The Bibliometric Landscape of Infectious Disease Research in Panama (1990 - 2019): An Evaluation of the Country's Capability on One Health

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Abstract

Background: This work aims to analyze the landscape of scientific publications on subjects related to One Health and infectious diseases in Panama. We asked the following specific questions: *How does the One Health research landscape look like in Panama? Are historical research efforts aligned with the One Health concept? What infectious diseases have received more attention from the local scientific community since 1990?*

Methods: Boolean searches on the Web of Science, SCOPUS and PubMed were undertaken to evaluate the main trends of publications related to One Health and infectious disease research in the country of Panama, between 1990 and 2019.

Results: 4,547 publications were identified since 1990, including 3,564 peer-reviewed articles interconnected with One Health related descriptors, and 211 articles focused particularly on infectious diseases. There was a pattern of exponential growth in the number of publications with various contributions from Panamanian institutions. The rates of multidisciplinary, inter-institutional and inter-sectoral research ranged from moderate to low, to very low, respectively. Research efforts have centered largely on protozoan, neglected and arthropod-borne diseases with a strong emphasis on malaria, Chagas and leishmaniasis.

Conclusion: Panama has scientific capabilities on One Health to tackle future infectious disease threats, but the official collaboration schemes and strategic investment to develop further competencies need to be considered. Through future collaborative efforts, Panama can reduce the risk of pandemics by developing surveillance strategies to improve the prediction of disease spillover, spread and persistence while helping to mitigate the impact on public health and the economy, regionally.

Background

Neglected and emerging infectious diseases are the most alarming public health challenges of the twenty-first century [1–3]. Globally, risky areas for pathogen spillover (e.g., disease hotspots) are projected to occur in tropical and developing regions where human population has grown significantly, increasing the interactions between wildlife, domestic animals and people, particularly in the context of habitat disturbance, climate change and socioeconomic inequality [4–8]. Lately, the world has seen a rising number of infectious disease threats with alarming consequences. Ebola, Chikungunya, Zika and, currently, severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) exemplify the modern epidemiological era, where increased global travel can suddenly and rapidly turn local pathogen spill-over events into pandemics, resulting almost immediately in hundreds of thousands of infected people and devastated economies worldwide [9, 10]. In the case of the coronavirus disease of 2019 (COVID-19), the new human illness caused by SARS-CoV-2, the overwhelming epidemiological scenario is characterized by collapsed public health systems that could no longer cope with the abrupt escalation of human morbidity and mortality [11, 12]. Surprisingly, even though emerging infectious diseases are likely to continue rising in the future [13, 14], research about local zoonotic agents (i.e., animal origin) that can become pandemic is rare in most countries, meaning that nobody is preparing to contain or confront future threats [15]. This is a major concern for countries in Latin America and the Caribbean (LAC), with fragile health systems and poor medical infrastructure, which depend on regional research efforts to predict disease transmission and spread within their unique context [16, 17].

An effective response to infectious diseases requires high-quality basic and applied research to guide evidence-based interventions and strategic mitigation campaigns [18, 19]. The prevention plans targeting infectious diseases also need scientists and institutions to collaborate on the conceptualization of knowledge across multiple

disciplines, so that the ecological, epidemiological, and evolutionary complexities of zoonotic – pandemic pathogens are fully taken into consideration [20, 21]. The “One Health” model has been advocated to facilitate cross-disciplinary research in response to challenges in human, animal, and environmental health [22]. In 2017, Xie and collaborators sought to study key One Health publications with a system dynamics approach, in order to define a conceptual framework for future descriptions of the interdisciplinary engagements involved in this concept [23]. The authors selected 19 articles of 2,368 to reveal a rich theoretical model of interactions among various disciplines and the systematic representation of the numerous components engaged in One Health problem solving. The overall goal of the One Health model is not to build institutions that can act under the One Health mandate, but to integrate scientific knowledge from existing ones that can be used to prevent or react to regional outbreaks and pandemic emergencies [19, 24].

The first step for countries to begin preparing for future infectious disease scenarios is to understand how research about One Health related subjects is shaped locally. In particular, it is valuable to know whether historical research efforts have been related to the One Health concept, and what are the infectious diseases that have received more research attention. A bibliometric analysis using indirect descriptors of relevant human, animal, and environmental health subjects is a valuable tool to describe the local landscape of scientific publications related to One Health [23, 25]. Nevertheless, priorities in low and middle-income countries in terms of research are not focused on rare zoonotic pathogens that can establish a *de Novo* human-to-human transmission cycle, nor is research focused on basic or applied multidisciplinary sciences that can aid to better understand complex zoonotic disease interfaces. Instead, only common health problems causing a significant burden to society are studied and tackled by local disease control programs [26].

Panama, a megadiverse tropical country from Central America, has a long history of successful research initiatives that led to the control of infectious diseases, dating back to the construction of the Panama Canal [27, 28]. However, the threat from novel pathogens has increased in recent years due to a rise in the worldwide shipping trade [29, 30], uncontrolled urban development and social inequality [6–8, 31], climate change [32–34], and anthropogenic habitat disturbance [35–44]. In particular, this ecological scenario can lead to the emergence of new pathogens from animals into people, which could then rapidly spread across the world to cause regional epidemics throughout LAC [17, 45]. Panama only reported its first official case of COVID-19 on March 9th, 2020, around the same time than the rest of Latin-American countries. As of July 27, 2020, there have been over 60,296 confirmed cases and more than 1,294 deaths in the country [46]. Currently, COVID-19 is adversely impacting the public health systems of LAC and the scientific community must see this challenge as an opportunity to contribute novel knowledge to its global study, which could better prepare the region to tackle future pandemic threats [47]. Herein, we aim to describe the pattern of scientific publications on topics related to the One Health model, in an effort to establish Panama’s research capability to tackle future pandemic threats. In doing so, we delineate potential goals and benefits of implementing a regional cooperative research program within Central America as well as more broadly across other territories of LAC. We focus on infectious disease research because, initially, the One Health model was concentrated on this topic. Nonetheless, we are aware that, in time, the term has become much broader, targeting themes such as food safety, chronic diseases and antimicrobial resistant, among many others [48], thus in order to avoid bias in the scope of this study our definition of One Health does include some of these themes as defined by Xie et al. [23].

