amblyomma* sp., *O. bacoti,* and *A. fahrenholzi* can be vectors of viruses and bacteria such as *Hantavirus, Flavirus*, *Rickettsia, Borrelia,* and *Bartonella*, (Moro et al., 2005; Kabeya et al., 2010; Zapata et al., 2017). There is evidence that the increased abundance of *O. bacoti* is associated with disease incidence in domestic animals and humans (Rosen et al., 2002; Beck 2008; Beck and Fölster 2009). There are no current

reports on human infections associated with *A. fahrenholzi* however, the presence of *Rickettsia* and *Bartonella* has been reported in Mexico (Zapata et al., 2017).

We also recorded the presence of parasitic larvae of arthropods in the order Trombidiformes (*C. mexicana, P. brennani, P. kansasensis, D. mojavense,* and *E. batatas*). There are no records of these species been associated with etiological agents; however, the larvae of other trombiculid species such as *Neotrombicula autumnalis, Microtrombicula* sp. and, *Leptotrombidium scutellare* are known to be vectors of pathogens including Caulobacter *yokenella* and species in the genera *Actinomycetospora, Coxiella,* and *Bosea* (Masakhwe et al., 2018). The parasitic larvae of the species in these genera are causing important affectations of health in both wild mammals and humans by producing severe dermatitis (Chaccour 2005; Santibañez et al., 2014). Some authors have suggested trombiculids are benefited from forest loss due to the fact organisms in this group are adapted to live in areas where short vegetation and weeds are common such as it occurs in anthropogenic forest edges (Chaccour 2005).

In this study, we did not detect the presence of fleas in the captured rodents. Fleas are of particular interest due to the fact they can carry the pest vector *Yersinia pestis* (Carlson et al., 2021). The continued monitoring of our study area will help to discard the possibility that this lack of detection of fleas is related to a stational variation in the abundance of these organisms (Herrero et al., 2021).

It is important to highlight the fact that not in all the cases arthropods found in the fur of small rodents are true parasites. Some arthropod species take advantage of rodents for transportation purposes (phoresis) or that establish relationships of commensalism or proto cooperation (Kim 1985). These species receive less attention due to the fact they are not associated with disease transmission (Guzmán et al., 2020; Morales et al., 2020; Cornejo et

al., 2021). However, the study of this group of species is needed to gain a deeper understanding of the response of biodiversity to anthropic perturbation.

From the different 23 groups of ectoparasites we recorded, we were only able to identify 15 to the species level and the remaining 8 to the genus level. In some instances, samples corresponded to individuals in the larval stage (e.g., *Amblyomma* sp.) complicating their taxonomic determination. Likewise, mites belonging to the genus *Echinonyssus* (species 1 to 5), *Prolistrophorus,* and *Dermacarus* had morphological traits that did not match exactly those of the currently described species therefore, they might constitute new species. Threre is an ongoing study to explore this possibility.

To have a more accurate description of the ectoparasite fauna associated with rodents in our study area we rested on euthanization. This approach has been used in previous studies focused on studying the ectoparasite fauna in rodents (Estébanes and Cervantes 2005; Nava et al., 2007; Gómez et al., 2015). We conducted a test to compare the information we obtained by brushing the rodent´s body in situ and when conducting the corresponding analysis at the lab. In this test, we found that the number of ectoparasite individuals we recorded in situ was approximately 5% of the corresponding amount recorded in the lab, this also affected the recording of ectoparasite species presence in the rodents. This contrast likely relates to the fact that some ectoparasites (e.g., trombiculids and thicks) are strongly attached to the rodent's skin or hidden in corporal cavities which make it difficult to reach them with a brush. Using euthanization caused we preferred to reduce our rodent's sample size. The continuation of a monitoring program of rodent's ectoparasites could help to define the most effective monitoring protocol to reduce the unnecessary impact on forest native rodents. On the other hand, the incorporation of other techniques to capture rodents such as pitfall traps could help

to increase capture success and reduce the costs of trap loss when they are located in very exposed areas (e.g., cattle pastures) (Noblecilla 2020).

The health, social and economic impacts of zoonotic disease associated with wild fauna have generated great concern among scientists, medical institutions, and people in general (El Amri et al., 2020; Saba and Balwan 2021). Unfortunately, this generalized concern has not been reflected yet in a significant change in the factors propelling tropical forest deforestation and wildlife overexploitation as well as their potential interactions with climate change (Romero 2021; Stenvinkel et al., 2021). A more active impulse in making operative public policies and conservation strategies focused on protecting tropical forests and wildlife looks like the most effective way to reduce the emergence of zoonotic diseases and to reduce their potential impacts on humans.

## References

Allen T, Murray KA, Zambrana TC, Morse SS, Rondinini C, Di Marco M, Daszak P (2017). Global hotspots and correlates of emerging zoonotic diseases. Nature communications, 8(1), 1-10. https://doi.org/10.1038/s41467-017-00923-8

Arrivillaga J, Caraballo V (2009). Medicina de la Conservación. Revista Biomédica, 20(1), 55-67. https://doi.org/10.32776/revbiomed.v20i1.528

Bassols BI (1975). Mesostigmata de los mamíferos de México, con especial referencia a la subfamilia Laelapinae (Acari: Parasitiformes). Esc. Nal. Cien. Biol. IPN Tesis Doctoral, 340-340.

