Title Page

**Rabies Virus: Understanding and Responding to the Public Health Problem**

by

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**Abstract**

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University of Pittsburgh, 2020

**Abstract**

Despite available preventatives and treatments rabies virus is still a major health threat around the world. In the United States and other developed nations, the prevalence of the virus has decreased substantially since implementation of post-exposure prophylaxis (PEP) protocols. However, rabies remains a significant threat to public health in developing nations that do not have the resources to sufficiently combat against the rabies virus and are losing a dangerous fight. Rabies virus is a special public health problem because anyone can be at risk. This essay reviews the primary and secondary prevention strategies for rabies and contrasts public health interventions internationally, with specific emphasis on the challenging nature of establishing comprehensive rabies prevention programs in developing nations. Next. This essay will explore the differing approaches by states to control rabies domestically. Finally, the essay will make context-specific recommendations for rabies control. The public health significance of this essay is to represent the glaring differences between developing nations and how they combat the rabies virus and compare that to developed nations and their fight against the virus.

Table of Contents

[Preface viii](#_Toc49537774)

[1.0 Rabies Virus Overview 1](#_Toc49537775)

[2.0 Burden of Disease: Developing vs. Developed 6](#_Toc49537776)

[3.0 Rabies in the United States 15](#_Toc49537777)

[3.1 Discussion 22](#_Toc49537778)

[Appendix A Rabies Virus Overview 24](#_Toc49537779)

[Appendix B Rabies in the United States 27](#_Toc49537780)

[Appendix C Rabies in Allegheny County 35](#_Toc49537781)

[Bibliography 37](#_Toc49537782)

List of Tables

[Table 1: Rabies cases per species in Pennsylvania, 2017 27](#_Toc49538155)

[Table 2: Cases of rabies in animals per county, California, 2018 29](#_Toc49538156)

[Table 3: Rabies cases by county and species. New York, 2016 32](#_Toc49538157)

[Table 4: Reported animal bites, Allegheny County, 2018 35](#_Toc49538158)

List of Figures

[Figure 1: Layout of Rabies virus cell 24](#_Toc49538160)

[Figure 2: Cross-Section of inside Rabies virus 25](#_Toc49538161)

[Figure 3: DFA stain showing rabies antigens 26](#_Toc49538162)

[Figure 4: Rabid animals per year, Pennsylvania, 2008-2017 27](#_Toc49538163)

[Figure 5: Rabid animal cases by month, Pennsylvania, 2017 28](#_Toc49538164)

[Figure 6: Wild and domestic animal rabies cases in California, 2009-2018 30](#_Toc49538165)

[Figure 7: Cases of rabies in wild animals by zip code, California, 2018 31](#_Toc49538166)

[Figure 8: Animals examined and positive cases, New York, 2001-2017 33](#_Toc49538167)

[Figure 9: Positive rabies cases by month, New York, 2016 34](#_Toc49538168)

[Figure 10: Reported animal bites by month, Allegheny County, 2018 36](#_Toc49538169)

[Figure 11: Reported bite rates per 100,000 people by age group and sex, Allegheny County, 2018 36](#_Toc49538170)

# Preface

I would like to express my deepest appreciation to all those who provided me the possibility to complete this report. I would especially like to thank my essay board. You each have contributed into my knowledge of public health and I could not have done it without all of you. To the professors at the Graduate School of Public Health, the last three years have been an incredible journey and has shaped me into the professional I am today. So, I than each and every one of you for giving me the knowledge needed to succeed. Lastly, to the people at the Allegheny County Health Department, thank you so much for providing guidance and a practicum experience that shaped this essay.

**Nomenclature:**

PEP- Post-exposure prophylaxis

AfroREB- Africa Rabies Expert Bureau

DALY- Disability-adjusted life year

PAHO- Pan-American Health Organization

WHO- World Health Organization

ACHD- Allegheny County Health Department

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# Rabies Virus Overview

Rabies belongs to the Rhabdoviridae family and genus Lyssavirus and causes a viral encephalitis in humans and animals that is incurable and fatal. Rabies virus is found all over the world, and everyone, regardless of demographics, can be affected by rabies, though as we will explore in this essay, currently those with lower SES are more likely to contract the disease.

Lyssaviruses are all genetically related and have adapted to replicate within the central nervous system (1). Early on many researchers believed that only one of the species of the virus was able to cause rabies, but we understand now that at least seven species of the virus can cause rabies (1). Rabies virus has a bulleted capsule and can range from 75nm to around 200nm with the membrane surrounded by a studded lipoprotein envelope (1). Once inside a host, the lyssavirus has three tasks to complete. The first is to gain access to a host cell, the fusion of the virus to the host cell initiates the entire infection process (2). The virions then congregate in the large endosomes (2). The second is to transcribe, translate, and replicate which involves the N, P, M, G and L proteins synthesizing in the free ribosomes (2). Lastly, the virus must reassemble its components and leave the cell through budding from the plasma membrane of the host cell (1,2).

Rabies is found throughout the world and in a variety of animal hosts, but the main reservoir is rabid dogs, and other members of the order Carnivora. Lyssaviruses are extremely fragile and cannot survive in the open environment, hence why a host is so important for the transfer of the virus (1). The main transfer of the virus is from a bite from an infected host; however, this is not the only way transfer occurs. Scratches, abrasions or open wounds exposed to saliva or infectious material are other possible modes of infection (2). Although it is uncommon, inhalation of aerosolized rabies virus has occurred through laboratory workers (2). Lastly, there have been cases of rabies has been transmitted through organ transplants (2). Once the virus is deposited in the system, passage occurs towards the central nervous system (1). As the virus begins replicating, it moves towards exit points within the host for movement to a new host. The researchers state that the incubation period can be anywhere between 1-3 months after exposure, but some incubation periods have lasted days or years after the exposure (1).

Symptoms pertaining to rabies virus can vary depending on the person. Early after the infection, people with rabies virus have been seen to have symptoms that are closely related to influenza (2). After a few days the symptoms become more severe with cerebral dysfunction, hallucinations, insomnia with many other symptoms (2). Sadly, once these symptoms show, rabies is almost always fatal without treatment.

Diagnosis in animals is fairly easy. Technicians use a direct fluorescent antibody test that requires brain tissue and checks for the presence of the antigens related to rabies (2). Diagnosis in humans is more complicated. Diagnosing rabies virus before the human has died requires multiple tests. Saliva samples are tested by virus isolation, spinal fluid samples are tested for antibodies related to rabies, and hair samples are examined for antigens in the nerves at the base of the hair (2).

Once it is determined that a person has been exposed to rabies it is imperative that the person/animal receives care as soon as possible. Post-Exposure Prophylaxis (PEP) is available for rabies virus and consists of, wound care, rabies immune globulin, and vaccine administration (3). It has been shown that cleaning the wound with soap and water soon after a bite from an infected host can reduce the risk of developing rabies. There are three rabies vaccines currently licensed in the United States and have tested well when used with humans. When taking the vaccine, it must be administered for two weeks at days 0,7 and day 14. Although the vaccines are potent, the effect they carry lessens as time goes on. Researchers state that additional doses are needed to keep the antibody titers strong (3). The rabies immune globulin offers given passively is an important part of postexposure prophylaxis. The immune globulin allows neutralizing antibodies to enter the wound and help the victim even before they can mount an immune response (3). Human rabies immune globulin is administered once, usually with the PEP vaccine (3). However, the expense as well as the limited distribution of the immune globulin are problems still seen throughout the world (3). It should be known that the commercially made rabies immune globulin are completely safe and cannot transfer disease (3). Monoclonal antibodies have been administered in mouse models and have shown that they can clear rabies virus from the central nervous system (4). Researchers suggest that therapy with more than one antibody could be effective in the treatment of rabies virus in the near future (4). Ribavirin is a broad-spectrum antiviral agent with mechanisms that can influence its overall properties (4). This agent induces mutations by acting as a template for the incorporation of cytidine and uridine (4). Cytidine and uridine are major players in central nervous system and brain function. Ribavirin has shown in the research to have immunomodulatory properties which could account for its antiviral capacity in vivo experiments (4). Although Ribavirin seems very promising, much more need to be understood about the agent. In some of the studies efficacy was not studied, as well as limited information about penetration of the blood-brain barrier (4). IFN-a is an immunoregulatory and immunotherapeutic drug for viruses (4). During the immune response, IFNs create an environment that restricts viral replication, in turn, not allowing the rabies virus to manipulate host cells and increase numbers (4). IFNs have also shown to have a big role in the transition of the immune response from the innate to the adaptive response, as well as antigen presentation and activation of the cytotoxic T-cell response (4). However, it was also shown that three patients treated with high-doses of IFN-a experience no beneficial effect throughout the study (4). Ketamine is a known anesthetic agent and an antagonist of the NMDA receptor (4). Ketamine could be an important player in rabies virus treatment since it has shown that it inhibits *in vitro* replication of rabies by targeting the transcription of the virus (4). It has been shown that the NMDA receptor may be a factor for rabies virus. With this knowledge, it is even more important to continue to study ketamine as a rabies virus treatment. Lastly, research has been done on corticosteroids to see if they could help with treatment. It was quickly shown in mouse models that the administration of corticosteroids actually increased the mortality rate and shortened the incubation period (4). In certain situations, an aggressive approach to rabies could be a solution. Much research has gone into this approach and many outcomes have shown that while an aggressive approach may help treat rabies, it is extremely rare that it does and, in some aspects, can lead to permanent disabling neurological deficits (4).

In the U.S., prevention measures are currently used in conjunction with rabies virus. Around the United States much of the research and emphasis is on prevention and intervention since complete eradication is not a realistic goal currently. Around 55,000 people receive PEP each year and saves the United States millions per human life saved (2). Prevention in animals starts with vaccinations. A domestic animal owner should visit the veterinarian annually to keep all the animal’s vaccinations up to date (2). People should call animal control whenever a person sees a stray animal around their neighborhood since these animals could be unvaccinated and could cause rabies (2). Rabies prevention in people is essentially bite-prevention, people should avoid wild or unfamiliar animals as well as follow professional recommendations about PEP with contact with an infected animal. It is imperative that people understand the risk that rabies has, 92.7% of reported rabies cases were from wild animals and infected bats were the most frequently reported rabid species (2). However, most people do not follow the recommendations or are unaware of the threats rabies possesses (2). Always check yourself and your surroundings. (2). Lastly, it is important that humans stay up to date on vaccines of pets, for both animal and human health (2).