Methods

Data source

A bibliometric analysis using Boolean searches on the Web of Science (WoS, Clarivate Analytics, Philadelphia, PA, USA), SCOPUS (Elsevier, Amsterdam, Netherlands) and PubMed (National Center for Biotechnology Information, NIH, Bethesda, MD, USA) was carried out to evaluate the main trends of publications about One Health and infectious disease research in the country of Panama, between 1990 and 2019. We used two independent search tactics in several languages (e.g., English, Spanish, German, Portuguese, Italian). Firstly, broad-spectrum search engines such as WoS and SCOPUS were used to look for publications related to the One Health model. Secondly, a more public health-oriented search engine like PubMed was used to quest for publications specifically regarding infectious diseases (Supplementary Figure S1).

For the first search strategy, we looked exclusively for peer-reviewed scientific articles from international journals (Supplementary Figure S1). The set of keywords included “Panama” listed in the affiliation field plus roughly 140 indirect descriptors associated with the One Health model, listed in the title or abstract (e.g., "Panama"[Affiliation]) AND "Infectious Diseases"[Title/Abstract] OR "Veterinary medicine"[Title/Abstract]), which were extracted from Xie et al. [23] (Supplementary Table S1). Next, all references obtained from WoS and SCOPUS were downloaded in BibTex format and double-checked to eliminate duplicates using the semi-automatic count function of Mendeley Reference Manager Version 1.19.4 (Mendeley, London, UK) (Supplementary Figure S1). One Health related publications were assigned to one of the roughly 250 subject areas included in the Category field from the Web of Science Core Collection [49]. Here the goal was to identify areas of discrete or complementary research concentration among local institutions. The terms “Inter-institutional”, “Multidisciplinary”, and “Inter-sectoral” were assigned to publications involving authors from more than one research institution based in Panama; authors from more than one research area; and authors from the Panamanian Ministry of Health (MINSA), respectively (Table 1). A preliminary search depicted a negligible participation from the Panamanian Ministry of Agriculture (MIDA) in scientific publications regarding One Health descriptors, thus we excluded this governmental organization from the analysis. We omitted publications that were not conducted in Panama or did not have our targeted search strings as references in their affiliations, titles, or abstracts. Additional criteria for exclusion were incorrect time frame (e.g., only articles between 1990 and 2019 were considered in the analysis), and review articles (Supplementary Figure S1).

Table 1
Number of peer-reviewed scientific publications on subjects related to the One Health model in the country of Panama, between 1990 and 2019.

Research institutions	Total # of publications	Total # of publications on One Health	Inter-institutional *	Multi-disciplinary **	Inter-sectoral ***
STRI	5,482	2,523 (70.7%)	358 (14.1%)	151 (5.9%)	1 (< 0.01%)
ICGES	622	365 (10.2%)	142 (38.9%)	80 (22.1%)	42 (11.5%)
UP	1,125	360 (10.1%)	241 (67.3%)	206 (57.2%)	27 (7.5%)
INDICASAT	319	177 (5.0%)	107 (61.2%)	107 (60.4%)	9 (5.8%)
MINSA	84	54 (> 1.0%)	< 10%	< 10%	N/A
Others	N/A	85 (> 1.0%)	< 10%	< 10%	< 10%
Total	7,630	3,564	848	544	79

Boolean searches on the WoS and SCOPUS databases were undertaken.

Inter-institutional, Multidisciplinary and Inter-sectoral publications were assigned to articles involving authors from different institutions *, disciplines/ subjects **, and from the Panamanian Ministry of Health (MINSA) ***, respectively. Abbreviations: STRI (Smithsonian Tropical Research Institute), the only unit of the Smithsonian based outside the United Sate of America; ICGES (Gorgas Memorial Institute for Health Studies); UP (University of Panama); INDICASAT AIP (Institute for Scientific Research and High Technology Services - AIP); MINSA (Panamanian Ministry of Health); Others: UTP (Technologic University of Panama = 52 articles); IDIAP (The Panamanian Agriculture Research Institute = 10 articles); IU (Interamerican University = 11 articles); LU (Latina University = 12 articles).

For the second search strategy, we conducted analogous queries in PubMed for all the scientific documents (e.g., controlled clinical trials, books, datasets, journal articles, letters, and reviews), and refined the exploration by searching for the neglected and emerging infectious diseases listed in Mackey et al. [2], Maxwell et al. [15] and Klohe et al. [3] (Supplementary Table S2) (e.g., "Panama"[Affiliation] AND "Dengue virus"[Title/Abstract]). The latter references are key articles regarding pathogens and diseases with spillover potential in LAC and more broadly as well.

Statistical analysis

The variables of analysis encompassed the year of publication, research institution, research subject, type of collaboration (e.g., Inter-institutional, multidisciplinary, and inter-sectoral), type of disease (e.g., agent name and transmission mode) and type of document. We calculated and compared relative frequencies, percentages, sum, and the population median with descriptive and inferential statistics using the software Prism 8 (Graphpad Software, San Diego, CA, USA). Data collection and exploration was performed during the same week (from April the 5th to April the 12th, 2020) to avoid bias owing to changes in publication patterns over time.

Results

4,547 publications about One Health related subjects were identified using combined Boolean searches in WoS and SCOPUS from the country of Panama since 1990, representing 59.5% (4,547 / 7,632) of the total publication output of the country in these databases during the same time frame. Of these 4,547 publications, 78.3% (3,564 / 4,547) were reliable peer-reviewed articles from international journals after eliminating duplicates (Table 1; Supplementary Figure S1). Four institutions in Panama, the Smithsonian Tropical Research Institute (STRI), the Gorgas Memorial

Institute for Health Studies (ICGES), the University of Panama (UP), and the Institute for Scientific Research and High Technology Services (INDICASAT), encompassed 96% (3,425 / 3,564) of the total scientific records related to the One Health concept between 1990 and 2019 (Table 1). We also gathered 256 scientific documents through refined searches in PubMed, with 82.0% (211 / 256) focusing specifically on neglected and/or emerging infectious diseases (Supplementary Figure S1).

