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Projecting the future of the HIV/AIDS epidemic in Tijuana, Mexico

A dissertation submitted in partial satisfaction of the  
requirements for the degree of Doctor in Philosophy

in

Public Health (Epidemiology)

by

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2009



The dissertation of Esmeralda Iniguez-Stevens is approved, and it is acceptable in quality and form for publication on microfilm:

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## DEDICATION

I dedicate this doctoral dissertation to family - my late uncles Francisco Méndez Flores and Benjamin Méndez Flores, my late aunt Linda Méndez de Gutierrez, my late grandparents Benjamin Méndez Gutierrez and Vicenta Flores de Méndez, my mother Carlota Méndez Flores, and my aunt Margarita Méndez Flores. They instilled in me a passion for education, a strong work ethic, and a desire to persevere and achieve my life goals. I'm eternally grateful for their hard work and dedication. The foundation they have given me has allowed me to achieve both my personal and educational goals.

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**E. Iñiguez**, Brouwer KC, Strathdee SA, Patterson TL, Lozada R, Magis-Rodriguez C, Elder JP, Viani R, Hogg RS. HIV Prevalence Estimates by Gender and Risk Group in Tijuana Mexico: 2006. [In Press].



ABSTRACT OF THE DISSERTATION

Projecting the future of the HIV/AIDS epidemic in Tijuana, Mexico

by

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Doctor of Philosophy in Public Health (Epidemiology)

University of California, San Diego, 2009

San Diego State University, 2009

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Referred to as an “Epidemic Without Borders,” the escalating HIV/AIDS epidemic in the U.S./Mexico border region is in urgent need of attention. Although the epidemic is currently concentrated there is potential for it to advance to a generalized level. Recent studies have estimated that 1 in 125 adults aged 15-49 in Tijuana is HIV-infected, with sub-groups most affected being men who have sex with men (MSM), injection drug users (IDUs), and female sex workers (FSWs). Given this there is urgent need to targeted HIV prevention initiatives for these populations. As a result we proposed the following: 1) estimate the total number of men and women aged 15-49 years infected with HIV in 2006; 2) project the new number of HIV infected adults ages 15-49 among non-IDU/FSWs over the next 30 years; 3) evaluate the potential impact of increasing condom use between non-IDU/FSWs and their client on the HIV epidemic curve over a period of 30 years.

We calculated HIV prevalence estimates among men and women aged 15-49 in Tijuana, Mexico for 2006, overall and by risk groups (MSM, IDUs, FSWs, pregnant women, low risk men and women). General demographic data such as total population size, gender ratio, and age distribution were obtained from the 2005 Mexican census. To obtain the most updated estimates of HIV prevalence, a review of published literature and available data from community-based studies was conducted. Results of this modeling project allowed us to develop a range of possible estimates for the number of HIV infected individuals, both overall and for each of the at-risk sub-groups. A mathematical model to predict the course of the HIV epidemic over a 30-year period (2006-2036) among FSWs who are not injection drug users (non-IDU/FSWs) was developed. More specifically a deterministic compartmental mathematical model was constructed based on biological (i.e., probability of HIV transmission per sexual act, prevalence of sexually transmitted infections), behavioral (i.e., number of unprotected sexual encounters), and demographic (i.e. population age distribution

and population sizes) parameters. Data for the model were derived from community-based studies, literature searches, population census, and communication with Mexican public health officials. A second deterministic compartmentalized model was developed to assess the impact of decreasing unprotected sex among non-IDU/FSWs on the prevalence and incidence of HIV/AIDS. More specifically decreases of 5%, 10%, 20%, 50% and 75% in unprotected sex were modeled. Data on baseline levels of unprotected sex among non-IDU/FSWs was taken from a community-based study. Sensitivity analysis for both deterministic models consisted of developing low- and high-growth scenarios for each of the modeled estimates.

The estimated overall prevalence of HIV in Tijuana Mexico among adults ages 15-49, is 0.54% (N = 4,347) (Range: 0.22% (N = 1,750) – 0.86% (N = 6,944)). This means that as many as 1 in every 116 male and female adults between the ages of 15-49 could potentially be infected with HIV. However, HIV prevalence is most concentrated among sub-groups of the population such as men who have sex with men (MSM), female sex workers who are injection drug users (FSW-IDUs), female-IDUs, non-IDU/FSWs and male-IDUs. Results of the deterministic mathematical model show that accumulative HIV incidence will continue to rise over the 30-year modeled period (2006-2036). According to the low- and high-growth scenarios the HIV epidemic will become sustained at approximately 19% by the year 2036. A greater reduction in future HIV prevalence was observed when unprotected sex was decreased by greater than 50% among non-IDU/FSWs. The model also predicted that the greater the reductions in unprotected sex, the lower the level at which the epidemic would become a sustained epidemic.

## **Chapter I.**

### **INTRODUCTION**

#### **Introduction**

Directly south of San Diego County lies the city of Tijuana, Mexico. This border crossing is one of the largest and busiest ports of entry into the U.S., with 48 million north bound border crossings per year.[1] Estimated population for Tijuana, Mexico has been reported around 1.27 million[2]; and estimates of the total number of inhabitants in this U.S.-Mexico border region, have been estimated at greater than 5 million.[2] Due to the large numbers of residents that reside on each side of the border, mobility between the two countries is high. Moreover, Tijuana has become a major drug trafficking route, which has contributed to a burgeoning population of IDUs, estimated at 10,000.[3] Since prostitution is quasi-legal in Tijuana, an estimated 9000 FSWs fulfill the demand of clientele from both sides of the border. Both drug use and the sex trade have led to increases in HIV risky behaviors. As a result, there is concern among health officials on both sides of the border, about transmission of communicable diseases such as HIV/AIDS.

#### **Epidemiology of HIV/AIDS in Mexico**

There is a need for improved HIV surveillance systems in countries with low level and concentrated epidemics such as Mexico.[4] HIV surveillance systems are integral to understanding HIV transmission dynamics, especially when attempting to elucidate which sectors of the population are most vulnerable. A recent study estimated there are approximately 160,000 HIV+ people in Mexico, while HIV prevalence in the general population is estimated at 0.3% among 15-49 year olds.[5] Among Mexico's 32 states, Baja California had the second highest accumulative AIDS incidence in 2005, after the *Distrito*

*Federal*. [6] Comparisons of selected areas in the U.S. by demographics and residential characteristics (rural, suburban, urban and U.S.-Mexico border region), showed that the U.S.-Mexico region had the highest race-adjusted rates of HIV diagnosis (21.1 per 100,000) [7]. Recently, members of our research team estimated that as many as 1 in 125 residents, ages 15-49 were infected with HIV in 2005, corresponding to an HIV prevalence of 0.80%. [5] Prevalence of HIV was highest among population sub-groups, particularly MSM, IDUs and FSWs. Another study conducted at the Tijuana General Hospital among >1000 women in labor found the overall percentage of HIV to be 1.2%. [8] This study suggests that HIV may become generalized in Tijuana outside of major risk groups.

### **Mexico's Effort to Fight HIV**

Given limited economic resources in Mexico, it is crucial that we appropriately allocate funding to target the most vulnerable groups. A 1998 study of different countries' response to HIV/AIDS, reported the following expenditures for each of the countries (adjusted for purchasing power): Brazil, US\$587.4 million, Mexico US\$257 million, Honduras US\$33.9 million, Uruguay US\$32.5 million and Guatemala US\$29.5 million. [9] In Mexico, two thirds of these funds were allocated towards HIV care, while only 29% went towards HIV prevention. In fact, the proportion of funds allocated for prevention decreased from 1997 to 1998, from 38% to 29%. [9] It is our hope that mathematical simulations of the HIV epidemic in Tijuana and the potential impact of various interventions can be used to leverage resources for prevention.

### **HIV Prevention Interventions & Risk Behaviors**

Three of the common HIV prevention interventions have focused on expanding the following: 1) Voluntary counseling and testing (VCT), 2) increasing condom use, and 3) sterile syringe use among IDUs. Studies have shown that VCT is feasible and cost effective as a means of reducing HIV transmission when delivered to individuals or groups in

developed and developing country settings[10, 11]. Results of ongoing community-based studies in Tijuana show that only half of IDUs and FSWs had ever had an HIV test[12] (and personal communication with Strathdee), indicating the need to scale-up this proven HIV intervention among high risk populations in Tijuana.

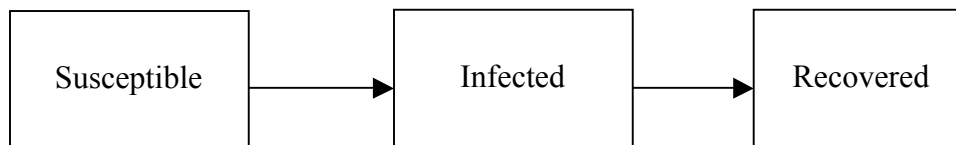
Interventions geared at promoting increased condom use can avert future HIV infections[13]. However, some studies have suggested that Hispanic men may be more reluctant to use condoms than other men.[14] Some Hispanic men do not perceive themselves at risk for HIV, even though they may have sexual contact with FSWs.[15] In a study of MSM in Tijuana, 72% of participants reported having unprotected anal intercourse (UAI), 80% unprotected vaginal intercourse, and greater than 40% reported having UAI with a female.[16] Furthermore, one report estimated that FSWs in Mexico are offered up to a 24% monetary pay increase for having unprotected sex.[15]

Another target area for HIV prevention is prevention of risky behaviors among IDUs. Nationally in Mexico, estimates are that approximately 6% of all IDUs are HIV-infected[17], which corresponds to recent HIV prevalence data from Tijuana.[5] However, HCV prevalence among IDUs in Tijuana is 95%[18], suggesting that needle sharing is normative and that predisposing conditions for an HIV epidemic exist among IDUs in Tijuana. Given the high prevalence of risky injection behaviors, programs geared at increasing access and ease of availability to sterile syringes are necessary. Despite the effectiveness of needle exchange programs (NEPs), only a third of countries where HIV is a problem among IDUs have a NEP.[19] There is only one NEP in Mexico operating in Cd. Juarez, and no formal NEPs in Tijuana.[3] Currently there are 1630 pharmacies in Tijuana where IDUs can legally purchase sterile syringes; however, in-depth interviews conducted with IDUs revealed that pharmacists either refused to sell syringes to IDUs, would sell them at higher prices, or that police confiscated their syringes, which led many IDUs to borrow or rent used syringes.[3]

Structural changes that will expand access to sterile syringes for IDUs are necessary, given the high prevalence of IDUs and existence of barriers to accessing sterile syringes.

### **Modeling of Epidemic & Its Applications**

Theoretical principles for epidemic modeling extend as far back as the early 18<sup>th</sup> century, when Bernoulli used mathematics to help explain the effectiveness of variolation to control smallpox.[20] Later, in 1906 Hamer pioneered some of the earlier work, through the realization that the future of an epidemic depends on the contact rate between infected and susceptible individuals.[21] This idea now forms the backbone of mathematical epidemiology, and has been coined the ‘mass action principle’.[22] More specifically the ‘mass action principle’ specifies that future propagation of an epidemic is dependent upon the density of infected and susceptible individuals within a population; and is the theory that drives deterministic and stochastic modeling of epidemics.[22] Modelling of infectious diseases entails use of sophisticated mathematical processes, due to the complex and dynamic nature of epidemics. Stochastic and deterministic modelling are two mathematical processes that have been traditionally used to help understand and predict the course of dynamic epidemics.[23] Both of these approaches rely on usage of compartmental models, which divide individuals according to key attributes.[23] The most basic model is one with three compartments, and is referred to as the Susceptible-Infected-Recovered (SIR).[23] Following is a schematic of such a model:



An essential part of the modelling process entails determining key attributes for a particular disease, and developing mathematical equations which best represent the movement of the

population from one compartment to the other. As will be discussed in the analysis section in this paper, development of a compartmentalized model for HIV will entail starting with this simple SIR model and tailoring it to the specific attributes of HIV (e.g., rate of transmission, mode of transmission).

### **Application of Modelling Techniques**

A quick look at the scientific literature will reveal that the future of the HIV epidemic has been modeled for many different populations across the globe.[24-26] Results of in-depth literature searches revealed that despite the abundance of the application of modelling techniques, there have been no attempts to model the future of the HIV/AIDS epidemic for Tijuana, Mexico. Nonetheless, the following is a discussion of several HIV modelling examples, in which we highlighted some utilities of mathematical modeling as well as salient characteristics pertinent to our project.

Mathematical modeling exercises have a wide range of applications. These applications extend from projecting the number of new HIV infections over a certain period of time, estimating how many future infections can be averted given certain prevention intervention, to conducting comparative analysis of prevention interventions. For example, Stover et al. estimated that a total of 31.1 million new HIV infections could be prevented worldwide over the next ten years, given implementation of appropriate comprehensive prevention interventions.[27]

Not unlike many other parts of the world, high-risk behaviors (e.g., needle sharing, sex work) have propelled the HIV epidemic in many parts of China.[24] Hence, studies comparing the utility of interventions geared at reducing certain high-risk behaviors and consequently new HIV infections have the potential to guide public health professionals in the right direction. Bacaër et al., modelled the epidemic among injection drug users and female sex workers in Kunming, China.[24] Similarly to the current proposed study, they



used a series of differential equations to predict the course of the epidemic in this community. The results of this simulation exercise showed that the reproductive number ( $R_0$ ) (average number of people an infected person will infect) for IDUs is 32 while that for sexual transmission is much lower. Given these results, they concluded that needle exchange programs and education on how to clean needles should reach 97% of the IDU population, to effectively stop the spread of the epidemic. On the other hand, it was found that a 50% reduction in risk behavior among FSWs, would be sufficient to stop the spread of the epidemic for Kunming China. The authors conclude that based on  $R_0$  numbers alone, prevention efforts geared at reducing risk needle sharing are greatly needed. Conversely, they also note that the major mode of HIV transmission in China is sexual transmission.[24]

In the previous example we saw how the reproductive number was utilized to assess which intervention was more urgently needed, but that other factors such as major mode of transmission need to be considered to make a better informed decision. In yet another study, compartmental simulation was utilized to model the HIV/AIDS epidemic in Botswana and India.[25] In this case the model was compartmentalized by gender or high versus low-risk HIV individuals. Of primary interest was to assess the impact of various prevention interventions on the future of the HIV epidemic. The effect of the following interventions was modeled: a behavioral intervention focused on female sex workers, treatment of STIs, prevention of mother to child transmission, antiretroviral treatment for the whole population (based on single regimen), and antiretroviral single regimen treatment of female sex workers. Results of this modeling exercise showed that the sex worker intervention could have the potential of ending the HIV epidemic in India; while the epidemic in Botswana would not be eliminated by any of the interventions but would however be reduced by half.[25] Given this modeling scenario, the investigators concluded that the effect of interventions targeting sexual transmission of the virus have great potential to help stop the spread of the virus. It

was also noted that although HIV prevention should be as comprehensive as possible, some interventions (e.g. sex worker intervention) may have the ability to individually extinguish the epidemic.[25] Differential equations were also used in a study by Murray et al., to examine the impact of number of needle sharing partners on the HIV epidemic.[28] This study took quite a novel and uncommon approach. Rather than assessing the impact of prevention interventions on the future of the epidemic, as many other modeling studies have done, they modelled the effect of the frequency of risky behavior (e.g. needle sharing) on the future of the epidemic. Results of this study showed that in Australia, if IDUs had less than 17 injection partners per year, the HIV epidemic would remain at very low levels in the population.[28] Given that currently IDUs report about six partners per year in that country, they estimate that HIV prevalence will remain under 1% for the country.[28] This study also shed light on the potential of needle exchange programs to contain the epidemic.

The utility of mathematical modeling ranges from predicting the epidemic in sub-groups of a particular population, to predicting the future course of the epidemic for a whole country. An example of using mathematical modelling to predict the epidemic curve for a country as a whole can be found in the work of Tim Brown.[26] Brown has examined the forces that have driven the epidemic for Asia, as well as projected the future of this epidemic for Asian countries.[26, 29] Through his work he has recognized that there are strong behavioral linkages between sub-groups of the population, which help propagate the HIV epidemic.[30] The primary behavioral linkage in many countries has been that between IDUs and FSWs as well as MSM.[26, 30] Hence a rise in HIV prevalence among one sub-group, may signal a subsequent rise in another sub-group of the population, and eventually a rise in HIV prevalence of the general population. Given this linkage between sub-groups, Brown projected the future of the epidemic for Asian countries until the year 2020.[26] Parameters (e.g., percent condom use, magnitude of female sex trade, date of start of epidemic) for this

simulation were based on what is characteristic for these countries.[26] Projections were done for a country in which there is no epidemic among drug users (i.e., no transmission due needle sharing), but there is an epidemic among FSWs. Conversely, projections were also done for a country in which there is an epidemic among drug users as well as an epidemic among sex workers. The following three different epidemics among sex worker were modelled: a high risk (20% of men visit sex workers & 2 clients per night), a medium risk (10% of men visit sex workers & one client per night) and a low risk (5% of men visit sex workers & one client per night). Results showed that regardless of whether there was an epidemic among IDUs, if a country was a “high risk” country (i.e., 20% of men visited FSWs), the epidemic would almost spread to 20% of the population by the year 2020. The only difference here would be that in countries where there was also an epidemic among IDUs, the prevalence of HIV would reach 20% at an earlier time point. In medium risk (i.e., 10% of men visit FSWs) countries with an epidemic among IDUs the prevalence would reach approximately 5-7% by the year 2020. Here too, regardless of the presence of an epidemic among IDUs the prevalence of HIV would be somewhat similar by the year 2020; however, the epidemic in countries with no epidemic among IDUs, HIV prevalence would grow at a much slower rate in the beginning and escalate toward the end (i.e., by the year 2020). In the third scenario (i.e., in countries with a ‘low risk’ epidemic among FSWs), the prevalence of HIV would reach approximately 2-3% by the year 2020. In countries of “low risk” and no epidemic among IDUs, the course of the HIV epidemic would be negligible.[26] The results of this modelling study shed light on the impact of the linkage between sub-groups and the future course of the HIV epidemic. The primary message here, being that the HIV epidemic appears to be driven very strongly by sexual transmission in the sex working population and through needle sharing among IDUs. However, in countries where there are epidemics

among both of these populations (FSWs & IDUs), the epidemic will escalate at a much higher rate.

The role of mathematical modelling studies in helping avert future HIV/AIDS cases is quite evident. We have seen how results of modelling scenarios have been used to examine primary factors that may drive the HIV epidemics[26], the effect of linkages between at-risk sub-groups on the prevalence of HIV[30], as well as the effectiveness of behavioral interventions in containing the epidemic.[24] The HIV epidemic has been shown to be driven initially by at-risk sub-groups of the population, and subsequently extending itself to the general population. In Tijuana the HIV epidemic trails behind other epidemics in terms of the time, but may eventually reach the same alarming proportions as it has in other countries. As it is the prevalence of HIV among at-risk sub-groups is already starting to parallel the earlier history of the epidemic in other populations. A study projecting the future of this epidemic at this point in time has the potential to prevent this epidemic from spreading further. Given previous findings regarding modeling of the HIV epidemics, we not only projected the course that this epidemic will take, but also evaluated the effectiveness of increasing condom use between FSWs and their clients.

### **Summary of Rationale & Specific Aims**

We propose the following study to help guide health professionals and governmental institutions on both sides of the border. The goal of this project is to forecast the future of the HIV/AIDS epidemic within the next 30 years in Tijuana, Mexico. The Tijuana/San Diego border is the busiest border crossing in the world[2], and over 80% of Tijuana's residents originate from other cities, mostly in southern Mexico. It was recently estimated that 1 in 125 adults aged 15-49 in Tijuana is HIV-infected[5], and thus there is potential for increased HIV transmission for both the USA and Mexico. Recent studies have reported high levels of risk behaviors in injection drug users (IDUs), female sex workers (FSWs) and men who have sex

with men (MSM).[3, 16, 31] Given the urgency of this situation, there is a need to project the magnitude of potential increases in HIV/AIDS prevalence and incidence; as well as the potential impact of appropriate HIV interventions geared at increasing HIV voluntary counseling and testing (VCT), increased utilization of condoms and sterile syringes. Since HIV transmission is an important public health concern for both sides of the border, interventions aimed at reducing transmission in Mexico will impact the HIV/AIDS epidemic in the U.S. Given the rising threat of this epidemic, this study proposes to estimate the current number of HIV infections and model the future of the HIV/AIDS pandemic in Tijuana, Mexico, as outlined by the following aims:

1. Estimate the number of men and women aged 15-49 years by gender and risk-group infected with HIV in Tijuana as of August 2006.
2. Develop a deterministic mathematical model based on existing data, to project HIV/AIDS incidence and prevalence among non-IDU/FSWs over the next 30 years in Tijuana, Mexico.
3. Determine the potential impact of various increasing condom use on the future of the HIV epidemic in Tijuana, Mexico non-IDU/FSWs over the next 30 years.

### **Enumeration of Chapters**

The second chapter of this manuscript reports on the prevalence of HIV/AIDS by gender and risk-group (i.e., MSM, IDUs, FSWs, and low risk) in 2006 for the city of Tijuana, Mexico. A population-based model of HIV prevalence was developed resulting in an overall HIV point prevalence and a corresponding range based on standard errors (95% confidence).

