Epidemiology and modeling report on HIV/AIDS in the Philippines

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Introduction

The Philippines is an archipelago of over 7000 islands and islets with a population of over 90 million. While the remainder of Southeast Asia is encountering varying degrees of HIV epidemics, the Philippines has been a setting in which the HIV prevalence has remained relatively low, at less than 1%, even among populations considered to be high risk [1-4]. It is important that an understanding of the HIV epidemic be obtained in order to ensure that lessons learnt for effective control in other countries are put in place so that a large HIV epidemic does not emerge in the Philippines. The first recorded case of HIV infection in the Philippines was in 1984 [1-9], and since then the cumulative number of HIV diagnoses is just over 3300 [10]. This report will attempt to evaluate the current epidemiology and the "low and slow" development of the HIV epidemic in the Philippines. It will also review behavioural and epidemiological conditions that are of concern for the possible onset of an epidemic and develop a mathematical transmission model for HIV in the Philippines, paying particular attention to the MSM population.

Background

Since the first recorded case of HIV in the Philippines, the epidemic's spread has been described as 'low and slow' [5, 8, 11]. Reasons for this are not entirely clear because all the factors for an explosive epidemic are already present in the Philippines [12]. However, reports produced by the Philippine Department of Health, the Philippine National Health AIDS Council (PNAC), the World Health Organisation (WHO) and the United States Agency for International Development (UNAID) have pointed to several factors which could account for the low and slow development of the epidemic. These include:

- The network of sex workers in the Philippines is less extensive than networks in other countries with high HIV prevalence [3].
- Sex workers in the Philippines tend to have fewer clients than their counterparts in other countries, with the average number of clients between 2 – 4 per week compared with ~15 in various other settings [3, 12-16].
- Filipino men do not seem to frequent brothels as often as their counterparts in other countries, for example Thailand.
- There has been the establishment of social hygiene clinics to allow for regular examination and treatment of HIV-infected establishment-based female sex workers [5, 13, 15].
- The majority of the male population has only one sexual partner at any time and relatively low partnership breakup rates [17]. Accordingly, Filipinos tend to have fewer sexual partners than their counterparts in countries with higher HIV/AIDS rates [18].
- The country has implemented an accelerated, multi-sectoral response to the epidemic through the use of local resources, active engagement of individuals and organisations, the establishment of surveillance systems, education and communication campaigns and the establishment of HIV/AIDS policies [5, 6, 13, 15, 16].
- There are low levels of intravenous drug users (IDUs) in the country [5, 6, 13, 14, 16].

- compared with other countries such as Vietnam. At present, there are only an estimated 10,000 IDUs [16] in the Philippines (out of its population of ~90 million people). In comparison, Australia has ~175,000 IDUs in its population of 20 million people [19].
- There is a low prevalence of ulcerated STDs (which are known to facilitate HIV transmission) [14, 16].
- There is a low occurrence of penile-anal sex [14, 16].
- The complicated geography of the country, its archipelagic nature and its separateness from mainland Asia could be helping to shield it from the epidemic [1, 3, 16, 20].
- There is a high rate of circumcision, of ~ 93% [1, 14, 21]. Circumcision is known to reduce the risk of males acquiring HIV in heterosexual intercourse [22-24].
- There exists a culture of sexual conservatism [1, 25].

While these reasons may account for the low prevalence and slow growth of HIV/AIDS in the Philippines, they may also provide a false sense of security. Current conditions may actually enable the emergence of a rapidly spreading HIV epidemic in the Philippines. In fact, the Philippines National AIDS Council (PNAC) claim that for every documented case of HIV/AIDS, there is likely to be 3 or 4 cases being missed [3]. This is likely to be true, especially considering that up to one-half of HIV cases in parts of the United States and the United Kingdom are thought to be undiagnosed [26, 27].

Conditions for the rapid spread of a HIV epidemic

While the prevalence of HIV/AIDS in the Philippines is currently low, other countries such as Vietnam, Indonesia, and Papua New Guinea have shown that a delayed epidemic is possible [7]. Current data from the PNAC shows that young adults, men who have sex with men (MSM), male and female sex workers, injecting drug users (IDUs), overseas Filipino workers (OFWs), and the sexual partners of people in these groups are particularly vulnerable to HIV infection [16]. In the Philippines, the 'ingredients' and conditions for an established HIV epidemic are already in place, including the low rate of condom use, unsafe IDU practices, large migration rates, increasing trends in extramarital and premarital sex occurring, a lack of education and misconception about HIV/AIDS, the influence of religion on everyday life and the sexual conservatism and culture of the country that inhibits public discussion of issues of a sexual nature [9].

Condom use

The Philippines has the lowest rates of condom use in Asia [6, 28], at around 30% [12, 29, 30], with some reports even quoting rates as low as 23% [14], even among high-risk groups such as sex workers [3, 5, 8, 12, 25, 31]. Such a low rate is concerning since the vast majority of HIV transmission in the Philippines is through sexual contact [9, 16, 25, 28]. A survey in 2003 by Aquino et al [6] found that 63% of male respondents said that they had never used a condom, while Mydans (2003) [14] found that only 2 out of 5 sex workers say they use condoms with any regularity with their clients. A 1998 survey found that 72% of respondents reportedly 'never used' condoms with their extramarital partners [8].

The reasons for such low rates of condom use include:

- A common perception is that condoms are only for birth control, not for HIV and STD prevention and protection [8]. This perception is reinforced by the view that condoms are taboo in the eyes of the Roman Catholic Church [29] and that their use is associated with sin rather than any sort of protection against HIV and other sexually transmissible infections (STIs).
- Government family planning programs have policies against condom supply to unmarried people [5, 32], which is of concern due to the increasing rates of casual sex.
- The cost of condoms is relatively high [19], and the condom supply provided by the government comes primarily from the WHO and USAID [8, 29, 32].
- Many female sex workers (FSWs) assert that 'knowing' their client was reason enough to not use a condom. FSWs and the general female population also tend to believe that the decision to use a condom is up to the man [8].

- Men tend to feel the need to keep up their machismo image to the extent that they refuse to practice safe sex [33].

The low condom rate, while concerning, is not the only factor that could result in an explosive HIV epidemic in the Philippines.

Injecting drug users

The size of the IDU population in the Philippines is currently reported to be low [5, 9]. However, there is concern that this data may be inaccurate as serosurveillance of IDUs has only been available at the Cebu City HSSS site. It is estimated that for Cebu City, at worst, between 1 and 3% of adults inject drugs [7]. As no data exists for other cities, it is difficult to obtain an accurate figure and it is possible that the actual number of IDUs is much larger than previously estimated. Regardless of this, there is additional data of concern associated with IDUs. In its 2008 report, the Philippine National AIDS Council estimated that only 48% of IDUs reported using sterile injecting equipment the last time they injected, and most IDUs reported that they regularly share injecting equipment [7]. The IDU population, particularly if the sharing of HIV-contaminated injecting is being used, will become an important one if this population increases.

Overseas Filipino Workers

There are approximately 7.5 million Filipinos working in 170 countries around the world, with over 2,000 workers departing daily [28, 34]. Each of these workers is a potential carrier of HIV upon their return home. By participating in casual unprotected sex and risky behaviour while overseas, overseas Filipino workers (OFWs) put their partners back home at risk. OFWs may be a bridge population for the spread of HIV and other STIs [14, 28, 35, 36]. Of all the HIV/AIDS cases reported in the Philippines, OFWs account for about 30% of all cases [3, 16, 28]. This population will no doubt play a large part in any HIV epidemic in the Philippines.

Casual sex

Casual sexual activity, particularly among the male population aged 15–25 is increasing. An estimated 55% of young men have engaged in premarital sex with girlfriends and acquaintances, compared to 23% of young women [5]. While most premarital sex turned out to be with the person who was their future spouse, men are more likely to have at least one additional partner compared with women [5, 6, 8]. Most casual sexual encounters are unprotected [12, 37, 38].