How does the One Health research landscape look like in Panama ?

We identified a statistically significant correlation between the number of cumulative peer-reviewed articles associated with the One Health model in Panama and the year of publication (*rho* = 0.99, two-tailed $P < 0.05$), depicting a strong monotonic positive relationship between scientific productivity and time. The results could not be explained by the increase in the number of scientists alone, as the data fitted an exponential growth pattern [Y = 2.0e-044*exp(0.052*X); R^2 = 0.98] better than a classic tendency of linear population growth [Y = 11.04 *X − 22018; R^2 = 0.80] (Fig. 1A). The growth in scientific productivity about One Health related subjects appears to be influenced heavily by STRI, taking off around the year 2000 (Fig. 1B). A similar but much lesser tendency was also observed among other Panamanian institutions, although the increase in publication records started approximately 10 years later, closer to 2010 (Fig. 1B). Excluding STRI from the growth chart, the increase in scientific productivity about One Health related subjects in Panama seems associated to, and continues to be propelled by, the launch of City of Knowledge in 1995, INDICASAT in 2002, the National Secretariat for Science, Technology and Innovation's (SENACYT) scholarship programs in 2005, SENACYT's National Research System (NRS) in 2007, and the first PhD program of the country in 2011 (Fig. 1C). Overall, we detected low to moderate rates of multidisciplinary (5.9% − 60.4%) and inter-institutional research (14.1% − 67.3%), respectively, reflecting a modest but rising effort by local institutions to combine knowledge and competencies. However, the rate of inter-sectoral research was very low (< 0.01% − 11.5%) (Table 1).

Are historical research efforts aligned with the One Health concept ?

STRI has significantly more peer-reviewed articles about One Health related subjects since 1990, with a total of 2,523 (70%) and a median of 80 articles per year compared to other institutions in Panama [H(4) = 51.39, p = 0.0001] (Table 1; Fig. 1D). ICGES and UP have significantly more publications related to the One Health concept than INDICASAT [H(3) = 14.66, p = 0.0007] (Fig. 1D). Despite the aforementioned differences, the proportion of One Health associated publications relative to the total institutional output was higher in ICGES (58.6% − 365/622) and INDICASAT (55.4% − 177/319) followed by STRI (46.0% − 2,523/5,482) and UP (32.0% − 360/1125) (Table 1). There was a noticeable difference between STRI and the rest of the institutions in terms of areas of concentration (Fig. 2A). STRI had the lowest rate of multidisciplinary research, and its One Health related publication record focused largely on environmental ecology, evolutionary biology, plant science and biodiversity (Table 1; Fig. 2A; Supplementary Figure S2). In contrast, ICGES's had a greater percentage of multidisciplinary research than STRI, and its record of One Health related publications focused mainly on tropical medicine, infectious diseases, and parasitology (Fig. 2C; Supplementary Figure S2). UP and INDICASAT showed the widest distribution of One Health related publications by area of concentration as compared to STRI and ICGES, and these two institutions also have the greatest percentage of multidisciplinary research, with 52.2% and 60.4%, respectively (Table 1; Fig. 2C; Supplementary Figure S2). One Health related publications by UP and INDICASAT focused broadly on pharmacology, science technology,

environmental health, ecology, plant sciences, tropical medicine, biodiversity, and infectious diseases (Fig. 2C; Supplementary Figure S2).

What infectious diseases have received more attention from the local scientific community since 1990 ?

Infectious disease research in Panama during the last three decades has centered largely on protozoan, neglected and arthropod-borne diseases, with a strong emphasis on malaria, Chagas disease and leishmaniasis, especially during the last 10 years (Fig. 3A-F). Additional bacterial and viral infections such as tuberculosis, influenza, Hantavirus and leptospirosis, have received considerably less attention from the scientific community than the group of arthropod-borne diseases. No articles were discovered from Panama through PubMed searches about Bovine tuberculosis in humans, Shigellosis, Salmonellosis, *Escherichia coli* infection, Onchocerciasis or the rest of the disease terms listed in the previous studies used for our methodology. The rate of inter-institutional and inter-sectoral research particularly concerning neglected and emerging infectious diseases in Panama was low, with most work done by a single institution and without the enrolment of MINSA (Fig. 3D, G).

Discussion

The zoonotic spillover of SARS-CoV-2 in Wuhan, China, in December 2019, and its subsequent human-to-human transmission out of Asia, has underlined the need to adopt the One Health model to effectively combat the current COVID-19 pandemic and prepare for the next spillover event [50]. Key to the adoption of a One Health research program is the advancement of multidisciplinary, inter-institutional and inter-sectoral research among local and international institutions with a broad range of expertise and disciplines [18]. A recommended first step for countries trying to prepare for future infectious disease scenarios is to understand how the local One Health publication landscape looks like. Here we make progress toward this end, describing the scientific output about infectious disease research from Panama in the last 30 years. Our evaluation strives to serve as a tool for local health authorities to determine the country's research capability on specific aspects of zoonotic pathogens within the One Health umbrella [48].

