THE PATH TO MEASLES ELIMINATION IN THE AMERICAS: A
RETROSPECTIVE ANALYSIS

by

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Abstract

Despite many successes, measles elimination remains a challenge in many parts of the world. In the region of the Americas, endemic transmission of measles was interrupted in 2001, and such interruption has been primarily attributed to immunization strategies. However, during the three decades in which the Americas implemented the measles elimination strategies, the continent experienced different demographic contexts and transitions. In this study, we used measles surveillance and demographic, publicly available data to analyze the changes in country-level birth rates and its contribution to the decline in the force of infection of measles during the successful elimination campaign in the Americas from 1974 to 2013. We used a non-linear state space based model to reconstruct the susceptible population and therefore calculate the force of infection. In our analysis, we found the contribution of the demographic shifts in the Americas, specifically of the birth rate decline during the elimination of measles autochthonous transmission, varies between and within sub-regions. This work contributes to the understanding of the demographic factors that aided in the success of measles elimination programs in the Americas, and can provide additional insight into why elimination programs elsewhere are not successful regardless of the effort.

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EPI - Expanded Program on Immunization
FOI - Force of infection
BR – Birth Rate
DR – Death Rate
PAHO – Pan American Health Organization
WHO – World Health Organization
1. Introduction

Despite many successes, measles elimination remains a challenge in many parts of the world (1). Even with stepped up immunization efforts, measles still causes 2% of global child mortality (2). In the Americas, endemic transmission of measles was interrupted in 2001 (3) and maintained until 2014 when it was briefly reestablished in Brazil (4). The interruption of the endemic transmission has been primarily attributed to three immunization strategies: Catch-up, consisting of single-time mass vaccination of children and adolescents; Keep-up, routine immunization of successive birth cohorts and; Follow-up, periodic mass vaccination of young children (5). In North America, the inclusion of a second-dose was considered crucial for elimination, particularly given that massive vaccine campaigns were not implemented in this sub region (6,7).

These immunization strategies have been documented (8–13), analyzed in several studies (7,12,14–16), and have guided the policy and different vaccination programs in the world (17,18). De Quadros et al. have qualitatively described the role of the vaccination campaigns (15) in the elimination of measles in the Americas. Sever et al. inquired about the role of surveillance, the difference between vaccination schemes (7), and Keegan et al. have compared this strategy with previous eradication programs (19).
During the three decades in which the Americas implemented the measles elimination strategies, the continent faced different demographic contexts and transitions (20,21). However, the role of local demographic changes on the interruption of measles transmission has not been fully described in this region during this period. The aim of this manuscript is to quantify the relative contribution of different measles elimination activities and the demographic shifts in the force of infection of measles during the successful elimination campaigns in the Americas. More specifically, to describe the reduction in the number of cases of measles and the birth rate (BR); to illustrate the timing and implementation of the elimination campaigns; and to calculate the force of infection during the course of endemic transmission elimination in the countries of the Americas from 1974 to 2003.

2. Literature Review

2.1. Overall Strategy

The four strategies that resulted from the Americas experience to attain measles elimination were catch-up, keep-up, follow-up (9), and speed-up. (12) The first, catch-up was a 1-time mass vaccination of children between one and 14 years-old; keep-up entailed immunization of successive birth cohorts with routine vaccination targeting 1 year-olds. The third strategy was to conduct massive vaccination to children between 1 to 4 years old regardless of their immune status. Finally, speed-up, the fourth strategy referred to the 1-time mass vaccination to older adolescents
and adults with combined measles-rubella (MR) vaccines, as part of the rubella elimination plan in the Americas (5). An exception to this process was North America, where the school entry immunization requirement and second dose vaccination were the main strategies for elimination. (22–24)

In the context of the Americas, Castillo-Solórzano (5) described four stages since 1980 to 2010. The first stage was the early years of Expanded Program on Immunization (EPI) in which vaccination coverage rises in the region. The second stage, also called start-up phase, occurred from 1987 to 1994, and it was the period in which the main catch-up campaigns were conducted. Between 1995 and 2002 the elimination phase took place and all of the countries of the region reported their last case of measles and subsequent 18-month period without them. Finally, during the post-elimination phase from 2003 through 2010, special focus was given to strengthen surveillance systems and keep the desired vaccination coverage.

Orenstein (25) described a different process in the United States; he illustrated three elimination initiatives in 1966, 1978 and 1993. The lack of success of the first two led to the recognition of school entry requirement of immunization as a key strategy to attain high coverage among the pre-school population, this strategy was subsequently adjusted to also achieve high second-dose coverage. The other lesson learnt from these two efforts was the need of a second dose to achieve higher vaccination coverage in the school age population, this measure started to be progressively adopted in each state since 1989 and heavily required during 1993
successful initiative. In addition to these two strategies, an important emphasis was given to surveillance and outbreak control, for this endeavor the use of molecular epidemiology was widely used to trace and “identify potential endemic strains”. (22,25)

2.2. Application in the Americas

Since the introduction of Measles vaccine in 1963 in the Americas, remarkable achievements have been observed (26). In figure 1 it can be observed a gradual decrease in the number of cases according to the region and the different kinds of measures taken to strengthen immunization activities in the Americas. The efforts can be divided into individual and regional. Health authorities within each country mostly drove the individual efforts, and the regional endeavors mainly led by the Pan American Health Organization/World Health Organization.

The 1970’s

*Incidence Rates per 10,000 in 1974: South America IR: 6.8 | Caribbean 3.3 | North America: 1.4 | Central America 0.9*

While Canada introduced vaccination in 1970 in Quebec for infants up to 12 months (27), in South America, the first country to take a step forward was Argentina when in 1972 started extensive vaccination campaigns even before the creation of EPI (28). Consequently in 1973 Brazil began a National Vaccination Program (29) and in
1974 became one of the first countries in the region in adopting the EPI (28). During 1979 Bolivia (30) started EPI and once again Chile (31) and Argentina (32) innovated with the implementation of school-entry requirements to reinforce vaccination among school-aged children. In Central America, the first regional effort to control measles was conducted in 1977 with the implementation of EPI; and this endeavor resulted in successful interruption of biannual patterns in Panama by 1984 (33).

