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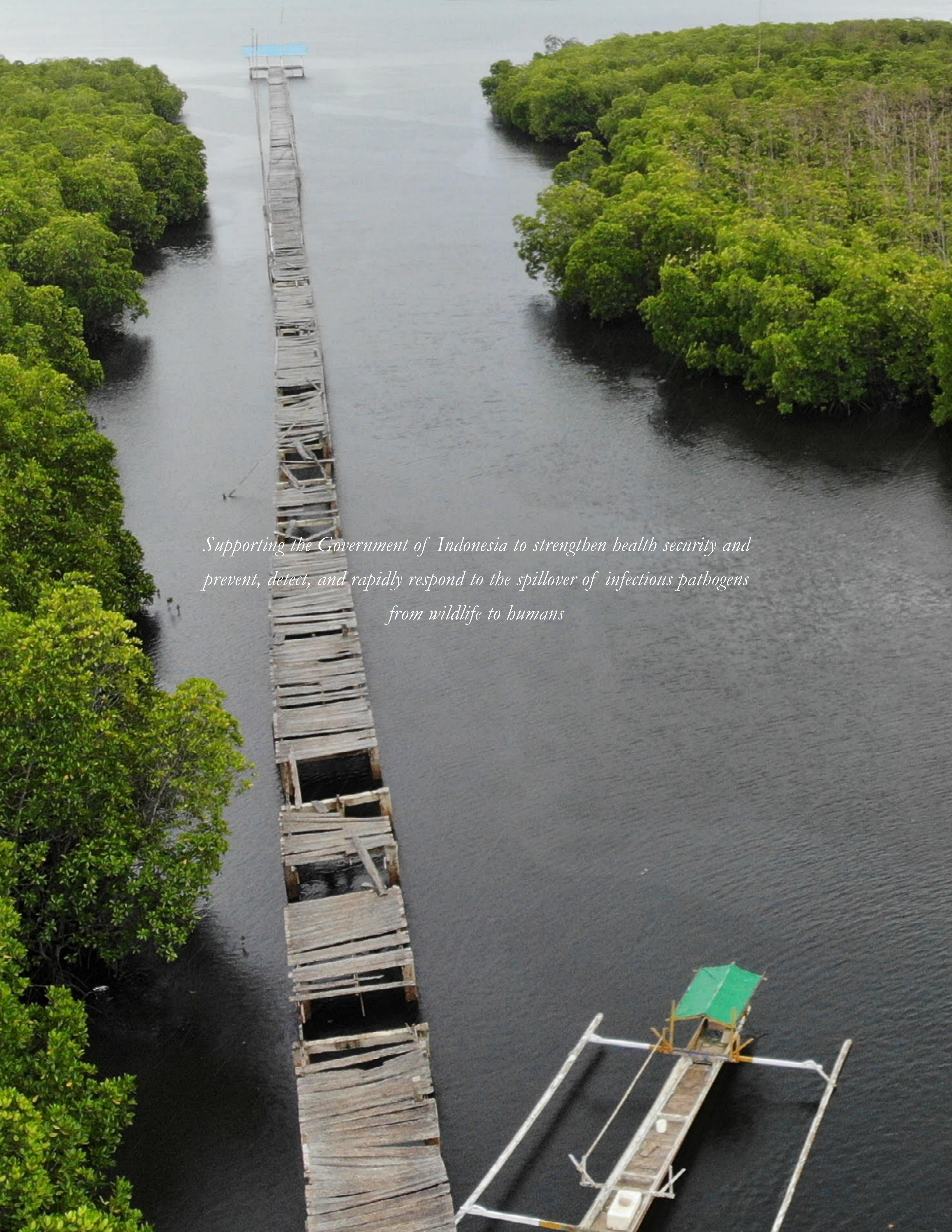
PREDICT INDONESIA

One Health in action (2009-2020)



Supporting the Government of Indonesia to strengthen health security and prevent, detect, and rapidly respond to the spillover of infectious pathogens from wildlife to humans

INDONESIA

Indonesia has abundant biodiversity, including non-human primates, rodents and bats. High rates of tropical deforestation, thriving wildlife trade and hunting networks, and a growing human population threaten Indonesia's unique biodiversity and increase the risk for zoonotic disease emergence. As an archipelago, Indonesia's seas and oceans may have historically limited the distribution of wild animal species and the pathogens they may carry. However, globalization and resulting changes in human activities are increasing movement across and beyond the country. This movement increases the risk for human-wildlife contact and the potential for cross-species transmission and spread of viruses. Rapid ecological change, such as clearing of peat swamps and tropical rain forests for oil palm plantations, are bringing humans into closer contact with wildlife species than in the past.

Since 2009, the PREDICT project has been active in Indonesia and worked with the central government and local partners from the Ministry of Agriculture (Local Animal Health Offices at the Provincial and District levels) to better understand the mechanisms of virus spillover from wildlife to livestock and people and to strengthen capabilities for the detection of priority zoonotic diseases and other viruses at high-risk, human-animal interfaces. Through analysis of project data and findings, the PREDICT team was able to identify risks and educate communities and health professionals on behavior change and intervention strategies designed to protect people and wildlife from disease threats. PREDICT project surveillance was performed at several sites on the Island of Sulawesi, the fourth largest island in Indonesia. Sulawesi is an important region for wildlife trade and is undergoing rapid land conversion and exploitation of local fauna. PREDICT One Health surveillance sites were targeted to capture high-risk animal-human interfaces along the wildlife value chain in Sulawesi.

