BMJ Global Health

The contribution of active case detection to malaria elimination in Thailand

Suravadee Kitchakarn,[1] Sathapana Naowarat,[2] Prayuth Sudathip,[1] Hope Simpson,[3,4] Rachel Stelmach,[2,5] Chalita Suttiwong,[1] Sombat Puengkasem,[6] Worawut Chanti,[7] Deyer Gopinath,[8] Jerdsuda Kanjanasuwan,[1] Rungrawee Tipmontree,[1] Niparueradee Pinyajeerapat,[9] David Sintasath,[9] Donal Bisanzio,[2,10] Jui A Shah [2]

To cite: Kitchakarn S, Naowarat S, Sudathip P, *et al*. The contribution of active case detection to malaria elimination in Thailand. *BMJ Glob Health* 2023;**8**:e013026. doi:10.1136/bmjgh-2023-013026

Handling editor Alberto L Garcia-Basteiro

► Additional supplemental material is published online only. To view, please visit the journal online (http://dx.doi.org/10.1136/bmjgh-2023-013026).

Received 2 June 2023
Accepted 1 October 2023

For numbered affiliations see end of article.

Correspondence to
Jui A Shah; juishah@rti.org

ABSTRACT

Introduction Thailand's malaria surveillance system complements passive case detection with active case detection (ACD), comprising proactive ACD (PACD) methods and reactive ACD (RACD) methods that target community members near index cases. However, it is unclear if these resource-intensive surveillance strategies continue to provide useful yield. This study aimed to document the evolution of the ACD programme and to assess the potential to optimise PACD and RACD.

Methods This study used routine data from all 6 292 302 patients tested for malaria from fiscal year 2015 (FY15) to FY21. To assess trends over time and geography, ACD yield was defined as the proportion of cases detected among total screenings. To investigate geographical variation in yield from FY17 to FY21, we used intercept-only generalised linear regression models (binomial distribution), allowing random intercepts at different geographical levels. A costing analysis gathered the incremental financial costs for one instance of ACD per focus.

Results Test positivity for ACD was low (0.08%) and declined over time (from 0.14% to 0.03%), compared with 3.81% for passive case detection (5.62%–1.93%). Whereas PACD and RACD contributed nearly equal proportions of confirmed cases in FY15, by FY21 PACD represented just 32.37% of ACD cases, with 0.01% test positivity. Each geography showed different yields. We provide a calculator for PACD costs, which vary widely. RACD costs an expected US$226 per case investigation survey (US$1.62 per person tested) or US$461 per mass blood survey (US$1.10 per person tested).

Conclusion ACD yield, particularly for PACD, is waning alongside incidence, offering an opportunity to optimise. PACD may remain useful only in specific microcontexts with sharper targeting and implementation. RACD could be narrowed by defining demographic-based screening criteria rather than geographical based. Ultimately, ACD can continue to contribute to Thailand's malaria elimination programme but with more deliberate targeting to balance operational costs.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Active case detection (ACD) has been a standard 'last mile' component of malaria elimination programmes.

⇒ The WHO recommends a varying mix of proactive ACD (PACD) and reactive ACD (RACD) along the elimination spectrum; however, there is no known threshold correlated with effectiveness of RACD and PACD strategies for malaria surveillance.

WHAT THIS STUDY ADDS

⇒ In Thailand, ACD yields are declining alongside decreasing malaria incidence, with a noticeably higher yield for RACD compared with PACD and significant geographical differences.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ This documentation of ACD implementation and results helps identify opportunities to simplify the complexity of Thailand's various ACD methods and to sharpen targeting and implementation of interventions.

⇒ In particular, a PACD protocol could outline specific microcontexts where PACD could meaningfully curb transmission in an elimination setting.

INTRODUCTION

The six countries in the Greater Mekong Subregion (GMS)—Cambodia, China (Yunnan province), Lao People's Democratic Republic, Myanmar, Thailand and Vietnam—collectively strive to eliminate malaria by 2030. Between 2000 and 2020, the number of *Plasmodium falciparum* malaria cases in the GMS fell by 93% and all-species malaria cases fell by 78%, resulting in just 82 000 malaria cases across the region in 2020.[1]

Thailand's progress has acceleratedsince the adoption of its National Malaria Elimination Strategy (NMES) and the flagship 1-3-7 surveillance and response approach in FY16 (1 October 2015 to 30 September 2016).[2] The

country reported just 2898 cases in FY21, representing a 91% reduction since the year prior to NMES adoption[3] and earning Thailand a place as one of eight new countries announced by the WHO as having the potential to eliminate malaria by 2025.[4] Malaria cases have become increasingly clustered into three distinct transmission zones in Thailand: the east (along the border with Cambodia), south (adjacent to Malaysia) and west (along the border with Myanmar). The drivers of this success are thought to be a combination of human and demographic factors rather than environmental factors alone.[5]

As GMS countries advance towards the malaria elimination goal, passive case detection is complemented by more intensive and targeted active case detection (ACD) methods to interrupt and prevent onward malaria transmission.[6 7] ACD strategies require health workers to actively identify and test populations that are at increased risk of malaria infection due to geography or behaviour.[8] By seeking malaria cases among people who do not present to health facilities for various reasons, including lack of symptoms or difficulty accessing health services, ACD supports early case detection and management.[9] It is a useful elimination strategy that is complementary to passive case detection, as passively detected cases and resulting case investigations can help identify areas or populations in which ACD could be most useful. ACD also provides an indication of the strength of a surveillance system to capture all cases, which is particularly important in a context with high *Plasmodium vivax* prevalence, and it supports credible documentation of malaria-free status.

In 1975, Thailand expanded its network of malaria clinics and concurrently launched ACD, with support from the United States Agency for International Development,[10] to complement passive case detection through both vertical malaria-specific facilities and in general health facilities.[11] ACD is usually planned and conducted by malaria officers or by village health volunteers (VHVs), who play an essential role to expand access to malaria services in rural and underserved communities. ACD comprises proactive ACD (PACD), which seeks new cases among areas and populations deemed high risk and reactive ACD (RACD), which targets people with known risk due to proximity with passively detected index cases. ACD is implemented in endemic areas with suitable vectors, comprising a broader geography than many malaria elimination activities focused on active foci areas only.

Thailand uses three PACD approaches: special case detection (SCD), mobile malaria clinics (MMCs) and fixed-schedule malaria clinics (FSMCs). SCD responds to unusual events, such as changes in population movement or unexpected increases in incidence. MMCs are ad hoc events reserved for remote, high-endemic areas; these events were initially designed under The Containment Project as a strategy to curb the spread of drug-resistant parasites by engaging mobile populations.[12] FSMCs are planned events to extend case detection services from facilities into communities (table 1).

There is no protocol for PACD in Thailand, so determination of both methods and screening criteria is decentralised. Malaria officers are expected to use routine surveillance data to identify high-risk populations before and during the peak transmission season. Furthermore, PACD is usually included in annual planning and limited to two administrations per year, limiting flexibility in its application.