The 1980's

*Incidence Rate per 10,000 population in 1980: South America IR: 6.8 | Caribbean 5.1 | North America: 1.1 | Central America 4.9*

North America moved at a different pace, in 1982 United States focused their vaccine campaigns in the hard-to-reach populations, and in 1989 Canada reported 3% of the number of cases reported (16) During the same year the United States introduced routinely second dose vaccination for children from 1 to 14 years old (25). Cuba was the first country in the world reporting the interruption of endemic transmission of the disease in 1988 and this attainment encouraged the rest of the continent to pursue the same goal (34). In 1989, the Caribbean excluding Dominican Republic, Haiti, and Puerto Rico, joined the regional effort by committing to the elimination of measles by 1995 (35).
The 1990's

*Incidence Rate per 10,000 in 1990: South America IR: 3.1 / Caribbean 2.6 / North America: 1.0 / Central America 7.7*

The first immunization campaign in the Caribbean, with the exception of Cuba, was done during may of 1990 and by 1991 the remaining countries added to the efforts in the sub-region (36). It was not until 1990 that the Andean region set an elimination goal for 1995 (37); in 1991 Brazil set an ambitious elimination goal for the following year (29); Mexico added to the 1995 target and Honduras and Roatan set a goal for 1997 (38).

1991 was a crucial year regarding interagency commitments and epidemiological successes. During the ninth meeting of the OPS’ Technical Advisory Group in 1991, Cuba, Brazil and the English Caribbean were proposed as pilots for the Elimination of Measles. These was of particular interest during the final stages in which the vaccination coverage was high, but the cases remained in the clustered, hard to reach populations (39). Additionally, given the concern about the sustainability of the campaigns during the last stages of the strategy, the countries created an Immunization Interagency Coordination Committee to summon international organizations to maintain the financial resources in the lower income countries in the region (38). By the end of 1991, the English Caribbean reported the last measles case (40).
After the successful introduction of MMR in the US and the advocacy of WHO and OPS (41) in 1992, Brazil, Costa Rica and Paraguay promoted the inclusion of this vaccine in their EPI and their supplementary immunization activities (SIA), however it was not until 1998 that these countries were included. During this year and 1993, South America was the subject of multiple catch up national campaigns in addition to a regional effort to improve surveillance systems (13). As a result of the success of such strategy, the whole region set a new elimination goal to 1998. On the other hand, Canada proposed an elimination goal to 2005.

In 1994, Chile was announced to be the first non-insular country to achieve interruption of autochthonous circulation of the virus for 18 consecutive months and was declared free of measles (42). With this antecedent, and even though “nearly every country in the region has now set an elimination target for measles” (42), the nations of the region during the Pan American Sanitary Conference in Washington DC decided to set a common goal for the elimination of measles to 2000.

During 1995, several efforts were made to improve the surveillance systems of the region. The network of laboratories of measles in the Americas was formed in 1995 in Atlanta with the National Laboratories of Argentina, Brazil (Oswaldo Cruz Foundation), Chile, Colombia, Cuba, Mexico, United States and Venezuela along with the Regional Laboratories of the Caribbean and The Gorgas Memorial Institute for Health Studies. Each of the institutions mentioned above was in charge of
supporting the strengthen of the national laboratories of the remaining countries as well as the confirmation of cases in the region (13). By the end of the year, a new regional report guideline was published to unify the confirmation and report of the cases along with a new recommendation for the age of vaccination moving from 9 to 12 years-old (43).

While El Salvador reported its last measles case in 1996, an unexpected increase in cases occurred in South America; Brazil reported an outbreak in November of the same year and during 1997(44). By the same time in the year reintroduction of measles virus occurred in Costa Rica(45), and as a response to these outbreaks, PAHO reinforced the promotion of follow-up activities in South and Central America (46) during the next year. By 1998 the USA declares interruption of measles virus(47), and after the success of Central America, PAHO published a “practical guide for measles eradication” in 1999 compiling the success stories of both the Caribbean and Central America(48).

2000’s

*Incidence Rate per 10,000 in 2000: South America IR: 0.0 | Caribbean 0.1 | North America: 0.0 | Central America 0.0*

During 2001 and 2002 South America conducted aggressive vaccination campaigns to contain the 2001 epidemic in the north of Colombia and Venezuela.(49) These campaigns concluded in the last report of an autochthonous case for the region on
November 16 of 2002 (50, 51). Once the Americas were able to stop the autochthonous transmission of measles in the whole continent, the elimination of rubella was established and with it massive campaigns in women between 13 and 39 years were conducted in the region (13).

2.3. Analysis on the pathway of elimination

After the development of a vaccine, measles has been considered the most likely disease for elimination following the success of Smallpox and the ongoing polio campaigns (52). Sencer et al. in 1967 stated the epidemiologic basis for such eradication and included the evidence of herd immunity as well as the inexistence of asymptomatic infection and chronic carriers as factors of success. He also mentioned four strategies for successfully eradication of measles, which included routine immunization of infants (approximately 1 year of age), immunization on school entry (catching up schedules), surveillance and epidemiologic control (52).

Fine discussed the concept of herd immunity and consolidated the evidence by using the example of Measles in the USA and England and Wales; in the context of elimination, his work highlighted the relevance of elucidating other aspects of measles behavior in the population that might facilitate herd immunity, like “long duration of maternal antibodies” and waning immunity. These two factors affect the “prescription of vaccination” and is a crucial process to reach a sustained herd immunity and finally elimination (53).
In 1996 De Quadros published an optimistic analysis stating that successful interruption of the transmission of measles was attained in 1993 in most of the countries in the Americas. He provided examples of particular approaches to the elimination, specifically from USA and Cuba, and analyzed the impact of Catch Up campaigns evidencing that one year after such activities, cases were reduced to practically zero in the English Caribbean, Chile, Brazil and some Central American countries. (8)

In 1998, the team of experts from PAHO analyzed the causes of the “resurgence of measles in the Americas in 1997” (9) and highlighted the importance of follow-up campaigns given that the countries in that skip such campaigns were those that reported peaks. Additionally proposed that high population density was a possible catalyst for reintroductions. (9)

These series of outbreaks led to the analysis of immunity within age groups and the relevance of analyzing vaccination coverage and its effect in birth cohorts.(54). With the clear example of Chile that concluded that Follow-up campaigns should be done in the subsequent cohorts born after the Catch Up activity was done(55). Although Fine & Clarkson in England and Wales(56); as well as Hethcote in 1983 in the USA(57) did a more detailed analysis underlining the importance of birth cohorts and the distribution of immunization, the outbreaks in Chile and Brazil provided a practical point of view in the context of the ongoing elimination efforts in the region. Jamaica declared measles elimination after detecting an imported case in 1998 and
not finding any additional case despite active surveillance (58). After six years in the absence of measles cases, the Jamaican health authorities were able to trace every contact of a newly and single introduced measles case into the island and evidenced no further infection from such contacts. The absence of cases confirmed that levels of immunization were sufficient to avoid transmission of measles and in this way, the country was able to confirm elimination. Although ideal, the Jamaican scenario is idyllic, given that it is possible to have more than one introduced case or small outbreaks but still have a contained transmission, this is why De Serres and collaborators (27) calculated the expected size and duration of outbreaks due to imported infections in the context of elimination. They examined the interpretation of the three criteria for assessing elimination (proportion of cases imported, distribution of outbreak sizes and distribution of the duration of outbreaks) in Canada, USA and England and Wales. The researchers determined that it is crucial to rule out links of transmission within outbreaks to make sure the population is still within “the elimination threshold” (27).