Overall, publication output for One Health related research has grown significantly in Panama since 1990. Although the country's research agenda has not explicitly focused on One Health, almost 60% of the entire country's research productivity is interconnected with this concept. We revealed a significant pattern of temporal growth in publication records associated with the One Health model, with noticeable differences in the number of peer-reviewed articles and the range of scientific areas tackled by different institutions. Institutional variation in research focus and publication output related to One Health might be due to differences in the task, budget, number of scientists and/or operation time in the country (Supplementary Figure S3). For instance, STRI is the only unit of the Smithsonian located outside the USA, and researchers have conducted pioneering studies on plant and animal ecology in Panama for more than 100 years. STRI has 15 research facilities scattered across the country, 40 staff scientists and more than 1,400 scientific visitors every year [51], which may explain its larger input to One Health related studies compared to other institutions (Table 2). Similarly, the ICGES, the oldest public health institute in Panama (formerly, Gorgas Memorial Laboratory) [52], dating back to the heroic efforts of the USA to combat mosquito-borne diseases during the construction of the inter-oceanic Canal; and the UP, the firstborn Panamanian University, have more publications about One Health subjects than INDICASAT [53]. This may be explained by the significantly lower resources, fewer personnel, and less time in operation (16 years) at INDICASAT, which represents 55% of the total time range used in this study (Supplementary Figure S3). Despite a relatively recent origin, INDICASAT shows a broad multidisciplinary emphasis in terms of areas of concentration and collaborators, both locally and

internationally, showing also the highest rate of inter-institutional publications along with UP (Table 1). The institute's task is to support translational research from basic sciences to multidisciplinary applications to solve real-world problems. Notwithstanding the differences about One Health associated publication output and areas of concentration among research institutions, jointly STRI, ICGES, and INDICASAT house the necessary equipment, human resources, areas of expertise and infrastructure to implement a One Health research program, and are well positioned to rapidly apply effective actions against pandemic pathogens through a close working relationship with the UP and the Panamanian Health authorities at MINSA.

Table 2
Targets and products from implementing a One Health research program in Panama and LAC.

Order of Actions	Goals for the country of Panama	Benefits for LAC
(A)	Launch a One Health regional center to promote multidisciplinary, interdisciplinary and intersectoral research activities between local and international institutions	A roadmap towards a regional plan to monitor, predict and control new invasive pandemic threats
(B)	Improve research facility and infrastructure to tackle infectious diseases with a focus on both experimental and field research about ecology, genomic, chemistry, molecular biology, biotechnology and vaccine development	* Capacity building and technology transfer on experimental and field research on zoonoses
(C)	Reinforce the surveillance system for neglected and emerging infectious diseases through improved study designs, data gathering and sharing between academia, MINSA and MIDA in spatial epidemiology, statistical analysis, predicting models, disease ecology and social sciences	** Permanent sentinel field sites for zoonotic pathogen watch at the human-animal-environment interface
(D)	Create funding instruments specifically to tackle pandemic threats that favor the collaboration between multiple local and international research institutions over single and local institution projects	Financial support for local and regional partnerships to acquire extra funding overseas
(E)	Broaden the One Health research, education, and training programs to incorporate non-arthropod-borne diseases, sexual, respiratory and fecal-oral transmitted infections, and chronic health-related issues such as cardiovascular disease, diabetes, cancer, hypertension, obesity, and neurodegenerative illnesses	Extension of One Health areas other than infectious diseases (i.e., food safety, biodiversity, chronic diseases, animal companion, antimicrobial resistant pathogens, etc.)
(F)	Strengthen the career development of students, junior faculty and independent researchers, through senior mentorship, close collaboration, and improved research capacities	Innovative *Curricula* on One Health studies and academic activities
(G)	Increase the volume of One Health actions, including high impact publications, annual symposia, workshops, a seed grant program, the core research facilities, and new graduate and postgraduate international programs	Long-term education to modernize the workforce and increase the critical mass of research scientists, lab technicians and field assistants
(H)	Develop long-term collaborations with countries from LAC, including academic, research, governmental institutions and NGOs from developing nations	*** Effective preparedness and integral response for future pandemics (i.e., establish a laboratory network for diagnostics)
(I)	Promote community engagement in problem solving through collaborative actions with stakeholders to move beyond knowledge to actions and gain trust from affected populations	Communication and knowledge transfer about risk and mitigation in the context of cultural and societal understating

* A BSL3 laboratory and insectary, a core genomic sequencing center, and a vaccine development institute are just a few examples of new infrastructure that are needed in Panama. ** Early detection of spillover events can help to assess the potential for infectious diseases to evolve into pandemics. Real time observations are also essential for priming and evaluating the end products of prediction models. *** The diversity of tropical infectious diseases in LAC is high, and some tropical infections mimic COVID-19 symptoms at the onset of illness. Hence, a network of regional specialized laboratories for accurate diagnoses using validated protocols will allow countries to distinguish among closely related diseases, yet with different pandemic potential.

Order of Actions	Goals for the country of Panama	Benefits for LAC
(J)	Foster close cooperation with the Pan American Health Organization /World Health Organization (PAHO /WHO), World organization of animal health (OIE)and other leading actors to coordinate better responses to emergency due to emerging zoonoses	Compliance with international health regulations and guidance and R & D Blue print on emerging infectious diseases (https://www.who.int/research-observatory/analyses/rd_blueprint/en/
* A BSL3 laboratory and insectary, a core genomic sequencing center, and a vaccine development institute are just a few examples of new infrastructure that are needed in Panama. ** Early detection of spillover events can help to assess the potential for infectious diseases to evolve into pandemics. Real time observations are also essential for priming and evaluating the end products of prediction models. *** The diversity of tropical infectious diseases in LAC is high, and some tropical infections mimic COVID-19 symptoms at the onset of illness. Hence, a network of regional specialized laboratories for accurate diagnoses using validated protocols will allow countries to distinguish among closely related diseases, yet with different pandemic potential.		

Infectious disease research in Panama has concentrated on arthropod-borne zoonotic infections, with a strong inclination for protozoan pathogens transmitted by mosquitoes (i.e., Anophelinae - *Plasmodium*), sandflies (i.e., Phlebotominae - *Leishmania*) and kissing bugs (i.e., Triatominae – *Trypanosoma*). Malaria, Chagas disease, and leishmaniasis have been equally and greatly investigated in the country, reflecting the persistence of these neglected tropical diseases in poor rural settings and isolated indigenous communities [6, 32–37, 44, 54, 55], but also SENACYT's steady motivation to sponsor research projects about vector-borne infectious diseases [56]. The Ministries of Health and Agriculture from LAC have recognized some of these zoonoses as endemic or emerging priorities, including Chagas disease and leishmaniasis [15]. However, other zoonoses with spillover potential have received relatively less attention by the Panamanian scientific community thus far [16]. This is the case of influenza, Hantavirus, tuberculosis and leptospirosis, plus rare veterinary diseases such as rabies, brucellosis, salmonellosis, and also recent pandemic infections like West Nile, Chikungunya and Zika arboviruses (Fig. 3). In fact, 60% of the infectious diseases classified as priorities for LAC, have not been studied in Panama whatsoever [15, 16]. Generally, these outcomes mirror the low publication record seeing in this study by MINSA, MIDA and the Agriculture Research Institute (IDIAP), which are the governmental agencies in charge of investigating these topics, or they may just be due to the recent emergence time of some of these pathogens. Our findings underline the limited inter-sectoral research between academia and MINSA/MIDA in Panama during the last three decades. Future efforts will have to align the needs among local academic and governmental institutions, and between them and those from the Ministries of Health and Agriculture in LAC [15, 57, 58].