HIV/AIDS education

HIV transmission and the risk of a HIV epidemic is also being impacted by the lack of education in the general population related to HIV. Misconceptions of HIV/AIDS among sex and health workers, as well as the general population [6] are widespread, even though awareness of the disease is high [3]. A survey of 1200 males found that many respondents believed that antibiotics, prayer and keeping fit would keep them protected against HIV/AIDS [28]. Many young people also believe that HIV/AIDS can be prevented or treated by a concoction of drinks, douching with detergents, coitus interruptus and by washing the penis [3]. The Young Adult Fertility Survey (YAFS) found that a large proportion (60%) of young people believed that there was now a cure for HIV/AIDS and as such they could become more complacent [39, 40]. Such misconceptions, accompanied by risky (unprotected) behaviour could play a large part in a HIV epidemic.

Other factors

Other factors that could be important in an impending HIV epidemic include:

- Increasing practice of anal sex [3, 7], accompanied by low condom use.
- Women in the Philippines are not largely empowered to protect themselves and negotiate for safe sex due to cultural, physiological and socio-economic factors. An estimated 43% of women have admitted to being forced into sex and 15% believed that they were obligated to have sex with their partners [3].
- Discrimination, harassment and intolerance of homosexuality, particularly male homosexuality, have resulted in MSM becoming a 'hidden' population group even

though 20% of reported HIV cases involve male-to-male transmission [3]. With intolerance still high, there is difficulty in providing HIV/AIDS information, education and treatment to MSMs.

While HIV is currently low and slow in the Philippines, conditions for enabling a large, growing, and generalised HIV epidemic are already in place.

Government and NGO Response to the HIV threat in the Philippines

The Filipino government and other interested parties have responded to the HIV/AIDS threat in the Philippines in a number of ways in order to circumvent a large HIV epidemic from arising. The Philippine National AIDS Council (PNAC) was created in 1992 by President Fidel V. Ramos to act as an advisory body to the President for the development of policy for the control of AIDS. The PNAC consists of members from the government, public, civil society, private sectors and NGOs and is the central advisory, planning and policy making body for the comprehensive and integrated HIV/AIDS prevention and control program [3]. But due to its advisory role, the PNAC did not have much power to enact policies for the control of HIV/AIDS. Its small budget and reliance on NGOs for funding also limited its ability to be an effective group.

The official response of the Philippines government to the HIV threat was to enact the Philippine AIDS Prevention and Control Act of 1998 (Republic Act No 8504). This Act was enacted by Congress after a long process of deliberation and advocacy by the PNAC and other stakeholders [17]. The Philippine AIDS Prevention and Control Act [41] lays down the basis for various strategies and mechanisms that were to be adopted by the government and other sectors in order to contain HIV infections. It called for [7]:

- a comprehensive nationwide HIV/AIDS educational and information campaign;
- full protection of the human rights of known and suspected HIV-infected persons;
- promotion of safe and universal precautions in practices and procedures that carry risks of HIV transmission;
- the eradication of conditions that aggravate spread of HIV infection;

- and recognition of the important role that affected individuals could have in promoting information and messages about HIV/AIDS.

The Act also reconstituted and revitalised the PNAC which now composed of 26 members representing different national and local government agencies, legislature, medical and health professionals and NGOs [7]. Additionally, the Act states that local governments are to provide community-based HIV/AIDS prevention, control and care services. While the Act is a step in the right direction and has been praised by the WHO as an example of best practice, it is far from effective due to a lack of monetary commitment from the government, relying heavily on NGOs for funding for HIV/AIDS education and prevention programs, and its seemingly unwilling attitude to promote wide condom use for fear of angering the Roman Catholic church [32].

Other programs have also been established for monitoring the spread, and planning the control, of HIV in the Philippines. There are currently four (4) types of surveillance systems in place in the Philippines [12]:

- HIV/AIDS Registry – a passive surveillance system established in 1987. It continuously logs Western Blot-confirmed HIV cases reported by hospitals, laboratories, blood banks and clinics that are accredited by the Department of Health.
- The HIV Sentinel Surveillance System (HSS) – established in 1993 with a grant from USAID. It monitors 10 key cities: Baguio City, Angeles City, Iloilo City, Zamboanga City, Pasay City, Quezon City, Cebu City, Cagayan de Oro City, Davao City and General Santos City, and pays particular attention to establishment-based female sex workers, freelance female sex workers, MSMs and IDUs [2, 7, 28].
- Behavioral Sentinel Surveillance (BSS) – was added in 1997 at the 10 HSSS sites and is a systematic and repeated cross-sectional survey of behaviour related to the transmission of HIV and other STIs [2, 28, 42]. Its major purpose is to detect trends among vulnerable and populations at high-risk whose behavioural change would have the greatest impact on the HIV epidemic.
- Sentinel STI Etiologic Surveillance System (SSESS) was set up in December 2001, made operational in 2003, and monitors STI trends that could guide program interventions to prevent the transmission of HIV.

These surveillance systems have been monitoring the progress of HIV in the Philippines and have provided valuable data to allow for planning the control of the spread of HIV.

The PNAC's 4th AIDS Medium-Term Plan (AMTP IV) for 2005 to 2010 is one of the plans that have utilised the data from the surveillance systems currently in place. AMTP IV's seeks to [3, 12]:

- Scale-up and improve the quality of preventive interventions that aim to identify highly vulnerable groups (sex workers and their clients, IDUs, MSMs and OFWs).
- Strengthen institutional and general public preventive interventions.
- Scale up and improve the quality of treatment, care and support (TCS) services for people infected and affected with HIV/AIDS.
- Integrate stigma reduction measures in the preventive treatment, care and support services and in the design of management systems.
- Strengthen and institutionalise management systems in support of the delivery of HIV/AIDS information and preventive services.

The WHO, other international groups and NGOs have applauded the response of the Philippine government to the threat of HIV. Despite this, the measures that are in place are no guarantee of preventing the emergence of a looming large-scale, generalized HIV epidemic. Greater government funds for education, prevention and treatment programs, and culturally-sensitive but influential promotion of condom use appear to be gaps in which greater commitment could be made.

Epidemiology of HIV/AIDS in the Philippines

A review and analysis of the data from the HIV Sentinel Surveillance System (HSSS) over the period from March 2003 to June 2008 will now be conducted [10]. The first reported case of HIV was in 1984 [1-9], and since then, the HIV epidemic in the Philippines has been described as low and slow. The cumulative number of cases as of March 2003, according to HSSS data, was 1,850. Since then, there has been a steady increase in the cumulative number of notifications (Figure 1).