# Burden of Disease: Developing vs. Developed

Geographically, rabies knows no boundary. Rabies has been found all over the world and remains a significant threat to health in many places, particularly throughout much of the developing world (5). Exact numbers of the burden of disease can be difficult to obtain. Within these developing nations there is little to no data on the public health impact of this virus, though estimates can be reached through a variety of metrics. (5). Despite the lack of comparable data, it is apparent though that there is a clear discrepancy in rabies care in developing nations.

On approach to assessing the burden of rabies is to calculate disability adjusted life year (DALY) (5). The DALY number describes the number of years lost due to ill-health, disability or early death for a given condition and is used to assess the relative impact of different diseases within different economic and public health stages (5). This can be useful because it can be used to organize disease control since health interventions can be prioritized based on impact of reducing the disease (5). Researchers have estimated the global number of DALY for rabies to be around 1.16 million, which they note is a conservative estimate since the number was based off years of life lost only and not years of life lived with a disability (5). 1.16 million puts rabies as a less significant DALY number than those malaria and tuberculosis, but above Chagas, dengue, and onchocerciasis (5). When looking at the scope of rabies, this is a massive problem, especially in developing countries, particularly considering that rabies is still highly unreported. How much underreporting occurs is hard to access, the researchers suggest that rabies may in fact be up 100 times higher than official reports suggest (5).

Another metric by which the burden of disease can be calculated is the economic costs it generates. Since canine rabies is a major problem globally, researchers have focused specifically on the economic burden caused by rabies in dogs. Globally, the economic cost of canine rabies was 8.6 billion USD (6). That number is staggering considering that it is only one species, and not the total economic burden of rabies, which remains unknown. To calculate the costs of canine rabies, research included, productivity losses from death, direct expenditure on PEP and lost income while seeking PEP (6). There are differences in how economic losses occur in different parts of the world. In Asia and Africa, the largest cost was due to premature death as well as $512 million USD lost to livestock deaths while relatively less money was spent on PEP (6). In the Americas the largest amount single costs were for dog vaccinations (6). In the developed world those costs may be bearable, but for developing countries with live-stock dependent economies, the losses can be crippling. Globally, 70% of the economic burden fell within societal reasons (deaths, seeking PEP), 20% was in the medical sector, and around 8% was in the veterinary sector (dog vaccination) (6).

Rabies deaths in Africa comes second only to that of Asia, with 24,000 of the reported 55,000 rabies deaths annually, a statistic made particularly troubling by the fact that Africa has a smaller population than Asia. Africa has the highest rate of rabies deaths of any of the continents (7). Within African nations, the burden of rabies falls mostly within rural communities that are in poverty (7). When the burden of disease falls within communities that do not have the education needed to understand the severity of rabies many people do not seek appropriate medical attention, including PEP for a multitude of reasons (7). Some people are unaware of the risk, some people are too far away from clinics located in the cities and vaccine shortages have also been reported in several of the nations (7). It has become such a problem in African nations that 14 public health experts from francophone African countries in 2008 formed an organization called the Africa Rabies Expert Bureau (AfroREB) to bring more rabies education and support to struggling nations by bringing active and continuous support, and improving access to effective rabies prevention (7). The AfroREB set goals for every nation to reduce the burden of rabies. An early priority was to make rabies data reporting a priority (7). The group believed that to make reporting a priority, they needed to provide actionable information to national authorities so that limited public health budgets could be allocated efficiently (7). AfroREB also prioritized every nation having a rabies control program. The group suggests close collaboration between human and veterinary health services (7). The group is looking for epidemiological surveillance of human cases, information and education programs, vaccination of owned dogs, and controlling stray dogs as well as increased awareness by health authorities within their nations (7). Since many of the nations within the group do not have the infrastructure needed to support a full rabies clinic domestically, the group is looking for other laboratories regionally for testing and administering PEP when needed to constituents (7). This would require coordinated collaboration and networking between countries.

By sheer numbers, the continent with the most cases of rabies is in Asia. Within Asia, India has a disproportionate burden of rabies. India is also a major problem. Between 1990-2002 India reported 30,000 rabies deaths over those twelve years which accounted for 60% of the global mortality (8). It has become such a problem that the WHO established a nation-wide epidemiological study on rabies specifically within the country (8). India has seen productivity losses from death shoot up to $1.65 million USD, livestock losses of around tens of thousands of dollars, as well as $62, 348 USD spent on dog population management (6). However, India spends relatively little on surveillance measures (6). When examining the human rabies within the population of India things become a little clearer. Professionals saw that 76% of rabies victims in India were from rural areas (8). They also saw that adult men were the overwhelming majority of victims at 71% (8). Finally, the majority of victims were poor and had a low socioeconomic status (87.6%) (8). The overwhelming majority of rabies cases in India came from dogs (96.2%) and 75.2% of those were strays (8). In these years, routine rabies vaccination was not a thing in India. When looking deeper into the stats, the researchers saw that 79.1% of the rabies bite cases did not receive any kind of rabies vaccine beforehand (8). Those that did receive vaccines, only 15% and 21% completed the entire course (8). Analysis of the management of rabies in India identified the major risk factors to be the sheer number of stray dogs and lack of work to control the population, under vaccination of humans against and the fact that within India that rabies virus is not a notifiable disease, so there is absolutely no surveillance system to keep track of any cases, human or animal (9).

Virologists and public health practitioners within India recommended many approaches to reduce and eradicate rabies and deaths from rabies within India. First and foremost, there needs to be collaboration set between veterinarians, public health professionals and health care providers (9). With the collaboration set, different stakeholders will have a say in finding a solution to this increasing problem. The professionals also suggest implementing strict guidelines for licensing and vaccinating pet dogs (9). Local authorities must work to control the population of stray dogs through breeding programs, mass vaccinations and euthanizing suspected infected animals (9). Education is extremely important; educational programs would create awareness and ease the populations questions about proper wound care and postexposure prophylaxis (9). The intramuscular vaccine is being used throughout India, if they switched to the intradermal rabies vaccine prices would decrease and would allow the vaccine to be more easily accessible (9). Lastly, facilities around India are sorely lacking. If facilities are improved, surveillance and diagnosis of rabies virus will be mandatory throughout the country (9).

Developed countries have been much more successful in their rabies control efforts and their efforts can provide a roadmap to reducing the global burden of rabies. The Americas serve as good examples of the successes of rabies vaccinations and other public health interventions including educational campaigns and PEP. From 1993-2002 it has been estimated that rabies cases in the Americas have fallen 80% with majority of the cases being transmitted through dogs (10). In 1983, the Pan American Health Organization (PAHO) created a plan of action for the cities of Latin America, however, this plan did not encompass small villages (10). In 1991, this plan of action was expanded to include those recently neglected areas and small villages (10). Many of the countries in this region eliminated the circulation of dog rabies virus in domestic dogs back in the 1960s through their focus on dog vaccination programs (10). Within American countries we see that the city hubs and suburban areas have very few instances of human rabies, however, when looking at more rural areas, we see the same problems arising that we do in developing nations, a problem combating rabies (10). During the period from 1993-2002, the Americas region saw a decrease of 82% in the number of human rabies cases, from 216 total cases in the region to 39 total cases (10). We still do see dogs as the main culprit for transmission (10). In 2002, of the 39 cases of human rabies reported, these reports only came from five countries (10). Researchers also saw that canine rabies had the same downward curve, falling 81% during the period, 6716 cases to 1311 cases reported in only 17 countries in the region (10). Cats were shown to also play a role in transmission of rabies, although not as much as dogs. Cases reported with cats involved dipped 20% from 532 cases to 449 cases in 2002 (10). Although cases involving cats were much fewer than ones involving dogs, this could be a good place to look when thinking about future targets. Most wildlife reports came from the United States that saw a total of 57,184 rabies diagnoses with the majority being raccoons (10). Lastly, livestock cattle were shown to be the species with the highest number of rabies cases. 31,187 cases total were analyzed (10).

Rabies effort in this region has been largely successful. When looking at what this region of the world does, it is easy to see why developing nations want and need to implement what is successful here. Success in this region results from each country’s actions (10). With the help of the PAHO, these countries were able to establish programs that would help them combat rabies permanently. Mass vaccination of dogs, treatment of persons exposed to the virus, and surveillance all play a major role in this success (10). In this region, each year around 1 million people seek care following an animal bite, and around 30% of those people receive PEP against rabies. Vaccination is so successful in this region because there were 2.73 million available doses of the Fuenzalida vaccine and 1.88 million available doses of the cell culture vaccine (10). WHO has reported that 75% of the canine population within a community should be vaccinated within a period of one month (11). This is important, as researchers see firsthand that if a community does not vaccinate dogs in that one-month period, the transmission of the virus is much more common (10). Vaccinations of domestic pets are increasing because vaccines are being made within the region and are safe and easy to receive (10). Overall, professionals should continue to help the community get to 75% vaccinations to canines within the area (10). They should also continue to reach out to communities in more rural areas and provide them with communication and education on rabies virus (10). The researchers suggest that implementing a system of collaboration would be key in maintaining fight against rabies. Controlling wildlife, post-exposure treatment as well as pre-exposure vaccinations to populations with increased risk to rabies (10).

Turning the attention to the United Kingdom, researchers say that terrestrial rabies is not present in the UK as well as Western Europe, however, the possibility always remains that rabies virus could be reintroduced to England (12). Since rabies virus can be contracted by mammals, the most competent hosts would be the red fox and the badger (12). Many professionals in the UK understand that rabies is a major problem and could introduce itself in the populations. However, rabies in the United Kingdom used to run rampant in packs of stray dogs from 1886-1903 (13). This resulted in more than 160 human deaths, it became such a problem that the Board of Agriculture enforced muzzling of dogs in districts where rabies virus was most prevalent (13). The United Kingdom started earlier than most when it comes to trying to combat the rabies virus. Years later, researchers at the Central Science Laboratory knew that the red fox could be an important host for rabies and surveyed 139 councils and 44 mammal conservation groups around England and Wales (14). Researchers wished to determine if the population of urban red fox was increasing since the densities of red fox populations and their proximity to populated areas was critical data in developing a rabies plan in the United Kingdom (14). Overall, between 1987-1997 researchers believed there was an increase in red fox numbers in urban areas (14). Given the apparent availability of food, the authors concluded that the red fox population will continue to grow and represents a growing potential host for rabies should it be re-introduced to the country (14).

