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Characterization of Illegal Wildlife Trade Networks

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Abstract
The legal and illegal trade in wild animals and their products is a multi-billion dollar industry that threatens the health and well-being of humans and animals alike. The management of the wildlife trade is a crisis-driven area, where decisions are made quickly, and, often, inefficiently. In particular, the regulation and control of the illegal wildlife trade is hampered by a dearth of formal quantitative analysis of the nature of the trade. This thesis represents a preliminary attempt to rectify that knowledge gap. It describes an investigation into the factors that support and promote the trade and is based upon information in two databases: CITES (the legal trade) and HealthMap (the illegal trade). The study 1) quantified the relationship between the illegal wildlife trade and several key factors thought to contribute to the illegal wildlife trade, namely road development, unemployment, and Corruption Perception Index (a score related to the perceived level of corruption); 2) measured the extent to which the product types, origins, destinations, and trade routes in the legal and the illegal wildlife trade are alike; and 3) identified locations to place resources to (a) restrict trade by causing the greatest network destabilization and (b) disseminate an educational message that would cause the greatest impact to the network. Several key factors and the legal trade were associated with the magnitude of various indices of the illegal trade at a country-level, but no generalizable findings can be asserted at this time. With regard to the best placement of regulatory resources, China was key with respect to network disruption and information dissemination targets. This thesis has begun the urgently needed analysis of the complex relationships of the illegal wildlife trade and identified specific ways to bring about change using network science. These findings offer hope for regulatory and enforcement agencies, NGOs, and governments that it will be possible to find more effective ways of combating the illegal wildlife trade and problems it brings with it.

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CHARACTERIZATION OF ILLEGAL WILDLIFE TRADE NETWORKS

Nikkita Gunvant Patel, MPH, VMD

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CHARACTERIZATION OF ILLEGAL WILDLIFE TRADE NETWORKS

DEDICATION

This thesis is dedicated to my husband, Neel, my parents, Gunvant and Sunayna, my daughter, Kiskoli, my son, Premal, my grandfather, Papa, my cat, Frosty, and one of my best friends, Raju, who all fostered my passion to make the world a better place. You made me the person that I am today. Neel, you have truly been the driving force behind making my dreams into reality. I love you for your strength and endless support in any dream I have. I couldn't have a better partner in life. Dad, I love how you are always so proud and supportive of me no matter what. This means the world to me, and I am so lucky to call you my dad! Mom, your love and respect for all of life's living things have driven me to work to protect all forms of life for future generations to come. Kiskoli and Premal, you have taught me so much about myself in the little time I have known you. While this dissertation has caused you a lot of tears and heartache, I hope you are proud of your mommy. Papa, your career of working in gaushallas set the stage for mom and me to be driven to support and advance animal causes. Frosty, you were the best brother that I could have asked for, and your unconditional love guided me through so many challenging times. Raju, you were always so positive and so very excited about my work. I love and miss you two dearly! Finally, I dedicate this to all the animals that have had tragic or untimely deaths as a result of the illegal wildlife trade. On behalf of my species, I am truly sorry.

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ABSTRACT

CHARACTERIZATION OF ILLEGAL WILDLIFE TRADE NETWORKS

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The legal and illegal trade in wild animals and their products is a multi-billion dollar industry that threatens the health and well-being of humans and animals alike. The management of the wildlife trade is a crisis-driven area, where decisions are made quickly, and, often, inefficiently. In particular, the regulation and control of the illegal wildlife trade is hampered by a dearth of formal quantitative analysis of the nature of the trade. This thesis represents a preliminary attempt to rectify that knowledge gap. It describes an investigation into the factors that support and promote the trade and is based upon information in two databases: CITES (the legal trade) and HealthMap (the illegal trade). The study 1) quantified the relationship between the illegal wildlife trade and several key factors thought to contribute to the illegal wildlife trade, namely road development, unemployment, and Corruption Perception Index (a score related to the perceived level of corruption); 2) measured the extent to which the product types, origins, destinations, and trade routes in the legal and the illegal wildlife trade are alike; and 3) identified locations to place resources to (a) restrict trade by causing the greatest network destabilization and (b) disseminate an educational message that would cause the greatest impact to the network.

Several key factors and the legal trade were associated with the magnitude of various indices of the illegal trade at a country-level, but no generalizable findings can be asserted at this time. With regard to the best placement of regulatory resources, China was key with respect to network disruption and information dissemination targets. This thesis has begun the urgently needed analysis of the complex relationships of the illegal wildlife trade and identified specific ways to bring about change using network science. These findings offer hope for regulatory and enforcement agencies, NGOs, and governments that it will be possible to find more effective ways of combating the illegal wildlife trade and problems it brings with it.

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The trade in wild animals and their products is a multi-billion dollar industry that threatens the health and well-being of humans and animals alike. In this chapter, we begin by describing the size and scope of the wildlife trade, size in terms of dollar value and numbers of animals traded and scope in terms of which animals and animal parts are traded. We also mention some of the drivers of the trade. We then discuss the most pressing reasons for concern about the wildlife trade and the ways the trade is being managed. Finally, we outline the rationale for the research described in the following chapters.

1.1 Size of the wildlife trade

Travel and the trade in goods, including wildlife, are happening with an unprecedented efficiency and are a defining feature of the modern globalized economy (1–3). The United States, one of the largest importers of wildlife, imported more than 1.48 billion live wild animals from 2000 to 2006, yet much of the wildlife trade that occurs is not legal (4–6). Recent figures suggest that each year, billions of live wild animals and animal products are illegally traded around the world (valued estimated between US$5 billion and hundreds of billions of dollars) (7–9).

1.2 Scope of the wildlife trade

A wide variety of animals are traded alive, dead, or as a processed product. Wildlife killed at the time of harvest are most likely to be mammals, while birds, reptiles, and amphibians are more likely to be captured alive (10). Mammalian fur and elephant ivory each account for a quarter of all illegal wildlife trade seizures, while 69% of live animal seizures are of reptiles (11).

These animals are traded to meet a broad range of demands. While much of the trade is conducted primarily for economic gain, social and cultural drivers are also recognized as detailed below (12, 13).

Wildlife is traded to meet local, subsistence dietary demands, as well as to satisfy international demands for ancestral foods; novelty and medicinal foods have also been reported as drivers (14–18). Wild animals, such as grasscutter cane rats, bats, monkeys, leopards, bush hogs, and lions are commonly hunted for meat (19). Globally, bushmeat has been seen in African restaurants, street markets, butcher shops as well as special events like weddings, christenings, and circumcision ceremonies catering to African communities abroad (19–21). Subsistence food accounted for 7% of the global demand for wildlife, while luxury and non-subsistence foods accounted for 36% (10). Furthermore, there is evidence that the international demand for bushmeat is one of the most important causes of loss of biodiversity (22–25).

There is a significant trade in wildlife for medicinal purposes; a quarter of the demand for wildlife stems from use in traditional medicine (10, 26). Approximately 80% of the world relies on traditional medicine derived from animal and plant sources (27). In Nigeria, 45 animals including primates, bats, lions, leopards, and cane rats were used for traditional medicinal purposes; more than 1500 animals were reported to be used in China and 180 animals in Brazil (28–30). Medicinal demands for rhinoceros horn in Traditional Chinese Medicine have led to the extinction of the Javan rhinoceros (*Rhinoceros sondaicus*) and sharp declines in other rhinoceros populations in the last decade (31).

Live wild animals are traded to supply public and private animal collections and to meet demands for pets. Wildlife enthusiasts often target rare animals for personal collections: after the rediscovery of the Borneo earless monitor lizard (*Lanthanotus borneensis*), it is estimated that at least 100 animals have been illegally harvested and shipped worldwide to collectors (32–34). Pet and entertainment demands for wildlife account for 20% of the illegal global trade (10). Parrots, iguanas, and freshwater turtles and tortoises are some commonly traded animals as pets (35, 36, 10, 37, 38).

Wildlife is used in the fashion and home décor industries. Skins, leather, fur, feathers, and fiber are used in clothing, and sea turtle shells, pearls, ivory, feathers, and bone are used in jewelry (12, 39). As one example, the Tibetan antelope (*Pantholops hodgsonii*) experienced a 90% reduction in population size in the last century and is now in imminent danger of extinction due to the demand for shahtoosh shawls (40–42). Ivory, coral, skins, feathers are also used in ornaments, decorations, and curios (12). Hats, coats, and wall hangings made of snow leopard skins are desired luxury items in China, Kyrgyzstan, Kazakhstan, and Mongolia (43), and seahorses are a popular tourist curio sold in the tropical souvenir shops (44).

Religious ceremonies can involve the use of live animals and animal parts (12, 45). Buddhists and Taoists take part in prayer or ceremonial animal releases where birds, turtles, and fishes are set free as an act of kindness (32, 45–47).

Wildlife is hunted for sport purposes as well (e.g. trophies and bird hunts) (12). Trophy hunting of African lions and leopards is the main cause of population decline of these animals (48–50).

1.3 Scale of wildlife trade

Precise estimates of the volume and species involved in the wildlife trade are difficult to obtain given its illicit nature, and as a result, fully understanding impacts on economies, wildlife populations and ecosystem health is also problematic (24, 36, 51). Nevertheless, the data that do exist describe a thriving business operating on a huge scale. In one year, 15,000 dead animals, including 293 chimpanzees, were seen in Brazzaville, Congo markets (52). An estimated 40,000 primates, four million birds, 640,000 reptiles and 350 million tropical fish are traded alive across the globe each year (8). Individual shipments have been reported to contain upwards of 10,000 Asian turtles (53). Between 2 and 30 tons of live wild animals enter China from Vietnam every day (54). Every year, approximately 7,500 tons of bushmeat are imported into Great Britain (55). Another study found that 7% of searched passengers arriving to Paris on Air France carriers from Africa had bushmeat in their luggage; an estimated 273 tons of bushmeat is imported into Charles de Gaulle Airport every year (56). US Customs and Border Protection seized over 69,000 different bushmeat items, including dried bats and smoked monkeys, from 2009 to 2013; US bushmeat imports are estimated to currently value $50 million annually and are expected to grow to hundreds of millions of dollars over the next two decades with the growth of the African immigrant population (19, 57).

1.4 Reasons for concern

The wildlife trade is a threat to species survival and adversely affects the health and well-being of individual animals and people. It has also been suggested to have links to terrorism, drugs, and arms trades (58, 59). Each of these threats is considered below.

1.4.1 Population decline

Many endangered species are commoditized, or offered for sale, and therefore the harvest of these animals may easily reach unsustainable levels resulting in population declines, extirpations, and extinctions (17, 22, 60–63). Overharvesting or exploitation is a risk for extinction for many primates, carnivores, ungulates, bats and rabbits (64, 65). Rhinoceros are currently facing this risk following a sharp increase in poaching; in South Africa, home to 80% of African rhinoceros, the number of rhinoceros poached jumped from 13 in 2007 to over 1000 in 2013 (66). Large-bodied, ornate, and fit animals within a species are often targeted and are at the highest risk of extinction due to overexploitation, and therefore a shift to smaller bodied animals in ecosystems and reduced fitness of species has been observed as forests are “emptied” (67–70). In northern Republic of Congo, 5-7% declines in populations of chimpanzees and gorillas are seen each year, and the crowned guenon monkey is hunted at rates that are 28 times greater than the estimated sustainable hunting levels in Equatorial Guinea (52). Parrot nestling mortality during the process of harvesting varied from 0-48.4% by species (71).

1.4.2 Mortality through trade

Animals sicken and die during transit because of dehydration, starvation, infection, overcrowding, cannibalism, injuries, and temperature and other stressors (72). A study of an international wildlife wholesaler with 26,400 animals from 171 species revealed 80% of the animals were sick, injured, or dead (72). Mortality rates during a 10-day observation period were 18% for invertebrates, 44.5% for amphibians, 41.6% for reptiles, and 5.5% for mammals (72). Overall mortality for an animal in the facility during a 6-week “stock turnover” period was 72% (72). Crowding, poor hygiene and inadequate food, water, heat, humidity, and environmental enrichment were contributing factors (72). A study of confiscated birds in Sao Paolo, Brazil found 78.6% of the mortality in these birds was attributed to infectious diseases (73). Furthermore, 75% of pet reptiles in Great Britain were found to die within their first year of life as a pet in a home (74).

1.4.3 Invasive species

The wildlife trade facilitates the intentional or unintentional introduction of non-native species to new regions where they can become invasive and compete with native species for resources, cause the slow demise of native species, damage infrastructure and crops, and introduce infectious agents that threaten biodiversity (4, 72, 75–77). In London, 51 species of free-ranging amphibians and reptiles are known to have been introduced by the wildlife trade (72, 78). In the United States, over 200 non-native fish species have been introduced following importation, and 85 of these have established breeding populations harming ecosystems (57, 79). The Burmese python has become a major predator to native Florida wildlife after its introduction (80), and similarly the introduced Gambian giant pouch rat has become an agricultural pest in the Florida Keys (81). Moreover, the volume and direction of trade have predicted invasive species introductions (82–87).

1.4.4 Spread of disease

Infectious diseases are a significant public health burden and new infectious diseases are emerging at a rapid rate (88–92). Emerging infectious diseases are defined as diseases that have recently increased in incidence, geographic range, or host range, or diseases that are newly discovered (93). An estimated 61% of all human diseases and 68-75% of emerging human diseases come from wild and domestic animals (91, 94–97). A majority (71.8%) of emerging human diseases with animal origins comes from wildlife (91). This is an increasing trend with time with 52% of the diseases that emerged from 1990-2000 having a wildlife origin (91). Wildlife plays a key role in disease emergence, as it provides a zoonotic pool from which known and unknown viruses, bacteria, and parasites emerge and cause disease in new host species (98–102).

While wildlife trade can be quite profitable, it is extremely risky from a disease perspective. The wildlife trade has been increasing in size and scope over the years due to liberalization of markets (72, 103, 104). The transportation networks enable large numbers of live animals to move a great distance in a short period of time (3, 105). The wildlife trade catalyzes outbreaks by acting as a Trojan horse, covertly carrying potential pathogenic organisms, all while increasing the contact rate and the potential for transmission to more individuals, more species, and more geographies encountered in supply chains as depicted in Figure 1 (8, 36, 51, 74, 98, 99, 102, 106–113). Pre-import housing and importation increases opportunities for cross-species transmission and amplification of infectious organisms due to the housing of animals at unnaturally high densities combined with close intermingling of species not typically seen interacting in the wild (114, 115). The stress of transport may lead to increased shedding of microorganisms and immunosuppression thereby increasing susceptibility to infectious diseases (113). Markets, quarantine facilities, and ports of entry have an important role as contact nodes where individuals and species can share microbes and result in their rapid and widespread dissemination to distant locales, be it in captivity or release back into the wild (114, 116). The trade in wild animals in Asia alone is estimated to result in several billion direct and indirect contacts among wildlife, domestic animals, and humans each year (114, 116). Our anxiety about the risk that the trade in wildlife poses to animal and human health is exacerbated by our continuing uncertainty about microbial diversity and, specifically, our relative ignorance of how many microbes there may be that are potentially infectious to other species (117). Only 1% of all viruses are estimated to have been discovered (118, 119).

A period of quarantine is required for birds, primates, and some ungulates upon importation into the United States, but there are very few diseases requiring mandatory testing (i.e., psittacosis, foot and mouth disease, Newcastle disease, avian influenza) (115). Other animals are typically only screened for physical signs of disease, and microbiological testing is delegated to the importer (115). However, an investigation of an importer in the US revealed a high burden of disease with little to no hygiene management or quarantine protocols;

furthermore, multiple accessible exits from the building were found from which the animals could escape the building and result in disease spread to native animals (72). Even if quarantine periods were lengthened and expanded to cover more animals, the illegal wildlife trade would continue to be a great risk factor as it would evade any veterinary control protocols (72, 116).

Despite our understanding of the general risks of disease transmission of the wildlife trade, human and animal outbreaks continue to occur (111, 116, 120–122). We present a number of examples of disease spread in humans and animals as a result of the trade in wildlife here.

1.4.4.1 Spread of disease to humans

The trade in wildlife is a major public health threat illustrated by a number of outbreaks of disease in humans.

In 1999, West Nile virus emerged in the New York area (123). The initial outbreak resulted in 62 human cases of severe encephalitis and 7 deaths, as well as significant equine and avian morbidity and mortality (124, 125). Three years later, the virus had spread to California (126, 127). Previously, West Nile virus had only been seen in the Eastern Hemisphere (128). While the exact mechanism of introduction of West Nile virus to the US is not known, one likely possibility suggested by experts is that infected birds arrived in the US via legal or illegal importation (126, 129).

In 2003, a child contracted monkeypox after being bitten by a pet prairie dog purchased at a swap meet near Milwaukee, Wisconsin (130). An outbreak of 72 human cases across six states ensued, all involving contact with pet prairie dogs or premises with pet prairie dogs (131, 132). The virus was traced back to Gambian pouched rats (*Cricetomys gambianus*) imported from Ghana which shared an exotic animal distribution warehouse in Texas with the prairie dogs (130, 132–134). This was the first case of community-acquired monkeypox outside of Africa. In Africa, monkeypox is often transmitted via hunting of nonhuman primates and rodents (135).

Severe Acute Respiratory Syndrome (SARS), a respiratory illness caused by a coronavirus, emerged in 2003 in China infecting over 8,000 people and causing 774 human deaths in 37 different countries (136, 137). The trade in horseshoe bats (*Rhinolophus* species) is likely to have brought virus-shedding animals into contact with humans. A market cycle in the Guangdong live animal market was established where other susceptible species, like the Himalayan masked palm civet (*Paguma larvata*) contracted the virus from humans (138–140). In 2012, another coronavirus emerged in humans called Middle East Respiratory Syndrome Coronavirus. As of June 2014, it has caused 699 known infections and 209 deaths (141). The virus has also been found in a bat (*Taphozous perforates*) and dromedary camels (*Camelus dromedaries*), however the exact mechanism of cross species transmission is not yet known (142, 143).

Acquired immune deficiency syndrome (AIDS) is caused by human immunodeficiency virus type 1 (HIV-1) or type 2 (HIV-2) infections. HIV-1 is comprised of four distinct lineages, groups M, N, O, and P, and HIV-2 of eight, groups A-H, each of which resulted from independent transmissions from non-human primates to humans. Group M is predominantly responsible for the AIDS pandemic, which has caused 75 million infections and 2.6 million deaths (144, 145). HIV-1 group M appears to have emerged in humans from chimpanzees (*Pan troglodytes troglodytes*) in southeast Cameroon in the beginning of the twentieth century (146–152). After local transmission, likely from the hunting of chimpanzees, the virus likely spread via ferry along the Sangha River system from southeastern Cameroon to Kinshasa, a route used in rubber and ivory trades during German colonization of Cameroon from 1884 to 1916 (146, 152, 153). HIV-1 group N likely emerged from chimpanzees (*Pan troglodytes troglodytes*) in south-central Cameroon, HIV-1 group P from gorillas (*Gorilla gorilla gorilla*), and HIV-1 group O from either chimpanzees or gorillas in west central Africa (147, 148, 154–158). Independent transmissions from sooty mangabey monkeys (*Cercocebus atys*) from Cote d'Ivoire (groups C, G, and H), Liberia (group D), and Sierra Leone (groups E and F) are the likely source of HIV-2 (159–162). Cutaneous or mucous membrane exposure of bushmeat hunters to simian immunodeficiency virus in the blood or bodily fluids of non-human primates likely via hunting, butchering and/or consumption allowed for entry of this HIV-precursor into humans and to slowly gain the mutations that led to HIV (147, 158, 163, 164).

Ebola virus disease was a previously rare disease of humans and nonhuman primates that causes severe gastrointestinal disease and death within few days. Epidemiological studies found that eight of seventeen Ebola outbreaks through 2005 were clearly linked to contact with dead gorillas, chimpanzees, monkeys and duikers (165). Most of these had index cases who were hunters who had found and handled these animals in the forest (166–168). For example, the 2014 outbreak in the Democratic Republic of Congo began with a woman who butchered a dead animal from the bush (169). Fruit bats (*Pteropodidae* family) are believed to be the natural reservoir of the virus (170). An outbreak in the Occidental Kasai province of Democratic Republic of Congo in 2007 was found to have originated in a man who purchased freshly killed bats (165). In 1989, the Reston Ebola virus was found in crab-eating macaques (*Macaca fascicularis*) imported to the United States from the Philippines; while this virus has not yet been seen to be pathogenic in humans, humans have been found to have antibodies to the virus (171, 172).

In 1967, Marburg virus emerged when hemorrhagic fever cases were seen in association with laboratories in Germany and Serbia. Human cases were linked to exposure to African green monkeys (*Chlorocebus* species) or their tissues, which were imported for research (173).

Highly-pathogenic avian influenza (HPAI) causes pandemics in humans after the exchange of avian influenza virus genes between wild and domestic birds, pigs, and humans (111). While the exact role wildlife plays has been debated, it is believed that wild aquatic birds (order *Anseriformes*) are the reservoir; the trade in wild birds as pets, food, prayer animal release, or release from fear of HPAI transmission is a potential source for cross-species transmission (5, 104, 146–150). The importation of two infected crested hawk eagles (*Nisaetus cirrhatus*) on a passenger plane from Thailand to Belgium led to the death of a quarantine veterinarian (179, 180). In other cases, traded wild birds with HPAI were intercepted before humans were infected. In 2005, a Mesia songbird (*Leiothrix argentauris*) imported to the UK from Taiwan tested positive for HPAI, however genetic studies suggested its origins were likely China (177, 181). Taiwan found HPAI in 8 birds in a container carrying 1000 exotic birds smuggled over sea in 2005 and in pet birds smuggled by air in 2012; both shipments originated in China (182, 183). To further support the importance of trade, the chronology and route of the recent westward expansion of HPAI across Asia and Europe was found to follow human commerce routes such as the Trans Siberian railway closely (184). Research has shown that the wild bird trade also played a role in large geographic jumps, including the introduction of highly pathogenic avian influenza A into Japan, Indonesia, and Malaysia (175, 185).

Herpes B virus (cercopithecine herpesvirus 1) is often fatal to humans if transmitted from an infected macaque by bite, scratch, or contact with a mucous membrane; macaques (Macaca species) are endemic for the virus and are used in research and kept as pets and in zoos (186, 187). Over 43 cases have been reported since 1930 with eight infections from 1987-1994 (188–190).

In 1975, an increase in the number of salmonellosis cases associated with pet turtles prompted the US Food and Drug Administration (FDA) to ban the importation of turtles less than 4 inches in length. Despite these efforts, from 2009-2011, 224 people contracted *Salmonella typhimurium* from contact with pet frogs (191, 192). It is also estimated that at least 11% of the 1.2 million annual US salmonellosis cases in children were associated with direct or indirect reptile or amphibian contact (193–195). *Salmonella* is typically associated with snakes, lizards, and turtles, but can also be seen in African pygmy hedgehogs, sugar gliders, rodents, and birds; many of these animals do not show signs of *Salmonella* infections (195–197). Reptiles can carry multiple serotypes of *Salmonella* simultaneously, and the prevalence varies greatly by species, animal history, and animal housing (198–214). US imports of wild Indonesian Tokay geckos (*Gekko gecko*) group prevalences ranged from 31-73% with 6.8% showing resistance to multiple antibiotics; an increase in prevalence and number of serotypes per individual was found from the time of import to six months later (113). Pet rodents have also been associated with multidrug resistant *Salmonella* (215).

Contact with or ingestion of water from tanks holding aquarium fish has caused infections from *Mycobacterium* species, *Salmonella* species, *Aeromonas* species, *Vibrio* species, *Edwardsiella* species, *Legionella* species, *Streptococcus iniae*, and *Erysipelothrix rhusiopathiae* (187, 216, 217). Animal organs, bones and bile used for medicinal purposes can be a source of *Salmonella* species, *Mycobacterium tuberculosis*, and rabies (36, 218). Skin infections that can be acquired from exotic pets include ringworm, monkeypox, orf, cutaneous anthrax, tularemia, erysipeloid, *Mycobacterium marinum* infection, *Yersinia pseudotuberculosis* infection, and ectoparasites (187, 196, 219–224). Hantavirus, lymphocytic choriomeningitis, tularemia, rabies, plague, ringworm, *Bartonella* infections, *Mycobacterium* infections, and *Yersinia* infections have also been seen in the context of exotic pets (187, 225).

The previous paragraphs dealt with the known disease risks posed by the wildlife trade; however, there is a burgeoning literature on the potential risks. For example, human *Anaplasma* infections are a possibility as *Anaplasma* organisms have been isolated from *Amblyomma javanense* ticks (which also feed on humans) on imported pangolins (order *Pholidota*) (226, 227). Futhermore, co-infection of multiple tick-borne agents (e.g. *Borrelia burgdorferi*, *Ehrlichia* sp., *Babesia* sp., *Rickettsia* sp., and tick-borne encephalitis virus) from one tick bite is possible (228). Bushmeat smuggled into John F. Kennedy airport was found to harbor two types of viruses that have the potential of infecting humans: simian foamy virus and herpes viruses (229). Hunters and people occupationally exposed to wild animals through butchering, cooking, and animal skin preparation were more likely to have antibodies to microbes seen in the context of wildlife hosts; to add, with the growing number of animals entering markets, this risk is likely to increase (102, 230–236). In 1994, several thousand Egyptian tomb bats (*Taphozous perforates*), which are banned from US importation due to a rabies risk, were imported into the US for the pet trade due to a permit error; a similar lapse in the future could have more disastrous outcomes (237).