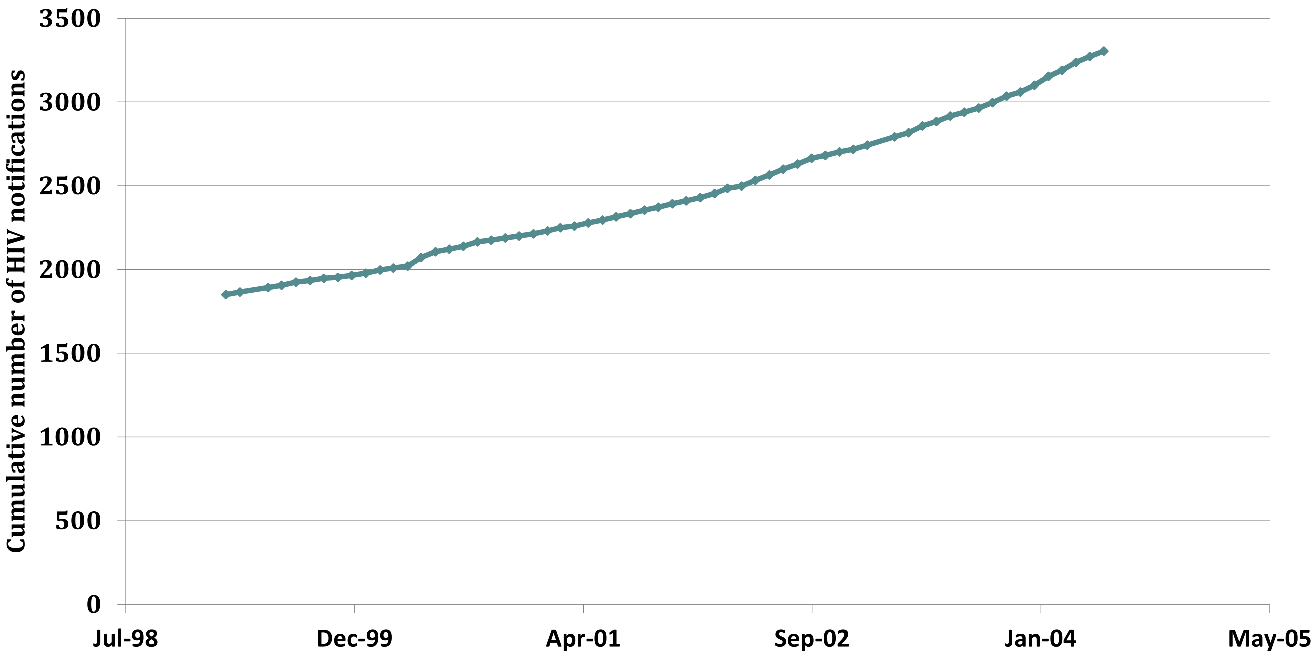

Figure 1: Cumulative number of HIV notifications from March 2003 to June 2008

An examination of the monthly notifications, as seen in Figure 2, supports the notion that the rate of new HIV notifications has been increasing from March 2003 to June 2008. This suggests that incidence rates are increasing in the Philippines.

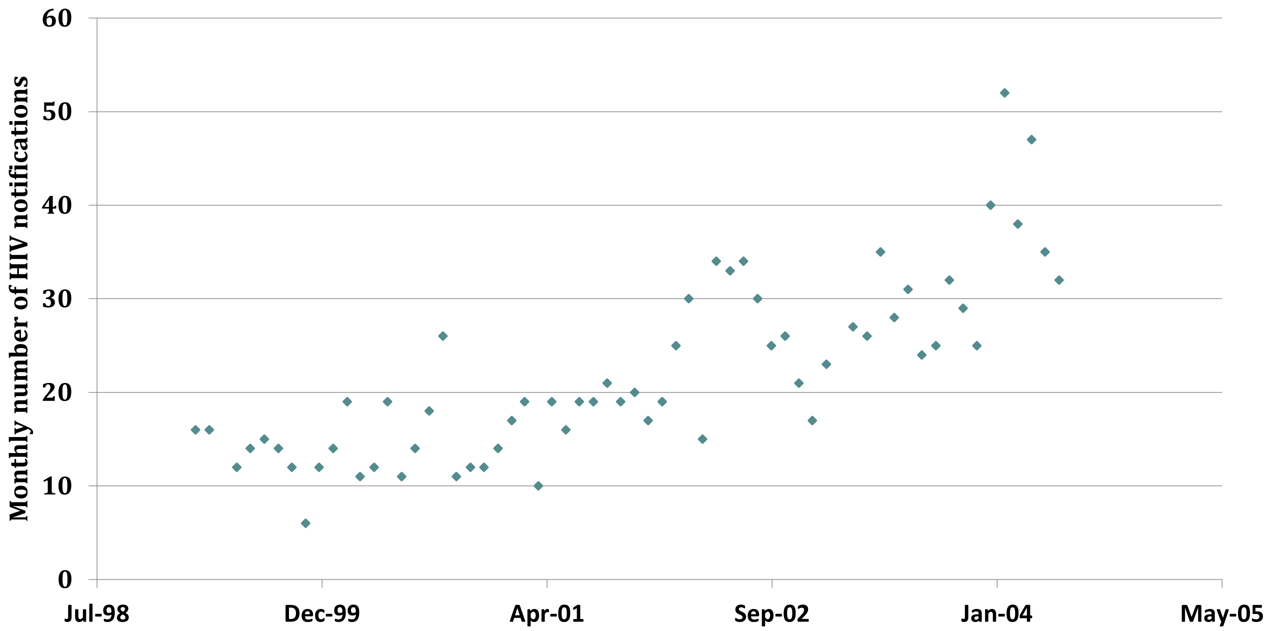

Figure 2: Monthly HIV notifications from March 2003 to June 2008

It is important to understand which populations are contributing to this increase. By looking at the cumulative number of male and female HIV notifications from March 2003 to June 2008, it can be seen that the increase in notifications is largely due to an increase in HIV notifications among males (Figure 3).

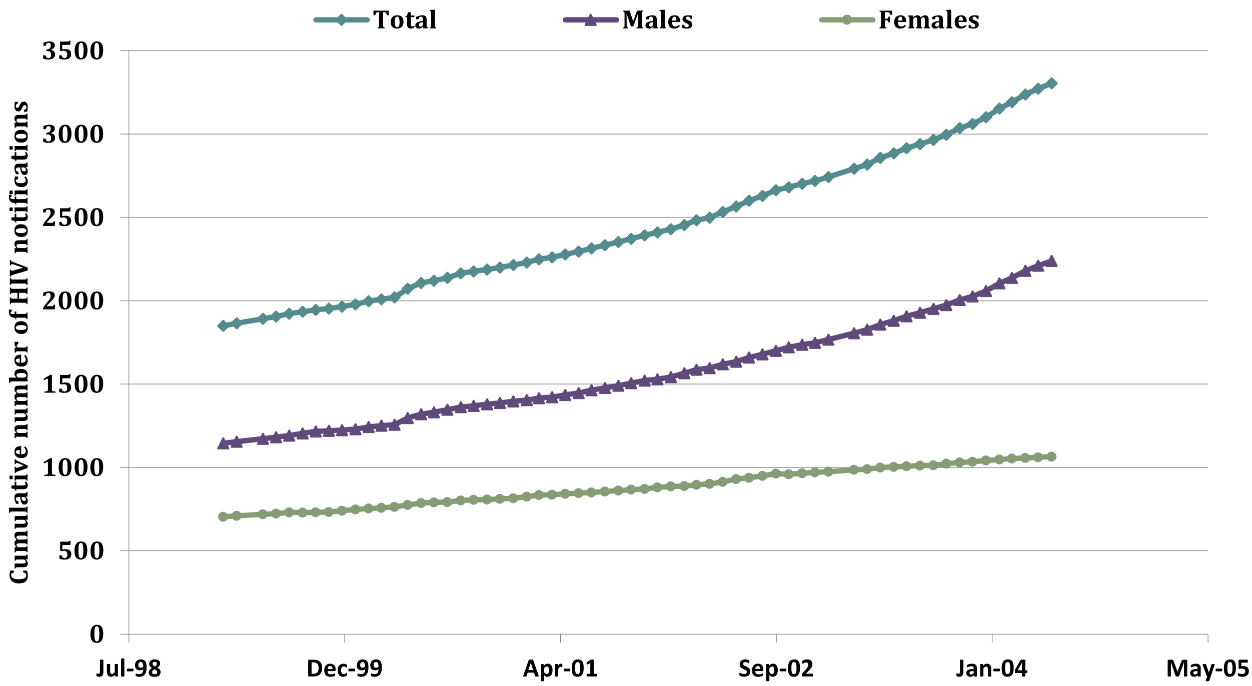

Figure 3: Cumulative number of HIV notifications from March 2003 to June 2008, with notifications separated in sexes.

The increase in HIV notifications is largely due to sexual transmission (results not shown). Of the different sexual routes of exposure, the largest increases in HIV notifications that contribute to the overall increasing trends are due homosexual and bisexual contact, and not heterosexual contact (Fig. 4).