As part of Thailand's 1-3-7 surveillance and response strategy, which is detailed in national protocols and the scientific literature,[2 3] RACD is conducted within 7 days of identifying a confirmed index case to prevent onward transmission. Depending on the focus classification where the index case was found, RACD will either consist of a case investigation survey (CIS), which traces relatives, neighbours and community members within 1 km of an index case, or a mass blood survey (MBS), which screens all community members in a focus where an indigenous case was confirmed but unexpected, such as due to the absence of a suitable vector or long time without indigenous cases (table 1).

ACD has been a standard 'last mile' component of malaria elimination programmes where passive case detection is not sensitive enough to serve all surveillance needs.[13] RACD specifically has been implemented in 13 of Asia Pacific region's 14 countries, including China, which reached malaria-free status in 2021.[14 15] Despite its wide implementation and acknowledged contributions to malaria elimination, ACD requires substantial labour and resource inputs, since methods rely on screening—often large—numbers of people. RACD yield in GMS countries ranges from just 0.13% to 1.65%, varying by study site and testing method.[7]

A meta-analysis of ACD studies showed that the average costs were US$38.63 per person tested and US$32.07 per case detected under RACD and US$4.79 per person tested and US$37.80 per case detected under PACD.[16] A study from a low-transmission setting in Indonesia estimated microscopy-based RACD cost US$1178 per index case[17]; this is relevant for Thailand, where nearly all cases are confirmed by microscopy. ACD typically costs more than passive surveillance; however, the relative cost-effectiveness varies by context, including differences in vector distribution, community activities and malaria incidence rates.[6] Thus, accurate identification and targeting of high-risk populations and areas where malaria cases are likely to be found, plus high-quality deployment of ACD methods including appropriate timing and duration, is crucial for efficient and effective use of resources.

ACD has diminishing gains as malaria burden decreases, and WHO recommends a varying mix of PACD and RACD along the elimination spectrum.[18] Since FY20, Thailand's incidence has been very low, at <0.1 per 1000 population; however, there is no known threshold correlated with effectiveness of RACD and PACD strategies for malaria surveillance.[6 7] It is unclear if these resource-intensive surveillance strategies are yielding the same output as in the past and whether the ACD programme could be

Table 1 Description of Thailand's various case detection methods

Method	Brief description	Screening and implementation criteria	Specific benefits and contribution	Challenges
1. Passive case detection	Testing of symptomatic individuals who seek healthcare treatment in either facilities or the community, both from Thailand's vertical programme (malaria clinics (MCs) and malaria posts (MPs)) and its general health services.	Health personnel test suspected malaria cases using diagnostic methods appropriate for the facility type: microscopy with confirmatory PCR at provincial hospitals or regional reference laboratory centres, microscopy at MCs and MPs, rapid diagnostic tests (RDTs) at some health promotion hospitals, MCs, and MPs, and in communities.	Symptomatic cases are treated efficiently with point-of-care diagnostics and treatment. Information from passive case detection and case investigations is useful for identifying ongoing transmission areas or newly emerging areas that require additional interventions, including ACD methods. It can also help identify risk groups.	Passive case detection may miss mild or asymptomatic cases because, generally, only sick people will seek healthcare services for correct diagnosis and treatment.
2. Active case detection (ACD)	Supplemental case finding at household or community levels to reach both asymptomatic and symptomatic cases outside of routine health services. Microscopy is used for all members of the target population; if unavailable, RDT is used.	ACD can be implemented reactively as a result of reported cases or proactively based on previous screening for behaviours, populations, or areas associated with a higher risk for malaria.	Can capture both asymptomatic and symptomatic cases for diagnosis and treatment. ACD supports interruption of malaria transmission and preventing onward transmission, particularly in lower transmission settings.	ACD methods recruit a huge population for screening and testing, thereby consuming significant resources. Effective deployment requires appropriate identification and targeting of groups at high risk for malaria.
2.1 Proactive case detection (PACD)	Seeks new cases in groups or areas at higher risk of malaria based on either pre-existing surveillance data or unplanned/unusual events. A description of the schedule, plan and population of interest will be shared with the community to increase participation and inform community members and local leaders.	Does not require an index case to be implemented. All community members who meet screening criteria, such as living in a high endemicity area, reporting malaria risk factors or travelling to or staying overnight in active transmission areas inside or outside of Thailand are tested.	Directly addresses populations and areas at a high risk of malaria, regardless of symptoms or care-seeking behaviour. Can be scheduled to prevent or interrupt transmission before and during peak season (June–October).	Requires local information and community participation to reach target areas and groups, which may include undocumented persons or minority communities, at the ideal time and place.
2.1.A. Special case detection (SCD)	Screening at community screening sites based on disease and vector surveillance data from previous years during annual planning. The annual plan is shared with the community health network (village health volunteers (VHVs), malaria volunteers and community leaders) for risk communication activities and scheduling of screening times— usually 1 month prior to transmission season or during unusual events. Communicable disease control units or surveillance and rapid response teams comprising provincial health office (PHO) and vectorborne disease unit (VBDU) staff go to targeted foci and set up community screening sites. All community members in the population are screened using microscopy or RDTs.	Local staff (PHO, VBDU) set an annual plan early in the fiscal year to target areas where: ► Reported malaria incidence was higher in the previous year than the median incidence in the three consecutive years before that. ► Active foci (A1 and A2) have a higher incidence than the prior year. Local staff may also reallocate resources for additional SCD based on unusual surveillance data or community information regarding: ► Increasing migration or mobility ► Infected mosquitoes from vector survey ► Increasing incidence (ie, potential outbreak).	SCD is Thailand's main PACD method, contributing the highest number of conducted screenings. It combines routine surveillance data with community information to design a robust plan that can be flexibly applied to various scenarios.	Relies on annual strategic planning and the previous year's surveillance data, so real-time response to emerging challenges relies on availability and prioritisation of local resources. Measuring SCD's tailored and varied implementation can be challenging.