LOCAL PARTNERS

- Food & Agriculture Organization of the United Nations (FAO)
- Gorontalo University
- Indonesia One Health University Network
- International Federation of Red Cross and Red Crescent Societies
- Ministry of Agricultural Republic Indonesia—Directorate General of Livestock and Animal Health Services
- Ministry of Environment and Forestry Republic Indonesia
- Ministry of Health Republic Indonesia
- Ministry of Research, Technology and Higher Education
- Noongan Hospital and a local Minihasa Regency clinic, North Sulawesi
- Sam Ratulangi University of Manado
- USAID Preparedness and Response
- World Health Organization of the United Nations

>250

DEVELOPED the One Health Workforce by training more than 250 people in Indonesia.

>3.6K

OPERATIONALIZED One Health surveillance and sampled over 3.6K animals and people, to identify ways to help minimize the spillover of zoonotic disease threats from animals into human populations.

LABORATORY STRENGTHENING

- Primate Research Center of the Institut Pertanian Bogor (IPB University)
- Eijkman Institute for Molecular Biology (EIMB)

>49,395
TESTS

30 PREDICT

20 KNOWN

DETECTED 50 unique viruses in both animal and human populations.

TINA KUSUMANINGRUM

Field Coordinator
Emerging Virus Research Unit, Eijkman Institute for Molecular Biology

"There is no doubt that joining PREDICT is one of the best decisions in my researcher career. Learning how to design and implement a surveillance project, maintain networking and professional relationships with partners, and communicate the results back to the communities and decision makers—these were all exceptional experiences that will be very useful for my future career."

RACHMITASARI NOVIANA

Wildlife Data Manager
Microbiology & Immunology Laboratory, PRC - IPB University

"Since working with PREDICT/Indonesia, I've learned so much and I have changed my point of view about animal and viral findings. I have also improved my ability in information technology. I am honored to be a member of the Data Management team."

ACHIEVEMENTS

- Trained > 130 people in Indonesia's One Health workforce in core skills required for zoonotic disease surveillance and detection.
- Sampled > 3,600 individuals (2,966 animals and 673 people) at high risk interfaces with potential for exposure to and spillover of zoonotic viruses.
- Interviewed > 300 people to better understand the social and behavioral factors associated with exposure to zoonotic diseases.
- Strengthened two laboratories essential for supporting the national laboratory system to improve the detection of priority zoonoses and other viruses, and improving capabilities for bioinformatics analysis.
- With FAO and the Ministry of Agriculture, trained and empowered eight National Veterinary Disease Investigation Centers (DICs – Banjarbaru, Bukittinggi, Denpasar, Lampung, Maros, Medan, Subang, and Wates) to detect new and emerging viruses in domestic animals.
- Provided government partners with disease detection support during two outbreak response investigations for diseases of unknown origin.
- Promoted safe behaviors and practices for risk reduction in communities at-risk for exposure to zoonotic diseases.
- Engaged with Government of Indonesia partners and advocated for zoonotic disease and prevention programs.

ONE HEALTH SURVEILLANCE

The PREDICT project in Indonesia put One Health in action by sampling wildlife taxa and people at several sites on the Island of Sulawesi. Domestic animal surveillance was also performed at these same sites in collaboration with the Ministry of Agriculture and FAO-ECTAD. Sulawesi is an important site for emerging zoonotic diseases given the widespread and high-volume of wildlife trade, rapid land conversion, and increasing connectivity of communities via road building and other infrastructure changes. PREDICT project surveillance sites targeted high-risk animal-human interfaces along the wildlife value chain pathway in Sulawesi (primarily sampling bats and rodents, as well as non-human primates and other taxa). These sites include different stages of the wildlife value chain, from wild source populations of animals, to hunters and middlemen, to urban wildlife markets. Hunted wild animals, mostly bats and rodents, were sampled at hunting sites in Gorontalo, West Sulawesi, Southeast Sulawesi and North Sulawesi provinces. Wild animals were also sampled in markets in North Sulawesi where the markets selling wildlife products are located.

Community-based surveillance and behavioral risk investigations occurred concurrently with wildlife sampling with the aim to detect viral sharing among people and animals and to characterize behavioral risk factors for exposure in Gorontalo, West Sulawesi, Southeast Sulawesi and North Sulawesi provinces. Wildlife hunters, market vendors and wildlife consumers were enrolled as participants, and a wider sample of community members and occupations were also recruited. Clinical surveillance was performed at Noongan Hospital (Rumah Sakit Umum Daerah Noongan) and at a local clinic, both within Minahasa Regency, North Sulawesi. Sampling sites were chosen to capture individuals associated with the wildlife value chain that may be at risk for illness. Patients with acute febrile and respiratory illness were enrolled at clinics. The PREDICT team coordinated with local hospitals, primary health care centers, community leaders, as well as universities to implement human behavioral surveillance and to conduct syndromic and community surveillance. This coordinated approach included several scoping visits to sensitize target communities in Sulawesi, training events with hospital staff and other personnel, and other meetings for partner engagement.