Borcard D, Gillet F, Legendre P (2018) Ordenación canónica. En: Ecología numérica con R. Use R!. Springer, Cham. https://doi.org/10.1007/978-3-319-71404-2_6

Cajimat MN, Milazzo ML, Bradley RD, Fulhorst CF (2012). Ocozocoautla de Espinosa Virus and Hemorrhagic Fever, Mexico. Emerging Infectious Diseases, 18(3), pp. 401-405. https://doi.org/10.3201 /eid1803.111602

Carabias J, De La Maza J, Cadena R (2015). Conservación y desarrollo sustentable en la Selva Lacandona. Natura y ecosistemas mexicanos, AC México.

Carabias LJ, Provencio E, De la Maza EJ, Gutiérrez CD, Gómez CM, López PA (2000). Programa de manejo Reserva de la Biosfera Montes Azules. Instituto Nacional de Ecología INE. México.

Carlson CJ, Bevins SN, Schmid BV (2021). Pest Risk in the Western United States During Seven Decades of Environmental Change. bioRxiv. https://doi.org/10.1101/2021.02.26.433096

Cavada N, Worsøe HR, Scharff N, Rovero F (2019). A landscape-scale assessment of tropical mammals reveals the effects of habitat and anthropogenic disturbance on

community       occupation.       PloS       one,       14       (4),       e0215682.

        https://doi.org/10.1371/journal.pone.0215682

Ceballos G, Oliva G (2005). Los mamíferos silvestres de México (Vol. 986). México:

        Fondo de Cultura Económica.

Chaccour CJ (2005). Trombiculiasis: reporte de dos casos y revisión de la literatura.

        Dermatología venezolana, 43(2).

Chao A, Chiu CH, Jost L (2014). Unifying species diversity, phylogenetic diversity,

        functional diversity, and related similarity and differentiation measures through

        Hill numbers. Annual review of ecology, evolution, and systematics, 45, 297-324.

        https://doi.org/10.1146/annurev-ecolsys-120213-091540

Cornejo CG, Mares AH (2021). Parásitos y pelos: historias de la selva de Chamela.

        Revista               Digital               Universitaria,               22(3).

        http://doi.org/10.22201/cuaieed.16076079e.2021.22.3.2

Cruz LE, Lorenzo C, Retana OG, Sántiz EC (2010). Interspecific variability in the

        abundance of small rodents in the highlands of Chiapas, Mexico. Therya, 1(2),

        129-135. https://doi.org/10.12933/therya-10-11

Cruz LL, Lorenzo C, Soto L, Naranjo E, Ramírez ME (2004). Diversidad de mamíferos

        en cafetales y selva mediana de las cañadas de la Selva Lacandona, Chiapas,

        México. Acta Zool. Mex. vol.20 no.1 Xalapa.

de la Torre JA, Medellín RA (2011). Jaguares Panthera onca en el Gran Ecosistema

        Lacandona, Chiapas, México: estimaciones poblacionales y perspectivas futuras.

        Oryx, 45 (4), 546-553. https://doi.org/10.1017/S0030605310001511

Dudley N, Alexander S (2017). Agriculture and biodiversity: a review. Biodiversity, 18(2-

        3), 45-49. https://doi.org/10.1080/14888386.2017.1351892

Egeru A, Dejene SW, Siya A (2020). Short report on implications of Covid-19 and emerging zoonotic infectious diseases for pastoralists and Africa. Pastoralism, 10(1), 1-10. https://doi.org/10.1186/s13570-020-00173-2

El Amri H, Boukharta M, Zakham F, Ennaji MM (2020). Emergence and reemergence of viral zoonotic diseases: concepts and factors of emerging and reemerging globalization of health threats. In Emerging and Reemerging Viral Pathogens (pp. 619-634). Academic Press. https://doi.org/10.1016/B978-0-12-819400-3.00027-2

Estébanes GM, Cervantes FA (2005). Mites and ticks associated with some small mammals in Mexico. International Journal of Acarology, 31(1), 23-37. https://doi.org/10.1080/01647950508684413

Fain A, Lukoschus FS (1984). New observations on the genus Prolistrophorus Fain, 1970 (Acari: Astigmata: Listrophoridae). Systematic Parasitology, 6(3), 161-185.

Froeschke G, van der Mescht L, McGeoch M, Matthee S (2013). Life history strategy influences parasite responses to habitat fragmentation. International Journal for Parasitology, 43(14), 1109-1118. https://doi.org/10.1016/j.ijpara.2013.07.003

Gayley K, Sridith K (2020). The vegetation status of regrowth forests in abandoned farmlands in the subtropical forest of Eastern Bhutan Himalaya. Taiwania, 65(3), 336. https://taiwania.ntu.edu.tw/pdf/tai.2020.65.336.pdf.

Gómez RR, Gutiérrez GG, Montiel PG, Rodríguez M.Á, Sánchez CV (2015). Diversity and coexistence of ectoparasites in small rodents in a tropical dry forest. Biotropica, 47(4), 484-490.