3. Methods

3.1. Data collection

**Number of cases:** We collected data on the age and the total number of measles cases from the PAHO/WHO/UNICEF Joint Reporting Form (JRF) for immunization data for all the countries in The Americas from 1974 to 2013 (59). Additional sources of information included directly contacting the Ministries of Health each
country, previously published literature and a review of all the Expanded Program of Immunization Newsletters from 1979 to 2009 (13).

**Interventions:** The dates and detail of the interventions implemented by each country were extracted from the Retrospective Measles Data on Supplementary Immunization Activities (SIAs) 2000-2015 available from the World Health Organization (60). Additional information about SIAs from 1979 to 2000 and further was extracted from the Expanded Program of Immunization Newsletters as well as changes in vaccination schedules and local policies (13).

Vaccine coverage of routine immunization was taken from the administrative records of the WHO (61); however, the information is only available from 1980 onward. For the previous years an assessment of published literature was done as well as consultation of the Demographic Health Surveys; however, most of these started after 1980, so those were not useful or informative about vaccination in previous years.

**Population:** We extracted the number of births, birth rates and population from 1974 to 2013 from the United Nations population estimates calculated by the Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat (62). Neonatal, Infant and less than five-years-old deaths were obtained from the UN Inter-agency Group for Child Mortality Estimation (63).
**Case Fatality Ratio:** The proportion of deaths given the presence of disease was obtained from the systematic review done by Wolfson in 2009 (64).

### 3.2. Analysis:

The analysis is divided into two steps. 1. Estimation of the number of cases and susceptible reconstruction; and 2. Calculation of the force of infection

#### 3.2.1. Estimation of the number of cases and susceptible reconstruction

To estimate the number of cases accounting for report uncertainty, we fit a non-linear state space based model with a Kalman Filter method following Simons *et al.* (65). Two sets of equations characterize this model; the process equation describes the transmission itself and relates the susceptible population and real trend of measles infections in each country taking into account the births, child deaths and vaccination. The observation equation connects the unobserved cases in the population with the reported figures. This equation takes into account the changes in notification due to modifications in the surveillance systems during outbreaks. The method used to connect both equations is known as the state-space model, more specifically for this analysis we used the Kalman Filter method for the generation and weighting of the likelihood of each simulation.

The biological process we want to understand is described in terms of the states that progress in time according to a pre-established idea of how measles
transmission occurs. Our observation of this process occurs by looking at what is reported. The process, what is actually occurring, and what we observe are connected only through an observation model that accounts for biases and additional variation. The most important bias we are aimed to account for is underreporting. Since we anticipated an increase in reporting during outbreaks, we have included an additional correction for underreporting during outbreaks.

The equations mentioned above come from a SIR (Susceptible-Infected-Recovered) model in which the population begins as susceptible and, moves to either vaccinated or either infected and subsequently recovered and remain immune to the disease. (more detail in figure 2). This model adapts well to measles because it is a non-recurrent event that provides lifetime immunity. The following equations can also be found in Simons et al(65) from where we extracted them. The Process equations for the susceptible population at time $t$ are as follows:

$$S_t = \left[ S_{t-1} - \left( 1 - e^{-\theta_1 \left( \frac{S_{t-1}}{N_{t-1}} \right)} \right) S_{t-1} + X_t \right] \left( 1 - Y_{t-1} \right) + \theta_4 \quad \text{Process Equation}$$

$S_t$ = Susceptibles at time $t$
$S_{t-1}$ = Initial number of susceptibles
$\theta_1$ = Infectiousness
$N_{t-1}$ = Population at year $t - 1$
$X_t$ = Potential Susceptible (Births $-$ $< 5$ deaths $-$ Vaccination)
$Y_{t-1}$ = Coverage of SIA at time $t - 1$
$\theta_4$ = Process variance

$$S_t = \left[ S_{t-1} - \left( 1 - e^{-\theta_1 \left( \frac{S_{t-1}}{N_{t-1}} \right)} \right) S_{t-1} + X_t \right] \left( 1 - Y_{t-1} \right) + \theta_4 \quad \text{Process Equation}$$

While the observation equation includes a reporting term that will vary if an outbreak occurs or not.
Outbreak year:

\[ C_t = (\theta_2 + \theta_3) \left( 1 - e^{-\theta_1 \left( \frac{S_{t-1}}{N_{t-1}} \right)} \right) S_{t-1} + \theta_5 \]  

No outbreak year:

\[ C_t = (\theta_2) \left( 1 - e^{-\theta_1 \left( \frac{S_{t-1}}{N_{t-1}} \right)} \right) S_{t-1} + \theta_5 \]

\[ C_t = \text{Cases at year } t \]
\[ \theta_2 = \text{Base reporting rate} \]
\[ \theta_3 = \text{Increase in reporting rate while an outbreak} \]
\[ \theta_5 = \text{Observation variance} \]

To calculate the values of thetas, the Kalman filter is used along with an estimation of the likelihood by an optimization routine. Notice that \( \theta_2 \) and \( \theta_3 \) are estimates of the under report, once calculated these values remain constant during all the time period.

### 3.2.2. Calculation of the force of infection

Given the same SIR model proposed for the spaced based model, we calculated the force of infection (FOI) using the calculation of the basic reproductive number from the average age of infection as the probability density function for exit from the susceptible state while conditioning on not dying (66), the rationale for this calculation is at follows:
If:

$$Ro = \frac{L}{A}, \quad \lambda = \mu Ro$$

And:

$$I(t) = S_{t-1} + N\mu - \lambda S_{t-1}$$

$$I(t) = (1 - e^{-\lambda})S_{t-1}$$

$$\frac{I}{S_{t-1}} = 1 - e^{-\lambda}$$

$$\left(1 - \frac{I}{S_{t-1}}\right) = e^{-\lambda} = \frac{1}{e^\lambda}$$

$$e^\lambda = \frac{1}{1 - \frac{I}{S_{t-1}}}$$

$$\lambda = \ln \left(\frac{1}{1 - \frac{I}{S_{t-1}}}\right)$$

$$\lambda = -\ln \left(1 - \frac{I}{S_{t-1}}\right) \quad \text{Equation 4}$$

A separate force of infection was calculated for each country in each year. British and French territories such as Bermuda, Cayman Islands and Turks and Caicos were excluded due to the lack of historic number of cases and Saint Vincent and the Grenadines, Suriname and Saint Kitts and Nevis were excluded because of incomplete records during early years.
Afterwards, we estimated the expected number of susceptible population due to BR alone. We did this calculation assuming constant childhood deaths and vaccination coverage. Constant values were taken from 1975. We fitted linear regressions per each country to roughly assess the slope of decrease of birth rate and FOI. We used the R statistical software, version 3.3.2, for all of our analyses (http://cran.r-project.org)

4. Results

We fit a non-linear state space based model with a Kalman Filter, which generated a new set of number of cases, from this we reconstructed the susceptible population and with it we calculated the force of infection (FOI).