The third chapter presents results of projected HIV/AIDS incidence and prevalence among non-IDU/FSWs over a 30-year period in Tijuana, Mexico. A deterministic mathematical model based on behavioral, biological and demographic input parameters was

developed. Sensitivity analysis consisted of low-growth and high-growth scenarios resulting from high and low standard error of parameter estimates.

The fourth chapter shows results of a deterministic mathematical model developed to project the effect of decreasing unprotected sex among non-IDU/FSWs on the future of the HIV/AIDS epidemic in Tijuana, Mexico. Decreases of 5%, 10%, 20%, 50% and 75% in unprotected sex was modeled over a period of 30-years. Sensitivity analysis consisted of low-growth and high-growth scenarios resulting from upper and lower ranges of parameter estimates.

Appendix I provides a description of the parameter inputs utilized for chapters three and four. The description includes sources for the parameter estimates as well as the mathematical derivation of parameters estimates utilized.

## CHAPTER II.

### HIV PREVALENCE ESTIMATES BY GENDER AND RISK GROUP IN TIJUANA MEXICO: 2006

#### A. ABSTRACT

Objective: To estimate HIV prevalence among men and women between the ages of 15-49 in Tijuana, Mexico - among the general population and at-risk subgroups in 2006.

Methods: Demographic data was obtained from the 2005 Mexican census, while HIV prevalence data was obtained from published literature and community-based studies. A population-based HIV prevalence model for the overall population and stratified by gender was developed. Sensitivity analysis consisted of estimating standard errors in the weighted-average point prevalence and taking partial derivatives with respect to each parameter.

Results: According to our model, HIV prevalence among adults was 0.54% (N = 4,347) (Range: 0.22% (N = 1,750) – 0.86% (N = 6,944). This suggests that 0.85% (Range: 0.39-1.31) of men and 0.22% (0.04-0.40) of women could have been HIV-infected in 2006. Men who have sex with men (MSM), followed by female sex workers who are injection drug users (FSW-IDUs), FSW-nonIDUs, female IDUs, and male IDUs contributed the highest proportions of infected individuals.

Conclusions: The number of HIV-infected adults among at-risk subgroups of the Tijuana population is considerable, underlining the need for prevention interventions focused on their specific needs. According to this model, as many as 1 in 116 adults could potentially be HIV-infected.

## B. INTRODUCTION

According to the *Centro Nacional para la Prevencion y Control del SIDA* (CENSIDA) [National Center for the Prevention and Control of AIDS], the total number of HIV positive people in México in 2006 was 182,000, which translates into a prevalence of 0.3% among people aged 15 to 49 years.[32] As in most countries, there are disparities in both the geographical distribution of HIV infection, as well as its distribution among different risk groups in México. Among México's 32 states, Baja California has consistently had the one of the highest accumulative AIDS incidences, after the capital of city México Federal District.[6]

The Tijuana/San Diego border is the busiest land border crossing in the world[2], with approximately 48 million north bound border crossings per year.[33] Tijuana is situated on a major drug trafficking route and has a thriving *zona roja* that attracts thousands of 'sex tourists' each year. Strong migratory forces from the interior of the country to Tijuana have created a city with one of the highest population growth rates in Latin America.[34] In 1940, Tijuana's population was 21,977; by 2005, it had risen 1.4 million.[34, 35] It is estimated that the population of Tijuana will increase to 2.2 million by the year 2010 and to 3 million by the year 2030.[36]

Based on available HIV prevalence data in 2005, Brouwer and colleagues estimated the numbers of HIV-infected adults in Tijuana by gender and risk group.[5] Using both a low- and a high-growth scenario, they estimated that overall HIV prevalence among 15-49 year olds ranged from 0.26%-0.80%. Extrapolating to the population, this analysis suggested that up to 1 in 125 adults aged 15-49 in Tijuana was HIV-infected in 2005. By subgroup, this model suggested that men who have sex with men (MSM), followed by male injection drug users (IDUs) were the risk groups comprising the largest numbers of HIV-positive persons.[5]



Recent availability of more refined prevalence estimates from community-based studies suggested that HIV prevalence in Tijuana may be higher, especially among female sex workers (FSWs).[37] For example, a study of 924 FSWs conducted in Tijuana and Cd. Juarez, revealed that HIV prevalence among FSWs who injected drugs (FSW-IDUs) was 12.3%, and 4.8% among other FSWs.[38] Brouwer et al<sup>8</sup> utilized the Mexican population census from 2000 to construct their models, since the 2005 census was not yet available. In light of the availability of more refined HIV prevalence estimates among some risk groups and availability of more recent census data, we estimated the number of HIV-positive adults aged 15-49, as well as HIV prevalence among population sub-groups for which data were available through 2006.

### **C. MATERIALS & METHODS**

Using a similar approach as Brouwer et al,[5] a population-based model of HIV prevalence was constructed for Tijuana, México. Updated population size estimates from the most recent Mexican census, as well as the most recent estimates of HIV prevalence among population subgroups were used to develop the model.[35] HIV prevalence models were developed for the overall population, and were also stratified by gender and population subgroups (e.g., high risk pregnant women, low risk pregnant women, low risk women, low risk men, MSM, male IDUs, female IDUs, FSWs, and FSW-IDUs). For the purpose of this model “low risk” groups were categorized as groups of people not involved in sex work or injection drug use, while “high risk” pregnant women were defined as those women who sought prenatal care. Availability of more comprehensive data sets and a different mathematical approach, allowed us to further refine the models created by Brouwer et al[5] by stratifying IDUs by gender and FSWs by IDU status. All models were based on the 15-49 age group, because this age group reflects the segment of the population most at risk for acquiring HIV.

The two parameters of interest were the population size and HIV prevalence estimate for each group (Table I). The most recent Mexican population census available from 2005 was utilized to obtain Tijuana population estimates. Data from this census was stratified by gender and restricted to the 15-49 year old age group. Age-specific fertility rates were used to construct updated population size estimates; these rates were taken from the U.S. Census Bureau International database, which compiles data from a variety of Mexican government sources.[39]

To obtain HIV prevalence estimates, we first reviewed available published literature. This entailed an in-depth search of medical and social sciences databases (e.g., PubMed, PsychINFO and RIIMSIDA) in English and Spanish using key words such as: HIV prevalence, Tijuana, México, MSM, IDUs and FSWs. The search also included non-indexed major databases (e.g., LILACS), both federal and state health and policy related websites (from the México and USA), as well as the most up-to-date information from Mexican health officials. Our search also encompassed data available from CENSIDA, which is responsible for HIV/AIDS surveillance in México. Lastly, we derived HIV prevalence estimates from published reports, community based studies, professional conference abstracts, and personal communications with field experts.

A population-based model of HIV prevalence was developed by estimating the weighted-average of HIV prevalence for the city among all at-risk adults between the ages of 15-49. For this purpose the population was broken down into 9 different sub-groups (see Table II). Calculations of the weighted-average HIV prevalence were based on two main parameters: 1) the size of the individual population sub-groups, and 2) the respective HIV prevalence for each of the population sub-groups. The weighted-average HIV prevalence was obtained by multiplying the point HIV prevalence estimate for each of the sub-groups by

the respective proportion of all adults in the city that belong to that sub-group. Sensitivity analysis consisted of estimating the standard error in the weighted-average point prevalence using the chain rule: taking (the absolute value of the) partial derivative of the formula for the weighted-average HIV prevalence with respect to each parameter, multiplying it by the standard error of that parameter, and adding. These estimates were based on the following 4 parameters: 1) the point HIV prevalence for each of the sub-groups, 2) the standard errors (two standard deviations from the point prevalence – 95% confidence) of the HIV prevalence point estimate for each of the sub-groups, 3) the midpoint of the range of each of the sub-group sizes, and 4) the range in sub-group population sizes. This resulted in three separate population-based HIV prevalence estimates (i.e., overall population, male and female) and the corresponding ranges for each. Estimates of crude number of HIV cases for the overall population and by gender were calculating using the respective HIV prevalence estimates. This way of calculating the standard error yields an interval for each estimate that differs from those calculated using the methodology of Brouwer, et al.<sup>8</sup> Their approach consisted of developing low and high growth scenarios by combining the low end and high end of 95% confidence intervals, resulting in less precision. The present methodology gives a more reliable estimate of the 95% confidence interval for each HIV prevalence estimate.

The current models incorporated further stratification of some of the at-risk population subgroups, such as IDU by gender and by sex work status among females. According to the results of the 1998 National Survey of Addictions [*La Encuesta Nacional de Adicciones*] the male to female ratio of the drug using population in Tijuana is approximately 6 to 1.[40] This gender ratio was applied to the HIV prevalence models (Table II) to estimate the total number of IDUs by gender. The model also stratified FSWs by IDU status, hence female IDUs engaging in sex work were excluded from the female IDU subgroup to avoid double counting.

Sources of HIV prevalence estimates for various sub-populations were derived from various community and hospital based studies (Table II). Estimates of HIV prevalence among MSM were obtained from a cross-sectional study, which remains the only study of its kind in Tijuana.[16] HIV prevalence among IDUs stratified by gender were derived from a longitudinal, ongoing community based study in Tijuana, México, *Proyecto El Cuete*. [41] Another community based study *Mujer Segura* conducted in Tijuana, México, was used to estimate the prevalence of HIV among FSWs stratified by IDU status.<sup>[42]</sup> A hospital-based study investigating HIV prevalence and correlates of HIV infection among pregnant women in Tijuana was used to derive an estimate of HIV prevalence among high risk pregnant women.[8] Regional and national surveys were used to obtain estimates of HIV prevalence among low risk pregnant women, and low risk men and women. To our knowledge, there are no available estimates of the prevalence of HIV among low risk pregnant women for the city of Tijuana; hence, the prevalence among low risk men and women was used for the low risk pregnant women sub-group. Estimates for low risk men and women were obtained from both the *Consejo Nacional para la Prevencion y Control del SIDA* and UNAIDS reports.[43, 44]

#### **D. RESULTS**

The 2000 Mexican census estimated that there were 686,600 persons aged 15-49 years residing in Tijuana; by the time the 2005 census was administered this estimate had increased to 808,835.[35] There were 407,554 males and 401,281 females within the 15-49 age group. In 2003, a study conducted by CENSIDA estimated that there were approximately 6,400 IDUs in Tijuana; this estimate was based on time location sampling conducted in shooting galleries and outdoor injection sites.[45] However, a subsequent community-based study of IDUs in Tijuana found that 60% of IDUs inject in other venues,[46] suggesting that there were approximately 10,000 IDUs in the city. Based on

these studies it was assumed that the range of IDUs in the city was 6,400-10,000 with a midpoint of 8,200, of which the majority were males (Table II).

Estimates for the proportion of the male population in México that has had sex with another male (MSM), were taken from a study by Diamond[47] and personal communications with researchers conducting research in the MSM community, which agreed that approximately 3-5% of the Mexican male population are MSM. It was therefore assumed that N = 16,302 (4%) of the total male population was MSM, with the range being N = 12,227 -20,378 (3%-5%).

The number of FSWs was taken from an ongoing community based study, which reported that the likely range was 4,850-9,000 .[31] Since data on HIV prevalence were available from a community based study of FSWs in Tijuana conducted from 2004 to 2006, which showed that HIV prevalence varied significantly depending on whether or not FSWs injected drugs, we further stratified by FSWs who ever injected drugs and those who had not.[38] This community-based study found that approximately 18.4% of all FSWs had injected drugs in their lifetime.[38] Taking this into consideration, we estimated there were 5,648 (Range: 3,957-7,338) FSWs who were not IDUs, and 1,276 (Range: 893-1,662) FSW-IDUs (Table II).

As shown in Table II, HIV prevalence among adults 15.49 living in Tijuana in 2006 was 0.54% (Range: 0.22%-0.86%), compared to the Brouwer et al[5] study, which estimated that HIV prevalence ranged from 0.26% to 0.80%. When stratifying by gender males have a much high prevalence (0.85%, Range: 0.39-1.31), as opposed to females (0.22%, Range: 0.04-0.40). However, it is noteworthy to mention that the proportion of infected female IDUs was almost twice as high as that of male IDUs (female = 5.9% & male = 2.5%), and that the FSWs (IDUs and nonIDUs) subgroup had the second highest HIV prevalence among all the

subgroups. For most sub-groups (with the exception of high risk pregnant women), the updated HIV prevalence was higher when compared to the previous model. Subgroups with the highest HIV prevalence were the following: MSM (18.9%, Range: 13.92-23.83), FSW-IDUs (11.0%, Range: 4.81-17.40), female IDUs (5.9%, Range: 2.14-9.66), and FSW-nonIDUs (6.4%, Range: 3.78-9.07).

## **E. DISCUSSION**

Based on available data, we found that 0.54% (0.22%-0.86%) of 15-49 year olds living in Tijuana in 2006 were likely to be HIV-infected, suggesting that as many as 1 in 116 adults in this age range may be HIV-infected. When stratifying by gender, HIV prevalence among males was much higher than among females; however, apart from the MSM subgroup, female sub-groups had the highest HIV prevalence. Although this modeling scenario suggests that the HIV epidemic in Tijuana is concentrated, the intensification of the epidemic in at-risk groups raises the potential for transmission to the general population. While HIV prevalence estimates among FSWs and IDUs were somewhat higher than previously estimated by Brouwer et al,[5] we can not conclude that this constitutes an actual increase but rather represents a more refined estimate as a result of better surveillance efforts and improved analytic techniques. As results from community-based studies among these populations have recently become available, our updated estimates are likely to better reflect the current HIV prevalence for Tijuana and have important implications for HIV prevention and treatment for high-risk sub-groups. Not surprisingly, we found that the sub-groups with the highest percentage of HIV-positive persons in Tijuana were MSM, FSWs, FSW-IDUs and to a lesser degree other IDUs. Despite the recent UNAIDS revised HIV prevalence estimates which were shifted down substantially[48], the estimates presented here serve to

confirm that Tijuana's HIV prevalence is at least as high as that previously reported by Brouwer et al.[5]

The present model further delves into the dynamics of this epidemic as it pertains to certain at-risk subgroups. For example, more comprehensive surveillance efforts allowed us to further refine HIV prevalence estimates among high-risk pregnant women. While the former range for the proportion of high-risk pregnant women who were HIV positive was estimated at 5.6-11.6%, more recent data suggested a much lower range (2.48%, Range: 0.96-4.0). In the previous model, high-risk pregnant women were defined as those who engaged in drug use and other risky behaviors, whereas in the current model, pregnant woman who did not seek prenatal care were categorized as high risk. This difference in categorization was intentionally done to reduce the likelihood of double counting pregnant IDUs, since the model already accounted for some of these subgroups (i.e. female IDUs).

This model was further refined by the availability of new data, which allowed stratification of IDUs by gender as well as of FSWs by IDU status. Conversely, due to lack of updated prevalence estimates for the "pregnant low risk," "low risk women" and "low risk men" subgroups, the same estimates used by Brouwer et al were used in this model. Despite the unavailability of updated data for these sub-groups, it was felt that the estimates utilized may closely resemble the current scenario in Tijuana for the general population. Data collected from *ISSTECALI (Instituto de Seguridad Social al Servicio de los Trabajadores de Baja California)*, a system of healthcare which serves both government and state employees, showed that HIV prevalence among pregnant women was probably less than 0.001% for this group (personal communication with *ISSTECALI* health officials). Nonetheless, *ISSTECALI* only serves a small percentage of the employed population of Tijuana. UNAIDS reports the Mexican national adult HIV prevalence as approximately 0.3%, with HIV prevalence for

urban populations least at risk (e.g. pregnant women, people with no known risk factors) as 0.1%, and populations at risk (e.g. FSWs, clients of FSWs) at 0.3%.[49] The prevalence utilized for the current model lies between the *ISSTECALI* and UNAIDS estimates.

To our knowledge, one of the few studies to have estimated HIV prevalence among MSM in Tijuana found a prevalence of 18.9% in 2002 (95% CI: 14.0-23.7).[16] A second study conducted in Tijuana from 1999-2000 by the California Department of Health Services found that HIV prevalence among MSM was 20.1%.[50] This same study also estimated the prevalence of HIV among MSM in San Diego and found that it was 35.3%.[50] The 2002 study[16] was used for the current modeling scenario given that it is the most recent. However, estimates derived from the California Department of Health Services study lie within the range of estimates utilized for our model. Furthermore, in 2004 HIV prevalence among MSM in México overall was believed to be about 15%.[17] Despite the growing sub-epidemic among MSM, studies have suggested that Hispanic men in California (comprised primarily of men of Mexican origin) are oftentimes reluctant to use condoms.[14] In a study of MSM in Tijuana, 70.7% of participants reported having unprotected insertive anal intercourse with a man, 28.1% reported having unprotected receptive intercourse with a man, 77.5% reported unprotected vaginal intercourse, and 43% reported having unprotected anal sex with a female.[16] These data underscore the need for continued prevention efforts to focus on MSM populations in Tijuana, as is the case elsewhere in México.

The male-to-female ratio for HIV infection in México is 6:1; however, the country seems to be experiencing a ‘feminization’ of the epidemic as recent reports show the rate of HIV infection among women is increasing.[51] This reported increase of HIV infection among women parallels what has been reported globally. In 2004, there were 16.5 million women living with HIV, by 2006 this number had increased to 17.7 million.[51] In sub-



Saharan Africa, the majority of those infected with HIV are women.[51] Other regions such as China have also experienced a growing rate of HIV infection among women.[51] At the national level in México, both female IDUs and FSWs have experienced disproportionate increases in HIV prevalence as opposed to other sub-groups.[49] Tijuana has not been spared from this disproportionate shift in the distribution of HIV cases, since HIV prevalence was recently reported to be more than twice as high among female IDUs compared to male IDUs,[52] and HIV prevalence among FSWs has risen, especially among FSW-IDUs.[38] While the majority of HIV cases in Tijuana are among males, results from this study do in fact support the ‘feminization’ of the epidemic in the city.

Reasons for the reported higher prevalence among FSW and FSW-IDUs may vary depending on their source. For example, data collected on sexual risk behaviors in a sample of high risk Mexican FSWs showed that one third had unprotected anal sex with clients in the past month.[53] Many FSWs reported being reluctant to ask their clients to wear condoms, did not know how to use condoms properly, and reported that it was not uncommon for some clients to pay more for unprotected sex.[15, 53] Recent studies in Tijuana reported that only 49% of FSWs and one third of IDUs had ever had an HIV test,[12, 54] indicating the need to expand voluntary testing and counseling to these and other high risk groups. Recently, CENSIDA and state health officials implemented mobile vans called ‘condonetas’ in Tijuana and other Mexican cities in an effort to deliver condoms and HIV prevention materials to high risk neighborhoods. Baja California has also integrated routine HIV screening into prenatal care in an effort to identify HIV infections earlier and offer appropriate HIV treatment to mother and child.

Despite availability of updated data, the number of studies that provide estimates of HIV prevalence among population sub-groups in Tijuana, especially MSM, are relatively

few. Assumptions regarding sizes of population sub-groups were dependent upon available data, and therefore our model could potentially under- or over-estimate the true prevalence. To circumvent these biases, we developed a midpoint HIV prevalence model with a corresponding range. Although some of our data sources allowed us to stratify by specific characteristics, we were not able to stratify our MSM sub-group by IDU status due to small numbers. Given that MSM and IDUs are two sub-groups in which HIV prevalence is considerable, one can only assume that HIV prevalence among MSM-IDUs would be higher as opposed to MSM who are not IDUs. This limitation may have led us to overestimate the true HIV prevalence, especially among males.

Our model utilized a recent population census with recent demographic variables such as age-specific fertility rates. However, the effect of in- and out-migration was not accounted for in the model. Due to the large numbers of residents that reside on each side of the border and hence the strong economic, social and tourist ties, mobility between México and the USA is substantial. For example, a study of IDUs in 2005 found that 20% of IDUs in Tijuana reported having traveled to the US in the prior year.[55] Approximately 45% of Tijuana MSM and 75% of San Diego MSM have male sex partners from across the border.[16] One study found that HIV prevalence among Mexican male migrant workers in San Diego and Fresno counties could be as low as 0.2% and as high as 2.0%.[56] Over two thirds of FSWs in Tijuana report being patronized by U.S. clients.[57] Lack of adjustment for migration suggests that our model could either underestimate or overestimate the true HIV prevalence. Prevention interventions should take into consideration the presence of international networks among sub-groups of the San Diego/Tijuana population.

The HIV epidemic in Tijuana continues to be driven by dynamic sub-epidemics among at-risk groups, especially among FSW, MSM and IDUs. These sub-epidemics give

rise to the need for aggressive public health interventions that are tailored to meet the specific needs of the various sub-groups. A recent study predicted that if prevention efforts were targeted at reducing sexual transmission and IDUs, a total of 28 million infections could be prevented between 2005 and 2015 in low- and middle-income countries.[27] According to UNAIDS/WHO criteria.[58] Tijuana is currently in a concentrated state of the HIV epidemic. At the very least, our model suggests that HIV prevalence in Tijuana is not decreasing, and may be increasing significantly especially among certain sub-groups such as MSM, IDUs and FSWs. Since 48% of adults living in Tijuana were born outside of the state[59] and tend to originate from other regions in México, the public health response to Tijuana's HIV epidemic has important implications for the future of the HIV epidemic across México.