Gordon L, Kirkland Jr. (1998). Guidelines for the Capture, Handling, and Care of Mammals as Approved by the American Society of Mammalogists, Journal of Mammalogy, Volume 79, Issue 4, 3 December 1998, Pages 1416–1431.

https://doi.org/10.2307/1383033

Guzmán CC, Herrera MA, Ugalde MA, López PA, Del Castillo ML, Acosta GR, Morales MJ (2020). Arthropods associated with mammals. Their importance as part of the richness in a Biosphere Reserve in Mexico. Journal of medical entomology, 57(3), 780-787. https://doi.org/10.1093/jme/tjz237

Guzmán CC, Robbins RG, Guglielmone AA, Montiel PG, Pérez TM (2011). The *Amblyomma* (Acari: Ixodida: Ixodidae) of Mexico: identification keys, distribution and hosts. Zootaxa, 2998(1), 16-38. https://doi.org/10.11646/zootaxa.2998.1.2

Hammond TT, Hendrickson CI, Maxwell TL, Petrosky AL, Palme R, Pigage JC, Pigage HK (2019). Host biology and environmental variables differentially predict flea abundances for two rodent hosts in a plague-relevant system. International Journal for Parasitology: Parasites and Wildlife, 9, 174-183. https://doi.org/10.1016/j.ijppaw.2019.04.011

Hernández BS, Cimé Pool JA, Medina PS, González VM (2008). Fluctuación poblacional de Ototylomys phyllotis Merriam, 1901 (Rodentia: Muridae) en una selva mediana subcaducifolia del sur de Yucatán, México. Acta zoológica mexicana, 24(2), 161177.

Herrero CS, Flechoso MF, Rodríguez PR, Luque LJ, Mougeot F (2021). Patterns of flea infestation in rodents and insectivores from intensified agro-ecosystems, Northwest Spain. Parasites & Vectors, 14(1), 1-13.

https://doi.org/10.1186/s13071-020-04492-6

Howe HF, Davlantes J (2017). Waxing and waning of a cotton rat (Sigmodon toltecus) monoculture in early tropical restoration. Tropical Conservation Science. https://doi.org/10.1177/1940082917704772

Hsieh TC, Ma KH, Chao A (2019). iNEXT: Interpolation and extrapolation for species diversity. R package version 2.0.19. https://doi.org/10.1111/2041-210X.12613

INAFED (2010) Instituto Nacional para el Federalismo y el Desarrollo Municipal. http://www.inafed.gob.mx. Accessed 12 February 2019.

Jacobson AP, Riggio J, Tait AM, Baillie JE (2019). Global areas of low human impact ('Low Impact Areas') and fragmentation of the natural world. Scientific Reports, 9 (1), 1-13. https://doi.org/10.1038/s41598-019-50558-6

Johnstone CP, Lill A, Reina RD (2014). Habitat loss, fragmentation and degradation effects on small mammals: Analysis with conditional inference tree statistical modelling. Biological Conservation, 176, 80-98. https://doi.org/10.1016/j.biocon.2014.04.025

Jongejan F, Uilenberg G (2004). The global importance of ticks. Parasitology, 129(S1), S3-S14. https://doi.org/10.1017/S0031182004005967

Kabeya H, Colborn JM, Bai Y, Lerdthusnee K, Richardson JH, Maruyama S, Kosoy MY (2010). Detection of Bartonella tamiae DNA in rodent ectoparasites in Thailand and its sequence similarity to bacterial cultures from Thai patients. Zoonotic and Vector-Borne Diseases, 10 (5), 429-434. https://doi.org/10.1089/vbz.2009.0124

Kamani J, Morick D, Mumcuoglu KY, Harrus S (2013). Prevalence and diversity of Bartonella species in commensal rodents and ectoparasites from Nigeria, West Africa. PLoS Negl Trop Dis, 7(5), e2246. https://doi.org/10.1371/journal.pntd.0002246

Kiene F, Andriatsitohaina B, Ramsay MS, Rakotondramanana H, Rakotondravony R, Radespiel U, Strube C (2020). Forest edges affect ectoparasite infestation patterns of small mammalian hosts in fragmented forests in Madagascar. International Journal for Parasitology. https://doi.org/10.1016/j.ijpara.2020.01.008

Kim KC (1985). Coevolution of parasitic arthropods and mammals. Wiley.

Ladds Z (2015). Impacts of tropical rainforest disturbance on mammalian parasitism (Doctoral dissertation, Department of Life Sciences, Silwood Park, Imperial College London).

Lareschi M, Savchenko E, Urdapilleta M (2019). Ectoparasites associated with sigmodontine rodents from northeastern Argentina. Therya, 10(2), 103-108. https://doi.org/10.12933/therya-19-758

Lorenzo MC, Rioja PT, Carrillo RA, Bolaños CJ, Sántiz EC, Navarrete GD (2017). Enfermedades zoonóticas virales emergentes. Importancia ecológica y su evaluación en el sureste de México. Sociedad y ambiente, (15), 131-146.

Madinah A, Abang F, Mariana A, Abdullah MT, Mohd AJ (2014). Interaction of ectoparasites-small mammals in tropical rainforest of Malaysia. Community Ecology, 15(1), 113-120. https://doi.org/10.1556/comec.15.2014.1.12

Main AR, Bull CM (2000). The impact of tick parasites on the behaviour of the lizard *Tiliqua rugosa*. Oecologia, 122(4), 574-581.

Martínez RM, Anten NP, Ackerly, DD (2009). Defoliation and ENSO effects on vital rates of an understorey tropical rain forest palm. Journal of Ecology, 97(5), 1050-1061.