Targets and benefits from implementing a One Health research program in Panama and LAC

A cooperative research approach for bioscience and health has been advocated for Panama before, echoing the need for a connection of research priorities among the social, environmental, agricultural and health sectors [59]. To be successful though, this proposal needs to involve a synergistic collaboration among SENACYT, MINSA, MIDA and researchers from various Panamanian institutions with strongly complementary research traditions and strengths [26, 59]. However, the rates of multidisciplinary, inter-institutional and inter-sectoral research in Panama are moderate to low, and very low, respectively, which means that the links among academic institutions and between them and stakeholders, are still limited making the implementation of the One Health model challenging. To overcome these problems, the government of Panama needs to create funding instruments that favor inter-institutional and inter-sectoral collaborations, particularly between those institutions that have published little about One Health related subjects (i.e., UTP, IDIAP, private universities, MINSA and MIDA), over single institutional research plans, which do not

include the participation of MINSA or MIDA. Recent examples of successful inter-institutional and inter-sectoral research, sponsored by MINSA through SENACYT, have been conducted in Panama. In 2016 ICGES, INDICASAT, STRI, UTP and the UP carried out a joined research project about the Zika pandemic, funded through a fast-track institutional agreement [60] that resulted in various scientific publications, and a plan of actions for future emerging arthropod-borne disease threats [7, 29–31, 45, 61–63]. Nonetheless, funding was discontinued after two years with no factual impact on the control of this pandemic event. More recently, SENACYT issued a fast-track request for proposals trying to address the immediate needs relevant to the COVID-19 pandemic in Panama and likely applicable to other countries in LAC, including innovative initiatives for accurate diagnostic and treatment methods, viral isolation and genome sequencing, seroprevalence, social aspects and the development of technology-based innovations such as the use of artificial intelligence, and software developments to track down virus spread and persistence. Rapidly, this call for proposals, with an overall investment of 6.6 million dollars, resulted in 32 prioritized projects as the first important step in trying to minimize the impact of COVID-19 in the country. However, funding must be accelerated, sustained and extended in the post-pandemic phase, as SARS-CoV-2 is likely to become the next neglected infection in poor communities of LAC [16, 17, 47].

In addition to local funding instruments, international collaborations, including partnerships among the Ministries of Health and Agriculture along with prominent academic institutions from LAC, need to be considered and sponsored to increase local competitiveness while building the necessary technological capacity to compete for extra funding overseas (Table 2). The long-term Hanta virus research program, sponsored by the United States National Institute of Health (ICIDR-NIH), ICGES, MINSA, SENACYT and Ministry of Economy and Finance together with partners from the University of New Mexico and the University of Development of Chile, is one example of successful international collaborative research in Panama. Since 2000, this multidisciplinary, inter-institutional and intersectoral alliance has uncovered key findings about *Orthohantavirus choclo*, identified as the cause of cardiopulmonary syndrome in Panama [64, 65], the ecology of the main reservoir *Oligoryzomys fulvescens* (*= costaricensis*) [38, 66, 67] and the epidemiology of an important neglected zoonosis [68, 69]. This ongoing effort has strengthened the national diagnostic capacity by MINSA, MIDA and Caja de Seguro Social (CSS), trained a significant number of young scientists, and helped establish a sentinel surveillance protocol and prepare an educational guide to sensitize affected communities and decision makers [8]. The benefits of the Hantavirus program are evident and can be easily extrapolated to other disease system as part of a solid One Health research agenda.

The government of Panama needs to allocate extra funding to improve the research infrastructure nationwide, create additional scholarship programs to continue training undergraduate and graduate students, and to build competitive leadership by increasing manpower and job opportunities in interdisciplinary areas across the country (Table 2). Non-Governmental Organizations (NGOs), both local and international, also need to be part of the One Health agenda, as they may provide in-kind support to strengthen research opportunities during training, response, and post-pandemic activities. Moreover, Panama needs to invest resources to create the first One health research Centre in Central America in order to coordinate the best available resources to solve complex infectious disease events through building new competencies in bioinformatics, genomics, and vaccine development, while promoting inter-sectoral studies and joint governmental efforts across LAC (Table 2). Since Panama is historically important in terms of disease research with the institutional infrastructure in place, and a Center of commerce and trade, the country is perfectly located to continue carrying out research about infectious diseases. Given Panama's position as a global logistical hub, and major airline center between North and South America, the research and intellectual knowledge generated by a collaborative One Health research program will position the country to respond quickly to newly emerging pathogens of pandemic potential. This has the advantage of stopping or at least slowing the spread of an epidemic regionally and provides a sophisticated research infrastructure for monitoring new pandemic foci

(Table 2). While research institutions in Panama differ in various degrees of expertise and scientific interest, each of them brings a unique visualization of the disease spillover process, which can effectively supplement joint research efforts about pandemic zoonotic pathogens (Fig. 2). Panama has one of the most species-rich and best-characterized faunas of the world, and researchers from STRI, ICGES, INDICASAT and UP bring expertise in tropical ecology, public health, disease epidemiology, and the population and evolutionary dynamics of pathogens, vectors and hosts relationships, which could be easily integrated into a solid research plan under the One Health framework. The high level of research complementarity among Panamanian institutions can be used to enable an information system for the prediction and mitigation of future zoonotic spillover events, including enhanced voucher collections of wildlife, domestic animal and human tissues plus associated pathogens and vectors [70].