1.4.4.2 Spread of disease to wild animals

Infectious diseases in wildlife have recently been found to be emerging at high rates, a phenomenon that is, in part, due to the growing scope, size, scale and efficiency of the wildlife trade (76, 238–240). The trade in wildlife exposes wildlife species to exotic infectious agents (122, 241–243). We detail some examples here.

As mentioned above, in the spring of 2003, monkeypox emerged in captive prairie dogs (*Cynomys* spp.) by way of Gambian pouched rats (*Cricetomys gambianus*) imported into the US for the pet trade. In an exotic animal distribution warehouse, the rats were housed next to a group of prairie dogs, which are native to the United States (131). Monkeypox was also isolated from two rope squirrels (*Funisciurus* spp.) and three dormice (*Graphiurus* spp.) (134). With the numerous routes of accessible exits noted for animals to escape from the distribution warehouse, the potential of spread to native wildlife in the US is clear (72).

Reptiles imported for the pet trade are known to frequently harbor *Salmonella*. *Salmonella* can be pathogenic for wildlife and cause septicemia, pneumonia, and abscesses (198, 199).

Imported fish can harbor novel infectious agents that pose threats to native wildlife, especially when contaminated aquarium water or fish is released into natural systems (79). In Florida, 95% of the emerging infectious agents in native fishes were introduced from imported fish (244). *Vibrio* organisms can quickly spread in the trade when fishes are transported in heavily stocked confinements; morbidity has been seen to reach 100% in such settings (245, 246). *Aeromonas* outbreaks in ornamental fishes are frequently associated with poor water quality (low oxygen, high ammonia, high nitrate, high water temperature), rough handling, and overcrowding (245, 247, 248). Bacteria are shed from stressed, dying and dead fishes during shipment and through shared aquarium water (79).

The amphibian trade is connected to the emergence of a number of amphibian diseases. Shipments of fish and amphibians contributed to ranavirus epizootics in freshwater fish and wild herpetofauna (121, 249–252). It has been suggested that the trade in the American bullfrog (*Rana catesbeiana*) and the Cane toad (*Rhinella marina*) may have led to the spread of tadpole edema virus (116, 253). The trade in frogs is the basis of the main theories of how cutaneous chytridiomycosis spread globally and caused amphibian mortality, widespread decline and possible extinctions in American and Australian rain forests (253–256). In Latin America, chytridiomycosis is implicated in the extinctions of 27% of 113 species of *Atelopus* harlequin toads (257, 258). The disease is thought to have impacted the ecosystem by altering food webs, nutrient cycling, algal biomass, and insect abundance (5).

Recent *Pseudamphistomum truncatum* fluke infections in English otters (*Lutrinae* subfamily) is believed to be related to the introduction of the sunbleak (*Leucaspius delineates*) and the topmouth gudgeon (*Pseudorasbora parva*) (116). An ornamental fish supplier brought these fishes to the UK, and the fishes were able to successfully colonize river systems in southern England following their escape (259).

SARS-like viruses were found in Himalayan palm civets (*Paguma larvata*) and a raccoon dog (*Nyctereutes procyonoides*) in a Guangdong, China live animal market (138). The virus is believed to have been passed from traded bats to humans to civets and raccoon dogs (139, 140).

Bushmeat hunting can result in small, fragmented populations of the hunted animal, which are more prone to disease-mediated populations declines. Populations decline indices revealed a 50% reduction for gorillas and 88% for chimpanzees between 2002 and 2003 in central Africa and 25% reduction in chimpanzees in Cote d'Ivoire in 1994 in the context of Ebola outbreaks (168, 260).

There is also known potential for disease transmission. *Anaplasma* organisms have been isolated from *Amblyomma javanense* ticks on imported pangolins (order *Pholidota*). These ticks are known to feed on wild boar, monitor lizards, phythons, skinks, hill turtles, bats, hyenas, bears and Sambar deer as well, so the potential for anaplasmosis exists in many other animals (226, 261–263).

1.4.4.3 Spread of disease to domestic animals

Wildlife trade also poses disease risks to domestic animals (4). In 1987, African Horse Sickness virus emerged in central Spain due to the importation of sub-clinically infected zebras from Namibia to a safari park (264, 265). The outbreak persisted in Spain (1988–1990) and moved to Portugal (1989) and Morocco (1989–1991) causing over 400 cases in equines in Spain alone (265, 266).

A shipment of leopard tortoises (*Geochelone pardalis)* imported to Florida from Zambia were found to have *Amblyomma sparsum* ticks carrying *Ehrlichia ruminantium,* a bacterium responsible for heartwater disease in ruminants (267). Other potential risks include Foot-and-Mouth Disease, African swine fever, and Ebola via the bushmeat trade (8).

1.4.5 Personal and public safety

Exotic pets in captivity have been known to cause harm to caretakers and visitors and to the public when they escape or are intentionally released; injuries include scratches, bites, maulings, severe mutilations, strangulations and death (268–270). Recently, there have been reports of strangulations by snakes, bites by pet alligators, and attacks by nonhuman primates and big cats (270–274). Many owners may not be aware of the ecology, life span, and behavioral needs of a pet; some birds can require many hours of stimulation throughout the day and live 40 years or more (195, 275). A study found that lapses in animal management protocols, lack of adult supervision of children and intoxication were some of the factors that led to severe injuries caused by exotic large feline pets (276).

1.4.6 Allergies

Allergies to wildlife have also been reported. Allergies are typically a result of sensitization to animal dander, scales, fur, feathers, body waste, or saliva (187). Exposure to birds is one of the most common causes of hypersensitivity pneumonitis in children (277). People with hedgehog contact have reported hives (278). Allergic rhinitis, asthma, and contact hypersensitivity have been seen with iguana contact (221–223, 279). Allergies to wildlife used in traditional medicines is another concern (187, 195, 218).

1.4.7 Links to other illicit activities

Poaching is reported to be a significant source of funding for criminals, militias, and terrorists (59, 280–289). Rebels in Bangladesh, India, and Mozambique have all been linked to poaching to finance their operations (282). Recent reports show that the Janjaweed, the Sudanese government-backed horse militia implicated in the genocide in Darfur, have traveled far into Cameroon and the Central African Republic to empty the area of ivory (282). Groups linked to Chad, Niger, and the Lord's Resistance Army have also poached ivory to finance their operations (282). Al-Shabaab, a terrorist group which claimed responsibility for a Nairobi mall attack in 2013, is reported to receive up to 40% of its funds through ivory trafficking (283–288).

Linkages between the drug trade and the wildlife trade have been reported (58). Some examples include legal shipments of wildlife being used to conceal drug trading, wildlife being laundered for drugs, and trafficking routes running in parallel for drugs and wildlife products (58, 290, 291). Parrots and drugs were found smuggled together from Cote d’Ivoire to Israel (292). Australian birds have been traded for heroin in Thailand and South African abalone for Chinese methamphetamine components (290, 293, 294).

1.4.8 Welfare

The concept of animal welfare originated in western cultures, and it is a concept still being introduced to many societies (295–298). Factors that are thought to impact the levels of concern for animal welfare in a society include human welfare standards and poverty levels (296, 299).

Animal welfare is a concern at all stages of the wildlife trade beginning with the capture of animals from the wild. One common method of bird capture involves applying an adhesive to trees that results in feather and limb damage in the capture of the bird (300). Juvenile primates are oftentimes acquired by killing their adult parent or unintentionally acquired as a by-product of the bushmeat trade (301, 302). When the capture involves killing the animal, poisons, snares, landmines, and explosives are often used, which oftentimes results in a prolonged and painful death (15, 259–262).

For wildlife traded alive, welfare concerns exist through transport of the animal (10, 307–309). For every one animal that arrives alive to the consumer, an estimated three die during transit (63). Common causes include dehydration, starvation, infection, overcrowding, cannibalism, temperature shock, and injuries (10, 38). A study found a quarter of traded animals that were alive were affected by disease or injury, 20% by environmental problems, 20% by behavioral or interactive restriction, 18% by anxiety, fear, or pain, and 13% by food or water deprivation (10). A study of confiscated birds in Sao Paolo, Brazil found 61.4% were in poor condition with severe changes in feather color, broken or missing feathers, and moderate to severe atrophy of pectoral muscles (73). A study of three European wildlife markets revealed moderate levels of stress behaviors: persistent interaction with transparent caging was seen in 27.5% of animals, hyperactivity in 11%, head-hiding in 4.6%, flattened body posture in 2.4%, rapid body movement in 2.1%, hyperalertness in 1.8%, and inflation of the body in 0.5% (310).

Husbandry of wild animals often involves substantial changes in the animals' normal behavior and diet (311, 312). Animals are confined to cages small relative to the animal's needs (313). In effort to maximize shipment efficiency, reptiles and amphibians, in particular, are packed in so tightly that they cannot move (53, 314). Wild-caught birds in Brazil are given generic dry bird seeds, which often does not meet the nutritional requirements for many species or ages (300, 315). Bears are housed in cages not much bigger than their bodies with catheters attached to their gallbladders for the bear bile trade (316). Some species are unsuitable in captivity, such as slow loris (*Nycticebus* sp.); its teeth are forcefully extracted to prevent toxic bites but this also often causes the lori a slow, painful death (302, 317, 318). Animals are also known to display stressed behaviors and aggression due to human contact and multispecies housing (314). Traders may utilize a cost-benefit calculation in husbandry practices; they care for animals sufficiently to avoid the animal's death or "unacceptable" condition for the sale of the product (10).

1.5 Trade management

International wildlife trade regulations pertain to border protection from animal and human diseases, invasive alien species, animal welfare violations, and overexploitation of endangered and threatened species (120, 319, 320). US Fish and Wildlife Service, the FDA, the Centers for Disease Control and Protection (CDC), and US Department of Agriculture are agencies responsible for enforcing US import restrictions, and the Customs and Border Patrol is responsible for coordinating these four agencies (321).

The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) is an international treaty where signatory countries monitor and take action on behalf of threatened and endangered species (322, 323). Under CITES, animals are classified as Appendix I species (trade permitted only under exceptional circumstances), Appendix II species (non-detriment finding and export permits are required for trade), Appendix III species (one member country has asked other CITES parties for assistance in controlling trade), or non-CITES species (322, 323). A challenge to CITES enforcement is accurate identification of wildlife products, which are often processed and can be difficult to identify using morphological techniques (24).

There are no overriding health regulations within the wildlife trade and much of the existing regulations are bilateral agreements between countries (120). However, World Trade Organization member countries are bound by the Sanitary and Phytosanitary Agreement to adopt standards around food safety of animal imports (120). The World Health Organization for Animals developed international health standards to be used by veterinary authorities for the prevention of animal health diseases and zoonoses in the international trade in terrestrial animals and their products (116). The World Conservation Union has also developed guidelines on minimizing disease risks associated with the movement of wildlife for conservation or game management purposes (116, 120). The CDC and FDA have also regulated particular exotic animal species following disease outbreaks, such as in the case of *Salmonella* and SARS (116). Despite the international and domestic legislation, the enforcement of wildlife trade regulations and subsequent prosecutions for offenders has had significant challenges resulting in a low risk-to-reward ratio for traders and therefore continued high levels of illegal trading (324).

1.6 Rationale for the work described here

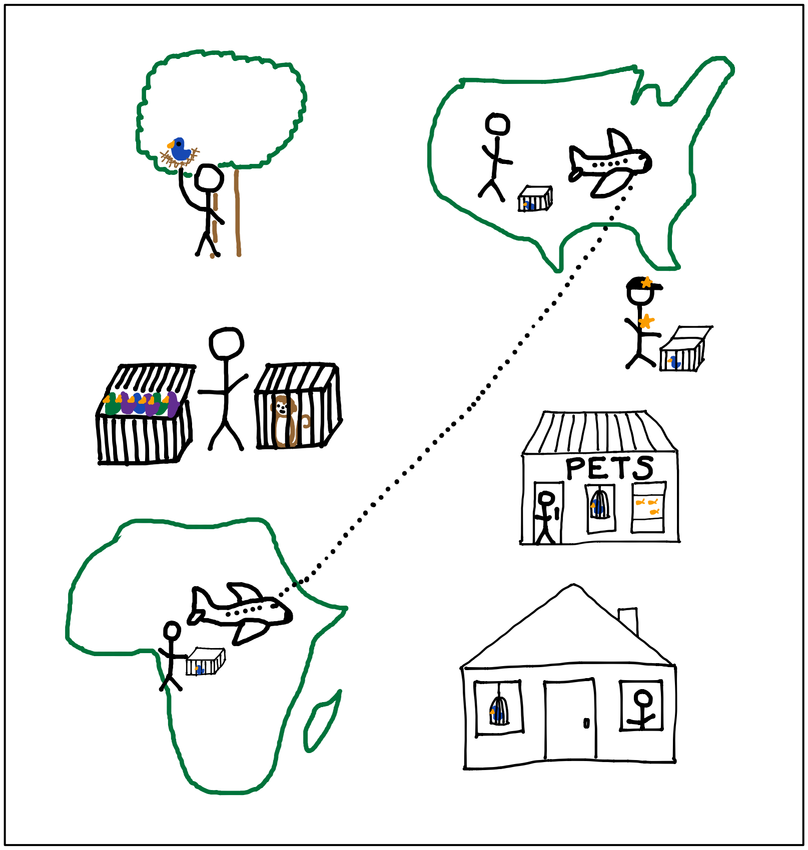
The management of wildlife trade is a crisis-driven area, where decisions are made quickly (325). Most actions on the part of governments to regulate live wildlife imports have been a reactive response to an urgent public health or invasive species issue (326, 327). Much of the wildlife trade research consists of case reports and anecdotal evidence, and very little is formal analytical work.

Experts have called for more science-based analyses of risks of the wildlife trade to assist in decision-making processes and more effective strategies (137, 328–332). Accordingly, the research presented here advances the current literature pertaining to the magnitude, threat and control of the illegal wildlife trade. In particular we hope that the work presented here will enable authorities to take more effective action to manage the important public health and conservation consequences of these activities.

An understanding of the routes of animal movement is essential to the effective management of the illegal trade in wildlife (87, 332, 333). As no internationally-sanctioned database on the volume, frequency, composition and routes of the illegal wildlife trade is publicly available, we used reports in the HealthMap Wildlife Trade database to summarize the network and composition of the illegal wildlife trade. The HealthMap Wildlife Trade database combines official data with informal media coverage on illegal wildlife trade seizures. This automated web crawling surveillance system uses a text-mining algorithm based on keyword search strings to pull from over 50,000 English and Japanese web-based news sources (334). The data on the illegal trade in wildlife compiled from the HealthMap Wildlife Trade database were the basis for the analyses described in Chapter 2, 3, and 4.

Chapter two is a quantitative examination of factors associated with increased illegal trade activity. We quantify the relationship between illegal wildlife trade activity and several key factors thought to contribute to the illegal wildlife trade, namely road development, unemployment, and Corruption Perception Index (a score related to the perceived level of corruption). Chapter three is a quantitative examination of the claim that the infrastructure that serves the legal trade is co-opted by and facilitates the illegal trade. Chapter four deals with a novel methodology for deciding where to allocate the limited resources available for controlling the illegal trade.

Figure 1. Diagram depicting a sample of settings of the wildlife trade where the potential for pathogen transmission from animals to humans exists



CHAPTER 2: KEY FACTORS IN THE ILLEGAL WILDLIFE TRADE

Key Words

Corruption, elephant, press, roads, rhinoceros, tiger, wildlife trade, unemployment

Abstract

Identification and evaluation of risk factors of the illegal wildlife trade are requisite steps in effectively developing measures to impede the trade. We quantify the relationship between the illegal wildlife trade and several key factors thought to contribute to the illegal wildlife trade, namely road development, Corruption Perception Index (a score related to the perceived level of corruption) and unemployment. Focusing on the illegal trade in elephants, rhinoceros, and tigers (and their products), we measure the association between the key factors and the magnitude of the illegal wildlife trade in a country.

We found a decrease in corruption was associated with a decrease in tiger exports and an increase in elephant imports and in an elephant, rhinoceros, or tiger import in a country. We also found an increase in unemployment was associated with a decrease in exports of rhinoceros products and in exports of an elephant, rhinoceros, or tiger product in a country via negative binomial regression. Given the supportive evidence we found in select settings, further investigation into the understanding of these key factors is warranted.

2.1 Introduction

The illegal wildlife trade is a lucrative trade of enormous size; it is estimated to generate ten to hundreds of billion dollars annually (282, 335). Wild birds, reptiles, mammals, fish, insects and their products are traded as pets and for food, musical instruments, hunting trophies, clothing, and traditional medicines. Confiscated shipments range in size from a small animal part to multi-ton packages with thousands of animals (7). An estimated 38 million wild animals are shipped out of Brazil every year (336).

Several key factors are thought to contribute to increased illegal wildlife trade activity. They include access to wildlife markets, increased connectivity to wildlife habitats via road development, increasing disposable income, rising affluence, unemployment, corruption, poor regulations, weak law enforcement, lack of awareness of regulations and conservation concerns, and poor wildlife management practices (7, 289, 311, 332, 337–339).

Road development could have a direct impact on wildlife trade by increasing access for hunting, decreasing hunting costs, improving transport time of animals to market, and attracting new settlements which can include hunters and traders (64, 235, 337, 338, 340–353). It has supported the transformation of hunting from a subsistence to a commercial venture (346, 354, 355): wildlife extraction rates in a newly accessible forest can have three to six times greater yields (356). Paved roads are often being built for timber, plant, oil, and mineral exploration, and inadvertently provide year-round access to areas of high biodiversity. Workers in these industries often hunt for provide food for themselves, and some workers end up settling in the area after their employment has ended and continue to hunt to provide food and to generate income (344, 348, 354, 357–360). While most reports have been case studies, some have examined the relationship of roads and hunting in very specific contexts of select logging and oil extraction sites (337, 338, 357).

The level of corruption is frequently regarded as one of the most critical risk factors for wildlife trafficking (361). Bribery takes place at all points in the trade chain including poaching, trafficking, and law enforcement as well as allowing fraudulent permits and falsifying certificates (362–364, 364–370). The high value of wildlife, the low penalties for infractions, and the understaffed, undertrained, and under-resourced wildlife departments are thought to perpetuate the problem (371–374). Cameroon rangers often wait months before receiving salaries, and not surprisingly, they have high bribery rates; 85% of Cameroon's field enforcement operations are compromised by bribery and 80% of all cases presented in courts involve bribery attempts (370, 375). While Vietnam reports 45% of wildlife outlets with corrupt officials, an estimated US$18,000–30,000 per day is given in bribes to border officials at three Vietnam-China border posts (370, 376, 377). Many case reports cite corruption impacting wildlife trade by reducing effectiveness of funds for programs and law enforcement (371, 374, 378–387). Bennett (2014) reports that 75% of the worst ivory trafficking countries are in the bottom half of the world's most corrupt countries, but little research has been conducted on the nature of the relationship between corruption and the wildlife trade (332, 370, 372, 388). Smith et al. (2003) found strong associations between corruption and African elephant and black rhinoceros mortality; however, Katzner (2005) and Underwood (2013) found opposing results with European farmland bird population changes and ivory seizures, respectively (332, 371, 389).

Trading in wildlife is often reported to be a means of survival during times of high unemployment (365). There are many case reports in the literature; however, more formal relationships between unemployment and wildlife trade have yet to be demonstrated. Unemployment has been suggested as an explanation for bushmeat hunting in Africa (390–392), illegal fishing and hunting in Venezuela (393), bird trading in Brazil (394), snow leopard poaching in Central and South Asia (395) and deer poaching in Missouri (396). Researchers have described Yemeni markets to be more plentiful of a multitude of species during times of a weak economy (397).

With very few exceptions, the literature has done little more than report cases of illegal wildlife trade in the context of road development, corruption, poverty, and unemployment, factors which are often cited as important drivers of the illegal wildlife trade (332, 339, 366, 371, 389, 398). Here, we quantify the relationship of the illegal wildlife trade with road development, the Corruption Perception Index (a quantification of the perceived level of corruption), and unemployment. We choose these putative key factors in particular because summary measures at country level are available for each of them. We include animal species abundance as an addition key factor because of its obvious potential as a confounding factor in the analysis (392, 399, 400). We also include the World Press Freedom Index to account for the reporting bias inherent in the wildlife trade dataset (332, 334). We also limited the scope of the wildlife trade to elephants, rhinoceros, and tigers, the most frequently cited of 118 species in a database of illegal wildlife trade reports (HealthMap Wildlife Trade database), to reduce media reporting bias (334). Specifically we test the idea that there is an association between the listed key factors and the number of illegal (1) shipments of elephants, (2) shipments of rhinoceros, (3) shipments of tigers, and (4) shipments of elephants, rhinoceros, and tigers (combined) exported or imported by a country (389).

Conservation is a crisis discipline where actions are made quickly, but there is a dearth of analytical work on the effectiveness of interventions on species loss (325, 372, 388). We believe that a more formal evaluation the risks posed by the key factors often identified in the literature is a requisite step in effectively developing measures to impede the illegal trade in wildlife (372, 401).

2.2 Materials and Methods

2.2.1 Data on Illegal Wildlife Trade: the HealthMap Wildlife Trade Database

Because no internationally-sanctioned database on the volume, frequency, composition and routes of the illegal wildlife trade is publicly available, we relied upon the formal and informal reports in global digital media described by Hansen et al. (2012) that summarize the network and composition of the illegal wildlife trade (334). These reports are contained in the HealthMap Wildlife Trade (HWT) database (http://www.healthmap.org/wildlifetrade/). The HWT database combines official data with informal real-time media stories and reports from the public on illegal wildlife trade seizures. It is an automated web crawling surveillance system of the wildlife trade similar to those used for infectious disease events (e.g. GPHIN, HealthMap). Official sources include TRAFFIC, WildAid, The Coalition Against Wildlife Trafficking, World Wildlife Fund, and the International Fund for Animal Welfare. Unofficial sources include free and publicly available websites, discussion forums, mailing lists, news media outlets, and blogs. The database uses a text-mining algorithm based on keyword search strings, which uses news indexers that draw from over 50,000 possible web-based sources in English and Japanese (334).

We focused on the period between August 1, 2010 and December 31, 2013 (3 years and 5 months) and limited the scope of our wildlife trade analysis to elephants, rhinoceros, and tigers. From each report of a unique trade interception of an "elephant", "rhinoceros", and "tiger" listed in the wildlife trade database, we extracted the type of product(s) traded, country of origin of the product, and the actual or intended country of destination of the product. A report that listed a trade interception involving multiple types of products, multiple origins, or multiple destinations was parsed so that each product type, origin, and destination was entered separately into our own database. For example, a report with an interception of tiger skins, a tiger cub, and elephant tusks resulted in three corresponding separate entries. We delineated by product type to reflect the distinctive market demands. If these items were traveling from India to Nepal to China, they were entered separately for traveling from India to Nepal and from Nepal to China. If they were sourced in India and being sent to China and Vietnam, they were entered as traveling from India to China and India to Vietnam. Each entry in our database, hereafter referred to as a "shipment," corresponded to an animal product transported between two countries; this "shipment" was the unit of analysis Shipments without a country of origin and destination were excluded from the dataset. Shipments with the same country of origin and destination were included here. Duplicate shipments were identified and discarded based on the identification of an identical shipment route reported within a 30 day period with the same combination of products. We tabulated the number of total exported and imported shipments of elephants, rhinoceros, and tigers by country from August 1, 2010-December 31, 2013 reported in the HWT database.

2.2.2 Key factors and control variables

We investigated three key factors: road development, Corruption Perception Index, and unemployment. We also controlled for animal species abundance and

World Press Freedom Index in the analyses.

2.2.2.1 Road development

Road development was measured as the percentage increase in the total paved road network size from 2010 to 2011 per country (402). Roads were defined as motorways, highways, main roads, secondary roads, and all other roads. We used the latest available data. For countries with missing data, we carried forward the last two available years (403).

2.2.2.2 Corruption Perception Index

The 2012 Corruption Perception Index was an expert opinion measure of the perceived level of public sector corruption (404). The index ranged between 0 and 100 and was construed so that it could be used as an inverse proxy for weakened law enforcement and poor quality of regulations (405, 406).

2.2.2.3 Unemployment

The number of people actively looking for a job divided by the number of people in the entire labor force (multiplied by 100) was used to represent unemployment. We used the unemployment percentage by country for 2012 (402).