Masakhwe C, Linsuwanon P, Kimita G, Mutai B, Leepitakrat S, Yalwala S, Waitumbi J (2018). Identification and characterization of Orientia chuto in trombiculid chigger mites collected from wild rodents in Kenya. Journal of clinical microbiology, 56(12), e01124-18. https://doi.org/10.1128/JCM.01124-18

McMurray A, Casarim F, Bernal B, Timothy P, Sidman G (2017). The ecosystem services of tropical forests and a proposed framework to assess them. Analysis of the ecosystem services provided by tree plantations and agroforestry systems.

Mendoza E, Dirzo R (1999). Deforestation in Lacandonia (southeast Mexico): evidence for the declaration of the northernmost tropical hot-spot. Biodiversity & Conservation, 8(12), 1621-1641. https://doi.org/10.1023/A:1008916304504

Mendoza H, Rubio AV, García PG, Suzán G, Simonetti JA (2020). Does land-use change increase the abundance of zoonotic reservoirs? Rodents say yes. European Journal of Wildlife Research, 66(1), 6. https://doi.org/10.1007/s10344-019-1344-9

Mendoza SV. Horváth A (2013). Rodents and bats in the coffee zone from Tacaná Volcano, Chiapas, Mexico. THERYA, Vol. 4(2):409-423. https://doi.org/10.12933/therya-13-116

Milazzo ML, Cajimat MN, Romo HE, Estrada FJ, Íñiguez DL, Bradley RD, Fulhorst CF (2012). Geographic Distribution of Hanta Viruses Associated with Neotomine and Sigmodontine Rodents, Mexico. Emerging Infectious Diseases, 18(4), pp. 571-576. https://doi.org/10.3201/eid1804.111028

Morales MJ, Castaño MG, Klompen H, Mancina CA (2020). New species of the Genus *Periglischrus* (Acari: Spinturnicidae) from Monophyllus bats (Chiroptera:

Phyllostomidae) in the West Indies, including a morphometric analysis of its intraspecific variation. Journal of medical entomology, 57(2), 418-436. https://doi.org/10.1093/jme/tjz198

Morand S, Blasdell K, Bordes F, Buchy P, Carcy B, Chaisiri K, Tran A (2019). Changing landscapes of Southeast Asia and rodent-borne diseases: decreased diversity but increased transmission risks. Ecological Applications, 29(4), e01886. https://doi.org/10.1002/eap.1886

Morante FJ, Arroyo RV, Pessoa MD, Cazetta E, Faria D (2018). Direct and cascading effects of landscape structure on tropical forests and non-forest frugivorous birds. Ecological Applications, 28 (8), 2024-2032. https://doi.org/10.1002/eap.1791

Moro CV, Chauve C, Zenner L (2005). Vector role of some dermanyssoides mites (Acari, Mesostigmata, Dermanyssoidea). Parasite, 12 (2), 99-109. https://doi.org/10.1051/parasite/2005122099

Moyer BR, Drown DM, Clayton DH (2002). Low humidity reduces ectoparasite pressure: implications for host life history evolution. Oikos, 97(2), 223-228. https://doi.org/10.1034/j.1600-0706.2002.970208.x

Muench C, Martínez RM (2016). ¿Can community-protected areas conserve biodiversity in human-modified tropical landscapes? The case of terrestrial mammals in southern Mexico. Tropical Conservation Science. Vol. 9 (1): 178-202. https://doi.org/10.1177/194008291600900110

Mysterud A, Byrkjeland R, Qviller L, Viljugrein H (2015). The generalist tick *Ixodes ricinus* and the specialist tick *Ixodes trianguliceps* on shrews and rodents in a northern forest ecosystem–a role of body size even among small hosts. Parasites

& vectors, 8(1), 1-10. https://doi.org/10.1186/s13071-015-1258-7

Nava S, Lareschi M, Rebollo C, Benítez UC, Beati L, Robbins RG, Guglielmone AA

(2007). The ticks (Acari: Ixodida: Argasidae, Ixodidae) of Paraguay. Annals of

Tropical Medicine & Parasitology, 101(3), 255-270.

https://doi.org/10.1179/136485907X176319

Noblecilla HM (2020). Efectos de la pérdida de bosque sobre los roedores cricétidos en

Carpish, Huánuco, Perú. Revista peruana de biología, 27(4), 499-508.

http://dx.doi.org/10.15381/rpb.v27i4.17211

Ogle DH, Wheeler P, Dinno A (2021). FSA: Fisheries Stock Analysis. R package version

0.8.32, https://github.com/droglenc/FSA.

Oksanen JF, Blanchet GM, Kindt RP, McGlinn D, Minchin PR, O'Hara RB, Simpson GL,

Solymos P, Stevens HH, Szoecs E, Wagner H (2020). vegan: Community Ecology

Package. R package version 2.5-7. https://CRAN.R-project.org/package=vegan.

Ostfeld RS, Holt RD (2004). ¿Are predators good for your health? Evaluating evidence

for top-down regulation of zoonotic disease reservoirs. Frontiers in Ecology and

the Environment, 2(1), 13-20. https://doi.org/10.1890/1540-9295(2004)002 [0013:

APGFYH]2.0.CO;2

Ostfeld RS, Keesing F (2013). Straw Men Don't Get Lyme Disease: Answer to Wood and

Lafferty. Trends Ecol Evol, 28 (9), 502-503.

http://dx.doi.org/10.1016/j.tree.2013.05.009

Palacios VJ, Mejía RB (2007). Técnicas de colecta, montaje y preservación de

microartrópodos edáficos. 1era edición 2007. Pp. 47-60.