Continued

Table 1 Continued

Method	Brief description	Screening and implementation criteria	Specific benefits and contribution	Challenges
2.1.B. Mobile malaria clinics (MMCs)	Ad hoc and unscheduled screening services before and during the peak season designed to reach the unreached where they congregate. Target groups often include border populations, hill tribes, armed forces or villagers from remote, epidemic-prone areas. During malaria outbreaks, MMCs could be set up during special events or festivals until malaria prevalence reduces. A team of 2–3 malaria staff work with specially trained VHVs (about 10% of VHV have received this training). Community members who walk in or those with scheduled appointments from community health network offices are screened using microscopy or RDTs. Confirmed cases are treated on site and given a schedule for follow-up visits.	Local staff (PHO, VBDU) work together with community malaria networks to identify unreached groups based on community information. Sites, duration and timing are determined through community discussions but may include rubber or fruit exchanges, weekend markets, or temples on festival days.	Takes malaria services beyond facilities to reach local communities or villagers from remote, high endemicity areas. Utilises community health network to build trust and schedule activities to meet the community's availability and needs. Can be combined with SCD if target population overlaps.	Takes more planning and immediate action to deploy MMCs using the most up-to-date information. MMCs do not have a fixed schedule or place, so it may be hard for community members to rely on the plan and find out about the services. Community information may be affected by local political issues or perceived benefit of continued malaria programming.
2.1.C. Fixed schedule malaria clinics (FSMCs)	Planned services at MCs, MPs or other predetermined locations to seek new cases in areas with high risk for malaria (A1, A2 foci). Community members who walk in or those with scheduled appointments from community health network offices are screened using microscopy or RDTs. Confirmed cases are treated on site.	Sites, duration and timing are determined through community discussions but can include border crossings and village focal places like temples. Other criteria include poor geographical accessibility, high population mobility and low human density areas.	FSMCs can reach people in the community and can be useful during outbreaks to provide surge case management. Easy for community members to plan their schedules and make time for screening due to the fixed schedule, which can be optimised to reach the most people (ie, during peak migration times, such as start and end of seasonal work).	FSMCs are only scheduled 1–2 days a week, so may miss community members unavailable at that time.
2.2 Reactive case detection (RACD)	Seeks new cases living near a confirmed index case identified by either passive case detection, MMCs or FSMCs and reported in the surveillance database.	As part of the 1-3-7 surveillance strategy, RACD is conducted within 7 days after a confirmed index case.[2 3] The target population varies by focus classification; in typical transmission areas, CIS targets a specific subpopulation, whereas in unusual transmission areas, MBS targets the full population.	RACD prompts interventions to prevent further transmission. It is efficient because it focuses on people with known risk of malaria due to proximity with confirmed cases.	RACD screens based on geographical residence and source of infection and may not addressall other risk factors, such as coworking and co-travelling, especially outside the focus of the index case.

Continued

Table 1 Continued

Method	Brief description	Screening and implementation criteria	Specific benefits and contribution	Challenges
2.2.A. Case investigation survey (CIS)	Active screening of households or individuals around a locally acquired index case, with the goal of preventing further malaria transmission. Initiated as a component of a focus investigation for all new detected cases.	Tracing 50+ persons or 10+ households comprising family members, neighbours and community members within 2 km of an index case.	Conducted quickly, within 7 days as part of Thailand's 1-3-7 surveillance strategy, so does not require additional protocols.	Can be difficult to match timing of CIS with daily schedules of index case's contacts. To mitigate this issue, Thailand offers convenience screening at health facilities for those who miss the household call. Contact tracing recommended to include persons who participate in the same activities as the index case, including working, travelling, or staying overnight in the 2 weeks prior to onset of symptoms,[2] but does not often occur in practice.
2.2.B. Mass blood survey (MBS)	Active screening among the whole population living in new active areas (foci) or outbreak areas where the situation is unusual: ► In cleared foci (B1, B2), where an indigenous case is detected, or ► In active foci areas (A1, A2), after CIS was completed but cases continue to increase over 2 weeks.	Tracing all community or foci (subvillage) members living in the area of interest.	When cases continue to increase after CIS, MBS can identify the additional cases and prompt further interventions to prevent the reestablishment of malaria.	Consumes significant resources compared with CIS due to a wider population of interest. Screening is based on foci boundaries, but if the index case is located near the border, MBS may use a radius to identify additional contacts in the neighbouring focus.

further optimised in response to Thailand's changing epidemiology.

This study aimed to document the evolution of the ACD programme as Thailand aims for malaria elimination by 2024 and to assess the potential to optimise both PACD and RACD. The study examined ACD implementation, temporal and geospatial differences in ACD yield, and a summary of estimated costs per ACD instance. As ACD requires significant investment in staff, time and funds, these findings could support improved targeting and implementation of ACD, thereby increasing efficiency and releasing resources for other emerging priorities. This is particularly important with the anticipated fiscal contraction of public health expenditures in the aftermath of the COVID-19 pandemic.

METHODS

Data sources

This analysis used two epidemiological datasets (case level and foci level) from Thailand's Division of Vector-Borne Diseases (DVBD), in the Department of Disease Control of the Ministry of Public Health. The case-level dataset included all malaria cases confirmed by microscopy, rapid diagnostic test (RDT) or PCR reported in the national Malaria Information System from October 2014 to September 2021, representing FY15–FY21. The study used fiscal years because Thailand's malaria programme and database are based on fiscal year targets.

The costing analysis collated the direct incremental financial costs from the perspective of the Thai malaria programme for one instance of ACD per focus. The time frame and analytical horizon for the analysis both equal the time spent in the field for each instance of the activity, which is up to 2 days. Based on the availability of unit count and unit cost data versus top-line budget data, we used a combination of a bottom-up ingredients approach—our preferred method—and a top-down activity-based approach.[19] We divided costs according to the unit by which they accrued to the project: costs per sample gathered, costs per person-day of activity or costs per person-day of travel. We gathered most cost data from the budgets prepared for the Global Fund to Fight AIDS, Tuberculosis and Malaria (Global Fund) and supplemented these through discussions with DVBD staff that had experience conducting ACD.

Data analysis

ACD trends in Thailand

To assess trends over time, ACD yield was defined as the proportion of cases detected among total screenings. Variation in the yield of PACD and RACD was also documented by case finding strategies and screening criteria. We conducted parametric t-tests for mean difference in yield between foci with recent malaria transmission (A1 and A2 foci classifications, representing the presence of an indigenous case within the last 3 years) and foci without recent transmission (B1 and B2 classifications) but with the presence of indigenous cases in the current fiscal year.[20] To ensure high-quality data and meaningful results, we verified, cross-checked and cleaned data using IBM SPSS Statistics V.25 (IBM SPSS Statistics for Windows, V.25.0., IBM). The final dataset comprising all methods of case finding over the study period excluded 3588 malaria cases (4.64%) with unknown parasite identification. An additional 818 cases (1.06%) did not have a case finding method available in the database and, therefore, were also dropped.

Spatial variation in ACD implementation

To compare the geographical variation of PACD from FY17 to FY21 (ie, after the 1-3-7 strategy was launched), we used an intercept-only generalised linear regression model (binomial distribution) with yield as the dependent variable.[21] The model allowed random intercepts for tambons (subdistricts), nested within districts, nested within provinces. We calculated the overall intraclass correlation coefficient (ICC), representing the tendency for observations within groups to be similar.[21] To quantify the degree of variation in yield at different geographical levels, we also compared ICCs at tambon, district and province levels. We then mapped total numbers screened through PACD and PACD yield by tambon in the three main transmission areas. To investigate the strength of geographical variation in the implementation of RACD, we ran four generalised linear regression models (binomial distribution), with dependent variables aligned to the 1-3-7 strategy: (1) the proportion of RACD activities conducted out of the total number required, (2) the proportion of RACD activities conducted on time (ie, within 7 days of case notification), (3) the proportion of cases investigated on time (ie, within 3 days) and (4) the proportion of cases reported within 1 day of detection. Models 1 and 2 included all foci where RACD activities were required (n=2344), and models 3 and 4, which serve as comparisons for other components of the 1-3-7 strategy, included all foci with reported cases (n=3340). As above, we calculated the overall and group-level ICCs for all models. Geographical variation in the implementation and yield of RACD activities was mapped by tambon. Analyses were conducted in R (V.4.2.1).