**Table II.1. Model parameters, data sources, and values used**

<b>Key Parameters</b>	<b>Sources</b>	<b>Source Year</b>	<b>Values Used</b>
<i><b>Population Data</b></i>			
Tijuana total and low risk populations	Mexican 2005 Census <sup>6</sup>	2005	Age and sex specific
Gay and Bisexual Males	Diamond, M <sup>21</sup>	1993	Proportion of total male population
Injection Drug Users	CENSIDA surveys <sup>19,20</sup> National Survey on Addictions <sup>12</sup>	2004, 2006	Count
Female Sex Workers	Community Based Study of Female Sex Workers <sup>20</sup>	2006	Count
Pregnant Women	Mexican 2005 Census <sup>6</sup>	2005	Estimate
<i><b>HIV Prevalence</b></i>			
Gay and Bisexual men	Ruiz, J <sup>13</sup>	2002	Cross-sectional Estimates
Injection drug users	Community Based Study <sup>14</sup>	2006	Cross-sectional Estimates
Female sex workers	Community Based Studies <sup>15</sup>	2006	Cross-sectional Estimates
Pregnant women	Hospital Based Data <sup>16</sup>	2006	Cross-sectional Estimates
Low-risk men and women	Various Surveys <sup>17,18</sup>	2000, 2004	Cross-sectional Estimates

**Table II.2. Input Assumptions for total population and HIV Prevalence Estimates for Tijuana Population ages 15-49 years, by sub-group**

<b>Variable</b>	<b>2005 Census Population</b>	<b>HIV Prevalence –)</b>
<i>Total Population</i>		
Males	407,600	0.85%(0.39-1.31)
Females	401,300	0.22%(0.04-0.40)
Total	808,835	0.54%(0.22-0.86)
<i>Transmission Groups</i>		
Men Who Have Sex With Men	16,302(12,227-20,378)	18.90%(13.92-23.83)
Injection Drug Users	8,200(6,400-10,000)	---
Males	7,029(5,486-8,571)	2.50%(1.28-3.71)
Females	1,171(914-1,429)	5.90%(2.14-9.66)
Female Sex Workers (non-IDUs)	5,649(3,957-7,338)	6.40%(3.78-9.07)
FSWs-IDUs	1,276(893-1,662)	11.00%(4.81-17.40)
High-risk pregnant women	3,140	2.48%(0.96-4.00)
Low-risk pregnant women	28,260	0.055%(0.01-0.10)
Low-risk women 15-49	363,061(361,115-365,010)	0.055%(0.01-0.10)
Low-risk men 15-49	384,223(378,604-389,841)	0.055%(0.01-0.10)

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The dissertation author was the primary researcher and author.

**CHAPTER III**

**MODELING THE FUTURE OF THE HIV/AIDS EPIDEMIC AMONG  
FEMALE SEX WORKERS IN TIJUANA, MEXICO: 2006-2036**

**A. ABSTRACT**

Background: Female sex workers (FSWs) in Tijuana, Mexico have been disproportionately affected by the HIV epidemic. We sought to forecast HIV cases due to sexual transmission among FSWs who are not injection drug users over the period 2006-2036.

Methods: Using deterministic mathematical models based on biological, behavioral, and demographic parameters, we analyzed data from a variety of sources and developed two future HIV/AIDS epidemic scenarios (low and high).

Results: The model predicted between 6,760 (1,997-11,708; low scenario) to 13,149 (4,161-22,457; high-scenario) incident HIV cases in Tijuana, Mexico among FSWs by 2036. In terms of AIDS incidence, between 4,484 (1,388-7,562; low scenario) and 8,810 (2,987-14,586; high scenario) new cases were predicted. HIV incidence was projected as  $\approx 40$  (Range: 27-50) cases/1000 person-years, suggesting that the HIV epidemic would stabilize at  $\approx 19.03\%$  (14.42-22.98).

Conclusions: In the absence of additional interventions, available data suggest that the HIV epidemic among FSWs in Tijuana would become a sustained epidemic, and accumulative incidence would continue to rise. These results indicate the need for interventions focused on HIV education, testing, and reduction of risky sexual behaviors among FSWs and their clients.

## B. INTRODUCTION

Tijuana, Mexico, a city bordering the southwest US, has experienced dramatic changes both demographically and economically in the past few decades. Population growth in Tijuana is expected to increase, and could potentially reach 3 million by the year 2030,[36] from approximately 1.5 million in 2005,[35] due in part to greater availability of jobs and the subsequent increase in migration. Along with these changes the city has seen the establishment of a large sex worker network, which has become quasi-legal, and attracts a large number of sex tourists. Although all female sex workers (FSWs) in the city are required to register with the Municipal Health Services, only about half of them do so. It is believed there are an estimated 4,850-9,000 FSWs in Tijuana.[31]

Surveillance efforts have shown that Baja California, the state in which Tijuana is located, has one of the highest accumulative AIDS incidence rates compared to other Mexican states.[60] A recent modeling study for the city of Tijuana, showed that among male and female adults aged 15-49 HIV prevalence ranged from 0.26% to 0.86%.[61] Tijuana's HIV epidemic remains concentrated among at-risk subgroups (e.g., FSWs, injection drug users (IDUs) and men who have sex with men (MSM)),[61] but recent studies suggest that HIV prevalence among FSWs in Tijuana has increased to 6%.[37]

Studies of FSWs in US-Mexico border cities have shown that high levels of sexually transmitted infection (STIs) and risky behaviors (i.e., unprotected vaginal and anal intercourse) are not uncommon. For example, recent studies have shown that among FSWs in Tijuana and Ciudad Juarez, the median reported number of unprotected sexual episodes in the last month is 16 (IQR: 7-35), that 27% of FSWs are positive for at least one STI (e.g., gonorrhea, Chlamydia, syphilis), and that HIV incidence is 2 per 100 person-years.[31, 62]



High HIV prevalence coupled with risky sexual practices, has led field experts to accentuate the need for scaled-up prevention efforts to avoid a generalized epidemic.[63] A more in-depth understanding of sub-epidemics dynamics driving the overall HIV epidemic is key to appropriately allocating and tailoring HIV prevention efforts. The purpose of this study was to project the future of the HIV/AIDS epidemic among FSWs from 2006 to 2036 in Tijuana, México.

### **C. METHODS**

A deterministic compartmentalized mathematical model was constructed to forecast the HIV/AIDS epidemic for FSWs over a thirty-year period. The objective of the study was to determine the impact of sexual transmission on the HIV epidemic among FSWs, for this purpose the model was limited to FSWs who were not injection drug user. A system of ordinary differential equations was developed to simulate the transition of individuals from one compartment of the model to another. Model parameters were classified into three main categories: demographic, behavioral, and biological (Table 1). Parameter estimate information was obtained from a variety of sources, including community-based studies, published literature, publically available data and communication with field experts. Sensitivity analysis consisted of taking high- and low- end estimates of parameter estimates, and developing corresponding low- and high-scenarios.

#### Demographic and behavioral parameters

FSWs – General demographic parameters such as age, population growth rate, death rate and population size were derived from a variety of sources. The initial FSW population size for the model was based on the number of registered sex workers for Tijuana, and an estimate of the number of unregistered sex workers. To limit the modeled population to FSWs who are

not IDUs (i.e., focus on sexual transmission only), data to determine what proportion of FSWs are IDUs was derived from *Mujer Segura*, a community-based study of 474 FSWs in Tijuana, Mexico.[31] It was assumed that the FSWs population size would grow proportionally to the annual growth of the general female population, and that it would have an age distribution equal to that found in the *Mujer Segura*.[31] The overall population growth stratified by age group was calculated using census data from 2000 and 2005.[35, 59] Rate of retirement from sex work was estimated using responses to a 6-month follow-up survey from *Mujer Segura*, in which women were asked if they were still in sex work.[31] Death rates for FSWs were stratified by age group, and were assumed to be equal to reported statewide estimates.[64] Information regarding behavioral parameters was also obtained from *Mujer Segura*; these consisted of average number of male clients per year and proportion of unprotected sex acts (i.e., vaginal and anal).[31]

Male Clients of FSWs – Evidence suggest that HIV prevalence varies significantly by risk-group.[61] To account for this, the male client population was stratified into four risk categories as follows: 1) men who have sex with men who and are also injection drug users (MSM-IDU), 2) MSM-nonIDU, 3) IDU-nonMSM, and 4) low risk. Low-risk clients were defined as those that were not MSM or IDUs. A recent community-based study of FSW clients was used to determine what proportion of clients belonged to each risk group.[65]

#### HIV, Sexually Transmitted Infections (STIs) and other biological parameters

HIV & STI parameters – Central to this model was the initial number of HIV-positive FSWs in the population, and the corresponding number of susceptible (i.e., at risk for HIV infection) FSWs. The initial number of HIV-positive FSWs was derived from a recent model of the HIV epidemic in Tijuana;[61] while the number of susceptible FSWs was calculated by the

subtracting the number of HIV-positive FSWs from the reported number of FSWs in the city. Given that the probability of HIV transmission per sexual act is dependent on the presence of other STIs, [66-68] it was necessary to estimate FSW STI prevalence. STI prevalence (gonorrhea, chlamydia and syphilis) was derived from *Mujer Segura*. [31] To determine syphilis prevalence, only those FSWs with a syphilis titer of  $\geq 1:8$  were utilized; these titers are consistent with active infections.[69]

Among FSW clients, studies have shown that HIV prevalence varies drastically by risk group.[61] Thus, a client-weighted average HIV prevalence was used for model projections. This consisted of first obtaining client HIV prevalence stratified by risk group, for which a variety of sources were utilized.[52, 70-72] Secondly, the client-weighted average HIV prevalence was derived by utilizing estimates for the proportion of clients that belonged to each of the risk groups coupled with the respective HIV prevalence estimate. Confidence intervals (95%) for this estimate were obtained by taking the sum of the products of partial derivatives and standard errors with respect to each parameter in the client-weighted average HIV prevalence.

Probability of HIV transmission varies by a number of biological factors,[73, 74] including stage of HIV infection, time spent in each stage of infection, and presence of other STIs. Parameter estimates for probability of HIV transmission stratified by type of intercourse (i.e., anal versus vaginal) and stage of HIV infection were derived from studies of FSWs conducted by White et. al.; and Pinkerton et. al. [73, 74] Estimates for time spent in the pre-AIDS and stage of HIV infection were taken from the study by White et. al.<sup>20</sup> Increase in probability of HIV transmission per sexual contact given the presence of STIs (e.g., gonorrhea, chlamydia, syphilis) were also taken from the White et. al. study.[73]

### Modeling

Mathematical model – A deterministic compartmentalized model was developed based on demographic, behavioral, and biological parameters for FSWs and their clients. Sensitivity analyses were based on low and high parameter estimates, from which low and high scenarios for HIV incidence and prevalence were developed. All modeling was conducted using Berkeley Madonna Software Version 8.3.[75] The model consisted of three compartments (i.e., susceptible, HIV-infected, and AIDS cases)(see Figure III.1).

The number of FSWs susceptible to HIV infection  $\{S(t)\}$ , was assumed to change under the following circumstances: 1) every time an FSW becomes HIV-infected, 2) when new sex workers enter the population, 3) when sex workers exit the population, and 4) when sex workers die. The number of HIV-positive FSWs  $\{I(t)\}$ , at any given time varies depending on the following: 1) the number of new FSWs who become HIV-positive, 2) the number of sex workers who exit the population, 3) the number of sex workers who die, and 4) the number of FSWs who progress from HIV infection to AIDS. Subsequently the number of FSWs in the AIDS phase  $A(t)$ , depends on the following: 1) the number of HIV-positive FSWs who progress from HIV infection to AIDS, and 2) the number of FSWs who exit due to death or from AIDS related debilitation. Thus flow from one compartment to another is represented by a system of differential equations as follows:

$$dS(t)/dt = -\lambda(t)S(t) + \varepsilon - \eta - \rho$$

$$dI(t)/dt = \lambda(t)S(t) - \gamma I(t) - \rho - \eta$$

$$dA(t)/dt = \gamma I(t) - \mu A(t)$$

$$\text{Where: } \lambda(t) = [1 - (1 - \beta_x)^{\frac{c}{x}} * (\text{Client-weighted Average HIV Prevalence})]$$

The force of infection  $\{\lambda(t)\}$  is a function of the number of contacts( $c$ )(frequency of sex with clients) and the corresponding probability of transmission( $\beta$ ) for type of sex act(vaginal or anal). This parameter was calculated by taking one minus the probability of HIV

transmission (stratified by type of sex act (i.e., anal or vaginal) and the presence of other STIs (i.e., gonorrhea, Chlamydia, syphilis), and exponentiating this to the product of the number of contacts (anal or vaginal) times the client-weighted average HIV prevalence. The aggregate result of this calculation was again subtracted from one. The median number of unprotected sexual contacts with clients was utilized rather than the mean, which was highly skewed by a few outliers. To adjust for probability of HIV transmission given the different stages of infection (i.e., primary, asymptomatic, symptomatic, AIDS), a weighted-average of time spent in each HIV infection stage of infection was utilized. Given that the probability of transmission also varies by presence or absence of STIs, it was adjusted for the increase in likelihood of HIV transmission given the presence of three specific STIs: Chlamydia, gonorrhea, and infectious syphilis.

Other key parameters were initial number of susceptible FSWs  $\{S(t)\}$ , initial number of HIV-positive FSWs  $\{I(t)\}$ , number of individuals in the AIDS phase of the epidemic at any given time ( $A$ ), death rate of susceptible and infected FSWs ( $\eta$ ), percentage of FSWs who exit sex work ( $\rho$ ), FSW population growth (entry into FSW population) ( $\epsilon$ ), time spent in the pre-AIDS stage, the rate of progressing from HIV infection to AIDS ( $\gamma$ ) ( $\gamma = 1/\text{duration of pre-AIDS stage}$ ), the rate of loss of individuals from the AIDS compartment either due to death or discontinuation of sex work ( $\mu = 1/\text{duration of the AIDS phase of infection}$ ), and the client-weighted average HIV prevalence (see Table 1).

A sensitivity analysis was conducted using parameter estimates for the initial number of HIV-positive and susceptible FSWs. Lower and upper boundaries of these parameter estimates were used to develop corresponding low and high scenarios. For both the low and high scenarios, projections were modeled as a function of the average-weighted client HIV prevalence and corresponding 95% confidence intervals. Results are presented in terms of

projected accumulative numbers of incident HIV/AIDS cases, total number of HIV-positive FSWs that could potentially exit the population over the 30-year period, and HIV prevalence.

## **D. RESULTS**

### Major characteristics

Demographic, behavioral, biological parameters are presented in Table III.1. HIV prevalence among FSWs in 2006 ranged from 3.78-9.07% (n = 150 – 666). Number of susceptibles (i.e., FSWs at risk for HIV infection) ranged from 3,597-7,338. The median number of unprotected sexual contacts with clients per year was approximately 60 for vaginal intercourse and 48 for anal intercourse. Prevalence of gonorrhea in the sample was 7.1%, Chlamydia: 15.7%, and syphilis: 3.8% (syphilis-positive was defined by >1:8 titers). The average growth of the general female population was approximately 3.09% per year.[35, 59] In a recent Tijuana community-based study, results showed that approximately 21.5% of FSWs quit sex work per year.[31] Thus, the annual growth rate for the FSW population was assumed to be 24.59%.

The majority of FSW clients were low-risk, followed by IDU/nonMSMs, MSM/nonIDUs, and IDU/MSMs respectively.[65] HIV prevalence stratified by risk group was higher among MSM/nonIDUs followed by IDU-MSMs, IDU nonMSM and lastly low-risk clients.[52, 71, 72, 76] Given the proportion of males belong to each of the risk-groups and the respective HIV prevalence for each, the client-weighted average HIV prevalence was 2.27% (95%CI: 0.65-3.89).

### Behavioral and biological parameters

Parameter estimates for probability of HIV transmission per sex act were the highest during primary infection, followed by asymptomatic and symptomatic stages, and lastly the

AIDS phase (Table III.1).[73] Probability of transmission also differs when a person is infected with other STIs (e.g., syphilis, Chlamydia, and gonorrhea). Transmission increases by a factor of 7.5 when the person is positive for syphilis, and by a factor of 3 when the person is positive for Chlamydia or gonorrhea.[73] The probability of HIV transmission from male to female via anal intercourse was 0.02[74]. The pre-AIDS phase of the infection for FSWs was assumed to last approximately 7.5 years, while that of the AIDS stage was assumed last less than a year (0.83 of a year).[73]

### HIV/AIDS projections

Figure III.1A-1D represents model projections in terms of low and high scenarios as a function of the client-weighted average HIV prevalence. Given the baseline number of HIV-positive FSWs, projected accumulative HIV incidence could increase from 150 to 6,760 (Range:1,997-11,708; low-scenario) over 30 years, or from 666 to 13,149 (Range:4,161-22,457; high scenario) (Figure III.1A). Given the dynamic nature of the model, the model predicted that 7,230 (Range:2,238-12,195; low-scenario) or 14,206 (Range:4,816-23,520); high-scenario) HIV-positive FSWs would retire from sex work over 30 years (see Figure III.1C). There could be as few as 4,484 (Range:1,388-7,562); low-scenario), or as many as 8,810 (2,987-14,586; high-scenario) incident AIDS cases over the projected period (see Figure III.1B).

For both low- and high-scenarios, HIV prevalence would initially rise but would stabilize at approximately 19.00% (14.40-22.98; low- and high-scenarios) by the year 2028-2030 (see Figure III.1D). HIV incidence between the years 2006 and 2036 was 39 (Range:27-50; low and high scenarios) per 1000 person-years.

## **E. DISCUSSION**

Results from our modeling exercise suggest that even in the most conservative scenario predicted by our low growth estimates, the HIV epidemic among FSWs in Tijuana Mexico will grow and not dissipate over the next 30 years. Although our model predicted an initial increase in HIV prevalence, it appears to equilibrate or become stabilized by  $\approx$ 2028-2030. Over time, the projected increase in HIV incidence among FSWs could potentially contribute to a significant increase in HIV prevalence not only among sex worker's clients, but among the general population as well.

Our model begins to shed light on the intricate sub-dynamics of the FSW HIV epidemic in Tijuana, and as such has great potential to guide public health professionals. However, there are several factors that could have potentially have led to under- or over-estimation of the future of the HIV epidemic. First or all, our data are conservative since we excluded FSWs who inject drugs from the models, who have a much higher HIV prevalence (i.e. 12%).<sup>[38]</sup> Furthermore, HIV incidence among FSWs is highly dependent on the client-weighted average HIV prevalence, the contact rate, prevalence of STIs, and probability of transmission. For the purpose of the model it was assumed that these parameters remained constant throughout the projected period, which could potentially lead to an under- or over-estimation of the true situation. For example, if client HIV prevalence were to increase over the modeled period, our results would represent an underestimate of the true accumulative HIV incidence. We modeled the effect an increase in the client-weighted average HIV prevalence (e.g., 2.0% and 5%) would have on projected FSW HIV prevalence and incidence. For example, over a 30-year period, an increase of 2.0% in client HIV prevalence could increase accumulative FSW HIV incidence by 1.98%, whereas an increase of 5.0% would increase cumulative HIV incidence by 4.82%. Furthermore, assuming a potential increase in STI prevalence or number of unprotected sex acts, current projections may be an underestimate. Lastly, data on viral load as a proxy of clients' stage of HIV infection was not



available, and as a result model adjustment by this parameter was not possible. To circumvent this limitation we adjusted the probability of HIV transmission by the time spent in each stage of infection.

While some parameter estimates were derived from self-report data, others were based on serological tests of community samples. Self-reported data of sensitive behaviors can be subject to socially desirable responding, which in turn could influence modeled projections. Estimates of HIV and STI prevalence from community-based studies may also be subject to bias, since FSWs recruited in the *Mujer Segura* study were required to have engaged in unprotected sex with at least one client in the last 2 months. However, this study also excluded FSWs who were knowingly HIV-infected, and thus HIV/STI prevalence and incidence estimates obtained from this study may be under- or over-estimates. On the other hand, sensitivity analysis was made possible by the availability of data from recent studies regarding the range of potentially HIV-positive FSWs. The model was also enhanced by the ability to create a client-weighted average of HIV prevalence among clients, but we lacked data on FSWs' non-paying partners, among whom unprotected sex occurs more commonly.[77]

The magnitude of the HIV epidemic among FSWs due to sexual transmission predicted by this model corroborates observations from others who have noted that the overall national HIV prevalence in Mexico is masked by an underlying heterogeneity of the epidemic.[63] Despite the estimated overall HIV prevalence in Tijuana (0.26%-0.86%), prevalence among FSWs is substantially higher, [61] and our model predicts that it will continue to grow until approximately one fifth of this population is HIV-infected. Prevention efforts tailored specifically to meet the needs of FSWs and their sex partners are greatly needed. Programs such as the mobile clinics (*condonetas*) implemented by Mexican state and health officials, serve as an example of prevention efforts that are innovative and serve as

an effective means by which to increase HIV/AIDS awareness. *Condonetas* are mini-vans that travel throughout neighborhoods and deliver condoms, rapid HIV testing kits, and educational materials.[63] The program has been implemented in Tijuana as well as in other Mexican cities. While the current study only focuses on sexual transmission of HIV among FSWs, it sheds lights on the sub-dynamics of the overall HIV epidemic for Tijuana. Further studies examining the dynamics of HIV sub-epidemics among other population sub-groups (e.g., men who have sex with men and injection drug users), and the extent to which these sub-epidemics will affect overall HIV prevalence are needed as well. Nonetheless, public health professionals and governmental institutions can use findings of this study to help guide resource allocation and focus HIV/AIDS prevention efforts geared at the FSW population. A recent study predicted that if prevention efforts were targeted at sexual transmission and IDUs, a total of 28 million infections could be prevented between 2005 and 2015, in low- and middle-income countries.[76] Knowledge of the potential number of HIV cases that can be averted by appropriate prevention efforts is an extremely important tool for public health professionals attempting to fight this epidemic. Currently, México is considered a “country of low prevalence but high risk”[63], and the potential of the HIV epidemic becoming generalized is significant given the trends we observed.