Panama's One Health research program will need to cover research efforts oriented towards field monitoring and ecological understanding of highly pathogenic disease agents, and the animal hosts that act as reservoirs or vectors in both natural and anthropogenic environments [20, 21]. Nevertheless, the focus should also be extended to experimental research, basic epidemiology, mathematical modeling, molecular ecology, clinical trials and social sciences [63] (Table 2). Furthermore, One health's research efforts in Panama need to tackle not only diseases that are transmitted by arthropods, but also sexual, respiratory, and fecal-oral parasitic infections plus chronic and non-infectious health-related issues such as cardiovascular disease, diabetes, cancer, hypertension, obesity, and neurodegenerative illnesses, which have not been studied comprehensively in the country thus far [56]. The country needs to establish an innovative and broad research, education, and training *Curricula* on One Health by incorporating areas other than infectious diseases, including more recent development within this framework such as food safety, biodiversity, chronic diseases, animal companionship, and antimicrobial resistant, among many others (Table 2). Finally, the private sector, pharmaceutical and biotechnological companies, need to play a role in developing partnerships with academic and governmental agencies to increase research activities towards appropriate medical technologies and therapeutic products, ensuring their availability to, and affordability for the populations in need.

Limitations

To the best of our knowledge, there has been no bibliometric study about One Health research-associated literature in Panama, despite the prominent history of neglected and emerging infectious disease research in the country. Our work has certain limitations that we discuss as follows. The proportion of publications related to One Health may have been overestimated by including indirect descriptors from Xie et al. [23] in the search window, instead of using "One Health" directly as a key word. Furthermore, the proportion of publications about One Health could have been underestimated by focusing exclusively on research concerning the field of infectious diseases and overlooking various other components currently studied by this approach (e.g., chronic diseases, animal companionship, and antimicrobial resistance). While these are valid possibilities, we acknowledge that zoonotic infectious diseases were central to the One Health movement initially and continue to be a core element of it to date. Also, to avoid bias in our search strategy by picking One Health related terms subjectively, we used information and terminology from 19 scientific publications, which were recently identified through a system dynamics approach, to delineate the central dogma of the One Health concept [23].

In addition, we could have missed articles from scientific journals that were not indexed in the WoS, SCOPUS or PubMed during the study period, but these are the largest abstract and citation databases of peer-reviewed literature, including medical, technical and social sciences. These search engines have been used before to assess the publication trend of important infectious diseases, including those studied under the One Health framework [18, 19,

24, 25, 71]. Finally, we only included the last 30 years of research in the analysis because this is the time period when major science development events occurred in Panama, including the transfer of the Gorgas Memorial Laboratory, a United States institution working on tropical diseases since 1921, to MINSA in 1990, and the subsequent launch of the City of Knowledge, SENACYT and INDICASAT [26, 59]. Our work is the first to evaluate Panama's research capacity on One Health and infectious disease research, and it is intended as a preliminary hypothesis for future studies.

Conclusion

Findings recognize the publication trend associated with the One Health concept in Panama and provide a better understanding as to how collaborative research from local institutions could better prepare health authorities to tackle future infectious disease threats. Research about the control of infectious diseases has a long history in Panama, and the launch of the One Health research program, related to the current situation of COVID-19 in LAC, can build on this proud tradition. Emerging infectious diseases are likely to continue rising in the future due to continuous and COVID-related social and economic pressures on natural resources and deforestation. The global health impact of COVID-19 and the renewed local interest on major construction projects (e.g., mining, highways, timber extraction) in protected areas due to the related economic pressures, highlights the relevance of One Health research in Panama to reduce the risk of pandemics by developing surveillance strategies to improve the prediction of disease spillover, spread and persistence while helping to mitigate the impact on public health and the economy. The local scientific community must collaborate to learn more about zoonotic spread between animals, humans and the environment, so that the outcome of high-quality basic and applied research can be used to guide the implementation of effective mitigation strategies. This scientific knowledge can be used as the starting point to design a proactive strategy to survey, contain and mitigate future pandemic threats across LAC. We posit that an interdisciplinary approach based on research experience, strong collaboration, stakeholder involvement, and the use of high-tech research instruments while recognizing the constraints of health system in Panama will lead to realistic and sustainable solutions for the ever-growing public health challenges of pandemic threats. These actions will also provide a model for other highly impacted tropical countries globally, including developing nations in LAC.

Abbreviations

SARS-CoV-2: Severe acute respiratory syndrome coronavirus 2; COVID-19: the coronavirus disease 2019; WHO: World Health Organization; LAC: Latin America and the Caribbean; STRI: Smithsonian Tropical Research Institute; ICGES: Gorgas Memorial Institute for Health Studies; INDICASAT AIP: Institute for Scientific Research and High Technology Services; SENACYT: National Secretariat for Science, Technology and Innovation; NRS: National Research System; UP: University of Panama; UTP: Technologic University of Panama; MINSA: Panamanian Ministry of Health; MIDA: Panamanian Ministry of Agriculture; IDIAP: The Panamanian Agriculture Research Institute.

Declarations

Ethics Approval and consent to participate (Ethics statement)

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

JRL and RZ developed the idea, prepared analyses, tables and figures, and wrote the first draft of the paper with contributions from RK, RAG, EM, OIS, RZ, VSU, LIR, LF, BA, JGS, EOB. RZ extracted and curated the bibliographic data. All authors read and approved the final manuscript.