Cost estimates

We gathered all costs in their initial transaction currency and year, inflated them in their initial currency to their 2021 values using the consumer price index,[22 23] and then converted them to 2021 USD at a conversion rate of THB31.98 to US$1.[24] This order of operations allows us to account for different rates of inflation between USD and THB. To account for depreciation of capital goods, such as microscopes, we used a baseline discount rate of 0.45% based on an average 1.68% rate of return to a 10-year Thai Government bond in 2021[25] and a 1.23% average rate of inflation in Thailand for 2021.[19 22] This approach follows the best practices for costing malaria programmes as outlined by Larson *et al*,[19] but creates

quite a low discount rate compared with the 3%–5% often suggested in health economics literature, so we provided for a variation in the discount rate of 0%–7% in our sensitivity analyses.[26]

For personnel costs, we considered staff salaries and benefits and divided them equally across the 240 workdays in Thailand in 2021.[27] In addition, all personnel, except for military escorts, receive annual training on general malaria elimination activities from the DVBD; we similarly divided the costs of these annual trainings evenly across the working days. Together, these training and salary costs compose the cost per working day of each personnel member. Please see online supplemental table 1 for the full list of line items included in our calculations.

Costs were gathered in Excel spreadsheets. Preliminary analyses were conducted in R (V.4.2.1), and final calculations were carried out in an Excel spreadsheet. To see the exact formulae and calculations used, please see online supplemental file 1.

Patient and public involvement

This study highlights use of Thailand's routine health information, with no primary data collection. As such, patients were not engaged nor involved in this work.

RESULTS

ACD trends over time in Thailand

In Thailand from FY15 to FY21, among the 6 292 302 patients who received malaria blood testing, 66 502 (1.06%) were positive for malaria. ACD, compared with passive case detection, accounted for 73.75% of all blood tests and 5.53% of all confirmed cases (range 4.54%–6.31%). The test positivity rate (TPR) of ACD methods was 0.08% (range 0.14%–0.03%), compared with 3.81% for passive case detection (range 5.62%–1.93%) (figure 1).

FY15 represents a baseline year before the implementation of RACD under the 1-3-7 strategy, which launched in FY16.[2] TPR declined over time, with a spike in FY17 for ACD as the 1-3-7 surveillance strategy took full effect. Previously, RACD was conducted for 100–150 people (approximately 20–30 households) or within a radius of 1–2 km. In FY16, reduced malaria burden narrowed RACD screening to 50 people (approximately 10 households) within 1 km. The policy change was reflected in the number of blood samples screened, which notably decreased from 251 446 in FY15 to 169 363 in FY16. During FY15–FY17, RACD TPR was 0.24% (range 0.19%–0.26%); under the revised screening criteria launched in FY17, TPR for FY18–FY21 was 0.11% (range 0.07%–0.25%).

PACD and RACD yields have declined alongside malaria incidence in Thailand (figure 2).Whereas PACD and RACD contributed nearly equal proportions of confirmed cases at the start of the study period, by FY21 PACD represented just 32.41% of ACD cases, with 0.01% test positivity (range 0.09%–0.01%). Reciprocally, RACD increased from 55.14% to 67.63% of ACD cases (0.26%–0.07% test positivity).

Among all five ACD methods in Thailand, SCD made up the largest proportion of malaria tests conducted (51.46%), followed by CIS (24.77%) and MMC (17.78%) (figure 3A). Regarding the number of confirmed malaria cases identified, CIS (51.13%) and MMC (22.36%) were the highest yielding ACD methods, while FSMC (3.32%) was the lowest (figure 3B). PACD methods (SCD, MMC and FSMC) are shown in purple tones and constitute a higher proportion of tests, while RACD methods (CIS, MBS) are shown in blue tones and comprise a higher proportion of confirmed cases.

PACD test positivity varied by method across the study period, with decreasing yield over time: SCD (0.07%–0.01%), MMC (0.11%–0.02%) and FSMC (0.23%–0.00%). RACD test positivity also varied: CIS (0.24%–0.07%) and MBS (0.78%–0.05%) (table 2).

As expected, both PACD and RACD contributions were a significantly higher yield among active foci (A1 and A2) than other foci with a confirmed index case (B1 and B2) ($p<0.05$). There were also about triple the number of people screened in active foci than other foci (3 444 484 vs 1 152 809). PACD yield in active foci from FY15 to

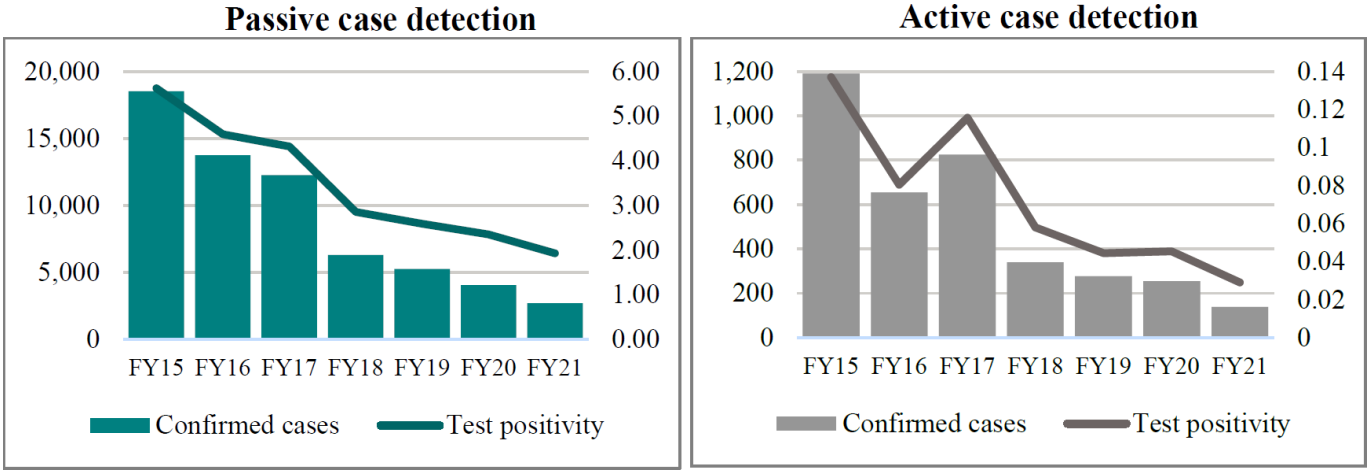

Figure 1 Malaria cases and test positivity, FY15–FY21.