Panti MJ, Torres CM, Hernández BS (2021). Zoonotic parasites and micromammals in the

yucatan peninsula, mexico: contributions of the CCBA-UADY. Tropical and

Subtropical Agroecosystems, 24(1).

Peña RJ, López CJ, Alarcón ZB, Vargas MM, Vázquez L, Landeros SC (2009). Composición de la dieta de *Sigmodon hispidus* (Rodentia: Cricetidae) en caña de azúcar. Mastozoología neotropical, 16(2), 365-378.

Pérez J, Brescia F, Becam J, Mauron C, Goarant C (2011). Rodent abundance dynamics and leptospirosis carriage in an area of hyper-endemicity in New Caledonia. PLoS neglected tropical diseases, 5(10), e1361. https://doi.org/10.1371/journal.pntd.0001361

Portela R, Dirzo R (2020). The fragmentation and defamation of forests lead to an unusual ecological cascade: release of predations, explosion of the monkey population, and plant population collapse. Biological Conservation, 252, 108852. https://doi.org/10.1016/j.biocon.2020.108852

Prist PR, Prado A, Tambosi LR, Umetsu F, de Arruda Bueno A, Pardini R, Metzger JP (2020). Moving to healthier landscapes: Forest restoration decreases the abundance of Hantavirus reservoir rodents in tropical forests. Science of The Total Environment, 752, 141967. https://doi.org/10.1016/j.scitotenv.2020.141967

R core team (2020). R: A language and enviroment for statistical computing. R Foundation for statistical computing, Vienna, Austria. URL https://www.Rproject.org/

Racelis AE, Davey RB, Goolsby JA, De León AP, Varner K, Duhaime R (2012). Facilitative ecological interactions between invasive species: Arundo donax stands as favorable habitat for cattle ticks (Acari: Ixodidae) along the US–Mexico border. Journal of medical entomology, 49(2), 410-417. https://doi.org/10.1603/ME11104 Rahman M, Sobur M, Islam M, Ievy S, Hossain M, El Zowalaty ME, Ashour HM (2020).

Zoonotic Diseases: Etiology, Impact, and Control. Microorganisms, 8(9), 1405. https://doi.org/10.3390/microorganisms8091405

Ramalho OM, Gubler DJ (2020). Human Diseases Associated with Vectors (Arthropods in Disease Transmission). In Hunter's Tropical Medicine and Emerging Infectious Diseases (pp. 1063-1069). Content Repository Only. https://doi.org/10.1016/B978-0-323-55512-8.00147-2

Reeves WK, Durden LA, Ritzi CM, Beckham KR, Super PE, OConnor BM (2007). Ectoparasites and other ectosymbiotic arthropods of vertebrates in the Great Smoky Mountains National Park, USA. Zootaxa, 1392(1), 31-68. https://doi.org/10.11646/zootaxa.1392.1.2

Rengifo CL, Stephens CR, Morrone JJ, Téllez RJ, Gonzalez SC (2017). Understanding transmissibility patterns of Chagas disease through complex vector-host networks. Parasitology, 144(6), 760. https://doi.org/10.1017/S0031182016002468

Romero LE (2021). Crisis ambiental y colapso en América Latina. In Alternativas al colapso socioambiental desde América Latina (pp. 14-31). Bielefeld University Press, transcript. https://doi.org/10.14361/9783839448939-004

Rubio AV, Ávila FR, Suzán G (2014). Responses of small mammals to habitat fragmentation: epidemiological considerations for rodent-borne hantaviruses in the Americas. EcoHealth, 11(4), 526-533. https://doi.org/10.1007/s10393-014-0944-9

Rubio AV, Simonetti JA (2009). Ectoparasitismo por larvas de Eutrombicula alfreddugesi (Acari: Trombiculidae) en el lagarto Liolaemus tenuis en un bosque templado fragmentado chileno. Revista de parasitología, 95 (1), 244-245.

Rynkiewicz EC, Hawlena H, Durden LA, Hastriter MW, Demas GE, Clay K (2013).
Associations between innate immune function and ectoparasites in wild rodent
hosts. Parasitology research, 112(4), 1763-1770. https://doi.org/10.1007/s00436-
013-3335-1

Saba N, Balwan WK (2021). Potential Threat of Emerging and Re-Emerging Zoonotic
Diseases. Annals of the Romanian Society for Cell Biology, 29-36.

San José M, Arroyo RV, Sánchez CV (2014). Association between small rodents and
forest patch and landscape structure in the fragmented Lacandona rainforest,
Mexico. Tropical Conservation Science, 7(3), 403-422.
https://doi.org/10.1177/194008291400700304

Santibañez SP, Palomar UA, Imaña RE, Oteo RJ (2014). Dermatitis pruriginosa tras paseo
por la montaña. Enferm. infecc. microbiol. clín. (Ed. impr.), 610-611.
https://doi.org/10.1016/j.eimc.2014.04.009

Sayer CA, Bullock JM, Martin PA (2017). Dynamics of avian species and functional
diversity in secondary tropical forests. Biological Conservation, 211, 1-9.
https://doi.org/10.1016/j.biocon.2017.05.004

Soto PL, Jiménez FG, Castillo SM (2012). Agroforestry systems and local institutional
development for preventing deforestation in Chiapas, Mexico. INTECH Open
Access Publisher. https://doi.org/10.5772/35172