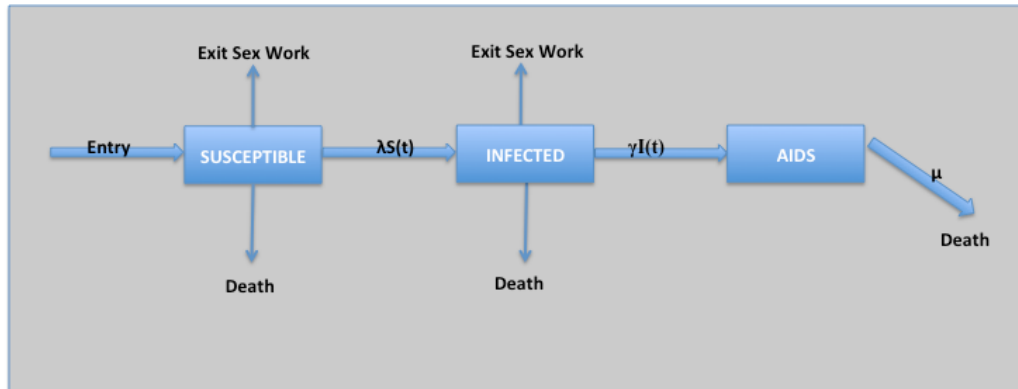


Figure III.1. Flowchart of Compartmentalized Deterministic HIV Transmission Model

Table III.1. Description and Sources of Demographic, Behavioral & Biological Parameters

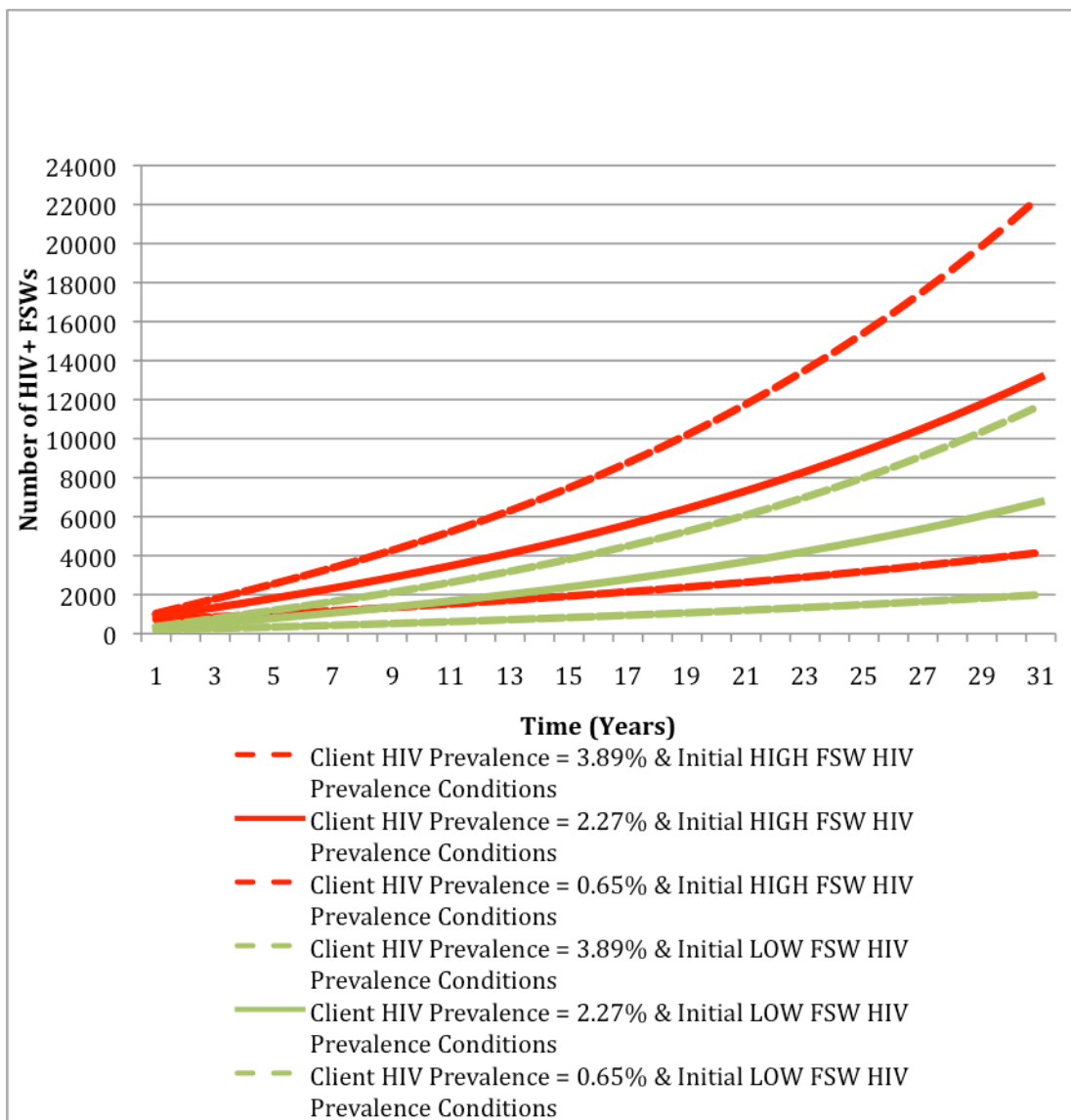
Parameter Description	Parameter Source	Parameter Value	
		Low Scenario	High Scenario
<b>Demographic Parameters</b>			
Initial FSW Population Size*	Community-Based Study of FSWs[31]	3,957	7,338
FSW Age Distribution	Community-Based Study of FSWs[31]		
15-24			1,340
25-34			1,265
35-44			1,006
45-59			345
Female Death Rate Stratified by Age Group	2005 Population Census[35]		
15-24			2.8/1000
25-34			4.2/1000
35-44			6.0/1000
45-59			9.1/1000
Total Female Population Growth per Year	2000 & 2005 Population Census[35, 59]		4.01%
FSWs Exiting Sex Work per Year	Community-Study of FSWs[31]		21.50%

**Table III.1 Continued**

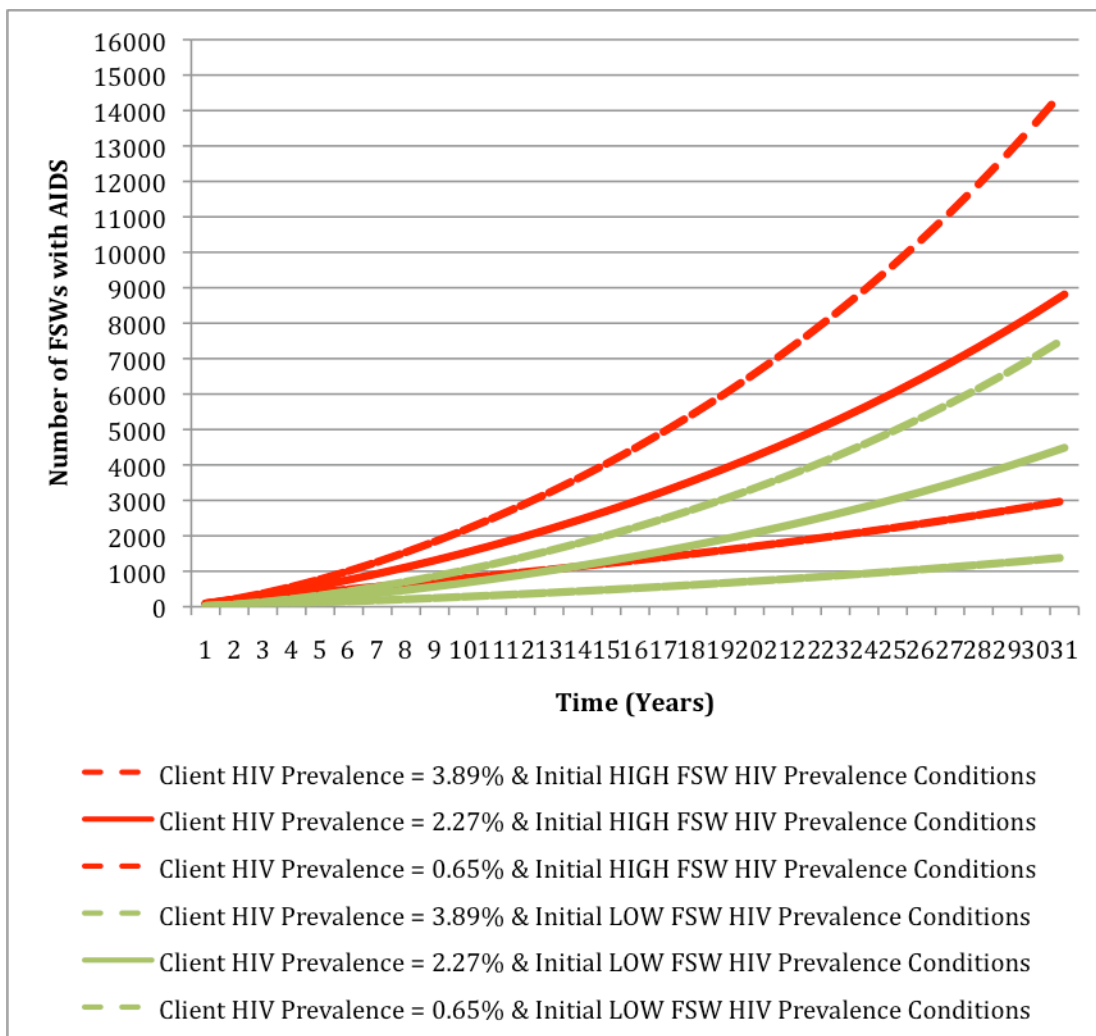
Proportion of FSW Clients By Risk-group	Community-Based Study[65]		
IDU-MSM		0.07%	
IDU-nonMSM		18.7%	
MSM-nonIDU		8.3%	
Low Risk		66.0%	
<b>Behavioral Parameters</b>			
Median Number of Unprotected Sexual Contacts per Year Among FSWs Stratified by Type of Intercourse	Community Based Study of FSWs[31]		
Vaginal		60/Year	
Anal		48/Year	
<b>HIV/AIDS &amp; Other Biological Parameters</b>			
FSW HIV Prevalence	Community-Based Study of FSWs [61]	3.78	9.07
Initial Number of HIV-positive FSWs @ Year 1	Community-Based Study of FSWs [61]	150	666
Initial Number of Susceptible (HIV-) FSWs @ Year 1	Community-Based Study of FSWs [61]	3,807	6,672
Client HIV Prevalence by Risk Group	Community Based Study of IDUs[16, 52, 71]		
IDU-MSM		2.8(0.09-5.3)	
IDU-nonMSM		2.5(1.3-3.4)	
MSM-nonIDU		18.9(14.0-23.7)	
Low Risk		0.055(0.01-0.10)	
Client-weighted average of HIV Prevalence - Point Prevalence	Community Based Study of Sew Worker Clients[65]	2.27(0.65-3.89)	
Duration of pre-AIDS Stage	Published Literature[73]	7.5 Years	
Length of AIDS Stage	Published Literature[78]	0.83 Years	
FSW STI Prevalence	Community Based Study of FSWs[31]		
Syphillis		3.8%	
Chlamydia		15.7%	
Gonorrhea		7.1%	

**Table III.1 Continued**

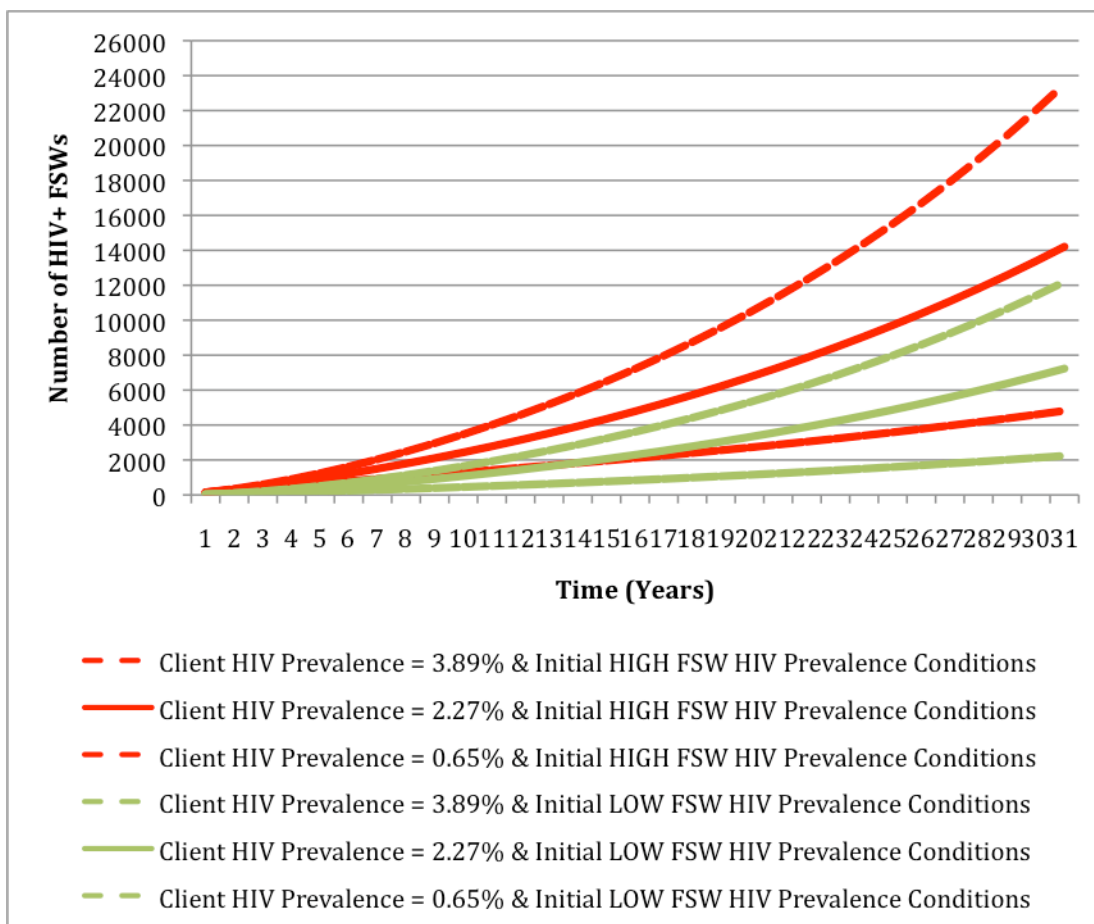
No STIs		61.2%
Probability of HIV Transmission per Anal Sex Act from Male to Female	Published Literature[74]	0.02
Probability of HIV Transmission per Vaginal Sex Act from Male to Female by Stage of HIV Infection	Published Literature[73]	
Primary Infection		0.072
Asymptomatic Stage		0.004
Symptomatic Stage		0.004
AIDS		0.018
Cofactor Increase in Probability of Sexual Transmission of HIV Given STI Status	Published Literature[73]	
Syphillis		7.5
Chlamydia		3
Gonorrhea		3
Note: * All FSW included in modeling are non- injection drug users.		



**Figure III.1A. Low and High Scenarios – Projected FSW Accumulative HIV Incidence 2006-2036.**

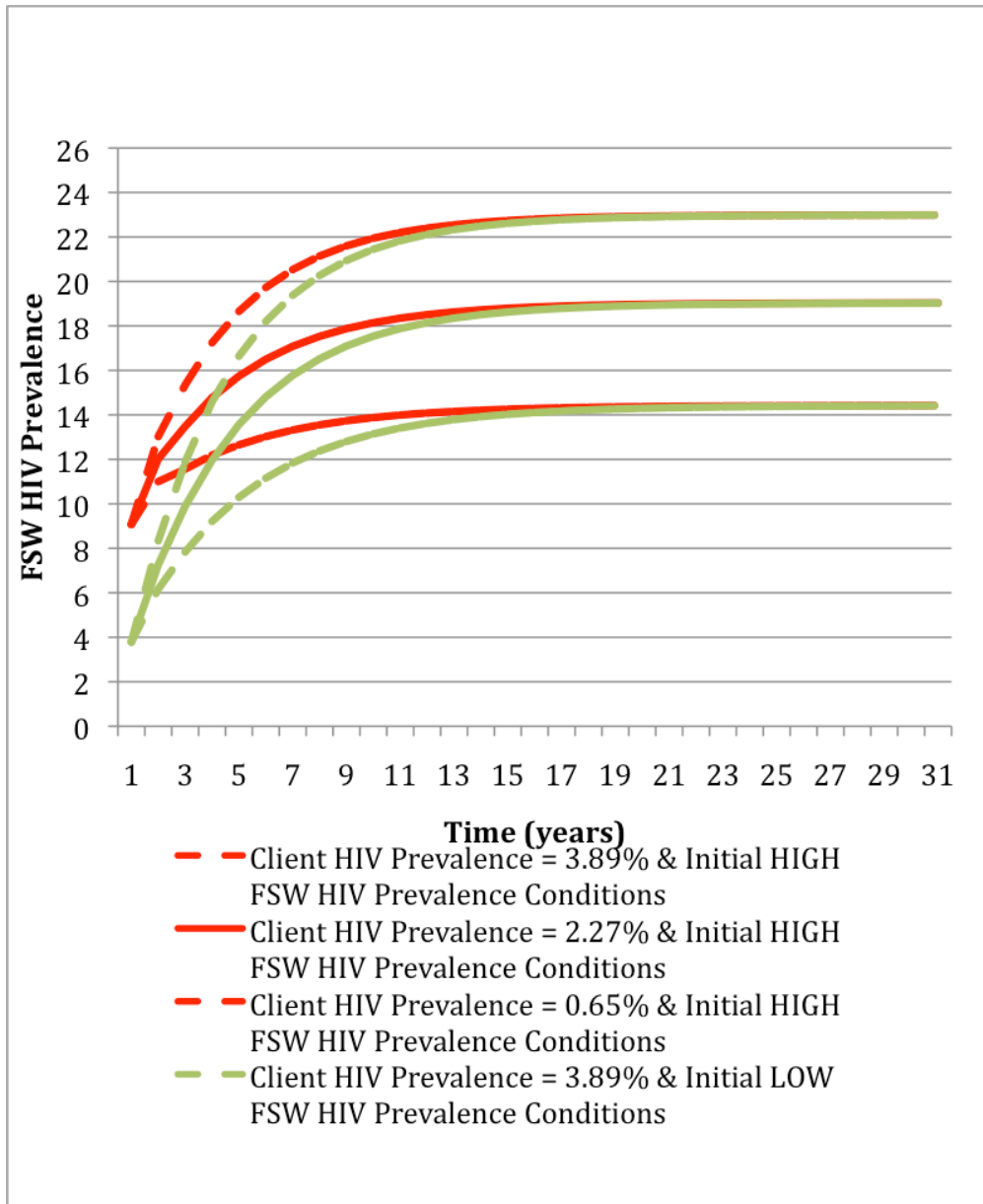


**Figure III.1B. Low and High Scenarios – Projected FSW Accumulative AIDS Incidence: 2006-2036.**



**Figure III.1C. Low and High Scenarios – Projected Accumulative Loss of HIV+ FSWs: 2006-2036.**





**Figure III.1D. Low and High Initial Conditions for 2006 – Projected FSW HIV Prevalence as a Function of Client HIV Prevalence: 2006-2036. Figure III.1A-1D.**

Comparison of the HIV epidemic among FSWs in Tijuana, Mexico was based on low initial conditions [e.g. low non-IDU/FSW population size (N = 3,957), low non-IDU/FSW HIV prevalence (3.78 per 100 person-years)], and high initial conditions [e.g. high non-IDU/FSW population size (N = 7,338), high non-IDU/FSW HIV prevalence (9.07 per 100 person-years)], over a 30-year period. Each figure presents projections based on the client-weighted average HIV point prevalence (2.27%) and its range (95% CI: 0.65-3.89). Figure III.1A shows projections of accumulative HIV incidence based on initial low and high conditions. Figure B – Accumulative AIDS incidence based on initial low and high conditions. Figures III.1C – Accumulative loss of HIV+ FSWs based on initial low and high conditions. Figure III.1D – Projected HIV prevalence among FSW based on initial low and high conditions.

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in Tijuana, Mexico: 2006-2036,” 2009.

The dissertation author was the primary researcher and author.