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Figures

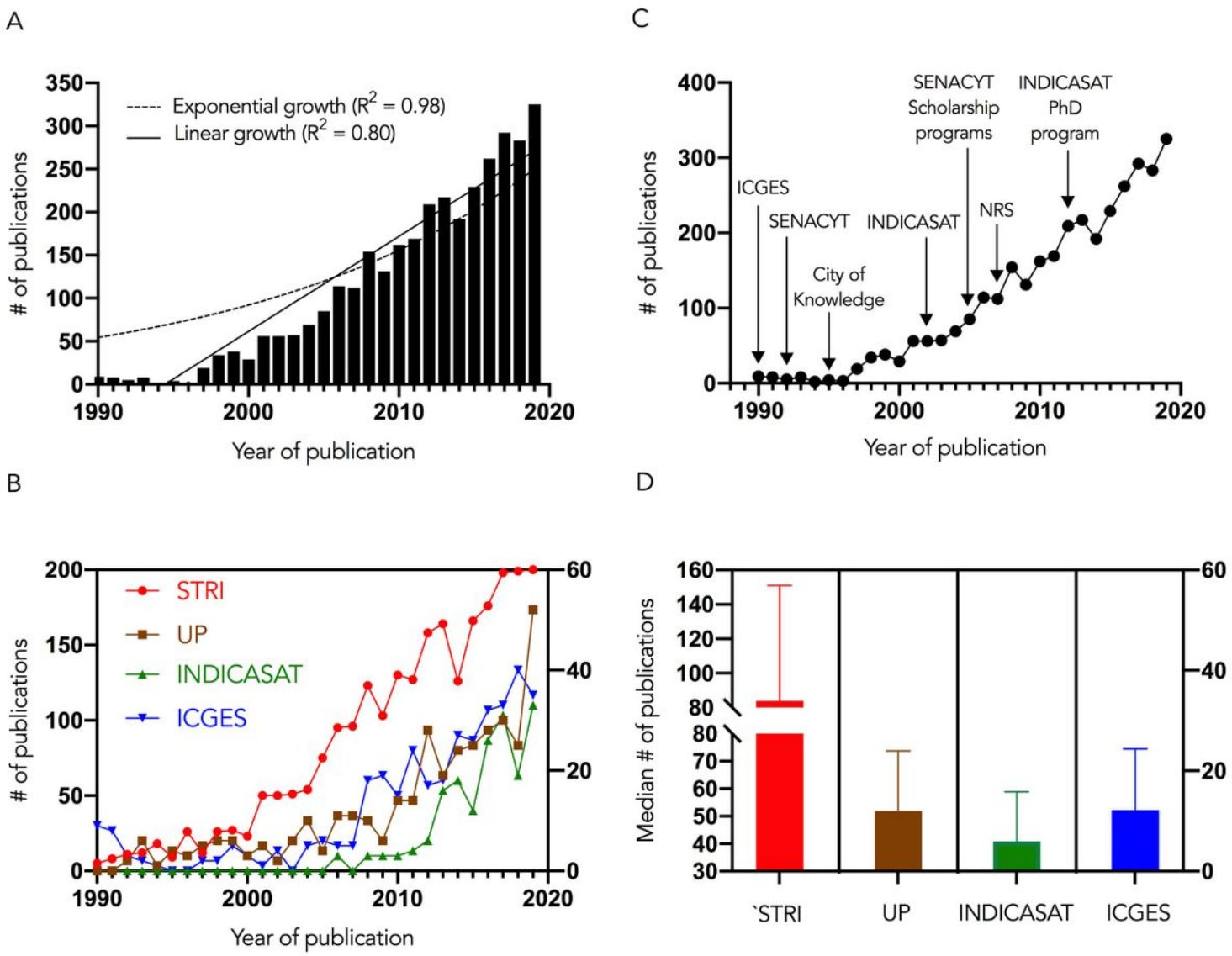
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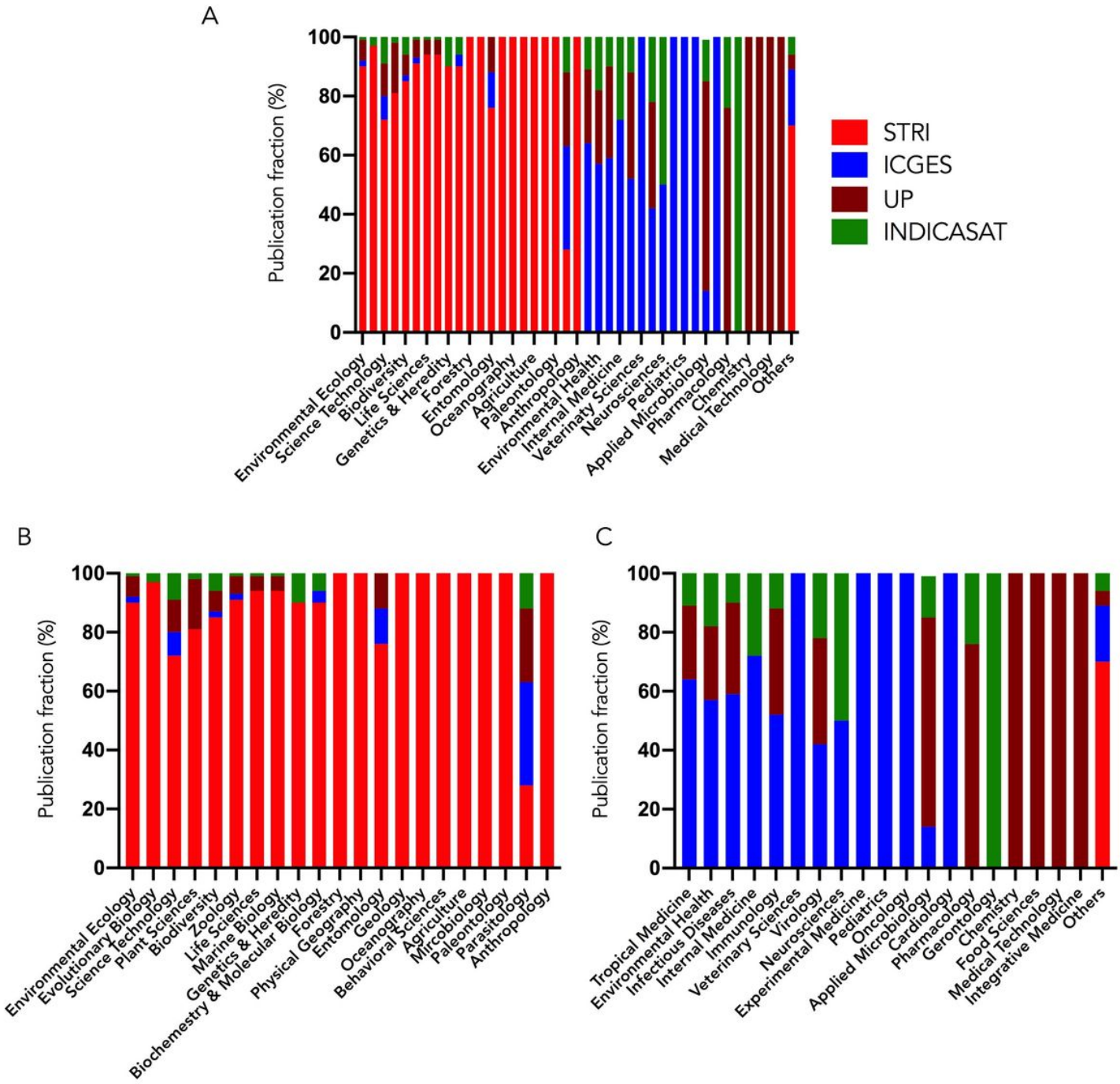
Figure 1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Science Technology
Biodiversity
Life Sciences
Genetics & Heredity
Forestry
Entomology
Oceanography
Agriculture
Paleontology
Anthropology
Environmental Health
Internal Medicine
Veterinaty Sciences
Neurosciences
Pediatrics
Applied Microbiology
Pharmacology
Chemistry
Medical Technology
Others
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Environmental Ecology
Evolutionary Biology
Science Technology
Plant Sciences
Biodiversity
Zoology
Life Sciences
Marine Biology
Genetics & Heredity
Biochemestry & Molecular Biology
Forestry
Physical Geography
Entomology
Geology
Oceanography
Behavioral Sciences
Agriculture
Mircobiology
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Environmental Health
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Internal Medicine
Immunology
Veterinary Sciences
Virology
Neurosciences
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Applied Microbiology
Cardiology
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Gerontology
Chemistry
Food Sciences
Medical Technology
Integrative Medicine
Others