Ssuuna J, Makundi RH, Isabirye M, Sabuni CA, Babyesiza WS, Mulungu LS (2020).
Rodent species composition, relative abundance, and habitat association in the
Mabira Central Forest Reserve, Uganda. Journal of Vertebrate Biology, 69(2),
20021-1. https://doi.org/10.25225/jvb.20021

Stafford III KC, Bladen VC, Magnarelli LA (1995). Ticks (Acari: Ixodidae) infesting wild

    birds (Aves) and white-footed mice in Lyme, CT. Journal of Medical Entomology,

    32(4), 453-466. https://doi.org/10.1093/jmedent/32.4.453

Stenvinkel P, Painer J, Shiels PG, Bansal A, Fereidouni S, Natterson HB, Miranda JJ

    (2021). SARS-COV-2 and biomimetics: What saves the planet will save our

    health. Journal of Internal Medicine. https://doi.org/10.1111/joim.13128

Stojanovich CJ, Pratt HD (1961). Key to the North American sucking lice in the genera

    *Hoplopleura* and *Neohaematopinus* with descriptions of two species:(Anoplura:

    Hoplopleuridae). The Journal of Parasitology, 47(2), 312-316.

    https://doi.org/10.2307/3275316

Suzán G, Armién A, Mills JN, Marcé E, Ceballos G, Ávila M, Yates TL (2008).

    Epidemiological considerations of rodent community composition in fragmented

    landscapes in    Panama.    Journal    of    Mammalogy, 89(3),

    684-690. https://doi.org/10.1644/07-MAMM-A-015R1.1

Suzán G, Marcé E, Giermakowski JT, Mills JN, Ceballos G, Ostfeld RS, Yates TL (2009).

    Experimental evidence for reduced rodent diversity causing increased *hantavirus*

    prevalence. PloS one, 4(5), e5461. https://doi.org/10.1371/journal.pone.0005461

Symes WS, Edwards DP, Miettinen J, Rheindt FE, Carrasco LR (2018). Combined

    impacts of deforestation and wildlife trade on tropical biodiversity are severely

    underestimated.    Nature    communications,    9(1),    1-9.

    https://doi.org/10.1038/s41467-018-06579-2

Thompson ME, Donnelly MA (2018). Effects of secondary forest succession on

    amphibians and reptiles: review and meta-analysis. Copeia, 106 (1), 10-19.

    https://doi.org/10.1643/CH-17-654

Van WN, Canto LS, Sosa BE, Rivero CN, Andrade NF (2009). Comparison of small mammal prevalence of *Leishmania* (*Leishmania) mexicana* in five foci of cutaneous leishmaniasis in the state of Campeche, Mexico. Revista do Instituto de Medicina Tropical de São Paulo, 51(2), 87-94. https://doi.org/10.1590/S0036-46652009000200006

Vélez GF, Pérez TJ (2010). Remoción de semillas por roedores en un fragmento de bosque seco tropical (Risaralda-Colombia). Revista MVZ Córdoba, 15(3), 2223-2233.

Wells K, Smales LR, Kalko EK, Pfeiffer M (2007). Impact of rain-forest logging on helminth assemblages in small mammals (Muridae, Tupaiidae) from Borneo. Journal of Tropical Ecology, 35-43. https://doi.org/10.1017/S0266467406003804

Wies G, Arzeta SN, Martínez RM (2021). Critical ecological thresholds for conservation of tropical rainforest in Human Modified Landscapes. Biological Conservation, 255, 109023. https://doi.org/10.1016/j.biocon.2021.109023

Young HS, Dirzo R, Helgen KM, McCauley DJ, Billeter SA, Kosoy MY, Dittmar K (2014). Declines in large wildlife increase landscape-level prevalence of rodentborne disease in Africa. Proceedings of the National Academy of Sciences, 111(19), 7036-7041. https://doi.org/10.1073/pnas.1404958111

Zapata MR, Guzmán CC, Acosta GR, Martínez NY, Sánchez MS, Hernández SM (2017). Detection of bacteria associated with ectoparasites from *Sigmodon toltecus* from the Biosphere Reserve Sierra del Abra Tanchipa, San Luis Potosí (México). ENICIP C. Trabajos presentados-VI Congreso Latinoamericano de Enfermedades Rickettsiales & I Encuentro de Ecología y Control de Ectoparásitos. Revista Colombiana de Ciencias Pecuarias, 30, 295-333, pp 303.

Zar JH (2010). Biostatistical analysis Pearson Prentice-Hall. Upper Saddle River, Nueva

Jersey, EE. UU.

## VI.    Discusión general

Los resultados de este estudio apoyan el que la transformación de los paisajes tropicales, puede promover una mayor incidencia de ectoparásitos hematófagos potenciales transmisores de enfermedades zoonóticas.