2.2.2.4 Animal species abundance by country

Animal species abundance was estimated by the number of free-ranging elephants, rhinoceros, and tigers in a country in 2012 (407–416). Minimum population estimates were used for Asian elephants and definite estimates for African elephants. For analyses examining elephant, rhinoceros, and tigers trade collectively, we summed the number of free-ranging elephants, rhinoceros, and tigers for each country.

2.2.2.5 World Press Freedom Index 2012

The 2012 World Press Freedom Index was a measure of the level of freedom of information in 180 countries based upon a questionnaire sent to Reporters Without Borders partner organizations, their network of 150 global correspondents, and other journalists, researchers, jurists and human rights activists (417). Scores ranged from -10 to 142, where -10 was the highest level of freedom and 142 the lowest level of freedom (417).

2.2.3 Analysis

2.2.3.1 Statistical analysis

All statistical analyses were carried out using STATA 11.2 (418).

2.2.3.2 Magnitude of illegal shipments exported or imported by a country

If the selected key factors are true risk factors for the illegal wildlife trade, then we expected there to be an association between the magnitude (number of illegal shipments/unit time) and the magnitude of the key factors. To test this idea we examined illegal (1) exports of elephant products, (2) imports of elephant products, (3) exports of rhinoceros products, (4) imports of rhinoceros products, (5) exports of tiger products, (6) imports of tiger products, (7) exports of elephant, rhinoceros, or tiger products, and (8) imports of elephant, rhinoceros, or tiger products with the selected key factors (road development, the Corruption Perception Index, and unemployment). In each case, the total number of illegal (exported or imported) shipments by country from August 1, 2010 to December 31, 2013 in the HWT database was the dependent variable, and road development, Corruption Perception Index and unemployment were the independent variables. We also adjusted for animal species abundance and World Press Freedom Index. There were two steps. Step one was exploratory: we were interested in establishing whether there were any obvious associations between the selected key factors and the illegal wildlife trade. Collinearity between independent variables was explored graphically and by examination of tolerance values. Preliminary analysis suggested that there was a non-linear association for several combinations of the key factors and the number of shipments, so we created variables containing a linear spline with one knot for the key factors using the MKSPLINE command in STATA. Akaike Information

Criterion was used to select single variable models with the best fit and lowest level of complexity. Key factors including linear splines were re-examined for collinearity. Plausible interactions (corruption with road development and corruption with unemployment) were considered (419). Preliminary analysis also suggested the dependent variables were skewed, so we used generalized linear modeling with the log link and gamma family in this exploratory step (420). In the second step, we performed the more appropriate negative binomial regression analysis since the dependent variables consisted of non-negative integers and overdispersed dependent variables (mean < variance). Since the sample sizes were small, we used bootstrapped bias-corrected confidence intervals for odds ratios and rate ratio estimates. Bootstrapping (SWBOOT command in STATA) was used to validate the selection of variables included in the model: 2,000 bootstrap samples were drawn from the original dataset (421). Variables where >50% of bootstrap samples identified it as an independent predictor of the outcome were used in the final model. Because there is minimal information published on quantitative analysis of risk factors of illegal wildlife trade, we did not correct for multiple comparisons in this preliminary study. Countries with one or more illegal exported or imported shipment of an elephant were used in elephant analyses, one or more shipment of rhinoceros in rhinoceros analyses, one or more shipment of a tiger in tiger analyses, and one or more shipment of an elephant, rhinoceros, or tiger in the combined elephant, rhinoceros, or tiger analyses.

2.3 Results

A total of 232 international shipments of elephant products were exported from 49 countries and imported to 39 countries, 165 international shipments of rhinoceros products were exported from 32 countries and imported to 26 countries, and 108 international shipments of tiger products were exported from 15 countries and imported to 16 countries, for a total of 505 international shipments exported from 58 countries and imported to 51 countries. Shipment and key factor data by country for elephants, rhinoceros, tigers, and combined elephant, rhinoceros, and tigers are presented in Tables 1-4.

Graphical analysis of cross-classification of the key factors revealed no obvious relationship between the independent variables (Figure 2). This was confirmed by statistical analysis of collinearity (tolerance>0.1 for all variables). Graphical analysis of the number of shipments by country for each dependent variable revealed that the data was positively skewed justifying the choice of generalized linear model with the log link and gamma family (Figure 3). Graphical examination of the number of shipments by each key factor revealed evidence of non-linearity (Figure 2), so piecewise regression was explored. Models with the lowest AIC are highlighted in Table 5. About half of the associations between the key factors and the number of shipments were best described by a linear spline. Plausible interactions were found not to improve the model.

Multiple linear regression revealed very few significant associations between key factors and the number of illegal shipments (Table 6). Negative associations were found between corruption[1] and elephant imports for countries with a Corruption Perception Index greater than 25 and between unemployment and rhinoceros exports for countries with unemployment rates greater than 12% (Table 6). However, only five of the eight models were able to run, likely due to inadequate specification of the model.

The more appropriate negative binomial regression ran all models successfully (Table 6). Here we again found negative associations with corruption and animal imports and unemployment (for countries >12%) and animal exports (Table 6). When we resampled the data to see how often the key factors would be selected as independent predictors, one to two variables were selected greater than 50% of the time for each model (Table 7), and these were the key factors used in the final models. In our final models, we found an association between corruption and the exports of tigers and the imports of elephants and the imports of an elephant, rhinoceros, or tiger (Table 8). Every unit increase in the Corruption Perception Index is associated with a 6% decrease in tiger exports, a 4% increase in elephant imports (for countries with Corruption Perception Index>25), and a 6% increase in an elephant, rhinoceros, or tiger import (for countries with Corruption Perception Index<48) over a 2 year 5 month period. In other words, a decrease in corruption (high Corruption Perception Indices) was associated with a decrease in tiger exports and an

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[1] Low Corruption Perception Indices correspond to countries with more perceived corruption.

increase in elephant imports and in an elephant, rhinoceros, or tiger import. We also found an association between unemployment and exports of rhinoceros products and exports of an elephant, rhinoceros, or tiger product (Table 8). Every percent increase in a country's unemployment is associated with a 29% decrease in rhinoceros exports (for countries with unemployment>12%) and a 12% decrease in the export of an elephant, rhinoceros, or tiger product (for countries with an unemployment<12%) over a 2 year 5 month period. In other words, an increase in unemployment was associated with a decrease in exports of rhinoceros products and in exports of an elephant, rhinoceros, or tiger product.

2.4 Discussion

This paper considered the possibility that selected key factors were associated with the illegal trade in wildlife. If it is true that unemployment, corruption, and road development impact the illegal wildlife trade, there should be an obvious relationship between these factors and the trade. We examined this hypothesis with respect to the magnitude of exports and imports of illegal (1) exports of elephant products, (2) imports of elephant products, (3) exports of rhinoceros products, (4) imports of rhinoceros products, (5) exports of tiger products, (6) imports of tiger products, (7) exports of elephant, rhinoceros, or tiger products, and (8) imports of elephant, rhinoceros, or tiger products. Despite the inherent variability of the wildlife trade data and our limited sample size, there was suggestive evidence that associations between the selected key factors and certain aspects of the illegal wildlife trade did exist. For example, in our final models, when we examined the magnitude of the trade, there was an association between Corruption Perception Index and illegal trade; countries with less corruption were more likely to import elephant products or and elephant, rhinoceros, or tiger product and countries with more corruption were more likely to export tiger products. The relationship between exports and corruption was expected, and the relationship between imports and decreased corruption may be more of an indication of a country's wealth; future work should assess if country wealth is a confounding variable. We also found an association between unemployment and illegal trade; for countries with unemployment greater than 12%, rhinoceros exports decreased as unemployment increased. This finding was the opposite of the trend that was expected, however people in countries with extreme unemployment may be incapacitated and lack the means (e.g. transportation, arms, contacts with market chain) to acquire and trade wildlife. However, in countries with relatively low unemployment (less than 12%), exports of an elephant, rhinoceros, or tiger product increased as unemployment decreased. The economic markets in countries with low unemployment rates may be efficient and optimized in legal as well as illegal means (see Chapter 3). Further study into the key factors is warranted to better understand their role.

In summary, we did find some associations between the magnitude of various indices of the illegal trade and the Corruption Perception Index and unemployment, but not with road development, at a country-level. Refinement of the model in terms of scale, time, taxa, and usage of interaction terms, confounders, and instrumental variables could yield differing results (388, 389, 422, 423). The data are aggregated here at the *country-level*; however the key factors may play a more significant role at differing spatial scales or distinct settings. Examples include roads being built in areas of high biodiversity or an increase in the level of unemployment near wildlife reserves. We examined wildlife trade at *one point in time* mainly due to the limited of timespan of HWT, however future work could account for the changes over time. We chose to examine three *animal taxa as a whole*; further research could examine if there is an association for particular animal products, such as elephant ivory or rhinoceros horn or tiger bones, or different taxa. In addition to interaction terms, there may also be *confounders* for which we did not account. We allude to unemployment, corruption and road development confounders earlier. For example, one may see greater illegal wildlife imports in more affluent countries which tend to have less unemployment, corruption, and media censorship, but the affluence of a country is a better variable to examine in order to explain the association with greater wildlife importation; the opposite effect would be expected for exports. Finally, corruption may not be independent of wildlife trade but rather *jointly determined* as Ferraro (2005) suggested (388). We are not aware of an appropriate instrumental variable to test for this.

Missing data was a limitation in this study. HWT data involves illegal actions and it captures these actions through the web, so there will naturally be missing data inherent to this dataset. We accounted for media censorship, however there could still be missing data due to variability in media coverage and the language of the curated reports (334). HWT database has tried to minimize any bias from missing data through a systematic approach to collecting data and using a number of languages (Japanese and English).

There may also be selection bias. An intercepted illegal transaction without its known origin or destination was discarded. We also only examined the most frequently traded animals. This selection method could have had an effect on the regression results and could be an area for future study.

A limitation of this analysis is that it is based on a relatively small sample size. The unit of analysis was country, and there are not many countries that trade elephants, rhinoceros, and tigers. In order to gain a larger sample size, we conducted the same analyses for all three animals collectively. Given the exploratory nature of the study and small sample size, we did not correct for multiple comparisons. Future research should include repeating these analyses with a larger and more diverse dataset; as HWT continues to expand its database by time, geographic coverage, and taxa, sample size concerns should improve.

Table 1. Data on 2012 Key Factors and Number of Imported and Exported Illegal Elephant Shipments Based on HealthMap Wildlife Trade Reports from August 2010-December 2013

Country	Corruption Perception Index	Unemployment	Elephant Population Size	Road Development	World Press Freedom Index	Number of Exported Shipments	Number of Imported Shipments
Angola	22	6.9	818	0	58.43	3	0
Bangladesh	26	4.5	300	5.099324	57	1	2
Benin	36	1	916		31	1	2
Bhutan	63	2.1	60	20.89535	24	1	1
Burkina Faso	38	3.3	4154	0.2128133	23.33	2	0
Burundi	19	7	0	-3.725829	57.75	2	0
Cambodia	22	0.2	250	0.7115038	55	2	1
Cameroon	26	3.8	775	-0.0512028	35	5	1
Central African Republic	26	6.9	1019	0	20	3	0
Chad	19	7	454	0	37.67	2	1
China	39	4.5	178	2.448912	136	2	50
Cote d'Ivoire	29	4.1	211	0.8316666	83.5	3	1
DRC	21	8.2	1708	-0.5578026	67.67	10	0
Egypt	32	12.7	0	10.74937	97.5	1	8
Ethiopia	33	5.4	628	10.22513	56.6	3	2
France	71	9.9	857	0.2795761	9.5	3	0
Gabon	35	20.3	9253	0	36.5	6	0
Germany	79	5.4	0	-0.0124266	-3	3	2
Ghana	45	4.2	857	-9.355394	11	2	0
Greece	36	24.2	0	0	24	1	0
Hong Kong	77	3.3	0	0.4816956	17	5	27
India	36	3.6	26000	2.354707	58	8	0
Indonesia	32	6.1	3600	1.906984	68	0	2
Italy	42	10.7	0	0.3107153	19.67	0	1
Japan	74	4.3	0	0.7308856	-1	0	2
Kenya	27	9.2	26427	159.7156	29.5	40	16
Laos	21	1.4	600	-13.60679	89	4	0
Liberia	3.2	3.7	0	0	40.5	1	0
Malawi	37	7.6	865	-0.101311	68	0	1
Malaysia	49	3	1223	7.634191	56	5	10
Mozambique	31	8.3	17753	0	21.5	8	4
Myanmar	15	3.3	1181	9.913605	100	6	0
Namibia	48	16.7	16054	3.414292	-2	1	0
Nepal	27	2.7	109	3.802162	38.75	6	4
New Zealand	90	6.9	0	0.1147788	-5.33	0	1
Niger	33	5.1	85	1.678189	2.5	0	1
Nigeria	27	7.5	0	-0.1023694	56.4	7	3
Philippines	34	7	0	-0.0115103	64.5	1	5
Portugal	63	15.6	0	1.136364	5.33	1	0
Qatar	68	0.5	0	-7.171923	46	1	0
Republic of Congo	26	6.6	7198	0	30.38	1	0
Russia	28	5.5	0	8.964144	66	4	0
Rwanda	53	0.6	34	4.183333	81	1	0
Singapore	87	2.8	0	1.036423	61	2	3
Somalia	8	6.9	0	0	88.33	0	2
South Africa	43	25	93	0.5611725	12	11	2
Sri Lanka	40	4	5879	2.467981	87.5	0	1
Sudan	13	14.8	1172	0	100.75	5	3
Switzerland	86	4.2	0	0.0069973	-6.2	0	1
Taiwan	61	4.2	0		13	0	2
Tanzania	35	3.5	95351	3.263712	6	22	2
Thailand	37	0.7	1000	25.5314	61.5	7	26

Table 1. Continued

Country	Corruption Perception Index	Unemployment	Elephant Population Size	Road Development	World Press Freedom Index	Number of Exported Shipments	Number of Imported Shipments
Togo	30	7	4	7.849544	28.5	6	0
UAE	68	4	0	0.3101737	45	4	4
Uganda	29	4.2	2223		64	9	5
UK	74	8	0	0.0102472	2	2	1
USA	73	8.2	0	0.2492924	14	2	9
Vietnam	31	1.8	83	5.577319	114	3	22
Zimbabwe	20	5.3	47366	0.7522951	55	3	1

Table 2. Data on 2012 Key Factors and Number of Imported and Exported Illegal Rhinoceros Shipments Based on HealthMap Wildlife Trade Reports from August 2010-December 2013

Country	Corruption Perception Index	Unemployment	Rhinoceros Population Size	Road Development	World Press Freedom Index	Number of Exported Shipments	Number of Imported Shipments
Australia	85	5.2	0	-0.2876724	4	0	1
Bangladesh	26	4.5	0	5.099324	57	0	2
Belgium	75	7.5	0	0	-2	4	0
Cambodia	22	0.2	0	0.7115038	55	1	0
China	39	4.5	0	2.448912	136	2	50
Czech Republic	49	7	0	-0.0076528	-5	1	1
DRC	21	8.2	0	-0.5578026	67.67	0	1
Ethiopia	33	5.4	0	10.22513	56.6	2	2
France	71	9.9	0	0.2795761	9.5	3	0
Germany	79	5.4	0	-0.0124266	-3	3	0
Guinea	24	1.7	0	0	30	1	0
Hong Kong	77	3.3	0	0.4816956	17	4	5
India	36	3.6	2619	2.354707	58	10	0
Ireland	69	14.7	0	-0.0322806	-4	2	5
Italy	42	10.7	0	0.3107153	19.67	3	0
Japan	74	4.3	0	0.7308856	-1	0	1
Kenya	27	9.2	959	159.7156	29.5	8	1
Laos	21	1.4	0	-13.60679	89	1	1
Malaysia	49	3	0	7.634191	56	3	3
Mozambique	31	8.3	7	0	21.5	10	12
Myanmar	15	3.3	0	9.913605	100	6	2
Namibia	48	16.7	2219	3.414292	-2	1	0
Nepal	27	2.7	460	3.802162	38.75	1	0
Nigeria	27	7.5	0	-0.1023694	56.4	5	0
Philippines	34	7	0	-0.0115103	64.5	4	1
Poland	58	10.1	0	1.512328	-0.67	0	1
Portugal	63	15.6	0	1.136364	5.33	1	0
Qatar	68	0.5	0	-7.171923	46	5	3
Singapore	87	2.8	0	1.036423	61	1	0
Somalia	8	6.9	0	0	88.33	1	1
South Africa	43	25	20711	0.5611725	12	51	3
South Korea	56	3.2	0	0.3467058	12.67	0	4
Taiwan	61	4.2	0		13	0	4
Thailand	37	0.7	0	25.5314	61.5	5	9
Uganda	29	4.2	9		64	2	1
UK	74	8	0	0.0102472	2	7	1
USA	73	8.2	0	0.2492924	14	7	0
Vietnam	31	1.8	2	5.577319	114	4	49
Zimbabwe	20	5.3	721	0.7522951	55	6	1

Table 3. Data on 2012 Key Factors and Number of Imported and Exported Illegal Tiger Shipments Based on HealthMap Wildlife Trade Reports from August 2010-December 2013

Country	Corruption Perception Index	Unemployment	Tiger Population Size	Road Development	World Press Freedom Index	Number of Exported Shipments	Number of Imported Shipments
Bangladesh	26	4.5	440	5.099324	57	1	2
Botswana	65	17.7	0	5.49172	12	0	1
Cambodia	22	0.2	10	0.7115038	55	1	1
Canada	84	7.2	0	0	-5.67	2	0
China	39	4.5	40	2.448912	136	1	45
India	36	3.6	1200	2.354707	58	29	2
Indonesia	32	6.1	450	1.906984	68	2	0
Iran	28	13.1	0	15.18158	136.6	0	1
Japan	74	4.3	0	0.7308856	-1	0	3
Laos	21	1.4	30	-13.60679	89	14	7
Malaysia	49	3	300	7.634191	56	4	1
Myanmar	15	3.3	100	9.913605	100	17	13
Nepal	27	2.7	121	3.802162	38.75	12	6
Russia	28	5.5	350	8.964144	66	9	0
Singapore	87	2.8	0	1.036423	61	0	1
South Africa	43	25	0	0.5611725	12	3	0
Sri Lanka	40	4	0	2.467981	87.5	1	0
Thailand	37	0.7	250	25.5314	61.5	7	12
UAE	68	4	0	0.3101737	45	0	2
UK	74	8	0	0.0102472	2	0	1
Vietnam	31	1.8	100	5.577319	114	5	10

Table 4. Data on 2012 Key Factors and Number of Imported and Exported Illegal Elephant, Rhinoceros and Tiger Shipments Combined Based on HealthMap Wildlife Trade Reports from August 2010-December 2013

Country	Corruption Perception Index	Unemployment	Elephant, Rhinoceros, and Tiger Population Size	Road Development	World Press Freedom Index	Number of Exported Shipments	Number of Imported Shipments
Angola	22	6.9	818	0	58.43	3	0
Australia	85	5.2	0	-0.2876724	4	0	1
Bangladesh	26	4.5	740	5.099324	57	2	6
Belgium	75	7.5	0	0	-2	4	0
Benin	36	1	916		31	1	2
Bhutan	63	2.1	60	20.89535	24	1	1
Botswana	65	17.7	0	5.49172	12	0	1
Burkina Faso	38	3.3	4154	0.2128133	23.33	2	0
Burundi	19	7	0	-3.725829	57.75	2	0
Cambodia	22	0.2	260	0.7115038	55	4	2
Cameroon	26	3.8	775	-0.0512028	35	5	1
Canada	84	7.2	0	0	-5.67	2	0
Central African Republic	26	6.9	1019	0	20	3	0
Chad	19	7	454	0	37.67	2	1
China	39	4.5	218	2.448912	136	5	145
Cote d'Ivoire	29	4.1	211	0.8316666	83.5	3	1
Czech Republic	49	7	0	-0.0076528	-5	1	1
DRC	21	8.2	1708	-0.5578026	67.67	10	1
Egypt	32	12.7	0	10.74937	97.5	1	8
Ethiopia	33	5.4	628	10.22513	56.6	5	4
France	71	9.9	857	0.2795761	9.5	6	0
Gabon	35	20.3	9253	0	36.5	6	0
Germany	79	5.4	0	-0.0124266	-3	6	2
Ghana	45	4.2	857	-9.355394	11	2	0
Greece	36	24.2	0	0	24	1	0
Guinea	24	1.7	0	0	30	1	0
Hong Kong	77	3.3	0	0.4816956	17	9	32
India	36	3.6	29819	2.354707	58	47	2
Indonesia	32	6.1	4050	1.906984	68	2	2
Iran	28	13.1	0	15.18158	136.6	0	1
Ireland	69	14.7	0	-0.0322806	-4	2	5
Italy	42	10.7	0	0.3107153	19.67	3	1
Japan	74	4.3	0	0.7308856	-1	0	6
Kenya	27	9.2	27386	159.7156	29.5	48	17
Laos	21	1.4	630	-13.60679	89	19	8
Liberia	3.2	3.7	0	0	40.5	1	0
Malawi	37	7.6	865	-0.101311	68	0	1
Malaysia	49	3	1523	7.634191	56	12	14
Mozambique	31	8.3	17760	0	21.5	18	16
Myanmar	15	3.3	1281	9.913605	100	29	15
Namibia	48	16.7	18273	3.414292	-2	2	0
Nepal	27	2.7	690	3.802162	38.75	19	10
New Zealand	90	6.9	0	0.1147788	-5.33	0	1
Niger	33	5.1	85	1.678189	2.5	0	1
Nigeria	27	7.5	0	-0.1023694	56.4	12	3
Philippines	34	7	0	-0.0115103	64.5	5	6
Poland	58	10.1	0	1.512328	-0.67	0	1
Portugal	63	15.6	0	1.136364	5.33	2	0
Qatar	68	0.5	0	-7.171923	46	6	3
Republic of Congo	26	6.6	7198	0	30.38	1	0

Table 4. Continued

Country	Corruption Perception Index	Unemployment	Elephant, Rhinoceros, and Tiger Population Size	Road Development	World Press Freedom Index	Number of Exported Shipments	Number of Imported Shipments
Russia	28	5.5	350	8.964144	66	13	0
Rwanda	53	0.6	34	4.183333	81	1	0
Singapore	87	2.8	0	1.036423	61	3	4
Somalia	8	6.9	0	0	88.33	1	3
South Africa	43	25	20804	0.5611725	12	65	5
South Korea	56	3.2	0	0.3467058	12.67	0	4
Sri Lanka	40	4	5879	2.467981	87.5	1	1
Sudan	13	14.8	1172	0	100.75	5	3
Switzerland	86	4.2	0	0.0069973	-6.2	0	1
Taiwan	61	4.2	0		13	0	6
Tanzania	35	3.5	95351	3.263712	6	22	2
Thailand	37	0.7	1250	25.5314	61.5	19	47
Togo	30	7	4	7.849544	28.5	6	0
UAE	68	4	0	0.3101737	45	4	6
Uganda	29	4.2	2232		64	11	6
UK	74	8	0	0.0102472	2	9	3
USA	73	8.2	0	0.2492924	14	9	9
Vietnam	31	1.8	185	5.577319	114	12	81
Zimbabwe	20	5.3	48087	0.7522951	55	9	2

Table 5. Comparison of Models with and without a Linear Spline Function Describing the Effects of the 2012 Key Factors on Number of Shipments Based on HealthMap Wildlife Trade Reports from August 2010-December 2013[2]

Model	*N*	Number of knots	AIC
Elephant exports + roads	56	0	4.541002
	56	1	4.576477
Elephant imports + roads	56	0	4.682355
	56	1	4.463349
Rhinoceros exports + roads	37	0	5.061259
	37	1	5.115215
Rhinoceros imports + roads	37	0	5.033634
	37	1	4.801103
Tiger exports + roads	21	0	5.465386
	21	1	5.549034
Tiger imports + roads	21	0	5.445304
	21	1	5.508704
Elephant, Rhinoceros, and Tiger exports + roads	66	0	5.957842
	66	1	5.987916
Elephant, Rhinoceros, and Tiger imports + roads	66	0	6.001512
	66	1	5.896224
Elephant exports + Corruption Perception Index	59	0	4.670425
	59	1	4.696602
Elephant imports + Corruption Perception Index	59	0	4.775783
	59	1	4.672755
Rhinoceros exports + Corruption Perception Index	39	0	4.969704
	39	1	4.894346
Rhinoceros imports + Corruption Perception Index	39	0	4.768587
	39	1	4.402106
Tiger exports + Corruption Perception Index	21	0	4.61083
	21	1	4.704126
Tiger imports + Corruption Perception Index	21	0	5.140457
	21	1	5.097451
Elephant, Rhinoceros, and Tiger exports + Corruption Perception Index	69	0	5.89631
	69	1	5.888153
Elephant, Rhinoceros, and Tiger imports + Corruption Perception Index	69	0	6.0125
	69	1	5.868535
Elephant exports + unemployment	59	0	4.78848
	59	1	4.81609
Elephant imports + unemployment	59	0	4.635901
	59	1	4.669614
Rhinoceros exports + unemployment	39	0	4.575745
	39	1	4.571008
Rhinoceros imports + unemployment	39	0	4.805802
	39	1	4.654881[3]
Tiger exports + unemployment	21	0	5.280721
	21	1	5.220359
Tiger imports + unemployment	21	0	4.88555
	21	1	4.960355
Elephant, Rhinoceros, and Tiger exports + unemployment	69	0	6.012694
	69	1	5.95725

[2] Lowest AIC values are highlighted.