As stated earlier, the United Kingdom was one of the first countries to implement programs and laws to combat against diseases and viruses. Early on England wanted to prevent the spread of disease and implemented the Dogs Act of 1901 which mandated that all imported dogs be isolated at approved kennels for 6 months (13). This made it possible for professionals to inspect the dogs and determine if the dog had rabies, which made it easier to control and eliminate with minimal to no transmission to humans (13). In 1974, English legislation passed the “Rabies Importation of Dogs, Cats and other Mammals Order (13). This mandated that 10 orders of susceptible mammals were to be imported at specific seaports or airports and must be moved by approved carriers and put in quarantine for 6 months (13). The United Kingdom also has a program for domestic animals leaving the UK and then re-entering the country. Pet Travel Scheme (PETS) is a scheme brought to England in 2000 and served to allow companion animals easier movement within certain countries (13). The companion animal needs to meet several requirements to meet PETS exempt such as microchipping, rabies vaccination, and blood testing (13). Officials have deemed this practice extremely successful, however, this practice is only allowed within PETS approved countries (13). In 1996 researchers in East Sussex discovered a strain of bat lyssavirus which concerned officials that rabies might be present within the United Kingdom (13). It was determined that rabies was endemic within the UK and European bat populations (13). Since the discovery in 1996, England has both active and passive surveillance measures in place to continuously monitor the bat populations (13). In the United Kingdom it is strongly recommended that travelers receive pre-immunization if traveling to areas where rabies virus is a problem. The cost of the vaccination as well as lack of information of rabies potential threat has many travelers not receiving the vaccine (13).

When trying to estimate the potential impact of a re-introduction of rabies in a country it is imperative that professionals use past data and current numbers to create different scenarios. Researchers also wanted to see what would happen within England if rabies was introduced in two high density populations (12). They looked at red fox and badger populations and simulated different scenarios (12). The first scenario put forth was of a single species host. Researchers introduced rabies into the red fox population, and they found that with two major culling campaigns or five vaccination campaigns, rabies would be eradicated from the population (12). They ran another simulation in which both red fox populations and badger populations were introduced to rabies and found that vaccination on its own was not enough to control rabies (12). They found that to be successful, the badger population had to be culled as well as some sort of vaccination program developed to properly combat rabies virus (12).

# Rabies in the United States

In the United States, 92% of the animal rabies cases are from wild animals (15). Raccoons being reported most frequently followed by skunks, bats and foxes (15). Humans and domestic animals encountering wildlife has resulted in 16,000-39,000 people per year receiving PEP in the U.S. which is estimated to cost around $300 million per year (15). A total of three human rabies cases were reported in the United States in 2018 (19). Lastly, a total of 4,951 animal rabies cases were reported in the United States and 92.7% of those cases were from wild animals (19). Bats represented the highest percentage of cases at 33.0% followed by raccoons at 30.3% (19).

New York State since 1990 has seen a new raccoon variant of rabies show up from Pennsylvania (15). New York state has established an appropriation that will reimburse members within the community for PEP costs if it is not covered by third-party providers (15). The law also states that providers with knowledge of a person that has been exposed to an animal even suspected of carrying rabies virus must be reported to the local health unit (15). From there the health unit is required to have rabies control protocols that give 24-hour availability of staff to manage the possible exposure (15). From 1993-1998 New York state had a total of 56,947 animals submitted for rabies testing (15). In this same time period, NYS reported that the number of rabid animals declined from 2,688 in 1993 to 1,097 in 1998 (15). Researchers also saw a decrease in exposure incidents from 1,815 in 1993 to 1,006 in 2001 (16). Surprisingly, in New York cats were shown to account for the most exposure incidents (16). Cats only accounted for 303 cases in the state versus raccoons at 8,318 cases, further, cats accounted for 4,266 exposure incidents and 5,777 PEPs used (16). When looking at the gender and age of the exposed people during that time, researchers saw little difference in the gender of people receiving PEP (3,625 males, 3,569 female) (16). They saw that the 10-14 age group had the highest PEP usage rates (16). For males PEP rates were lowest in older age groups, but for females, the 40-44 age group had the highest PEP usage rates (16). Officials saw that in each age group, women received PEP more often from cat exposure and men received PEP more often after dog exposures (16). Notably, even though the number of rabies cases were decreasing, the number of humans receiving PEP was increasing (15). Many believe that this occurred because the fear of rabies in the state was extremely high and that there was a disconnect between professionals and community members when it came to definitions of exposure (15). New York state spent a total of $13.9 million dollars preventing rabies virus from 1993-1998 (15). It was shown that 547 people in the state received PEP when exposed to a non-rabid animal, this shows that more education is needed throughout the state in regard to rabies virus (15). This shows that providers need to be more aware of laboratory test results, and that the public needs more education when it comes to rabid animals and minimizing contact to exposed animals (15). The authors suggest that traditional methods of controlling rabies can work, but to really combat the wildlife population rabies oral rabies vaccines and baiting programs need to be implemented (15).

The Wadsworth Center Rabies Laboratory serves as the main rabies laboratory for New York State. In 2016 the laboratory tested 7066 samples and 6001 of the samples came from instate (17). 1065 samples sent to the lab were out of state submissions which were submitted for confirmatory testing (17). In New York, bats made up most of the cases tested at 2729, the next closest animal was cats at 1000 specimens followed up by raccoons at 784 specimens (17). Of the 6001 in-state samples that were tested, 329 animals were positive for rabies (17). Raccoons had the highest number of positive cases with 156 followed by bats with 81 cases and skunks with 79 cases (17). In New York state, cats are the main domestic animal that gets submitted for rabies testing (17). 1000 cats were submitted and 457 of those cats were owned, and only 6 of the 25 rabid cats were owned (17). Of the 2729 bats submitted for testing, the overwhelming majority were big brown bats (95%) and 77 big brown bats were positive for rabies virus (17). All of the specimens that tested positive for rabies virus in New York were typed using RT-PCR (17). The professionals found that the majority of the terrestrial animals were infected with raccoon rabies virus (17). The bats infected were shown with a homologous rabies virus variant (17).

In 2017, Pennsylvania had 347 animals tested positive for rabies virus (18). Since 1984, there have been zero human rabies cases reported within the state (18). This can be attributed to effective rabies PEP vaccines with education and guidance on the risk of rabies (18). Within Pennsylvania, animal rabies is tested by four agencies: The Department of Agriculture, Department of Health Bureau of Laboratories, Philadelphia Department of Public Health, and the Allegheny County Health Department Laboratory (18). In a normal year, these laboratories see around a total of 5,000-6,000 animals both domestic and wild (18). Before full-scale testing of an animal, the Pennsylvania Department of Health must be consulted to determine if it is justifiable to perform furthers tests on the animal (18). Once a justification is given, the labs perform rapid testing for rabies virus and must submit the results to the Pennsylvania Department of Health (18). In the rare case that an animal does test positive for rabies, community nurses then contact the submitter of the animal to determine if any human exposure has occurred (18). Once it is determined that a human exposure did occur, PEP is often strongly suggested (18). The data from these labs are then entered, reviewed and a summary drawn up and given to the Pennsylvania Department of Agriculture (18).

The latest Pennsylvania Department of Health animal rabies report (2018) reported on 2017 investigations. In 2017, 347 animals tested positive for rabies in Pennsylvania, which was below the state’s average (18). Most animals in Pennsylvania are tested by the Department of Agriculture and the Department of Health Bureau of Laboratories (18).

The Allegheny County Health Department laboratory tested 17 positive animals, the Department of Agriculture laboratory tested 203 positive animals, the Department of Health Bureau of Laboratories tested 112 positive animals, and the Philadelphia Department of Public Health Laboratory tested 13 positive animals (18). Just over half (50.7%) of the positive cases in 2017 were due to raccoons, cats were the next closest at 17.9% , followed by skunks and foxes (18). In Pennsylvania, rabid animals can be found year-round, but it is normal to have increased rabid animal identifications in the Spring and Summer months since people spend more time outside and thus more encounters occur (18). Pennsylvania Department of Health had the highest number of cases in July of 2017 with just over 45 cases, followed by August with just under 40 cases total but had the lowest number of cases in December with 14 and January with 16 cases (18). The Department of Health also saw that counties in the southeast and southcentral areas of the state had the most reports of rabid animals (18). Lancaster County had the highest number of rabid animal cases with 19, followed by Centre county with 18 cases, Chester county with 17 cases and Allegheny, Philadelphia and York Counties all tied with 15 cases (18). 2017 was a little different in the fact that normally the southcentral health district normally reports the most rabid animals, however, in 2017, the southeast district had the highest number of rabid animal reports at 101 (18).

