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Development of additional evidence to guide advocacy and decision-making for the control of canine rabies in West Timor, Indonesia:

Economic and epidemiological evaluation of current and future control options

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Table of Contents

Tables and Figures

Executive Summary

West Timor was rabies-free until May 23, 2023 when the disease was detected in a human patient from Timor Tengah Selatan (TTS) District. Since then, cases in both dogs and humans have been detected in the districts of Malaka, Timor Tengah Utara (TTU), Belu, and Kupang City. Human cases have also been detected in Oecusse, an enclave of Timor-Leste within West Timor. A University of Melbourne team, in collaboration with Indonesian and Australian partners, undertook a rapid data collection and outbreak evaluation exercise in mid-2024. This report presents findings from a field visit in late May 2024, and rapid epidemiological and economic evaluations, focusing on synthesizing outbreak response information, and conducting preliminary epidemiological and economic analyses. This work helps provide evidence and insights to support decision-making and advocacy for stronger rabies control in West Timor

From May 27 to 31 2024, three University of Melbourne staff (two veterinarians and one agricultural economist) visited West Timor. They participated in cross-sectoral workshops and conducted field trips across four districts (TTS, TTU, Belu, and Kupang) interviewing stakeholders including animal and human health authorities, disaster management authorities, quarantine officials, and local communities. They collected economic and epidemiological data that was used to parameterize a preliminary rabies model to evaluate the impact of different outbreak response actions, with a key focus on the effects of achieving different dog vaccination coverage rates across West Timor.

Preliminary descriptive epidemiological analysis of 11 months of data estimates the incidence risk of rabies detections in West Timor was 31 cases per 100,000 free-roaming dogs, with higher frequencies observed in peri-urban areas. The density of rabies-vaccinated dogs varied significantly across the island, ranging from 0 to 40 per square kilometre. There were fewer actual detections in areas with relatively high vaccination densities, and most rabies cases occurred in regions where vaccination density was below 15 vaccinated dogs per square kilometre, indicating that low dog vaccination coverage correlates with higher rabies incidence. Additionally, most detected canine rabies cases (45 out of 58) were found in less affluent areas, where the relative wealth index was below zero. These findings suggest that future surveillance and vaccination efforts should focus on less affluent regions of West Timor, particularly Timor Tengah Selatan, where most rabies cases have been reported.

Preliminary modelling compared a best-case scenario (current vaccination coverage intensified to achieve the recommended level of 70% in the next 12 months) and a worst-case scenario (current efforts declining to 25% coverage, similar to endemic areas in Indonesia). Reaching and sustaining 70% dog vaccination coverage would stop human deaths in the near future. Conversely, in the worst-case scenario an estimated 228–234 human deaths could occur over a ten-year period, highlighting the urgency of advancing vaccination coverage as quickly as possible. Failing to strengthen the rabies response now will also have significant economic impacts, with the total ten-year cost of the outbreak in the best-case scenario estimated at IDR 240.7 billion compared to IDR 773.4 billion in the worst-case scenario. This difference is primarily due to the significant costs of human treatment and the GDP loss associated with human deaths in the worst-case scenario. Furthermore, the total operational costs for rabies control for the best-case scenario are 12% less than the worst-case scenario.

Stakeholder consultations identified there is a critical need to rapidly develop a unified and coordinated rabies response across all districts in West Timor, with dedicated leadership and management resources. Sufficient operational resources must be provided for dog vaccination, which our analyses show will be highly cost-effective. It is also important to note that there are some uncertainties and gaps in the available data. With improved data quality and more detailed modelling, the outcomes from this preliminary analysis can be refined.

Key recommendations for future rabies control in West Timor from this preliminary work:

1) A unified rabies control plan for the whole of West Timor must be urgently developed and implemented. Sufficient staff should be dedicated to its leadership and management for rapid, successful implementation. The plan requires clearly-described procedures, personnel and timelines to facilitate progress against stated targets.
2) The most critical and urgent action of the control plan should be reaching and sustaining the target of vaccinating 70% of dogs in West Timor annually. Our analyses indicate that vaccination is working (evidenced by a relatively high proportion of cases in areas where vaccination coverage is low). Vaccination efforts need to concentrate on less affluent areas of West Timor, particularly Timor Tengah Selatan where, to date, most of the canine rabies cases have been detected.
3) Investment and support for public awareness and community engagement should be increased to achieve greater compliance with dog vaccination and widespread understanding of how to manage dog bites in humans to avoid contracting rabies.

4) Surveillance and reporting of suspected and confirmed rabies cases in dogs must be strengthened in communities throughout West Timor. Dates of case detection should be provided for the complete case dataset to facilitate greater monitoring and insights into the spatio-temporal evolution of the outbreak.

Acknowledgements

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Abbreviations

AIHSP	Australia-Indonesia Health Security Partnership
BPBD	Badan Penanggulangan Bencana Daerah: Indonesian Provincial Disaster Management Authority
GFP	gross domestic product
IBCM	integrated [dog] bite case management
IDR	Indonesian rupiah
PEP	post-exposure prophylaxis (against rabies)
RIG	rabies immunoglobulin
SAR	serum against rabies (synonym for RIG)
TTS	Timor Tengah Selatan District
TTU	Timor Tengah Utara District
VAR	vaccination against rabies

Introduction

Rabies is an endemic disease in much of Indonesia, but West Timor (*Timor Barat*) was rabies-free until the first human case of rabies was reported in Timor Tengah Selatan (TTS) District[1] on 23 May 2023. TTS has been the epicentre of the disease outbreak since then, but cases have spread across much of the island, including Malaka, Timor Tengah Utara (TTU), Belu, and Kupang City. Additionally, cases have been reported in Oecusse, an enclave of Timor-Leste that lies within West Timor, Indonesia.

In collaboration with key Indonesian and Australian partners, a team from the University of Melbourne conceived and implemented this project with the aim of developing evidence-based approaches to guide decision making for the control of canine rabies in West Timor, Indonesia. The purpose of this report is to present the outputs of the rapid appraisal conducted by the University of Melbourne team around a field visit in late May with a focus on the following key areas:

- A synthesis of information and data on the rabies outbreak response collected during the in-country visit in May 2024
- Descriptive epidemiological analyses of the West Timor rabies outbreak to describe the frequency of rabies (in animals and humans) and a preliminary analysis of associated factors, which differentiates this work from previous epidemiological analyses of the outbreak.
- Preliminary modelling and economic analysis evaluating the impact of different outbreak response actions, particularly different dog vaccination coverage levels.
- Based on the above, key findings to support decision-making and advocacy for rabies control and elimination in West Timor.

Methods

Three University of Melbourne staff (two veterinarians and one agricultural economist) spent one week in West Timor from 27 to 31 May 2024. The team participated in a cross-sectoral workshop on 27th May, with representation from the Department of Health, Department of Animal Health, Disaster Coordination (BPBD), and the Australia Indonesia Health Security Partnership (AIHSP). The team conducted two parallel field trips from 28 to 30 May. This involved visiting four districts in West Timor (TTS, TTU, Belu and Kupang). The team conducted semi-structured interviews with the following stakeholders to collect data and gather insight on the major strengths and gaps of the ongoing rabies response in West Timor:

- Animal health authorities (at provincial, district and sub-district levels).
- Human health authorities (at provincial, district and sub-district levels).
- Disaster Management authorities (at provincial level).
- Quarantine (at provincial level).
- Two village communities in TTS district.

Economic and epidemiological data collected during these interviews were used to parameterise a rabies economic model, *RabiesEcon* (Kunkel et al. 2021). RabiesEcon provided estimates of the expected number of dog and human rabies cases over a 10-year period for different control scenarios (see below). While this approach was acceptable for a rapid appraisal, it is our assessment that more detail can be provided by using agent-based modelling approaches to estimate likely responses to disease control interventions, as discussed at the end of the *Conclusions* and Section.

Economic analyses

Details of model input values and descriptions are provided in Annex 1. A fixed human population size for West Timor was used from the 2024 Indonesian Statistics Agency (Wikipedia 2024). The total West Timor dog population was estimated at three different human:dog ratios commonly considered by West Timor stakeholders, namely 6:1, 7.6:1 and 10:1 (Table 3 in Annex 1). Because RabiesEcon did not produce human rabies case numbers similar to reports to date, we adjusted the land area specified in the model down from 14,513 km^2 until the estimated Year 1 rabies deaths

[1] Indonesia's administrative system consists of *provinsi* (Provinces), *kabupaten* (referred to variably in English as "Regency" or "District"), *kecamatan* (confusingly, "District" or "Sub-district"), and *desa* (village administrative area). For disambiguation, we use "District" to refer to kabupaten and "Sub-district" for kecamatan in this report.

were equal to 24, the figure reported from West Timor over the 12-month period from May 2023 to May 2024 (model 'Year 1'). This decision is discussed more in the *Future epidemiological and economic modelling* section on page 16.

Two scenarios were modelled epidemiologically and economically based on different intensities of outbreak response efforts, including dog vaccination coverage rates, and intensity of community engagement/risk communications and disease surveillance in dogs (Table 2). In both scenarios, access to post-exposure prophylaxis and bite case management for humans was assumed to be the same (Table 3). Because the West Timor dog population is not precisely known, sensitivity analyses covering three populations using the three human-to-dog ratios described above were conducted.