Table 5. Continued

Model	*N*	Number of knots	AIC
Elephant, Rhinoceros, and Tiger imports + unemployment	69	0	5.732035
	69	1	5.641047
Elephant exports + animal	59	0	4.514608
	59	1	4.496514
Elephant imports + animal	59	0	4.797141
	59	1	4.787646
Rhinoceros exports + animal	39	0	4.407302
	39	1	4.436251
Rhinoceros imports + animal	39	0	4.976458
	39	1	4.369977[3]
Tiger exports + animal	21	0	5.04268
	21	1	5.129848
Tiger imports + animal	21	0	5.398308
	21	1	5.474139
Elephant, Rhinoceros, and Tiger exports + animal	69	0	5.672863
	69	1	5.583057
Elephant, Rhinoceros, and Tiger imports + animal	69	0	6.012702
	69	1	6.0387
Elephant exports + press	59	0	4.798691
	59	1	4.576294[3]
Elephant imports + press	59	0	4.482039
	59	1	4.486093
Rhinoceros exports + press	39	0	4.955536
	39	1	5.115272
Rhinoceros imports + press	39	0	4.013753
	39	1	4.830216
Tiger exports + press	21	0	5.346156
	21	1	5.465386
Tiger imports + press	21	0	4.576184
	21	1	5.445304
Elephant, Rhinoceros, and Tiger exports + press	69	0	6.0219
	69	1	5.987916[3]
Elephant, Rhinoceros, and Tiger imports + press	69	0	5.251872
	69	1	5.891728

[3] Despite improved AIC values, this term was not included as a spline function in final model due to collinearity.

Table 6. Multivariable Linear and Negative Binomial Regression Models of All 2012 Key Factors with the Number of Illegal Wildlife Shipments Based on HealthMap Wildlife Trade Reports from August 2010-December 2013[4]

Type of trade	N	Key factor	Linear Regression			Negative Binomial Regression		
			OR	95% bias-corrected CI		Rate Ratio	95% bias-corrected CI	
Elephant exports	56	Road development	1.01	0.98	1.03	1.01	0.95	1.03
		Corruption Perception Index	0.99	0.98	1.01	0.99	0.98	1.00
		Unemployment	1.02	0.96	1.06	1.02	0.96	1.06
Elephant imports	56	Road development (<20)	1.10	1.00	1.17	1.08	0.96	1.21
		Road development (>20)	1.01	0.50	1.12	1.01	0.01	1.69
		Corruption Perception Index (<25)	1.09	0.99	1.45	1.08	1.00	1.77
		Corruption Perception Index (>25)	1.04	1.02	1.05	1.04	1.01	1.06
		Unemployment	1.00	0.56	1.05	0.98	0.86	1.07
Rhinoceros exports	37	Road development	1.00	0.73	1.04	1.00	0.93	1.14
		Corruption Perception Index (<30)	1.04	0.93	1.11	1.04	0.93	1.17
		Corruption Perception Index (>30)	1.00	0.98	1.04	1.00	0.99	1.04
		Unemployment (<12%)	1.09	0.94	1.32	1.08	0.98	1.24
		Unemployment (>12%)	0.65	0.44	0.99	0.65	0.47	0.96
Rhinoceros imports	37	Road development (<20)	N/A[5]			1.02	0.93	1.12
		Road development (>20)				0.99	0.91	1.06
		Corruption Perception Index (<45)				1.09	0.98	1.15
		Corruption Perception Index (>45)				0.99	0.94	1.06
		Unemployment				1.04	0.83	1.18
Tiger exports	21	Road development	N/A[5]			0.99	0.85	1.08
		Corruption Perception Index				0.94	0.89	1.01
		Unemployment (<7%)				0.86	0.01	1.29
		Unemployment (>7%)				0.98	0.00	1.28
Tiger imports	21	Road development	N/A[5]			1.02	0.81	1.13
		Corruption Perception Index (<45)				1.02	0.95	1.18
		Corruption Perception Index (>45)				0.98	0.88	1.01
		Unemployment				0.86	0.66	1.25
Elephant, Rhinoceros, and Tiger exports	66	Road development	1.01	0.92	1.03	1.01	0.98	1.05
		Corruption Perception Index (<50)	0.99	0.95	1.03	0.99	0.96	1.02
		Corruption Perception Index (>50)	1.01	0.96	1.06	1.01	0.99	1.02
		Unemployment (<12%)	0.91	0.81	1.03	0.90	0.80	1.01
		Unemployment (>12%)	1.10	0.90	1.28	1.11	1.03	1.24
Elephant, Rhinoceros, and Tiger imports	66	Road development (<20)	1.03	0.88	1.16	1.03	0.94	1.09
		Road development (>20)	1.01	0.02	1.36	1.01	0.02	1.23
		Corruption Perception Index (<48)	1.06	0.98	1.11	1.05	1.03	1.09
		Corruption Perception Index (>48)	1.02	0.95	1.10	1.01	0.98	1.06
		Unemployment (<7%)	0.87	0.52	1.15	0.86	0.74	1.17
		Unemployment (>7%)	0.98	0.52	1.12	0.98	0.86	1.09

[4] Factors where the 95% confidence interval does not cross 1 are highlighted.
[5] Model was backed up and unable to run successfully likely due to misspecification of the model.

Table 7. Percentage Frequency Key Factors Were Selected by Bootstrap Resampling of 2000 Samples using Stata SWBOOT Program[6]

	Unemployment		Corruption Perception Index		Road Development	
Elephant export	43.5%		33.2%		73.4%	
Elephant import	10.8%		39.3% (<25)	72.2% (>25)	35.5%(<20)	61.7% (>20)
Rhinoceros export	36.8% (<12)	68.3% (>12)	26.0% (<30)	24.9% (>30)	29.1%	
Rhinoceros import	24.8%		89.9% (<45)	23.0% (>45)	13.7% (<20)	10.4% (>20)
Tiger export	35.0% (<7)	18.9% (>7)	59.6%		31.7%	
Tiger import	30.4%		44.1% (<45)	22.7% (>45)	33.4%	
Elephant, Rhinoceros or Tiger export	82.4% (<12)	62.5% (>12)	22.7% (<50)	10.6% (>50)	62.3%	
Elephant, Rhinoceros, or Tiger import	31.0% (<7)	2.7% (>7)	71.8% (<48)	5.1% (>48)	26.6% (<20)	32.5% (>20)

[6] Left and right portions of split cells represent the lower and upper ranges (ranges shown in parentheses), respectively, of the variable from piecewise regression. Factors selected in greater than 50% of the samples are highlighted.

Table 8. Final Multivariable Negative Binomial Regression Models of Bootstrap-Selected Key Factors and the Number of Illegal Wildlife Shipments Based on HealthMap Wildlife Trade Reports from August 2010-December 2013[7]

Type of trade	N	Key factor	Negative Binomial Regression		
			Rate Ratio	95% bias-corrected CI	
Elephant exports	56	Road development	1.01	0.97	1.02
Elephant imports	56	Road development (>20)	1.02	0.16	1.60
		Corruption Perception Index (>25)	1.04	1.02	1.07
Rhino exports	37	Unemployment (>12%)	0.71	0.60	0.96
Rhino imports	37	Corruption Perception Index (<45)	1.06	0.95	1.13
Tiger exports	21	Corruption Perception Index	0.94	0.90	0.99
Elephant, Rhinoceros, and Tiger exports	66	Road development	1.01	0.95	1.04
		Unemployment (<12%)	0.91	0.84	0.98
		Unemployment (>12%)	1.10	0.98	1.29
Elephant, Rhinoceros, and Tiger imports	66	Corruption Perception Index (<48)	1.06	1.02	1.11

[7] Factors where the 95% confidence interval does not cross 1 are highlighted.

Figure 2. Relationships between 2012 Key Factors and Illegal Shipments Based on HealthMap Wildlife Trade Reports from August 2010-December 2013

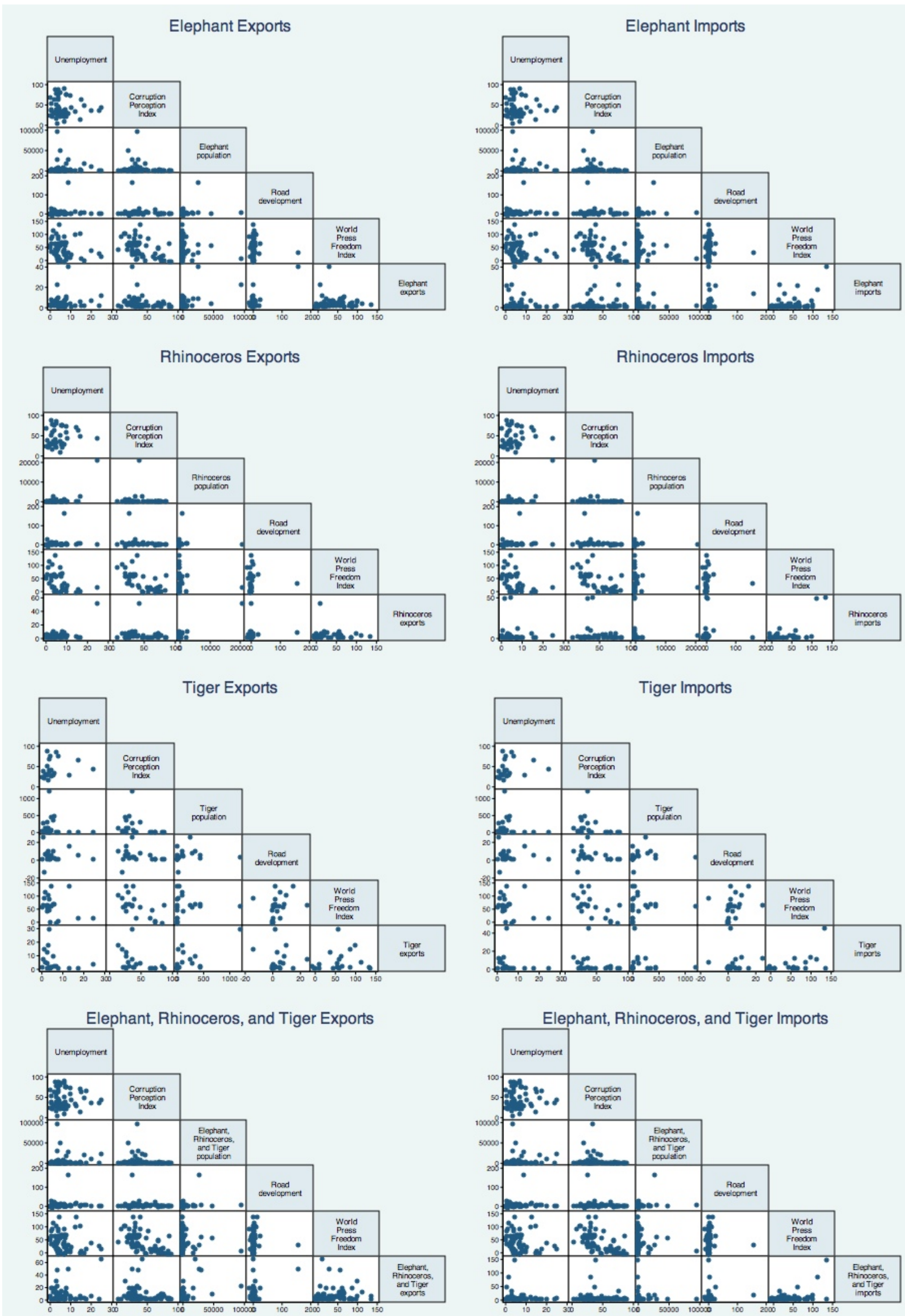
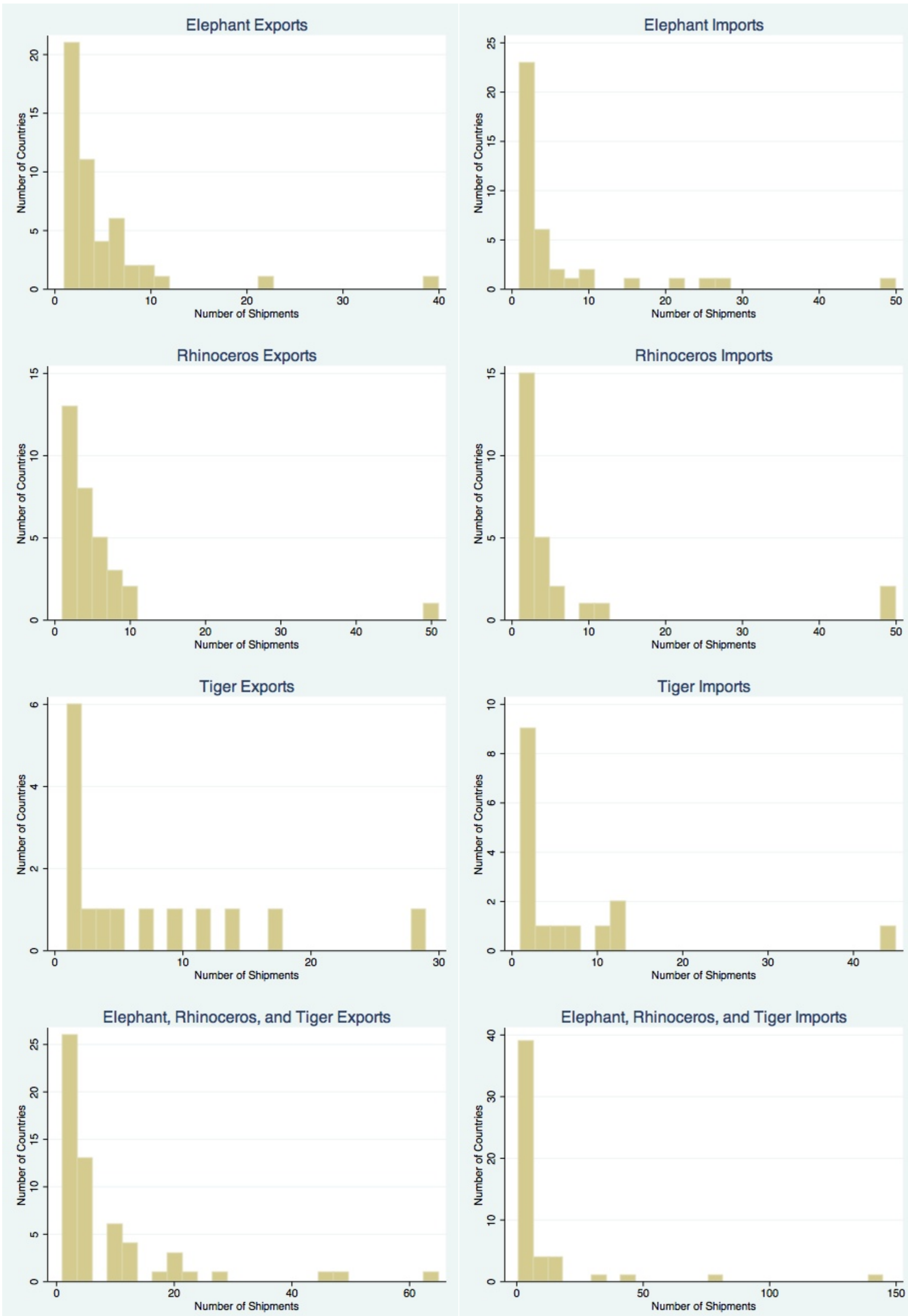


Figure 3. Frequencies of Number of Illegal Shipments by Country Based on HealthMap Wildlife Trade Reports from August 2010-December 2013



CHAPTER 3: DOES THE LEGAL INTERNATIONAL WILDLIFE TRADE PREDICT THE NATURE AND MAGNITUDE OF THE ILLEGAL WILDLIFE TRADE?

Key Words

CITES, HealthMap, elephant, rhinoceros, tiger, illegal wildlife trade, legal wildlife trade

Abstract

It has been asserted that the legal trade in wildlife provides an infrastructure that facilitates the illegal wildlife trade. If true, the legal and illegal wildlife trading networks should resemble one another. Here we explore this hypothesis by measuring the extent to which (1) the types of products traded and (2) the origins and destinations of legally and illegally traded animals and their products are the same in the HealthMap Wildlife Trade database (illegal trade) and CITES database (legal trade).

Differences between the proportions of products recorded in the HWT and CITES databases were found. As expected, the illegal elephant trade consisted mainly of ivory (94.9%) and the illegal rhinoceros trade mainly of horn (93.0%). By contrast, in the legal trade, ivory comprised only 59.2% of the elephant trade, and horn comprised only 47.1% of the rhinoceros trade. In testing the ability of the CITES database to predict the presence or absence of illegal trade in the same country in the HealthMap database, we found that the CITES database

correctly classifies countries that are involved in an illegal wildlife trade of a specific type between 44-80% of the time, and there is between 10-46% probability that a record of a legal trade of a specific type will truly predict that the country will also be involved in an illegal trade of the same type. We found two instances where the CITES database predicted the magnitude of the illegal shipments by country (elephant exports and elephant imports) and two instances where the CITES database predicted the magnitude of the illegal shipments between two countries (elephant and rhinoceros trading). While we did find some supportive evidence of the illegal trade using the infrastructure provided by the legal trade, given the limitations of the data, further exploration of the association of the illegal and legal wildlife trades is warranted.

3.1 Introduction

The illegal wildlife trade is costly to society (398). This unsustainable trade imperils biodiversity and ecosystem health through extirpations and extinctions (60, 425, 426). It facilitates disease spread in animals and humans (36, 73, 116, 233, 426), threatens international trade and rural livelihoods (427), and poses welfare concerns (10).

There are many challenges to be faced in controlling the illegal wildlife trade. Not least, it has been asserted that the legal trade not only creates a demand for wildlife products (428, 429), but also provides an infrastructure that is used by the illegal trade; the laundering of illegally-sourced wildlife into legal markets takes place by bribing officials, falsifying trade documents, and exploiting poor law enforcement (289, 294, 320, 368, 370, 425, 430–436). If this were a generalizable finding, the legal and illegal wildlife trading networks would resemble one another. The purpose of the current paper is to examine the extent to which the legal and illegal wildlife trading networks are in fact similar. In order to do this, we use the reports contained in the HealthMap Wildlife Trade database - a recently created database of illegal wildlife trade reports based on digital surveillance - and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) trade database - a global legal wildlife trade database (Hansen et al., 2012). Specifically, we measure the extent to which (1) the types of products traded and (2) the origin and destination countries of legally and illegally traded animals and their associated products are the same in the HealthMap Wildlife Trade and CITES databases.

3.2 Materials and Methods

3.2.1 Data on Illegal Wildlife Trade: the HealthMap Wildlife Trade Database

Because there is no internationally sanctioned equivalent of CITES for the illegal wildlife trade, we utilized the formal and informal reports in global digital media described by Hansen et al. (2012) to summarize the network and composition of the illegal wildlife trade. These reports are contained in the HealthMap Wildlife Trade (HWT) database (http://www.healthmap.org/wildlifetrade/). The HWT database combines official data with informal real-time media stories and reports from the public on illegal wildlife trade seizures. It is an automated web crawling surveillance system of the wildlife trade similar to those used for infectious disease events (e.g. GPHIN, HealthMap). Official sources include TRAFFIC, WildAid, The Coalition Against Wildlife Trafficking, World Wildlife Fund, and the International Fund for Animal Welfare. Unofficial sources include free and publicly available websites, discussion forums, mailing lists, news media outlets, and blogs. The database uses a text-mining algorithm based on keyword search strings, which uses news indexers that draw from over 50,000 possible web-based sources in English and Japanese (334).

We focused on the period between January 1, 2011 and December 31, 2013 and limited the scope of our wildlife trade analysis to elephants, rhinoceros, and tigers, which are the most frequently cited animals in the database (334). From each report of a unique trade interception of an "elephant", "rhinoceros", and "tiger" listed in the wildlife trade database, we extracted the type of product(s) traded, country of origin of the product, and the actual or intended country of destination of the product. A report that listed a trade interception involving multiple types of products, multiple origins, or multiple destinations was parsed so that each product type, origin, and destination was entered separately into our own database. For example, a report with an interception of tiger skins, a tiger cub, and elephant tusks resulted in three corresponding separate entries. We delineated by product type to reflect the distinctive market demands. If these items were traveling from India to Nepal to China, they were entered separately for traveling from India to Nepal and from Nepal to China. If they were sourced in India and being sent to China and Vietnam, they were entered as traveling from India to China and India to Vietnam. Each entry in our database, hereafter referred to as a "shipment," corresponded to an animal product transported between two countries; this “shipment” was the unit of analysis. Shipments without a country of origin and destination were excluded from the dataset. Shipments with the same country of origin and destination were not included here. Duplicate shipments were identified and discarded based on the identification of an identical shipment route reported in the same month with the same combination of products.

3.2.2 Data on Legal Wildlife Trade: the CITES Trade Database

The CITES trade database is a database of 7 million records of international wildlife transactions in 50,000 scientific names of taxa listed by CITES from 1975 onwards. It is publicly accessible at http://trade.cites.org. Most UN member nations participate in CITES[8]. CITES member countries are required to report all trade in CITES Appendix I and II listed species, animals that are or may become threatened with extinction. We queried the CITES trade database for all records

[8] UN members which do not participate include: Andorra, North Korea, Micronesia, Haiti, Kiribati, Marshall Islands, Nauru, South Sudan, Tajikistan, East Timor, Tonga, Turkmenistan, Tuvalu, Holy See, and Faroe Islands.

of elephants (i.e. *Loxodonta* spp., *Elephas* spp.*)*, rhinoceros (i.e. *Rhinoceros* spp., *Ceratotherium* spp., *Diceros* spp., *Dicerorhinus* spp.*)*, and tigers (i.e. *Panthera tigris)* for the dates January 1, 2011 to December 31, 2013 for all exporting and importing countries, all sources (e.g. wild sourced, born in captivity, etc.), all purposes (e.g. hunting trophy, circus, zoo, etc.), and all types of traded products referred to by CITES as trade terms (e.g. live specimens, horns, skins, etc.) (437). CITES country codes representing various and unknown were excluded from the dataset.

3.2.3 Analysis

3.2.3.1 Types of products

We investigated whether the proportions of types of traded products in the CITES database that recorded legal transactions were the same as the proportions of types of traded products in the HWT database that recorded illegal transactions. We tested this on an animal basis so an example of the hypotheses tested would be that the proportion of “ivory” transactions in CITES database elephant records differed from the proportion of “ivory” transactions in HWT database elephant records. In order to simplify the analysis we pooled the numerous types of products into groups of similar items. For example, in the records referring to “elephants,” the grouping “ivory” included all elephant products listed in the databases as ivory, carvings, ivory carvings, ivory pieces, tusk, tusks, trophies, skulls or teeth. The other similar pooled groups are described in detail in the Appendix. Despite pooling the data in this way, some groups contained less than 5 records and so Fisher’s exact test was used to test the following hypotheses: (1) the proportions of CITES database elephant records that referred to “ivory”, "live", and "other" were the same as the proportions of HWT database elephant records that referred to “ivory”, "live", and "other", (2) the proportions of CITES database rhinoceros records that referred to “horn”, "dead", and "other" were the same as the proportions of HWT database rhinoceros records that referred to “horn”, "dead", and "other", and (3) the proportions of CITES database tiger records that referred to “skin”, "live", "bones", "claws", and "other" were the same as the proportions of HWT database tiger records that referred to “skin”, "live", "bones", "claws", and "other". If the p-value associated with the Fisher's exact test was less than 0.05, we rejected the null hypothesis that the proportions of types of traded products were the same in each database.

3.2.3.2 Countries involved in trade

3.2.3.2.1 Presence or absence of shipments exported or imported by a country

If it is true that the legal trade in wildlife provides infrastructure support for the illegal trade, then we expected to predict the nature and magnitude of the illegal trade using the data recorded in the CITES database of legal trades. To test this idea, we investigated whether the presence or absence of legal trade in a country in the CITES database could predict the presence or absence of illegal trade in a country in the HWT database. We assessed the predictive ability of the CITES database in this context by calculating the sensitivity and positive predictive value (438) of one or more recorded legal shipments of a particular type as a predictor of one or more illegal shipments of the same type in the same country. Sensitivity referred to the probability that a country reports legal trade in the CITES database given that the same country reports illegal trade of the same type in the HWT database. Positive predictive value is defined here as the probability that a country reports illegal trade in the HWT database given that the same country reports legal trade of the same type in the CITES database. The presence or absence of reports of (1) elephant product exports, (2) elephant product imports, (3) rhinoceros product exports, (4) rhinoceros product imports, (5) tiger product exports, and (6) tiger product imports by country between January 1, 2011 and December 31, 2013 in the CITES database comprised the independent variable and in the HWT database comprised the dependent variable. We included all countries in the world for these analyses (N=186).