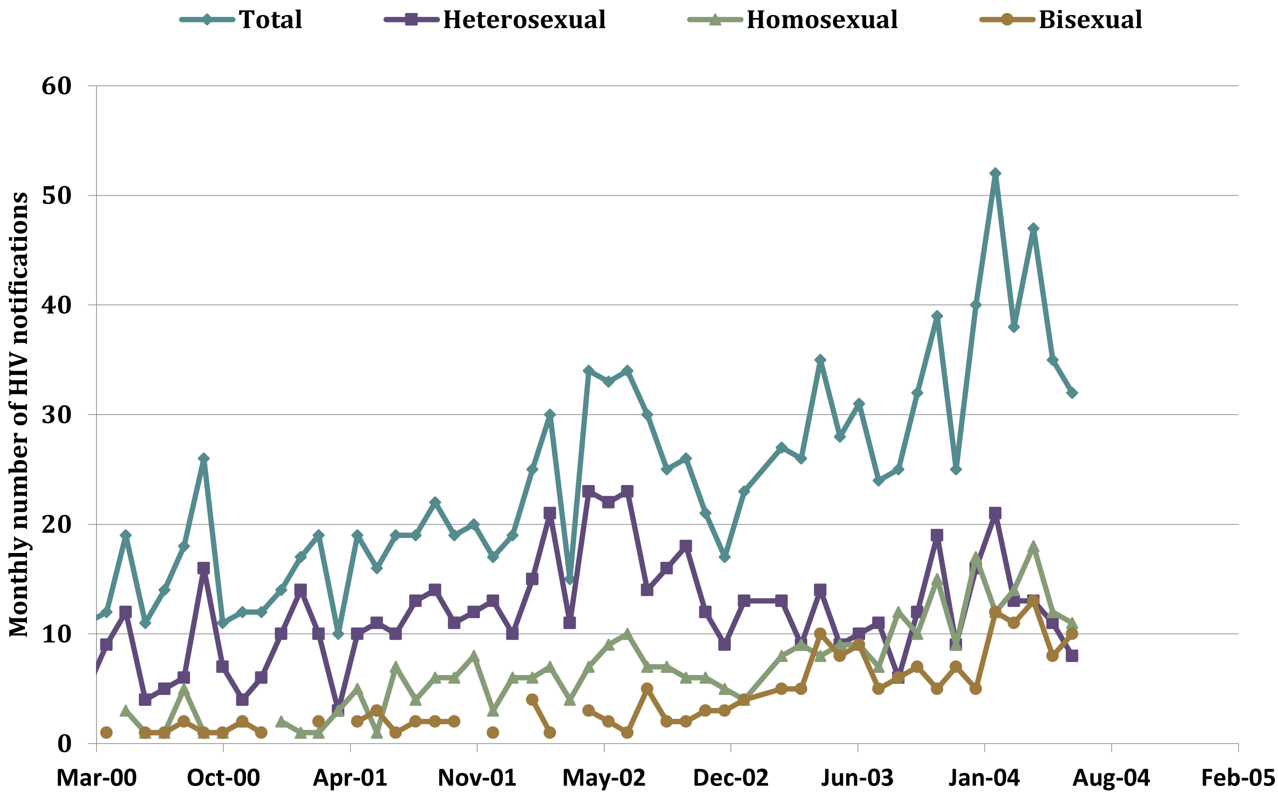

Figure 4: The increase in HIV transmission according to type of sexual contact.

The cumulative number of AIDS deaths during the period of March 2003 to June 2008 has been steadily increasing (Fig. 5), suggesting that AIDS death rates are relatively constant.

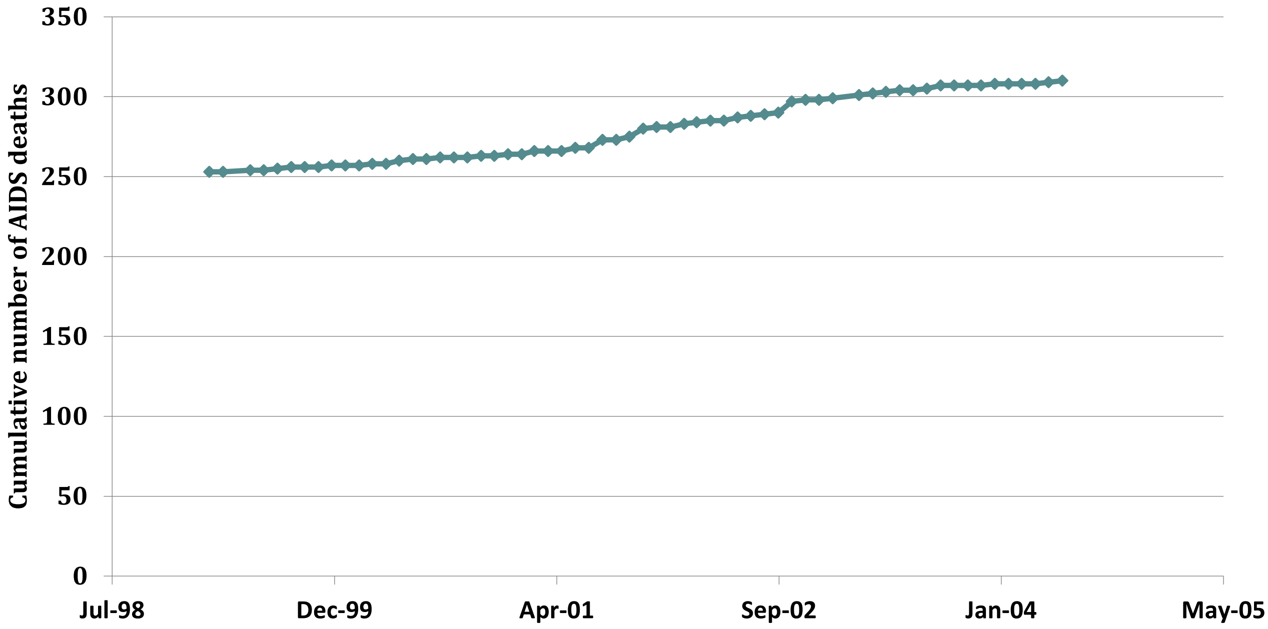

Figure 5: Cumulative number of AIDS deaths from March 2003 to June 2008.

One of the factors that could contribute to a significantly larger HIV epidemic in the Philippines is the number of OFWs. In Figure 6 the percentage (over time) of all diagnoses that were in OFWs is presented. OFWs account for about 30% of all HIV cases [3, 16, 28]. After an increase in the proportion of cases in OFWs, recently there has been a decreasing trend in the number of all HIV cases being attributed to OFWs (Fig. 6).

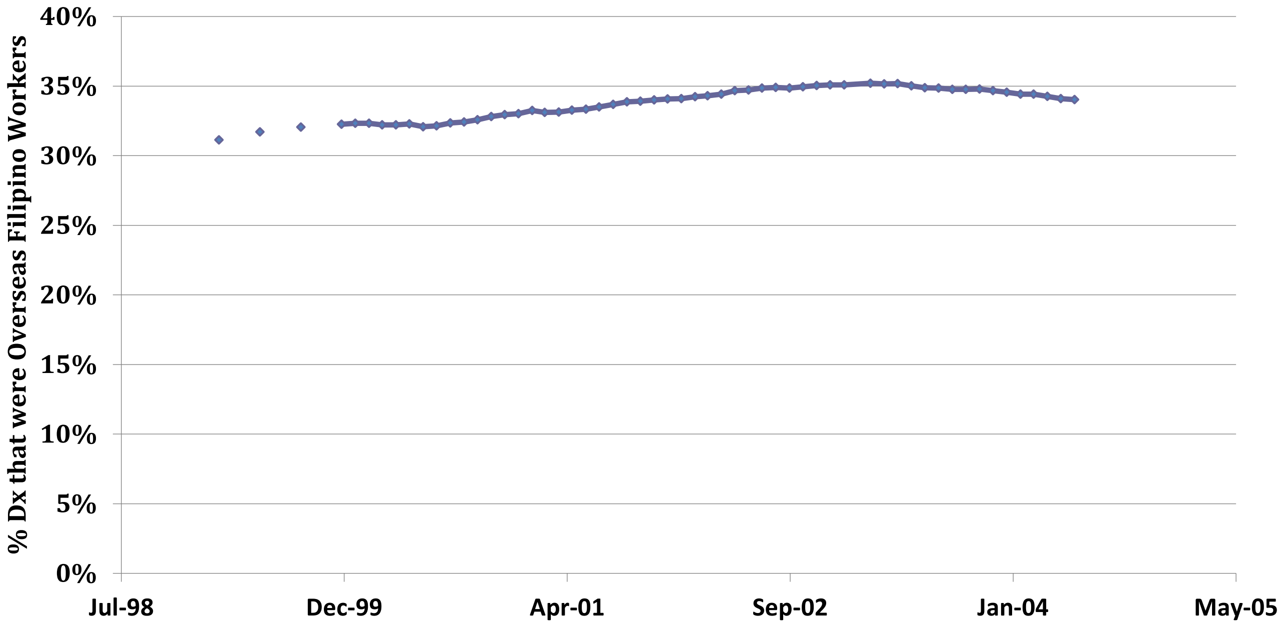

Figure 6: Overseas Filipino Workers as a percentage of HIV cases from March 2003 to June 2008.