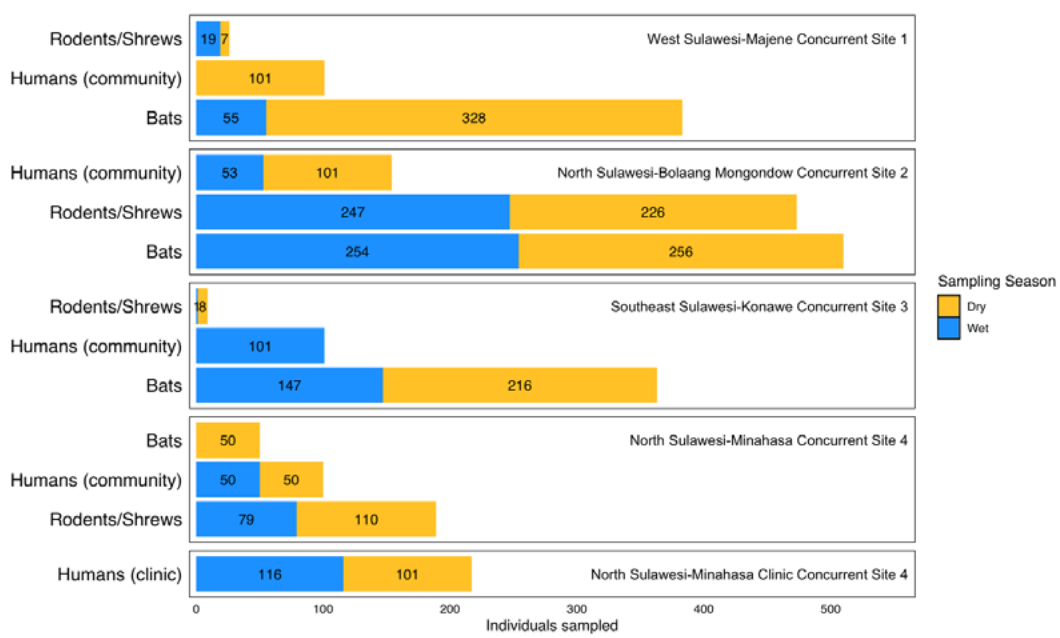


FIGURE 1. Summary of One Health sampling effort at multiple PREDICT sites in Indonesia. Gorontalo, an independent bat sampling site, is not represented here.

In Indonesia, human health is under the jurisdiction of the Ministry of Health and animal health is under split authority, as wildlife management is under the Ministry of Environment and Forestry, and animal health and husbandry under the Ministry of Agriculture. This shared governance of animal health creates an opportunity for miscommunication and unaligned agendas.

In both human and veterinary health sectors, government labs focus their surveillance on known diseases in humans and animals. As the PREDICT project's focus was to improve capacity to also detect novel viruses, we worked to fill in the gaps in data related to new and emerging viruses both in human and animal health.

One Health surveillance unified multi-sectoral stakeholders in Indonesia. Activities were initiated with permission requests from all relevant authorities, resulting in increased awareness and collaboration across the previously divided animal and human health sectors.

VIRUS DETECTION

VIRUS FINDINGS IN ANIMALS

The PREDICT project's strategy for viral detection included screening samples using broadly reactive consensus PCR (cPCR) for priority viral families, including corona, filo, flavi, and paramyxo families, and influenza virus. Positives detected using these assays were sequenced to identify the viruses and compare their relationship to known pathogens, and viruses were prioritized for further characterization. This approach allows for detection of both known and novel viruses and improves our understanding of the presence and diversity of viruses, as well as potential pathogens, in humans and animals.

Using this approach, the wildlife laboratory safely tested 1,822 bat and 723 rodent oral and rectal swab samples. Of 3,618 bat specimens tested, 119 were positive for coronaviruses, 17 for paramyxoviruses, and 46 for Influenza A. Of 1,393 rodent specimens tested, 57 were positive for coronaviruses, three for paramyxoviruses, and two for Influenza A (Table 1). We also performed species identification by barcoding for 168 virus-positive bats, 71 virus-negative bats of various species, and all 723 rodent samples.

VIRUS TABLE

VIRAL FAMILY	VIRUS	SPECIES	SAMPLING LOCATION	# OF POSITIVE INDIVIDUALS TOTAL	WET SEASON	DRY SEASON
Coronavirus	Betacoronavirus 1 (OC43)	Human	Clinic (Minahasa)	1	1	0
	PREDICT_CoV-16	Black Flying Fox	Gorontalo, Konawe, Majene	16	4	12
	PREDICT_CoV-67	Black Flying Fox, Spectacled Flying Fox	Gorontalo, Konawe, Majene, Parigi Mouton	48	9	39
	PREDICT_CoV-68	Black Flying Fox	Gorontalo, Majene	22	0	22
	PREDICT_CoV-73	Black Flying Fox, Sulawesi Fruit Bat	Bolaang Mongondow, Gorontalo, Konawe, Majene	19	10	9
	PREDICT_CoV-83	Black Flying Fox, Sulawesi Fruit Bat	Gorontalo	3	2	1
	Bat coronavirus HKU9	Black Flying Fox, Geoffroy's Rousette, Sulawesi Fruit Bat	Bolaang Mongondow, Majene	7	7	0
	Philippines/Diliman 1525G2/2008	Unidentified Cynopterus Bat, Unidentified Thoopterus Bat	Bolaang Mongondow	4	3	1
	Murine coronavirus	Black Rat, Giant Sulawesi Rat, Hoffmann's Sulawesi Rat, Montane Bunomys, Opossum Rat, Oriental House Rat, Ricefield Rat, Unidentified Rattus Rat, Yellow-Tailed Rat	Bolaang Mongondow, Gorontalo, Konawe, Majene, Minahasa	52	24	28
Paramyxovirus	Measles virus	Human	Minahasa	1	1	0
	Human parainfluenzavirus 4	Human	Clinic (Minahasa)	2	0	2
	PREDICT_PMV-10	Black Flying Fox	Gorontalo	1	0	1
	PREDICT_PMV-93	Sulawesi Fruit Bat	Gorontalo	1	1	0
	PREDICT_PMV-94	Black Flying Fox	Gorontalo	1	0	1
	PREDICT_PMV-95	Sulawesi Fruit Bat	Gorontalo	1	0	1
	PREDICT_PMV-100	Black Flying Fox	Gorontalo	1	0	1
	PREDICT_PMV-102	Black Flying Fox	Gorontalo	1	1	0
	PREDICT_PMV-111	Sulawesi Fruit Bat	Gorontalo	1	0	1
	PREDICT_PMV-112	Geoffroy's Rousette	Bolaang Mongondow	1	1	0