In California, bat rabies virus exists throughout the state as well as skunk rabies virus. Domestic animals can be infected through contact with these wild animals. However, in California it is extremely rare that domestic animals will contract rabies. In each year since 1987, the Director of the California Department of Public Health has declared that all 58 counties in California were a public health hazard due to rabies (19). California has a state-wide surveillance program that has collaboration between local health departments, animal control agencies, shelters, and medical and veterinary practitioners (19). This collaboration provides laboratory services, enforcement of rabies vaccinations, investigation of animal reports, recommendations for PEP, development of preventive education on rabies, and collecting, and reporting data on rabies in humans (19). Since rabies is a reportable disease in California, health care providers that have knowledge of a confirmed or suspected case must contact the local health officer (19). From there, multiple tests are run to confirm the rabies case (19). In California in 2018 5,084 animals were tested which is 15% less than the annual average (19). Of the 58 counties in California, 54 submitted at least one animal for rabies testing (19). Rabies was diagnosed in 226 animals all of them being wild animals (19). Bats had a total of 194 cases which made up 85.8% of the cases, followed by skunks that had 28 cases and made up 12.4% of the cases (19). A total of 1,738 bats were tested for rabies virus and the 194 was higher than the annual average within the state (19). Los Angeles County had the greatest number of rabid bats and has reported the greatest number of rabid bats eight out of the last ten years (19). The six counties in southern California accounted for 35% of the rabid bat cases in 2018 (19). Like most other rabid animal encounters, bat cases were more frequently reported in the Summer and early Autumn months totaling 131 (68%) of the annual reports (19). The Brazilian free-tailed bats were most commonly found to have rabies virus (19). Skunks were also seen to have rabies virus in their population. A total of 288 skunks were tested for rabies and 28 of them were confirmed with rabies virus (19). The 28 confirmed cases are higher than the annual average of 25 (18). 27 foxes were tested for rabies in California in 2018 (19). The fox population within the state had three positive identifications for rabies which is lower than the annual average that sits around 8 cases (19). Lastly, raccoons had a totally of 193 animals tested and only one single raccoon had rabies virus in Tuolumne county (19). 2018 saw 2,694 domestic animals (including livestock) tested for rabies and zero animals were confirmed rabid (19). Rabies in humans is extremely rare and in California no resident was confirmed to have rabies in 2018 (19).

Here in Allegheny County, we are on the very western edge of the raccoon rabies virus range. It is known that we are the last stop before the virus travels out west more. Health care providers within the county are required to report animal bites to ACHD so that proper follow up with the animal and victim can be conducted (20). The healthcare providers report animal bites to the health department by filling out an electronic form that can be found online, or by faxing in a bite report to ACHD (20). The Immunization Program then contacts the bite victim and owner of the animal to make recommendations about completing the form (20). The health department then places the domestic animal on an in-home quarantine period that lasts 10 days and can help the animal owner monitor the animal for any signs of rabies virus (20). If the animal is deceased, testing is requested and done via a direct fluorescent antibody test at the laboratory (20). PEP is strongly recommended to the victim especially if the animal cannot be placed into quarantine (20). If the victim is given the PEP, ACHD monitors the four-dose vaccine to ensure that the victim completes the treatment (20). In Allegheny County in 2018 there were 1,973 animal bite cases reported to the health department (20). 93.3% of the bite victims were county residents as well as 99.4% of bite locations and 98.9% of animal owner address were in Allegheny County (20). Most bite cases involved dogs at 74.9% followed by cats at 22.2% of the cases (20). Allegheny County had low reporting in the bat and raccoon populations with only 14 bat cases and 8 raccoon cases in 2018 (20). As we see with many other counties and states, the number of reported bite cases in Allegheny County peaked in the late spring and early summer months (20). This is due to more people being out and encountering possible infected wildlife as well as their animals encountering said wildlife. The health department saw that victims ranged from less than 1 year old to 96 years old and the median age was 35 years old (20). They saw that most victims (58%) were female and the minority was male (42%) (20). They saw that this difference came from between the ages of 15-69 where the female population had a much higher reported bite incidence rate versus males the same ages (20). There were 612 animals tested that were not associated with a bite case and 25 of those animals tested positive for rabies (20). Antibiotics were prescribed for 61.7% of the victims involved in a reported bite case, 28.6% received a tetanus diphtheria and Pertussis vaccine and 5.2% received at least one dose of the rabies virus PEP (19). 33.4% of victims did not receive any treatment (20).

The ACHD baiting program has been a staple for 18 years and has been a major factor in the reduction of human and pet exposures to rabies (20). The baits are delivered in partnership by volunteers that travel both in a vehicle and on foot to deliver by hand the fish oil baits (20) The volunteers are tasked with placing baits in high risk areas including heavily wooded areas as well as around dumpsters (20). The baits are also dispersed via helicopter. The helicopters fly in north-south transects that go over residential areas as the transects are close together to ensure sufficient baiting (20). The goal of this program is to vaccinate the wildlife within Allegheny County (20). For example, a raccoon becomes exposed to the vaccine through ingesting the fish oil bait and within 2-3 weeks the raccoon will develop antibodies that will protect the animal if it encounters an infected animal (20).

## Discussion

We see throughout the paper that rabies virus is a dangerous public health problem. Although here in the United States and other developed countries it is an afterthought, in developing nations it is a major problem. When looking at Africa, professionals have started taking the correct steps in identifying how other nations successfully fight against rabies. With the African nations it was imperative that they make informed decisions with a limited budget in mind. Having a focus on data reporting and surveillance is key and being able to have a collaborative effort throughout the countries is imperatively important. India’s problems are much more severe. India does not spend nearly enough money on combating rabies. It is a combination of many things within India that contribute to the public health problem. Large numbers of stray dogs coupled with the population in India not understanding the risks of rabies virus and not receving the full PEP. More money needs to be put into the country’s surveillance program as well as getting the population informed about the risks associated with the virus. We see in these two examples of how different the responses can be. Africa is understanding the risk associated with rabies while India is still behind in recognizing the threat.

When discussing the developed nations there is an understanding that rabies virus is not a persistant threat due to the measures instilled within the countries. We see that the United Kingdom that they established quarantine protocols for animals entering the country and updated the protocols as the knowledge about rabies grew. The UK was also ahead of the curve when they used software to predict how certain animal populations would carry the virus. Through those predictions, professionals were able to predict how to combat situations successfully. The United States relies more heavily on domestic animal vaccinations and PEP. The United States mandates that rabies virus is a reportable virus. This makes it easier to be able to track the specific cases whether it be animal or human.

Allegheny County has the responsibility of keeping the city of Pittsburgh safe. They have done a wonderful job when looking into how they work with rabies cases. The bite report paperwork can be accessed through the medical professional that the vicitm visits, or online at the health department website. ACHD relies on these reports so that it can now track the animal and speak with the owner and establish a protocol. The protocol that the health department has established is fair for both the owner and society. ACHD does not take the animal into custody and allows the owner to watch over the animal for any signs of sickness. The ACHD baiting program helps the USDA with their rabies eradication campaign with voulnteers within the county hand baiting. This will hopefully eliminate rabies in raccoons which in turn push the western edge of raccoon rabies back east all the way to the coast. Resulting in the complete elimination of raccoon variant rabies in the United States. These two steps have been monumental in stoping rabies virus from continuing west into Ohio. A good next step for the state could be a possible widening of the hand baiting program into surrounding counties as well as continuing knowledge of the rabies virus. PEP use should be continued indefinitely.

* + - * 1. Rabies Virus Overview

A picture containing dryer

Description automatically generated

Figure 1: Layout of Rabies virus cell

Forrester , F. (1972). Single rabies virion. Retrieved from https://phil.cdc.gov/Details.aspx?pid=16407

A picture containing device

Description automatically generated

Figure 2: Cross-Section of inside Rabies virus

*Cross Sectional view of bullet shaped virion*. (n.d.). Retrieved from https://phil.cdc.gov/Details.aspx?pid=971

A picture containing sitting, computer, table, monitor

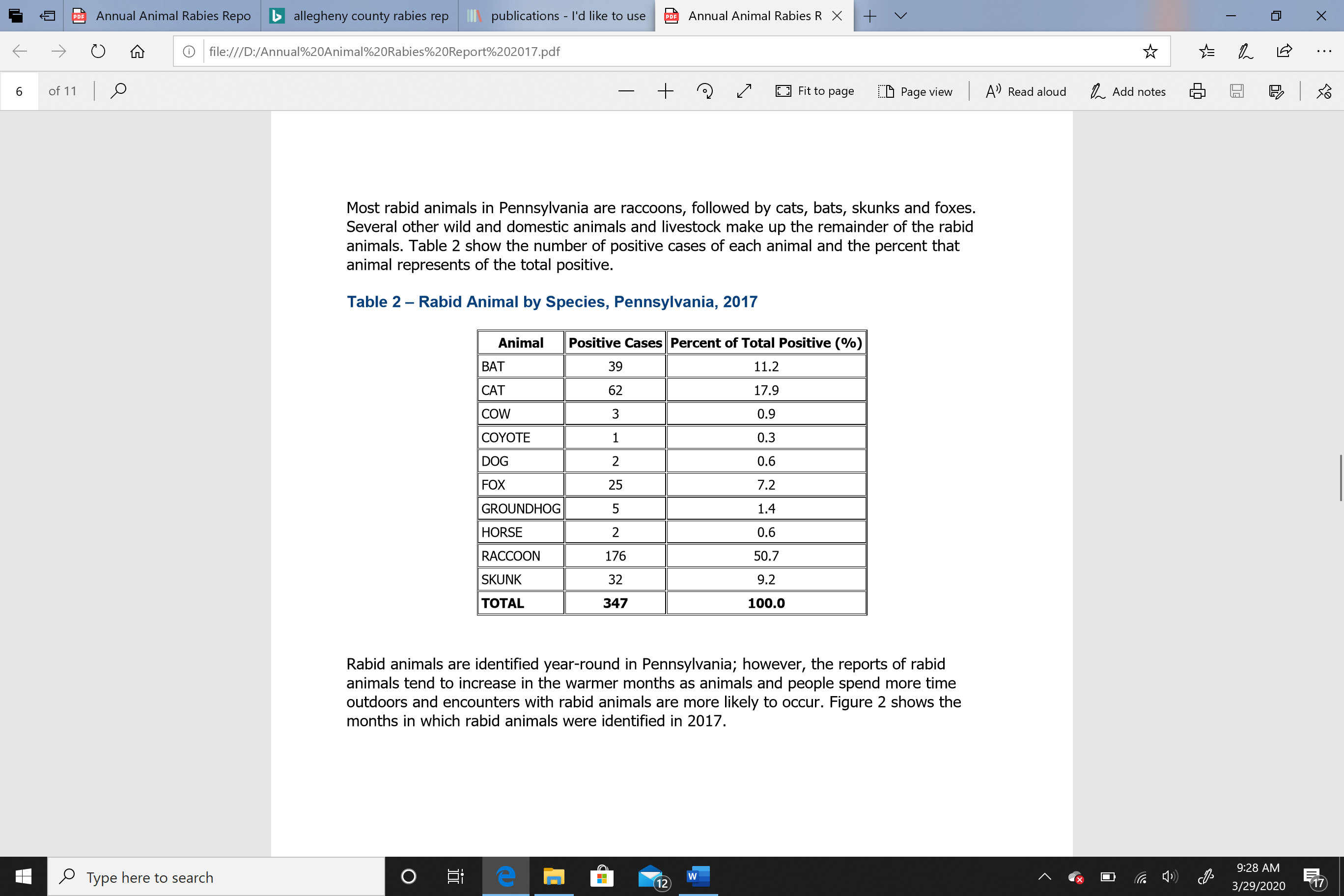
Description automatically generated

Figure 3: DFA stain showing rabies antigens

*Dfa stain showing rabies viral antigen*. (n.d.). Retrieved from https://phil.cdc.gov/Details.aspx?pid=15204

* + - * 1. Rabies in the United States

Table 1: Rabies cases per species in Pennsylvania, 2017



Pennsylvania Department of Health. (2018, April). Rabies cases per species in Pennsylvania, 2017.