## CHAPTER IV

### MODELING THE IMPACT OF INCREASING CONDOM USE ON THE HIV/AIDS EPIDEMIC AMONG FEMALE SEX WORKERS IN TIJUANA, MEXICO: 2006-2036

#### A. ABSTRACT

Objectives: Female sex workers (FSWs) HIV prevalence in Tijuana, Mexico is high, and is expected to increase. We assessed the impact of increasing condom use on sexual spread of HIV among FSWs who do not inject drugs (FSW-nonIDUs).

Methods: Demographic, behavioral and biological parameters were used to develop a deterministic model. A decrease in unprotected sex of 5%, 10%, 20%, 50% and 75% was modeled, using baseline levels of unprotected sex among FSWs from a community-based study. Sensitivity analysis consisted of developing low- and high-growth scenarios for modeled parameters.

Results: According to current projections HIV prevalence will increase to  $\approx 19.0\%$  by 2036. If unprotected sex is decreased by  $\leq 20\%$  HIV prevalence will be  $\leq 19.0\%$  by 2036, with a 50% decrease prevalence will be  $\approx 11.0\%$  and  $\approx 6.0\%$  with a 75% decrease. A 50% decrease in unprotected sex could avert 1,366 to 2,544 HIV cases, while a 75% decrease could avert 2,092 to 3,895 by 2021. By 2036, a 50% decrease in unprotected sex could avert 4,008 to 7,554 cases, while a 75% decrease could avert 5,960 to 11,242 cases.

Conclusions: Results suggest large decreases in unprotected sex are necessary to curve the HIV epidemic in Tijuana. This warrants the need for scaling up prevention efforts focused on condom use, voluntary counseling and testing, and HIV/AIDS related knowledge.

## B. INTRODUCTION

The HIV epidemic in México is primarily driven by sub-epidemics among population sub-groups, and has the potential to become a country of low prevalence and high-risk.[63] Moreover, reports have shown that HIV prevalence is highest in US-Mexico border cities.[79] In Tijuana, a recent study estimated HIV prevalence among adults between the ages of 15 to 49 likely ranges between 0.22% and 0.86%, but is much higher among at-risk population subgroups. [61] For example, among female sex workers that do not inject drugs (FSW-nonIDUs) prevalence ranges from  $\approx 3.8-9.1\%$ . [61]

Tijuana, located across the US-Mexican border from San Diego, has experienced both major demographic and economic changes within the past century. According to the last population census total estimated population was approximately 1.27 million. It is projected that the population will continue to grow and could reach 3 million by the year 2030.[36] Along with the significant population growth, the existence of a quasi-legal system of prostitution has in part contributed to a growing FSW population.[2] Currently, estimates of the size of the FSW population range from 4,850 to 9,000. [80] Given that recent community-based studies have reported high levels of unprotected sex between FSW and their clients,[80] the threat of a generalized epidemic may be real.

Worldwide in low- and middle-income countries it has been estimated that approximately 28 million HIV infections could be averted between 2005 and 2015, if intervention efforts effectively reduce HIV transmission through sexual intercourse and injection drug use.[76] The feasibility of behavioral interventions geared at sexual transmission (e.g. condom use) to prevent growth of the HIV/AIDS epidemic is well established. [13, 62] In this context, mathematical models can be very helpful to understand the dynamics of the epidemic, and serve as a tool to guide health professionals' efforts to control the epidemic. [81, 82] Projections of the HIV epidemic in Tijuana have shown that

without scaled-up prevention efforts sexual transmission of HIV will increase significantly over the next 30 years among FSW-nonIDUs.[83] Hence, modeling the impact of increasing condom use among FSWs on the future of the HIV epidemic, could be a very effective public health tool to inform allocation of resources as well as tailoring of prevention interventions. The purpose of the present study was to forecast the number of HIV cases that can be averted over 30 years, as a result of implementing potential prevention interventions geared at increasing condom use. The model is based on recent model projections of the FSW HIV epidemic for Tijuana,[83] and aims to assess the impact of decreasing the frequency of unprotected sex on the epidemic.

### **C. METHODS**

A deterministic compartmentalized mathematical model was developed to forecast the potential number of HIV cases that could be averted if unprotected sex is decreased between FSWs and clients. The model was limited to projecting HIV among FSW-nonIDUs, given that the objective of the study was to predict the spread of HIV as a result of sexual transmission alone. Model parameters consisted of demographic, behavioral and biological factors derived from a variety of sources (i.e., literature and community-based studies). Current projections for the future of the FSW HIV epidemic were used as baseline values[83], from which potential number of HIV cases averted was estimated. As a result, model parameters and methodology were consistent with the parent study.[83] The main parameters of interest were number of unprotected sex acts (i.e., contact rate)  $\{c\}$ , baseline HIV prevalence for FSWs and clients. Results are shown in terms of projected HIV prevalence and incidence as a function of decreasing unprotected sex.

#### FSW Parameter Sources

Initial FSW population size ( $N = 3,957-7,338$ ) and HIV prevalence (95% CI: 3.78-9.07) were taken from a recently study of the HIV epidemic in Tijuana[61]. Data for baseline prevalence of sexually transmitted infections (STIs), age distribution, level of risk behaviors (i.e., unprotected sex acts) were derived from *Mujer Segura*, a community-based study [31]. *Mujer Segura* was a randomized controlled behavioral risk intervention study aimed at characterizing the demographics, risk behavior, drug use, and prevalence of infectious diseases (e.g., HIV, gonorrhea, chlamydia, syphilis) among 450 FSWs in Tijuana conducted between 2004 and 2006. FSW population growth rate was assumed to be similar to the general female population age-stratified growth rate, and was derived from the Mexican census .[35, 59] To maintain a constant population size, the growth rate of the modeled population was adjusted to compensate for any loss from the population resulting from discontinuation of sex work, estimates for this were obtained from *Mujer Segura*.[31] Thus population growth rate per year was assumed to be the sum of the average growth rate (4% per year)[35, 59], and the proportion of women who exit sex work (21.5% per year).[42] The age distribution for the modeled population was assumed to be similar to *Mujer Segura* study sample.[31] Age stratified death rates were assumed to be consistent with statewide data obtained from the Mexican census.[35] Other parameters of interest such as duration of pre-AIDS and AIDS stages of infection, probability of HIV transmission per sexual contact stratified by type of sex (i.e. anal, vaginal), and probability of transmission stratified by presence of other STIs (gonorrhea, chlamydia, and syphilis), were derived from published literature.[73, 74]

#### Contact Rate {c}

Baseline estimates of unprotected sex were derived from *Mujer Segura*.[31] In the study FSWs were asked to recall past-month number of sex acts (e.g., vaginal and anal) with

clients, and the proportion that was protected (i.e. a condom was used). Reported number of past-month number of unprotected sexual acts was extrapolated to obtain a 1-year estimate. The mean rather than the mean number of sexual occurrences was utilized, to avoid a highly skewed mean as a result of extreme outliers.

Refer to parent study

#### Client Parameter Sources

As a result of the heterogeneity of HIV prevalence by population risk-groups,[61] a client-weighted HIV prevalence estimate was created. Male clients were divided into four sub-groups: injection drug users(IDUs) who are men who have sex with men (MSM), IDU-nonMSM, MSM-nonIDU, and low risk (i.e., all others). The weighted-average was developed taking into account two factors: (1) the proportion of customers that belong to each of the sub-groups, and (2) HIV prevalence for each sub-group. Estimates used to derive what proportion of clients belonged to each of the four risk-groups were obtained from a recent community-based study of 400 male FSW clients in Tijuana conducted in 2008.[65] Client HIV prevalence was obtained from published literature, and community-based studies.[16, 52, 71, 84] The estimated client-weighted average HIV prevalence was 2.27%(0.65-3.89).

#### Modeling

The deterministic model was divided into three different compartments as follows: susceptible, HIV-infected and AIDS. Berkeley Madonna® was used to solve the systems of differential equations, and SPSS® was used to obtain parameters estimates from community-based data.[75, 85] Flow of individuals (i.e., FSWs) from one compartment from another (e.g., from susceptible to infected, or infected to AIDS) was represented by the following system of differential equations:

$$dS(t)/dt = -\lambda(t)S(t) + \varepsilon - \eta - \rho$$

$$dI(t)/dt = \lambda(t)S(t) - \gamma I(t) - \rho - \eta$$

$$dA(t)/dt = \gamma I(t) - \mu A(t)$$

$$\text{Where: } \lambda(t) = [1 - (1 - \beta_x)^{c_x} \text{*(Client-weighted Average HIV Prevalence)}]$$

Transition from susceptible to infected was driven by the force of infection  $\{\lambda(t)\}$ , which is dependent on the contact rate (i.e. number of unprotected sex acts)  $\{c\}$ , probability of HIV transmission  $\{\beta\}$  per sexual act stratified by type of sex act (e.g. vaginal or anal), client HIV prevalence, and FSW STIs prevalence. Probability of transmission was adjusted to reflect the difference in client stage of HIV infection, and FSW STI prevalence (i.e., Chlamydia, gonorrhea, syphilis). The transition from infected to the AIDS  $\{\gamma\}$  compartment was driven by the amount of time spent in the pre-AIDS stage of the infection. Outflow of individuals from susceptible and infected compartments could be due to discontinuation of sex work  $\{\rho\}$  or death  $\{\eta\}$ . Outflow from the AIDS compartment was given by  $\{\mu\}$ , and was modeled as a function of the time spent in the AIDS stage of infection. Inflow into the susceptible compartment resulted from entry of new FSWs into the population  $\{\varepsilon\}$  (based on population growth rate and compensation for loss of FSWs from model), while inflow to the infected compartment resulted from susceptible individuals becoming infected. To estimate the current number of susceptibles  $S(t)$ , the number of existing HIV cases was subtracted from the estimated number of FSWs in the city. A more detailed description of the modeling is provided in the parent study by Iniguez et. al.[83]

A decrease of 5%, 10%, 20%, 50% and 75% from baseline levels of unprotected sex was modeled. Sensitivity analysis consisted of low- and high-growth scenarios based on two parameters: (1) FSW population size, and (2) FSW HIV prevalence. Both low- and high-growth scenarios were developed as a function of the client-weighted average HIV prevalence. Projections are presented in terms of the accumulative HIV incidence, HIV



prevalence, and accumulative loss of HIV+ FSWs from the FSW population as a function of decreasing unprotected sex.

## **D. RESULTS**

### **Baseline Model Characteristics**

Initial number of susceptible individuals ranged from 3,807 to 6,667. The range in initial number of HIV-positive cases was 150 to 666. Median number of unprotected sexual contacts independent of sexually transmitted diseases (i.e., Chlamydia, gonorrhea and syphilis) per year was 84 for vaginal and 24 for anal.

### **Accumulative HIV Projections**

Figures IV.1A-1G show the effect of decreasing unprotected sex on accumulative HIV incidence, accumulative number of HIV-positive FSWs lost from the population, and HIV prevalence. Separate figures are shown for the low- and high-growth scenarios, with a corresponding curve for each of the modeled percent decreases in unprotected sex (i.e. 5, 10, 20, 50, 75).

Accumulative HIV Incidence Projections - According to low- and high-growth scenarios (Figures IV.1A & 1B) accumulative HIV incidence at the end of 30 years would not change substantially from current projections with a 5%, 10% or 20% decrease in unprotected sex. The low-growth scenario predicts that with a 50% or 75% decrease in unprotected sex, 4,005 or 5,960 incident HIV cases could be averted respectively. On the other hand, according to the high-growth scenario, total number of incident HIV cases that could potentially be averted is 7,554 with a 50% decrease and 11,242 cases with a 75% decrease.

Accumulative HIV-Positive FSWs Lost Over Time Projections - In terms of accumulative number of HIV-positive FSWs lost from the infected population due to

discontinuation of sex work at the end of 30 years, the greatest impact is seen when unprotected sex is decreased by more than 50% (Figure IV.1C & 1D). According to the low-growth scenario a decrease of 50% could decrease the number of HIV-positive FSWs lost from sex work from 8,506 to 4,374, while a decrease of 75% could decrease it to 2,298 by the year 2036. The high-growth scenario predicts that a decrease of 50% in unprotected sex over the same 30-year period would decrease the estimate from 16,600 to 8,837, while a decrease of 75% would decrease it to 4,930.

HIV prevalence Projections – Assuming the level of unprotected sex remains the same as it is now over a 30-year period HIV prevalence would be  $\approx 19.0\%$  (low- and high-growth) by 2036. With a 20% reduction in unprotected sex this prevalence would be reduced to  $\approx 16.0\%$  (low- and high-growth). Larger decreases in HIV prevalence are seen with reduction of 50% or more in unprotected sex. A 50% decrease would reduce prevalence to  $\approx 11.00\%$  (low- and high-growth), while a 75% decrease in unprotected sex would decrease it to  $\approx 6.0\%$  (low- and high-growth) at the end of 30 years (i.e. 2036)(Figure IV.1E & 1F). The larger the percent reduction in unprotected sex, the lower the level at which the HIV epidemic will equilibrate. With a 50% reduction in unprotected sex the epidemic equilibrates at 11.0% (low- and high-growth); however, with a 75% reduction the epidemic equilibrates at  $\approx 6.0\%$  (low- and high-growth).

Projected Percent Reduction HIV Prevalence and Incidence – Projected percent reductions in HIV prevalence and incidence from baseline estimates are presented in Table IV.1. The model predicts more substantial percent reductions and thus a greater impact on the HIV prevalence and incidence, when the decrease in unprotected sex is  $\geq 50\%$ . According to current predictions, HIV prevalence would increase to  $\approx 18.0\%$  (low- and high-growth) by 2021, and  $\approx 19.0\%$ (low- and high-growth) by 2036. For low- and high-growth scenarios a decrease of 5%, 10%, and 20% in unprotected sex would only reduce HIV prevalence by less

than 20% by the year 2021 and 2036. On the other hand, the model projects that a decrease of 50% and 75%, would result in a much higher overall reduction in HIV prevalence. For example by 2021, if unprotected sex were decreased by 75%, HIV prevalence would be reduced by  $\approx 68.0\%$  (low-growth) or by  $\approx 67.0\%$  (high-growth). By 2036, the prevalence would be reduced by  $\approx 68.0\%$  (low- and high-growth). In terms of accumulative incident HIV cases current projections show that there will be 2,997 to 5,970 (low- and high-growth) by 2021, and 8,014 to 15,509 (low- and high-growth) by 2036. Decreasing unprotected sex by 20% or less would result in a reduction of less than 20% in accumulative incidence by 2036. A more significant percent reduction in HIV incidence is observed with a 75%. A 75% decreases could potentially reduce HIV incidence by 70.0% (low-growth) or 65.3%(high-growth) by 2021, or 74.4%(low-growth) and 65.3%(high-growth) by 2036.

## **E. DISCUSSION**

Current HIV prevalence projections show that if unprotected sex remains the same, the HIV epidemic would grow and eventually become sustained. The present model quantified the impact of decreasing unprotected sex in a population of FSW on the HIV epidemic. Although smaller (e.g. 5%, 10%, 20%) decreases in unprotected sex would reduce HIV accumulative incidence and prevalence, the more dramatic effect on the HIV/AIDS epidemic would be seen with larger (e.g. 50% or 75%) decreases. Decreasing unprotected sex would lower the level at which the epidemic becomes sustained, with higher decreases (i.e.,  $\geq 50\%$ ) resulting in much lower equilibrating point.

Previous studies worldwide have shown that behavioral interventions can be an effective means to increase condom use among population sub-groups and the general population. Examples of target populations for such interventions have ranged from sero-discordant couples[86], to IDUs [87], MSM[88] and FSWs[89-96]. Reported percent

condom has varied depending on the study. For example, among sero-discordant couples, in China one study reported condom use increased from 2.6% to 71.4%[86]. Among adolescents another study reported, condom use increased from 21.8% to 37.6% post-intervention [97]. Another study targeting men who have sex with men found that condom use with casual partners increased from 4.3% to 76.8% for anal intercourse and from 7.4% to 37% for vaginal intercourse post-intervention. Results of studies targeting FSWs, have seen varying levels of success. Some studies report a more modest increase in condom use from baseline to intervention, such as 74.9% to 92.2%[90], 55.2% to 67.5%[93], and 34% to 52.6%[91]. Other studies report much greater success increasing condom use post-intervention. In a rural study in China of FSWs, condom use was increased from 2.6% to 71.4% post-intervention[86]. In another study, less than 40% of FSWs reported using a condom in greater than 50% of all sexual encounters at pre-intervention, this percentage increased to approximately 80% at post-intervention[92]. Other studies among FSWs, have reported increases of as much as 94.5% in condom use rates[96].

Despite the proven efficacy of behavioral interventions geared at increasing condom use, one very important question remains to be answered. Do reported increases in condom use uptake translate into a decreased HIV prevalence? The fact that some communities report high use of condoms, but yet have high rates of HIV transmission, has been coined by some as the Condom Paradox[98]. According to Hearst et. al, this paradox could potential be explained by taking a look at who is using condoms. Perhaps condom use is higher among those who are lower risk, but lower among those at higher risk[98]. This highlights the need to appropriately target condom promotion interventions to at-risk sub-groups, to effectively fight the HIV/AIDS epidemic. Thus development of effective HIV transmission prevention interventions is key when targeting at-risk sub-groups. Studies aimed at increasing condom use, have all incorporated some form of intervention along with the physical provision of

condoms. These interventions have ranged from providing HIV and other STD related education, sex education, skill training on condom use, voluntary counseling and testing, STD testing, or condom social marketing. A recent review of the literature, for example, showed that effective prevention interventions included a number of factors among these were the following: condom use knowledge, problem solving skills, condom use barriers, peer norms[99]. Moreover, consistency of condom use especially as it pertains to high-risk partners should be at the center of all condom prevention interventions. From an evaluation perspective, behavioral surveillance efforts should focus on making the distinction of sexual behavior as it pertains to different types of partners (i.e., FSW clients, non-regular partners, and regular partners).

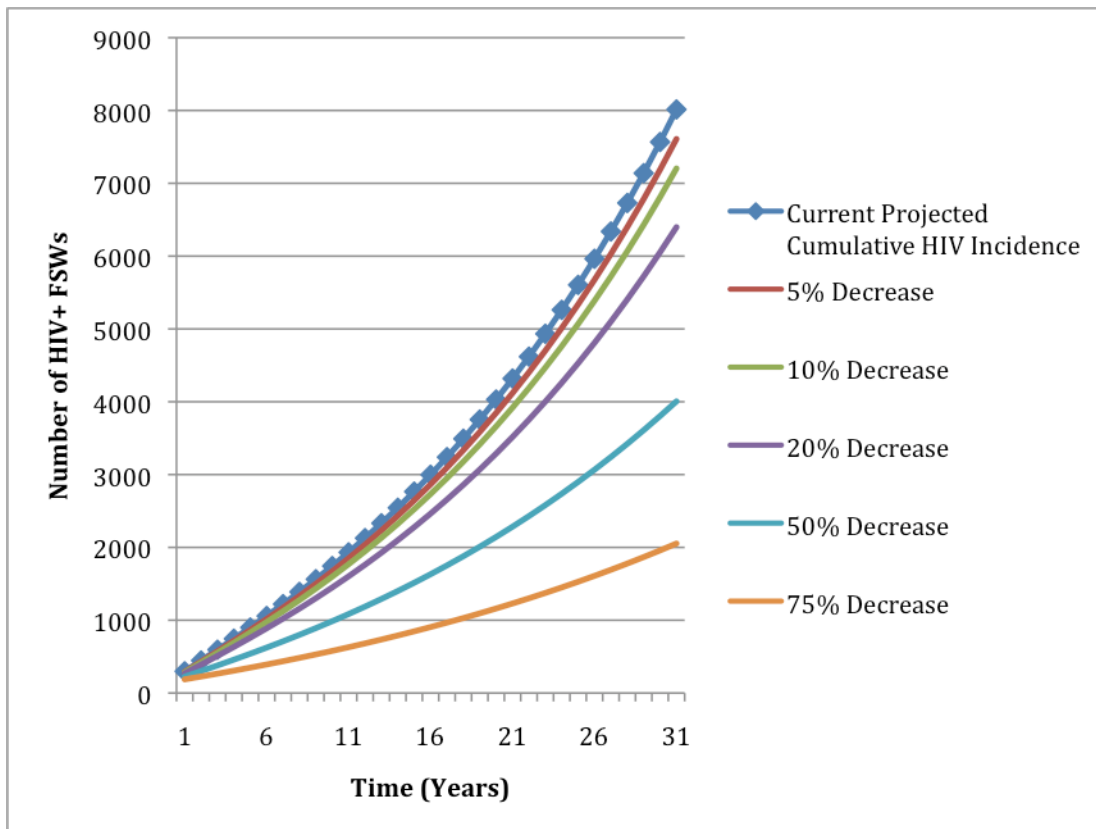
In Tijuana, Mexico results of a randomized controlled trial showed that behavioral interventions geared at reducing sexual risk behavior (e.g. unprotected sex) could potentially be an effective means to prevent the spread of HIV[13, 62]. Studies have shown that FSWs report clients do not want to use condoms and that are willing to pay more money for unprotected sex. On the other hand many FSWs in Tijuana also report low levels of knowledge regarding proper condom use and also reported not negotiating condom use.[53]. A recent study community-based study of clients of FSWs in Tijuana, the only of its kind to date, showed that clients tend to have a high-risk profile. In the study injecting drugs, frequenting sex workers, and having unprotected sex were behaviors commonly reported behaviors among clients[100]. Yet in this study only one-half of study participants reported ever having been tested for HIV[100]. This is in line with other studies among Hispanic men that have shown they are less likely to use condoms[14]. Despite this the inconsistent use of condoms and contact with FSWs, many men do not perceive themselves at risk for HIV[15]. Given the proven efficacy of behavioral interventions aimed at reducing risky behavior and the established lack of HIV/AIDS prevention knowledge among FSWs and their clients; there

is need for prevention interventions that meet the needs of both FSWs and their clients. This need for tailored prevention interventions has been well recognized by researchers conducting studies among FSWs in Tijuana. [31, 53]