Los roedores generalistas y sinantrópicos presentan características que les permiten llegar a convertirse en plagas que generan grandes pérdidas económicas para la industria agrícola (Sánchez & Martínez, 2000; Brown et al., 2007). Por el contrario, los bosques intactos o menos perturbados, exhiben mayor riqueza de especies de roedores, aunque una menor abundancia de individuos (Suzán et al., 2008; Morand et al., 2019). Esto último probablemente está asociado con la heterogeneidad de microhábitats, microclimas y recursos que se pueden encontrar en el bosque, los cuales pueden ser aprovechados por diferentes gremios de roedores (Melo et al., 2013). Se ha observado, que una alta riqueza de especies hospedadoras puede reducir la incidencia de microorganismos etiológicos, mediante un efecto de dilución (Khalil et al., 2016; Min et al., 2021). Esto debido a que en la naturaleza no todos los organismos se muestran como competentes a la hora de propagar patógenos, por lo que, una gran diversidad inmunológica entre taxones o poblaciones de la misma especie, contribuyen a amortiguar la propagación de estos organismos infecciosos (Schmidt & Ostfeld, 2001). Si bien, la prevalencia de patógenos se correlaciona negativamente con una alta diversidad de especies, existen factores como: la densidad poblacional de las especies y, el hábitat de acogida para el agente infeccioso, entre otros, que pueden modular la prevalencia y la dinámica de las zoonosis (Luis et al., 2018; Rodríguez et al., 2019).

El monitoreo del incremento o reducción en la diversidad de ectoparásitos es necesaria debido a que puede tener implicaciones negativas con la salud humana y doméstica. En primer lugar, nueva fauna ectoparásita puede actuar como un vehículo que conduzca patógenos desconocidos, desde ecosistemas naturales menos explorados hacia zonas rurales o urbanizadas donde se encuentran organismos domesticados que entran en contacto con el ser humano (Harrus & Baneth, 2005). En segundo lugar, es importante reconocer que tipo de organismos ectoparásitos predominan en los ambientes degradados, haciendo énfasis en parásitos, como: las pulgas, garrapatas y otros ácaros hematófagos, reconocidos como vectores innatos de diversas especies de bacterias pertenecientes a los géneros *Rickettsia,*

*Borrelia, Bartonella*, entre otros más (Moro et al., 2005; Kabeya et al., 2010; Zapata et al., 2017; Ramalho & Gubler, 2020).

Los roedores al no manifestar patologías relacionadas con los patógenos que transmiten, se han convertido en eficientes propagadores de enfermedades zoonóticas. Las adaptaciones inmunológicas que los pequeños mamíferos han adquirido evolutivamente (probablemente asociado a su gran diversificación y abundancias) les confirió una diversidad genética que favorece su resistencia y tolerancia ante agentes infecciosos (O'Brien & Evermann, 1988; Hernández, 2011; Rynkiewicz et al., 2013). Además, se ha argumentado que, los organismos con ciclos de vida cortos presentan una mayor inmunocompetencia, debido a que destinan mayores recursos energéticos a la respuesta inmunológica innata en comparación con la destinada a la respuesta adaptativa (Lee, 2006; Luis et al., 2013). Lo anterior, posiblemente se relacione con el grado de infestación ectoparásita que presentan los roedores en comparación con otros pequeños mamíferos. Un estudio demostró que los roedores silvestres que presentaban mayores grados de infestación de garrapatas (las cuales mantenían una mayor carga bacteriana infecciosa), eran más eficientes a la hora de eliminar las bacterias patógenas (respuesta innata eficiente) en comparación con roedores donde su carga ectoparásita era menor (Rynkiewicz et al., 2013). Sin embargo, es importante mencionar que como en cualquier otro organismo, los altos niveles de estrés debilitan la respuesta inmunológica, haciéndolos más vulnerables a los propios agentes infecciosos que transmiten, llegando a comprometer la vida del roedor (Ciuoderis & Ochoa, 2010).

La proliferación de pequeños mamíferos reservorios y sus ectoparásitos vectores de agentes infecciosos, aumenta el riesgo del incremento en los casos de transmisión de enfermedades zoonóticas (Tian et al., 2015; Tkadlec et al., 2019; Aminikhah et al., 2021). Por ello, es necesario seguir generando estudios que nos permitan tener una idea clara sobre qué factores ambientales son los que tienen mayor peso en la propagación de estos agentes infecciosos, considerando la rapidez con la que se están alterando los ecosistemas naturales. Así también, es de gran importancia dar seguimiento a largo plazo a los estudios acerca del monitoreos de la respuesta de las poblaciones de los diversos reservorios y vectores naturales de enfermedades, incorporando además, proyectos de investigación destinados a la detección de posibles zoonosis emergentes, esto entre otras cosas, nos permitirá establecer puntos críticos en sitios que puedan ser propensos a desencadenar enfermedades zoonóticas, y así

poder definir áreas estratégicas de conservación de los bosques, con el fin de prevenir futuros

brotes que puedan llegar a tener graves repercusiones para la salud humana.

## VII.    Referencias

Aminikhah, M., Forsman, J.T., Koskela, E., Mappes, T., Sane, J., Ollgren, J. & Kallio, E.R. (2021). Rodent host population dynamics drive zoonotic Lyme borreliosis and Orthohantavirus infections in humans in Northern Europe. Scientific Reports, 11 (1), 1-11.

Brown, P.R., Huth, N.I., Banks, P.B. & Singleton, G.R. (2007). Relationship between abundance of rodents and damage to agricultural crops. Agriculture, ecosystems and the environment, 120 (2-4), 405-415.

Ciuoderis, A.K.A. & Ochoa, A.J.E. (2010). Lesiones tuberculoides y neumonía piogranulomatosa en un Chigüiro (Hydrocharis hydrochaeris). Orinoquia, 14(1), 126135.

Harrus, S. & Baneth, G. (2005). Drivers of the emergence and reappearance of vector-borne bacterial and protozoal diseases. International journal of parasitology, 35 (11-12), 1309-1318.