The two scenarios modelled were labelled *Best* and *Worst* outbreak management. *Best* management represented a moderate intensification of the current efforts to achieve 70% dog vaccination coverage in Year 2 in line with international recommendations for rabies elimination and control (Coleman and Dye 1996; Bourhy et al. 2018), supported by widespread, coordinated community engagement, risk communication and disease surveillance activities. In this scenario, human deaths are estimated to drop to zero by Years 3 to 4 and we assumed this was followed by implementation of plans to attempt rabies elimination from West Timor in Years 8 to 10 as described in Table 2. In contrast, the *Worst* scenario described a situation where current outbreak activities could not be maintained, declining in Year 2 to 4 to those similar to other areas of Indonesia where canine rabies is endemic.

For each scenario and sensitivity analysis, dog vaccination coverage rates were calculated by applying the total number of dogs reported vaccinated in West Timor in the 12 months to May 2024 (approximately 122,000; AIHSP 2024) to the three different dog population estimates. These human and dog populations, and dog vaccination coverage figures were used in RabiesEcon to estimate numbers of human cases (deaths) in Years 1 to 10 of the outbreak, with Year 1 comprising the 12 months from the start of the outbreak in May 2023 (and using actual reported data where available for Year 1 in the economic model). Human dog bite cases per year were assumed to be constant, with fixed proportions seeking and receiving post-exposure prophylaxis ('PEP') entailing wound treatment and post-exposure vaccination (Table 3). However, in the *Best* scenario, those receiving PEP in the 'Control' zone did not receive a fourth vaccine dose, under the assumption that intensive risk communication, disease surveillance and coordination meant that suspect dogs were contained and monitored for two weeks after biting a victim, allowing confirmation they were not rabid and so posed no human infection risk (Bourhy et al. 2018).

A separate economic model was applied to each scenario and sensitivity. Annual line-item costs over 10 years for human bite case management, dog vaccination, dog disease surveillance, public awareness and community engagement were calculated using costs and rates gathered from stakeholder consultations during the May 2024 field trip. The discounted loss to GDP from human deaths was estimated assuming an average age of death of 27 years and average life expectancy of 67.2 years. Future values were discounted at 3% per annum (Neumann et al. 2016).

Epidemiological analyses

Data for our epidemiological analyses were obtained from several sources. Details of suspect canine rabies for the period 20 June 2023 to 26 May 2024 listing calendar date and desa (village) of detection were provided by West Timor district animal health authorities (Belu, Malaka, Kupang, TTS, TTU and Kota Kupang). Incident canine rabies counts were cross-checked with counts provided in the May 2024 canine rabies situation report. Counts of dogs vaccinated for rabies by date and desa were retrieved from iSikhnas, the national animal health reporting system.

High resolution population density maps and demographic estimates were obtained from the Data for Good at Meta project (HDX 2023) to develop a 5244 row by 6330 column raster map of West Timor listing (human) population counts in raster cells of dimensions 31 km × 31 km. Relative wealth indices for West Timor, expressed on a numeric scale ranging from -0.15 to +0.30 for a regular grid of point locations separated by a distance of 2.5 kilometres were obtained from the same source.

Using a Geographic Information System, a vector map of the boundaries of the n = 859 desas in West Timor were superimposed on the human population raster and population counts per desa calculated as the sum of the raster cell population counts within each desa's boundaries. Desas with a population density of greater than 500 individuals per square kilometre were classified as urban (Figure 4, Annex 2). Desas with a population of less than or equal to 500 per square kilometre were designated as rural. Human to dog ratio estimates[2] for urban and rural areas in West Timor (19, 95% CI 16–19 and 9, 95% CI 7–12, respectively) based on Ward (2023, Table 7) allowed us to approximate free-

[2] Assuming most dogs are owned but 'free roaming' in West Timor

roaming dog population counts per desa. Counts of dogs per desa were kernel smoothed (Kelsall and Diggle 1995) using a bandwidth of 5 kilometres and a regular grid cell size of 975 metres to return an image plot of free-roaming dog population density, expressed as the number of dogs per square kilometre (Figure 5).

The canine rabies data set for 20 June 2023 to 26 May 2024 provided by West Timor district animal health authorities listed date and desa of detection for *n* = 54 rabies cases compared with a total of *n* = 58 cases in the 24 April to 6 May 2024 situation report. Seven cases of rabies were listed for Timor Tengah Selatan in the district data set compared with 35 cases in the 24 April to 6 May 2024 situation report. Lack of unambiguous incident case details negatively impacts on our ability to provide analyses sufficient to support decision making. For this reason, we elected to digitise the rabies detection locations shown in Figure 1 of the 24 April to 6 May 2024 canine rabies situation report, assuming these represented the complete listing of rabies cases. While this allows us to make inferences about the geographic distribution of canine rabies risk the absence of a date of detection for each case means that we're unable to comment on the temporal and spatio-temporal features of the outbreak.

The rho hat procedure (Baddeley et al. 2012) was used to quantify the association between canine rabies detection density (expressed as the number of rabies detections per square kilometre) and the following hypothesised risk factors: (1) free roaming dog population density; (2) vaccinated dog population density; and (3) affluence, as quantified by the relative wealth index data provided by the Data for Good at Meta project. Here, a line plot was developed to show how canine rabies case detection density varied as a function of the numeric value of each risk factor of interest. These analyses provide a useful indication of the success or otherwise of interventions to control disease (e.g., vaccination programs) and characteristics associated with an increased risk of case detection (e.g., the geographic distribution of free roaming dogs and relative wealth index).

Results

Outcomes and costs of different approaches to current outbreak

Depending on the actual dog population in West Timor, dog vaccination coverage from the approximately 123,000 vaccines delivered to date may be as low as 36% or as high as 61%. However, we estimate that the total number of human rabies deaths will be much more strongly driven by the future course of vaccinations, and whether the current campaign can successfully intensify vaccination coverage to 70%, or will see it decline through under-resourcing and inadequate coordination to 25% like elsewhere in Indonesia.

Figure 1 shows that if coverage can be intensified and maintained—the *Best* scenario—our model estimates only a total of 26–32 human deaths over 10 years. Intensifying vaccination coverage to 70% in Year 2 quickly reduces human deaths to zero across the range of evaluated dog population numbers, with only small differences in how quickly this is achieved. However, about 10 times more people will likely die if vaccination coverage is not strengthened and maintained above the current rate, with 228–234 deaths predicted in the *Worst* scenario. In other words, vaccination should be advanced as quickly as possible to achieve coverage as close to 70% as possible, without delaying to assess the actual dog population in West Timor. An accurate dog population estimate will still be very helpful for coordinating the campaign across West Timor, but it should be conducted alongside the vaccination campaign rather than being done first and contributing to potential vaccination delays.

The health system response to rabies will likely be unable to overcome the disease risk from the largely unvaccinated dog population in the *Worst* scenario, as shown by the 8-fold greater human deaths in that situation despite our assumption of widespread access to PEP. This shows it is critical to support the animal health sector to intensify dog vaccination efforts now, because even a strong human health system will be unable to offset the dramatically greater infection risk created by low dog vaccination coverage in the next few years. Similarly, we predict the difference in vaccination coverage between the *Best* and *Worst* scenarios has a much greater effect on canine rabies case numbers than the actual rate achieved in Year 1 and the size of the dog population, as shown in **Error! Reference source not found.** and **Error! Reference source not found.**.

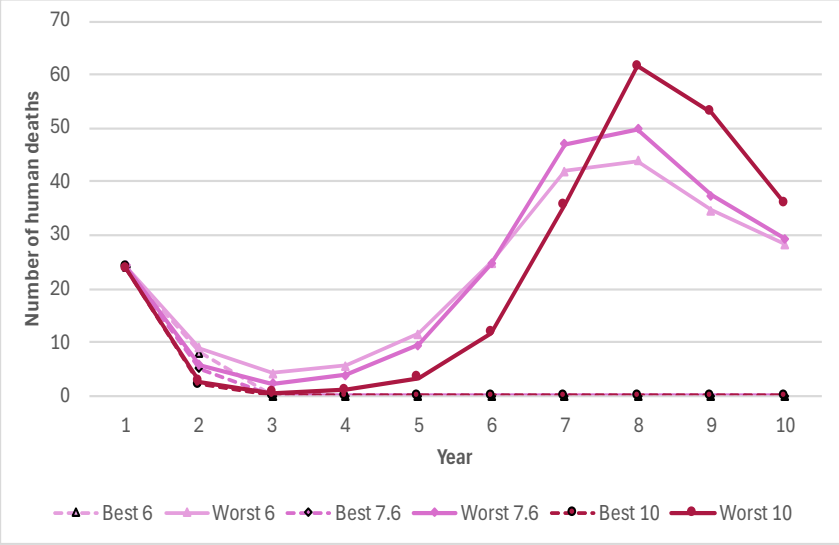


Figure 1: Estimated human deaths over 10 years in West Timor under *Best* and *Worst* outbreak response scenarios and different human:dog ratios