Behavioral estimates for the current mathematical model are based on the use of self-report data. FSW-nonIDUs were asked to recall past sexual experiences as well as what proportion was unprotected (i.e no condom was used). While data such as this is subject to recall bias the questionnaire design and the analytical approach used to determine these estimates could help reduce possible bias. First of all, FSW-nonIDUs were asked to report sexual experiences within the past month, in an effort to make the recall period shorter. These past-month estimates were then taken and extrapolated out to a year, to obtain median yearly estimates of unprotected sex. Secondly, participants were asked to answer two different questions as follows: 1) How many sexual encounters did they have within the past month, and 2) How many sexual encounters were unprotected. Third, the questions were asked separately by type of sexual activity (e.g. anal, vaginal). Fourth, given that differences in sexual behavior may differ by type of partner (i.e. regular client, non-regular client, regular partner), the question were asked separately for each type of partner. Estimates of unprotected sex for the current study only included unprotected sex occurring between the FSWs and regular and non-regular customers. Lastly, rather than using the mean number of unprotected sex acts which was highly skewed by extreme outlier, it was decided to use the mean for this estimate. Furthermore, estimates for biological parameters such as HIV and other STI status were derived from laboratory testing which are considered highly reliable results. There is however the possibility that the status of STIs in the current sample or the assumed size of the FSW population, is not representative of the general FSW population in Tijuana. To address this potential bias in the estimates the sensitivity analysis consisted of

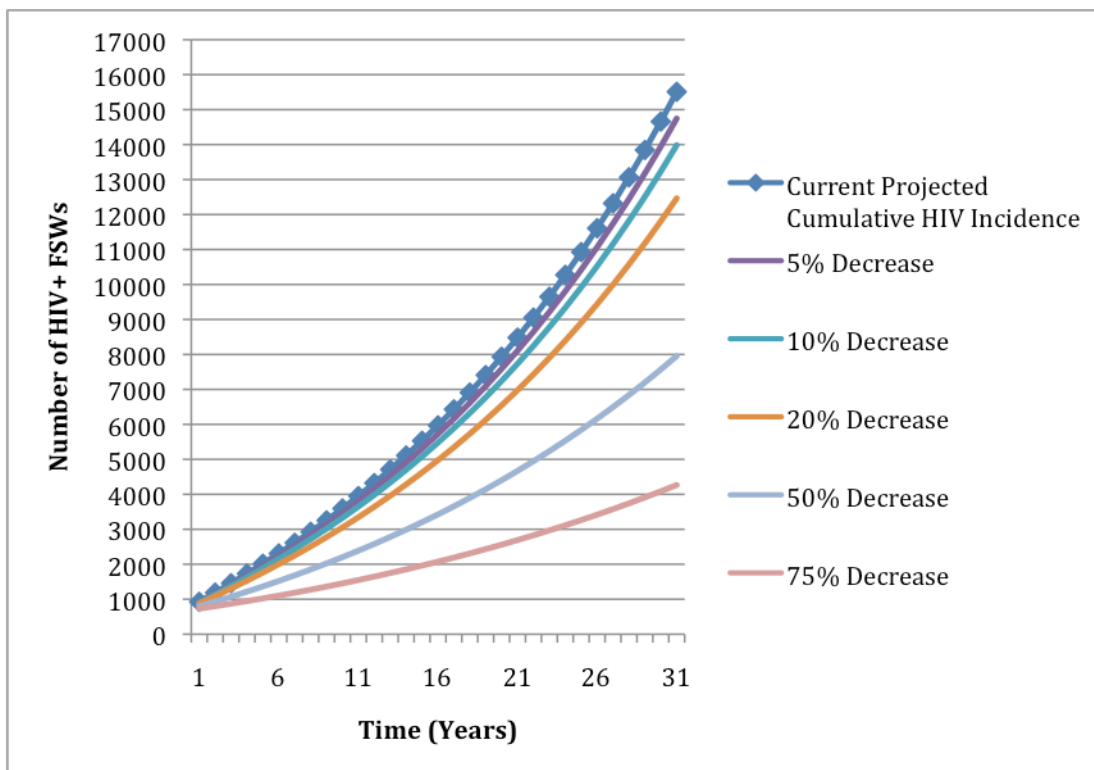
developing low-growth and high-growth scenarios. Direct access to recent behavioral and biological data from community-based studies in Tijuana, greatly enhances the validity of the estimates used for projections.

Mathematical models are a helpful tool to understand the dynamics of HIV transmission, and help guide prevention interventions[82, 101, 102]. To our knowledge the current modeling scenario is the first study aimed at evaluating the impact of increasing condom use among FSWs in Tijuana. Results of this model show that curbing the HIV epidemic will require aggressive interventions that will substantially reduce unprotected sex. A multi-faceted prevention intervention approach where both FSWs and their clients are targeted would be most effective. Community based studies have shown interventions geared at sex workers need to focus on increasing HIV/AIDS knowledge, increasing voluntary counseling and testing (VCT), reducing high-risk behavior (i.e. increasing condom use and increasing skills to negotiate condom use). Scaled up prevention efforts aimed at decreasing sexual transmission of HIV in Tijuana could very well help avoid a generalized epidemic. Future modeling studies should focus on understanding the dynamics of the HIV epidemic among other risk-groups as well (e.g. IDUs, men who have sex with men), and what impact these sub-epidemics will have on the overall HIV/AIDS epidemic in Tijuana.

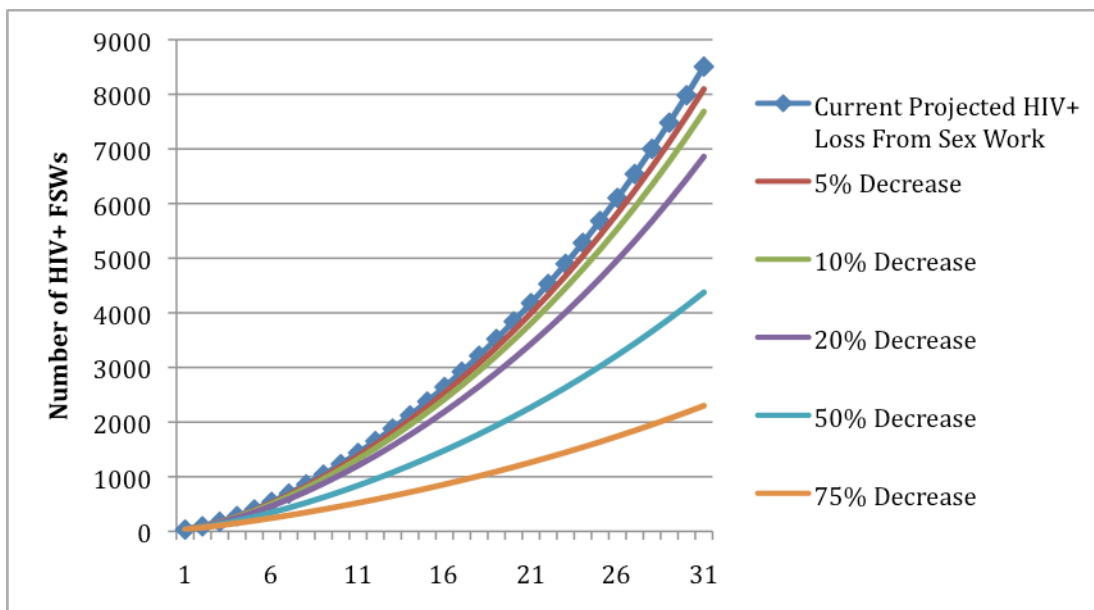


**Figure IV.1A. Low Growth – Projected Accumulative Number of FSW HIV Incident Cases as a Function of Decreasing Unprotected Sex Acts: 2006-2036.**

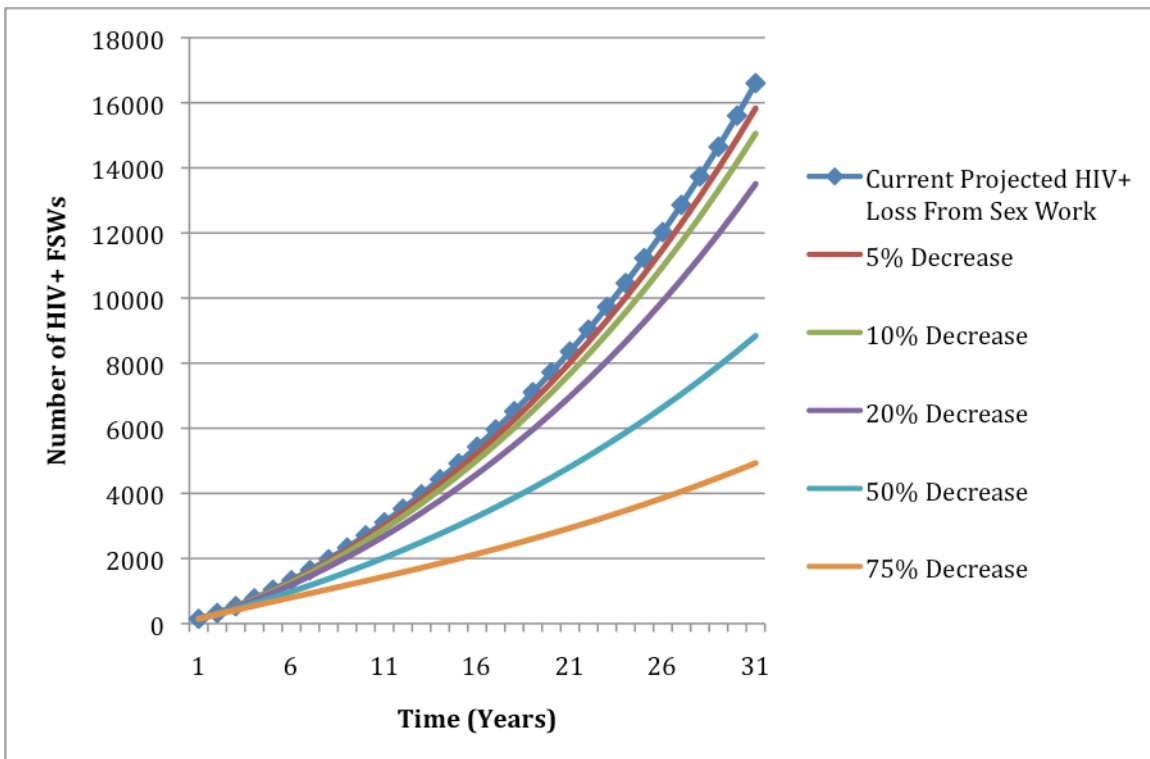




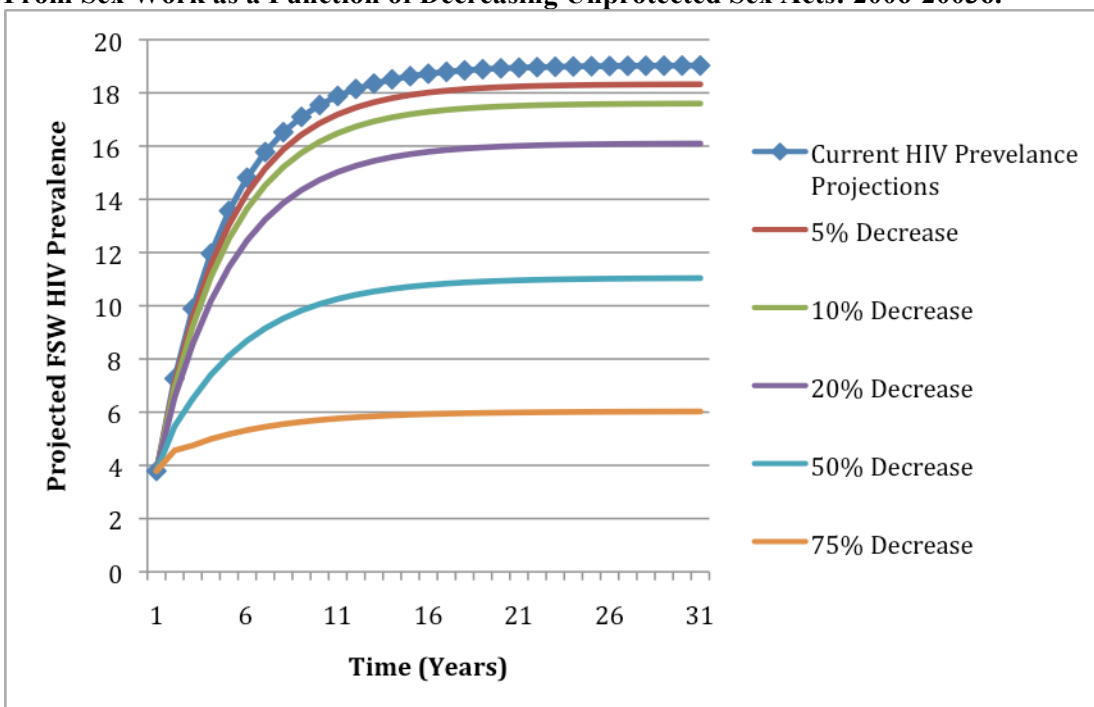
**Figure IV.1B. High Growth – Projected Accumulative Number of FSW Incident Cases as a Function of Decreasing Unprotected Sex Acts: 2006-2036.**



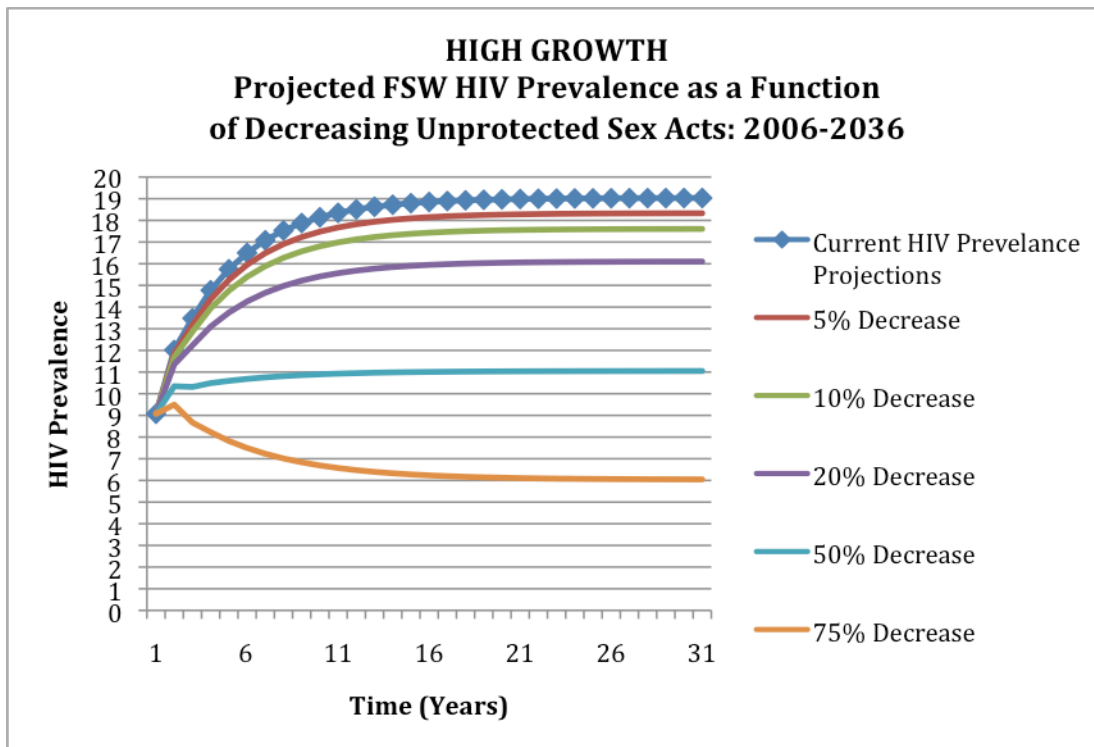
**Figure IV.1C. Low Growth – Projected Accumulative Loss of HIV+ FSWs From Sex Worker Population as a Function of Decreasing Unprotected Sex Acts: 2006-2036.**



**Figure IV.1D. High Growth – Projected Accumulative Number of HIV+ FSWs Lost From Sex Work as a Function of Decreasing Unprotected Sex Acts: 2006-2036.**



**Figure IV.1E. Low Growth – Projected FSW HIV Prevalence as a Function of Decreasing Unprotected Sex Acts: 2006-2036.**



**Figure IV.1F. High Growth – Projected FSW HIV Prevalence as a Function of Decreasing Unprotected Sex Acts: 2006-2036.** Figure IV.1A-1F. The impact of decreasing unprotected sex among FSWs in Tijuana, Mexico based the low-growth scenario (i.e. low initial FSW population size, low initial FSW HIV prevalence, and client-weighted average HIV prevalence) and high-growth scenario (i.e. high initial FSW population size, high initial FSW HIV prevalence, and client-weighted average HIV prevalence), on the FSW HIV epidemic over a 30-year period. All figures show projections for 5%, 10%, 20%, 50%, and 75% reductions in unprotected sex between FSWs and clients. Figures IV.1A and IV.1B – Accumulative HIV incidence projections based on low- and high-growth scenario. Figures IV.1C and IV.1D – Accumulative number of HIV-positive FSW loss from sex work population due to discontinuation from work based on low- and high-growth scenarios. Figures IV.1E and IV.1F – FSW HIV prevalence based on low- and high-growth scenarios.

**Table IV.1. Percent reduction in HIV Prevalence, HIV Incidence, HIV AIDS as result of decrease in unprotected sex. All percentages are rounded to the nearest tenth.**

<b>HIV Prevalence</b>				
	<b>Low-Growth</b>		<b>High-Growth</b>	
	<b>Year 2021</b>	<b>Year 2036</b>	<b>Year 2021</b>	<b>Year 2036</b>
Current HIV Prevalence				
Projections	18.5%	19.0%	18.8%	19.0%
Percent Modelled				
Decrease in Unprotected Sex	<b>Percent Decrease in Prevalence From Current Projections</b>			
5%	3.8%	3.7%	3.7%	3.7%
10%	7.7%	7.5%	7.5%	7.5%
20%	15.8%	15.4%	15.4%	15.4%
50%	42.5%	42.0%	41.6%	42.0%
75%	68.3%	68.4%	66.9%	68.3%
<b>Accumulative HIV Incidence</b>				
	<b>Low-Growth</b>		<b>High-Growth</b>	
	<b>Year 2021</b>	<b>Year 2036</b>	<b>Year 2021</b>	<b>Year 2036</b>
Current HIV				
Accumulative Incidence				
Projections	2,997	8,014	5,970	15,509
Percent Modelled				
Decrease in Unprotected Sex	<b>Percent Decrease in HIV Incidence From Current Projections</b>			
5%	4.4%	5.1%	4.1%	4.9%
10%	8.8%	10.0%	8.3%	9.8%
20%	17.8%	20.2%	16.6%	19.6%
50%	45.6%	50.0%	42.6%	48.7%
75%	70.0%	74.4%	65.3%	72.5%

The text of Chapter Four, will be submitted for publication as:

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Strathdee, S.A. “Modeling the impact of increasing condom use on the HIV/AIDS epidemic  
among female sex workers in Tijuana, Mexico: 2006-2036,” 2009.

The dissertation author was the primary researcher and author.

## Chapter V

### CONCLUSION

#### Study overview

Experts in public health have noted that the epidemic at the national level in Mexico is masked by underlying heterogeneity of the epidemic.[63] Findings of the present study mirrors what is happening at the national level. In Tijuana, Mexico, prevalence appears to be concentrated among sub-groups (e.g. MSM, IDUs and FSWs) of the population. If the current levels of risky health behavior continue or model predicts that over a period of 30 years HIV and AIDS incidence will continue to rise and the HIV epidemic will become sustained among the FSW-nonIDU population. However, targeting prevents at safer sex practices (i.e. increasing condom use between FSWs and clients), could be an effective means of curtailing the HIV/AIDS epidemic. According the current model prediction, over a period of three years, increasing condom use could potential avert a substantial number of HIV/AIDS cases. This issue calls for a concerted effort, geared at creating appropriately tailored HIV prevention interventions that meet the needs of population sub-groups, while at the same time promoting structural changes that will help fight this epidemic.[103, 104] Given the lack of scaled-up prevention effort the epidemic in Tijuana has the potential of becoming generalized.