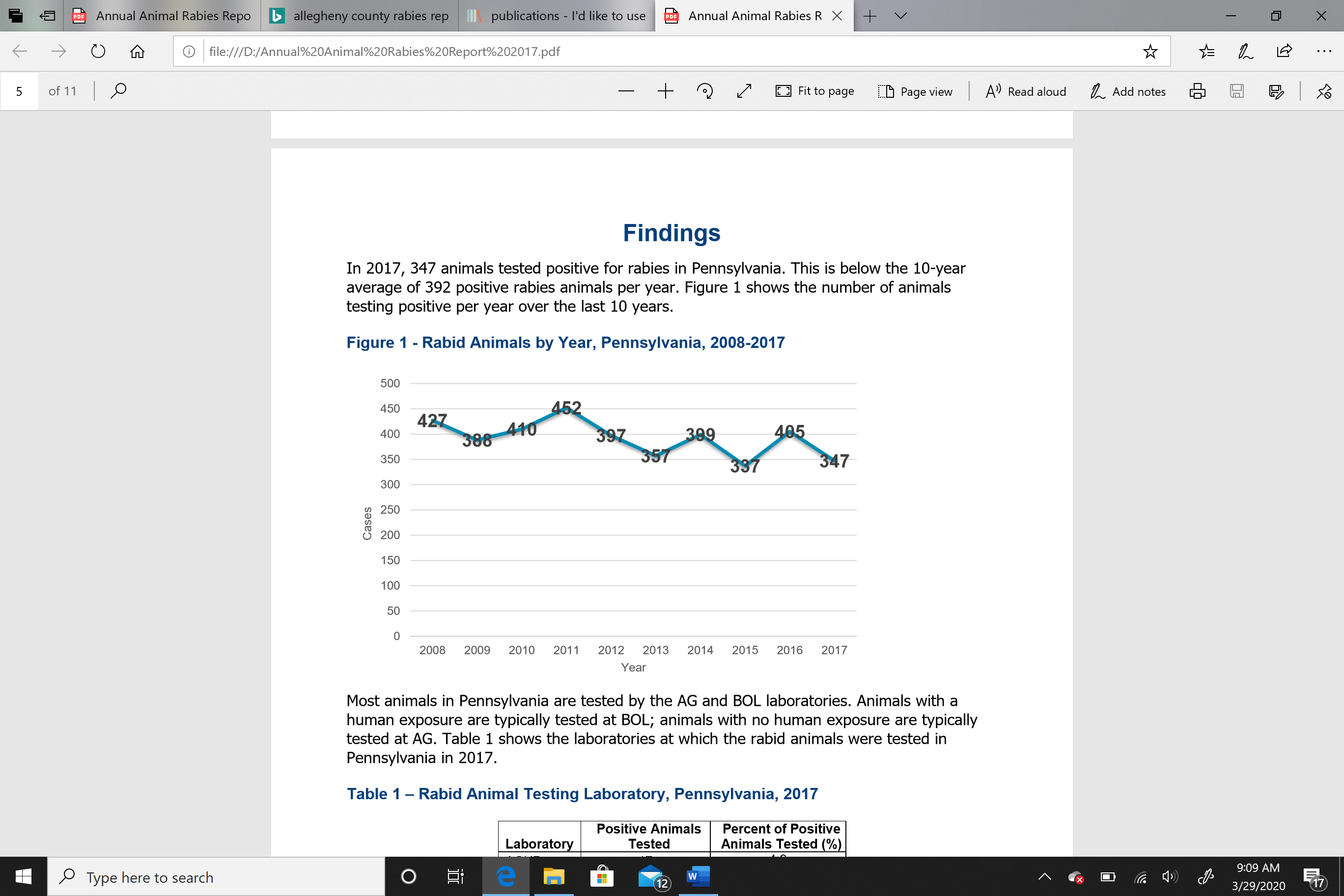


Figure 4: Rabid animals per year, Pennsylvania, 2008-2017

Pennsylvania Department of Health. (2018, April). Rabid animals per year, Pennsylvania 2008-2017.

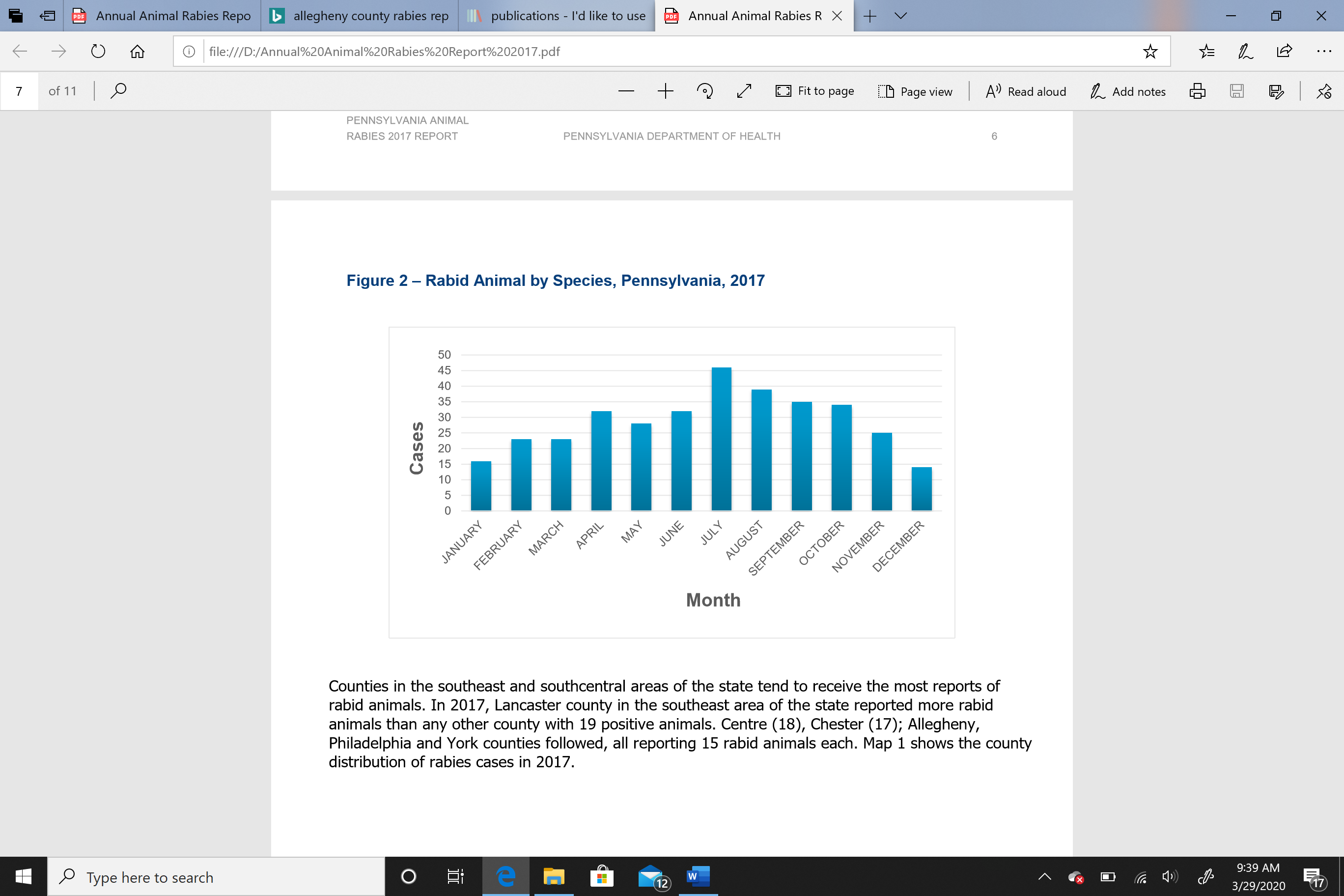
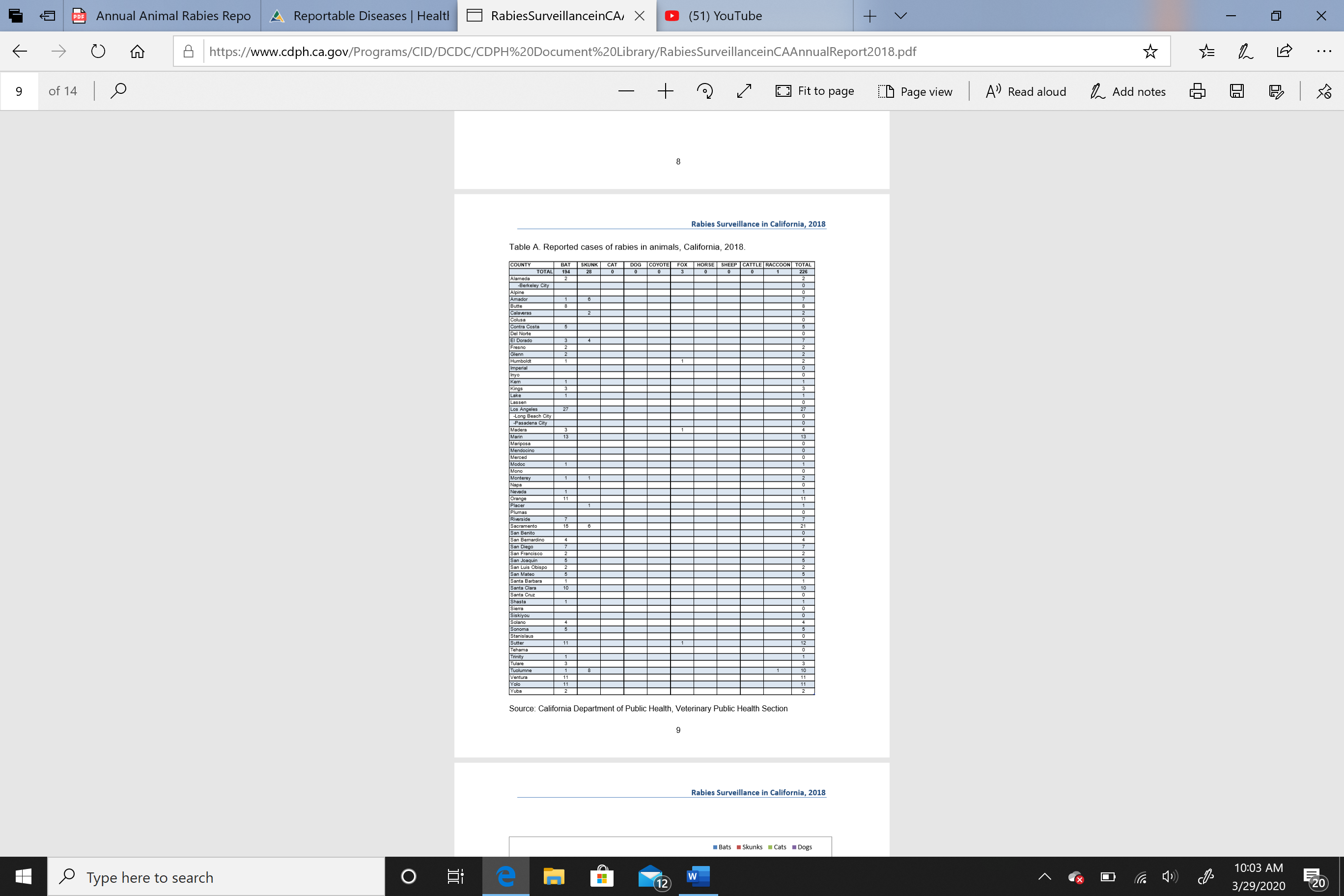