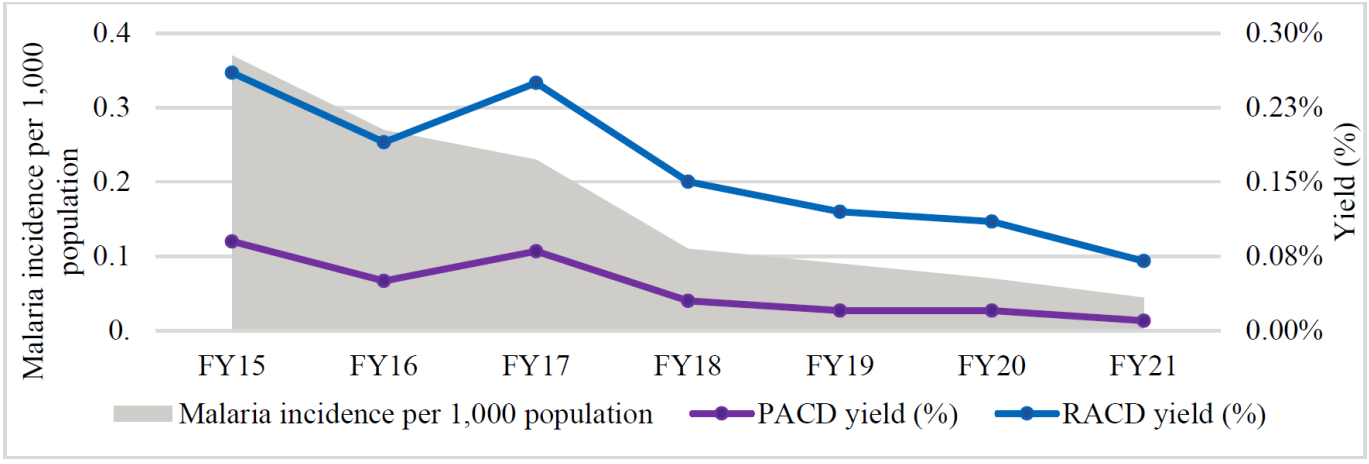

Figure 2 Malaria incidence and PACD and RACD yields (%), FY15–FY21. PACD, proactive active case detection; RACD, reactive ACD.

FY 21 was 0.06% (range: 0.09%–0.02%; total screened: 2 406 658), compared with 0.02% in other areas (range: 0.08%–0.01%; total screened: 937 137). RACD yield in the same time period among active foci was 0.17% (range: 0.22%–0.07%; total screened: 1 037 826) and among other foci was 0.15% (range: 0.09%–0.05%; total screened: 215 672) (table 3).

Geographical variation in ACD implementation and yield

A hallmark of Thailand's malaria elimination programme is decentralisation of funding and decision-making, allowing for flexibility in how the ACD programme is targeted and implemented. We analysed how PACD and RACD implementation and yield differed in these three areas during the era of 1-3-7 surveillance and response. From FY17 to FY21, PACD yield was 5.94 per 10 000 targeted (0.06%) and total RACD yield was 16 per 10 000 targeted (0.16%). RACD activities appear to be operating appropriately with 72.36% of cases reported within 1 day, 90.34% investigated within 3 days, 252 of 285 (97.72%) of required RACD implemented and 196 of the 252 (76.03%) having occurred within 7 days. These adherence rates are improving over time.[2]

Geographical variation in PACD implementation and yield

The model of PACD yield by tambon showed an overall ICC of 0.481, indicating that almost half of the variance in PACD yield was explained by the grouping structure of tambons, districts and provinces. Specific values of ICC were 0.196, 0.217 and 0.067 at tambon, district and province level, respectively. This indicates that foci with similar yield tended to cluster within tambons and districts.

Although relatively high numbers of people were screened through PACD in the eastern region, the yield was less than 0.01% in nearly all tambons. Yield exceeded 0.10% in only 6 tambons, 2 of which recorded fewer than

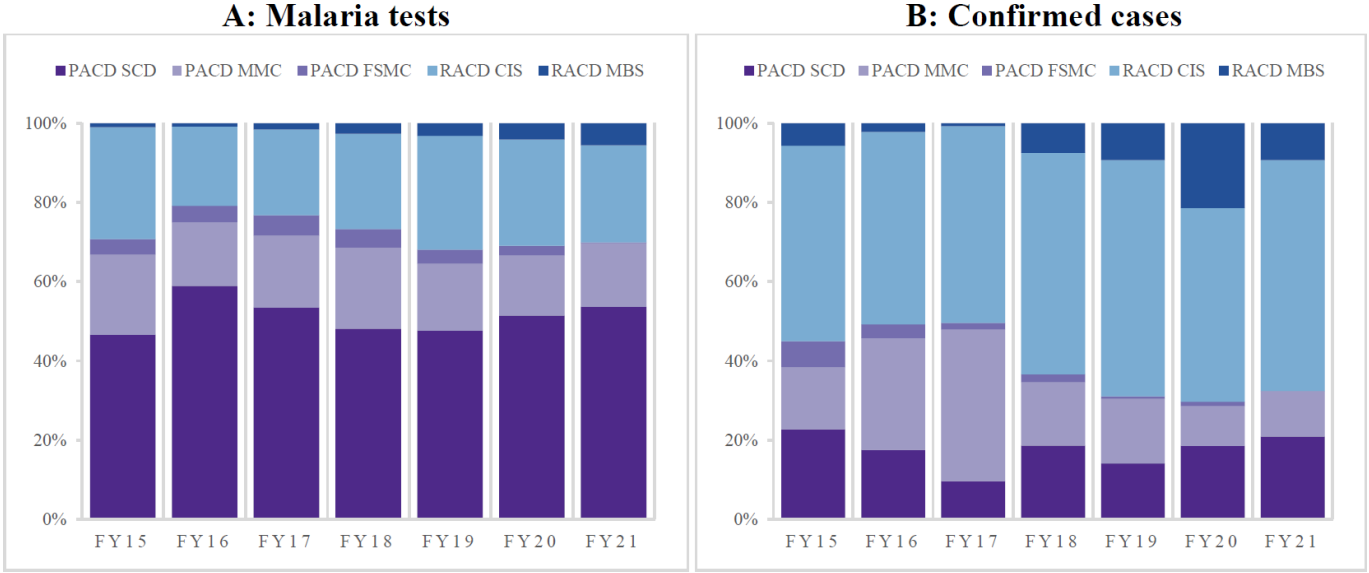

Figure 3 Contribution of malaria tests and confirmed cases, by ACD method, FY15–FY21. ACD, active case detection; CIS, case investigation survey; FSMC, fixed-schedule malaria clinic; MBS, mass blood survey; MMC, mobile malaria clinic; PACD, proactive ACD; RACD, reactive ACD; SCD, special case detection.