#### Summary of Findings – Aim 1 – HIV Prevalence Among Adult Men and Women in Tijuana, Mexico

The overall adult HIV prevalence for Tijuana is 0.54% ( N = 4,347) (Range: 0.22% (N = 1,750) – 0.86% (N = 6,944). This means that as many as 1 in every 116 adults could potentially be infected with HIV in Tijuana. When stratifying by gender the prevalence among males is 0.85% (Range: 0.39-1.31) and 0.22% (0.04-0.40) among females.

Nonetheless, the epidemic in Tijuana appears to be driven by sub-epidemics among population sub-groups. Sub-groups such as MSM, FSW-IDUs, female IDUs, FSW-nonIDUs and male IDUs appear to be disproportionately affected by this epidemic. Recent community-based studies have shown that risk behaviors (e.g. needle sharing and unprotected sex) are not uncommon practices among some of these sub-groups [12, 53]. Findings of the present study along with recent finding from community-based studies indicate the increased need for focusing public health efforts on the specific needs of at risk population. Prevention efforts should be geared at increasing VCT, condom use and HIV/AIDS knowledge and awareness.

#### Summary of Findings – Aim 2 – Projecting the Future of the HIV/AIDS Epidemic Among nonIDU-FSWs in Tijuana, Mexico

As a result of recent evidence showing that the HIV epidemic in Tijuana appears to be driven by sub-epidemic among sub-groups of the population, the current study aimed to project the course of the epidemic among one of these sub-groups. More specifically, the future of the HIV epidemic attributed to sexual transmission among FSW-nonIDUs was projected over a 30-year period. Given the current level or reported unprotected sex among FSW-nonIDUs and their clients, the model predicts that HIV/AIDS incidence will increase over the projected period. The model also predicts that the epidemic will become sustained as time progresses. Given the dynamic nature of the population (i.e. inflow and outflow), the projected increases in HIV incidence could potential lead to bridging of the epidemic between core (high risk sub-groups) and non-core groups (low risk sub-groups).

#### Summary of Findings – Aim 3 – Modelling the Impact of Increasing Condom Use on the HIV/AIDS Epidemic among FSW-nonIDUs

High levels of HIV prevalence among population sub-groups (Aim 1) and the projected future increase in HIV/AIDS incidence (Aim 2) arises the need to effectively fight

and prevent a generalized HIV/AIDS epidemic in Tijuana. The third aim of this study proposed to evaluate the impact of increasing condom use between FSW-nonIDUs and their clients on the future of the HIV/AIDS epidemic. According to the present model decreases of greater than 50% in unprotected sex could have a substantial impact on the future of the epidemic. The model from Aim 2 predicted that HIV epidemic would eventually become sustained at an HIV prevalence of approximately 19%. The current model projects that with a 50% decrease in unprotected sex HIV prevalence would eventually become sustained at approximately 11%, while a decrease of 75% would cause the epidemic to become sustained at approximately 6%. Hence results of the present model reveal the importance of increasing HIV/AIDS awareness and thus increasing condom use among the FSW population in Tijuana.

#### Mathematical modelling considerations

Unlike modelling of non-sexually transmitted diseases (e.g. tuberculosis), modelling of sexually transmitted infections (STIs) adds an additional level of complexity. Many times the population at risk for a particular sexually transmitted disease is a particular subset of the population as opposed to the entire population.[105] Such was the case in our study, where we HIV estimates have been reported to be the highest among selected sub-groups of the population (e.g. MSM, IDUs, and FSWs.).[5] For this reason our attempts to predict the future of this epidemic in Tijuana, focused on one of the three major sub-groups – FSW-nonIDUs. STIs are also different from other infections, in that probability of infection is dependent upon distribution of various types of sexual activity (e.g. unprotected sexual intercourse) and not population density.[105]. To address this issue our modelling scenarios accounted for the heterogeneity of sexual behaviors among of the sub-group of interest. Furthermore, some viral infections may have more than one mode of transmission, as is the case with HIV/AIDS, which can be transmitted through various routes (e.g. mother to child, needle sharing, sexual intercourse). The present modeling studies (Aims 2 and 3) focused on



sexual transmission of HIV. HIV also varies from other STIs, in that unlike the traditional course for most infectious diseases, the virus has the ability to evade an effective immune response. Hence rather than having a model which ends with an immune population, HIV modelling ends with people going into the AIDS category and ultimately leaving the population (i.e death). [105] Other important factors were accounted for in this modelling project were the presence of other STIs besides HIV in the population. It has been shown that chlamydia, syphilis and gonorrhoea all have the potential to increase the probability of acquiring HIV.[66, 68, 106] Probability of HIV transmission was adjusted to account for the presence of chlamydia, syphilis and gonorrhoea in the present study. Furthermore, the model was adjusted to account for the varying probability of HIV transmission as result of the type of sex act (e.g. anal versus vaginal sexual intercourse).

#### Statistical software considerations

HIV/AIDS experts have used a variety of software packages and statistical techniques to create projection models of the HIV/AIDS epidemic.[75, 107-110] Murray modeled the impact of behavioral changes on the prevalence of HIV and HCV among IDUs in Australia, and utilized differential equations followed by Monte Carlo simulations.[28] The Joint United Nations Programme on HIV/AIDS (UNAIDS) and the World Health Organization (WHO), have produced three distinct computer programs to produce HIV prevalence estimates based on HIV surveillance data.[107] The first is Workbook Methods™ - this program is best suited for low-level of concentrated epidemics.[111] This program works by identifying groups of people that are at higher risk of contracting HIV, and using estimates of the prevalence of HIV among them to project the future of the epidemic among a population.[111] The second program is called Estimation and Projection Package (EPP)™, which can be applied to generalized or concentrated epidemics to develop HIV prevalence estimates.[107] Thirdly, there is the Spectrum™ software package that gives estimates of the

following: number of people living with HIV/AIDS, incidence, mortality and orphan hood. Some examples of input information for the aforementioned models are the following: percent with risk behavior (e.g. MSM, IDU), prevalence of HIV, prevalence of STIs, and number of partners.

Berkeley Madonna has some of the similar functions of the previously mentioned soft wares. This program was created by Macey et al who are at the University of California Department of Molecular and Cellular Biology.[75] It has the ability to numerically solve systems of ordinary differential equations as well as difference equations. It is highly versatile and easy to use. Models can be created utilizing syntax for differential equation or flowcharts (see picture below). Once differential equations and parameters of interest have been input into the program, it has the ability to develop curves that represent the future of the epidemic. Furthermore, one can create additional input parameters (e.g. percentage condom use in a population) and vary the prevalence of these in a population, and evaluate the effect that these would have on the epidemic curve. Yet another program which has been used by some investigators is Model Maker.[108] This software program is very much like Berkely Madonnna, and has been use in a wide array of disciplines ranging from environmental science to physiology to epidemiology.[108] It also has the capability to solve differential equations through the use of compartmentalized models.

Two other software programs suggested by Carlo Magis-Rodriguez, who works for the *Centro Nacional Para Prevencion y Control Del VIH/SIDA* (Center for Control & Prevention of HIV AIDS) in Mexico, were GOALS and Allocation by Cost-Effectiveness (ABC).[109, 110] The first program ABC (developed by World Bank), is designed to aid policymakers in making decision regarding resource allocation that will optimize the number of HIV infections averted.[109] The program is excel spreadsheet based and can be applied to any country or region of the world. GOALS the second program (developed by Futures

Group with funding from USAID), is similar to ABC and is spread sheet based as well. It is somewhat of a cost-effectiveness program, which helps conduct strategic planning at the national level.[110] Given a certain goal, it will calculate the amount of funding that would be required to achieve that goal.[110] Furthermore, given limited resources it also has the capability to estimate what goals are achievable; as well as evaluating the efficacy of alternate patterns of resource allocation to attain preset goals.[110]

Having reviewed several different options that have been used for modeling techniques in the past, we have found that Berkeley Madonna appeared adequate to properly achieve the Aims of the study. Berkeley Madonna is very suitable for solving the differential equations pertaining to infectious diseases, and has been widely used in the field of HIV/AIDS. Use of this program allowed us to easily vary model parameters and evaluate the effect of these changes on the future of the epidemic curve. Given the limitations and uncertainties that are characteristic of cross-sectional data, this program also allowed us to conduct sensitivity analysis around our parameter estimates.

### Limitations

Although the study has many strengths there were also some limitations, which were addressed to the best of our ability during the course of the study. One assumption we made was that our data is valid and reliable, reliability of the estimates was improved by using more than one source of a given estimate when available. Data was accessed from a variety of sources including the following: in-house community-based studies, published literature, communication with public health experts in both Mexico and the U.S, governmental and public health institutions, as well as gray literature. In addition low- and high-growth scenarios were developed as a type of sensitivity analysis.

Another limitation is that a portion of the factors of interest for this study were self-reported by study participants; this type of data is subject to recall bias, and desirability bias.

To assess the potential of this bias we compared our estimates, with other studies that have collected data of similar nature. It is also noteworthy to mention that our in-house studies have addressed the potential for desirability bias in their study design. Even though part of the analysis incorporated self-report data on participant behaviors, data for the prevalence and incidence of HIV relied on results of serological test, which are highly reliable. Nonetheless, it may be possible that HIV prevalence estimates as reported by surveillance and research studies may be true underestimates of the actual HIV prevalence and incidence. Given that our estimates of HIV prevalence may be underestimates, projecting the epidemic curve over a 30-year period rather than a shorter period helped to more accurately assess the future of the epidemic. Furthermore, throughout the modeled period it was assumed that client HIV prevalence remained constant. Given that prevalence among customer increases over the next few years or decades, our projected estimates would prove to be underestimates. Our study was also limited to projecting incident HIV cases resulting from sexual transmission, and thus does not account for other routes of transmission.

Although our study is subject to limitations it also has many strengths. More importantly results of the present studies have great potential to impact the HIV epidemic in this U.S.-Mexico border region, by averting possible future HIV infections. The findings can help guide the development of prevention interventions that are specifically tailored to meet the needs of population sub-groups that are most affected. The results of this study can also be used to make public health decisions, policy decisions and help with resource allocation.

#### Directions for Future Research

To our knowledge there are no other studies that have attempted to project the future of the HIV/AIDS epidemic in Tijuana, Mexico. The present findings begin to explain the intricate dynamics of the HIV epidemic for the city, but much more remains to be explained. Future modeling studies should focus on understanding dynamics of the epidemics among

other sub-groups such as IDUs and MSM. They should also focus on examining the behavioral interactions between these sub-groups, and how these could potential aid in the future spread of the virus. The contribution of other modes of transmission such as needles sharing to the epidemic should also be considered. The effect of mixing patterns between core and non-core groups on the overall HIV epidemic for the city should be closely examined. Most importantly future modeling should focus in projecting the future of the HIV/AIDS epidemic for the entire city, while taking into consideration contributions from different population sub-groups.

### Closing

A recent study predicted that if prevention efforts were targeted at sexual transmission and IDUs, a total of 28 million infections could be prevented between 2005 and 2015, in low- and middle-income countries.[76] Total cost for preventing these cases would be approximately US\$122 billion, translating into US\$3900 per case prevented. Nonetheless, this would save approximately US\$4700 in treatment expenses per case prevented.[76] Hence prevention intervention cannot only prevent future infections but also will avert future cost in treatment.[76] These averted funds could then be re-channeled to create further prevention interventions. In Tijuana, Mexico, high HIV prevalence among population sub-groups (i.e., IDUs, FSW & MSM) and the projected increase in HIV prevalence, gives rise to the need for massive public health mobilization. More specifically, the need for prevention efforts that are tailored specifically to meet the needs of the various sub-groups that are affected by this epidemic are highly warranted. To our knowledge there are no studies that have attempted to project the future of this epidemic for Tijuana, Mexico. Studies of projection or forecasting are instrumental in helping prevent future epidemics.

Knowledge of the potential number of HIV cases that can be averted by appropriate prevention efforts is thus an extremely important tool for public health professionals if we are

to attempt to fight this epidemic. Thus continued use of mathematical models could be a highly valuable tool, for public health professionals. Possible applications would be in resource allocation, policy guidance, and structuring prevention interventions, on both side of the border. Since the HIV epidemic is in its early stage in Tijuana, the results of our study should not only raise awareness on the issue, but also have the potential to avert future HIV transmission.

## APPENDIX

### PARAMETER FORMULAS, DERIVATION & SOURCES

#### A. Mathematical Model Flowchart

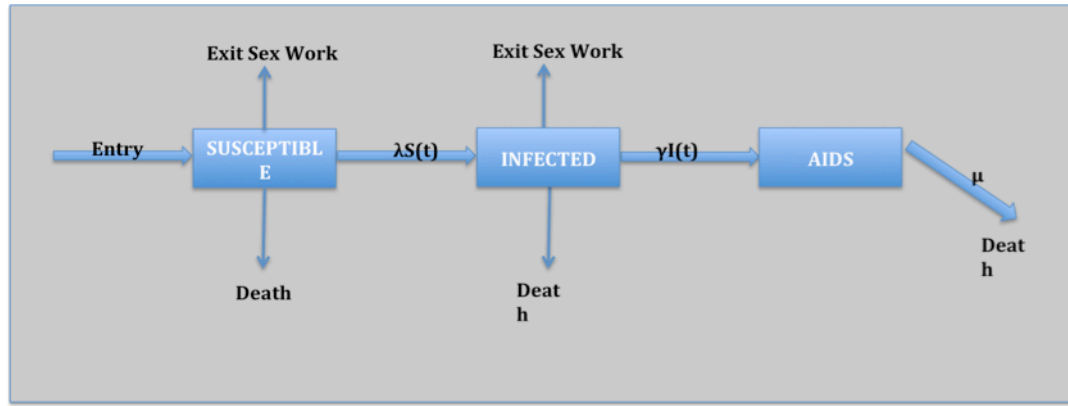


Figure 1. Flowchart for compartmentalized deterministic HIV transmission model

All modeling for Chapters 2 and Chapter 3 were conducted using Berkeley Madonna Software version 8.3 [75]. The model consisted of three different compartments (susceptible, HIV infected and AIDS cases). Figure 1 is a graphical representation of this compartmentalized model and depicts the flow of individuals from one compartment to another. The number of FSWs susceptible to an HIV infection changes under the following circumstances: 1) every time an FSW becomes infected, 2) when new sex workers enter the population, 2) when sex workers exit the population, and 3) when sex workers die. The number of HIV+ FSWs at any given time varies depending on the following: 1) number of new FSWs who become HIV+, 2) number of sex workers who exit the population, 3) number of sex workers who die, and 3) number of FSWs who enter the AIDS phase on an HIV infection. Subsequently the number of FSWs in the AIDS phase depends on the following: 1) the number of HIV+ FSWs progress from the infected stage to the AIDS stage, and 2) the

number of FSWs that exit the compartment due to an AIDS related death or exit from sex work due to infection related consequences. Thus flow from one compartment to another is determined by a series of factors and is represented by a system of differential equations.

## B. Mathematical Model Formulas

Modeling for Chapter 3 and Chapter 4 was based on a system of differential equations. The equations are as follows:

- $dS(t)/dt = -\lambda(t)S(t) + \text{Entry to SW Population} - \text{Deaths in SW Population} - \text{Exit SW}$
- $dI(t)/dt = \lambda(t)S(t) - \gamma I(t) - \text{Death in SW} - \text{Exit SW}$
- $dA(t)/dt = \gamma I(t) - \mu A(t)$
- $\lambda(t) = c\beta i(t)$

The force of infection ( $\lambda(t)$ ) is a function of the number of contacts( $c$ ) (frequency of sex with clients) and the corresponding probability of transmission( $\beta$ ) for the type of sex act (vaginal or anal). Median number of unprotected sexual frequency with customers was utilized rather than the mean, which was highly skewed by few outliers.

Following is the model syntax from the Berkeley Madonna program:

```
{Reservoirs}
d/dt (Susceptibles) = - New_Infections + Entry_to_SW_Pop - Susceptible_Deaths -
Exit_Sex_Work
INIT Susceptibles = 3782.5
d/dt (Infected) = + New_Infections - New_AIDS_ - Infected_Deaths - Exit_SW
INIT Infected = 174.10
d/dt (AIDS) = + New_AIDS_ - AIDS_Deaths
INIT AIDS = 0
```

```
{Flows}
```



$\text{New\_Infections} = \text{foi} * \text{susceptibles}$   
 $\text{New\_AIDS\_} = \text{prAIDS} * \text{infected}$   
 $\text{Entry\_to\_SW\_Pop} = \text{ngrow} * \text{entry\_rate}$   
 $\text{Infected\_Deaths} = \text{infected} * \text{m\_rate}$   
 $\text{AIDS\_Deaths} = \text{AIDS} * \text{AIDS\_exit\_rate}$   
 $\text{Susceptible\_Deaths} = \text{susceptibles} * \text{m\_rate}$   
 $\text{Exit\_Sex\_Work} = \text{susceptibles} * \text{exit\_sw}$   
 $\text{Exit\_SW} = \text{infected} * \text{exit\_sw}$

Label Definitions:

- $\text{foi}$  = force of infection
- $\text{susceptibles}$  = number of sex workers at risk for HIV infection at time 1
- $\text{prAIDS}$  = rate of transition from HIV to AIDS
- $\text{infected}$  = number of sex workers infected at time 1
- $\text{ngrow}$  = per year growth rate of sex worker population
- $\text{entry\_rate}$  = number of sex workers that enter population per year
- $\text{m\_rate}$  = sex worker mortality rate
- $\text{AIDS}$  = number of AIDS cases at time 1
- $\text{AIDS\_exit\_rate}$  = per year rate of exit from AIDS compartment
- $\text{exit\_sw}$  = rate for per year loss of sex worker from population

### C. Tijuana Sex Worker Population Size at Year 1 (2006)

**Source** – Estimates for population size of sex workers were taken from a community-based study of FSWs workers[31].

**Data** –

- FSW Population Size for Low-growth Scenario =3,957
- FSW Population Size for High-growth Scenario =7,338

### D. Number of HIV Positive Sex Workers at Year 2 (2006)

**Source** – Estimates for initial number of HIV+ FSW-nonIDUs were taken from Chapter 2.

**Data** –

- Number of HIV+ sex workers @ year 1 – Low-growth Scenario = 150
- Number of HIV+ sex worker @ year 1 – High-growth Scenario = 666

#### **E. Number of Susceptible Sex Workers At Year 1 (2006)**

Estimates for number of susceptible sex workers at year 1, was calculated using the initial number of FSW-nonIDUs (see Section C), as well as the initial number of HIV+ FSW-nonIDUs (see Section D). All FSW-nonIDUs not positive were considered “at-risk” for an HIV infection, and thus labeled as susceptibles.

**Formula** – Initially Susceptible sex workers = Total sex worker in Tijuana – Total HIV+ sex workers

#### **Data** –

- Tijuana sex worker population size:
  - Low-growth Scenario = 3,957
  - High-Growth Scenario = 7,338
- Number of HIV+ sex workers:
  - Low End = 150
  - High End = 666
- Number of Susceptible Sex Workers at Year 1 (2006)
  - Low-growth –  $S(t) = 3,956.5 - 174.1 = 3,807$
  - High-growth –  $S(t) = 7,377.7 - 734.50 = 6,672$

#### **F. Exit Into Population from Sex Work**

Inflow and outflow for modeled population was adjusted for discontinuation from sex work. Data for this estimate was taken from *Mujer Segura* risk reduction randomized controlled study. To more effectively estimate the rate of sex work discontinuation and come up with an estimate that is perhaps more representative of the general population only the participants in the control arm of the study were used to develop this estimate. Sex workers were asked at the 6-month follow up of the study whether they were still involved in sex work. Loss from sex work was also calculated using both arms of the intervention, for comparison purposes. Following is the formula derivation with the using only the control and using both the control and intervention group.

**Source** – *Mujer Segura* – 6-month follow-up [31]

***Estimate Derivation***

1. Using Only Control Group:

- a. Total N for Control = 114
- b. Not in Sex Work @ 6-month follow-up / Total N = Percent Lost @ 6-month follow-up
  - i.  $13 / 114 = 11.4\%$
- c. Still in Sex Work @ 6-month follow-up X Percent Lost @ 6-month follow-up = Number Lost in Second Part of Year
  - i.  $101 \times 11.4\% = 11.514$
- d. Still in Sex work @ 6-month follow-up – Sex Workers Lost in Months 6-12 = N @ 1-year
  - i.  $101 - 11.514 = 89.486$  Sex Workers Left @ 1 Year
- e. Total Sex Workers Lost Over 1 Yeager

- i.  $13 (1^{\text{st}} \text{ 6 months}) + 11.514 (2^{\text{nd}} \text{ 6 months}) = 24.514$
- f. Number of Sex Workers Lost Over 1 Year – Total N = Percentage Lost in 1 Year
  - i.  $24.514 / 114 = 21.55 \text{ Loss/Year}$
- g. Number of FSWs lost over 1 year – Total N = Percentage lost in 1 year
  - i.  $24.514 / 114 = 21.5\% \text{ loss/year}$
- 2. Using Control & Intervention Group:
  - a. Total N for Intervention = 254
  - b. Not in Sex Work @ 6-month follow-up / Total N = Percent Lost @ 6-month follow-up
    - i.  $31 / 254 = 12.2\%$
  - c. Still in Sex Work @ 6-month follow-up X Percent Lost @ 6-month follow-up = Number Lost in Second Part of Year
    - i.  $223 \times 12.2\% = 27.206$
  - d. Still in Sex work @ 6-month follow-up – Sex Workers Lost in Months 6-12 = N @ 1-year
    - i.  $223 - 27.206 = 195.794 \text{ Sex Workers Left @ 1 Year}$
  - e. Total Sex Workers Lost Over 1 Year
    - i.  $31 (1^{\text{st}} \text{ 6 months}) + 27.206 (2^{\text{nd}} \text{ 6 months}) = 58.206$
  - f. Number of Sex Workers Lost Over 1 Year – Total N = Percentage Lost in 1 Year
    - i.  $58.206 / 254 = 22.92\% \text{ Loss/Year}$

***Formula – Exit from Sex Work***

$$\text{Rate of Exit from Sex Work} = 1 / (21.5 / 100)$$

### **G. Sex Worker Population Growth**

Due to the lack of information regarding the per year growth of the FSWs population for Tijuana, the overall population growth used as a proxy for the growth of the FSW population. In other words it was assumed that the proportion of the female population that is FSW remains constant, but grows at the same rate as the general female population. Given that population growth rates vary by age group, it was necessary to develop an overall population growth rate estimate taking into account the age distribution of the modeled population. The age distribution of the modeled sex worker population was assumed to be similar to that of *Mujer Segura* study. Population growth rates were calculated using the two most recent Mexican population census (2000 & 2005).