Figure 5: Rabid animal cases by month, Pennsylvania, 2017

Pennsylvania Department of Health. (2018, April). Rabid animal cases by month, Pennsylvania 2017.

Table 2: Cases of rabies in animals per county, California, 2018



California Department of Public Health, Veterinary Public Health Section https://www.cdph.ca.gov/Programs/CID/DCDC/Pages/Rabies.aspx

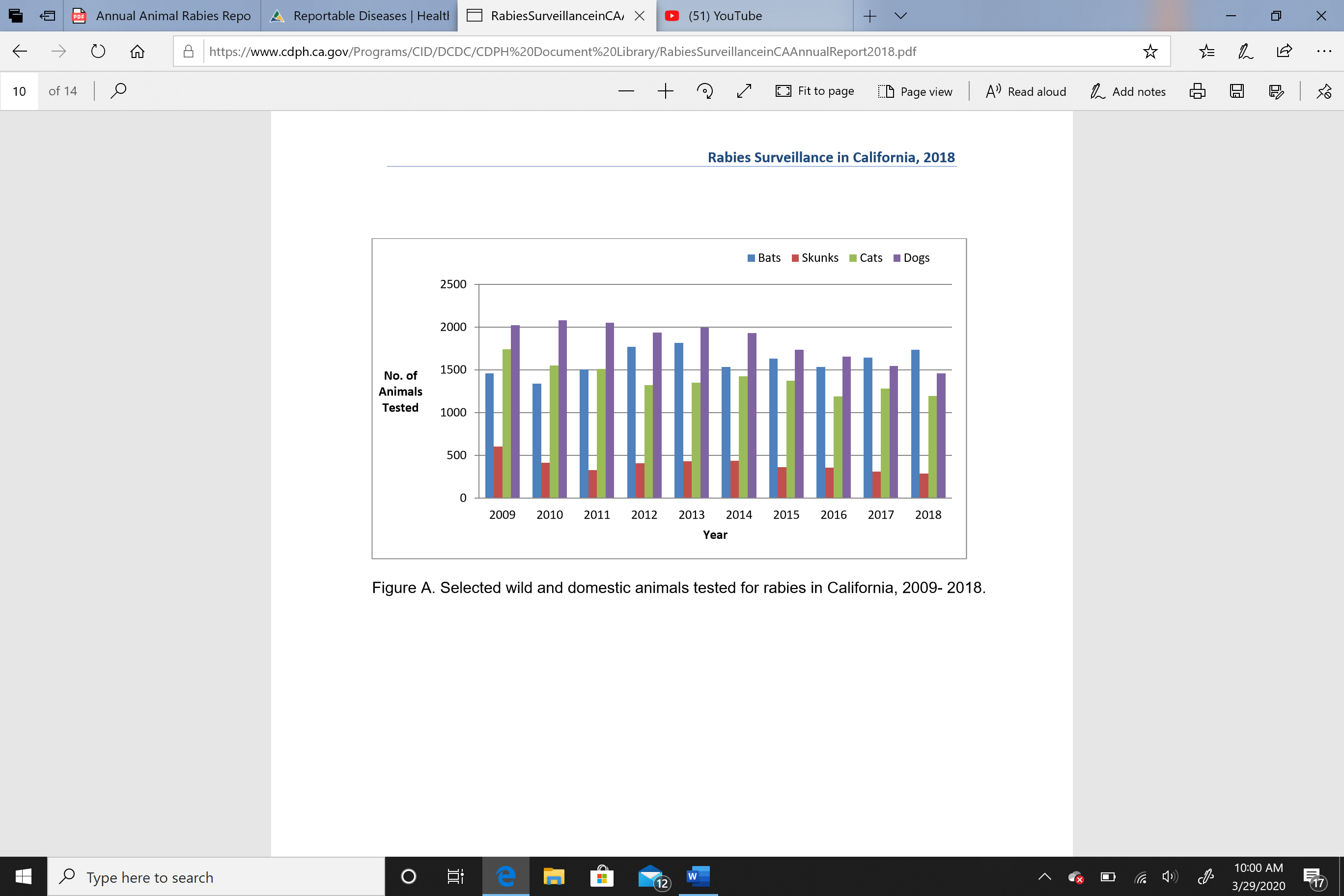


Figure 6: Wild and domestic animal rabies cases in California, 2009-2018

California Department of Health. (2020, January). Wild and domestic animal rabies cases in California, 2009-2018.