Table 2 Malaria tests and test positivity by active case detection method, FY15–FY21

	Fiscal year															
	2015			2016			2017			2018			2019			2020			2021		
	Tested	Positive	%	Tested	Positive	%	Tested	Positive	%	Tested	Positive	%	Tested	Positive	%	Tested	Positive	%	Tested	Positive	%
Active case detection	859 458	1 180	**0.14**	812 400	**644**	**0.08**	715 108	**830**	**0.12**	587 166	**360**	**0.06**	620 523	**332**	**0.05**	560 124	**276**	**0.05**	478 533	**139**	**0.03**
Proactive case detection	608 012	*530*	*0.09*	643 037	*317*	*0.05*	549 315	*412*	*0.08*	430 148	*132*	*0.03*	422 213	*103*	*0.02*	387 156	82	*0.02*	334 536	*45*	*0.01*
Special case detection	400 092	268	0.07	479 137	113	0.02	382 404	80	0.02	282 761	67	0.02	295 274	47	0.02	287 975	51	0.02	256 657	29	0.01
Malaria mobile clinic	174 587	185	0.11	129 864	182	0.14	130 082	318	0.24	120 024	58	0.05	105 748	54	0.05	85 812	28	0.03	77 607	16	0.02
Fixed schedule malaria clinic	33 333	77	0.23	34 036	22	0.06	36 829	14	0.04	27 363	7	0.03	21 191	2	0.01	13 369	3	0.02	272	0	0.00
Reactive case detection	251 446	*650*	*0.26*	169 363	*327*	*0.19*	165 793	*418*	*0.25*	157 018	*228*	*0.15*	198 310	*229*	*0.12*	172 968	*194*	*0.11*	143 997	*94*	*0.07*
Case Investigation Survey	242 866	583	0.24	162 832	313	0.19	154 901	412	0.27	141 554	201	0.14	178 279	198	0.11	149 957	135	0.09	117 465	81	0.07
Mass blood survey	8580	67	0.78	6531	14	0.21	10 892	6	0.06	15 464	27	0.17	20 031	31	0.15	23 011	59	0.26	26 532	13	0.05

10 people screened (figure 4A). In seven tambons, over 1000 people were screened. PACD was implemented more aggressively in the south, with several tambons screening more than 10 000 patients from FY17 to FY21 (figure 4B). There was a cluster of several tambons where the yield was >0.10% during this period, while the yield appeared to be lower in eastern and northern tambons along the region's periphery. PACD was also implemented thoroughly in Thailand's western provinces, particularly along the western border, where malaria incidence is highest. The yield was generally lower than in the south but higher than in the east. Tambons in the western region that had higher yields showed a lower degree of spatial clustering compared with those in the south (figure 4C).

Geographical variation in RACD implementation and yield

Table 4 shows the variation in the implementation of RACD at tambon, district and province levels. Variation was higher for the proportion of RACD activities conducted out of the total number required, and was lower for the proportion of RACD conducted within 7 days. The proportion of RACD activities conducted out of those required varied mostly within tambons, while the other model on timely RACD implementation had a higher proportion of variance at province level.

In model 1, the ICC of around 0.49 indicates that approximately half of the variance in the proportion of RACD conducted is explained by the structure of tambons nested in districts nested in provinces. The remaining 50% of variance reflects random variation or the influence of covariates which were not included. Higher values at tambon level compared with district and province indicate a higher share of this variation within tambons (eg, foci are similar within tambons), whereas higher values at higher levels indicate variation between foci within tambons, but similarity (or clustering) within higher levels. Models 3 and 4 offer comparisons for other components of Thailand's 1-3-7 surveillance strategy.

The yield of case detection through RACD was less than 0.01% in most tambons in eastern Thailand from FY17 to FY21, although there were three tambons with a yield over 0.50% (figure 5A). In the deep south, tambons in which the RACD yield was above 0.10% tended to cluster together, while most tambons on the periphery of the ACD area had a yield of <0.01 (figure 5B). In western Thailand, the yield was above 0.01% in most tambons where this activity was implemented, and tended to be higher along the Myanmar border (figure 5C).

ACD costs

Costs per unit

The financial inputs, including unit costs and unit counts for each line item, appear in online supplemental table 1. These values are discounted where appropriate and summed together to generate the costs per sample, per slide, per day and per trip reported in table 5.

Table 3 Malaria tests and test positivity by active case detection method and foci classification, FY15–FY21

	Fiscal year																			
	2015			2016			2017			2018			2019			2020			2021		
	Tested	Positive	%	Tested	Positive	%	Tested	Positive	%	Tested	Positive	%	Tested	Positive	%	Tested	Positive	%	Tested	Positive	%
Foci classification A1 and A2*																					
Active case detection (ACD)	694110	913	0.13	588812	570	0.10	511347	742	0.15	410787	267	0.06	459368	314	0.07	415676	237	0.06	364384	123	0.03
Proactive case detection (PACD)	464631	410	0.09	441282	262	0.06	381756	378	0.10	289357	99	0.03	294572	96	0.03	283560	63	0.02	251500	44	0.02
Special case detection (SCD)	315152	212	0.07	308247	86	0.03	255045	61	0.02	186390	48	0.03	206561	44	0.02	217508	40	0.02	200807	28	0.01
Malaria mobile clinic (MMC)	136280	151	0.11	108373	154	0.14	107150	305	0.28	90679	47	0.05	78446	50	0.06	61335	22	0.04	50462	16	0.03
Fixed schedule malaria clinic (FSMC)	13199	47	0.36	24662	22	0.09	19561	12	0.06	12288	4	0.03	9565	2	0.02	4717	1	0.02	231	0	0.00
Reactive Case Detection (RACD)	229479	503	0.22	147530	308	0.21	129591	364	0.28	121430	168	0.14	164796	218	0.13	132116	174	0.13	112884	79	0.07
Case Investigation Survey (CIS)	223355	465	0.21	142811	294	0.21	120521	360	0.30	109028	151	0.14	148474	188	0.13	117848	128	0.11	89933	69	0.08
Mass blood survey (MBS)	6124	38	0.62	4719	14	0.30	9070	4	0.04	12402	17	0.14	16322	30	0.18	14268	46	0.32	22951	10	0.04
Foci classification B1 and B2*																					
ACD	156789	254	0.16	209035	44	0.02	195616	84	0.04	175080	93	0.05	160220	18	0.01	143969	38	0.03	112100	16	0.01
PACD	135746	109	0.08	188503	28	0.01	161717	31	0.02	139657	33	0.02	127026	7	0.01	103238	18	0.02	81250	1	0.001
SCD	80808	53	0.07	160080	17	0.01	122023	16	0.01	95321	19	0.02	88109	3	0.00	70181	11	0.02	54069	1	0.00
MMC	34837	26	0.07	19049	11	0.06	22492	13	0.06	29301	11	0.04	27291	4	0.01	24405	5	0.02	27140	0	0.00
FSMC	20101	30	0.15	9374	0	0.00	17202	2	0.01	15035	3	0.02	11626	0	0.00	8652	2	0.02	41	0	0.00
RACD	21043	145	0.69	20532	16	0.08	33899	53	0.16	35423	60	0.17	33194	11	0.03	40731	20	0.05	30850	15	0.05
CIS	18716	117	0.63	18882	16	0.08	32192	51	0.16	32361	50	0.15	29580	10	0.03	31988	7	0.02	27269	12	0.04
MBS	2327	28	1.20	1650	0	0.00	1707	2	0.12	3062	10	0.33	3614	1	0.03	8743	13	0.15	3581	3	0.08

*A1=Active foci (reported indigenous transmission in the current year); A2=Residual non-active foci (no indigenous cases in the current yearbutwith indigenous cases in the previous 3 years); B1=Cleared foci but receptive (no indigenous transmission in at least3 years, but suitable environmental for vector *Anopheles* spp mosquitoes); B2=Cleared foci but not receptive (no indigenous transmission in at least 3 years, but unsuitable environmental for vector *Anopheles* spp mosquitoes).