4.1. Estimated measles incidence:

Figure 3 Shows that estimated measles incidence follows a downward trajectory by sub-regions. North America had a continuous decline from 75.5 in 1977 to 7.1 in 1983 cases per 10,000 population followed by a gradual increase with a maximum of 44.3 cases per 10,000 in 1991. Central America had an average of 103.6 cases per 100,000 (sd. 179.139, median 7.55), which is the highest on the continent. We observe a 4-year pattern of outbreaks that started in 1976 with 493.9 cases per 10,000 population, followed by 533.3 in 1980, 391.8 in 1985 and the last peak was observed in 1989 with 330.6 cases per 10,000 population. After 1991 with the implementation of catch-ups campaigns this pattern was no longer observed, and we see a continuous decrease in the sub-region. The Caribbean had a 3-year pattern
of peaks until 1991, and South America had less periodic peaks and a continuous decline in the rate since 1977.

North America had the lowest measles rates of the continent. In 1977 the United States had 232.5 cases per 10,000 and Canada had an outbreak of 568.8 cases per 10,000 in 1979, exceptionally high rates given the median values of 3.7 and 18.2 respectively for the whole time of the study. In 1981 the United States had 13.5 cases per 10,000 and continued a steady decrease. Canada joined this trend in 1994 when for the first time reported a rate of 7.2 cases per 10,000 population. (Annex 1A)

Antigua y Barbuda had one peak at 1980 (1,500 cases per 10,000 population) with a gradual increase ten years later in the 1990’s between 59.1 (in 1991) and 135.5 cases per 10,000 population (in 2001). We see the same pattern in Barbados with a single outbreak (762.0 cases per 10,000 population) in 1977 followed by a constant decline. Grenada was hit by two peaks of 1173.4 and 1270 cases per 10,000 population in 1977 and 1982 respectively, followed by incidences ranging 171.7 and 76.3; the last outbreak occurred 1992 with 106.5 cases per 10,000 population. Saint Lucia and Bahamas showed a similar pattern with two outbreaks followed by small incidences and one peak six years apart from the last outbreak in 1983.

Estimates in the Dominican Republic show three increases in rates separated by 4, 5 and six years, and the last peak was in 1991 of 306.5 cases per 10,000 population.
(Annex 1C) Dominica and Jamaica had among the lowest median estimated rates in the sub-region with 2.4 and 2.5 cases per 10,000 population. Both countries followed the sub-region first pattern of 4-year spaced outbreaks and subsequent lengthen of such peaks to interrupt such pattern by 1988 and 1991 abruptly.

Finally, Haiti had a sustained high incidence rate in comparison to the rest of the countries (mean: 195.067, sd. 227.93; median: 162.7). This country showed an endemic transmission with 2 to 4 years outbreaks and this trend did not fade even after the stop of indigenous transmission in the rest of the sub-region. It was not until 2001 that Haiti had its last outbreak. Trinidad and Tobago showed epidemics every four years with no subsequent spacing however cases abruptly decreased in 1991. The lowest estimated rates were observed in Cuba, where two outbreaks were seen before 1981. (Annex 1C)

When analyzing each country within Central America, all of them followed the trend previously described for the Caribbean with 4-year outbreak patterns, the subsequent spacing of such epidemics and a gradual decrease around 1991. At the beginning of the time series in 1975 Belize had the highest rate in the sub-region with 1332.7 cases per 10,000 population, followed by Nicaragua in 1980 with 1262 cases per 10,000 population. These two figures were abnormally high compared to the other countries that ranged between 716.9 cases (El Salvador in 1979) and 83.4 in Costa Rica during the last outbreak of the sub-region in 1994. (Annex 1B)
In South America, major outbreaks continued until 1995 in almost all countries. Contrary to what was observed in Central America, most of the countries of this sub-region maintained rates ranging from 150 to approximately 300 cases per 10,000 population between epidemics until 1998. The outbreaks progressively spaced and by 1999 the rates within countries did not exceed the 39.2 cases per 10,000 population that were observed in Bolivia this year.

Guyana was the only country of the sub-region that followed the Caribbean trend, the outbreak in 1979 was the highest with 1098.7 cases per 10,000 population; However, after this year, its incidence was among the lowest in South America. In Chile, we observed a combination of large outbreaks, like the ones seen in the Caribbean exceeding or approaching the 1000 cases per 10,000 population and also an underlying incidence rate of approximately 95 cases per 10,000 until 1991 when incidence started steadily decreasing to become the second country before Uruguay to achieve elimination by 1993.

With the lowest incidence of South America, Uruguay followed the described trend for the sub-region, but its last peak happened in 1987 with 96 cases per 10,000 population. Likewise, Argentina had a mean rate of 73.959 cases per 10,000 (sd. 103.534, median: 29.9) and had its last outbreak in 1992 of 221.9 cases per 10,000 population.
Brazil, Colombia, Ecuador, Paraguay, Peru, Bolivia and Venezuela showed a continuous decline in the incidence rate. Although such countries did not have outbreaks with the magnitude observed in the rest of the sub-region; those were the last in achieving elimination. Brazil, Colombia, and Peru showed endemic transmission until 1991 and Venezuela and Bolivia until 1994.

4.2. Estimated base reporting rate:

In the observation equation the number of cases reported is a proportion of the real incidence. Such proportion is the estimated base-reporting rate of measles cases, or $\theta_2$ from equation 2. The calculation of this parameter, along with the variance allows us to estimate the number of cases of measles accounting in certain degree for underreport. We estimated mean of reporting rate for the region of the Americas of 3.4%, median: 2.3% and IQR: 3.1. The lowest mean reporting rate was estimated in North America with a 1.5% (sd. 0.01) followed by South America (2.3%, sd. 0.01), Central America (3.18%, sd. 0.03) and the Caribbean (4.5%, sd. 0.04).