Figure 2: Estimated human deaths and dog rabies cases in *Best* scenario

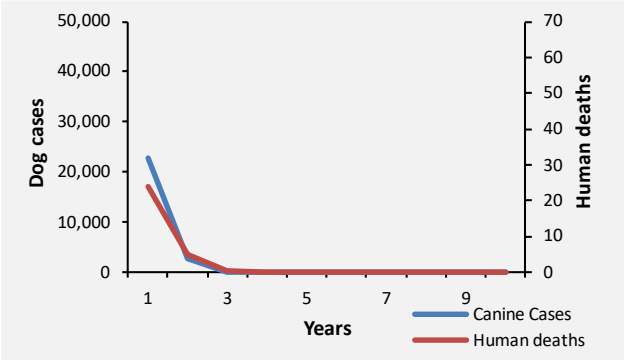
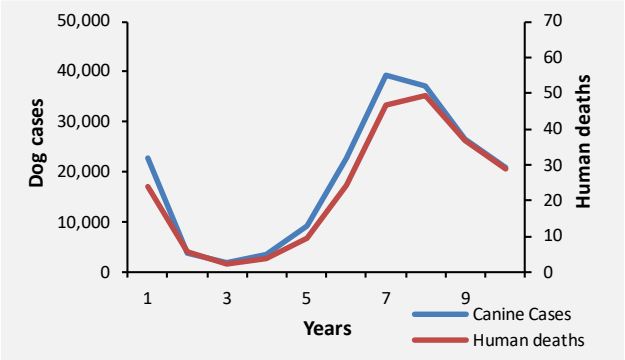


Figure 3: Estimated human deaths and dog rabies cases in *Worst* scenario



Both models assume a human:dog ratio = 7.6, giving a West Timor dog population of 264,641.
Year 1 = 12 months to May 2024

The significantly better outcome for human health in the *Best* scenario requires spending 29% more in the animal health sector in the *Best* scenario compared to the *Worst* scenario animal health sector expenditure (IDR 45.5 billion compared to 35.3 billion over 10 years; Table 1). This difference is still very modest, as we estimate the average animal health sector control costs to be only IDR 9.4 million per village per year over the first five years when activities are greatest. This amount would likely be easily covered by village discretionary budgets. Additionally, the total human and animal health operational costs are 12% less in the *Best* scenario than the *Worst* because of the savings in PEP and other treatment costs. Overall, the *Best* control program is predicted to deliver a very significant economic benefit to West Timor: IDR 532.7 billion of additional avoided costs and impacts over 10 years compared to the *Worst* program, equivalent to IDR 53.5 billion per year, because it avoids a significant impact to GDP by saving a large number of lives.

In summary, a modest investment intensifying dog vaccination and other efforts will likely rapidly reduce human deaths, achieve savings in the human health sector, and deliver a large economic benefit to West Timor in the next few years.

Table 1: Key costs and impacts of *Best* and *Worst* rabies control approaches in West Timor (all net present values over 10 years unless otherwise specified)

	Scenario	
	Best	***Worst***
Total human deaths	29	234
GDP loss from human deaths	IDR 87.7 billion	IDR 599.3 billion
Health sector costs	IDR 107.6 billion	IDR 138.8 billion
Animal health costs for control program	IDR 45.5 billion	IDR 35.3 billion
Total human & animal health operational costs	*IDR 153.1 billion*	*IDR 174.1 billion*
Peak* average animal health operational costs per village per year	IDR 9.4 million	IDR 5.2 million
Total cost & impact	**IDR 240.7 billion**	**IDR 773.4 billion**
Net benefit of *Best* compared to *Worst* approach	**IDR 532.7 billion**	
Net annual average benefit	**IDR 53.3 billion**	

Assumptions: *human:dog ratio = 7.6, total West Timor dog population 264,641*
** Average over Years 1-5, when activities are greatest*

Epidemiological analyses

As of 6 May 2024 there had been 58 canine rabies detections reported throughout West Timor. The incidence risk of rabies detections over the 11-month follow-up period was 31 (95% CI 23–40) cases for every 100,000 free-roaming dogs at risk.

Based on Figure 5 there are higher frequencies of canine rabies detections in peri urban areas (e.g., around Atambua, Besikama and Kefamenanu). A relatively large number of cases have been detected in Timor Tengah Selatan, particularly around Soe. It is difficult to determine if the case detection excess in Timor Tengah Selatan is due to a true excess of disease in that district or due to a higher level of surveillance intensity.

There was no obvious association between free roaming dog population density and rabies detection risk (Figure 6), though it is noted the distribution of dog population density across the study area is highly skewed with relatively large numbers (greater than 200 per square kilometre) in Kota Kupang. All of the canine rabies cases detected for the period June 2023 to May 2024 were in areas of relatively low free roaming dog population density (i.e., less than 50 dogs per square kilometre), Figure 5.

Across West Timor the density of rabies vaccinated dogs ranged from 0 to 40 per square kilometre (Figure 7). Figure 8 shows that while there was a higher density of rabies detections in areas of relatively high vaccination density the actual number of detections in these areas was low (as indicated by the vertical lines positioned on the horizontal axis of the plot). Conversely, most rabies detections were in areas where vaccination density was less than 15 per square kilometre. Figure 8 provides indirect evidence of a response to the rabies vaccination program in that most of the canine rabies detections for the period June 2023 to May 2024 occurred in areas of relatively low vaccination density.

Figure 9 shows the geographic distribution of affluence across West Timor, as measured using the relative wealth index (Chi et al. 2022). As expected, relative wealth indices were relatively high in city areas (e.g., Kota Kupang). Most of the detected canine rabies cases (45 of 58) were in areas where the relative wealth index was less than zero, i.e., less affluent areas (more blue lines towards the left end of Figure 10). These results show that surveillance (and vaccination) efforts need to concentrate on less affluent areas of West Timor, particularly Timor Tengah Selatan where, to date, most of the canine rabies cases have been detected.

Current rabies response and challenges

The Provincial Disaster Management Agency (BPBD) currently leads the rabies response efforts in West Timor and collaborates closely with animal and human health authorities. It should be noted that this structure may change as the declared 'emergency' period for rabies comes to an end in mid-2024. In the animal health sector, the primary response measure is to deliver mass dog vaccination programs. In the human health sector, the primary response

measure is to manage humans who have been bitten by dogs ('dog bite victims'). Both animal and human health authorities also focus heavily on public awareness and community engagement. The Indonesian Quarantine Authority is also involved in the rabies response with the primary task of detecting and stopping animal movement to West Timor from other parts of Indonesia. The following section provides more specific information relating to each sector.

Animal Health (Directorate General of Livestock and Animal Health)

- Mass dog vaccination is undertaken by animal health teams comprised of approximately 4-6 staff who implement both central point and door to door vaccination campaigns in villages and other centres.
- The Indonesian army and police also assist in dog vaccination campaigns. When involved, they play an important supporting role to animal health teams by encouraging engagement and compliance from communities.
- The number of dogs vaccinated per day ranges from 30 to 150. This large range is partly due to variability in factors such as village compliance, transport to and around villages and the level of engagement between village authorities and animal health staff. However, the number of dogs vaccinated has also been influenced by changes in the staff payment system. Previously, staff were paid per dog vaccinated and this generally correlated with higher numbers of dogs vaccinated per day. The incentive system was then changed to a flat daily rate, based on a minimum 30 dogs being vaccinated. Accumulated dog vaccination data (as recorded in iSikhnas) indicates that this policy change has had an adverse impact and reduced the speed of dog vaccination coverage, with recent estimates of the number of dogs vaccinated per desa per day limited to 30 dogs/day.
- Diagnostic testing of dogs (conducted post-mortem) is limited. Ad-hoc tests have been performed at Diseases Investigation Centre (DIC) in Bali and rapid tests have also been used in West Timor through support from the AIHSP program.
- There is some adoption of a 'One Health approach' for rabies response with collaboration between Animal and Human Health authorities. In response to confirmed human rabies cases, a joint Animal-Human team visits affected areas to undertake public awareness and dog vaccination activities. In response to some dog bites, animal health authorities will also collaborate with human health authorities to undertake follow-up testing and monitoring of dogs, although the low number of dog test submissions and case detections relative to human bite cases suggests that this is infrequently performed. There appear to be other considerable challenges in cross-sectoral collaboration. Integrated Bite Case management (IBCM), where dogs biting humans are assessed for rabies risk and confined for 14 days to monitor for clinical signs of rabies to guide PEP protocols (Bourhy et al. 2018), is not routinely performed. This appears to be due to limited animal health resources, absence of any standardised case coordination protocols between human and animal health, and no or unsuccessful efforts engaging dog owners to report, confine and follow-up suspect dogs. In addition, communities generally kill aggressive dogs or dogs that bite people. This makes testing and epidemiological investigation difficult as such cases are generally not reported to authorities; at best, samples from killed dogs are often unusable for diagnostic testing.

Animal health challenges

- Operational resources: Although there are enough vaccine doses available to vaccinate 200,000 dogs in West Timor, a lack of sufficient operational resources is the most significant challenge to achieving the target for dog vaccine coverage. Sufficient funding is needed for animal health teams to cover costs such as food, accommodation and travel to villages. Currently, there is no to limited standardised identification of vaccinates, funding to implement a standardised and consistent method for identifying vaccinated dogs (e.g., collars or long-lasting paint) is critically needed. In some cases, operational resources such as dog handling equipment, cold chain items (e.g., fridges, ice boxes etc.) is also required.
- Dog population: There are high levels of uncertainty regarding the size of the dog population in West Timor. Ward's (2024) estimate of a total of 192,461 dogs and a human to dog ration of 10 to 1 conflicts with the local working ratio of 6:1. If the former figure is used, the number of dogs vaccinated already exceeds the estimated total population, even though villages report a non-trivial proportion of dogs remaining unvaccinated. Nonetheless, our preliminary epidemiological modelling suggests it is more important to continue progressing dog vaccination and not lose momentum. Ward recommended using the enumerators trained in early 2024 to train others so that dog numbers can be estimated in parallel with vaccinations, an approach we endorse.
- Dog ecology and husbandry: The majority of dogs in West Timor are free roaming. This makes vaccination challenging as owners will not always have dogs secured and accessible. As a result, animal health teams generally revisit villages more than once to vaccinate dogs that were missed on the first visit. There are also

challenges in community engagement as the notion of needing to vaccinate dogs is novel to many owners and it takes time for them to understand and appreciate the importance of this action. There are some reports of vaccine hesitancy, with owners concerned a vaccine may make their dog slow or dumb. However, reports from field staff suggests that the portion of villagers who adopt this attitude is relatively minor (less than 5 to 10%). Thus, there appears to be an important need for more widespread and pragmatic/efficient community engagement prior to vaccination visits to increase the number of dogs presented for vaccination. This would benefit from advice from local community engagement specialists, and using approaches beyond traditional animal health sector 'command and control' styles.