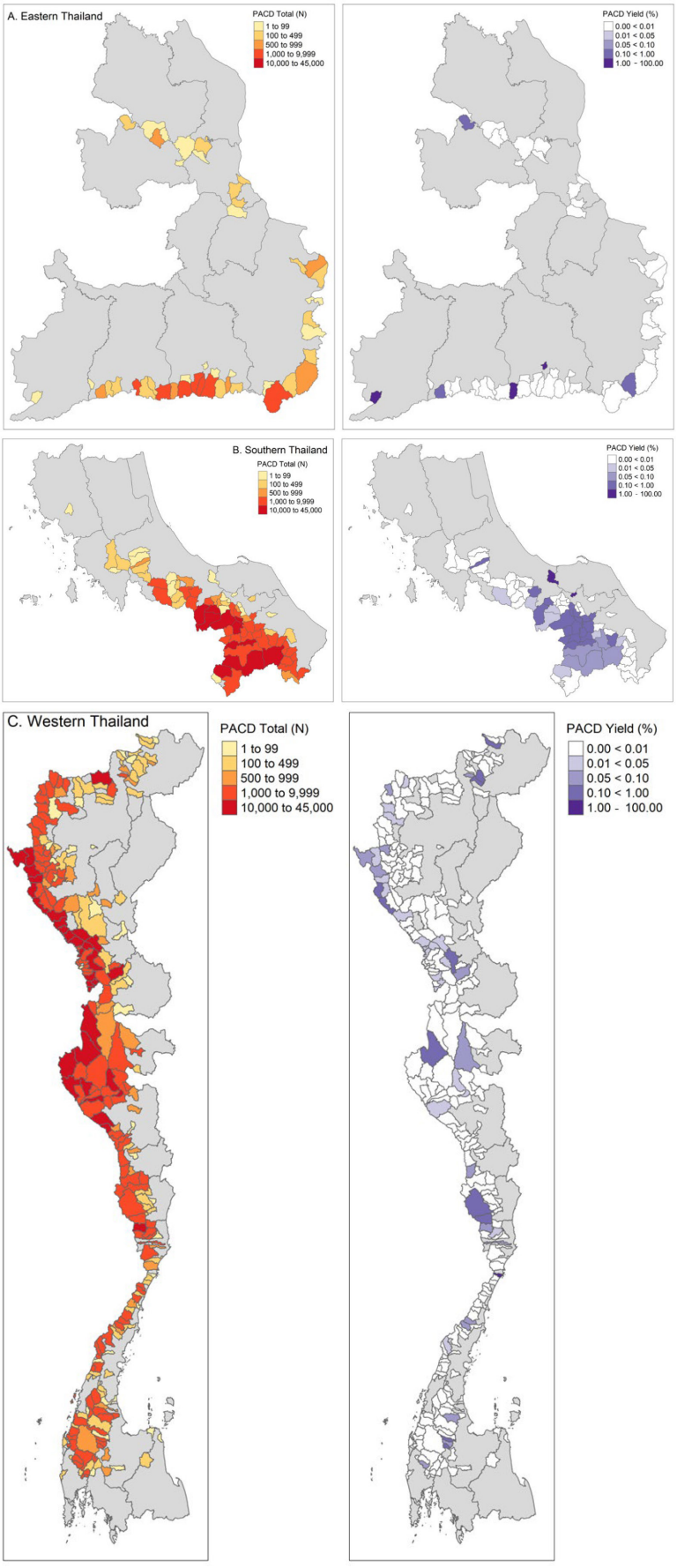

Figure 4 Total screened and yield of malaria cases detected through PACD, FY17–FY21. PACD, proactive active case detection.

Table 4 Strength of spatial variation in implementation of RACD activities

Model	ICC overall	ICC tambon level	ICC district level	ICC province level
The proportion of RACD activities conducted out of the total no required	0.488	**0.232**	0.124	0.132
The proportion of RACD activities conducted within 7 days of case notification	0.264	0.034	0.058	**0.173**
The proportion of cases investigated within 3 days of notification	0.544	**0.177**	0.106	0.26
The proportion of cases reported within 1 day of notification	0.323	0.091	0.058	**0.173**

The highest ICC, by level, for each model is indicated in bold.
ICC, intraclass correlation coefficient; RACD, reactive active case detection.

Costs of PACD per instance

The costs of ACD vary as a function of the number of personnel required, the number of people who must travel for the activity, and the number of people screened. Due to the decentralised nature of Thailand's malaria elimination programme, it is challenging to quantify an expected cost for an 'average' instance of each ACD method, particularly for PACD activities, which unlike RACD activities, vary widely in practice. Given this high degree of variability, we provide an Excel-based calculator (online supplemental file 1) into which readers can input their own values to calculate the expected costs of ACD.

As an example for PACD costs, if a health worker takes about 15 min to administer an RDT, 1 day of an MMC staffed by one clinic worker who travelled to the site plus two local VHVs could administer 252 RDTs at an expected maximum cost of US$213.39 per day per focus, or US$0.70 per person tested. If the clinic was staffed solely by two VHVs administering 168 tests per day, costs would change to US$119.89 or US$0.71 per person tested.

Costs of RACD per instance

In RACD, activities are generally well defined. The expected cost of a standard CIS, in which a team of two malaria clinic workers travel to a focus for 2 days and gather microscopy samples from 50 households with an average household size of 2.8 people per household,[28] would be US$226.31 per instance per focus, or US$1.62 per person tested. For an MBS, which requires the same team and number of person-days visiting or gathering 150 households at a central location, the expected cost would increase to US$461.78 per instance per focus, but drop to US$1.10 per person tested. If these activities used RDTs only (instead of microscopy or a combination of testing), the expected costs per instance per focus would change to US$203.81 and US$394.28, respectively. For the microscopy scenario, varying the discount rate from 0% to 7% would vary the expected cost from US$226.10 (US$1.62 per person) to US$229.83 (US$1.64 per person) for CIS and from US$461.16 (US$1.10 per person) to US$472.23 (US$1.12 per person) for MBS. A six-person military escort in southern provinces for the 2 days of activity would increase costs by US$45.03 per instance per focus.

DISCUSSION

Synthesis of the results of this study

ACD supports early detection and appropriate management of patients in communities at risk for malaria, which is essential for successful elimination of malaria transmission. In Thailand, ACD yields from FY15 to FY21 declined, mirroring the decline in malaria incidence as the DVBD accelerated elimination interventions. Whereas PACD contributed almost the same number of confirmed cases as RACD at the start of the study period, with a yield of 0.09%, by FY21 PACD represented just 32.37% of ACD cases with a yield of 0.01%. These results align with evidence from other settings, which suggests that ACD yields fall at very low incidence.[7 29–33]

Comparing the scale of screening with the scale of confirmed cases shows that some methods more efficiently identify malaria patients than others, with a noticeably higher yield for RACD compared with PACD. More specifically, SCD represented more than half of the ACD tests conducted, but with a total yield of 0.03%, represented only 17.46% of all confirmed cases identified by ACD. CIS, on the other hand, represented 25% of screening but more than 50% of confirmed cases, indicating that CIS efforts are well targeted. These analyses suggest that it could be the right time in Thailand's malaria epidemiology to revise screening criteria, concentrating on the areas and populations in which cases are most likely to be found.