4.3. Birth Rates

Figure 4 shows a decline in birth rate (BR) in the entire continent. However this decline was faster in the Central America where decreased by an average of 0.305 (SE. 0.025) births per 1000 population per year while North America, the slowest,
had an average reduction of 0.052 (SE. 0.012) births per 1000 population. The Caribbean and South America’s decrease estimates were 0.197 (SE. 0.022) and 0.225 (sd. 0.020) births per year respectively.

Other indicator of demographic transition is death rate (DR). Central America had the fastest decline with 0.068 (SE. 0.026), followed by South America’s negative slope of 0.225 (SE. 0.020) deaths per 1,000 population per year. The Caribbean decreased its DR by 0.068 (SE. 0.008) deaths per 1,000 population per year. Lastly, North America had the least and slowest decrease. (Figure 4)

All sub-regions except North America are in phase 3 of demographic transition or late transition, which is characterized by decreasing birth and death rates. Population growth is a result of these two changes. Figure 5 shows the relationship between such growth and the linear estimates of the decline in BR per region. We can roughly identify a pattern between sub-regions. Countries of Central America had high average population growth (>2% per year) and fast BR declines (>0.3 births per 1000 population per year). Most South American countries had a higher average annual population growth and a moderate BR decline (0.1 to 0.3 births per 1000 per year). Countries of the Caribbean were mainly located in the region of low population growth (<1% per year) and moderate BR decrease. And North America had moderate average annual population growth and slow BR decline.
4.4. Force of infection

When BR declines it is expected a decrease in the number of newly susceptible population. Since the Force of Infection is the per capita rate at which susceptible subjects are infected (67) and it depends, among others, on the rate of contact with such individuals with infectious ones, the reduction in susceptible individuals would reduce the FOI and thus decrease incidence.

Figure 6 shows a downward trend in the force of infection. Central America was estimated to have the highest force of infection starting in 1976 with 0.843 to 1991 when FOI was 0.250. The Caribbean was second, however after 1991 became the sub-region with the highest estimated FOI followed by South and North America in third and fourth place respectively.

When analyzing country level FOI, the mean across years was 0.186 (sd. 0.104); while the median per each country ranged between 0.019 and 0.390. FOI variation decreased over time as seen in Annex 3. Grenada was the country with the highest mean (0.582) and median (0.389) of the region and also had the highest FOI after 1991 (Annex 3). On the other hand, Costa Rica had the lowest mean (0.030) and median FOI (0.019). Additionally, the intra-cluster correlation coefficient is 0.293 meaning that the within-country variance is approximately 70% greater than the between-country variance.
As observed in the incidence rates, Canada had a higher FOI than the United States during all the study time. In 1975 the estimated chance of infection given susceptibility was 54.9% in Canada in comparison to 19.4% in the United States. From 1979 to 1987 the FOI was at least four times higher in Canada than in the USA, after this period the gap between them was reduced. The rate of FOI decrease in Canada was 0.011 (95%CI. -0.014,-0.008) in the chances of getting infected given susceptibility per year while the sub-region rate was 0.008 per year (95%CI. -0.010,-0.006). (Annex 4)

In Central America, before 1991 Mexico had the highest estimated FOI of the sub-region ranging between 1.103 in 1980 to 0.350 in 1991. Likewise, the rate of decline in FOI of Mexico was 0.022 per year (95%CI.-0.028, -0.016) while the mean sub-region decline was 0.013 (95%CI.-0.015,-0.011). After 1991, when the massive catch-up campaigns took place, the FOI of Nicaragua was estimated to be the highest in the sub-region (0.346). Costa Rica had a mean FOI of 0.029 (sd. 0.021), and it was the country with the lowest and more stable FOI (IQR 0.041) or the sub-region. (Annex 4)

In the Caribbean, Barbados, Dominican Republic, Haiti and Trinidad and Tobago presented a slower linear decline when compared to the 0.012 (95%CI.-0.014,-0.009) mean yearly reductions in the sub-region (Annex 5), however the estimates of the countries overlap with the confidence interval of the region. By 1988, year in which measles elimination was announced in Cuba, the estimated FOI was 0.09, the
lowest in the country’s history to that point. Along with Cuba, Barbados remained among the lowest FOI in the Caribbean with a mean FOI of 0.082 (sd. 0.139) and a median of 0.032 during the time of study. (Figure 5).

The mean estimated FOI in Brazil was 0.074 (sd. 0.068), and the median was 0.025, the lowest in the sub-region. Chile was also among the lowest FOI with a mean of 0.150 (sd. 0.174) and a median of 0.029. Argentina (-0.022; 95%CI. -0.027, -0.017) and Venezuela (-0.017; 95%CI. -0.020,-0.015) had a faster yearly rate of decrease than the average of the sub-region (-0.014; 95%CI. -0.015, -0.012); Ecuador also showed a steeper slope, however its 95%CI overlap to the one of the region. Additionally, these three countries also were estimated to have the highest baseline FOI, with 55.7, 53 and 42.7% chances of infection given susceptibility respectively.

4.5. Expected Force of infection in absence of vaccination and contribution of BR

Figure 7 shows the comparison between the trajectories of the estimated FOI in the absence of vaccination routine activities and SIAs (expected FOI due to BR), and the estimated FOI with such campaigns in place (FOI with vaccination). In the Americas we estimated decrease in FOI due to BR of 15.2% of the total estimated decrease in the FOI with vaccination.

During the first five years of the study period there was an increase of the expected FOI due to BR, however FOI declined after 1980 in all the sub regions. While the expected decline in FOI due to BR in North America was less than 1%, Central
America, The Caribbean and South America showed BR contributions of 26.02, 25.16 and 22.83% respectively. In annex 5 can be found the yearly rate of decrease.

North America showed a flat trend across the period of analysis. However, when analyzed separately, Canada showed an approximate rate of decline in FOI of 0.022 (95%CI. -0.025, -0.018) per each ten years when only BR is taken into account and a rate of decline in FOI of 0.113 (95% CI. -0.166, -0.122) per each ten years in which vaccination and SIAs are present. (Annex 6A).

The Caribbean showed a downward trend. However, only two countries evidenced such behavior. The rate of decline of the Expected FOI due to BR was approximately 0.023 every ten years in Cuba and 0.027 in Jamaica. whereas the rate of decline of the FOI with vaccination was 0.119 (95%CI -0.151, -0.087) and 0.126 (95%CI -0.16, -0.084) per each ten years respectively. Thus the BR contribution to the decline in FOI was of 19.39% in Cuba and 14.24% in Jamaica. The rest of the countries did not show a decrease in the expected FOI due to BR on a yearly basis. However, Bahamas showed a total long-term reduction in FOI of 17.27% due to BR.