	PREDICT_PMV-121	Black Flying Fox	Majene	2	0	2
	PREDICT_PMV-122	Swift Fruit Bat	Bolaang Mongondow	1	0	1
	PREDICT_PMV-124	Black Flying Fox	Majene	4	0	4
	PREDICT_PMV-126	Black Flying Fox	Majene	1	0	1
	Pteropus poliocephalus paramyxovirus	Black Flying Fox	Gorontalo	1	0	1
	PREDICT_PMV-96	Unidentified Rattus Rat	Gorontalo	1	1	0
	PREDICT_PMV-154	Hoffmann's Sulawesi Rat	Minahasa	2	0	2
Influenza virus	Influenza A	Human, Black Flying Fox, Geoffroy's Rousette, Sulawesi Fruit Bat, Unidentified Cynopterus Bat, Unidentified Fruit Bat, Opossum Rat	Bolaang Mongondow, Gorontalo, Konawe, Noongan Hospital (Minahasa), Clinic (Minahasa)	66	34	32
	Influenza B	Human	Noongan Hospital (Minahasa), Clinic (Minahasa)	2	2	0
Flavivirus	Dengue virus serotype 2	Human	Noongan Hospital (Minahasa)	7	3	4
	Dengue virus serotype 3	Human	Noongan Hospital (Minahasa)	7	5	2
	Dengue virus serotype 4	Human	Noongan Hospital (Minahasa)	1	1	0
Picornavirus	Rhinovirus A	Human	Noongan Hospital (Minahasa), Clinic (Minahasa)	5	2	3
	Rhinovirus B	Human	Noongan Hospital (Minahasa)	1	1	0
	Rhinovirus C	Human	Clinic (Minahasa)	1	1	0
Total				**285**	**114**	**171**

Coronaviruses were the most frequently detected virus family and were detected in well-sampled wildlife genera including *Pteropus* spp. (flying fox fruit bats); *Cynopterus* spp. (short-nosed fruit bats); and *Rattus* spp. (rats) with an overall observed prevalence of between 2-4%. Influenza viruses and paramyxoviruses were found in some of these same groups of animals, but at a much lower proportion (<1% of samples were positive). The heatmap (Figure 2) summarizes the virus positives by each genus of wildlife sampled and tested from 2014-2019.

Viral Test Type

	Coronaviruses	Filoviruses	Flaviviruses	Influenzas	Paramyxoviruses
Acerodon (bats)	1.6% (1388)	0% (695)	0% (1002)	1.3% (1388)	0.2% (1388)
Cynopterus (bats)	4.2% (120)	0% (60)	0% (82)	0.8% (120)	0% (120)
Dobsonia (bats)	0% (56)	0% (28)	0% (30)	0% (56)	0% (56)
Hipposideros (bats)	0% (4)	0% (2)	0% (2)	0% (4)	0% (4)
Neopteryx (bats)	0% (4)	0% (2)	0% (2)	0% (4)	0% (4)
Nyctimene (bats)	0% (60)	0% (30)	0% (31)	0% (60)	0% (60)
Pteropus (bats)	2.3% (3981)	0% (1992)	0% (2662)	0.6% (3984)	0.3% (3984)
Rhinolophus (bats)	0% (24)	0% (12)	0% (12)	0% (24)	0% (24)
Rousettus (bats)	0.6% (800)	0% (400)	0% (448)	0.1% (800)	0.1% (800)
Styloctenium (bats)	0% (36)	0% (18)	0% (18)	0% (36)	0% (36)
Thoopterus (bats)	0.3% (760)	0% (380)	0% (388)	0.1% (760)	0.1% (760)
Bunomys (rodents/shrews)	3.8% (26)	0% (13)	0% (13)	0% (26)	0% (26)
Echiothrix (rodents/shrews)	0% (42)	0% (21)	0% (21)	0% (42)	0% (42)
Lenomys (rodents/shrews)	0% (24)	0% (12)	0% (12)	0% (24)	0% (24)
Maxomys (rodents/shrews)	0% (72)	0% (36)	0% (46)	0% (72)	0% (72)
Paruromys (rodents/shrews)	1.5% (134)	0% (67)	0% (67)	0% (134)	0% (134)
Rattus (rodents/shrews)	3.6% (2480)	0% (1240)	0% (1417)	0.1% (2480)	0.1% (2480)
Suncus (rodents/shrews)	0% (4)	0% (2)	0% (2)	0% (4)	0% (4)
Taeromys (rodents/shrews)	0% (20)	0% (10)	0% (13)	0% (20)	0% (20)
Unknown (rodents/shrews)	0% (4)	0% (2)	0% (2)	0% (4)	0% (4)

We found a significant number of viruses detected in the market animal value chain, as compared to sites that were characterized as natural areas with free-ranging animals (Figure 3).