Figure 2

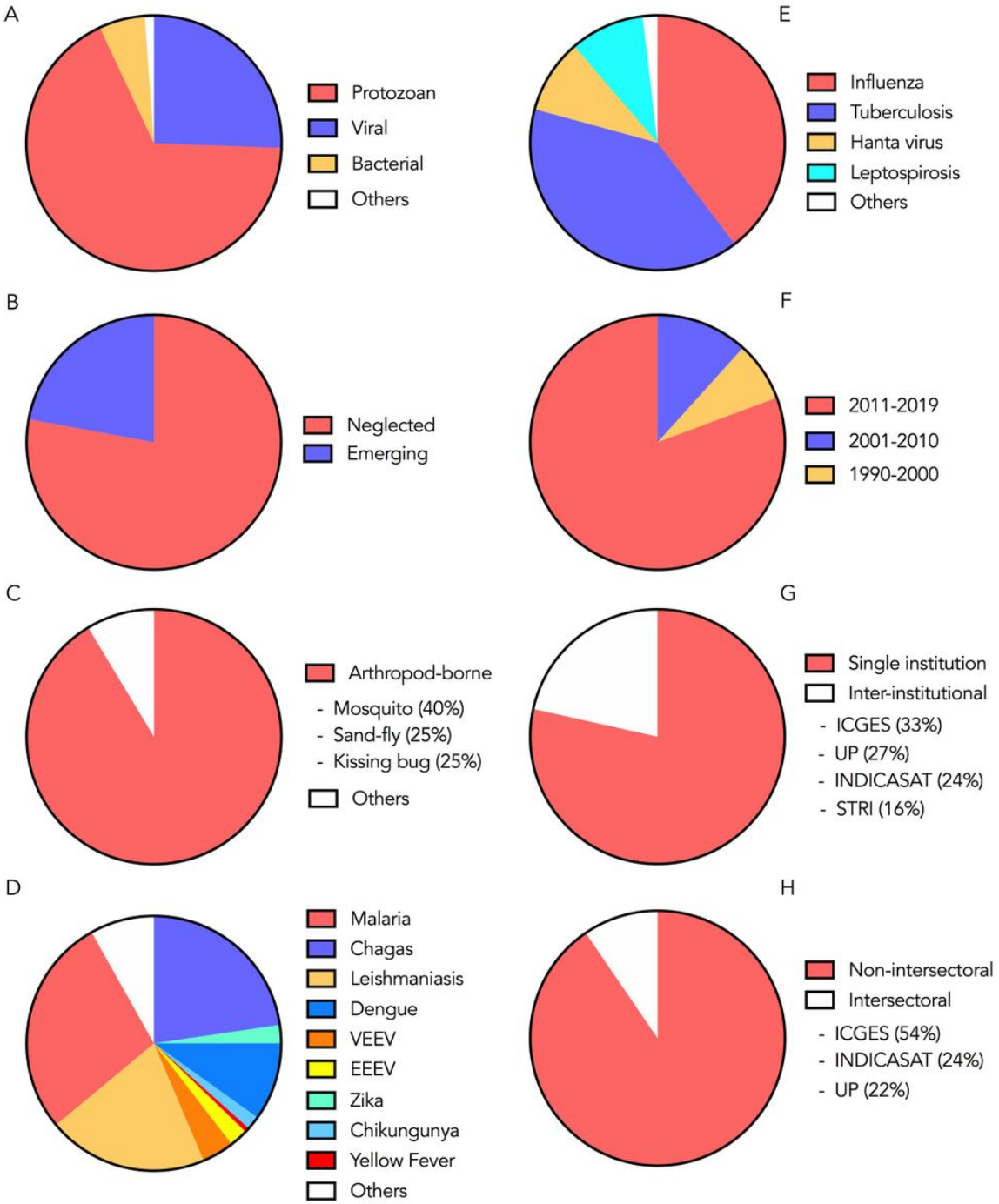

Figure 3

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