Of all HIV infections among OFWs, heterosexual sex is the dominant mode of transmission (Figure 7) and there is no significantly divergent trend in any mode of transmission among OFWs. Seafarers and domestic helpers are main occupations of OFWs who are infected by HIV (Figure 8).

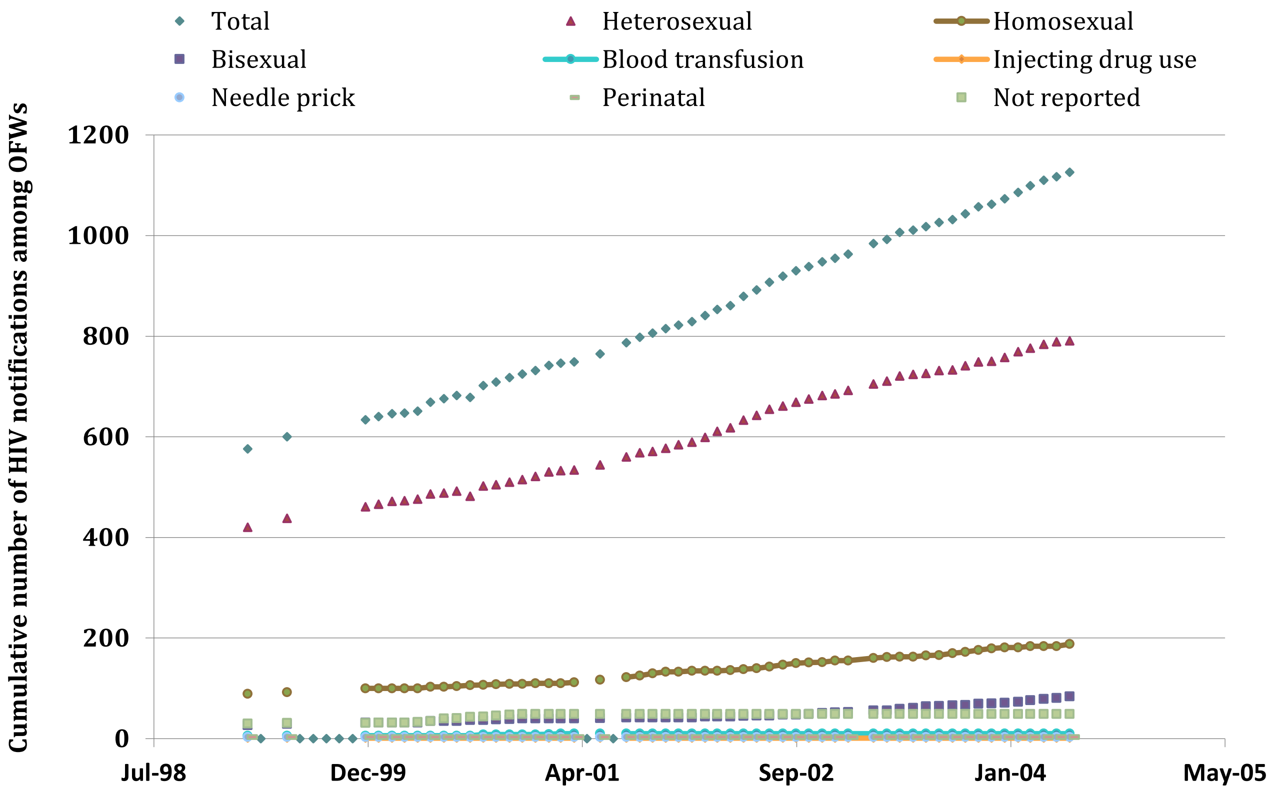

Figure 7: Reported mode of exposure to HIV by Overseas Filipino Workers from March 2003 to June 2008.

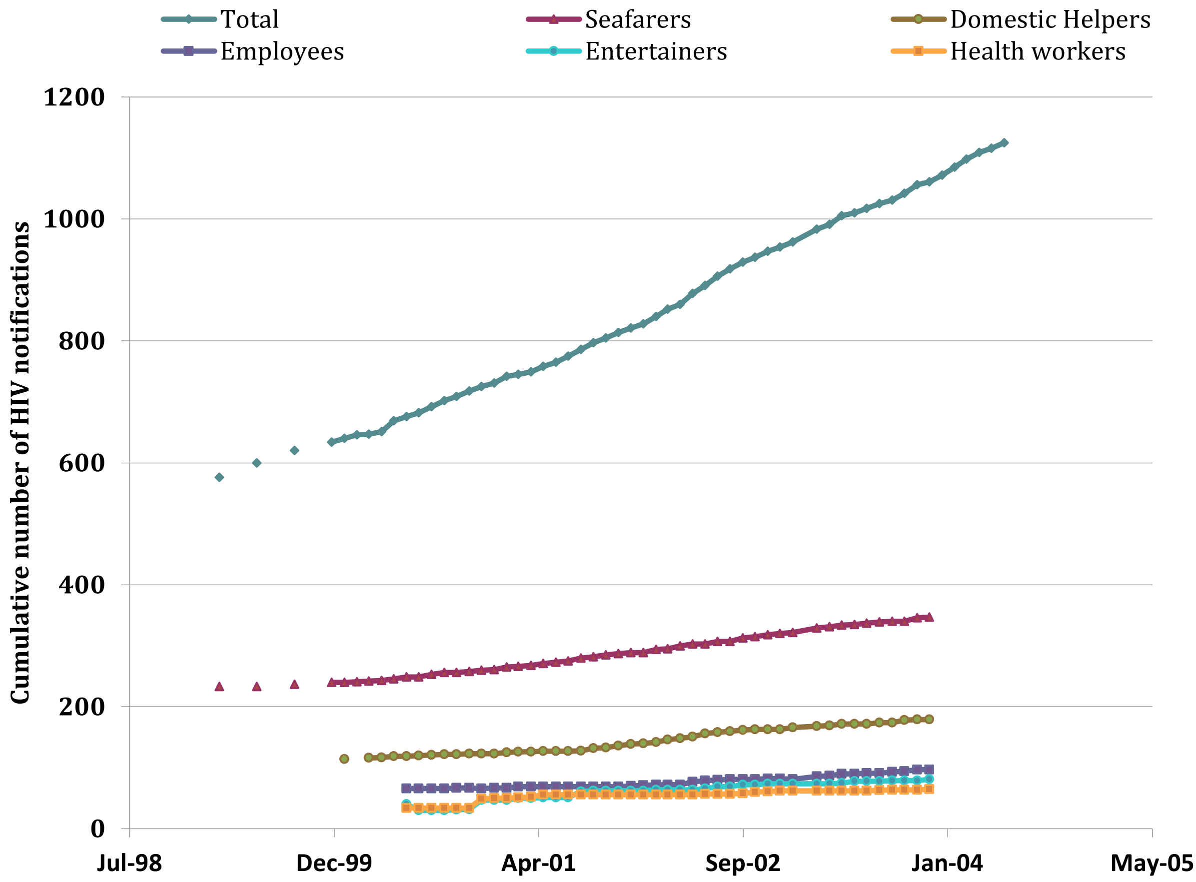

Figure 8: Occupation of Overseas Filipino Workers who reported

HIV infection from March 2003 to June 2008.