	Coronaviruses	Filoviruses	Flaviviruses	Influenzas	Paramyxoviruses
animal production; crop production; market and value chain	2.1% (910)	0% (455)	0% (455)	0% (910)	0.2% (910)
market and value chain	2.4% (7357)	0% (3681)	0% (4726)	0.6% (7360)	0.2% (7360)
market and value chain; natural areas	1.2% (1720)	0% (860)	0% (1037)	0.1% (1720)	0% (1720)
natural areas	0% (52)	0% (26)	0% (52)	0% (52)	0% (52)

FIGURES 2 & 3. Heatmaps providing a summary of sampling effort and detection of positives for the five priority viral families: Coronaviruses, Filoviruses, Flaviviruses, Influenzas, and Paramyxoviruses. The data are summarized by host at the genus level, and broader taxonomic groups are shown in parentheses (Figure 2, top). Data are also summarized by interfaces at the sampling sites (Figure 3, bottom). The heatmap data show the percentage of viral positives that were confirmed by sequencing (%) and the number of PCR tests performed (in parentheses). The red color scales with increased viral positives. Host taxa or interfaces that did not test

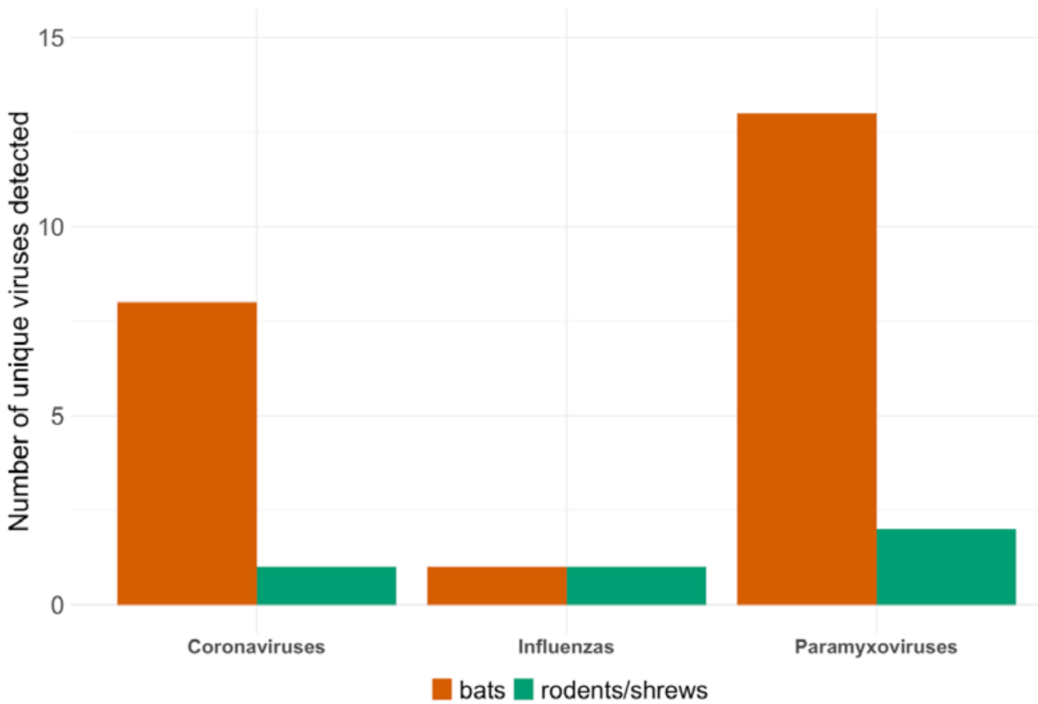


FIGURE 4. The number of unique viruses detected shown by taxa (bats in orange and rodents/shrews in green).

Overall, a diversity of novel viruses were detected from known pathogen groups in humans and animals, including 5 new coronaviruses and 14 new paramyxoviruses. It is not known if these novel viruses identified pose a threat to human health, but they provide important baseline information on the diversity present and can help to develop a risk mapping framework. Previously recognized viruses were also detected in wildlife, including Influenza A and Murine coronavirus. These findings for known viruses significantly expand the number of previously known mammal host species for these two virus species (see Figure 5) and improve our understanding of the natural host ranges for these viruses. Previous analyses (Olival et al. 2017; Johnson et al. 2015) have shown that the zoonotic, or spillover, potential of wildlife viruses is strongly tied to the breadth of hosts that a given virus is capable of infecting in nature.