3.2.3.2.2 Magnitude of shipments exported or imported by a country

We also explored whether or not the magnitude (number of shipments from January 1, 2011 and December 31, 2013) of the legal trade in a country could reliably predict the magnitude of the illegal trade in the same country. We investigated this using regression analysis. Because the data are counts and hence positive integers, Ordinary Least Squares linear regression was not suitable and the Poisson distribution (rather than the Normal distribution) was more appropriate. Preliminary analysis of each type of shipment revealed that the dependent variables were overdispersed (mean number of illegal shipments per country < variance). Therefore, we chose negative binomial regression rather than Poisson regression (439). Preliminary analysis also suggested the dependent variables were skewed, so we used generalized linear modeling with the log link and negative binomial family. Since the sample sizes were small, we used bootstrapped bias-corrected confidence intervals for rate ratio estimates. Analysis was carried out using STATA 11.2 (418). Some of the dependent variables contained substantial numbers of zeros; therefore additional analyses were carried out to see if zero-inflated negative binomial regression was warranted. An investigation of excess zeros is necessary when zeros might arise in more than one way. For example, the zeros in the HWT data might reflect adequate surveillance and real zeros or missed shipments and false zeros. The selection criterion was provided by a bias-corrected Vuong test (440, 441).

In the negative binomial analysis, it was important that the period of observation (“exposure” period) of the dependent and independent variables is the same. For this reason we limited our analysis to data collected in HWT and CITES for a three year period between January 1, 2011 and December 31, 2013. For each model, legal trade was used as the predictor variable and illegal trade as the dependent variable. Specifically, we examined the (1) exports of elephant products, (2) imports of elephant products, (3) exports of rhinoceros products, (4) imports of rhinoceros products, (5) exports of tiger products and (6) imports of tiger products. All countries which reported at least one legal or illegal transaction via the CITES or HWT database were included in the analysis.

3.2.3.2.3 Magnitude of shipments between countries

We then explored whether or not the magnitude (number of shipments from January 1, 2011 and December 31, 2013) of the legal trade between two countries could reliably predict the magnitude of the illegal trade between the same two countries in the same direction. We treated the CITES network as our "independent" variable, and we regressed each element (weighted, directed connection between two countries) in the HWT network on its corresponding elements in the CITES network. The matrices consisted of rows and columns of countries with each cell depicting the number of shipments between the countries. Specifically, we examined the (1) elephant trade, (2) the rhinoceros trade, (3) and the tiger trade. All countries which reported at least one legal or illegal transaction via the CITES or HWT database were included in the analysis. Structural autocorrelation (the lack of independence among observations within the rows and within the columns) in network data significantly biases standard OLS models, so we investigated this using negative binomial regression analysis via a quadratic assignment procedure (442–446). Analysis was carried out using a user-written command in STATA (447).

3.3 Results

3.3.1 Types of products

We analyzed a total of 169 shipments for elephants from HWT database and 4006 from CITES database, 144 shipments for rhinoceros from HWT database and 467 from CITES database, and 77 shipments for tigers from HWT database and 425 from CITES database. There were significant differences between the proportions of product types recorded in the HWT and the CITES databases for the elephant, rhinoceros and tiger trades ($p < 0.001$ in each case, Table 9). The illegal elephant trade consisted mostly of ivory (94.7%, ivory, carvings, ivory carvings, ivory pieces, tusk(s), trophies, skulls, teeth). The illegal rhinoceros trade consisted mostly of horn (93.1%, horn(s), carvings, horn carvings, horn pieces, trophies). This contrasts with the legal elephant and rhinoceros trade in which “ivory” comprised 59.2% of the elephant trade and “horn” comprised 47.1% of the rhinoceros trade. The differences between the legal and illegal tiger trade were less easy to define. The most commonly traded tiger product in the legal trade was “live” (63.8%, live and juvenile(s)), and only 10.4% of the illegal tiger trade comprised “live." The most commonly traded tiger product in the illegal trade was “bones” (37.7%, bones, carvings, bone pieces, teeth, skull(s), skeleton(s), head), and only 4.0% of the legal tiger trade comprised “bones" (Table 9).

3.3.2 Countries involved in trade

3.3.2.1 Presence or absence of shipments exported or imported by a country

The sensitivities ranged between 44-80% and the positive predictive values ranged between 10-46% (Table 10). In other words, the CITES database correctly classifies countries that are involved in an illegal wildlife trade of a specific type between 44-80% of the time, and there is between 10-46% probability that a record of a legal trade of a specific type will truly predict that the country will also be involved in an illegal trade of the same type.

3.3.2.2 Magnitude of shipments exported or imported by a country

A total of 103 countries exported and 126 countries imported elephant products, 41 countries exported and 63 imported rhinoceros products, and 74 countries exported and 87 imported tiger products from January 1, 2011 to December 31, 2013 for the legal and illegal trades combined. The number of illegal and legal shipments by country is shown in Tables 11-16 for each shipment type. Graphical analysis suggested that there was no consistent relationship between the legal and illegal shipments (Figure 4).

For each type of shipment, the index of overdispersion (α) in the dependent variable was significantly different from zero (p-value<0.001 in all cases) justifying the choice of negative binomial rather than Poisson regression, and the bias-corrected Vuong test also indicated that the negative binomial model was to be preferred to the zero-inflated negative binomial model. Negative binomial regression revealed that there was an association between legal and illegal elephant trades (Table 17). The legal export of 10 elephant products is associated with an estimated 2% increase in the illegal export of elephant products by a country over a three-year period. Additionally, the legal import of 10 elephant products is associated with an estimated 7% increase in the illegal import of elephant products by a country (Table 17). The results for other shipment types were not statistically significant.

3.3.2.3 Magnitude of shipments between countries

A total of 143 countries engaged in legal or illegal elephant trade, 69 in rhinoceros trade, and 98 in tiger trade. Using the quadratic assignment procedure method, we found an association between the magnitude of trade between two countries in the legal and illegal trade networks for elephants and rhinoceros (Table 18). The legal trade of an elephant product from one country to another is associated with a 16% increase in the illegal trade of an elephant product from the same country to the other. Additionally, the legal trade of a rhinoceros product from one country to another is associated with a 52%

increase in the illegal trade of a rhinoceros product from the same country to the other (Table 18).

3.4 Discussion

This chapter considered the possibility that the legal trade in wildlife provides an infrastructure that facilitates the illegal trade in wildlife. Felbab-Brown (2011) asserts that the expansion of the legal trade provides access to wilderness areas from which wildlife can be illegally sourced and traded, captive breeding programs and legally-sanctioned hunting may serve as conduits for laundering wildlife, and economic stakeholders may have little disincentive to overtake legal quotas for further gain in profits (425). Liljas (2013) provides evidence in China of difficulties in identification of illegal ivory with a concurrent legal ivory trade (432). Wyatt (2013) provides an example in Russia of legal hunters taking an excess of fur-bearing animal quotas (320). There are also reports of Laotian criminals hiring Thai prostitutes to exploit loopholes in South African trophy hunting laws of rhinoceros in order to supply the illegal horn trade in Asia (448).

If these notions are correct and the case reports generalizable, there would be an obvious relationship between the illegal wildlife trade and the legal wildlife trade. We examined the international trade in multiple ways using the most frequently recorded traded animals in the HWT database. Despite the inherent variability of the illegal wildlife trade data and our limited sample size, there was suggestive evidence that associations between certain aspects of the illegal and legal wildlife trade did exist. For example, when we examined the magnitude of the trade between two countries, we did find an association for elephants and rhinoceros trading. Refinement of the model in terms of scale, time, taxa, and products may yield stronger results. For example, in this Chapter we focused on international trade, but it may be that the legal trade infrastructure is more efficiently utilized by the illegal trade at the level of within-country trade. We examined wildlife trade at one point in time mainly due to the limited of timespan of HWT, however future work could account for the changes over time. Furthermore, we chose to examine elephants, rhinoceros, and tigers, but perhaps the infrastructure of the legal wildlife trade is more highly exploited by the illegal trade in other taxa such as those of smaller animals. Moreover, the infrastructure of the legal trade may be specialized to particular animal products and therefore limiting the analysis to a particular product rather than the entire taxa may be warranted.

We did find differences in the types of products traded in the legal and illegal trade datasets. This could be explained by the price of a product being driven up if it were less readily available through the legal trade, and therefore more enticing for profit-seekers to trade in illegal markets. Theoretically, the legal trade infrastructure does not need to be specific for an animal or animal part, and therefore the results are not surprising.

There are other limitations to this study. HWT data involves illegal actions and it captures these actions through the web, so there will be missing data.

There will also be missing data due to variability in media coverage, media censorship, and the language of the curated reports (334). However, HWT database has tried to minimize this bias through a systematic approach to collecting data and using multiple languages (Japanese and English).

We examined the trade by looking at individual connections between countries. The complete path of trading of a parcel may include multiple segments of travel before arriving at the final intended destination. We make the assumption that what we find based upon examination of the individual segments of travel in the HWT database will be the same as the complete path of trade. We could not compare the complete path since the CITES database does not provide this information.

There may also be bias introduced in the way we selected data. An intercepted illegal transaction without its known origin or destination was discarded. Countries with media censorship may be more reluctant to acquire more details on the route. Transactions that did not cross international borders were also discarded, since the CITES database only captured international legal trade. Future studies examining intranational trade may find different results. We also only examined the most frequently traded animals. This selection method could have had an effect on the negative binomial regression results and could be an area for future study.

There could be reporting delays for each database, especially in the case of 2013. An official annual report on permits must be submitted to CITES by member countries and then added and uploaded to the online CITES database. It has been reported that time delays from the time of the actual trade to the inclusion in the database can take up to 22 months (449). Future studies may exclude more recent years.

It may be true in certain instances that the illegal trade uses the infrastructure of the legal trade. While we did find some associations, the data are not yet strong enough to assert this with authority. The HWT database is in its infancy with its creation in 2010. Repeating this analysis in the future when added time and refinement of the system will generate more data may provide better predictive capabilities. In the meantime, based on these findings, illegal wildlife trade prevention strategies should continue to target the trade from all possible routes.

Table 9. Quantities of Shipments of Elephant "Ivory", Rhinoceros "Horn", and Tiger "Bone" Products in the Legal and Illegal Trade from January 1, 2011 to December 31, 2013. Fisher's exact test was used to determine if proportions of product types differed by the legality of the trade.

		Number and percent of illegal trade shipments		Number and percent of legal trade shipments		Fisher's exact test[9]
Elephant	**Total**	**169**	**100%**	**4006**	**100%**	p-value <0.001
	Live	3	1.8%	80	2.0%	
	Ivory	160	94.7%	2370	59.2%	
	Other	6	3.6%	1556	38.8%	
Rhinoceros	**Total**	**144**	**100%**	**467**	**100%**	p-value <0.001
	Horn	134	93.1%	220	47.1%	
	Dead	9	6.3%	4	0.9%	
	Other	1	0.7%	243	52.0%	
Tiger	**Total**	**77**	**100%**	**425**	**100%**	p-value <0.001
	Skin	21	27.2%	53	12.5%	
	Live	8	10.4 %	271	63.8%	
	Other	17	22.1%	79	18.6%	
	Bones	29	37.7%	17	4.0%	
	Claws	2	2.6%	5	1.2%	

[9] If the p-value associated with the Fisher's exact test was less than 0.05, we rejected the null hypothesis that the proportions of types of traded products were the same in each database.

Table 10. Number of Countries Involved in Legal and Illegal Trade from January 1, 2011 to December 31, 2013 (N = 176)

	Number of countries in legal trade	Number of countries with both legal and illegal trade	Number of countries in illegal trade	Sensitivity			Positive predictive value		
					95% confidence interval			95% confidence interval	
Elephant Imports	119	32	40	80.0%	64.4%	90.9%	26.9%	19.2%	35.8%
Elephant Exports	93	37	47	78.7%	64.3%	89.3%	39.8%	29.8%	50.5%
Rhinoceros Imports	56	17	26	65.4%	44.3%	82.8%	30.4%	18.8%	44.1%
Rhinoceros Exports	26	12	27	44.4%	25.5%	64.7%	46.2%	26.6%	66.6%
Tiger Imports	85	11	15	73.3%	44.9%	92.2%	12.9%	6.6%	22.0%
Tiger Exports	69	7	13	53.8%	25.1%	80.8%	10.1%	4.2%	19.8%

Table 11. Number of Illegal and Legal Exported Shipments of Elephants by a Country from January 1, 2011 to December 31, 2013 (N = 103)

Country	Illegal	Legal
Angola	3	0
Argentina	0	22
Australia	0	67
Austria	0	70
Bangladesh	1	1
Belarus	0	3
Belgium	0	36
Benin	1	0
Bhutan	1	0
Botswana	0	162
Brazil	0	3
Brunei	0	1
Burkina Faso	2	1
Burundi	2	0
Cambodia	1	0
Cameroon	4	29
Canada	0	83
Central African Republic	2	2
Chad	2	0
Chile	0	2
China	2	23
Colombia	0	1
Cote d'Ivoire	3	14
Denmark	0	25
DRC	7	1
Egypt	1	0
El Salvador	0	1
Ethiopia	2	1
France	3	171
Gabon	3	3
Georgia	0	1
Germany	3	138
Ghana	0	4
Greece	1	9
Greenland	0	1
Hong Kong	5	21
Hungary	0	14
India	6	1
Ireland	0	4
Israel	0	10
Italy	0	89
Japan	0	27
Jordan	0	1
Kenya	22	15
Kuwait	0	5
Laos	3	7
Lebanon	0	2
Lesotho	0	1
Liberia	1	2
Liechtenstein	0	2
Macedonia	0	4
Malawi	0	2
Malaysia	4	4
Malta	0	1
Mexico	0	34
Monaco	0	33
Morocco	0	3

Table 11. Continued

Country	Illegal	Legal
Mozambique	7	205
Myanmar	5	3
Namibia	1	133
Nepal	6	0
Netherlands	0	32
New Zealand	0	47
Nigeria	5	6
Norway	0	8
Oman	0	2
Panama	0	2
Philippines	1	1
Poland	0	2
Portugal	1	2
Qatar	0	8
Republic of Congo	1	0
Romania	0	1
Russia	3	8
Rwanda	1	0
Serbia	0	1
Singapore	1	5
Slovenia	0	1
South Africa	10	852
South Korea	0	7
Spain	0	29
Sri Lanka	0	3
Sudan	5	2
Suriname	0	1
Sweden	0	3
Switzerland	0	72
Syria	0	1
Taiwan	0	1
Tanzania	17	99
Thailand	4	8
Togo	6	1
Turkey	0	5
Turks and Caicos	0	1
UAE	3	23
Uganda	5	4
UK	2	260
Uruguay	0	12
USA	2	237
Vatican	0	1
Venezuela	0	4
Vietnam	2	9
Zambia	0	37
Zimbabwe	3	710

Table 12. Number of Illegal and Legal Imported Shipments of Elephants by a Country from January 1, 2011 to December 31, 2013 (N = 126)

Country	Illegal	Legal
Albania	0	1
Algeria	0	1
Angola	0	1
Argentina	0	32
Australia	0	78
Austria	0	89
Azerbaijan	0	4
Bangladesh	1	1
Belarus	0	3
Belgium	0	43
Benin	2	0
Bhutan	1	1
Botswana	0	12
Brazil	0	11
Brunei	0	1
Bulgaria	0	16
Cambodia	1	5
Cameroon	1	0
Canada	0	103
Chad	1	0
Chile	0	1
China	38	207
Colombia	0	4
Costa Rica	0	7
Cote d'Ivoire	1	0
Croatia	0	7
Cuba	0	4
Cyprus	0	3
Czech Republic	0	40
Denmark	0	70
Djibouti	0	1
Egypt	8	3
El Salvador	0	1
Estonia	0	3
Ethiopia	2	1
Fiji	0	1
Finland	0	16
France	0	195
Gabon	0	2
Germany	2	199
Ghana	0	1
Greece	0	10
Guatemala	0	2
Honduras	0	2
Hong Kong	23	142
Hungary	0	40
India	0	3
Indonesia	2	5
Iran	0	6
Iraq	0	1
Ireland	0	4
Israel	0	6
Italy	0	91
Jamaica	0	2
Japan	1	110
Jordan	0	1
Kazakhstan	0	4

Table 12. Continued

Country	Illegal	Legal
Kenya	10	0
Kuwait	0	4
Laos	0	1
Lebanon	0	9
Lesotho	0	2
Liechtenstein	0	2
Lithuania	0	6
Luxembourg	0	11
Macau	0	13
Macedonia	0	1
Malawi	1	2
Malaysia	7	22
Malta	0	13
Mauritius	0	1
Mexico	0	92
Moldova	0	1
Monaco	0	17
Morocco	0	3
Mozambique	4	2
Namibia	0	17
Nepal	4	0
Netherlands	0	41
New Caledonia	0	1
New Zealand	1	36
Nicaragua	0	1
Niger	1	0
Nigeria	1	12
North Korea	0	2
Norway	0	58
Oman	0	5
Pakistan	0	12
Panama	0	8
Paraguay	0	4
Peru	0	1
Philippines	2	2
Poland	0	33
Portugal	0	34
Qatar	0	23
Romania	0	5
Russia	0	104
Saudi Arabia	0	7
Senegal	0	1
Singapore	2	35
Slovakia	0	35
Somalia	1	0
South Africa	2	168
South Korea	0	14
Spain	0	151
Sri Lanka	1	1
Sudan	3	1
Sweden	0	22
Switzerland	1	122
Taiwan	2	17
Tanzania	2	4
Thailand	18	7
Turkey	0	14
Turkmenistan	0	1
UAE	3	29

Table 12. Continued

Country	Illegal	Legal
Uganda	5	1
UK	1	224
Ukraine	0	29
USA	5	873
Vatican	0	1
Venezuela	0	11
Vietnam	14	15
Yemen	0	1
Yugoslavia	0	2
Zambia	0	6
Zimbabwe	1	16

Table 13. Number of Illegal and Legal Exported Shipments of Rhinoceros by a Country from January 1, 2011 to December 31, 2013 (N = 41)

Country	Illegal	Legal
Argentina	0	4
Australia	0	6
Belgium	4	0
Canada	0	14
China	2	1
Czech Republic	1	2
Denmark	0	1
Ethiopia	2	0
France	3	8
Germany	3	8
Guatemala	0	3
Guinea	1	0
Hong Kong	2	3
India	10	0
Indonesia	0	2
Ireland	2	0
Italy	3	0
Japan	0	1
Kenya	6	11
Laos	0	1
Malaysia	3	1
Mexico	0	5
Mozambique	10	0
Myanmar	5	0
Namibia	1	31
New Zealand	0	2
Nigeria	5	0
Norway	0	1
Philippines	4	0
Portugal	1	0
Qatar	5	0
Russia	0	1
Singapore	0	3
South Africa	46	297
Swaziland	0	6
Thailand	4	0
Uganda	2	0
UK	6	21
USA	7	32
Vietnam	2	0
Zimbabwe	3	2

Table 14. Number of Illegal and Legal Imported Shipments of Rhinoceros by a Country from January 1, 2011 to December 31, 2013 (N = 63)

Country	Illegal	Legal
Algeria	0	1
Argentina	0	2
Australia	1	11
Austria	0	4
Bangladesh	2	1
Belgium	0	8
Botswana	0	3
Bulgaria	0	2
Canada	0	19
Chile	0	2
China	43	24
Czech Republic	1	13
Denmark	0	9
Egypt	0	1
Ethiopia	2	0
Finland	0	1
France	0	12
Georgia	0	4
Germany	0	29
Hong Kong	5	30
Hungary	0	12
Iceland	0	3
Ireland	5	0
Israel	0	1
Italy	0	10
Japan	1	2
Kazakhstan	0	1
Kenya	1	0
Laos	1	1
Lithuania	0	3
Macau	0	2
Malaysia	2	0
Mexico	0	11
Mozambique	10	0
Myanmar	2	0
Namibia	0	12
Netherlands	0	2
Norway	0	4
Pakistan	0	1
Philippines	1	0
Poland	1	17
Portugal	0	9
Qatar	3	4
Russia	0	17
Saudi Arabia	0	1
Singapore	0	1
Slovakia	0	9
South Africa	2	19
South Korea	4	5
Spain	0	22
Swaziland	0	1
Sweden	0	9
Switzerland	0	2
Taiwan	4	6
Tanzania	0	3
Thailand	9	2
Uganda	1	0

Table 14. Continued

Country	Illegal	Legal
UK	1	11
Ukraine	0	6
USA	0	55
Vietnam	40	26
Zambia	0	1
Zimbabwe	1	0

Table 15. Number of Illegal and Legal Exported Shipments of Tigers by a Country from January 1, 2011 to December 31, 2013 (N = 74)

Country	Illegal	Legal
Algeria	0	4
Argentina	0	3
Australia	0	6
Austria	0	2
Baharain	0	1
Bangladesh	1	0
Belarus	0	2
Belgium	0	16
Bermuda	0	1
Bosnia	0	1
Botswana	0	1
Bulgaria	0	6
Cambodia	0	4
Canada	2	10
Chile	0	4
China	1	15
Costa Rica	0	1
Cote d'Ivoire	0	2
Czech Republic	0	2
Denmark	0	2
Egypt	0	5
El Salvador	0	8
France	0	13
Gabon	0	1
Germany	0	11
Ghana	0	2
Greece	0	4
Guatemala	0	4
Honduras	0	3
Hong Kong	0	2
Hungary	0	2
India	26	0
Indonesia	0	0
Ireland	0	1
Italy	0	21
Japan	0	1
Jordan	0	5
Kazakhstan	0	1
Kuwait	0	1
Kyrgystan	0	1
Laos	7	2
Lesotho	0	1
Malaysia	2	0
Mexico	0	15
Monaco	0	6
Morocco	0	7
Myanmar	13	0
Nepal	11	0
Netherlands	0	10
Nicaragua	0	1
Norway	0	2
Oman	0	3
Panama	0	1
Philippines	0	2
Portugal	0	2
Qatar	0	1
Romania	0	5

Table 15. Continued

Country	Illegal	Legal
Russia	4	31
Slovenia	0	1
South Africa	3	36
South Korea	0	7
Spain	0	11
Sri Lanka	1	0
Switzerland	0	4
Syria	0	3
Taiwan	0	2
Tanzania	0	2
Thailand	3	6
Turkey	0	15
UAE	0	16
UK	0	18
USA	0	23
Uzbekistan	0	2
Venezuela	0	1
Vietnam	3	19
Zimbabwe	0	1

Table 16. Number of Illegal and Legal Imported Shipments of Tigers by a Country from January 1, 2011 to December 31, 2013 (N = 87)

Country	Illegal	Legal
Algeria	0	6
Argentina	0	7
Australia	0	3
Austria	0	3
Bangladesh	2	1
Belarus	0	7
Belgium	0	1
Belize	0	1
Bermuda	0	1
Bhutan	0	1
Botswana	1	0
Brazil	0	1
Bulgaria	0	4
Canada	0	7
Chile	0	2
China	34	28
Colombia	0	3
Costa Rica	0	1
Cote d'Ivoire	0	1
Cuba	0	2
Czech Republic	0	6
Denmark	0	1
Egypt	0	4
Estonia	0	2
Ethiopia	0	1
France	0	5
Gabon	0	4
Georgia	0	4
Germany	0	2
Ghana	0	1
Greece	0	3
Guatemala	0	7
Honduras	0	6
Hong Kong	0	7
Hungary	0	2
India	2	0
Indonesia	0	2
Iran	0	2
Iraq	0	2
Italy	0	22
Japan	3	9
Kazakhstan	0	5
Kuwait	0	3
Laos	4	0
Lebanon	0	4
Lesotho	0	1
Malaysia	0	0
Mauritius	0	2
Mexico	0	2
Moldova	0	1
Monaco	0	3
Morocco	0	1
Myanmar	8	1
Nepal	6	0
Netherlands	0	2
New Zealand	0	3
Nicaragua	0	5

Table 16. Continued

Country	Illegal	Legal
Oman	0	4
Pakistan	0	7
Panama	0	3
Peru	0	2
Philippines	0	1
Poland	0	5
Portugal	0	1
Qatar	0	2
Romania	0	2
Russia	0	8
Saudi Arabia	0	2
Serbia	0	1
Singapore	1	2
Slovenia	0	3
South Africa	0	17
South Korea	0	12
Spain	0	5
Switzerland	0	7
Syria	0	4
Taiwan	0	1
Tanzania	0	3
Thailand	7	1
Tunisia	0	4
Turkey	0	15
UAE	2	20
UK	1	9
Ukraine	0	5
USA	0	66
Venezuela	0	1
Vietnam	6	5
Zimbabwe	0	2