An interesting result of the analysis of the HSSS data shows that the average age of diagnosis since March 2003 has been decreasing (p=0.0067)(Figure 9). This is a very worrying trend and needs to be considered by any government and NGO plans to prevent a HIV epidemic. Younger age groups tend to have greater sexual activity. The fact that the average age is decreasing is a strong indicator that HIV incidence could increase substantially in the Philippines. This trend, of decreasing age at HIV diagnosis, is in contrast to most other settings where epidemics are being controlled. In Australia, where HIV has largely been contained (although incidence has been increasing in recent years) the average age of new diagnoses is ~38 years. Age at diagnosis in Australia is increasing at a rate of approximately 0.6 years of age per year [43].

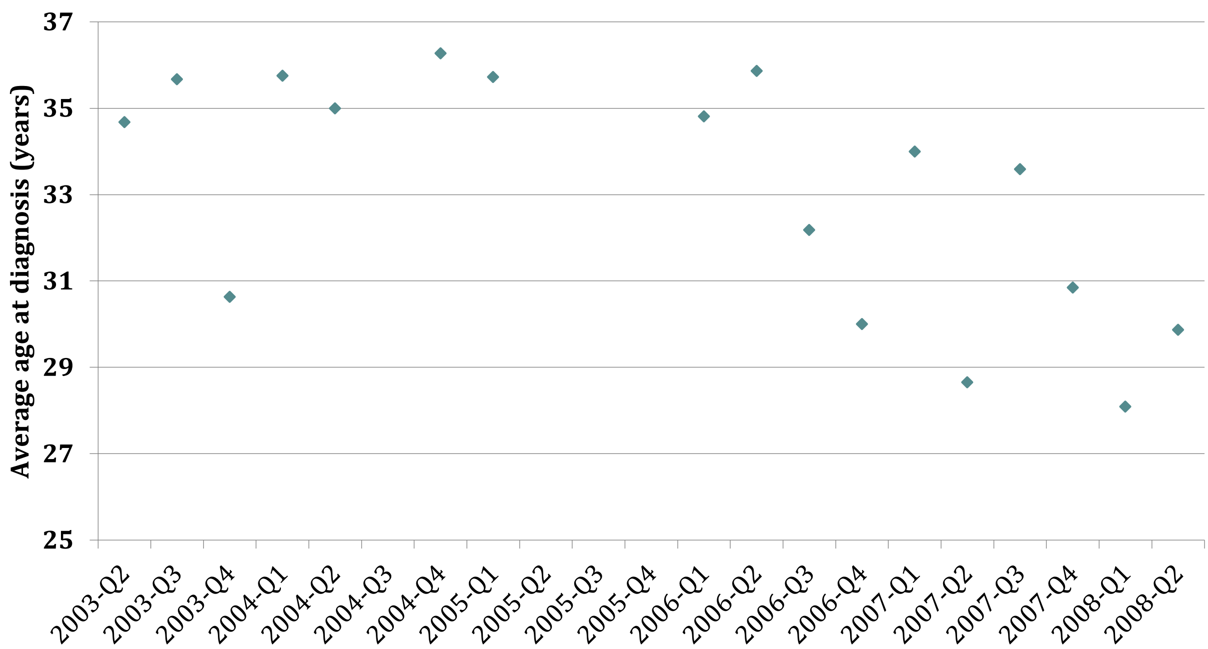

Figure 9: Average age of diagnosis in years from March 2003 to June 2008.

A primary research question is how the emergence of a large-scale generalised HIV epidemic can be prevented in the Philippines. An increase in testing is one strategy that is important for identifying and educating high-risk and at-risk groups. This has already started and has been effective: there has been a decrease in the percentage of diagnoses in the AIDS stage (Fig. 10). While this is encouraging, there is still a long way to go and other measures, not just increased testing, need to be implemented in order to stave of a broad HIV epidemic.

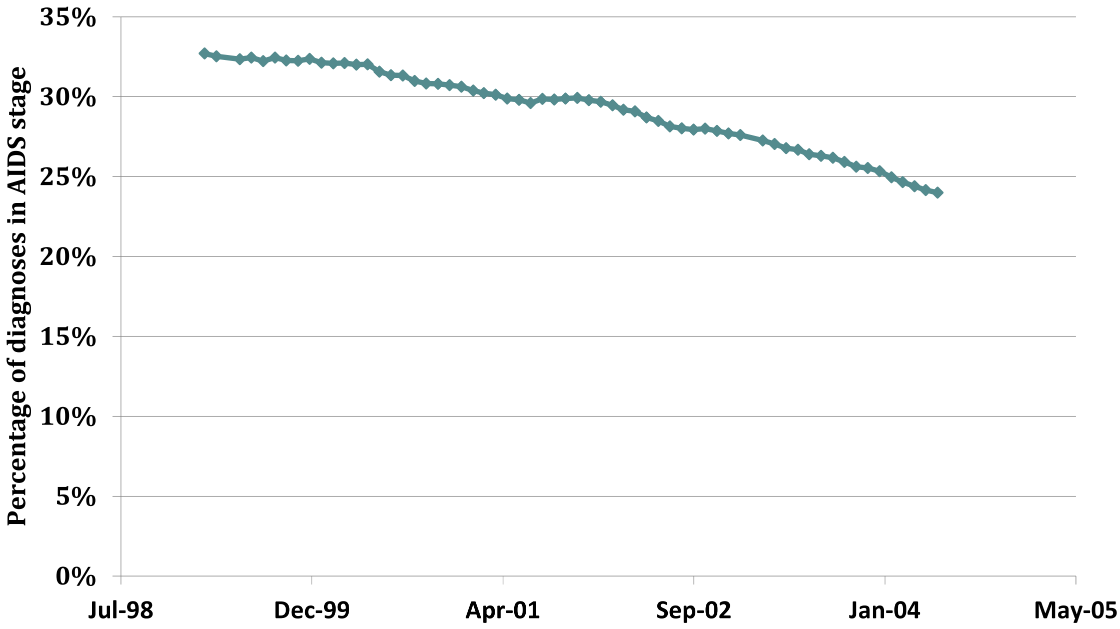

Figure 10: Percentage of diagnoses in the AIDS stage from March 2003 to June 2008.

Mathematical Model of MSM

Mathematical models are useful for understanding complex epidemics. Epidemiological transmission models contain explicit mechanisms linking individual-level behaviours with population-level outcomes (e.g., incidence and prevalence) and have been used to analyse a wide variety of infectious diseases [44]. Whilst some mathematical modelling of HIV epidemiology has been carried out for Southeast Asia in a general sense [45], no model has been applied specifically to the Philippines.

We develop a population-level mathematical transmission model of an HIV epidemic based on ordinary differential equations, looking specifically at the MSM population in the Philippines. Based on the notifications obtained from the HSSS, HIV diagnoses rates have noticeably increased among men, particularly among bisexual and homosexual men (114% and 214% respective increases over 2003-2008) [10].

Schematically, the model is presented in Figure 11. This diagram is mathematically translated into 9 ordinary differential equations, one equation for each compartment/state. The states represented in the model are: uninfected and potentially susceptible gay men (U_g), uninfected and potentially susceptible bisexual men (U_b) HIV-infected gay men who are undiagnosed with their infection (I_g), HIV-infected bisexual men who are undiagnosed with their infection (I_b), HIV-infected MSM who have been diagnosed with their infection (D), MSM who are receiving antiretroviral treatment (T), and MSM who are on antiretroviral treatment but experiencing treatment failure (F).