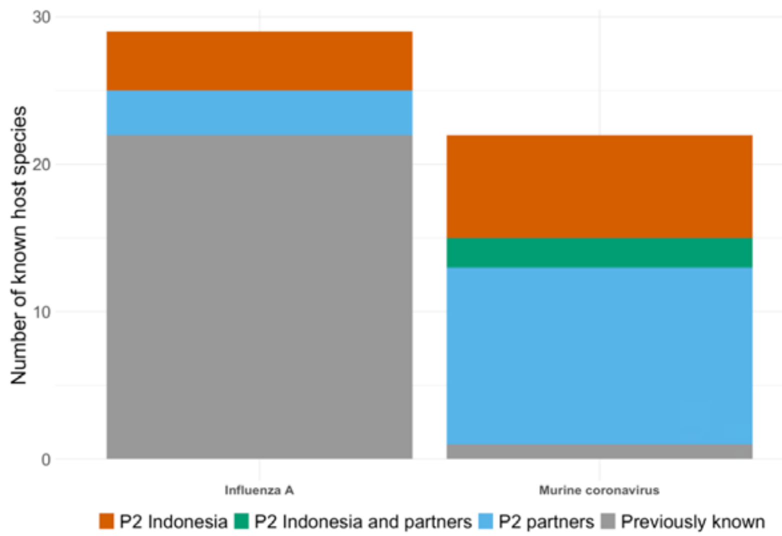


FIGURE 5. Expansion of the number of recognized mammal host species for previously-described viruses as a result of sampling in Indonesia. Each bar represents previously described (known) virus, i.e. those named by the International Committee on the Taxonomy of Viruses 8th edition. Previously known host species for each virus are based on Olival et al. 2017. The number of mammalian hosts for each virus are visualized using stacked bar plots, showing the number of pre-PREDICT-2 (P2; prior to 2015) recognized host species (gray portion), the number of newly recognized host species found in Indonesia (orange portion), and, where applicable, the number of newly recognized host species found in both Indonesia and other PREDICT-2 country sampling efforts (green portion) and the number of newly recognized host species found in other PREDICT-2 countries. Only previously described viruses detected in Indonesia in new host species are shown.

VIRUS FINDINGS IN PEOPLE

The human laboratory safely collected biological specimens from 217 patients from Noongan Hospital and the clinic in North Sulawesi, as well as samples from 454 participants in the community. The team tested 1,352 specimens for paramyxoviruses, influenza viruses, coronaviruses, flaviviruses, and filoviruses using conventional consensus PCR methods. Two patients were positive for Human Parainfluenzavirus 4, 19 were positive for influenza A viruses, one for Betacoronavirus 1 (OC43), 15 for Dengue virus and seven tested positive for Rhinoviruses. Only one virus, Measles virus, was detected in the community-based surveillance. These data show the effectiveness of using consensus viral family screening assays to detect important human pathogens not often included in surveillance efforts for both sick and healthy participants. Although Influenza A was the only virus detected in both people and wildlife, we were able to collect important data on viruses circulating in both symptomatic and community settings. The human viruses detected by site, specimen type, and frequency of detection are summarized in Table 2.

VIRUS NAME	VIRAL TEST TYPE	NUMBER OF DETECTIONS	SITE NAMES	SPECIMEN TYPES
INFLUENZA A	Influenzas	37	Noongan Hospital, Minahasa	Feces, nasopharyngeal swab, oral swab, oropharyngeal swab, nasal swab, blood (whole)
DENGUE VIRUS	Flaviviruses	15	Noongan Hospital	Blood (whole)
RHINOVIRUS A	Enteroviruses	5	Noongan Hospital, Minahasa	Oropharyngeal swb, nasal swab, nasopharyngeal swab
HUMAN PARAINFLUENZAVIRUS 4	Paramyxoviruses	2	Minahasa	Nasal swab
INFLUENZA B	Influenzas	2	Noongan Hospital, Minahasa	Oropharyngeal swab, oral swab
BETACORONAVIRUS 1 (OC43)	Coronaviruses	1	Minahasa clinic	Nasal swab
MEASLES VIRUS	Paramyxoviruses	1	Minahasa	Oropharyngeal swab
RHINOVIRUS B	Enteroviruses	1	Noongan Hospital	Oropharyngeal swab
RHINOVIRUS C	Enteroviruses	1	Minahasa	Nasal swab

TABLE 2. Virus findings in people by site, specimen type, and frequency of detection.

EPIDEMIOLOGICAL & BEHAVIORAL RISK

INSIGHTS FROM IN-DEPTH BEHAVIORAL RISK INVESTIGATIONS

In Indonesia a human questionnaire was administered in three provinces which each have different customs, cultures, and religious practices. The differences in each setting have implications for our findings related to the frequency of animal contacts and associated risk of exposure to zoonotic disease, as well as other differences such as hygiene practices, health-seeking behavior, and knowledge about zoonotic risk.

In general, the respondents at all study sites have implemented some hygiene practices in their household including for water treatment, food storage, and human waste management. Knowledge of the risk of zoonotic disease is still limited, even among individuals involved in the wildlife value chain, with only a few respondents under the perception that a wild animal can cause sickness. These preliminary findings imply that the communities, especially the ones categorized as high-risk, need to be better informed about zoonotic disease transmission.

We found that high-risk people such as wild meat hunters, vendors, and consumers lacked knowledge regarding the potential threat of zoonotic disease. It was found that these groups sometimes use traditional plants to treat wounds. While the active treatment of wounds shows the acknowledgment of risk from being bitten or scratched by an animal, the adoption of preventative measures, such as wearing personal protective equipment (PPE) while hunting, is not practiced.

Another interesting finding from the human survey was related to the knowledge of government regulation for wildlife protection. In 1999, the Government of Indonesia banned the hunting and sale of various wildlife species including large animals like babirusa and anoas. Some respondents said they knew about the regulation but continued to sell wildlife for economic reasons. This last finding presents a significant challenge to develop interventions for subsistence hunters despite existing knowledge of the government regulations. The development of solutions will require a multisectoral coordination by the government to find the most effective solution, as well as promotion of educational materials related to risk.

INSIGHTS FROM QUALITATIVE BEHAVIORAL RISK

Focusing on the thriving bushmeat trade in Sulawesi, the behavioral risk team conducted qualitative research to obtain a deeper understanding of how local communities interact with livestock, wildlife, bushmeat markets, and the surrounding bushmeat value chain. The multidisciplinary team, trained in qualitative research methodology and data collection used in-depth one-on-one interviews and focus group discussions to engaged community members from 15 locations within the main sampling sites in North, West, and South Sulawesi.