There was a mixed behavior in the countries of Central America. While Nicaragua (-0.109; 95%CI 0.137, 0.082), Guatemala (-0.037; 95%CI -0.043,-0.030), Honduras (-0.030; 95%CI -0.030,-0.021) and Belize (-0.026; 95%CI -0.031,-0.022) showed approximate rates of decline ranging from 2 to 10% in the probability of new infection given susceptibility per each ten years; Costa Rica, Mexico, Panama, and
Salvador did not show a change in the expected FOI due to BR. Costa Rica was the only country in which expected FOI due to BR and FOI with vaccination were similar across time. (Annex 6C) The contribution of BR to the FOI decline was 54.33, 41.56, 35.67 and 13.76% in Nicaragua, Guatemala, Honduras and Belize respectively.

In South America, Uruguay (-0.151; 95%CI.-0.286,-0.016), Venezuela (-0.096; 95%CI.-0.140,-0.051), Argentina (-0.066; 95%CI.-0.084,-0.048), Colombia (-0.030; 95%CI.-0.043,-0.018) and Chile (-0.022; 95%CI.-0.025,-0.019) showed a decline in the expected FOI due to BR per each ten years. However, countries such as Brazil, Ecuador, Bolivia, and Peru showed decreases of less than 1% per each ten years in the probability of getting infected given susceptibility. FOI due to BR did not change with time in Paraguay. Overall, our results showed BR contribution to FOI decline was of approximately 50% in Uruguay and Venezuela, 30% in Argentina and Colombia and 11% in Chile. Despite not encountering declines of FOI of less than 1% in the remaining countries, Brazil and Ecuador showed a total BR contribution of 41.10 and 25.88%.

5. Discussion:

The contribution of the demographic shifts in the Americas, specifically of the birth rate decline during the elimination of measles autochthonous transmission, varies between sub-regions. We found that there is a reduction in the force of infection between 7 and 23% due to birth rate depending on the sub-region. We also
identified different processes of demographic transition in the Americas. Central America, The Caribbean, and South America were in stage 3 or mid-transition, but their rate of decline was different. Central America seemed to be at the beginning of the stage while the Caribbean and South America were ahead in this process.

The role of transitions of birth rates has been addressed from theoretical points of view using metapopulation models (68), applying “term-time forced SEIR models” with single parameters (69,70) and also using realistic age-structured models (71). All of these approaches concluded that declines in BR lead to a decrease in the rate in which susceptible individuals are added to the population and therefore influence measles incidence. Our results reflect the same pattern in susceptibility and the FOI, describing such demographic changes in a country-wise and yearly scale can also show its role in transmission.

The Americas presents an opportunity to analyze different speeds in BR decline with a common elimination strategy. The difference of the relative contribution of BR to FOI decline between countries within the same region can be explained by spatial isolation. Metcalt et al found in 2011 that spatial isolation had a potential impact in age distribution of incidence and thus in FOI (72). In our results we found FOI’s ICCs consistent with a greater between-country variance. Countries that are highly heterogeneous such as Brazil and Mexico should be analyzed in more detail given that aggregated data might be masking the BR contribution in highly populated cities like Sao Paulo and Mexico City with other isolated regions.
in such countries.

FOI vary between groups of ages (73), and the effect of BR might differ between such groups given the number of susceptible population in each age group at a particular time. Since BR and DR declines are indicators of transitioning into an older population one might assume that age structure change is implicitly taken into account when BR decline is analyzed. However looking into specific age structures within and between countries can enrich this analysis. Recent studies in China have shown that “age incidence patterns” can vary according to BR decline even between provinces in the same country(74).

Other explanation to the difference in the BR contribution between countries can be the heterogeneity in the under reporting. Despite of our efforts in correcting for this phenomenon, historically we have seen changes in case definition and institutional straightening of the surveillance system in the region. Unfortunately these events were not contemplated in our model, hence in addition to a base rate reporting, and the increase of notification during outbreaks, we have the need to include a time varying reporting rate that allows us to include the administrative changes that occurred during the elimination phase in the countries of the Americas and that did not happen at the same pace in all the sub regions.
This analysis faced several challenges. One of them was the lack of age-specific data of measles cases in all of the countries of the region. Examples of analysis conducted in Mexico (75,76) and Peru (72) in Rubella indicate that disaggregated information might be available for later years, mostly from 1997 onward. However, long time series are preferred to analyze demographic changes. Although we used the best available information and performed a correction for underreporting, the analysis of age-specific time series available in Mexico would strengthen the results of this work.

Another significant limitation was the potential low accuracy of the state space model in settings of high levels of vaccination (65). We were able to see this in the amplitude of the maximum and minimum values of estimated cases for our analysis. Simultaneously with the elaboration of this analysis, Ferrari and colleagues were developing a more accurate approach to the calculation of the values of thetas in the process and observation equation (74). Additionally, Bayesian Markov Chain Monte Carlo (MCMC) methods can be used to this estimation (77). This two described methods will be used incorporated to later stages of this work.

The set of equations of the observation model can be also improved, as mentioned before, by the inclusion of a time varying or a set of different thetas that allows us
to take into account the dramatic improving in the surveillance systems in the region. An example of this change can be seen in the USA where by 1963 the completeness of report was approximately 10%, 58% in 1986 and by 2004, the researchers considered it as “adequate to detect outbreaks”(78). Other experience that it is worthy to include is the establishment of the laboratory network for proper diagnosis in Latin America that gradually refined the report of measles cases(14,79).

Finally, we used a simple linear model to roughly descriptive the rates of change of both BR and FOI. We are aware that linear approximations do not fully describe the trajectories in these timelines and also that the assumptions of linear models, such as independent errors are not met for this kind of data. This analysis can be improved by following previous analysis approaches such as fitting an inverse variance–weighted linear least squares regression to assess the relationship between FOI and BR change (80). Other approach in the comparison of FOI with or without vaccination can be the fitting of a random effects model was with year and country as crossed random effects.

This study provides a broad perspective of the role of BR in the Americas showing that it differed between and within sub-regions. Although there seems to be a quantifiable relative contribution of BR in FOI, routine vaccination and SIAs played a major role in the elimination of measles in the Americas. Age-specific FOI would
help us to better understand the impact of mop-up campaigns during the last phases of elimination.

6. Epilogue on current situation of measles in the Americas

During the elaboration of this document on September 27 of 2016, the Americas were declared the first region of the world to eliminate measles. The International Committee for Documenting and Verifying Measles, Rubella, and Congenital Rubella Syndrome Elimination in the Americas, reported that according to the epidemiological records provided by all the ministries of health of the countries of the region “have maintained the interruption of endemic transmission of this disease in their territories.”(81).