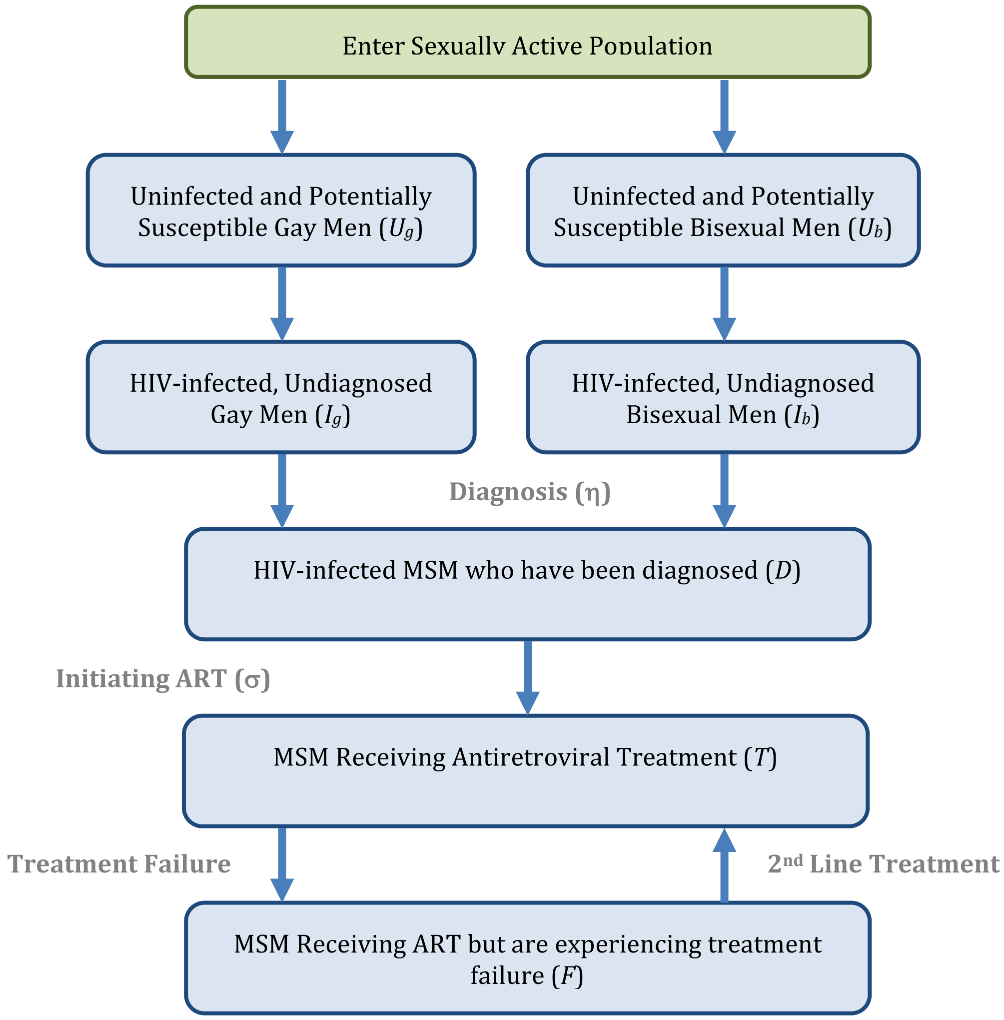

Figure 11: Schematic diagram of the population-level mathematical transmission model of an HIV epidemic based on ordinary differential equations, looking mainly at the MSM population in the Philippines.

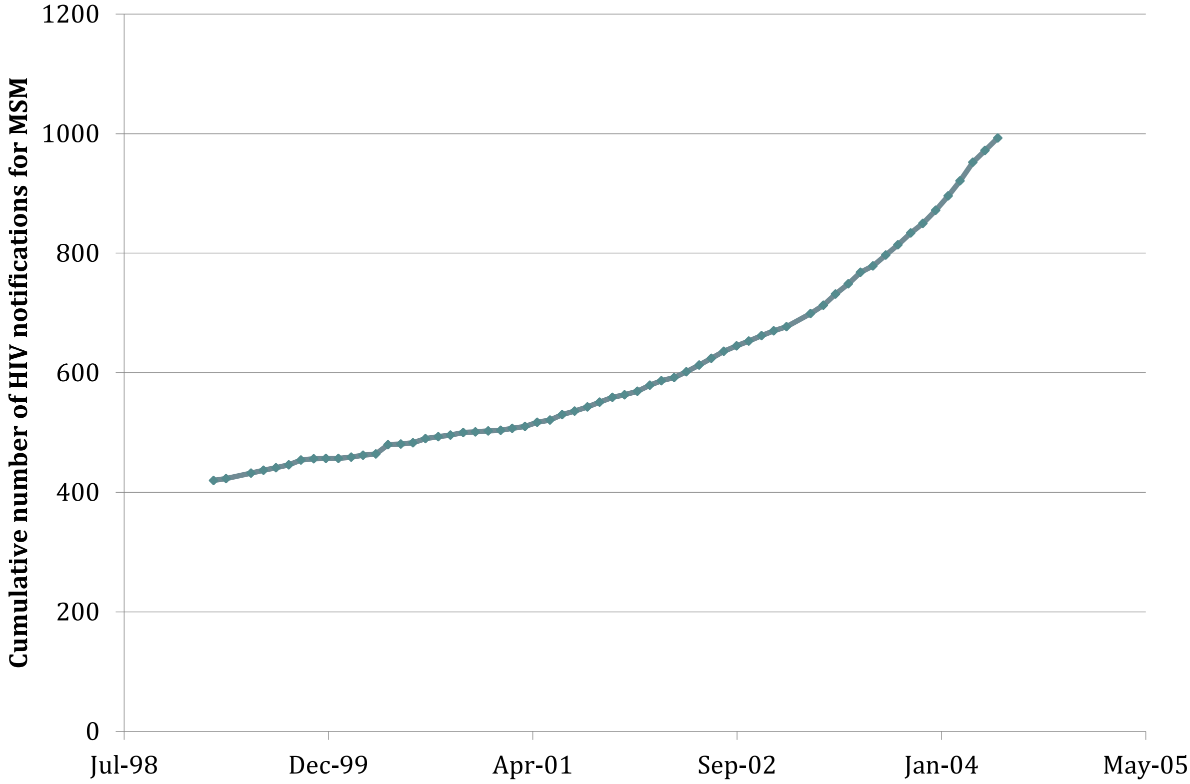

Figure 1#: Cumulative HIV notifications by gay and bisexual men, from the HSSS.

Appendix: Transmission Model Equations

The mathematical model for the dynamic transmission model is represented by ten ordinary differential equations, one equation for each of the compartments shown in Figure 11. The mathematical description of our schematic model is described here, each equation in turn. Individuals enter the MSM population as uninfected and potentially susceptible gay men (U_g) or as uninfected and potentially susceptible bisexual men (U_b) at a rate of π_g and π_b per year respectively. On average, they leave the population at a rate of μ per year. The other method by which individuals can leave this population is by acquiring HIV. These individuals who are newly infected with HIV will move into the HIV-infected, but undiagnosed population of gay men and bisexual men, I_g and I_b respectively. Then, the rate of change in the total number of uninfected gay men and uninfected bisexual men are respectively given by

$$\overbrace{\frac{dU_g}{dt}}^{\text{Rate of change in number of uninfected gay men}} = \overbrace{\pi_g}^{\text{Entry of new men into the population}} - \overbrace{\left[\lambda_g(V_1)\frac{I_g + I_b + D}{N} + \lambda_g(V_2)\frac{T}{N} + \lambda_g(V_3)\frac{F}{N}\right]}^{\text{Per-capita rate of acquiring HIV infection}} U_g - \overbrace{\mu U_g}^{\text{Rate of background death and leaving sexually active population}}$$

and

$$\overbrace{\frac{dU_b}{dt}}^{\text{Rate of change in number of uninfected bisexual men}} = \overbrace{\pi_b}^{\text{Entry of new men into the population}} - \overbrace{\left[\lambda_b(V_1)\frac{I_g + I_b + D}{N} + \lambda_b(V_2)\frac{T}{N} + \lambda_b(V_3)\frac{F}{N}\right]}^{\text{Per-capita rate of acquiring HIV infection}} U_b - \overbrace{\mu U_b}^{\text{Rate of background death and leaving sexually active population}}$$

.