The participants, many of whom were targeted for their involvement in the wildlife trade (hunters, bushmeat vendors, homemakers), described several types of contact with taxa such as rats, bats, wild boar, non-human primates, cuscus, snakes, anoas (wild cows), and yaki (non-human primates). Of these, rats, bats, and wild boar were the animals most often hunted, transported, and sold by the respondents. Among most vendors and hunters, it was more common to work with multiple taxa rather than exclusively with one, thus suggesting an increased risk for exposure to zoonotic viruses.

Among those questions on injuries obtained while handling live or dead wildlife, rats appeared to be the source of most bites, and bats the source of most scratches. Health-seeking behaviors, particularly wound care following bites and scratches were inconsistent. While respondents generally had a history of accessing care at established clinical facilities, they mostly relied upon those services for more severe injuries. Many participants opted for traditional ethnobotanic solutions or self-treatment following wildlife bites and scratches, and may be potential entry point to target audiences to implement future zoonotic disease prevention efforts.

When asked about individual consumption of wildlife, many respondents described how they ate any kind of animal from the forest, or any of the wildlife with which they worked. Among those who specified the kinds of animals they ate, rats, fish, bats, and wild boar were included. Several of the respondents shared that they continued to hunt and consume protected wildlife, such as anoa and yaki, despite being aware of the laws regarding those protected species.

These behavioral risk investigations at Sulawesi bushmeat markets were an immense success made possible by the local team's professional expertise to facilitate nuanced and sensitive discussions. The insights obtained will provide a valuable body of evidence for researchers and practitioners looking to build local evidence-based interventions to better protect the health of those living alongside and working in the bushmeat markets in Sulawesi.

QUANTIFYING & MAPPING THE WILDLIFE TRADE IN SULAWESI

To further explore zoonotic disease risk in the wildlife trade in Indonesia, we used field surveys, ethnographic interviews, and daily counts in markets to document terrestrial wildlife species for sale in North Sulawesi markets, and to identify the hunting sites, practices, and key actors within the trade. These data were collected to better understand the potential for exposure and risk for disease emergence along the wildlife value chain in Sulawesi, the species traded, occupations and behaviors of those involved in the trade, and volume of the trade. We quantified the volume of wild meat traded and the prices of items (to better understand socio-economic drivers associated with disease risk), with a particular focus on the flying fox trade. Wildlife meat was routinely available for sale in 73% of the markets and supermarkets surveyed in North Sulawesi. The wildlife taxa most commonly found in these markets were flying foxes, wild pigs, rats, and snakes. Wildlife hunting and trade networks extend to all provinces on the island through a well-organized, dynamic, and easy to access network involving many actors. We identified 45 flying fox roosts in Sulawesi, 38 of which were under active hunting pressure. A third of the active hunting sites are located in Southeast Sulawesi, which acts as a hub for bat hunting and trade - and a site of greatest risk where bat hunters are in direct contact with captured, live animals. We estimate that the number of flying foxes annually traded in Sulawesi ranges from 662,551 to more than one million individuals and conclude that current rates of flying fox harvest are unsustainable for the population. Stricter law enforcement, implementation of hunting quotas, and further research efforts are therefore urgently needed to improve the sustainability and biosecurity of the wildlife trade in Sulawesi. For details see: (Latinne et al. 2020)

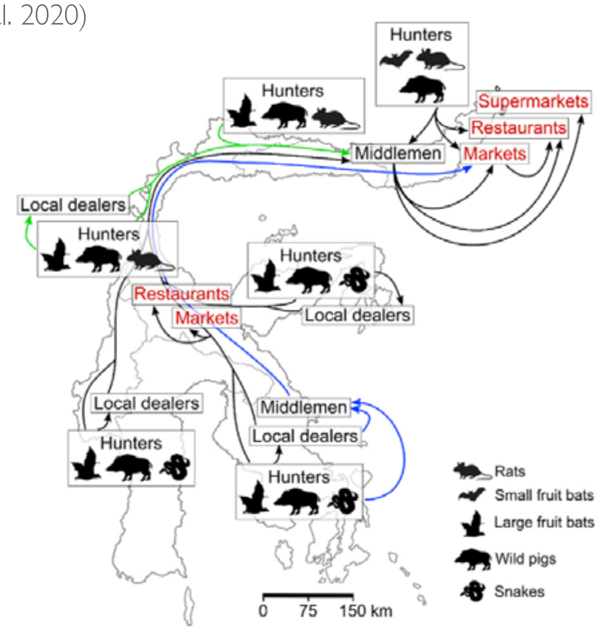


FIGURE 8. Overview of the wildlife trade network in Sulawesi and key actors involved in trading the four taxa most commonly traded, bats, wild pigs, snakes and rats.

FIGURE 6. (A) Wild meat for sale at a market in North Sulawesi; (B) Bats, wild pigs and birds for sale at a market in North Sulawesi; (C) Macaque, snakes and wild pigs for sale at a market in North Sulawesi (pictures: Suryo Saputro/Alice Latinne).

FIGURE 7. (A) Rat roasting in a North Sulawesi market; (B) Roasted rats for sale at a North Sulawesi market; (C) Roasted bats for sale at a North Sulawesi market; (D) Wild pigs, snakes, and bats and dogs for sale at a North Sulawesi market (pictures: Suryo Saputro/Alice Latinne).