According to the final report exposed in the 55th Directing Council of the PAHO_WHO, since achieving indigenous elimination in 2002, the region has reported 5,077 imported cases until 2014. Noticeable outbreaks occurred in Brazil, Canada, Ecuador, and the United States between 2010 and 2015. However during 2014 the major outbreaks were reported, and the incidence was 1.7 cases per million inhabitants, this was still the lowest in comparison to the rest of the world. And given the successful surveillance and immunization response of Canada, the United States and Brazil during 2016 the region remained free of measles (81).
Figure 1. Measles cases per 10,000 population in the Americas, 1974-2013

Source: PAHO/WHO/UNICEF Joint Reporting Form (JRF) for immunization. Elaboration: The Authors
The transmission of measles can be described with four compartments. Individuals enter into the **susceptible compartment (S)** when they are born at a rate $b$ and move to the **infectious compartment (I)** at a rate $\beta$ in which they are in contact with infectious individuals. Once in I, individuals either die due to measles at a rate $\mu_m$ or recover from the disease and move to the **recovered compartment (R)**, at a recovery rate of $\gamma$ where they remain until they die at a rate of $\mu$. When the population is vaccinated, they move to the **vaccinated compartment (V)** at a rate $\Upsilon$, equivalent to the vaccination coverage. Since the vaccine is not 100% effective, there is a fraction of vaccinated individuals who move from the vaccinated compartment (V) to the infectious compartment (I). This movement happens at an $X\%$ of the rate in which infectious population is in contact with vaccinated. The proportion $X$ depends on the coverage of the first and second dose. Effectiveness of vaccination with 100% of coverage was assumed to be 84% for only the first dose, 92.5% for only the second dose and 99% for both doses. Vaccinated individuals die at a rate $\mu$. These compartments are analyzed in yearly time periods; in the figure we can observe two periods. The number of susceptible individuals at each time depends on the remaining susceptible population in time $t-1$ and the newborns at time $t$.
Figure 3. Estimated measles incidence rate per 10,000 population in the Americas, 1975-2013
Figure 4. Death and Birth rate per 1000 population in the sub regions of the Americas, 1975-2013

A. North America

B. Central America

C. Caribbean

D. South America
Figure 5. Average annual population growth and yearly birth rate decline per 1000 population in the sub regions of the Americas, 1975-2013
Figure 6. Force of infection in the Americas, 1975-2013
Figure 7 Expected FOI in absence of vaccination and estimated FOI in the Americas, 1975 - 2013
7. References


11. Olivé JM, Risi JB, de Quadros C a. National immunization days: experience in 41


59. World Health Organization, UNICEF. PAHO Health Information Platform - Number of vaccine preventable disease (VPD) cases in the Americas [Internet]. Available from: http://ais.paho.org/phip/viz/im_vaccinepreventablediseases.asp

60. WHO/UNICEF. Supplementary immunization activities [Internet]. Data,


Annex 1. Incidence rate per 10,000 population in the Americas, 1974-2013

Annex 1A. North America

Incidence rate per 10,000 population in the Americas, 1974 – 2013
A. North America
Annex 1B. Central America

Incidence rate per 10,000 population in the Americas, 1974 – 2013
B. Central America

Country
- Belize
- Costa Rica
- Guatemala
- Honduras
- Nicaragua
- Panama
- Salvador

rate
Annex 1C. Caribbean

Incidence rate per 10,000 population in the Americas, 1974 – 2013
C. Caribbean
Annex 1D. South America

Incidence rate per 10,000 population in the Americas, 1974 – 2013
D. South America
Annex 2. Rate of change of birth and death rate per year in the countries of the Americas, 1975-2013

| Country                  | BR slope | 95% CI   | Pr(>|t|) | DR slope | 95% CI   | Pr(>|t|) |
|--------------------------|----------|----------|----------|----------|----------|----------|
| Antigua and Barbuda      | -0.062   | -0.092   | <0.001   | -0.005   | 0.007    | 0.393    |
| Argentina                | -0.207   | -0.219   | <0.001   | -0.037   | -0.040   | <0.001   |
| Bahamas                  | -0.373   | -0.409   | <0.001   | -0.001   | -0.006   | 0.004    | 0.683    |
| Barbados                 | -0.184   | -0.190   | <0.001   | 0.004    | -0.003   | 0.012    | 0.239    |
| Belize                   | -0.574   | -0.590   | <0.001   | -0.043   | -0.056   | <0.001   |
| Bolivia                  | -0.476   | -0.490   | <0.001   | -0.277   | -0.287   | <0.001   |
| Brazil                   | -0.522   | -0.548   | <0.001   | -0.097   | -0.107   | <0.001   |
| Canada                   | -0.142   | -0.157   | <0.001   | 0.007    | 0.005    | 0.009    |
| Chile                    | -0.327   | -0.345   | <0.001   | -0.084   | -0.092   | <0.001   |
| Colombia                 | -0.483   | -0.498   | <0.001   | -0.053   | -0.063   | <0.001   |
| Costa Rica               | -0.472   | -0.506   | <0.001   | -0.013   | -0.024   | <0.001   |
| Cuba                     | -0.236   | -0.260   | <0.001   | 0.042    | 0.034    | 0.049    |
| Dominican Republic       | -0.419   | -0.435   | <0.001   | -0.067   | -0.080   | <0.001   |
| Ecuador                  | -0.450   | -0.466   | <0.001   | -0.130   | -0.150   | <0.001   |
| Grenada                  | -0.447   | -0.514   | <0.001   | -0.045   | -0.052   | <0.001   |
| Guatemala                | -0.467   | -0.488   | <0.001   | -0.211   | -0.226   | <0.001   |
| Guyana                   | -0.510   | -0.556   | <0.001   | -0.030   | -0.038   | <0.001   |
| Haiti                    | -0.479   | -0.525   | <0.001   | -0.220   | -0.230   | <0.001   |
| Honduras                 | -0.653   | -0.684   | <0.001   | -0.186   | -0.212   | <0.001   |
| Jamaica                  | -0.370   | -0.381   | <0.001   | 0.017    | 0.010    | 0.023    |
| Mexico                   | -0.507   | -0.538   | <0.001   | -0.084   | -0.097   | <0.001   |
| Nicaragua                | -0.746   | -0.778   | <0.001   | -0.209   | -0.231   | <0.001   |
| Panama                   | -0.364   | -0.384   | <0.001   | -0.029   | -0.037   | <0.001   |
| Paraguay                 | -0.471   | -0.508   | <0.001   | -0.046   | -0.049   | <0.001   |
| Peru                     | -0.529   | -0.552   | <0.001   | -0.158   | -0.178   | <0.001   |
| Saint Lucia              | -0.662   | -0.693   | <0.001   | 0.005    | 0.009    | 0.020    | 0.465    |
| Salvador                 | -0.639   | -0.650   | <0.001   | -0.167   | -0.191   | -0.143   |
| Trinidad and Tobago      | -0.456   | -0.522   | <0.001   | 0.046    | 0.038    | 0.054    |
| United States            | -0.061   | -0.077   | <0.001   | -0.021   | -0.024   | <0.001   |
| Uruguay                  | -0.156   | -0.167   | <0.001   | -0.026   | -0.027   | <0.001   |
| Venezuela                | -0.409   | -0.425   | <0.001   | -0.016   | -0.022   | <0.001   |