- Dog movement: As mentioned above, most dogs in West Timor are free-roaming and may move short distances (< 15 to 30 km). However, large scale dog movement was commonly described in interviews, with dogs moving across and between districts (> 50 to 100 km). These movement distance estimates are consistent with the spatial distribution of the outbreak to date, with cases widely distributed across West Timor (Figure 4). Long-distance movement occurs through dog gifting and dog meat consumption. Dogs are commonly gifted between family and community members, especially after whelping when puppies are gifted to a family that may reside far away. Dogs for consumption are also traded over long distances and this may occur when dog meat is needed for weddings or cultural ceremonies. Dog traders also move animals over greater distances and between districts. Initial evidence suggests this commercial dog trade is primarily focused on meeting demand in urban areas such as Kupang city, where there are more dog meat restaurants and markets. However, dog movement patterns do not appear to be described in more detail, and few methods are currently being used to try to limit movement to reduce rabies spread. Given the commercial and cultural considerations associated with dog movement, it is highly unlikely that a regulatory or quarantine approach will be effective in limiting dog movement, and public awareness and risk messaging may be a more effective option.
- Technical capacity: Animal health staff would also benefit from additional training in topics such as safe dog handling and dog capture, disease investigation and outbreak response. We observed several instances of ineffective or risky dog restraint during vaccination. Poor restraint and poor vaccination technique (with animals injected on the rump instead of into the scruff of the neck) make handlers more hesitant, may lead to ineffective injections, and risks owners being bitten. One vaccination team anecdotally reported that 2–5% of owners restraining dogs are bitten during vaccination. If this estimate is correct, the cost of PEP for bites incurred during vaccination is greater than the cost of dog vaccines administered during the campaign.
- Following up vaccination efficacy: There has been some uncertainty around vaccine efficacy, based on a limited set of 'post-vaccination' tests. However, it is unclear whether or not samples were definitely from dogs that were supposed to have been vaccinated, and sample handling and transport do not appear to have been clearly documented. Post-vaccination serology is not always recommended (Mission Rabies, *personal communication*) over post-vaccination surveys. However, if serological testing is to be used, it must be conducted in animals that are clearly known to have been in a rabies vaccination program, to strengthen interpretation of test results. Diagnostic samples must be handled and stored according to test requirements.

Human Health (Ministry of Health)

- Management and treatment of dog bite cases is the major role of the human health sector. Training on dog bite management and administration of post-exposure prophylaxis (PEP) for rabies has been provided to all relevant human health staff in West Timor.
- The primary point of care for dog bite victims is the *Puskesmas* or Community Health Centres, which provide healthcare for the population at the sub-district level. For the majority of bite cases treatment is provided at the Puskesmas. This includes administration of post-exposure vaccination ('vaccine against rabies', VAR) and other PEP procedures. Public information material promoting immediate, effective dog bite wound management, a critical part of PEP, appears to be available although we did not assess community awareness or response to this messaging in detail.
- Human health authorities report that current levels of VAR supply are sufficient to meet requirements and patient compliance with treatment protocols is generally very good. One district reported having to put a lot of effort into moving human vaccine stocks between Puskesmas to maintain levels. More efficiency might be achieved through the use of a centralised supply and stock management system, and supporting training, although this would need to be investigated more before implementation.
- For more severe or high-risk bite cases, human victims are treated at district hospitals. This is also where anti-rabies immunoglobulin (often termed RIg but locally 'serum against rabies', SAR) is generally held and

administered. The costs of SAR are significantly higher than VAR and there have been some shortages in supply.

Human health challenges

- The most significant challenge for human health authorities is the lack of public awareness and understanding of rabies and dog bite risks. The majority of human fatalities have occurred in instances where the patient did not report or seek treatment for a dog bite with urgency.
- VAR is supplied by the central government and to date supplies have been sufficient to meet demand. However, there is uncertainty on the future level of supply and demand, and there are local reports of difficulty managing vaccine supply logistics in some districts.
- SAR supply is an issue due to high cost. There have already been shortages of SAR supply and this could continue in the future. It is unclear how SAR availability has affected case outcomes and we did not investigate decision-making around SAR use.

Quarantine (Indonesian Quarantine Agency)

- Movement of dogs and cats into West Timor was banned at the start of the rabies outbreak in 2023. The Quarantine Authority undertakes inspection of vessels entering West Timor and has detected cases of illegal dog and cat movement over the past 12 months. This potentially poses a risk to rabies-free islands in Nusa Tenggara Timur.
- Illegal or informal movements of animals does occur into West Timor, and the scale and source of such movements are unknown.
- The Quarantine Authority is responsible for monitoring and enforcing movement of animals into and out of West Timor. Movement within the geographical area of West Timor is the responsibility of local animal health and district authorities but this currently does not appear to be monitored, controlled or regulated in any way. This represents a significant risk of incursion into Kota Kupang and Kupang District.
- The Quarantine authority has engaged in public awareness activities highlighting animal movement restrictions with messages placed on ships and in ports. Similar pro-active messages could be cost-effectively implemented for domestic transport within West Timor.

Cross-sectoral challenges

- Overall, there appears to be no coordinated, clear plan within or between sectors for rabies control in West Timor, and this is critically hampering effective disease management. Dog vaccination and other animal health control activities are not coordinated between districts, and the border/ring vaccination approach used to date has not been effective at preventing disease seeding across West Timor, likely due to ongoing long-distance dog movements. In the face of these factors, West Timor urgently needs a unified rabies response plan that is clearly action-oriented, with straightforward lines of implementation, responsibility, and monitoring and evaluation. This plan should be based on standard global best-practice, as there is a risk that some local recommendations are sub-optimal and may erode the efficacy of particular activities. High level political support from district and provincial leaders is essential to ensure that the entire island can adopt an effective plan to stop rabies that is supported by sufficient operational resources.
- Coordinated public awareness remains an important challenge for the rabies response in West Timor. There needs to be greater investment extending information sharing and engagement with local communities across the whole of West Timor, using insightful, evidence-based risk communication practices. For animal health, the focus of public awareness should be on encouraging dog vaccination, limiting dog movement and increasing reporting of unusual diseases and deaths in animals. For the human health sector, the focus should be on ensuring the entire population is aware of appropriate dog bite management and treatment and reducing the risk of dog bites through education on safer dog interactions. A wide range of community education material is readily available that should be adapted to local conditions, avoiding the need to develop bespoke materials that are untested.

Conclusions and recommendations

Despite facing many challenges, the authorities in West Timor have made progress managing the rabies outbreak. Relatively high dog vaccination coverage rates have been achieved compared to other parts of Indonesia and many other countries in the region, where dog vaccination coverage is typically 15 to 40%. This said, it is imperative to sustain and intensify this effort to reach the critical goal of ongoing 70% dog vaccination, supported by effective risk communication and public awareness-raising, and appropriate disease surveillance.

Immediate priority (1–2 years)

1. Develop and implement a unified rabies control plan for West Timor that includes a dedicated and committed leadership and organisational structure with clearly outlined procedures, personnel and timelines to facilitate monitoring of progress.
2. The most critical and urgent action of the control plan should be reaching and sustaining annual vaccination of 70% dogs across West Timor. In relation to dog vaccination the additional specific recommendations are made:
    2.1. Provide operational and human resource support to match the amount of dog vaccine purchased to ensure effective and timely administration across the dog population.
    2.2. Adopt and use internationally recognised and tested methods for identifying-vaccinated dogs, such as nylon collars or long-lasting paint.
    2.3. Where necessary, use accepted international methods to estimate the dog population, using teams already trained in this procedure.
    2.4. Where necessary, use and clearly document standard protocols to assess vaccination efficacy.
3. Increase investment and support for public awareness and community engagement. For animal health, the focus of public awareness should be on encouraging dog vaccination, limiting dog movement and increasing reporting of unusual diseases and deaths in animals. For human health, the focus should be on ensuring the entire population is aware of appropriate dog bite management and treatment, and reducing risk of dog bites through education on safer dog interactions.
4. The incidence risk of canine rabies in West Timor for the period June 2023 to May 2024 is estimated to be in the order of 31 cases per 100,000 free-roaming dogs at risk. Canine rabies incidence (i.e., rabies cases per numbers of dogs in the population, as opposed to counts of rabies cases) should be reported as it allows comparisons of the frequency of disease to be made over place (i.e., district and subdistrict) and over time.
5. Surveillance and reporting of rabies cases in dogs (suspected and confirmed) must be strengthened. Dates of detection should be provided for the complete case dataset, to allow to insight into temporal and spatio-temporal evolution of the outbreak. This will allow authorities to estimate the distance and time ranges of elevated rabies risk following a given case detection. This is important for two reasons: (a) it allows public health messaging about rabies risk to the public to be more focused; and (b) it provides animal health authorities with guidance on where and when to target (scarce) surveillance resources to find additional canine rabies cases.
6. Our analyses show an increased risk of canine rabies detections in areas: (a) where relative wealth indices were low (i.e., low socio-economic areas); and (b) where vaccination coverage was relatively low (less than 15 dogs per square kilometre). Our analyses show that vaccinating dogs against rabies is working. Intensifying vaccination efforts in low socio-economic areas (particularly in Timor Tengah Selatan) is advised.