Hernández, G.R. (2011). Evolución de interacciones parásito-hospedero: Coevolución, selección sexual y otras teorías propuestas. Revista UDCA Actualidad & Divulgación Científica, 14(2), 119-130.

Kabeya, H., Colborn, J.M., Bai, Y., Lerdthusnee, K., Richardson, J.H., Maruyama, S. & Kosoy, M.Y. (2010). Detection of Bartonella tamiae DNA in rodent ectoparasites in Thailand and its sequence similarity to bacterial cultures from Thai patients. Zoonotic and Vector-Borne Diseases, 10 (5), 429-434.

Khalil, H., Ecke, F., Evander, M., Magnusson, M. & Hörnfeldt, B. (2016). The declining ecosystem health and the dilution effect. Scientific Reports, 6 (1), 1-11.

Lee, K.A. (2006). Linkage of immune defenses and life history at the level of the individual and the species. Integr. Comp. Biol. 46.

Luis, A.D., Hayman, D.T., O'Shea, T.J., Cryan, P.M., Gilbert, A.T., Pulliam, JR. & Webb, C.T. (2013). Comparison of bats and rodents as reservoirs of zoonotic viruses: are bats special? Proceedings of the Royal Society B: Biological Sciences, 280 (1756), 20122753.

Luis, A.D., Kuenzi, A.J. & Mills, J.N. (2018). Species diversity simultaneously dilutes and amplifies transmission in a zoonotic host-pathogen system through competitive mechanisms. Proceedings of the National Academy of Sciences, 115 (31), 79797984.

Melo, G.L., Miotto, B., Peres, B. & Caceres, N.C. (2013). Small mammal microhabitat at ground level and understory in a South Atlantic deciduous forest. Anais da Academia Brasileira de Ciências, 85, 727-736.

Min, K.D., Hwang, J., Schneider, M.C., So, Y., Lee, J.Y. & Cho, S.I. (2021). An exploration of the protective effect of rodent species richness on the geographic spread of Lassa fever in West Africa. PLoS Neglected Tropical Diseases, 15 (2), e0009108.

Morand, S., Blasdell, K., Bordes, F., Buchy, P., Carcy, B., Chaisiri, K. & Tran, A. (2019). Changing landscapes of Southeast Asia and rodent-borne diseases: decreased diversity but increased transmission risks. Ecological Applications, 29(4), e01886.

Moro, C.V., Chauve, C. & Zenner, L. (2005). Vector role of some dermanyssoides mites (Acari, Mesostigmata, Dermanyssoidea). Parasite, 12 (2), 99-109.

O'Brien, S.J. & Evermann, J.F. (1988). Interactive influence of infectious diseases and genetic diversity in natural populations. Trends in Ecology & Evolution, 3 (10), 254259.

Ramalho, O.M. & Gubler, D.J. (2020). Human diseases sssociated with vectors (Arthropods in Disease Transmission). In hunter's tropical medicine and emerging Infectious Diseases (pp. 1063-1069). Content Repository Only.

Rodríguez, P.R., Escudero, R., Lambin, X., Vidal, M.D., Gil, H., Jado, I. & Mougeot, F. (2019). Zoonotic pathogens in fluctuating populations of common vole (Microtus arvalis): occurrence and dynamics. Parasitology, 146 (3), 389-398.

Rynkiewicz, E.C., Hawlena, H., Durden, L.A., Hastriter, M.W., Demas, G.E. & Clay, K. (2013). Associations between innate immune function and ectoparasites in wild rodent hosts. Research in Parasitology, 112 (4), 1763-1770.

Sánchez, C.V. & Martínez, M.E. (2000). Museum sample data predict damage to crops by tropical rodents. Proceedings of the National Academy of Sciences, 97 (13), 70747077.

Schmidt, K.A. & Ostfeld, R.S. (2001). Biodiversity and the dilution effect on disease ecology. Ecology, 82 (3), 609-619.

Suzán, G., Armién, A., Mills, J.N., Marcé, E., Ceballos, G., Ávila, M. & Yates, T.L. (2008). Epidemiological considerations of rodent community composition in fragmented landscapes in Panama. Journal of Mammalogy, 89(3), 684-690.

Tian, H.Y., Yu, P.B., Luis, A.D., Bi, P., Cazelles, B., Laine, M. & Xu, B. (2015). Changes in rodent abundance and weather conditions potentially drive hemorrhagic fever with renal syndrome outbreaks in Xi'an, China, 2005-2012. PLoS Neglected Tropical Diseases, 9 (3), e0003530.

Tkadlec, E., Václavík, T. & Široký, P. (2019). The abundance of rodent hosts and climate variability as predictors of the risk of diseases transmitted by ticks 1 year in advance. Emerging Infectious Diseases, 25 (9), 1738.

Zapata, M.R., Guzmán C.C., Acosta, G.R., Martínez, N.Y., Sánchez, M.S., Hernández, S.M. (2017). Detección de bacterias asociadas a ectoparásitos de *Sigmodon toltecus* de la Reserva de la Biosfera Sierra del Abra Tanchipa, San Luis Potosí (México). ENICIP C. Trabajos presentados-VI Congreso Latinoamericano de Enfermedades Rickettsiales & I Encuentro de Ecología y Control de Ectoparásitos. Revista Colombiana de Ciencias Pecuarias, 30, 295-333, pp 303.