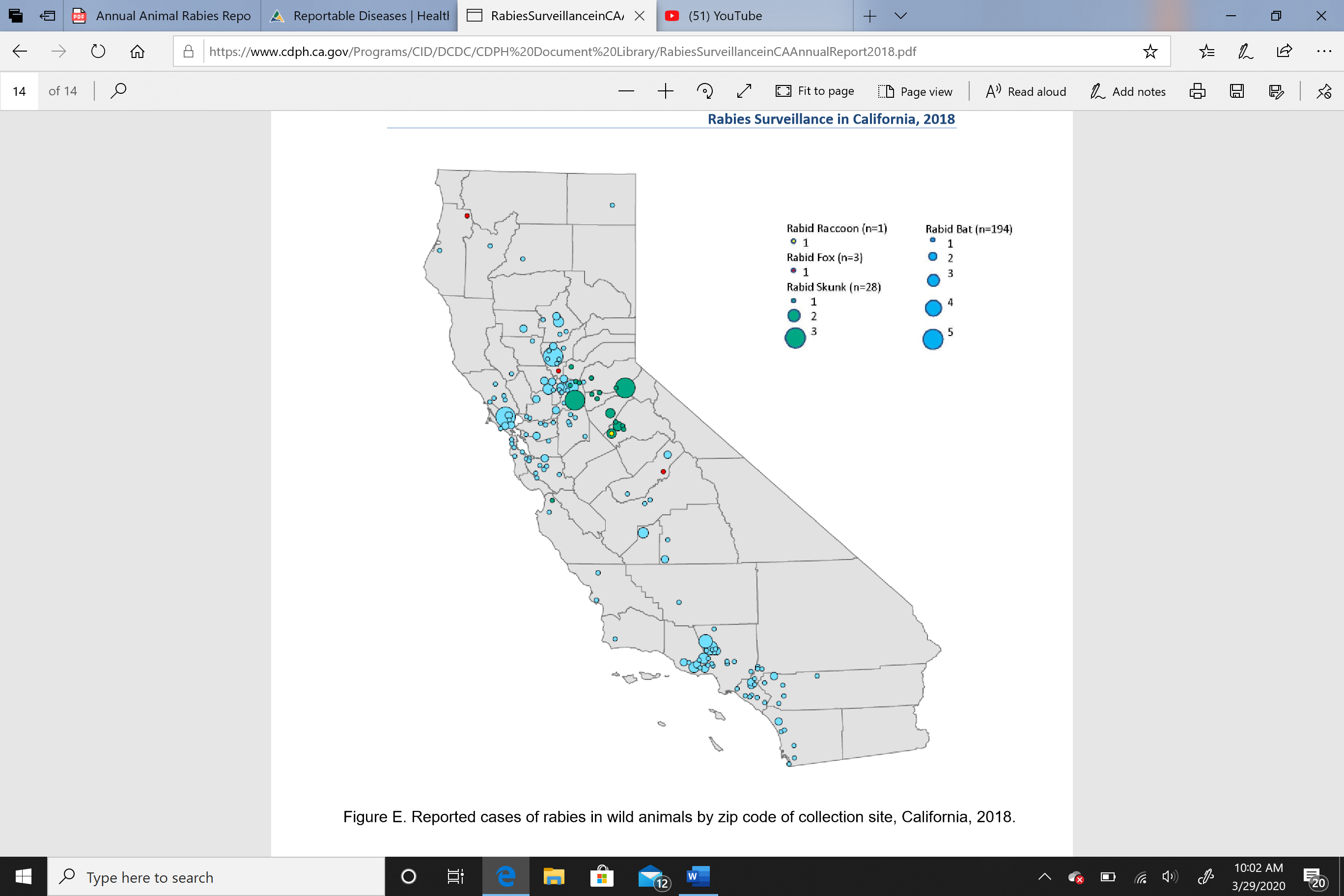
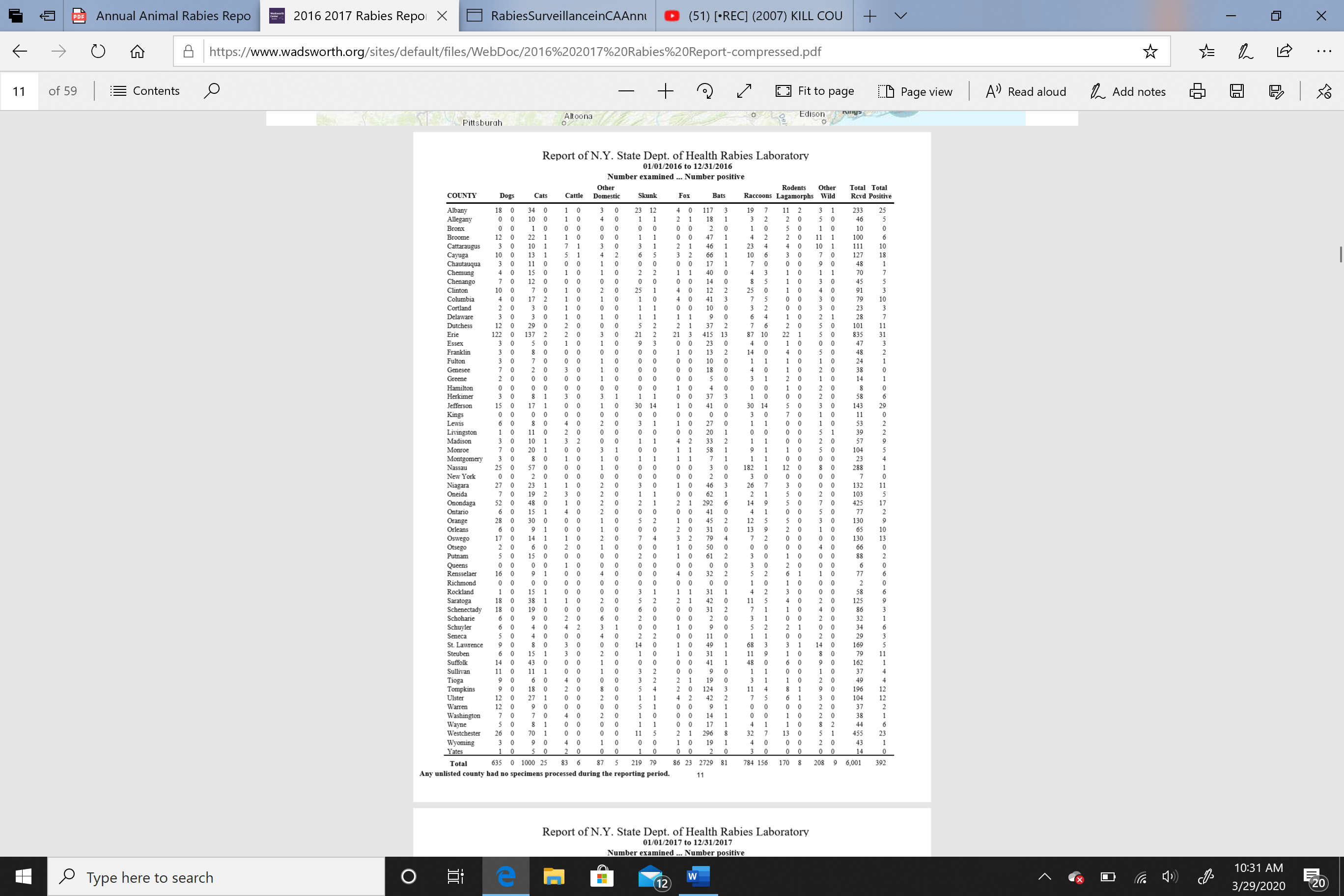


Figure 7: Cases of rabies in wild animals by zip code, California, 2018

California Department of Public Health. (2020). Reported cases of rabies in wild animals by zip code collection site, 2018.

Table 3: Rabies cases by county and species. New York, 2016



New York State Department of Health. (2017). Rabies cases by county and species, New York 2016.

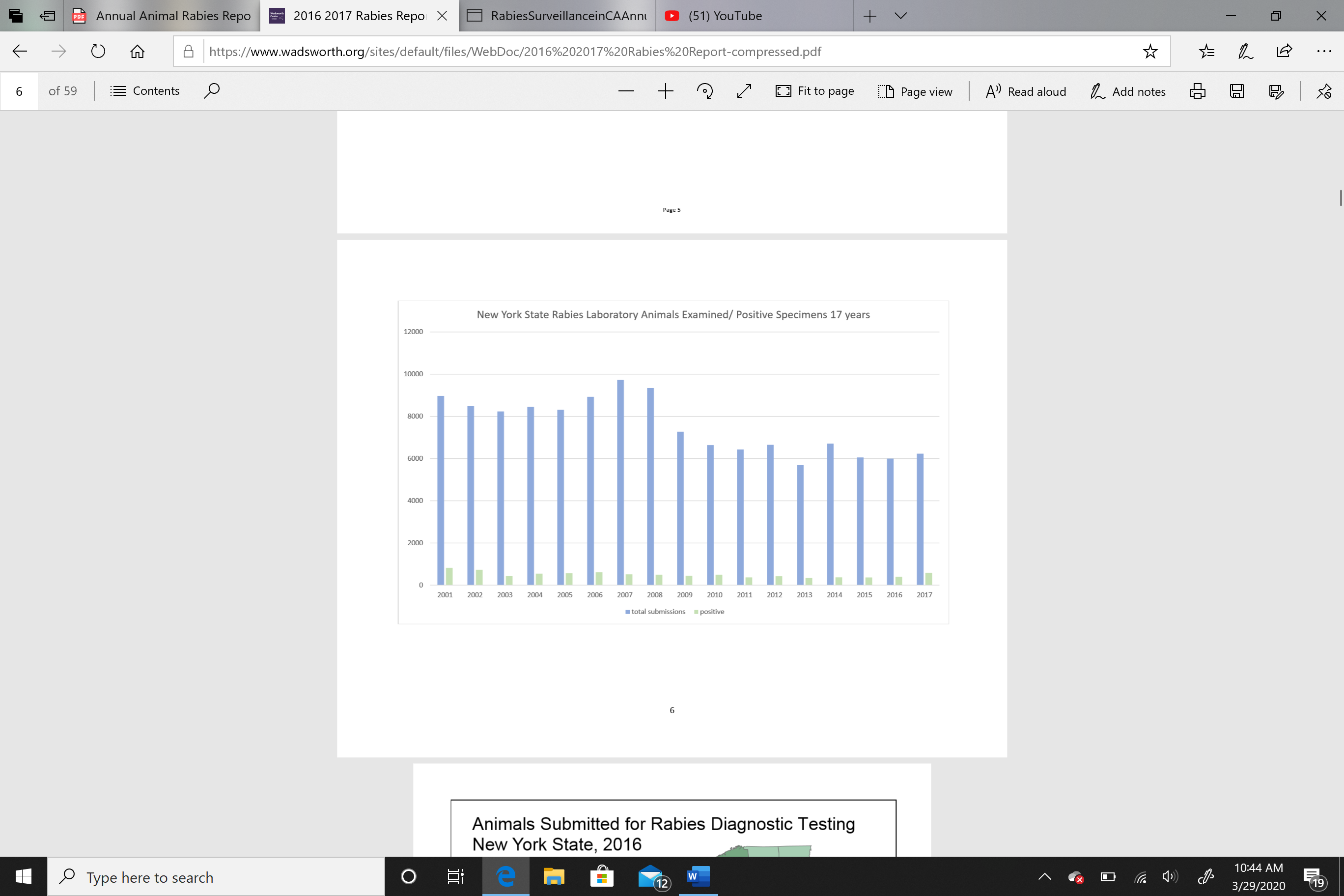


Figure 8: Animals examined and positive cases, New York, 2001-2017

New York State Department of Health. (2017). Animals examined and positive cases, New York 2001-2017.