Longer-term priority (2-5 years)

1. IBCM should be implemented more fully, as it can significantly improve the overall quality of rabies surveillance and provide large cost savings for PEP administration when bite cases are confidently confirmed to have come from non-infected dogs. However, training both animal and human health staff to consistently implement IBCM will require time and additional resources.
2. Implementation of mass dog vaccination campaigns in West Timor will lead to extensive interactions between animal health field staff and local communities. Animal health authorities should use this opportunity to strengthen community engagement, with a focus on improving passive disease surveillance and reporting. This will directly contribute to the objective of potential rabies elimination, which crucially requires demonstration of an effective surveillance system. Stronger community engagement also offers major ancillary benefits, as communities become more likely to report diseases or problems in their livestock and other animal species. In turn, this supports animal health and resilient production systems, improving food security and household income. Improved animal health surveillance can also help West Timor maintain its foot-and-mouth-disease-free status, supporting the region's major export cattle industry that services the rest of Indonesia.

Future epidemiological and economic modelling

As described in the Methods section, RabiesEcon was used for the epidemiological modelling of rabies in West Timor because it is a tested and published model. When we directly parameterised the model with West Timor's land area, and human and dog populations, we observed results that were inconsistent with reported case numbers. We suspect this is because RabiesEcon assumes transmission rates and other underlying factors for a more homogeneous population distribution, such as a single city, that do not match a heterogeneous dog and human population like West Timor, with densely populated cities and villages but areas of low population in between.

Although RabiesEcon allowed us to rapidly produce preliminary results, future costings and planning would be strengthened by creating a more specific epidemiological model to better reflect the situation in West Timor. This would allow much greater insight into the modes of spread within and between districts. Most importantly, an improved spatio-temporal model would be invaluable to assess the ongoing risk of disease spillover and persistence within and between 'control' (i.e., where disease has been largely supressed) and 'restricted' (with remaining persistent transmission) zones across West Timor and also Timor-Leste, which may be created under a coordinated rabies elimination program.

Annex 1
Parameters and assumptions used in economic modelling

Table 2: Overview of values and assumptions in modelled *Best* and *Worst* rabies outbreak management approaches

	Model					
	Best			**Worst**		
Description	*Achieve then strengthen current response to 'hold' current outbreak or possibly push to elimination using approaches described under 'Year', below. This is predicted to lead to zero human deaths in Year 3–4, and creates an opportunity for zoned control approaches, with 75% of West Timor assumed a lower-risk 'Control' zone and 25% higher-risk 'Restricted' zone requiring more intensive management(like current) after this time.*			*Current response declines to typical Indonesian endemic management (based on reported vaccination rates in Flores), requiring ongoing dog vaccination and human treatment.*		
PEP delivery & regime	• 70% dog bite cases report to puskesmas • 95% reporting cases receive PEP • From Year 5, good IBCM means that dog bite victims in Control zone receiving PEP only require day 0 & 7 doses (day 21 dose averted when suspect dog case confirmed free of rabies)			• All dog bite cases, ongoing: 70% report to puskesmas; 95% reporting cases receive full course of PEP		
Total number human dog bites/year	12,850			12,850		
Year	**Average dog vaccination rate**	**Public awareness budget[3]**	**Surveillance description & annual cost[4]**	**Dog vaccination coverage**	**Public awareness budget[3]**	**Surveillance description & annual cost[4]**
1	50%	100%	Current[5]	50%	100%	Current[5]
2	70%	100%	Moderate	45%	50%	Moderate
3	70%	100%	Moderate	35%	25%	25% of moderate
4	70%[6]	100%	Moderate	25%[7]	12.5%	"
5	17.5%[8]	50%	Intensive[9]	25%	12.5%	"
6	17.5%	50%	Intensive	25%	12.5%	"
7	17.5%	50%	Intensive	25%	12.5%	"
8	0%[10]	50%	Intensive	25%	12.5%	"
9	0%	50%	Intensive	25%	12.5%	"
10	0%	50%	Intensive	25%	12.5%	"

[3] See value in Table 3
[4] See Table 3 for values
[5] Ad hoc with negligible cost
[6] Epidemiological model estimates this achieves zero human deaths by Years 3 and 4
[7] Reflects typical vaccination coverage rate in endemic areas of Indonesia
[8] Average reflects ongoing widespread 70% vaccination coverage only being implemented in the Restricted zone, comprising 25% of West Timor
[9] To support zoning and greater outbreak management efforts
[10] Assumes moving into an 'elimination' phase with no remaining Restricted zone

Table 3: Parameters used in epidemiological and economic modelling

Variable	Value	Source/Description
Human population & case data		
Human population	2,011,269	Badan Pusat Statistik, Jakarta, 28 February 2024, Provinsi Nusa Tenggara Timur Dalam Angka 2024 (Katalog-BPS 1102001.53) (Wikipedia 2024)
Average human life expectancy	67.2 years	World Health Organisation figure for Indonesia: https://www.who.int/data/gho/data/indicators/indicator-details/GHO/life-expectancy-at-birth-(years)
Average age of death of human rabies cases	27 years	Average age at death of local cases of rabies in West Timor (n = 25; May 2023–May 2024)
GDP per capita	IDR 78,393,924	World Bank figure for Indonesia: https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?locations=ID
Dog population & demographics		
Human to dog population ratio	Three scenarios: 6:1; 7.6:1; 10:1	• 6 is working value currently used by Department of Animal Health staff for vaccine planning • 7.6 sourced from average used in *Settlement Type and Road Connectivity* analysis across West Timor and Timor-Leste (Boutelle and Wallace 2023). Because this analysis spans two areas but consolidates reporting into one main • 10 is estimate of Ward (2024) based on sight-resight field estimates. Ward estimated urban and rural ratios of 18:1 and 9:1, respectively. Using urban and rural human populations ≈ 618,000 and 1.35 million, respectively, these sub-ratios correspond to an overall weighted average ratio ≈ 10:1.
Total West Timor dog population at modelled human to dog ratios	6:1 7.6:1 10:1	335,212 264,641 201,127
Dog life expectancy, years	6.5	Multiple stakeholder interviews: pet dogs live to be about 8 years old, while dogs for meat consumption are eaten at 2 years old. Local experts suggest that about one in four dogs is raised for human consumption, producing weighted average $(0.25 * 2) + (0.75 * 8) = 6.5$
Medical costs and administration rates		
Average total cost of 'full' course of post-exposure rabies prophylaxis (PEP)	IDR 1,332,500	• Protocol used is two intramuscular vaccine doses on day 0, then one on day 7 and one on day 21, comprising a total of three visits (Bourhy et al. 2018).
Cost per vaccine dose	IDR 167,500	Average of reported costs from district and provincial stakeholders; only vaccine itself
Consumables cost per vaccine dose	IDR 25,000	Interview with District provincial health officer; includes needles, syringes, swabs, etc
Overhead costs per PEP visit	IDR 120,000	Interview with District provincial health officer; includes puskesmas clinic staff salaries and administration costs proportional to puskesmas rabies caseload. The average dog bite case takes 1 hour of staff time with 1-2 staff present
Cost of SAR/RIG	1,650,000	Average of reported costs from district and provincial stakeholders
Proportion of PEP recipients receiving SAR/RIG	5%	Interview with Provincial health officer

Proportion of patients completing required PEP course	92.5%	Interview with Provincial health officer
Human dog bite case/year	12,850	Estimated from current data from provincial human health authorities, collected across NTT province. Although there are some noted irregularities and inconsistencies, this figure fits within global reported ranges for dog bites of 5.2 dog bites/1000 human years (Mbilo et al. 2019).
Disease surveillance		
IFA test of suspect dog case	IDR 300,000	Indirect fluorescent antibody test
Net total annual surveillance cost	'Moderate': IDR 50 million	IFA test cost plus ancillary operational costs of ~IDR 150,000/submission for average 1 sample submitted per sub-district annually (110 sub-districts total; assuming staff costs covered in recurrent departmental costs)
	'Intensive': IDR 100 million	Costs as above for 2-3 tests per sub-district annually
	'Low': IDR 12 million	Total cost approximately one quarter of 'Moderate' total cost
Public awareness & community engagement		
Risk communication & community engagement	IDR 1.26 billion/year	Upper estimate of cost to cover all West Timor, extrapolated from AIHSP cost of AUD 500,000 provided to intensively deliver training & delivery across 85 sub-districts in 2023-24