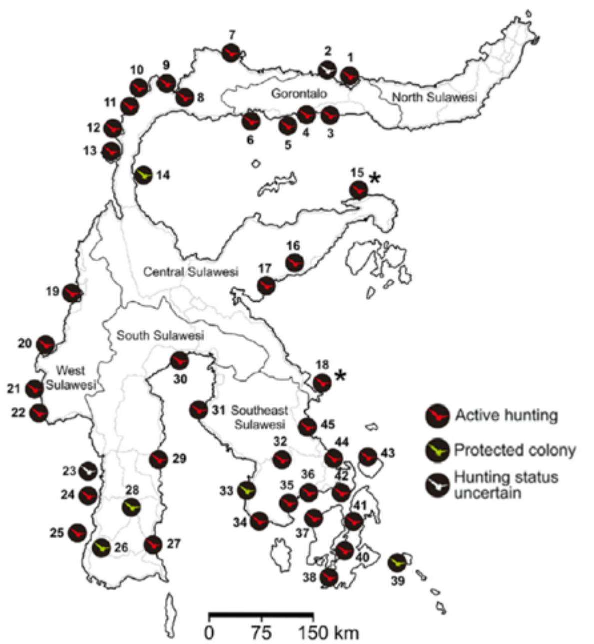


FIGURE 9. Map of Sulawesi showing the flying fox roosts identified in this study and whether they are hunted. The two *Pteropus griseus* roosts in Central Sulawesi are indicated by an asterisk. Other roosts are *Pteropus alecto* and/or *Acerodon celebensis*. The grey dotted lines corresponds to the provincial road network in Sulawesi.

COMMUNITY ENGAGEMENT & RISK COMMUNICATION

The PREDICT project in Indonesia facilitated several community meetings and outreach events within communities and health facilities where human surveillance activities were implemented in Sulawesi. Meetings were aimed at providing summaries of surveillance and laboratory findings and sharing resources and strategies to reduce risks for exposure to viruses, while balancing health and conservation goals. To raise community awareness of potential zoonotic diseases, the team promoted safe behaviors and practices related to hygiene, hunting, and wildlife handling. The PREDICT project-developed behavior change and risk communication resource, *Living Safely with Bats*, was one tool used for these activites. This resource was translated into Indonesian in order to be more easily understood by the communities.

CAPACITY STRENGTHENING

The PREDICT team in Indonesia hosted One Health trainings and collaborative workshops with the aim to increase capacity for such work across the country. These trainings ranged from field to laboratory topics and included collaborations with FAO in order to include and work with current professionals and emerging researchers. We also provided training opportunities to strengthen One Health capacity for zoonotic disease surveillance and laboratory testing for the government of Indonesia, including individuals from the Ministry of Environment and Forestry, Ministry of Health, and Ministry of Agriculture. In addition, we trained clinicians and laboratory staff from health facilities in North Sulawesi on biosafety and good clinical practices in biomedical research involving human subjects.

OUTBREAK PREPAREDNESS & RESPONSE

The team in Indonesia supported multiple responses at the request of the government of Indonesia, speaking to the success of the project. These included requests to perform viral family PCR testing from local district health offices, universities, and State-level Ministries, as well as providing technical support during outbreak investigations.

PRACTICAL IMPLICATIONS

- We believe a coordinated approach including the communities and local government can result in positive behavior change, and over time improve the health and resilience of community members in the face of zoonotic threats.
- At the policy level, the PREDICT team engaged the local government for promotion and prevention programs associated with understanding zoonotic diseases, and provided input for the development of the Cross-Sector Coordination Guidelines for Zoonotic Outbreaks and Emerging Infectious Diseases in collaboration with Kemenko PMK (Coordinating Ministry for Human Development and Cultural Affairs).
- We also provided technical advice to the national One Health Platform under the Coordinating Ministry of Human Development and Cultural Affairs (Kemenko PMK) on the Sistem Informasi Zoonosis dan Emerging Infectious Diseases (SIZE, EID and Zoonosis Information System) and participated in One Health Assessment for Planning and Performance Multisectoral Workshop organized by the same Ministry in 2018.
- Our data collection on wildlife trade markets in Indonesia showed that hundreds of thousands of bats, wild pigs, snakes, and rats are hunted and traded annually in Sulawesi. These markets have been found to be part of a well-organized and dynamic network involving many actors (Latinne et al., 2020).
- Our in-depth behavioral risk interviews have shown that flying fox hunting is an important source of income in Sulawesi. At the same time, our analysis suggests current rates of flying fox harvests are unsustainable, both from a conservation and food supply perspective (Latinne et al., 2020).
- Through the PREDICT project's investigation of the wildlife trade dynamic, we have found that the trade of protected species is ongoing, albeit at a lower scale. We assert that in North Sulawesi there is an urgent need for stricter law enforcement regarding the protection of theses species. Implementation of hunting quotas, as well as research and conservation efforts are urgently needed to improve the sustainability of the wildlife trade in Sulawesi. Further work and risk-based investigations using a One Health approach such as that utilized by the PREDICT project are needed, as the impact of this trade on Sulawesi local ecosystems remains mostly unknown (Latinne et al., 2020).

FURTHER READING

- Latinne, A. et al. (2020). Characterizing and quantifying the wildlife trade network in Sulawesi, Indonesia. *Global Ecology and Conservation*. 21. e00887. 10.1016/j.gecco.2019.e00887.

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