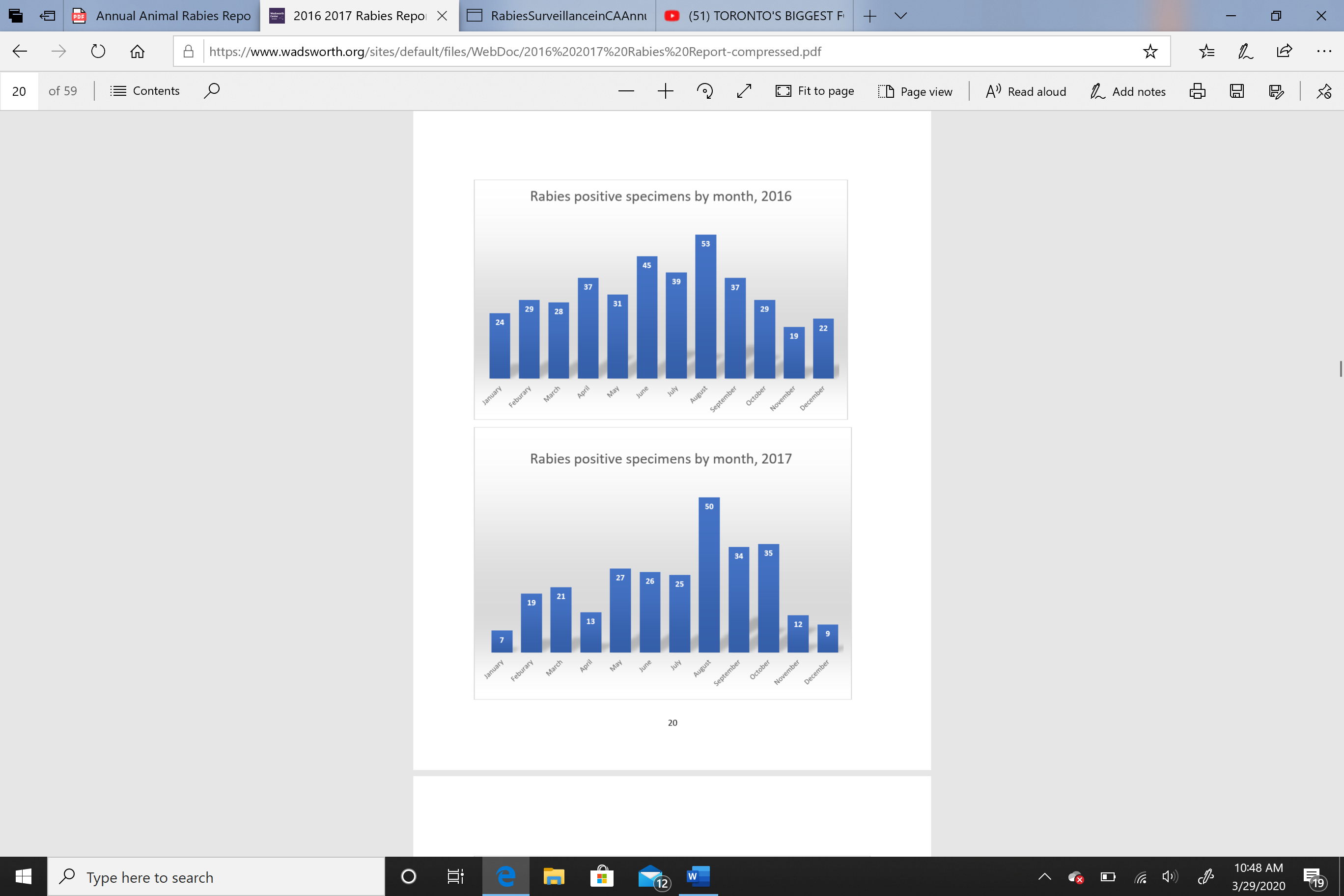
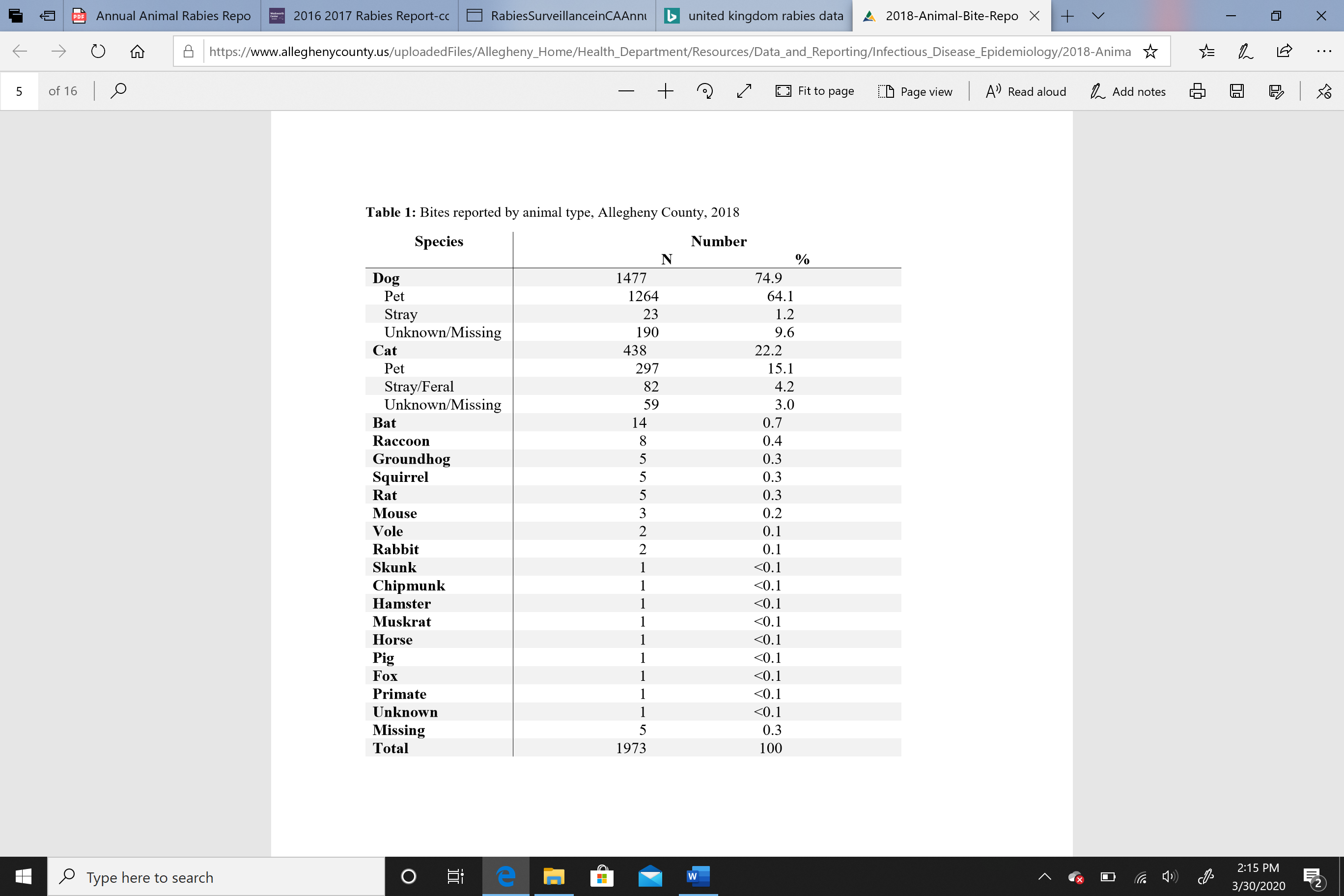


Figure 9: Positive rabies cases by month, New York, 2016

New York State Department of Health. (2017). Positive rabies cases by month, New York 2016.

* + - * 1. Rabies in Allegheny County

Table 4: Reported animal bites, Allegheny County, 2018



Allegheny County Health Department. (2019, September). Reported animal bites, Allegheny County 2018.

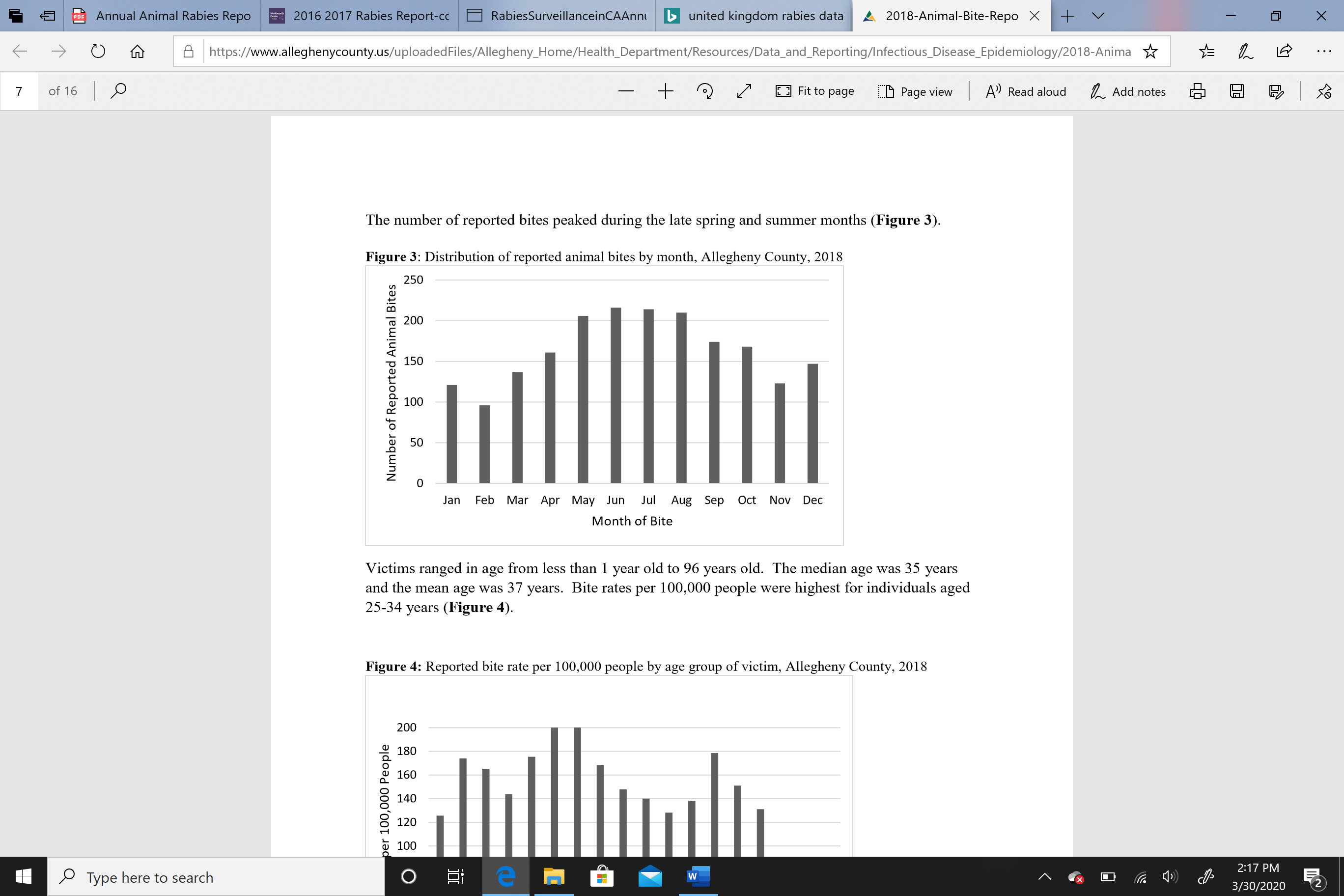


Figure 10: Reported animal bites by month, Allegheny County, 2018

Allegheny County Health Department. (2019, September). Reported animal bites by month, Allegheny County 2018.



Figure 11: Reported bite rates per 100,000 people by age group and sex, Allegheny County, 2018

Allegheny County Health Department. (2019, September). Reported bite rates per 100,000 people by age group and sex, Allegheny County 2018.

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