Annex 2

Descriptive epidemiology figures

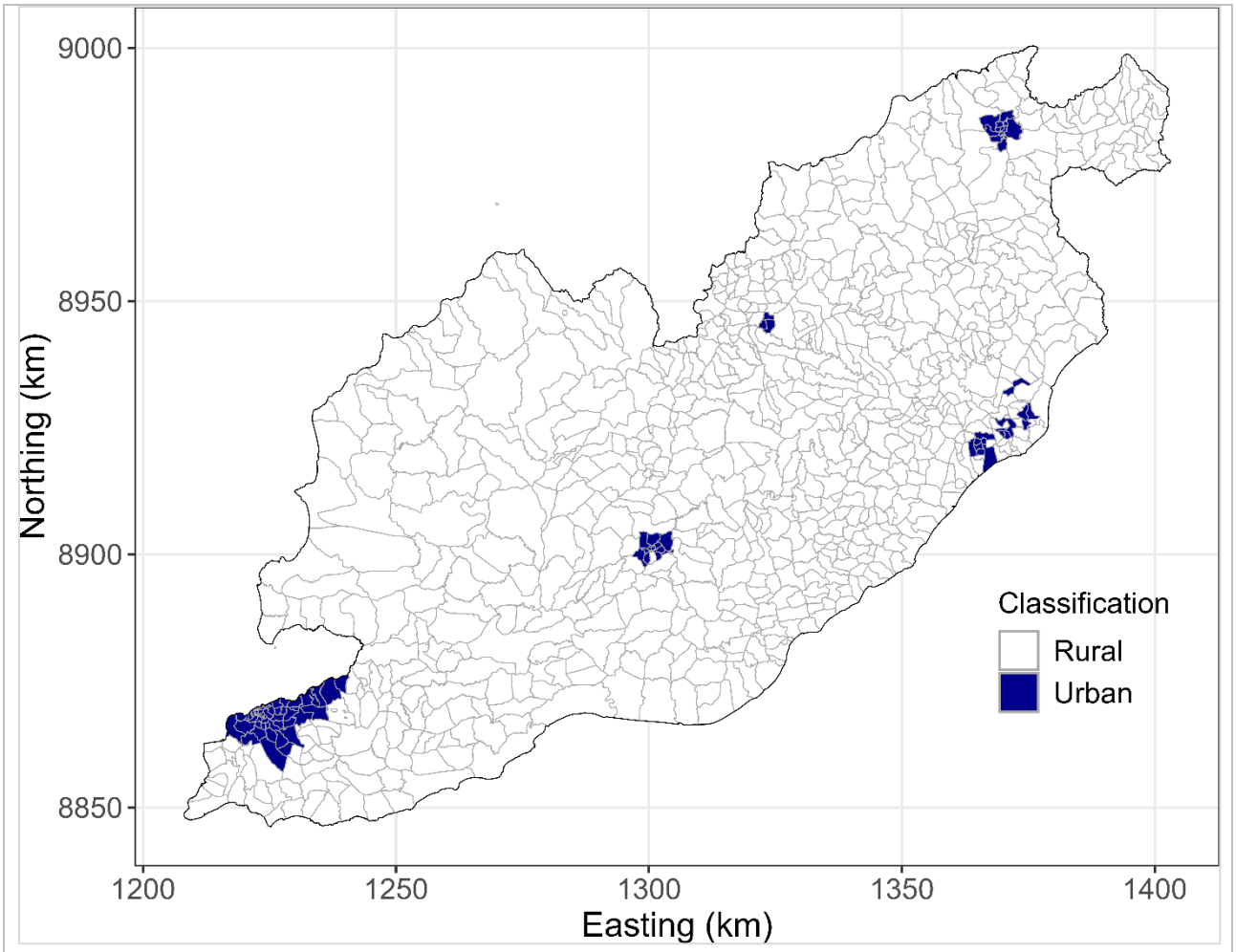


Figure 4: Map of West Timor showing the location of urban and rural desas, as described in the text.

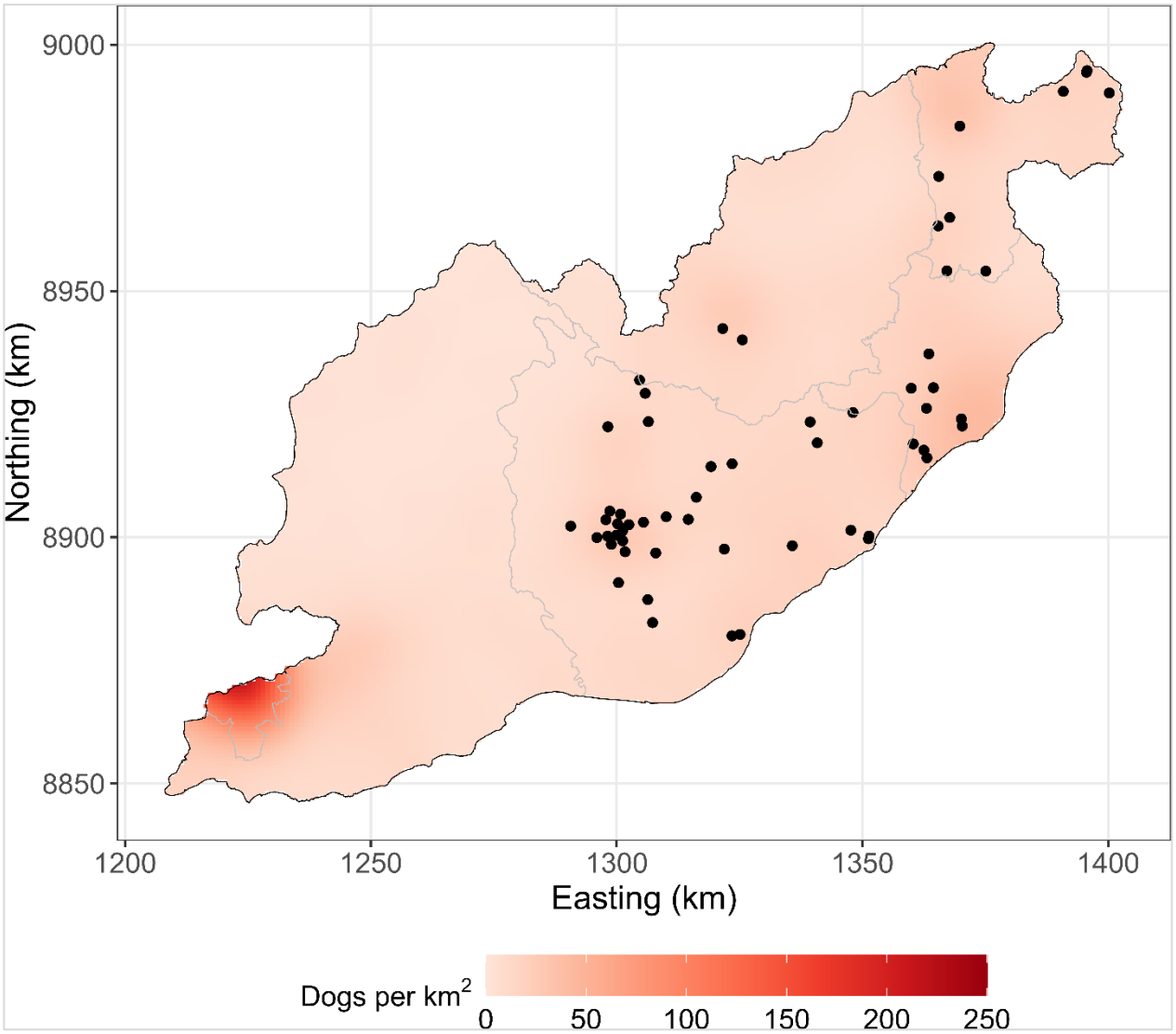


Figure 5: Image plot showing the estimated number of free-roaming dogs per square kilometre, West Timor. Superimposed on this plot as points (●) are the point locations of canine rabies detections as detailed in the 24 April to 6 May 2024 situation report.