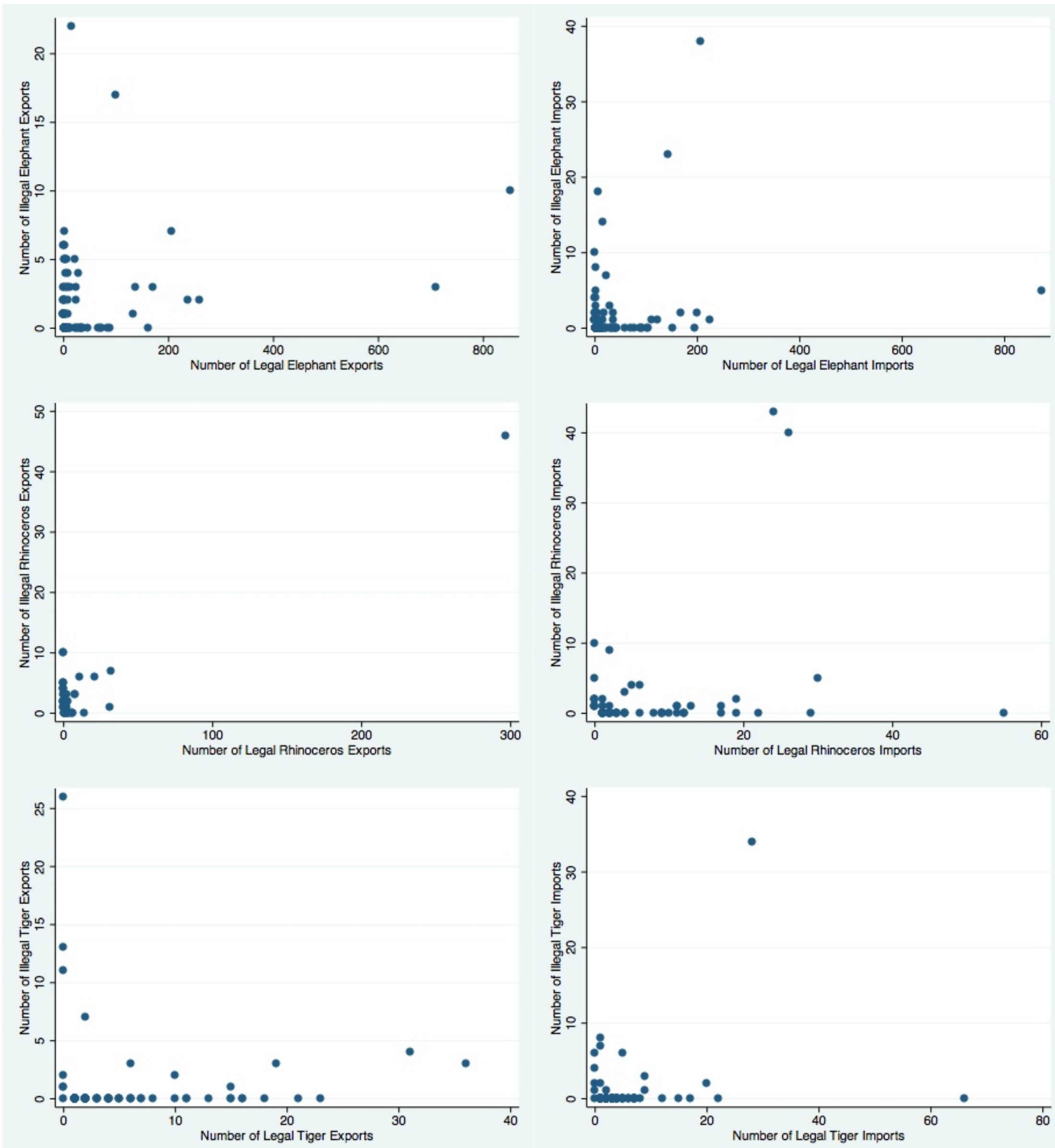
Table 17. Negative Binomial Regression Results Predicting Illegal Shipments for Every Ten Legal Shipments by a Country in a Three-Year Period from January 1, 2011 to December 31, 2013

	N	Rate Ratio	Bias-corrected 95% Confidence Interval	
Elephant exports	103	1.02	1.01	1.06
Elephant imports	126	1.07	1.00	1.13
Rhinoceros exports	41	1.10	.94	1.44
Rhinoceros imports	63	1.77	.59	3.39
Tiger exports	74	0.90	.15	1.42
Tiger imports	87	2.06	.66	5.74

Table 18. Negative Binomial Regression Results Predicting Illegal Shipments from Legal Shipments Between Two Countries in the Same Direction in a Three-Year Period from January 1, 2011 to December 31, 2013

	Matrix size (*N*)	Rate Ratio	95% Confidence Interval	
Elephants	143 x 143	1.16	1.02	1.31
Rhinoceros	69 x 69	1.52	1.11	2.07
Tigers	98 x 98	1.20	0.20	7.24

Figure 4. Relationship between Total Illegal Shipments and Total Legal Shipments by a Country from January 1, 2011 to December 31, 2013



CHAPTER 4: QUANTITATIVE METHODS OF IDENTIFYING THE KEY NODES IN THE ILLEGAL WILDLIFE TRADE NETWORK

Keywords

elephant, rhinoceros, tiger, wildlife trade, network analysis, flow betweenness centrality, key player

Abstract

Innovative approaches are needed to combat the illegal trade in wildlife. Here, we used network analysis and a new database, HealthMap Wildlife Trade, to identify the key nodes (countries) that support the illegal wildlife trade. We identified key exporters and importers from the number of shipments a country sent and received and from the number of connections a country had to other countries over a given time period. We used flow betweenness centrality measurements to identify key intermediary countries. We found the set of nodes whose removal from the network would cause the maximum disruption to the network. Selecting six nodes would fragment 89.5% of the network for elephants, 92.3% for rhinoceros, and 98.1% for tigers. We then found sets of nodes that would best disseminate an educational message via direct connections through the network. We would need to select 18 nodes to reach 100% of the elephant trade network, 16 nodes for rhinoceros and 10 for tigers. While the choice of locations for interventions should be customized for the animal and the goal of the intervention, China was the most frequently selected country for network

fragmentation and information dissemination. Identification of key countries will help strategize illegal wildlife trade interventions.

4.1 Introduction

The illegal wildlife trade is an industry in which thousands of wild animals and associated products are shipped daily around the globe as food, pets, medicines, clothing, trophies and religious amulets (7, 450). The complex illegal wildlife trade network structure often involves important intermediate stops for bulking or breaking down shipments, switching modes of transport, and manufacturing wildlife by-products (291, 451, 452). Despite advances in wildlife detection technology and general descriptive work on the illegal trade (5, 11, 58, 114, 289, 306, 332, 332, 361, 366, 451, 453–455), current prevention and control approaches are failing (339, 452). More quantitative research has been called for (289, 291, 330, 332). Accordingly, we take a more analytical approach to identify the key countries involved in the illegal wildlife trade network. Specifically, we use a new database of illegal wildlife trade reports, HealthMap Wildlife Trade (http://www.healthmap.org/wildlifetrade/), to identify (1) the key exporter, intermediary, and importer countries and (2) the countries where enforcement activities and educational campaigns might most effectively disrupt the networks. Identifying these key countries can provide useful information on how to allocate resources to combat the illegal trade in wildlife.

4.2 Materials and Methods

4.2.1 Data on Illegal Wildlife Trade: the HealthMap Wildlife Trade Database

As no comprehensive data on the volume, frequency, composition and routes of the illegal wildlife trade are publicly available, we relied upon the formal and informal reports in global digital media as described by Hansen *et al*. (2012) to summarize the network and composition of the illegal wildlife trade (334). These reports are contained in the HealthMap Wildlife Trade database (http://www.healthmap.org/wildlifetrade/). The HealthMap Wildlife Trade database combines official data with informal real-time media stories and reports from the public on illegal wildlife trade seizures. It is an automated web-crawling surveillance system of the wildlife trade similar to those used for infectious disease events (e.g. GPHIN, HealthMap). Official sources include TRAFFIC, WildAid, The Coalition Against Wildlife Trafficking, World Wildlife Fund, and the International Fund for Animal Welfare. Unofficial sources include free and publicly available websites, discussion forums, mailing lists, news media outlets, and blogs. The database uses a text-mining algorithm based on keyword search strings, which uses news indexers that draw from over 50,000 possible web-based sources in English and Japanese (334).

We focused on the period between August 1, 2010 and December 31, 2013 and limited the scope of our wildlife trade analysis to elephants, rhinoceros, and tigers, which are the most frequently cited animals in the database (334). From each report of a trade interception of an "elephant", "rhinoceros", and "tiger" listed in the wildlife trade database, we extracted the type of product(s) traded, country of origin of the product, and the actual or intended country of destination of the product. A report that listed a trade interception involving multiple types of products, multiple origins, or multiple destinations was parsed so that each product type, origin, and destination was entered separately into our own database. For example, a report with an interception of tiger skins, a tiger cub, and elephant tusks resulted in three corresponding separate entries. We delineated by product type to reflect the distinctive market demands. If these items were traveling from India to Nepal to China, they were entered separately for traveling from India to Nepal and from Nepal to China. If they were sourced in India and being sent to China and Vietnam, they were entered as traveling from India to China and India to Vietnam. Each entry in our database, hereafter referred to as a "shipment," corresponded to an animal product transported between two countries; this "shipment" was the unit of analysis. Duplicate shipments were identified based on the identification of an identical shipment route reported within a 30-day period with the same combination of products.

4.2.2 Analysis

Trade networks for elephants, rhinoceros, and tigers were mapped using Circos (http://mkweb.bcgsc.ca/tableviewer), software more widely used in genetics (456). Networks consisted of nodes joined by directed connections. The nodes in the network represented the countries of origin and destination of shipments based on the HealthMap Wildlife Trade database. Each connection was characterized by the direction of the shipment and its corresponding number of reported shipments. A pair of nodes could have two connections if trade was occurring in both directions. A connection that began and ended at the same node was not included in the analyses.

We generated basic demographics for each animal network including network size, average number of exported and imported shipments per country, and the average number of exporting and importing connections per country from August 1, 2010 to December 31, 2013 (446, 457). Network size was defined as the total number of countries, or nodes, in the network. The number of exported and imported shipments per country was defined as the total number of shipments that were sent from and received by a particular country, respectively, in a given time period. The number of exporting and importing connections per country was defined as the total number of countries to which a particular country exports and imports, respectively. For each animal, we analyzed countries that reported illegal export(s) or import(s) of that animal.

As described below, we identified the (1) the key exporter, intermediary, and importer countries and (2) the key countries where enforcement activities and educational campaigns might most efficiently disrupt the activities of the network. We identified the key exporter and importer countries based on (a) the number of shipments and (b) the number of connections departing from and arriving at a node. Key intermediary countries were identified from flow betweenness centrality, a measure of the extent to which the overall trade flow must pass through a particular node, or in other words, a node's gatekeeping role (446, 458, 459). Illegal shipments between any two particular countries will not always be directly between the two countries, but may pass through intermediate countries for processing or to avoid detection. Identifying these key nodes could help pinpoint key transit points where the trade could be stopped from moving from the source to consumers (289, 460–462). Flow betweenness was calculated using the sna package in R, but as a simple example, let us determine the flow betweenness of node A in Figure 5 (463, 464). We first observe that the only directed paths whose start or endpoint is not node A but that pass through A are BCAD, CAD, CAB, CADB and DCAB. These five paths have capacities of 1, 2, 2, 1, and 1, respectively, and so the flow betweenness of node A is 7, the sum of these five capacities. Similarly, nodes B, C, and D have flow betweennesses of 4, 5, and 3, respectively. We would then rank the four vertices in the order A, C, B, D as to their effectiveness as gatekeepers for the flow of the graph. Further details on flow betweenness calculations and R code are provided in the Appendix.

We identified sets of key countries using criteria Borgatti defined in the Key Player Problem (465, 466). We first found the set of countries whose removal from the network would maximize the fragmentation in the trade network. Fragmentation was defined as increasing the number of connections it takes to go from one node to another with an end point of having all the nodes be disconnected or isolated from one another, effectively preventing consumers from connecting with illegal wildlife products sources (465). A fragmentation index was calculated representing the proportion of the countries that are isolated after the removal of the key countries. We then found the set of nodes that act as the best seeds to disseminate information, via an educational campaign, most efficiently through the network. A reciprocal distance weighted reach index was calculated representing the weighted distance, in terms of connections, of the non-key countries to the key countries. Key countries and their associated fragmentation and reach indices were calculated using the Key Player Program (Analytic Technologies) version 1.45 (465, 466). Further details on the Key Player Program are provided in the Appendix. To examine the probability of a country being chosen as a key country, we conducted a Poisson parametric bootstrap. While methods for understanding a range of processes on networks has been described, we focused on examining each directed connection in the network as a random variable based on Poisson distribution. We assumed independence among network connections. Methods involving more relaxed homogeneity assumptions and modeling clustering and star configurations (propensity for a country to have connections with multiple network partners) have been proposed but are not examined here (467).

Borgatti's methodology was chosen because it explicitly selects the optimal set of nodes to fragment or disseminate information through the network. Since interventions are not always based on just one node, examining sets of nodes will provide more optimal results than selecting the top-ranked individual nodes in prioritizing locations for interventions (465). The Key Player Problem was developed as a general model that can be applied to public health and criminal justice problems (465). Examples include selecting a subset of people in a population to immunize in order to contain an epidemic and selecting players in order to dismantle a criminal or terrorist network (465, 468, 469). Examples of selecting the best seeds to transmit information through the network include the selection of people to promote good law abiding practices and health or implement a change initiative (465, 470–473). The Key Player Problem method lends itself well to the illegal movement of wildlife via its criminal justice and indirect public health implications.

4.3 Results

We analyzed a total of 232 international shipments of elephants, 165 shipments of rhinoceros, and 108 shipments of tigers for the period August 2010-December 2013. Because some shipment reports were duplicates, did not provide the countries of origin and destination, or involved only intranational trading, we excluded 153 shipments for elephants, 170 for rhinoceros and 197 for tigers (Table 19).

The networks, mapped in Circos, provided a visualization of the differences in the size and topology of the networks (Figure 6 A-C). Table 20 quantified what we saw in the visualized networks. The elephant trade had more nodes (59) than the rhinoceros trade (39), which had more nodes than the tiger trade (21).

For countries that engaged in elephant trading, there was an average of 3.9 shipments to 2.3 countries for the time period August 1, 2010 to December 31, 2013. Countries trading in rhinoceros products averaged 4.2 shipments to 2.2 countries, and countries trading in tiger products averaged 5.1 shipments to 1.8 countries. While the median number of shipments exported by a country was 2 for all animals, the total number of shipments was as high as 40 for elephants, 51 for rhinoceros, and 29 for tigers. Similarly the median number of countries exported to, by any country, was 1-2, but the total number of shipments was as high as 13 for elephants, 9 for rhinoceros, and 7 for tigers. The median number of shipments imported by a country was 1, but the total number of shipments was as high as 50 for elephants, 50 for rhinoceros, and 45 for tigers. The median number of countries imported from was 1, but the total number of shipments was as high as 27 for elephants, 23 for rhinoceros, and 9 for tigers (Table 20).

We next identified individual key nodes. For key exporters, Kenya and Tanzania had the highest number of exported shipments and connections to other nodes for elephants, South Africa for rhinoceros, and India for tigers (Table 21-23). For key intermediaries, Kenya, Thailand, China, and Hong Kong had the highest influence on the flow of the trade in the network (based on the flow betweenness centrality measurement) for elephants, China and Vietnam for rhinoceros, and India and Myanmar for tigers. For key importers, China, Hong Kong, Thailand, and Vietnam had the highest number of imported shipments and connections arriving from other nodes for elephants, China and Vietnam for rhinoceros, and China for tigers.

We found the set of nodes whose removal from the network (by isolating the node and effectively stopping trade in and out of the node) would cause the maximum disruption to the network. If we assume that we only have enough resources to completely remove or isolate the six nodes that would result in the most disruption to the network, we find that we can fragment 89.5% of the network for elephants, 92.3% for rhinoceros, and 98.1% for tigers (Table 24). This means that 89.5% of potential elephant trading partners cannot reach one another. The mapped networks provided a visualization of the effect of removing these six key player countries (Figure 6 A-F). China was selected as a key country for fragmenting the networks in 96.7% of bootstrapped samples for elephants and 100% for rhinoceros and tigers (Table 25).

We then found sets of one to six nodes that would disseminate information to the most nodes through connections in the network. These selected nodes would hypothetically share educational information on the perils or evils of the wildlife trade with all the nodes to which it is directly connected to in the network. Table 26 shows the percentage of the network reached by selecting the optimal set of one to six nodes. We found that we would need to select at least 18 nodes for an educational campaign to be able to reach 100% of the elephant trade network via direct connections from these nodes. Sixteen nodes would be needed for rhinoceros, and ten would be needed for tigers; however only five nodes for elephants and tigers and six nodes for rhinoceros would be needed to reach 80% of the network via direct connections. China was the most frequently selected key country with 93.3% of all bootstrap samples selecting China as a key country for information dissemination, 95.0% for rhinoceros and 80% for tigers (Table 27). The countries best identified for fragmenting the networks were not always the same as those best suited for disseminating information (though at least half are).

4.4 Discussion

Many wildlife species are facing imminent extinction. Targeted strategies and operational approaches to disrupt the illegal wildlife trade can benefit conservation and public health agendas (332, 474). Here, we quantified parameters to identify key nodes with major influence in the network in order to help develop strategies to combat the illegal wildlife trade. Key export nodes had large numbers of export shipments and connections; clearly the focus in these countries should be legislation and interdiction activities to decrease the supply. South Africa, the major exporter of rhinoceros products, should ramp up current efforts of drones and other security measures as well as integrate other novel tools to track the animals and products in the event of poaching. Key intermediary countries were transit points, which had a high influence on the flow of the trade. Key import nodes had large numbers of import shipments and connections. China, Vietnam, and Thailand have been identified in this and other studies as major intermediary and import nodes (289). The emphasis in these countries should be on improving baggage screenings at ports and airports in order to apprehend traders. Import countries can also work on reducing demand through educational campaigns and by increasing conviction rate of and penalties for consumers. Multinational organizations can allocate resources based upon the set of nodes whose removal from the network would cause the maximum disruption. It was interesting to see that the key players at best fragmenting the network were not always the countries that ranked high in import or betweenness centrality measures; the USA was selected as a key player over Malaysia in the elephant network and the UK was selected over Hong Kong, Qatar, and Kenya in the rhinoceros network. By visually examining these nodes in the networks, the importance of the distance from other key players and the diversity of the connections of the USA and the UK are seen. Finally, we have identified key countries where educational campaigns explaining illegal wildlife trade risks would likely be most effective. Again, China, Vietnam, Thailand, and India are important countries for educational programs. It is interesting to note that almost all key intermediary nodes, key import nodes, key nodes for network disruption, and key nodes for dissemination of information included China as one of its targets. With its increasing global economic importance, China has to be a major focus for wildlife trade reduction programs in order to make a real impact (331).

There are some limitations to this work. We analyzed trans-national rather than domestic smuggling here; looking into trade within a country could also be beneficial. The current approach yields 'culprit' countries; however there are forces at play exploiting wildlife in each country that are not so black and white. Thus, understanding the cultural and economic backdrop within these countries could improve our ability to devise better interventions. In addition, HealthMap data will have missing data due to variability in media coverage, media censorship, and the language of the curated reports (334). However, HealthMap has tried to minimize bias through a systematic approach to collecting data as well as sourcing data in other languages like Japanese. As the internet continues to expand and access increases by non-English users, internet-based surveillance will grow more powerful, though algorithms and assessment tools will need to continually adapt.

The key player program used an undirected (no direction for shipments between two countries) and unweighted (no frequency of shipments between two countries) network, and within-country trade was ignored. It may be possible to extend the key player algorithm to account for the direction and weight of the various routes in the future. However, for the purposes of dissemination of information, the locations of the connections between countries of the network are the most important, and not the direction or the weight, so results presented here will be of great value regardless of future studies.

Strategies for isolating nodes and dismantling the network could fail from short-term or variable enforcement efforts or non-resilient procedures (361, 451).

Disrupting the trade could push the trade to be even more underground (475, 476). To elaborate, we can think of networks as being on a spectrum from provincial (networks having mainly strong ties) to cosmopolitan (networks having mainly weak ties). Somewhere in between (a suburban network) is the most efficient dark network (475). When removing key nodes, we are pushing networks towards the cosmopolitan end of the spectrum. We need to be careful not to make provincial networks more efficient in this process. This was not a concern for the cosmopolitan wildlife trade networks we studied here. Furthermore, there are only a few ways that a shipment can make its way to international destinations, so the routes may not change too fundamentally. We recommend conducting regular analyses utilizing this database of near real-time reports to stay abreast of shifting trade routes. It would also be beneficial to expand this work to other animals heavily traded illegally, like pangolins and birds. This should be part of a varied toolkit of strategies to fight wildlife smuggling crime.

Table 19. Illegal Wildlife Trade Reports for Elephants, Rhinoceros, and Tigers Based on HealthMap Wildlife Trade Reports from August 2010-December 2013

	Elephant	Rhinoceros	Tiger
Reports listing two countries (international trade)	232	165	108
Reports listing two countries (intranational trade)	15	5	33
Reports listing only one country	123	141	147
Duplicate reports	15	24	17

Table 20. Elephant, Rhinoceros, and Tiger Network Characteristics for International Illegally Trading Countries Based on HealthMap Wildlife Trade Reports from August 2010-December 2013

	Elephant	Rhinoceros	Tiger
Size (Total number of countries)	59	39	21
Mean number of shipments	3.9	4.2	5.1
Median (Range) of exported shipments	2 (0-40)	2 (0-51)	2 (0-29)
Median (Range) of imported shipments	1 (0-50)	1 (0-50)	1 (0-45)
Mean number of connections	2.3	2.2	1.8
Median (Range) of exported connections	2 (0-13)	2 (0-9)	1 (0-7)
Median (Range) of imported connections	1 (0-27)	1 (0-23)	1 (0-9)

Table 21. Individual Node Statistics for Elephants Based on HealthMap Wildlife Trade Reports from August 2010-December 2013 (N = 59)

	Exported Shipments	Imported Shipments	Flow Betweenness[10]	Exporting Connections	Importing Connections
Angola	3	0	0	2	0
Bangladesh	1	2	1	1	1
Benin	1	2	8	1	2
Bhutan	1	1	1	1	1
Burkina Faso	2	0	0	2	0
Burundi	2	0	0	2	0
Cambodia	2	1	4	1	1
Cameroon	5	1	20	5	1
Central African Republic	3	0	0	3	0
Chad	2	1	12	2	1
China	2	50	187	2	27
Cote d'Ivoire	3	1	6	2	1
DRC	10	0	0	3	0
Egypt	1	8	24	1	4
Ethiopia	3	2	12	2	2
France	3	0	0	3	0
Gabon	6	0	0	5	0
Germany	3	2	11	3	2
Ghana	2	0	0	2	0
Greece	1	0	0	1	0
Hong Kong	5	27	111	2	13
India	8	0	0	4	0
Indonesia	0	2	0	0	1
Italy	0	1	0	0	1
Japan	0	2	0	0	2
Kenya	40	16	203	13	6
Laos	4	0	0	3	0
Liberia	1	0	0	1	0
Malawi	0	1	0	0	1
Malaysia	5	10	30	3	5
Mozambique	8	4	65	6	2
Myanmar	6	0	0	3	0
Namibia	1	0	0	1	0
Nepal	6	4	5	2	1
New Zealand	0	1	0	0	1
Niger	0	1	0	0	1
Nigeria	7	3	13	4	2
Philippines	1	5	3	1	3
Portugal	1	0	0	1	0
Qatar	1	0	0	1	0
Republic of Congo	1	0	0	1	0
Russia	4	0	0	4	0
Rwanda	1	0	0	1	0
Senegal	0	0	0	0	0
Singapore	2	3	50	2	3
Somalia	0	2	0	0	1
South Africa	11	2	29	5	2
Sri Lanka	0	1	0	0	1
Sudan	5	3	78	4	3
Switzerland	0	1	0	0	1
Taiwan	0	2	0	0	1
Tanzania	22	2	52	10	2

[10] Flow betweenness is a measure of the extent to which the overall trade flow must pass through a particular node.

Table 21. Continued

	Exported Shipments	Imported Shipments	Flow Betweenness[11]	Exporting Connections	Importing Connections
Thailand	7	26	194	4	14
Togo	6	0	0	3	0
UAE	4	4	33	3	3
Uganda	9	5	38	6	2
UK	2	1	2	2	1
USA	2	9	29	1	9
Vietnam	3	22	36	1	12
Zimbabwe	3	1	6	2	1

[11] Flow betweenness is a measure of the extent to which the overall trade flow must pass through a particular node.

