



The bibliometric landscape of infectious disease research in Panama (1990–2019)



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ARTICLE INFO

Keywords:

Bibliometrics

One health

Infectious diseases

Ecology

Anthropogenic stressors

Panama

Latin America and the Caribbean

ABSTRACT

Background: This work aims to analyze the landscape of scientific publications on subjects related to One Health and infectious diseases in Panama. The research questions are: *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: 4546 publications were identified since 1990, including 3564 peer-reviewed articles interconnected with One Health related descriptors, and 211 articles focused particularly on infectious diseases. A pattern of exponential growth in the number of publications with various contributions from Panamanian institutions was observed. The rate of multidisciplinary research was moderate, whereas those of interinstitutional and intersectoral research ranged from low to very low. 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 conciliated with modern times, aka the pandemics era. The main proposition here, addressed to the government of Panama, is to launch a One Health regional center to promote multidisciplinary, interinstitutional and intersectoral research activities in Panama and beyond.

Contents

1.	Background	2
2.	Methods	2
	2.1. Study model	2
	2.2. Data source	2
	2.3. Statistical analysis	3
3.	Results	3

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

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<http://dx.doi.org/10.1016/j.dialog.2023.100117>

Received 22 November 2022; Received in revised form 11 February 2023; Accepted 20 February 2023

Available online 24 February 2023

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3.1.	How does the One Health research landscape look like in Panama?	3
3.2.	Are historical research efforts aligned with the One Health concept?	3
3.3.	What infectious diseases have received more attention from the local scientific community since 1990?	3
4.	Discussion	3
4.1.	Gaps in the One Health research in Panama	4
4.2.	Benefits from implementing a One Health research program in Panama and LAC	4
4.3.	Limitations	7
5.	Conclusions	7
	Ethics approval and consent to participate (Ethics statement)	7
	Consent for publication	7
	Availability of data and materials	7
	Funding	7
	Authors' contributions	7
	Declaration of Competing Interest	8
	Supplementary data	8
	References	8

1. 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 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 world observed a collapse in emergency health systems which were no longer able to cope with the abrupt escalation of human morbidity and mortality [11,12]. As emerging infectious diseases are likely to increase in the future [13,14], research about local zoonotic agents (i.e., animal origin) should be funded and continued, and thus future threats (new pandemics) might be prevented [15]. This is key 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].

The first step for LAC countries to begin preparing for future infectious diseases is to undertake high-quality basic and applied research to understand ecological, epidemiological, and evolutionary complexities of zoonotic pathogens [18–21]. The One Health model has been advocated to facilitate cross-disciplinary research in response to challenges in human, animal, and environmental health [22,23]. The overall approach of the One Health model is to integrate scale of analysis from individuals to the biosphere to prevent global issues as pandemic emergencies [24]. Bibliometric analysis is a valuable tool to assess a country's landscape of scientific publications related to One Health [25,26].

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]. The emergence of a new pathogen from animals into people might be further accompanied by its rapidly spread across the world [45–48]. This is an opportunity to contribute with novel knowledge and specific analysis. Herein, we aim to analyze the pattern of scientific publications on topics related to the One Health model to assess Panama's research capability to tackle future pandemic threats.

A set of recommendations of implementing a regional cooperative research program in Central America and LAC is proposed.

2. Methods

2.1. Study model

The scope herein is the One Health model as defined by Xie et al. [23]. In this model, the connection of disease and health has proximate causes related to ecosystems, humans and animals, as well as ultimate causes including globalization, economy, education, biosecurity and so on [23]. This model also contains expected links between these causes, for instance, education has a positive causal link to human medicine which has a negative causal link to zoonotic disease outbreak [23]. The focus here is on infectious disease research because it is a key topic in the One Health model [49]. Through the lens of this model, we sought to understand how research about One Health is shaped locally in Panama.

2.2. 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 Fig. S1).

For the first search strategy, we looked exclusively for peer-reviewed scientific articles from international journals (Supplementary Fig. 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). 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 [50].

The terms “Interinstitutional”, “Multidisciplinary”, and “Intersectoral” 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. 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 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.