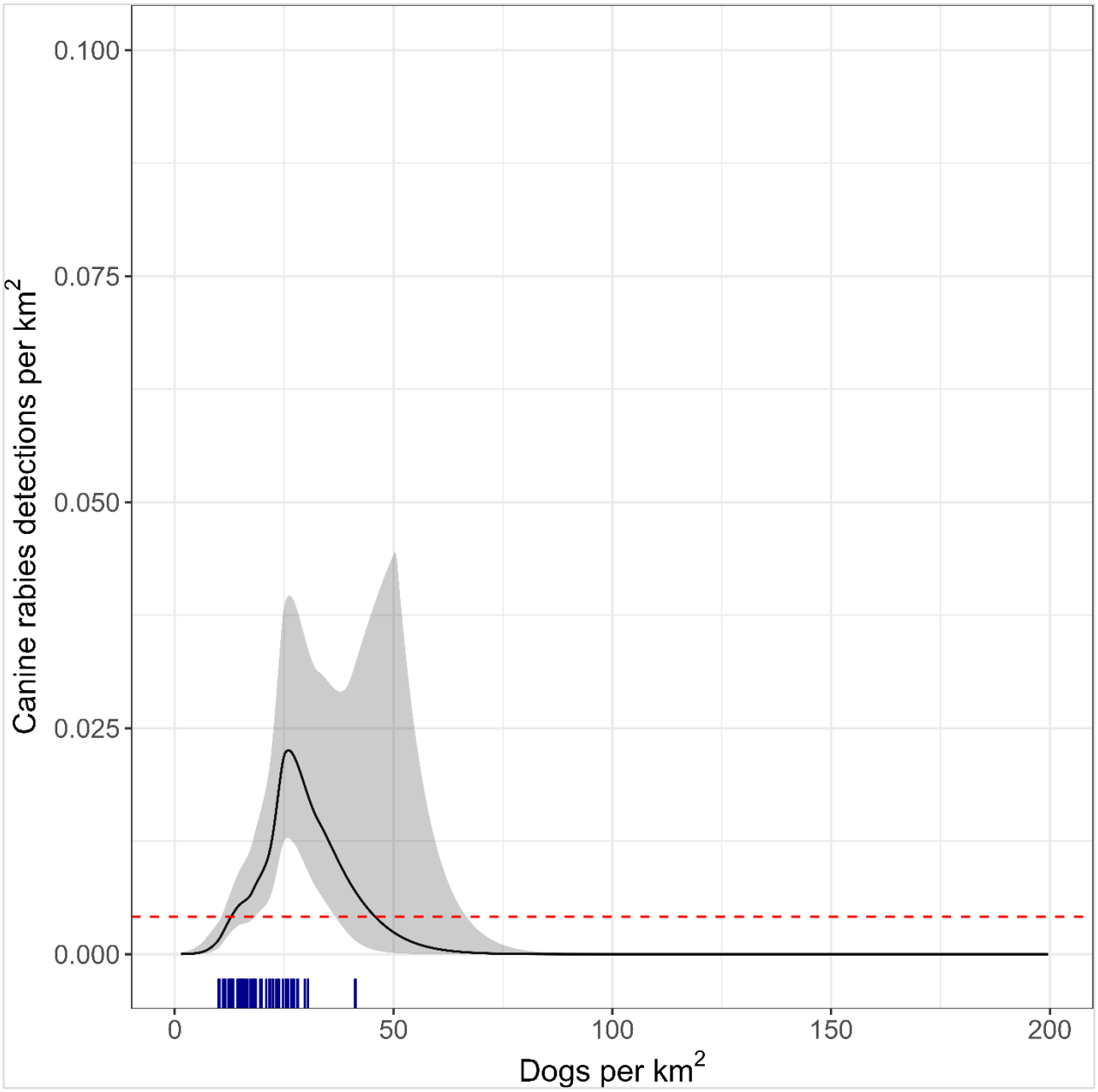


Figure 6: Line plot showing number of canine rabies detections/km2 in West Timor (grey band: 95% confidence interval) for June 2023—May 2024, as a function of the estimated number of free roaming dogs/km^2. Each of the blue vertical lines at the base of the plot represents a single canine rabies detection. The red dashed horizontal line represents the average number of detected canine rabies cases/km^2 across all six districts.

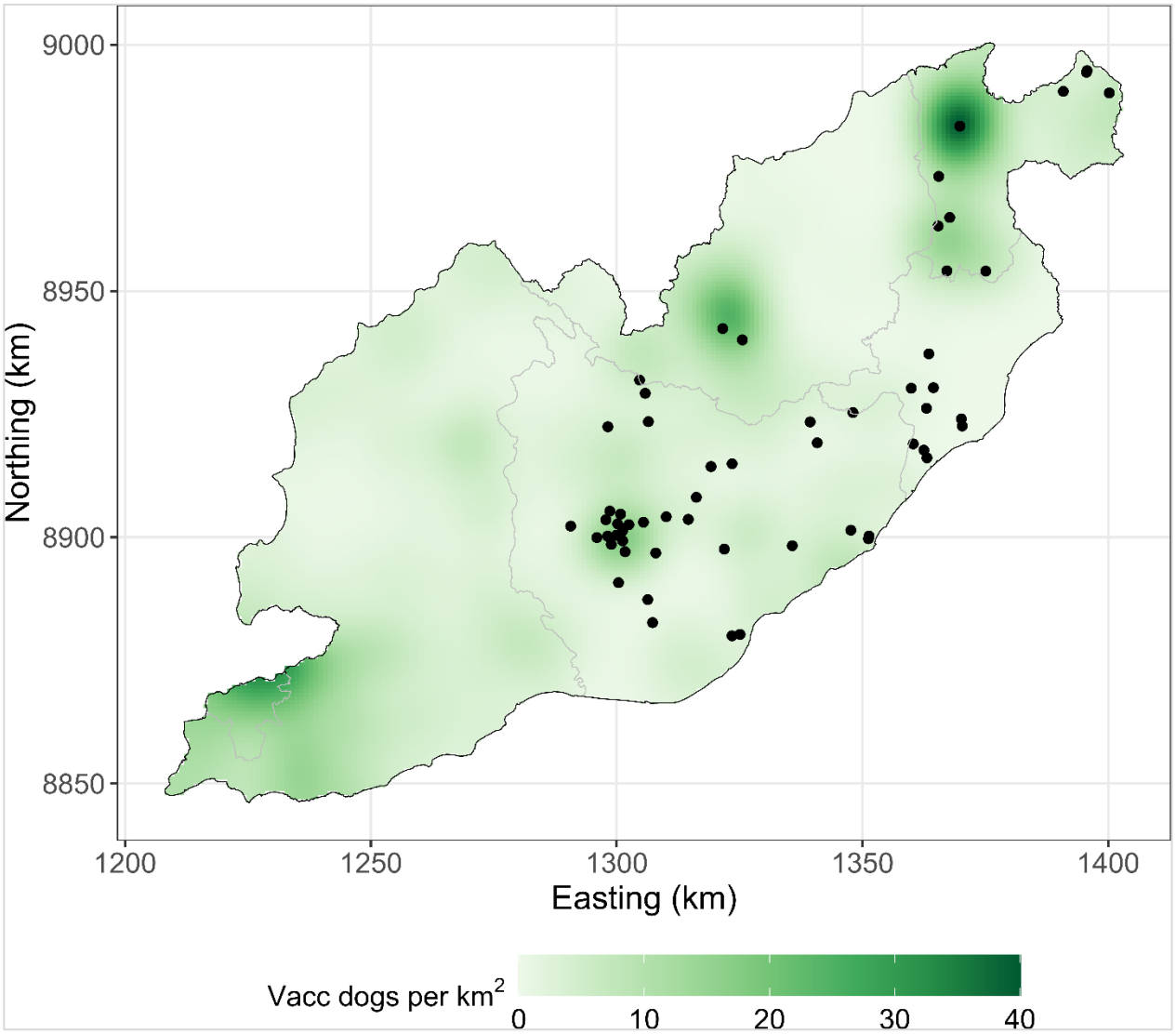


Figure 7: Image plot showing the estimated number of dogs per square kilometre vaccinated for rabies, West Timor. Superimposed on this plot as points (●) are the point locations of canine rabies detections as detailed in the 24 April to 6 May 2024 situation report.

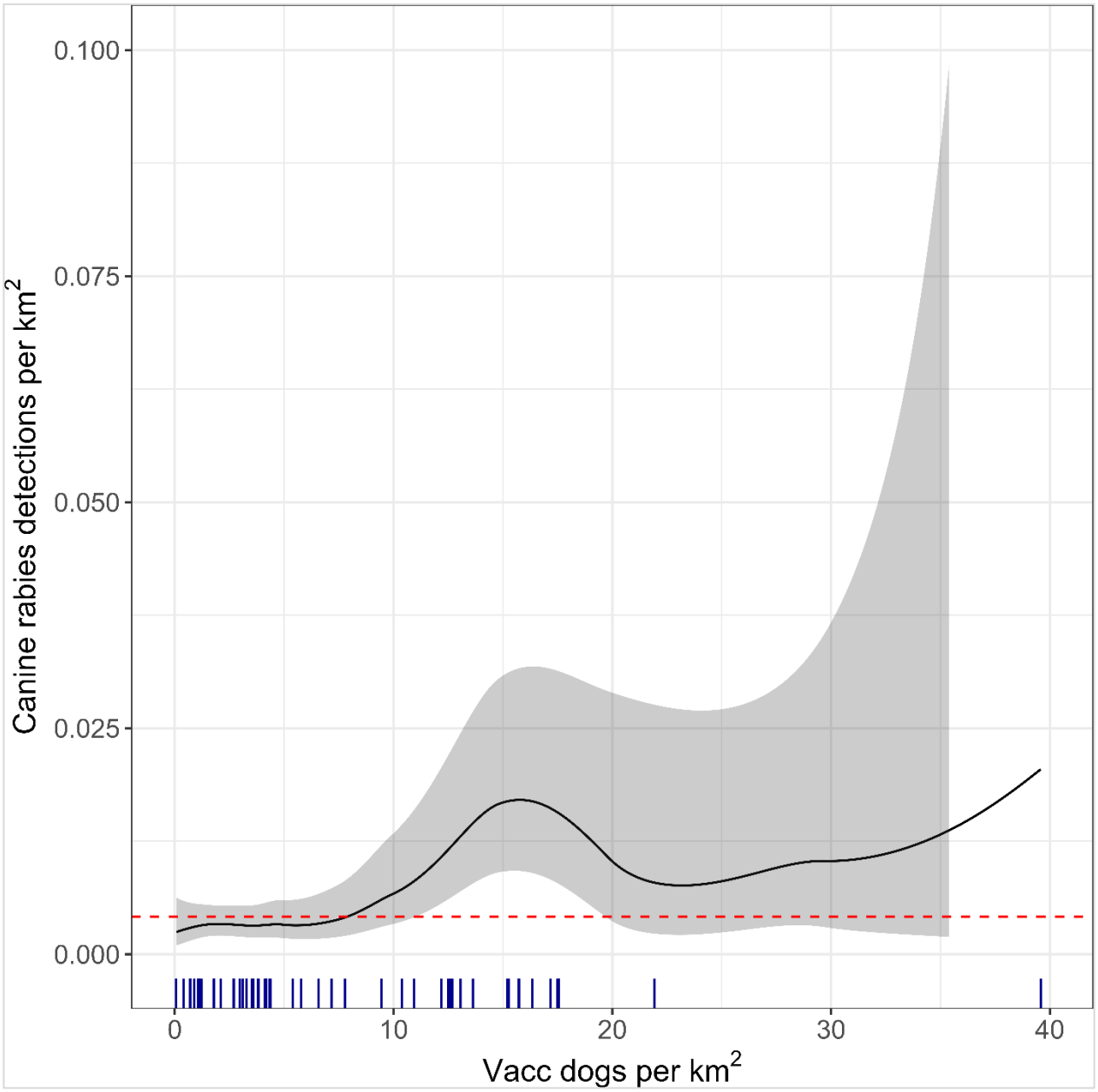


Figure 8: Line plot showing the number of canine rabies detections/km² in West Timor (grey band: 95% confidence interval) for June 2023–May 2024 as a function of the number of dogs vaccinated for rabies/km². Each of the blue vertical lines at the base of the plot represents a single canine rabies detection. The red dashed horizontal line represents the average number of detected canine rabies cases per square kilometre across all six districts.