Table 22. Individual Node Statistics for Rhinoceros Based on HealthMap Wildlife Trade Reports from August 2010-December 2013 (N = 39)

	Exported Shipments	Imported Shipments	Flow Betweenness[12]	Exporting Connections	Importing Connections
Australia	0	1	0	0	1
Bangladesh	0	2	0	0	1
Belgium	4	0	0	4	0
Cambodia	1	0	0	1	0
China	2	50	63	2	23
Czech Republic	1	1	4	1	1
DRC	0	1	0	0	1
Ethiopia	2	2	9	1	2
France	3	0	0	3	0
Germany	3	0	0	3	0
Guinea	1	0	0	1	0
Hong Kong	4	5	23	2	5
India	10	0	0	4	0
Ireland	2	5	10	1	4
Italy	3	0	0	3	0
Japan	0	1	0	0	1
Kenya	8	1	15	5	1
Laos	1	1	2	1	1
Malaysia	3	3	9	3	3
Mozambique	10	12	33	7	1
Myanmar	6	2	6	4	1
Namibia	1	0	0	1	0
Nepal	1	0	0	1	0
Nigeria	5	0	0	5	0
Philippines	4	1	7	3	1
Poland	0	1	0	0	1
Portugal	1	0	0	1	0
Qatar	5	3	18	3	3
Singapore	1	0	0	1	0
Somalia	1	1	1	1	1
South Africa	53	3	32	9	2
South Korea	0	4	0	0	4
Taiwan	0	4	0	0	4
Thailand	5	9	22	2	5
UK	7	1	5	4	1
USA	7	0	5	3	0
Uganda	2	1	0	2	1
Vietnam	4	49	38	1	17
Zimbabwe	6	1	4	4	1

[12] Flow betweenness is a measure of the extent to which the overall trade flow must pass through a particular node.

Table 23. Individual Node Statistics for Tigers Based on HealthMap Wildlife Trade Reports from August 2010-December 2013 (N = 21)

	Exported Shipments	Imported Shipments	Flow Betweenness[13]	Exporting Connections	Importing Connections
Bangladesh	1	2	0	1	1
Botswana	0	1	0	0	1
Cambodia	1	1	0	1	1
Canada	2	0	0	1	0
China	1	45	0	1	9
India	29	2	514	7	1
Indonesia	2	0	52	2	0
Iran	0	1	0	0	1
Japan	0	3	0	0	1
Laos	14	7	212	5	3
Malaysia	4	1	0	1	1
Myanmar	17	13	340	5	4
Nepal	12	6	0	1	1
Russia	9	0	0	1	0
Singapore	0	1	0	0	1
South Africa	3	0	120	3	0
Sri Lanka	1	0	0	1	0
Thailand	7	12	154	4	5
UAE	0	2	0	0	1
UK	0	1	0	0	1
Vietnam	5	10	0	3	4

[13] Flow betweenness is a measure of the extent to which the overall trade flow must pass through a particular node.

Table 24. Key Sets of Nodes for Best Fragmenting the Illegal Wildlife Trade Network Based on HealthMap Wildlife Trade Reports from August 2010-December 2013

Animal	Group Size	Key Player(s)	Fragmentation index[14]
Elephant	1	Kenya	0.620
	2	China, Kenya	0.673
	3	China, Thailand, Vietnam	0.735
	4	China, Kenya, Thailand, Vietnam	0.809
	5	China, Hong Kong, Kenya, Thailand, Vietnam	0.847
	6	China, Hong Kong, Kenya, Thailand, USA, Vietnam	0.895
Rhinoceros	1	China	0.670
	2	China, Vietnam	0.750
	3	China, South Africa, Vietnam	0.810
	4	China, South Africa, UK, Vietnam	0.850
	5	China, South Africa, Thailand, UK, Vietnam	0.895
	6	China, Mozambique, South Africa, Thailand, UK, Vietnam	0.923
Tigers	1	China	0.685
	2	China, India	0.799
	3	China, India, Vietnam	0.870
	4	China, India, Myanmar, Thailand	0.920
	5	China, India, Myanmar, South Africa, Thailand	0.967
	6	China, India, Laos, Myanmar, South Africa, Thailand	0.981

[14] The fragmentation measure represents the proportion of the network that would be isolated based on the removal of the key players.

Table 25. Bootstrap Results Showing How Often a Country Was Chosen as a Key Country for Fragmenting the Network

Animal	Key Players	Frequency chosen as key player
Elephant	China	96.7%
	Thailand	71.7%
	Kenya	65.0%
	Hong Kong	40.0%
	Vietnam	33.3%
	USA	21.7%
	Tanzania	8.3%
	Malaysia	5.0%
	Germany	3.3%
	Sudan	3.3%
	Uganda	1.7%
Rhinoceros	China	100.0%
	Vietnam	83.3%
	South Africa	46.7%
	Thailand	28.3%
	UK	28.3%
	Mozambique	21.7%
	Qatar	13.3%
	Ireland	11.7%
	Malaysia	6.7%
	Taiwan	5.0%
	Belgium	1.7%
	Ethiopia	1.7%
	Hong Kong	1.7%
Tigers	China	100.0%
	India	80.0%
	Thailand	50.0%
	Myanmar	48.3%
	Vietnam	31.7%
	South Africa	25.0%
	Laos	15.0%

Table 26. Key Nodes for Optimal Information Dissemination Based on HealthMap Wildlife Trade Reports from August 2010-December 2013

Animal	Group Size	Reciprocal distance reach index[15]	Key Players
Elephant	1	61.4%	China
	2	68.8%	China, Thailand
	3	74.4%	China, Kenya, Thailand
	4	79.5%	China, Kenya, Malaysia, Thailand
	5	82.3%	China, Hong Kong, Kenya, Malaysia, Thailand
	6	85.0%	China, Hong Kong, Kenya, Malaysia, Thailand, USA
Rhinoceros	1	53.6%	China
	2	62.6%	China, Vietnam
	3	70.3%	China, Hong Kong, Vietnam
	4	75.4%	Australia, China, Hong Kong, Vietnam
	5	79.3%	Belgium, China, Hong Kong, Portugal, Vietnam
	6	83.1%	Australia, China, Mozambique, South Africa, UK, Vietnam
Tigers	1	41.1%	India
	2	57.0%	China, India
	3	69.2%	China, India, Indonesia
	4	78.7%	China, India, Indonesia, Vietnam
	5	83.5%	China, India, Indonesia, Laos, South Africa
	6	87.7%	Cambodia, China, India, Indonesia, Russia, South Africa

[15] The reciprocal distance index represents the weighted distance, in terms of connections, of the non-key countries to the key countries

Table 27. Bootstrap Results Showing How Often a Country Was Chosen as a Key Country for Optimal Information Dissemination through the Network

Animal	Key Players	Frequency chosen as key player
Elephant	China	93.3%
	Kenya	58.3%
	Thailand	51.7%
	Hong Kong	36.7%
	Vietnam	33.3%
	Gabon	13.3%
	Malaysia	11.7%
	Tanzania	8.3%
	USA	8.3%
	Mozambique	6.7%
	Sudan	5.0%
	Cameroon	3.3%
	Germany	3.3%
	India	3.3%
	Portugal	3.3%
	Benin	1.7%
	Indonesia	1.7%
	New Zealand	1.7%
	Niger	1.7%
	Nigeria	1.7%
	Zimbabwe	1.7%
Rhinoceros	China	95.0%
	Vietnam	55.0%
	Qatar	21.7%
	Taiwan	21.7%
	Australia	18.3%
	Portugal	16.7%
	Nigeria	13.3%
	Malaysia	10.0%
	Mozambique	10.0%
	South Africa	10.0%
	India	8.3%
	Thailand	8.3%
	Kenya	6.7%
	Myanmar	6.7%
	Bangladesh	5.0%
	Ethiopia	5.0%
	UK	5.0%
	Zimbabwe	5.0%
	Cambodia	3.3%
	Italy	3.3%
	Japan	3.3%
	Nepal	3.3%
	Philippines	3.3%
	DRC	1.7%
	Ireland	1.7%
	Laos	1.7%
	Poland	1.7%
	Somalia	1.7%
	South Korea	1.7%
	Uganda	1.7%

Table 27. Continued

Animal	Key Players	Frequency chosen as key player
Tigers	China	80.0%
	India	66.7%
	South Africa	41.7%
	Malaysia	21.7%
	Thailand	20.0%
	Vietnam	20.0%
	Myanmar	18.3%
	Botswana	16.7%
	Indonesia	15.0%
	Cambodia	10.0%
	Iran	10.0%
	Laos	8.3%
	Japan	6.7%
	Sri Lanka	5.0%
	Russia	3.3%
	Singapore	3.3%
	UK	3.3%

Figure 5. Sample Network Depicting a Flow Betweenness Calculation

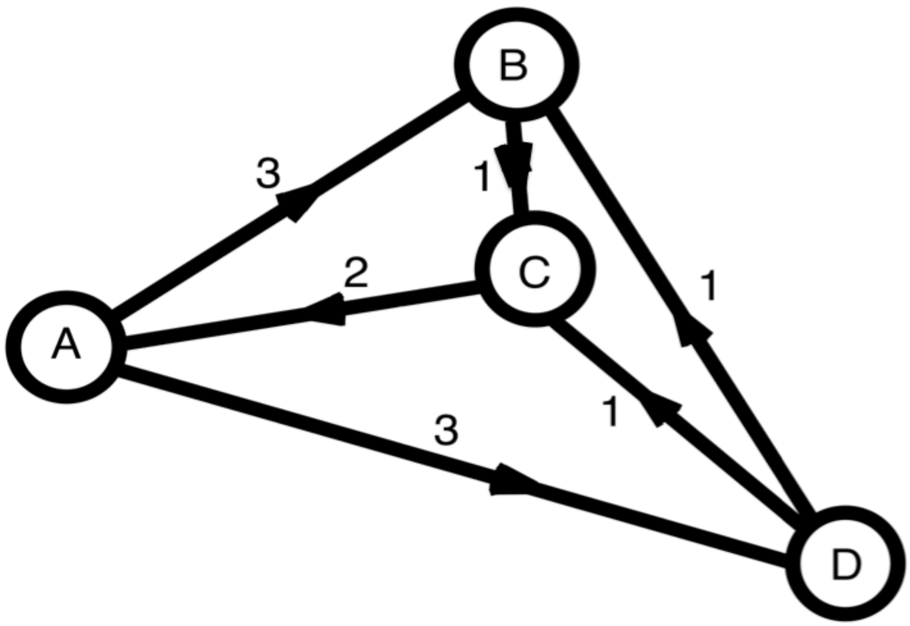


Figure 6. Illegal Wildlife Trade Flows from August 2010-December 2013 for Elephants (A), Rhinoceros (B), and Tigers (C). Networks before (A-C) and after removal (D-F) of trading by the six fragmentation key player countries (underlined in blue) shown here. Tick marks indicate the number of shipments. Trade flow ribbons adjacent to a country indicate outflow and ribbons with a gap next to a country indicate inflow (see arrows). Information dissemination key players are underlined in red. Figure created in Circos (see methods section)