#### ***Sources –***

2000 INEGI Mexican Population Census [59]

2005 INEGI Mexican Population Census [35]

Tijuana Sex Worker Population Stratified by Age Group [31]

#### ***Estimate Derivation –***

1. 2005 Female Population Size – 2000 Female Population Size = Population Growth Over 5 Years Period
  - a.  $401,281.3 - 339,281.2 = 62,000.1$  Population Growth Over 5 Years
2. Female Population Growth Over 5-year Period / 5 Years = Average Growth Per Year

a.  $62,000.1 / 5 \text{ Years} = 12,400.02 \text{ Average Growth Per Year}$

### 3. Sex Worker Population Size by Age Category

Age Category	Low-Growth	High-Growth	Population Census
15-24 (Cat. 1)	1,340.2	2,486.8	135,547.3
25-34 (Cat. 2)	1265.3	2,348.0	136,077.2
35-44 (Cat. 3)	1,006.3	1,866.7	97,276.8
45-49 (Cat. 4)	345.3	636.3	32,380.0
Total	3,954.1	7,337.8	401,281.3

Table 1. Proportion of FSW-nonIDUs in each of age categories, according to low- and high-growth scenarios and according to the 2005 Mexican population census.

### 4. Overall Proportion of Sex Workers in Each Age Category for the City

a. Sex Workers in Age Category 1 / Number of Women in Age Category 2005 = Proportion of Sex Worker in Age Category

#### i. Initial-Low

1.  $\text{Cat 1} = 1340.2 / 401,281.3 = 0.003340$

2.  $\text{Cat 2} = 1265.3 / 401,281.3 = 0.003153$

3.  $\text{Cat 3} = 1006.3 / 401,281.3 = 0.002508$

4.  $\text{Cat 4} = 345.2 / 401,281.3 = 0.0008602$

#### ii. Initial-High

1.  $\text{Cat 1} = 2,486.6 / 401,281.3 = 0.00619665$

2.  $\text{Cat 2} = 2,348.0 / 401,281.3 = 0.005851256$

3.  $\text{Cat 3} = 1,866.7 / 401,281.3 = 0.004701689$

4.  $\text{Cat 4} = 636.3 / 401,281.3 = 0.00158567$

### 5. Per Year Average Growth Stratified by SW Age Group

a. Proportion of all Females in Sex Work Stratified by Age Group X  
 Average Growth Per Year = Per Year Growth Among Sex Workers  
 Stratified by Age Group

## i. Initial-Low

1. Cat 1 –  $0.003340 \times 12,400.02 = 41.4$
2. Cat 2 –  $0.003153 \times 12,400.02 = 39.1$
3. Cat 3 –  $0.002508 \times 12,400.02 = 31.1$
4. Cat 4 –  $0.0008602 \times 12,400.02 = 10.7$
5. Total = 122.3 New Sex Worker Per Year

## ii. Initial-High

1. Cat 1 –  $0.00619665 \times 12,400.02 = 76.8$
2. Cat 2 –  $0.005851256 \times 12,400.02 = 72.6$
3. Cat 3 –  $0.004701689 \times 12,400.02 = 58.3$
4. Cat 4 –  $0.00158567 \times 12,400.02 = 19.7$
5. Total = 227.4 New Sex Worker Per Year

## 6. Annual Percentage Growth of FSW population

## a. Initial Low

- i.  $122.3 / 3,954.1 = 0.0309 = 3.09\%$
- ii.  $227.4 / 7,337.8 = 0.0309 = 3.09\%$

**Formula –**

FSW Population Growth Rate =  $1 / (\text{Average Growth Per Year for FSW Population} + \text{Percentage Loss Per Year from Sex Worker Population})$

$$\text{Entry\_Rate} = 1 / (3.09/100) + (21.5/100) = 1 / (24.59/100)$$

**H. Death Rate (nonAIDS)**

Death rates for the modeled population were stratified by age group, and were assumed to be equal to reported statewide estimates.

**Source –**

Death rates Stratified by age group - Dirrecion General De Information en Salud[35]

FSW age distribution - Mujer Segura Data[31]

**Data –**

Age Category (Cat.)	Low-Growth	High-Growth	Death Rate (DR)
15-24 (Cat. 1)	1,340.2	2,486.8	2.8/1000
25-34 (Cat. 2)	1265.3	2,348.0	4.2/1000
35-44 (Cat. 3)	1,006.3	1,866.7	6.0/1000
45-49 (Cat. 4)	345.3	636.3	9.1/1000
Total	3,954.1	7,337.8	

**Table 2. Proportion of FSW-nonIDUs stratified by age group and the corresponding**

**Formula**

Deaths/ Year = N for Cat. 1 \* (DR for Cat. 1) + N for Cat. 2 \* (DR for Cat. 2) + N for  
Cat. 3 \* (DR for Cat. 3) + N for Cat. 4 \* (DR for Cat. 4)

Death Rate = Number of Deaths Per Year / Total Number of Sex Workers

**Low-Growth**

$$\begin{aligned} \text{Death/Year} &= ((1340.2*(2.8/1000)) + (1265.3*(4.2/1000)) + (1006.2*(6.0/1000)) + \\ &(345.2*(9.1/1000))) = 3.75256 + 5.31426 + 6.0372 + 3.14132 \\ &= 18.24534 \end{aligned}$$

$$\text{Death Rate} = 18.24531 / 3,954.1 = 0.004614283 \times 100 = 0.46\%$$

$$\text{Death} = (0.46/100)$$



**High-Growth**

$$\text{Deaths/ Year} = ((2,486.8 \times (2.8/1000)) + (2,348.0 \times (4.2/1000)) + (1,866.7 \times (6.0/1000)) + (636.3 \times (9.1/1000)))$$

$$= 6.96304 + 9.8616 + 11.2002 + 5.79033$$

$$= 33.81517$$

$$\text{Death Rate} = 33.81817 / 7,337.8 = 0.004608761 \times 100 = 0.46\%$$

$$\text{Death} = (0.46/100)$$

**I. Rate of Transition from HIV to AIDS**

Estimates of time spent in the pre-AIDS stage of an HIV infection were taken from a surveillance study conducted in rural Uganda. This study found that median time from seroconversion to AIDS was 7.5 years.

**Source –**

Duration of pre-AIDS stage [73]

**Formula –**

$I(t)$  = Number of FSWs in Infected Compartment

Pre-AIDS = Average time spent in pre-AIDS stage = 7.5 Years

Rate of Transitioning from HIV to AIDS =  $1 / \text{Pre-AIDS} = 1 / 7.5$

**J. Proportion of Men That Are FSWs Clients in Each of the Four Client Risk Groups**

**Source –** Client Study[65]

**Risk Group Categories: I**

1. IDU-MSM
2. IDU-nonMSM
3. MSM-nonIDU
4. Low Risk

Risk Group	Proportion of Clients	
	in Risk Group	Actual N From Study
IDU-MSM	7%	21
nonMSM-IDU	18.7%	56
MSM-nonIDU	8.3%	25
All Others (Low Risk)	66%	198
Use Condom Always	40.7%	24
Don't Always Use Condom	59.3%	35

Table 3 – Proportion of Clients By Risk Group

**K. Client HIV Prevalence By Risk Group****Source –**

Client HIV Prevalence taken from different sources[16, 52, 71, 72]

Client HIV Prevalence from Client Study {Patterson, Unpublished Data #292}

**Data**

Risk Group	Prevalence*	Prevalence**
	Point Prevalence (+/- SE)	Point Prevalence (95% CI)

IDU-MSM	2.8(1.1-3.87)[52]	4.8(0.25-25.9)
IDU-nonMSM	2.5(1.9-3.1)[52]	3.6(0.62-13.4)
MSM-nonIDU	18.9(16.43-25.07)[16]	16(5.3-36.9)
Low Risk	0.055(0.01-0.10)[71, 72]	5.6(3.0-10.0)

Table 4. HIV prevalence stratified by client risk-group. \*Data from various sources.

\*\*Data from Client Study {Patterson, Unpublished Data #292}

#### L. Client-Weighted Average HIV Prevalence

*Source* – Please see section J & K of appendix.

*Variables* –

- p1 = IDU-MSM HIV Prevalence
- p2 = IDU-nonMSM HIV Prevalence
- p3 = MSM-nonIDU HIV Prevalence
- p4 = Low Risk HIV Prevalence

AWP = Weighted-Average Client Prevalence

- n1 = IDU-MSM sample size
- n2 = IDU-nonMSM sample size
- n3 = MSM-nonIDU sample size
- n4 = Low Risk sample size

N = Total sample Size

- $\alpha_1 = n_1/N$
- $\alpha_2 = n_2/N$
- $\alpha_3 = n_3/N$
- $\alpha_4 = n_4/N$

- $\Delta\alpha_{1-4} = SE/300$
- $\Delta p_{1-4} = SE/N*100$

**Data:**

Clients By Risk Group Category					
Risk Group	Size of Sample Population (n)	Standard Error (1SD)	Proportion of Clients in Each Risk Group $n/N = \alpha_{1-4}$	$\Delta\alpha_{1-4} = SE/N$ 1SD	$\Delta\alpha_{1-4} = SE/N$ 2SD
IDU-MSM (1)	21	4.42	0.07	0.0147	0.0294
IDU-nonMSM (2)	56	6.75	0.186	0.0225	0.045
MSM-nonIDU (3)	25	4.77	0.083	0.0159	0.0318
Low Risk (4)	198	8.20	0.66	0.0414	0.0828
Total Population (N)	300				

#### Various Sources for HIV Prevalence

Client HIV Prevalence						
Risk Group	Size of Sample Population (N)	Point Estimates HIV + (n)	Standard Error (SE) 1SD	Percent Positive for HIV $(n/N)*100 = p$	$\Delta P_{1-4} = SE/N*100$ 1SD	$\Delta P_{1-4} = SE/N*100$ 2SD
IDU-MSM (1)	234	7.00	2.52	2.8	1.07	2.15
IDU-nonMSM (2)	661	17.00	4.01	2.5	0.60	1.21
MSM-nonIDU (3)	249	47	6.17	18.9	2.47	4.96
Low Risk (4)				0.05	0.045	0.045

#### Standard Error Formula:

$$SE = \sqrt{[(n1/N * (1-(n1/N))]*N}$$

#### Weighted Average HIV Prevalence of Clients of Sex Workers:

Formula –

$$AWP = \alpha_1 * p_1 + \alpha_2 * p_2 + \alpha_3 * p_3 + \alpha_4 * p_4$$

Values for Alpha

- $\alpha_1 = 0.07$
- $\alpha_2 = 0.186$
- $\alpha_3 = 0.083$
- $\alpha_4 = 0.66$

Values for Prevalence

- $p_1 = 2.8$
- $p_2 = 2.5$
- $p_3 = 18.9$
- $p_4 = 0.05$

Weighted Average of Client HIV Prevalence = 2.27%  
Entered into model as = 0.0227

### Formula for Error Around Weighted Prevalence of Customers:

Error Formula:

$$\text{Error} = \alpha_1 * \Delta p_1 + \Delta \alpha_1 * p_1 + \alpha_2 * \Delta p_2 + \Delta \alpha_2 * p_2 + \alpha_3 * \Delta p_3 + \Delta \alpha_3 * p_3 + \alpha_4 * \Delta p_4 + \Delta \alpha_4 * p_4$$

1 = IDU-MSM

2 = IDU-nonMSM

3 = MSM-nonIDU

4 = Low Risk

Values for Alpha

- $\alpha_1 = 0.07$
- $\alpha_2 = 0.186$
- $\alpha_3 = 0.083$
- $\alpha_4 = 0.66$

Values for Change in Alpha

- $\Delta \alpha_1 = 0.147$
- $\Delta \alpha_2 = 0.0225$
- $\Delta \alpha_3 = 0.0159$
- $\Delta \alpha_4 = 0.0414$

Values for HIV Prevalence {p}

- $p_1 = 2.8$
- $p_2 = 2.5$
- $p_3 = 18.9$
- $p_4 = 0.05$

Values for Change in Prevalence

- $\Delta p1 = 1.07$
- $\Delta p2 = 0.60$
- $\Delta p3 = 2.47$
- $\Delta p1 = 0.045$

Error Around Weighted Average from Various Sources HIV Prev. = 0.82(1SD)

Error Around Weighted Average from Various Sources HIV Prev. = 1.62(2SD)

**Using Male HIV Prevalence from Various Sources – 2SD**

Weighted Average Client HIV Prevalence = 2.27(0.65-3.89)

**Using Male HIV Prevalence from Various Sources – 1SD**

Weighted Average Client HIV Prevalence = 2.27(1.45-3.09)

**M. Contact Rates – Unprotected sex between FSW-nonIDUs and their clients**

*Source – Mujer Segura Study[31]*

**Formula**

Mean Unprotected Vaginal Contact Per Year + Mean Unprotected Anal Contact per

Year = Total Number of Unprotected Sex Contacts Per Year

***Derivation***

i. Survey Questions

1. Question 1: Total vaginal sex occurrences in past month [Q1]
2. Question 2: Total times used protection during vaginal sex occurrences in past month [Q2]
3. Question 3: Total anal sex occurrences in past month [Q3]
4. Question 4: Total times used protection during anal sex occurrences in past month [Q4]

NOTE: Used questions for regular client, regular client & non-regular client. Only included anal & vaginal sex.

- ii. Total Unprotected Vaginal Sex = [Q1] – [Q2]
- iii. Total Unprotected Anal Sex = [Q3] – [Q4]
- iv. All estimates for vaginal sex were stratified by STIs (syphilis, gonorrhea, and chlamydia)
  - i. To per year estimates all estimates were multiplied by a factor of 12.

***Parameter Estimate Values –***

Unprotected Sex Between FSWs & Clients Per Year						
		Percent Decrease				
	Median	5%	10%	20%	50%	75%
Anal by STI Status						
Gonorrhea & Chlamydia Positive	66	62.7	59.4	52.8	33	16.5
Syphilis Positive	18	17.1	16.2	14.4	9	4.5
No STIs	48	45.6	43.2	38.4	24	12
Vaginal by STI Status						
Gonorrhea & Chlamydia Positive	48	45.6	43.2	38.4	24	12
Syphilis Positive	24	22.8	21.6	19.2	12	6
No STIs	60	57	54	48	30	15

Table 6. Median number of unprotected sexual encounters of a 1-year period along with projected percent decreases in unprotected sex among FSW-nonIDUs and their clients.

**N. Force of Infection – Probability of Transmission ( $\beta$ )**

**Sources –**

Probability of Transmission[73]

Time Spent in Each Stage of Infection[73]

Prevalence of STI among FSWs[31]

**Variables –**

- **Probability of HIV Transmission (POT)**
  - Anal Probability of HIV Transmission = 0.02
  - Vaginal Probability of HIV Transmission
    - Primary HIV Infection = 0.072
    - Asymptomatic Stage = 0.004
    - Symptomatic Stage = 0.004
    - AIDS = 0.018
- **Time Spent in Each Stage of HIV Infection**
  - Prop. Time 1 = Primary = 10 Weeks
  - Prop. Time 2 = Asymptomatic 150 Weeks
  - Prop. Time 3 = Symptomatic = 200 Weeks
  - AIDS = 40 Weeks
  - Total Time in Weeks = 400
  - Total Time Pre-AIDS = 360
- **Proportion of Time Spent in Each Stage Before AIDS**
  - Primary =  $10/360 = 0.0278 = 2.78\%$
  - Asymptomatic =  $150/360 = 0.4167 = 41.67\%$
  - Symptomatic =  $200/360 = 0.5556 = 55.56\%$
  - AIDS =  $40/400 = 0.10 = 10\%$
- **Weighted Average of Probability of Transmission (POT)**
  - POT Weighed by Proportion of Time Spent in Each Stage
    - $POT(\text{Primary}) \cdot \text{Prop. Time 1} + POT(\text{Asymptomatic}) \cdot \text{Prop. Time 2} + POT(\text{Symptomatic})$



\*Prop. Time 3 = Weighted Average of POT

- **POT no STIs (p2)**

$$(0.072*0.0278)+(0.004*0.4167)+(0.004*0.5556) + 0.0020016+0.0016668+0.0022224 = 0.0058908$$

- **POT for Syphilis (p3)**

$$\text{POT no STIs} * \text{Factor Increase (7.5)} = 0.0058908 * 7.5 = 0.044181$$

- **POT for Gonorrhoea (p4)**

$$\text{POT no STIs} * \text{Factor Increase (3.0)} = 0.0058908 * 3.0 = 0.0176724$$

- **POT for Chlamydia (p5)**

$$\text{POT no STIs} * \text{Factor Increase (3.0)} = 0.0058908 * 3.0 = 0.0176724$$

- **Weighted Average of Probability of Transmisión (POT)**

- $\beta_1 = \text{POT for anal intercourse} = 0.02$
- $\beta_2 = \text{POT for no STIs} = 0.0058908 = 0.059$
- $\beta_3 = \text{POT for syphilis positive} = 0.044181 = 0.044$
- $\beta_4 = \text{POT for gonorrhoea \& Chlamydia positive} = 0.0176724 = 0.017$

- **Proportion of Study Sample by STI Status among HIV- in *Mujer Segura***

- $F_1 = \text{proportion of sample with no STIs} = 77.4\%$
- $F_2 = \text{proportion of sample positive for syphilis} = 3.9\%$

- F3 = proportion of sample positive fro gonorrhea & chamydia = 18.7%
- **Median Number of Unprotected Contacts (c) Over the Past Year**  
**Stratified by STI Status**
  - c1a = Median number of anal contacts for FSWs with no STIS = 48
  - c1b = Median number of anal contacts for FSWs with syphillis = 18
  - c1c = Median number of anal contacts for FSWs with gonorrhea or chlamydia or both = 66
  - c2 = Median number of non-anal contacts for no STIs = 60
  - c3 = Median number of non-anal contacts among syphilis positive = 24
  - c4 = Median number of non-anal contacts among gonorrhea & Chlamydia positive = 48

**Formula – Force of Infection (FOI) ( $\lambda$ )**

Client-weighted HIV prevalence =  $C_{wHIV} = 2.27(0.65-3.89)$

$$\begin{aligned} \text{FOI}(\lambda) = & [1 - ((1 - \beta_1)^{(C_{1a} * C_{wHIV}}) * ((1 - \beta_2)^{(C_2 * C_{wHIV}})))] * [F1] + \\ & [1 - ((1 - \beta_1)^{(C_{1b} * C_{wHIV}}) * ((1 - \beta_3)^{(C_3 * C_{wHIV}})))] * [F2] + \\ & [1 - ((1 - \beta_1)^{(C_{1c} * C_{wHIV}}) * ((1 - \beta_4)^{(C_4 * C_{wHIV}})))] * [F3] + \end{aligned}$$

FOI ( $\lambda$ )

- When  $C_{wHIV} = 2.27$  –  $\lambda = 0.033120134 = 0.033$

- When  $C_{wHIV} = 0.97$  –  $\lambda = 0.0142957 = 0.0096$
- When  $C_{wHIV} = 3.89$  –  $\lambda = 0.051489672 = 0.056$

#### **O. Transition from Susceptible to Infected**

Transition from susceptible to becoming infected is a function of the force of infection and the number of susceptibles. The force of infection is a function of the probability of HIV transmission, the median number of unprotected contacts, the prevalence of STIs among FSWs and the prevalence of HIV among the customers.

##### ***Formula***

New HIV Infections = Force of Infection \* Susceptibles

#### **P. Outflow from AIDS Compartment Due to Death**

The average time spent in the AIDS stage is approximately 10 weeks . For the purpose of this model it was assumed that upon entering the AIDS stage of the infection FSWs spend 0.83 year in the population before exiting.

##### **Source**

Duration of AIDS stage[73]

##### ***Formula***

Average time person lives once in AIDS stage of infection = 40 weeks

Exit Rate from AIDS Compartment =  $1 / \text{Time Spent in AIDS Phase}$

Time Spent in AIDS Phase = 0.83

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