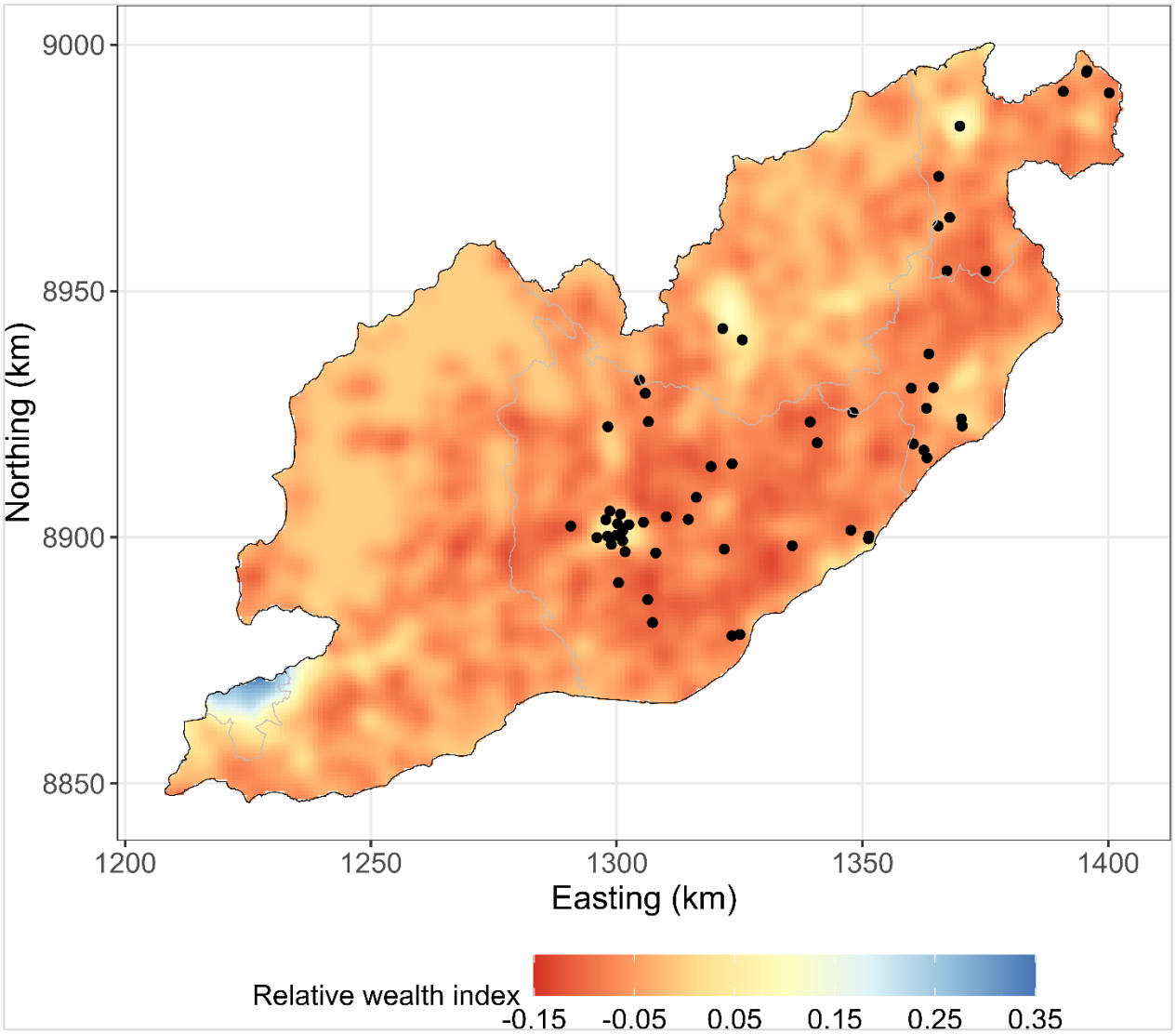


Figure 9: Image plot showing relative wealth index, West Timor. Superimposed on this plot as points (●) are the point locations of canine rabies detections as detailed in the 24 April to 6 May 2024 situation report.

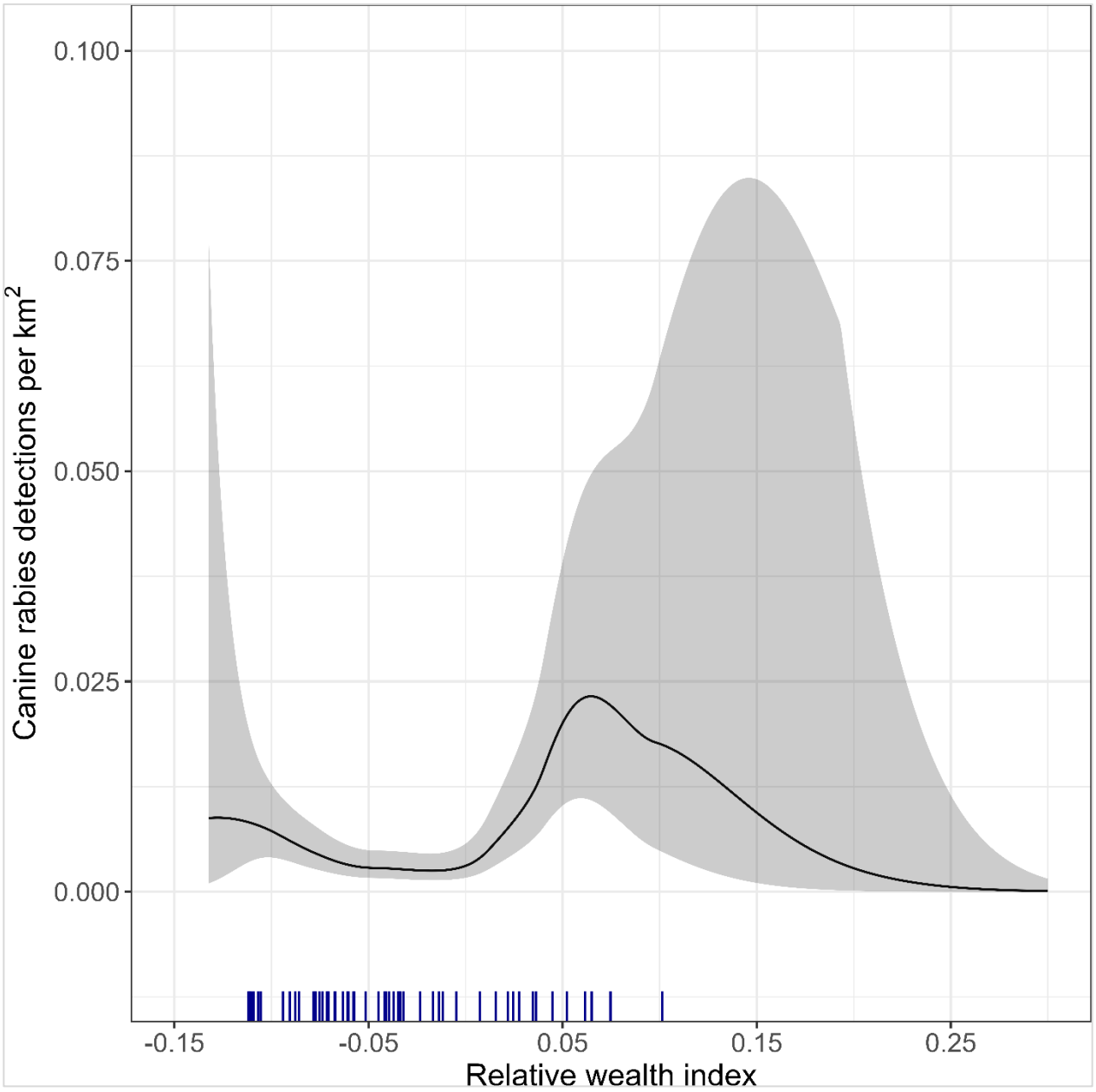


Figure 10: Line plot showing, for West Timor, the number of canine rabies detections per square kilometre (grey band: 95% confidence interval) for the period June 2023 to May 2024 as a function of relative wealth index. Each of the blue vertical lines at the base of the plot represents a single canine rabies detection. The red dashed horizontal line represents the average number of detected canine rabies cases per square kilometre across all six districts.

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