The left hand side of these equations is the time derivative of U_g and U_b respectively. The right hand side of the equation specifies what influences the change in the number of susceptible gay and bisexual men.

Once an individual has become infected with HIV, he moves into the HIV-infected but undiagnosed population, which is represented by I_g and I_b for the gay men and bisexual men population respectively. The ways in which men can leave the HIV-infected but undiagnosed population are: (i) becoming diagnosed with HIV (at a rate η_g for gay men and η_b for bisexual men), (ii) death (at a rate of (μ)), and (iii) leaving the sexually active population (at rate δ_I). Accordingly, the rate of change in the total number of HIV-infected but undiagnosed gay (I_g) and bisexual (I_b) men at time t is given by

$$\overbrace{\frac{dI_g}{dt}}^{\text{Rate of change in number of HIV-infected gay men}} = \overbrace{\left[\lambda_g(V_1)\frac{I_g+I_b+D}{N} + \lambda_g(V_2)\frac{T}{N} + \lambda_g(V_3)\frac{F}{N}\right]U_g}^{\text{Incidence of new HIV infections among gay men}} - \overbrace{\eta_g I_g}^{\text{Rate of diagnosis through HIV testing}} - \overbrace{(\mu+\delta_I)I_g}^{\text{Rate of death and leaving sexually active population}}$$

and

$$\overbrace{\frac{dI_b}{dt}}^{\text{Rate of change in number of HIV-infected bisexual men}} = \overbrace{\left[\lambda_b(V_1)\frac{I_g+I_b+D}{N} + \lambda_b(V_2)\frac{T}{N} + \lambda_b(V_3)\frac{F}{N}\right]U_b}^{\text{Incidence of new HIV infections among bisexual men}} - \overbrace{\eta_b I_b}^{\text{Rate of diagnosis through HIV testing}} - \overbrace{(\mu+\delta_I)I_b}^{\text{Rate of death and leaving sexually active population}}$$

respectively.

The HIV-infected individuals then move into the diagnosed population, D. Rates of movement out of this population can be due to (i) starting antiretroviral therapy (at rate ρ), (ii) death, and (iii) leaving the sexually active population (at rate δ_D). Then the rate of change in the total numbers of diagnosed but untreated HIV-positive men at time t is given by

$$\overbrace{\frac{dD}{dt}}^{\text{Rate of change in number of HIV-diagnosed MSM}} = \overbrace{\eta_b I_b + \eta_g I_g}^{\text{Rate of diagnoses through HIV testing}} - \overbrace{\rho D}^{\text{Rate of initiating antiretroviral therapy}} - \overbrace{(\mu+\delta_D)D}^{\text{Rate of death and leaving sexually active population}} .$$

The cumulative number of diagnoses is therefore:

$$\overbrace{\frac{dD_x}{dt}}^{\text{Cumulative Diagnoses}} = \overbrace{\eta_g I_g}^{\text{Rate of diagnoses of Gay men}} + \overbrace{\eta_b I_b}^{\text{Rate of diagnoses of Bisexual men}} .$$

Individuals diagnosed with HIV then start antiretroviral therapy (ART). The rate at which individuals move from untreated diagnosed to treatment is denoted by ρ. An increase in the treated population comes from the commencement of second-line ART, at rate σ. Decrease in the treatment population occurs from (i) treatment failure (at rate φ), (ii) death, and (iii) leaving the sexually active population (at rate δ_T). Thus the rate of change in the total number of HIV-infected men who are on treatment at time t is given by

$$\overbrace{\frac{dT}{dt}}^{\text{Rate of change in number of MSM on effective ART}} = \overbrace{\rho D}^{\text{Initiation of ART}} + \overbrace{\sigma F}^{\text{Treatment-failure cases initiating second-line ART}} - \overbrace{\phi T}^{\text{Rate of treatment failure}} - \overbrace{(\mu + \delta_T)T}^{\text{Rate of death and leaving sexually active population}} .$$

The population of individuals experiencing treatment failure is decreased by (i) those that start second-line ART, (ii) death, and (iii) those that leave the sexually active population (at rate δ_F). Then the rate of change in the total number of HIV-infected men experiencing treatment failure at time t is given by

$$\overbrace{\frac{dF}{dt}}^{\text{Rate of change in number of MSM experiencing treatment failure}} = \overbrace{\phi T}^{\text{Rate of treatment-failure}} - \overbrace{\sigma F}^{\text{Treatment-failure cases initiating second-line ART}} - \overbrace{(\mu + \delta_F)F}^{\text{Rate of death and leaving sexually active population}} .$$

The cumulative number of deaths is obtained by summing together all the respective death rate terms to produce:

$$\overbrace{\frac{dM}{dt}}^{\text{Cumulative number of HIV related deaths}} = \overbrace{\delta_I (I_g + I_b)}^{\text{Number of deaths of Gay and Bisexual Men at the HIV infected, but undiagnosed stage}} + \overbrace{\delta_D D}^{\text{Number of deaths at the diagnosed stage}} + \overbrace{\delta_T T}^{\text{Number of deaths at the treatment stage}} + \overbrace{\delta_F F}^{\text{Number of deaths at the treatment failure stage}} .$$

Appendix: The force of infection

To be completed

Appendix: Parameter Estimates

Parameter	Description	Value	Reference
c	Number of contacts MSM have per year	72	[46]
Si	Proportion of MSM who always take the insertive role	0.25	Assumption
Sr	Proportion of MSM who always take the receptive role	0.25	Assumption
Sv	Proportion of MSM who take both roles	0.5	Assumption
circ	Proportion of MSM who are circumcised	0.925	
e_{cond}	Efficacy of condoms	0.95	
n	Number of acts per partner	1	Assumption
r	Condom use	0.21	[46]
e_{ART}	Efficacy of ART	0.8	
β_i	Transmission risk for insertive	0.00875	
β_r	Transmission risk for receptive	0.01	
β_{i_circ}	Transmission risk for insertive when circumcised	0.0013	
β_{i_ART}	Transmission risk for insertive with positive partner on ART	$\beta_i * (1-e_{ART})$	
β_{r_ART}	Transmission risk for receptive with positive partner on ART	$\beta_r * (1-e_{ART})$	
$\beta_{i\_circ\_ART}$	Transmission risk for insertive (circumcised) with positive partner on ART	$\beta_{i\_circ} * (1-e_{ART})$	
β_{i_fail}	Transmission risk for insertive when positive partner is failing ART	β_i	
β_{r_fail}	Transmission risk receptive when positive partner is failing ART	β_r	

$\beta_{i\_circ\_fail}$	Transmission risk for circumcised insertive when positive partner is failing ART	β_{i_circ}	
λ_{G1}	Force of infection for gay men by MSM not on ART		
λ_{G2}	Force of infection for gay men by MSM on ART		
λ_{G3}	Force of infection for gay men by MSM failing ART		
λ_{B1}	Force of infection for bisexual men by MSM not on ART		
λ_{B2}	Force of infection for bisexual men by MSM on ART		
λ_{B3}	Force of infection for bisexual men by MSM failing ART		
μ	Death rate / rate at which MSM leave the sexually active population		
ε_G	HIV diagnosis rate for gay men		
ε_B	HIV diagnosis rate for bisexual men		
δ_I	HIV related death - undiagnosed MSM		
δ_D	HIV related death - diagnosed MSM		
δ_T	HIV related death - treatment		
δ_F	HIV related death – treatment failure		
ρ	Rate of going onto treatment		[47]
ϕ	Treatment failure rate		[47]
σ	Rate of going back onto treatment after experiencing treatment failure		[47]

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