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 beyond.

2.3. Statistical analysis

The variables of analysis encompassed the year of publication, research institution, research subject, type of collaboration (e.g., Interinstitutional, multidisciplinary, and intersectoral), 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.

3. Results

4546 publications about One Health related subjects were identified using combined Boolean searches in WoS and SCOPUS from the country of Panama since 1990, representing 59.6% (4546 / 7630) of the total publication output of the country in these databases during the same time frame. After eliminating 982 duplicated articles, a total of 3564 peer-reviewed articles from international journals were included in bibliometric analysis on the One Health model. 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% (3425 / 3564) of the total scientific records related to the One Health concept between 1990 and 2019 (Table 1). Low to

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 articles	Total # of articles on One Health	Interinstitutional	Multidisciplinary	Intersectoral
STRI	5482	2523	358 (14.2%)	151 (6%)	1 (<0.1%)
ICGES	622	365	142 (38.9%)	80 (22%)	42 (11.5%)
UP	1125	360	241 (67%)	206 (57%)	27 (7.5%)
INDICASAT	319	177	107 (60.5%)	107 (60.5%)	9 (5.1%)
MINSa	84	54	0	0	0
Others	N/A	85	0	0	0
Total	7630	3564	848	544	79

Abbreviations: STRI (Smithsonian Tropical Research Institute); 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: Technologic University of Panama, The Panamanian Agriculture Research Institute, Interamerican University, and Latina University.

moderate rates of multidisciplinary (6%–60%) and interinstitutional research (14%–67%) reflect a modest but rising effort by local institutions to combine knowledge and competencies. However, the rate of intersectoral research was very low (0.1%–11%) (Table 1).

3.1. 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 ($r_{ho} = 0.99$, 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 better than a classic tendency of linear population (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 in Panama has been associated to 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. 1 C).

3.2. 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 2523 (71%) and a median of 80 articles per year compared to other institutions in Panama [$H(4) = 51.39$, $p = 0.0001$] (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). STRI's One Health related publication record focused largely on physical and natural sciences (Fig. 2A, B). One Health related publications by ICGES, UP, and INDICASAT focused mainly on health sciences (Fig. 2C). In addition, INDICASAT and UP showed wider distribution of One Health related publications by area of concentration as compared to STRI and ICGES (Supplementary Fig. S2).

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

In PubMed, 211 articles focusing specifically on neglected and/or emerging infectious diseases were included in bibliometric analysis (Supplementary Fig. S1). 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. 3 A-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 on Bovine tuberculosis in humans, Shigellosis, Salmonellosis, *Escherichia coli* infection, or Onchocerciasis on Panama were discovered. Most research of neglected and emerging infectious diseases in Panama are single institution and non-intersectoral studies (Fig. 3G, H).

4. Discussion

Publication output for One Health related research has grown significantly in Panama since 1990, 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 Table S3). For instance, STRI is the only unit of the Smithsonian located outside the USA, and researchers have conducted pioneering studies on