This is a linear regression for each country assuming normal distribution and independence of the residuals.
Annex 3. Force of infection distribution in the Americas per year, 1975-2013
Annex 4. Central tendency measures of FOI per country in the Americas
### Annex 5. Rate of FOI decrease per country

<table>
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<th>Expected FOI without vaccination</th>
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Annex 6. Comparison between FOI in absence of vaccination and FOI with vaccination in the countries of the Americas, 1975-2013

A. North America

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B. Central America

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Note: EXP indicates the Expected Value.
### D. South America

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8. Curriculum Vitae

**DIANA ROCIO HIGUERA-MENDIETA**

15 Charles Plaza. Apt 2702  Calle 104 # 19A 56 Apt 601
Baltimore, MD. 21201  Bogotá, Colombia
dhiquer1@jhu.edu  •  (443) 6767191
Birth March 5 of 1988, Bogotá Colombia

Public health professional with four years of experience in study design, data collection, quantitative data analysis and implementation of new strategies for prevention and control of Dengue, with training in geospatial and modelling of infectious diseases dynamics. Interested in data analysis and the design, implementation, and evaluation of surveillance systems for vector-borne diseases.

**EDUCATION**

**Master of Science (ScM) in Epidemiology**
Johns Hopkins Bloomberg School of Public Health
Baltimore MD, USA
Exp May 2017

**Doctor of Medicine**
Dissertation: 1993 health reform impact on vector borne diseases, Colombia.
Universidad de los Andes
Bogotá, Colombia
June 2010

**Minor on Government**
Universidad de los Andes
Bogotá, Colombia
June 2010

**RESEARCH EXPERIENCE**

**Graduate Research Assistant with Dr. Justin Lessler**
Department of Epidemiology, Johns Hopkins Bloomberg School of Public Health
Towards measles elimination in the Americas: The role of demographic transition
Baltimore, MD
2015 – 2017

- Assess the potential effects of the birth rate decline in measles force of infection in the Americas during the elimination phase
- Use state space models to correct surveillance data
- Search, review and extract surveillance and immunization data from official documents in the countries of the Americas

**Research Associate**
Centro de Estudios e Investigación en Salud, Fundación Santa Fe de Bogotá
Ecosystemic approach for the design and implementation of sustainable strategies for Dengue control in two regions of Colombia
Bogotá, Col.
2012 – 2014
entomological data collection

**Research Assistant with Dr. Olga Lucia Sarmiento**  
Faculty of Medicine, Universidad de Los Andes – Bogotá, Colombia  
- Wrote two research proposals for the assessment of programs for the promotion of physical activity in community and scholar settings  
- Participated in construction of the protocol for the National Health and Nutrition Examination Survey, Colombia 2015  

**Research Assistant with Dr. Gabriel Carrasquilla**  
Centro de Estudios e Investigación en Salud, Fundación Santa Fe de Bogotá  
- Ecohealth approach on the determination of associated factors to Malaria in Latin America  
- Participated in the identification of success strategies in the published literature about the use of the Ecohealth approach in Malaria research in Latin America  
- Consolidation of “Así Vamos en Salud” as a National health Observatory  
- Calculated, assessed and compared national, regional and municipal health indicators and interpreted them for the general public.  
- Facilitated the discussion between different stakeholders in the Colombian health system.

**Research Assistant with Dr. Olga Lucia Sarmiento**  
Faculty of Medicine, Universidad de Los Andes  
- Assessed data quality for the Physical Activity Chapter of the National Health and Nutrition Examination Survey, Colombia 2010

**Intern with Dr. Maria Luisa Latorre**  
Centro de Estudios e Investigación en Salud, Fundación Santa Fe de Bogotá  
- Collaborated in organizing discussion and analysis spaces between different stakeholders in the Colombian health system

**Research Assistant with Drs. Sandra García Jaramillo and Olga Lucia Sarmiento**  
School of Government, Universidad de Los Andes  
Malnutrition and context among children in Colombia, a multilevel study  
- Reviewed literature and collaborated in the writing of the research protocol

**GRANT WRITING EXPERIENCE**

**Drafting of proposals**  
Ecosystemic approach for the design and implementation of sustainable strategies for dengue control in two regions of Colombia  
Awarded: 5,000,000,000 COP (2,782,415 USD, 1USD=0.000556 COP in Sept 2011)

Assessment of Recreovía Program for the promotion of Physical activity in community environments, Awarded: 221,812,460 COP (115,527USD)
Assessment of Muevete Escolar Program for the promotion of Physical activity in Scholar environments, Awarded: 237,904,745 COP (123,908 USD same rate as above)

SKILLS AND TECHNIQUES

• Quantitative data analysis using R, STATA and M-plus
• Spatial Analysis using Arc-GIS and R
• Qualitative data collection and systemization with Atlas TI
• Native Spanish speaker, Proficient English speaker, Portuguese beginner level.

PUBLICATIONS AND PRESENTATIONS

PEER-REVIEWED ARTICLES:


SELECTED PRESENTATIONS AND ABSTRACTS:


BOOK CHAPTERS


HONOR AND AWARDS
Master’s Tuition Scholarship, Department of Epidemiology, Johns Hopkins 2015
Bloomberg School of Public Health Colfuturo Loan-Scholarship Program awardee for postgraduate studies 2014-2016

LEADERSHIP EXPERIENCE

**Bloomberg School of Public Health, Johns Hopkins University** 2015 –2016
Infectious Disease Epidemiology Journal Club Coordinator
Alumni and Funding Chair, The Epidemiology Student Organization
Communications Chair, Latino Public Health Network

VOLUNTEER EXPERIENCE
Prevalence determination of Chagas in the Latino population of Virginia 2015 – 2017
Data collection and informed consent administration to study subjects
The CJR Newcomer Student Support Team (NeSST) Spanish support in science classes to newcomer students whom English is their Second Language 2016 – 2017