Figure 6. Continued

A. Illegal Elephant Network

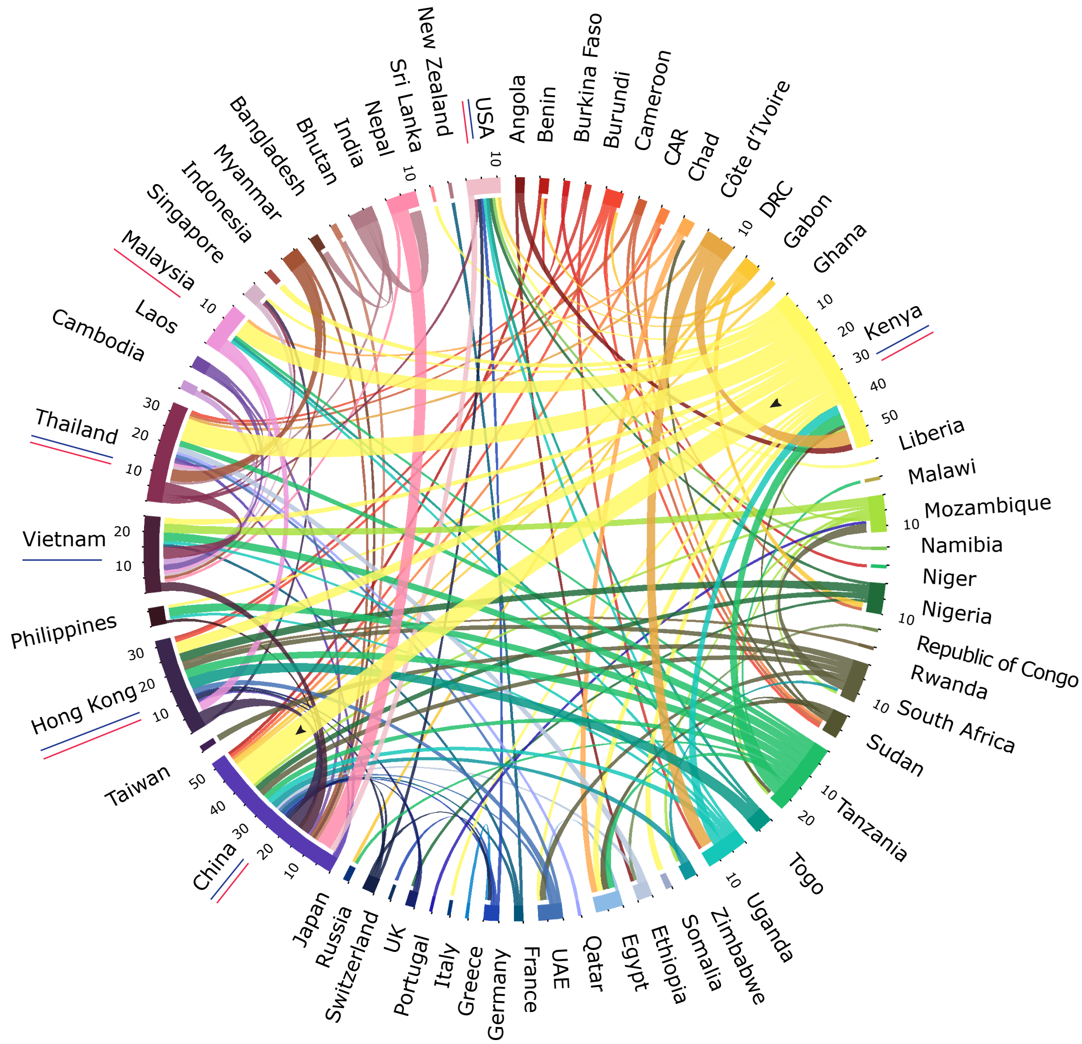


Figure 6. Continued

B. Illegal Rhinoceros Network

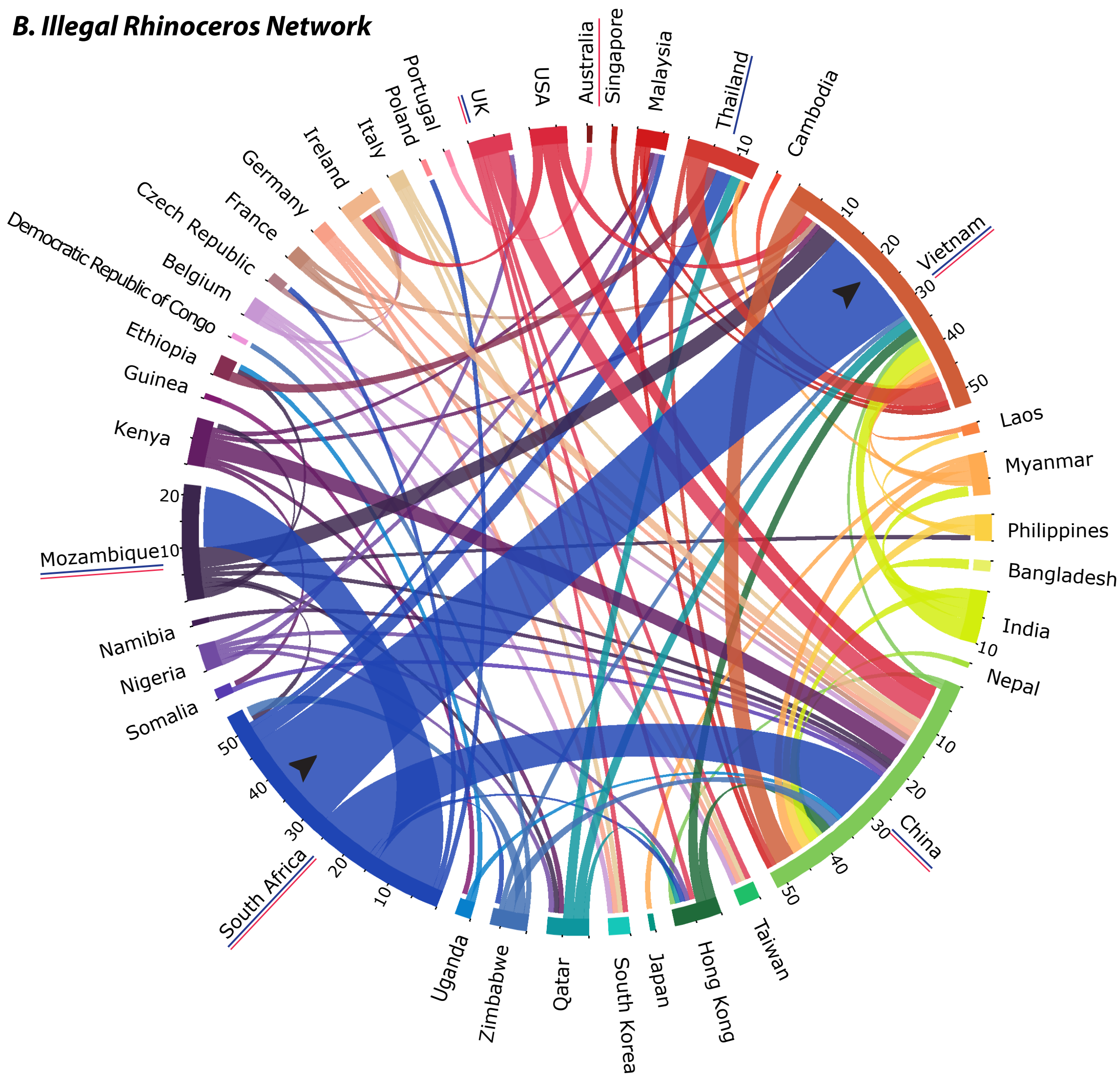


Figure 6. Continued

C. Illegal Tiger Network

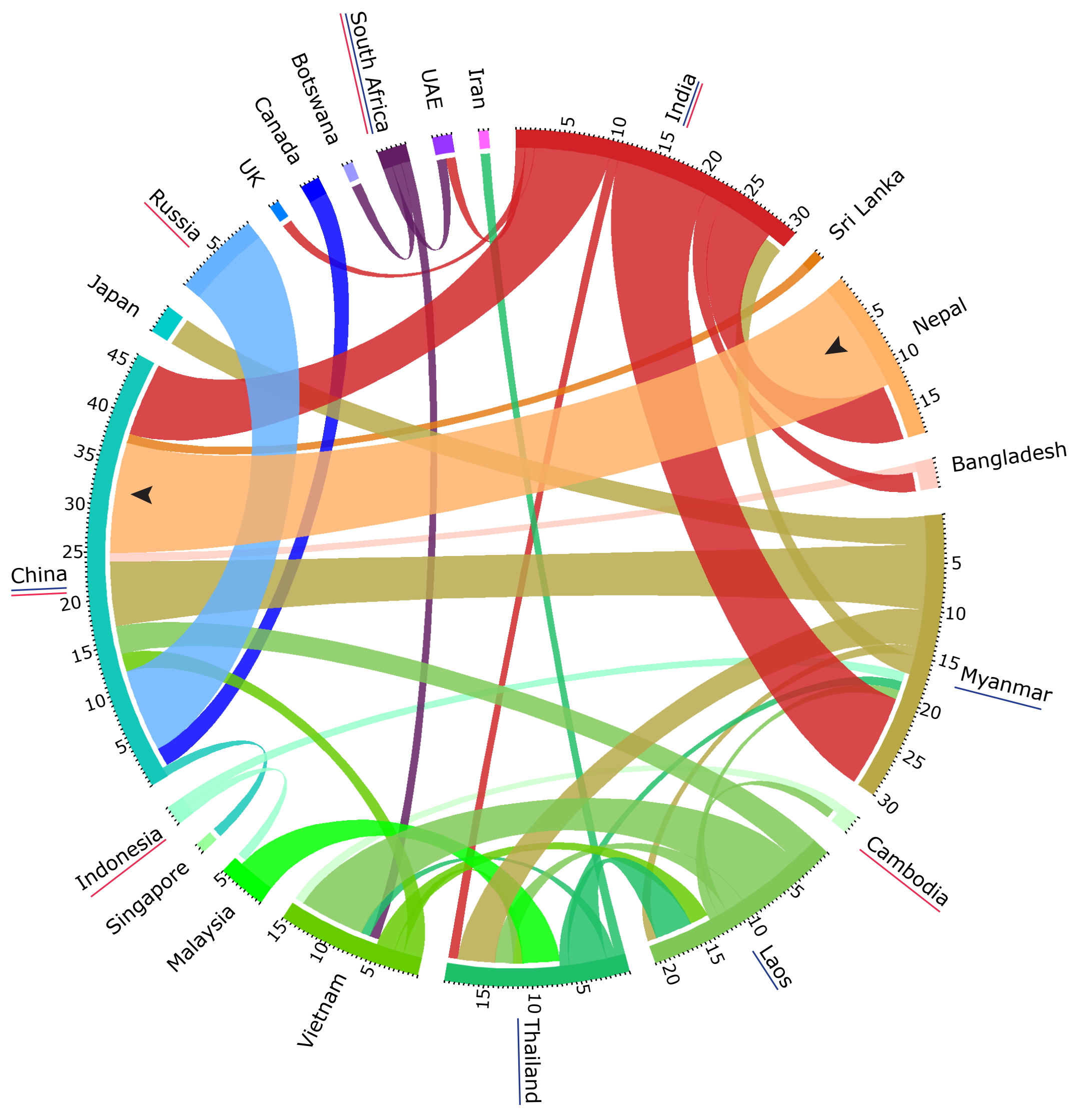


Figure 6. Continued

D. Elephant Network Post-Fragmentation

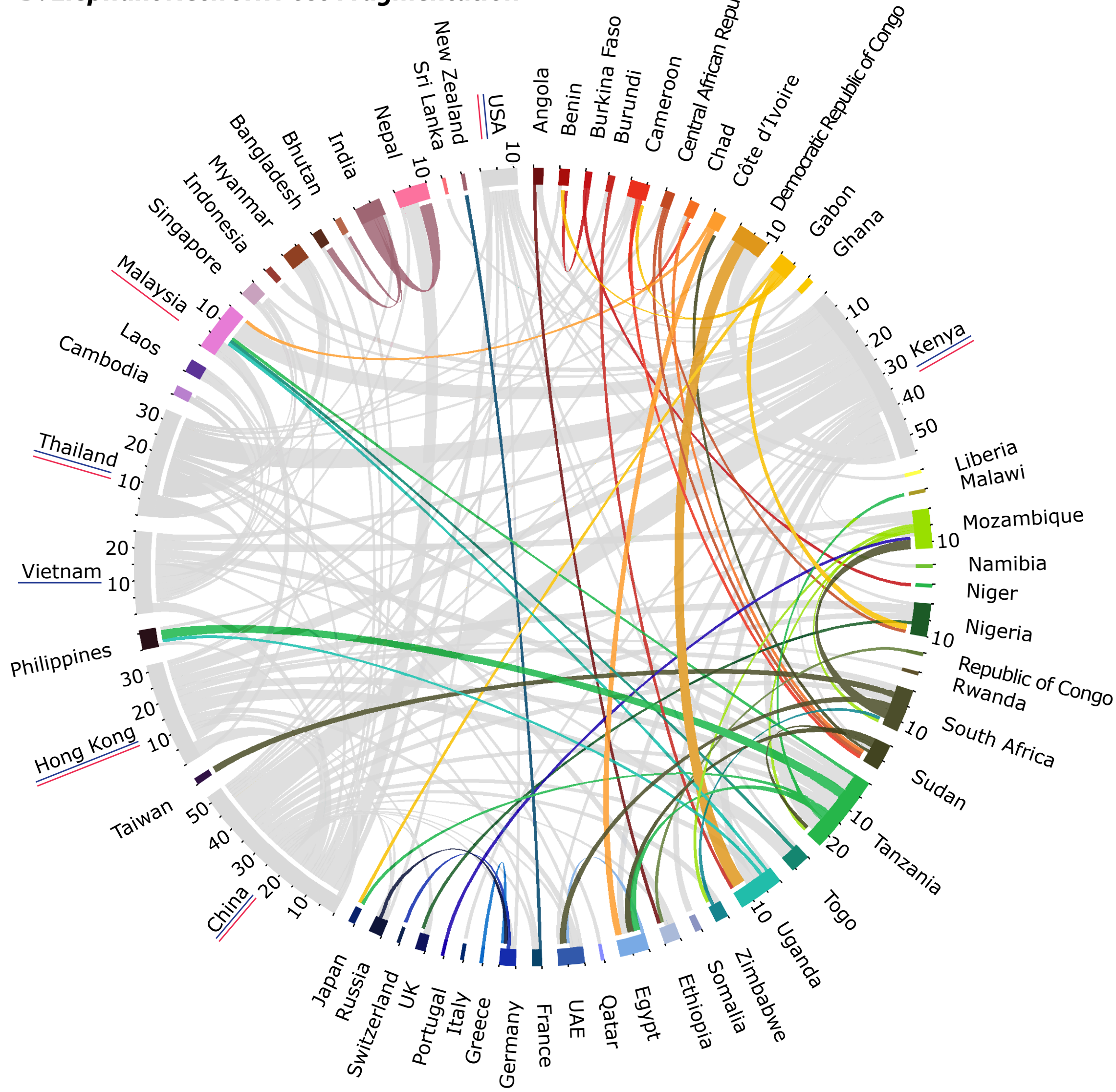


Figure 6. Continued

E. Rhinoceros Network Post-Fragmentation

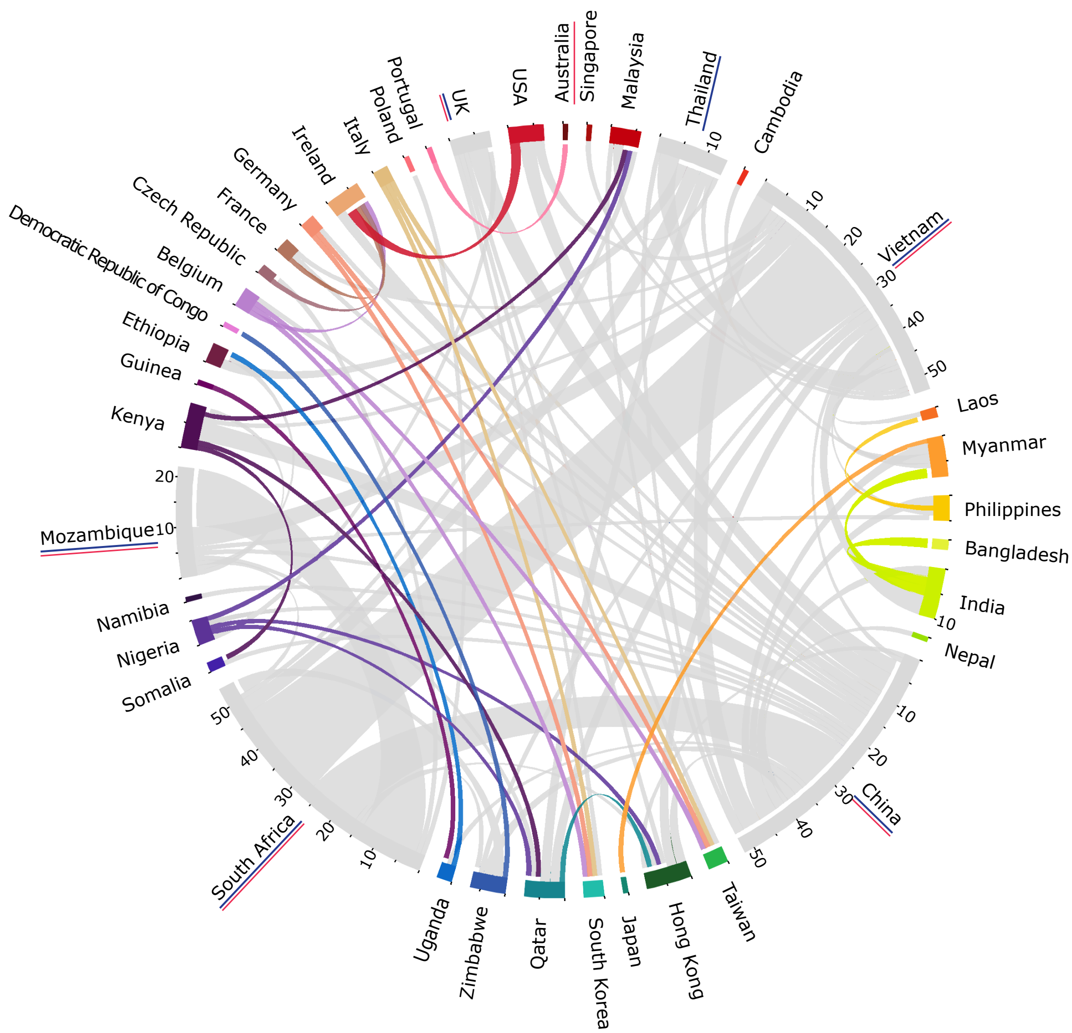
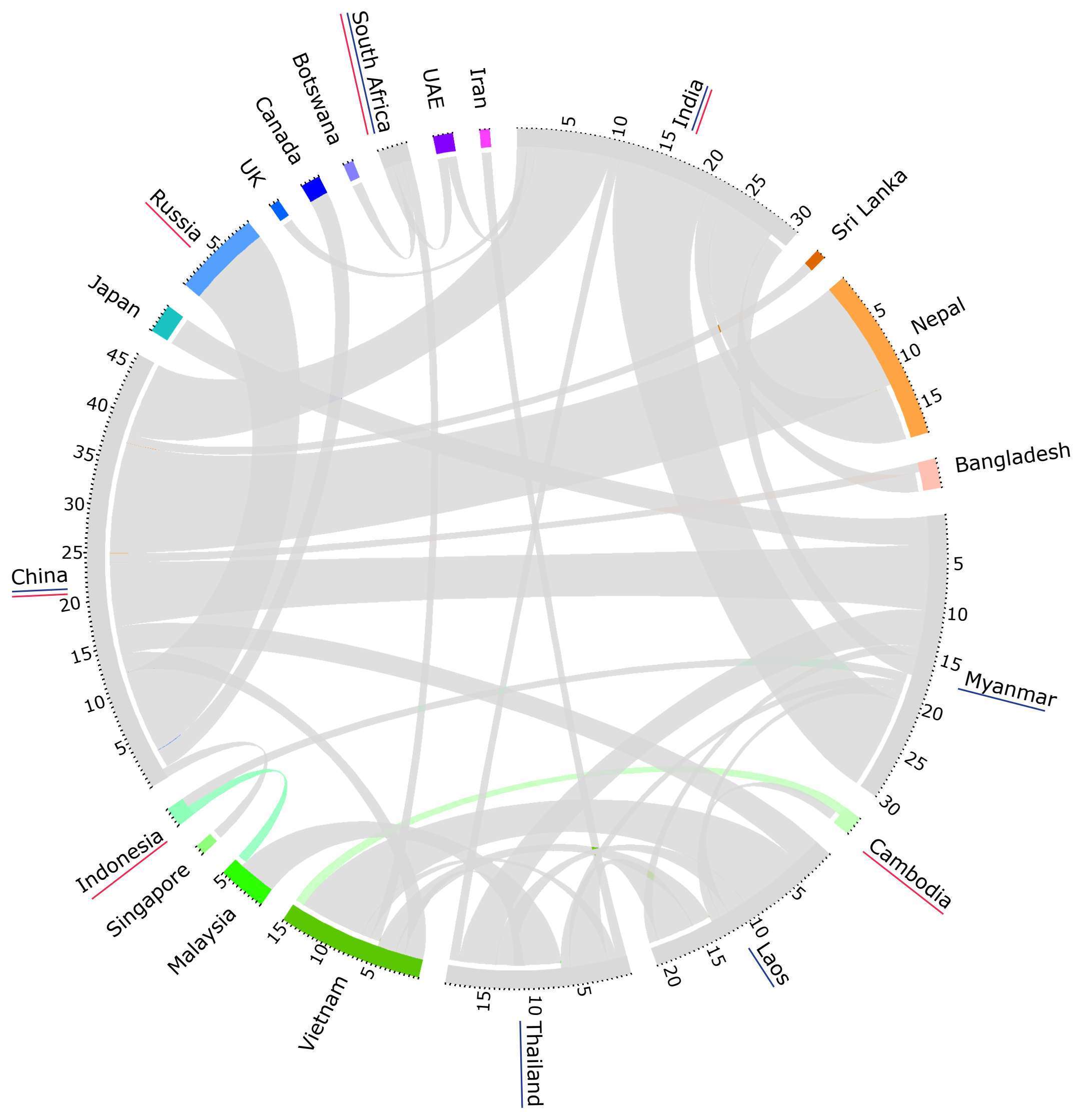


Figure 6. Continued

F. Tiger Network Post-Fragmentation



CHAPTER 5: SUMMARY AND FUTURE DIRECTIONS

The global trade in wildlife and its products is a massive multibillion-dollar industry. It is a cause of animal mortality, population declines, species extinctions, the introduction of invasive species, and the spread of disease to humans, domestic animals, and wildlife. Furthermore, it is a public safety hazard and a serious welfare concern, and it is believed to have links to other illicit activities like terrorism. The size, scale, scope, and illicit nature of the trade, along with the poor funding of the agencies responsible for regulation make controlling the trade very challenging. Current strategies are failing. There is a need for more effective, pre-emptive strategies based on quantitative descriptions of what is actually happening.

The aim of this dissertation was to advance the current literature pertaining to the illegal wildlife trade so that it may, eventually, be possible to design more effective wildlife trade control interventions. An important first step was the characterization of the illegal wildlife trade network. We used information on the illegal wildlife trade contained in the HealthMap Wildlife Trade database, to summarize the network and composition of the illegal wildlife trade. We utilized all reports of the illegal international trade in elephants, rhinoceros, and tigers from August 2010 to December 2013 to build a network of trading countries.

We quantified the relationship between the illegal wildlife trade and several key factors thought to contribute to the illegal wildlife trade, namely road development, Corruption Perception Index (a score related to the perceived level of corruption) and unemployment. We also quantitatively examined if the legal and illegal wildlife trade networks resemble one another. We tested these hypotheses in a number of ways: different animals, different outcomes (exports, imports), different parts of the trade (sent from a country, arriving in a country, between two countries) and different methods (linear regression, negative binomial regression). We did find evidence of some associations between the Corruption Perception Index, unemployment, and the legal trade with certain aspects of the illegal wildlife trade; however, no generalizable findings can be asserted at this time. Refinement of the model in terms of scale, time, and taxa may yield differing results. Furthermore, with the creation of HealthMap Wildlife Trade database beginning in only 2010, it is clear that this database is in its infancy. Repeating this analysis in the future when added time and refinement of the system will generate more data may provide better predictive capabilities.

We also analyzed the illegal wildlife trade as a network. We identified locations to place resources in effort to regulate and restrict trade, which would result in the greatest destabilization of the network. We identified countries, which were key exporters, importers, and intermediaries of trade. We also found sets of countries where enforcement activities and educational campaigns might most effectively disrupt the networks. We found removing six countries from the network (interdiction) would fragment 89.5% of the network for elephants, 92.3% for rhinoceros, and 98.1% for tigers. Selection of 18 nodes is needed for an educational message to reach 100% of the elephant trade network, 16 nodes for rhinoceros and 10 for tigers via direct connections. Almost all interventions required China to be included as a target.

This thesis has begun the urgently needed analysis of the complex relationships between the illegal wildlife trade and unemployment, road development, corruption, and the legal wildlife trade. We found specific ways to bring about change using network science. These findings offer the hope that it will be possible to find more effective ways of combating the illegal wildlife trade and the problems it brings with it. This research can be of benefit for many including international trade regulatory and enforcement agencies, NGOs, and governments by providing a model for resource allocation.

It is possible that there exists variability in the effects and relationships described related to changes in cultural norms, national and international political and economic conditions, and Internet reporting through time. These could be explored further via analyses of networks involving trade of multiple animals intra- and inter-nationally over time. This analysis could be converted into an automated, real-time analytic tool that could be utilized by regulatory agencies. Customized features could include various filters such as which databases are used, what animals and animal parts are considered, and what time frame is observed. Real-time analysis will be critical in order to perform valuable interventions by regulatory agencies and NGOs, and to make informed recommendations to law-making bodies.

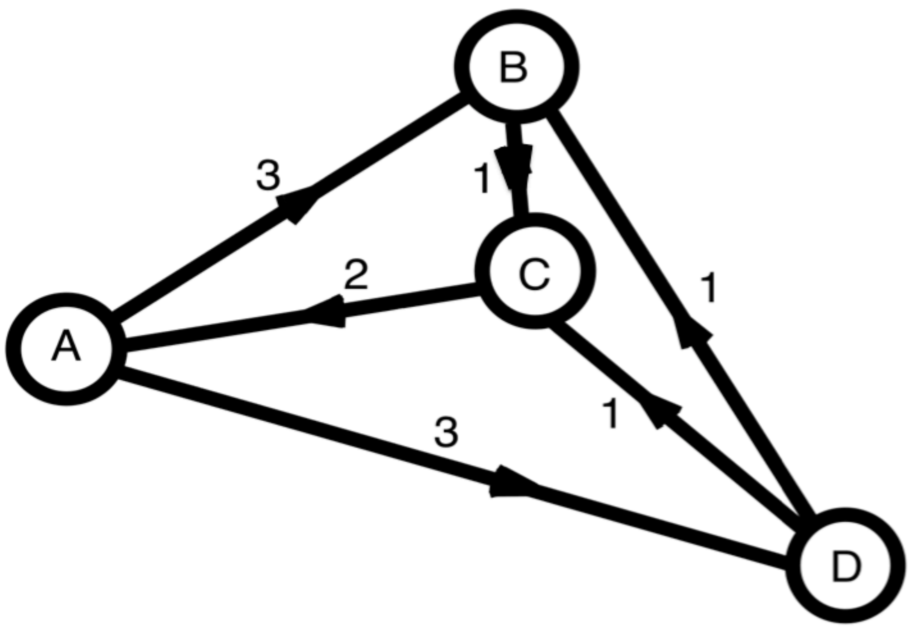
APPENDIX

Flow Betweenness

To calculate the flow betweenness of a node in a weighted directed graph with *n* nodes, we first labeled the nodes as x(i), for i = 1, 2, ..., *n*. Recall that a directed path from node x(j) to node x(k) is a sequence of connected directed edges and nodes beginning at x(j) and ending at x(k) in which no edge or node is repeated. Also, recall that the capacity of a weighted directed path is the smallest weight of its edges. (In our networks, the weight of an edge is the number of shipments/unit time associated with the corresponding connection.) For a particular node x(i), consider a pair of nodes x(j) and x(k), where i, j, are k and all different. Determine the capacity of each distinct directed path from x(j) to x(k) that passes through x(i) and let w(i, j, k) be the sum of those capacities over all such paths. Then the flow betweenness of node x(i) is defined as the sum of w(i, j, k) for all j and k with i, j, and k all different (458, 461).

For our networks, the flow betweenness of a node (country) is a measure of its role as a gatekeeper for the flow of international illegal shipments between any two countries. The assumption is that illegal shipments between any two particular countries will not always be directly between the two countries, but may pass through intermediate countries for processing or to avoid detection. Although originally defined for the analysis of communication within social networks, flow betweenness appears to be an appropriate parameter for the determination of the key countries in the international flow of illegal wild life shipments.

The sna package in R was used for the calculations of flow betweenness of the nodes of the networks in this paper (463, 464). As a simple example, let us determine the flow betweenness of node A.



We first observe that the only directed paths that pass through node A, but neither start or end at node A, are BCAD, CAD, CAB, CADB, and DCAB. These five paths have capacities of 1, 2, 2, 1, and 1, respectively, and so the flow betweenness of node A is 7, the sum of these five capacities. Similarly, nodes B, C, and D have flow betweennesses of 4, 5, and 3, respectively. We would then rank the four vertices in the order A, C, B, D as to their effectiveness as gatekeepers for the flow of the graph. Below is the R code that was used to calculate the raw flow betweenness values for the tiger network:

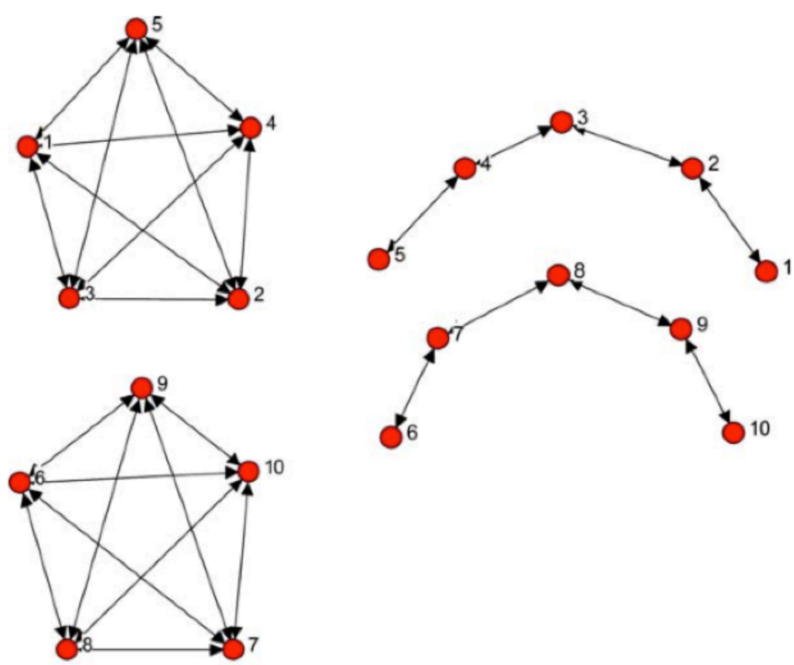
```
dat.tiger <- read.table(file="tigers.txt", header=T, sep="\t")
dat.tiger[is.na(dat.tiger)] <- 0
rownames(dat.tiger) = dat.tiger[,1]
dat.tiger = dat.tiger[1:(nrow(dat.tiger)-1),2:ncol(dat.tiger)]
dat.tiger = rbind(dat.tiger, flowbet.raw.tiger = flowbet(dat.tiger), flowbet.norm.tiger = flowbet(dat.tiger,cmode="normflow"),
flowbet.frac.tiger = flowbet(dat.tiger,cmode="fracflow"))
write.table(dat.tiger, file=paste("tigers.wFlow.txt", sep=""), append=F, quote=F, sep="\t", eol="\n", na="NA", dec=".",
row.names=T, col.names=T)
```

Fragmentation

We identified sets of key nodes (kp-sets) that would best fragment a network or best serve as seeds for the transmission of information using criteria Borgatti defined in the Key Player Problem (465).

We found the set *K* with a specified number of nodes, say *k* nodes, such that when all links of the *k* nodes in *K* are removed the fragmentation to the trade network will be maximized using the KPP-NEG criterion. This criterion is a fragmentation measure of an undirected network defined as: $D_F = 1 - \frac{2\sum_{i>j}\frac{1}{d_{ij}}}{n(n-1)}$, where *n* is the number of nodes of the network and d_{ij} is the distance between nodes *i* and *j*, defined as the minimum number of edges among all undirected paths between nodes *i* and *j*. If nodes *i* and *j* do not connect, d_{ij} is set equal to infinity and $1/d_{ij}$ is set equal to 0. Thus, $1/d_{ij}$ is a measure of the degree of reachability between nodes *i* and j and has values from 0 (not reachable) to 1 (reachable in one step). The D_F measure is 1 when all nodes are isolated (maximum fragmentation) and is 0 when all nodes are directly connected to each other (minimum fragmentation). For a fixed number *k* of nodes to be disconnected we determined a particular subset *K* of *k* nodes that maximizes D_F using a combinatorial optimization algorithm of Borgatti (465).

To illustrate this, here are two networks, each with two components, or connected sets of nodes (465).



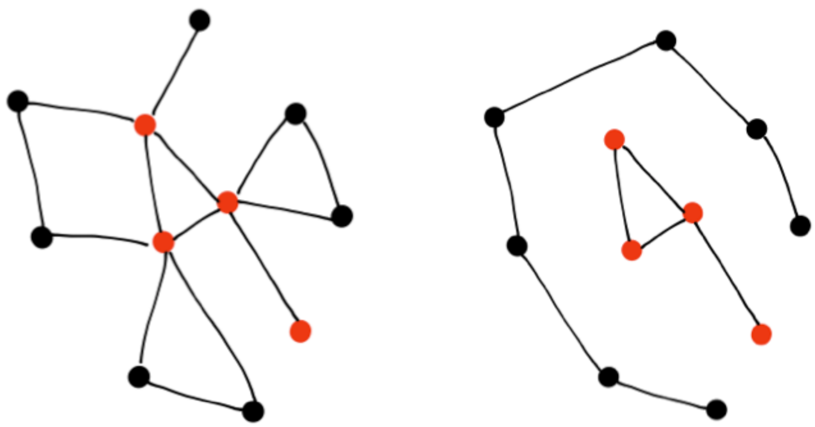
The network on the left has a D_F measure of 0.556 and the network on the right a measure of 0.715, indicating less cohesion.

The Key Player Program version 1.45, using the key player algorithm developed by Borgatti, was used to identify key countries and calculate the fragmentation metric for the networks in this paper (465, 466).

Information Dissemination

We found the set *K* of a specific number nodes, say *k* nodes, that act as the seeds to transmit information most efficiently through the network using the KPP-POS criterion. This criterion utilizes a measure that we wish to maximize of a subset *K* of *k* nodes of an undirected graph defined as: $D_R = \frac{\sum_j \frac{1}{d_{Kj}}}{n}$, where *n* is the number of nodes in the graph, the summation is over all indices *j* of nodes not in the set *K*, and d_{Kj} is the distance between the set *K* and node *j*, defined as the minimum number of edges among all undirected paths between any node within the set K and node j. The value of $1/d_{Kj}$ is set equal to 0 if there is no path from any node in *K* to node *j*. Thus D_R is the weighted proportion of nodes not in K where the weight of each node is its reciprocal distance to *K*. The value of D_R is 0 when *K* is isolated; that is, when no node of *K* has a path to any node outside of *K.* As with D_F, we determined a set *K* with *k* nodes that maximizes D_R using a combinatorial optimization algorithm of Borgatti (2006) (465).

To illustrate this, here are two networks (465).



The measure equals 1 for the network on the left as every outside node (shown in black) is 1 link away to at least one member of K (shown in red). The measure equals 0 for the network on the right as K is completely isolated from the outside nodes.

The Key Player Program version 1.45 was used to identify key countries and calculate the information dissemination index for the networks in this paper (465, 466).

In our determinations of D_F and D_R we treated the trade network as undirected (the direction of shipments between two countries was disregarded) and unweighted (the number of shipments/unit time between two countries was not considered). It may be possible to extend Boragtti's definitions of D_F and D_R to account for the direction and weight of the various routes in future work.

Pooling of trade products

Animal	Original category[16]	Pooled category
Elephant	Live (83)	Live
	Ivory (142) [including carvings (606), ivory carvings (583) and ivory pieces (202)]	Ivory
	Tusk (4) [tusks (573)]	
	Trophies (288)	
	Skulls (75)	
	Teeth (64)	
	Skins (139) [including skin pieces (217)]	Other
	Leather products [large (88) and small (225)]	
	Feet (241)	
	Tails (187)	
	Ears (181)	
	Hair (88) [including hair products (4)]	
	Bones (64) [including bone carvings (1) and bone pieces (2)]	
	Specimens (40)	
	Derivatives (37)	
	Bodies (11)	
	Genitalia (9)	
	Garments (5)	
	Dead (2)	
	Meat (3)	
	N/a (2)	
	Parts (2)	
	Sides (2)	
	Unspecified (11)	
	Carapaces (1)[17]	
	Cloth (1)	

[16] Frequency of product type in HWT and CITES databases noted in parentheses.
[17] This was dropped from analysis since carapace is not an anatomical part of an elephant.

Pooling of trade products continued

Animal	Original category[18]	Pooled category
Rhinoceros	Horn (133) [horns (70); including carvings (36), horn carvings (14) and horn pieces (1)]	
	Trophies (99)	Horn
	Dead (9)	Dead
	Bodies (4)	
	Live (60)	Other
	Skins (31) [including skin pieces (13)]	
	Specimens (42)	
	Feet (38)	
	Skulls (27)	
	Tails (9)	
	Leather products [large (2) and small (6)]	
	Bones (6)	
	Genitalia (4)	
	Hair (2)	
	Unspecified (2)	
	N/a (1)	
	Teeth (1)	

[18] Frequency of product type in HWT and CITES databases noted in parentheses.

Pooling of trade products continued[19]

Animal	Original category	Pooled category
Tiger	Bones (16) [including carvings (1) and bone pieces (2)]	Bones
	Teeth (12)	
	Skull (2) [skulls (11)]	
	Skeleton (1) [skeletons (1)]	
	Claws (6) [including ground claw (1)]	Claws
	Live (276)	Live
	Juveniles (3)]	
	Derivatives (33)	Other
	Specimens (25)	
	Bodies (17)	
	Parts (9)	
	N/a (5)	
	Dead (1)	
	Unknown (2)	
	Extract (1)	
	Hair (1)	
	Oil (1)	
	Unspecified (1)	
	Skin (14) [skins (36); including skin pieces (3)]	Skin
	Trophies (18)	
	Pelts (1)	
	Leather products (1)	
	Fur (1)	

[19] Frequency of product type in HWT and CITES databases noted in parentheses.

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