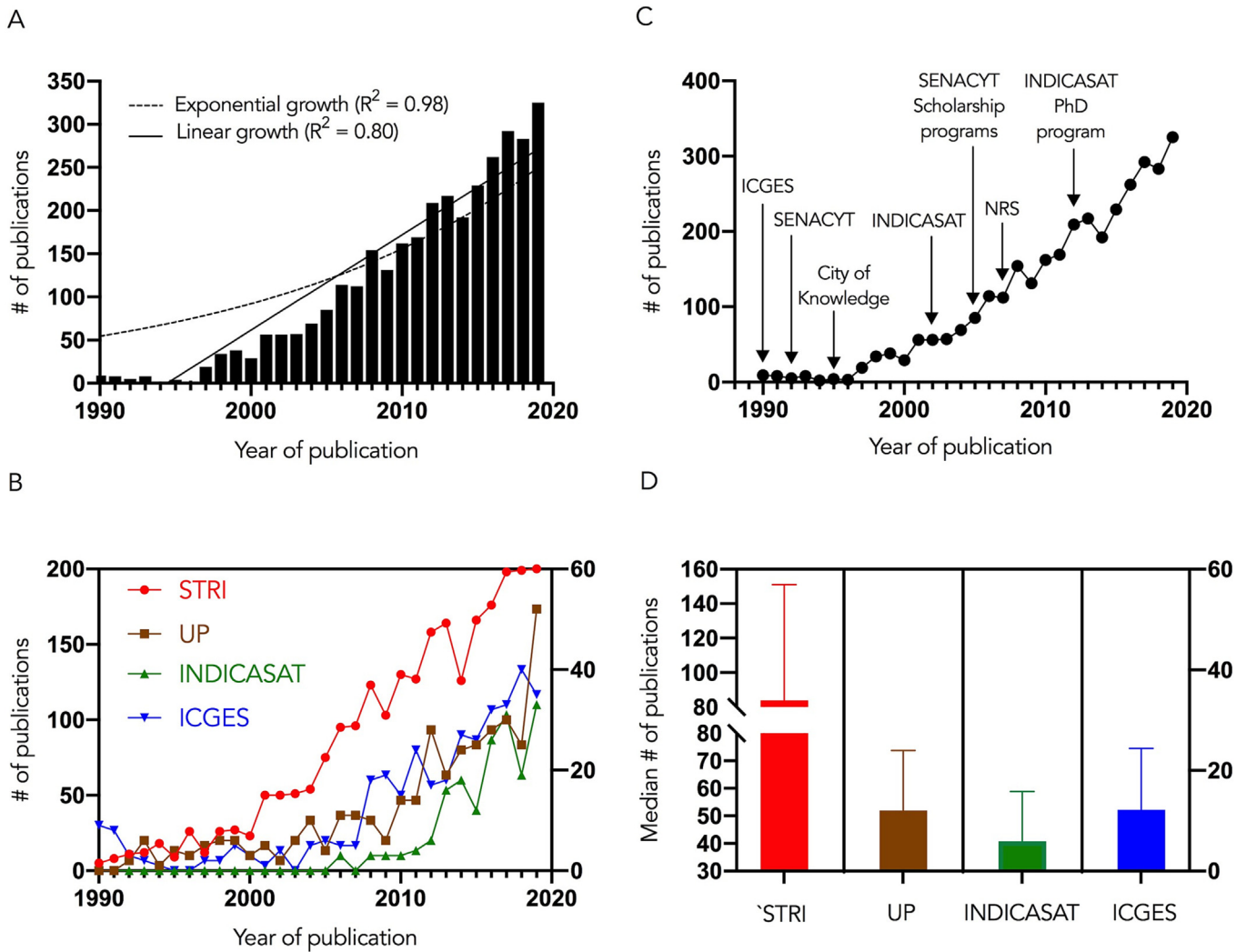


Fig. 1. Trends of scientific publications on subjects related to the One Health model in the country of Panama, between 1990 and 2019. (A) Total number of publications per year, depicting growth trends (exponential – dashed black line and linear – solid black line); (B) Total number of publications per institution, per year; (C) Temporal publication trend in Panama, excluding STRI, with key events marked with back arrows based on Romero and Quental [26]; (D) Median number of publications/year per institution.

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 1400 scientific visitors every year [51], which may explain its larger input to One Health related studies compared to other institutions. 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 at INDICASAT. However, INDICASAT shows a broad multidisciplinary emphasis and high rates of interinstitutional publications with both local and international collaborators.

4.1. Gaps in the One Health research in Panama

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. This is because of the persistence of these neglected tropical diseases in poor rural settings and isolated

indigenous communities [6,32–37,44,54,55], but also due to 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 emerging infections as chikungunya and zika arboviruses. In fact, 60% of the infectious diseases classified as priorities for LAC, have not been studied in Panama whatsoever [15,16]. Governmental agencies, including MINSa and MIDA, have a low publication record with these topics. Our findings show the limited intersectoral 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].

4.2. 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

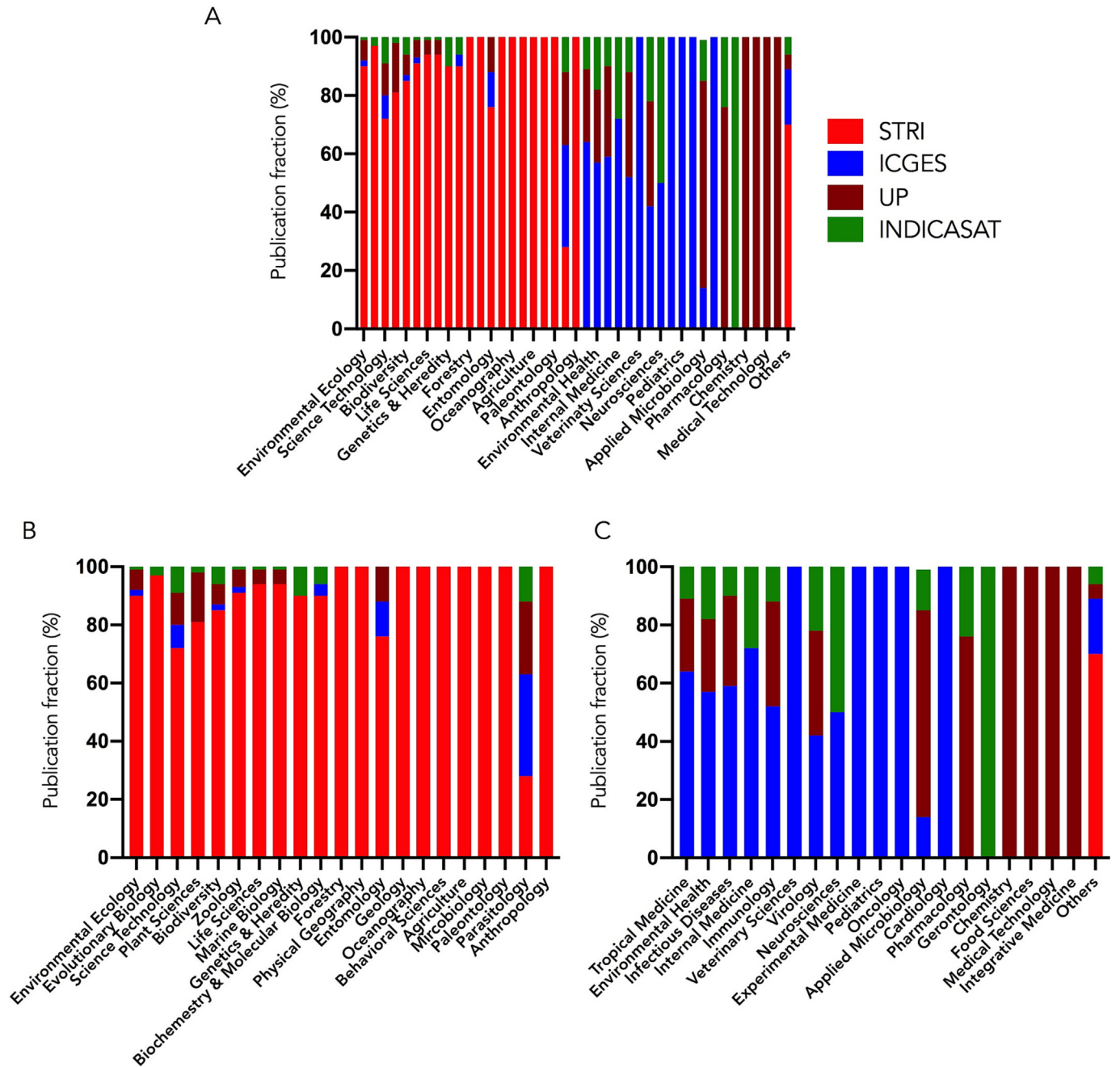


Fig. 2. Trend of scientific publications on subjects related to the One Health model in the country of Panama, between 1990 and 2019. (A) Publication fraction (%) of research institutions in Panama broken down by scientific area. (B) The first 22 and (C) The last 21 scientific areas of 41 in total are represented. Publications were assigned to Category fields or concentration areas from the Web of Science Core collection.

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]. The government of Panama needs to create funding instruments that favor interinstitutional and intersectoral collaborations. Recent examples of successful interinstitutional and intersectoral research, sponsored by MINSA through SENACYT, have been conducted in Panama. In 2016 ICGES, INDICASAT, STRI, Technologic University of Panama (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. 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.

International collaborations need to be considered and sponsored to increase local competitiveness while building the necessary technological capacity to compete for extra funding overseas. The long-term hantavirus 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

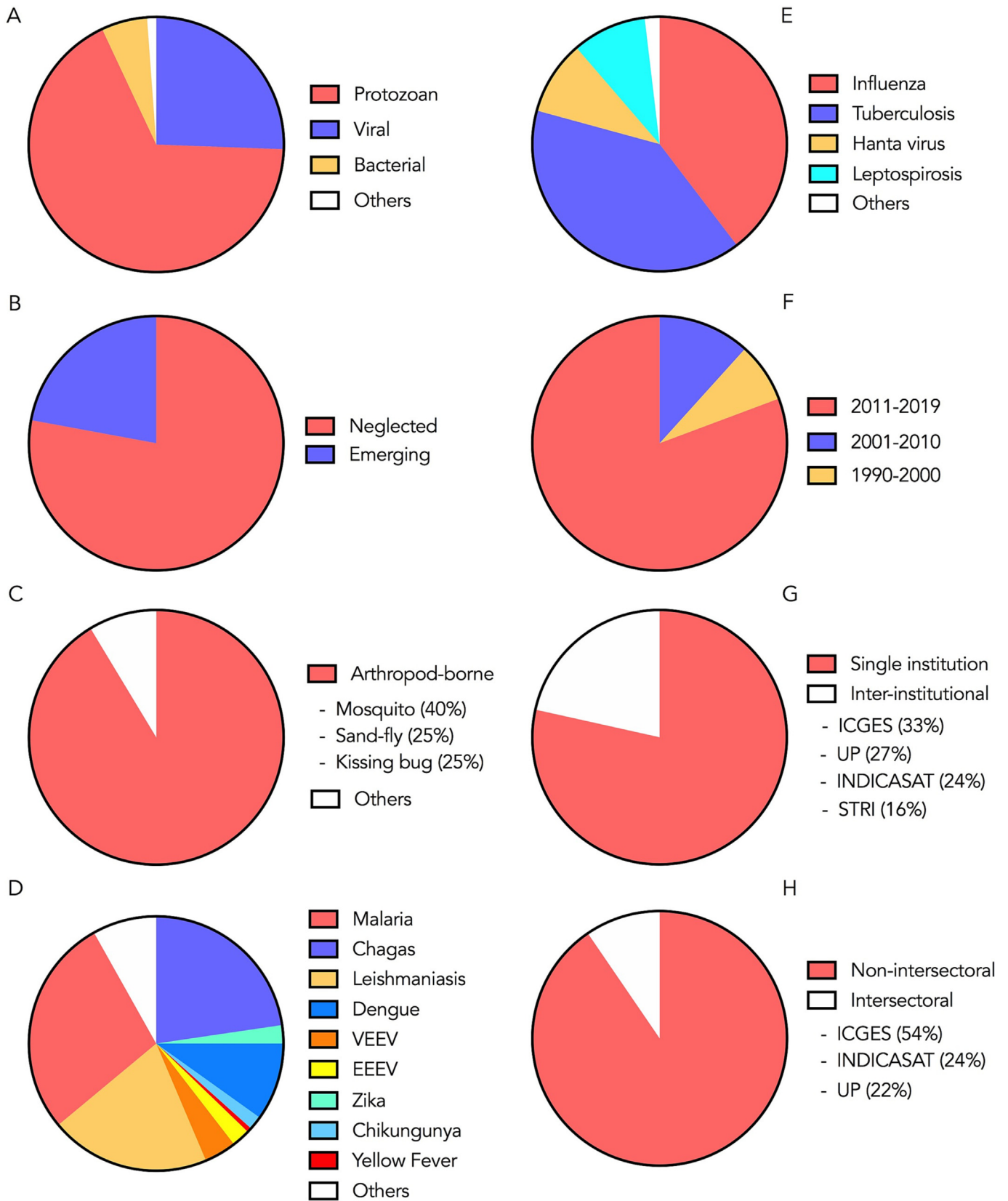


Fig. 3. Fraction of scientific publications about neglected and emerging infectious diseases from the country of Panama, between 1990 and 2019. Pie charts are classified based on (A) Agent type, (B) Disease type, (C) Transmission mode, (D) Arthropod-borne disease/agent name, (E) Non-arthropod-borne disease/agent name, (F) Time of publication in decades, (G) Interinstitutional research, and (H) Intersectoral research.

multidisciplinary, interinstitutional 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, trained a significant number of young scientists, and helped in the design of a sentinel surveillance protocol for decision making [8]. The benefits of this program are evident and can be easily extrapolated to other disease systems as part of a solid One Health research agenda.

The government of Panama needs to invest resources to create the first One health research Centre in Central America and 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). 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 in LAC. 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. 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].

Table 2
Recommendations of and benefits from implementing a One Health research program in Panama and LAC.

Order of Actions	Recommendations for the country of Panama	Benefits for LAC
(A)	Launch a One Health regional center to promote multidisciplinary, interdisciplinary and intersectoral research activities	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	Capacity building and technology transfer on experimental and field research on zoonoses
(C)	Reinforce the surveillance system for neglected and emerging infectious diseases	Permanent sentinel field sites for zoonotic pathogen watch at the human-animal-environment interface
(D)	Create funding instruments specifically to tackle pandemic threats	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	Extension of One Health areas other than infectious diseases
(F)	Strengthen the career development of students, junior faculty, and independent researchers	Innovative <i>Curricula</i> on One Health studies and academic activities
(G)	Increase the volume of One Health actions	Long-term education to modernize the workforce
(H)	Develop long-term collaborations with countries from LAC	Effective preparedness and integral response for future pandemics
(I)	Promote community engagement in problem solving	Communication and knowledge transfer
(J)	Foster close cooperation with the Pan American Health Organization and World Health Organization	Compliance with international health regulations and guidance

4.3. 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. As the One Health model [23] shows several interconnections among multiple disciplines, the approach with indirect descriptors herein used is justifiable.

The selected papers are limited to their indexation in the databases WoS, SCOPUS or PubMed. As these are ones of the largest databases of peer-reviewed literature, the analyses shown here can be used to assess the publication trend of important infectious diseases related to One Health [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 to MINSA in 1990, and the subsequent launch of the City of Knowledge, SENACYT and INDICASAT [26,59].

5. Conclusions

Our work is the first to evaluate Panama's research capacity on One Health and infectious disease research. 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. The local scientific community and institutions must collaborate to achieve interinstitutional, multidisciplinary, and intersectoral research approaches. The proposed recommendations of implementing a One Health research program in Panama might provide a model for other highly impacted tropical countries globally, including developing nations in LAC.

Ethics approval and consent to participate (Ethics statement)

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

Not applicable.

Funding

The Panamanian Secretariat for Science, Technology, and Innovation (SENACYT) supported this study through academic exchange (01 MOV) and infrastructure (EIE18-008) grants to JRL. The National System of Investigation of Panama (SNI) at SENACYT supports the research activities of JRL (grant numbers 05-2016, 157-2017, 16-2020) and RAG (grant numbers 91-2015, 146-2017, 08-2020). JGS was funded by the Ministerio de Economía y Finanzas de Panamá (MEF), grant number 19911.012, and partially supported by the Sistema Nacional de Investigación (SNI) from SENACYT, grant number 23-2021. GZL is supported by São Paulo Research Foundation grant no. 2021/06669-6 and a National Council for Scientific and Technological Development grant no. 307432/2019-0.

Authors' contributions

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

Declaration of Competing Interest

The authors declare that they have no competing interests.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.dialog.2023.100117>.

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