Each of Thailand's three main malaria zones showed different yields, with eastern Thailand showing the lowest yield and southern Thailand the highest. In the eastern

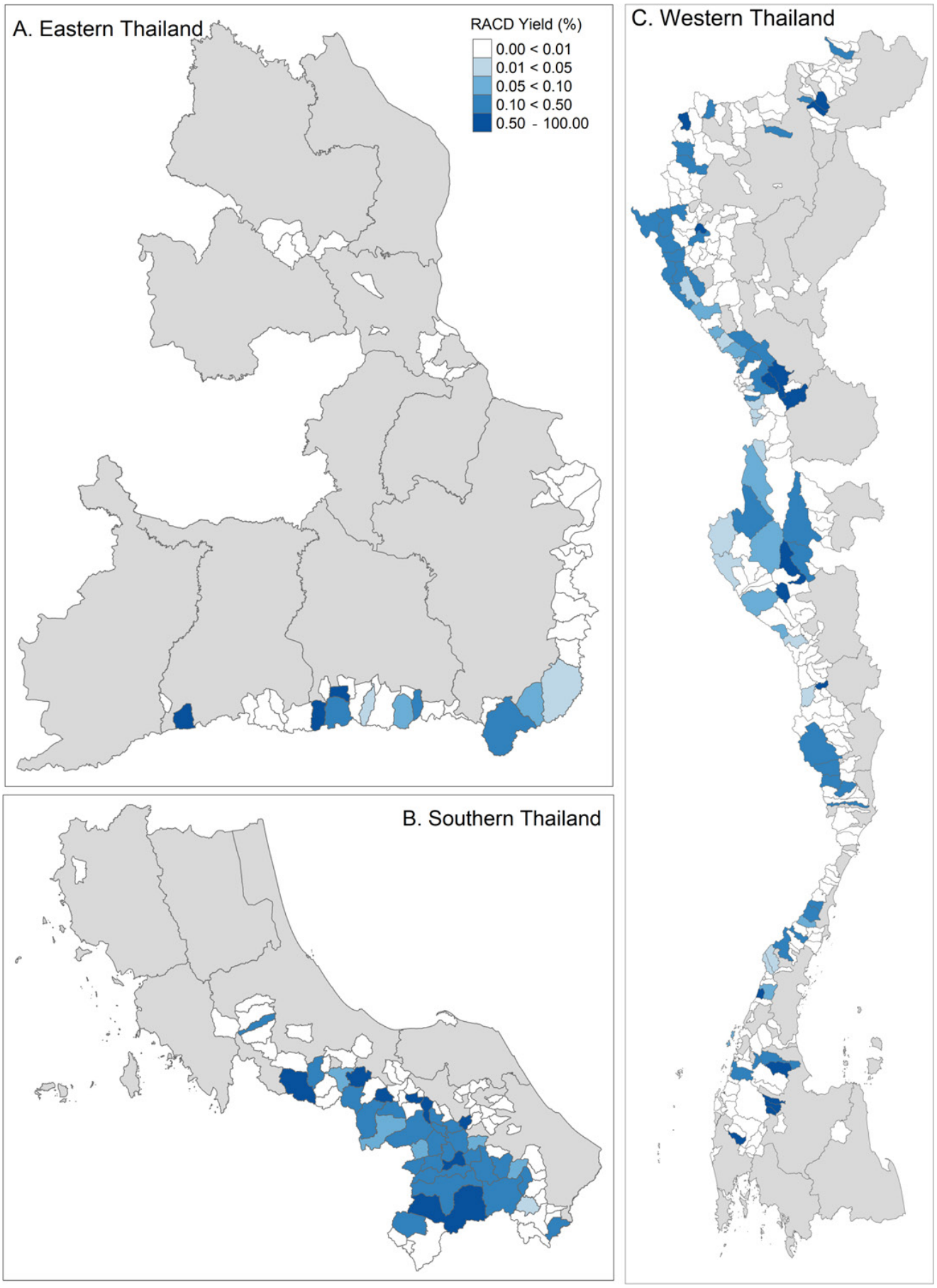

Figure 5 RACD yield by tambon, FY17–FY21. RACD, reactive active case detection.

Table 5 Summary unit costs for active case detection in Thailand (2021 USD)

Input	Cost	Unit	Notes
Rapid diagnostic test	0.68	Per sample	Includes supplies (not counting time for person to process, as that would be double counting)
Microscope slide analysis: total	0.84	Per slide	—
Microscope slide analysis: supplies	0.14	Per slide	Includes all consumable supplies for microscopy
Microscope slide analysis: microscope	0.03	Per slide	Includes wear and tear on microscope
Microscope slide analysis: microscopist	0.59	Per slide	Includes salary, training and per-slide subsidy
Microscope slide analysis: quality assurance	0.07	Per slide	Includes regional and national quality assurance
Microscope slide analysis: cool boxes	0.01	Per slide	Includes transportation in cool boxes
Malaria post and clinic workers	5.08	Per day	Includes salary and training
VHVs	2.71	Per day	Includes salary and training
Military escorts	3.75	Per day	Flat rate
Travel	31.27	Per trip	Flat rate
Lodging	25.32	Per day	Average rate
Tablet	0.19	Per day	Includes cost of wear and tear on tablet

VHVs, village health volunteers.

region bordering Cambodia, the malaria caseload has fallen dramatically; however, it remains an important area for the DVBD due to the need for close drug efficacy monitoring in this region.[34] Our results show that yields for both PACD and RACD were less than 0.01% in nearly all tambons in this border area from FY17 to FY21. As the local teams are quite active, it is perhaps unsurprising that PACD screening counts were high. However, the waning cases and low yield could justify a less aggressive package of ACD interventions in this region.

In the deep south along the border with Malaysia, tambons with PACD yield over 0.1% during this period and tambons with RACD yield above 0.05% tended to cluster in the centre of the province. In Yala province in particular, local teams have implemented PACD and RACD intensively and with greater frequency than in other areas of Thailand. Yala province provides a good model of accurate targeting of population at high-risk for malaria, with strong collaboration between the malaria programme staff, border police and armed forces, which has enhanced malaria prevention and elimination activities. Since a successful 2016 pilot project implemented by the vectorborne disease unit to provide PACD to military members at a high risk of malaria, in collaboration with the Southern Medical Army Centre based in Patani province, PACD has been a core part of the southern provinces' malaria elimination strategy. Between 2017 and 2020, ACD was expanded to include civilian populations.

The higher incidence western provinces saw higher yield tambons concentrated along the border with Myanmar. Most tambons had an RACD yield over 0.01%, which is consistent with the epidemiological reality of regular malaria transmission in these areas. As local malaria transmission continues to decline, imported parasites from neighbouring countries may represent a greater proportion of future malaria cases and become the main risk for onward transmission. As the region also has high population mobility, more frequent PACD that meets the right target groups at the right time and place in a safe way, could support Thailand's elimination goals.

The costs of ACD vary as a function of the number of personnel required, the number of people who must travel for the activity, and the number of people screened. For PACD, implementation in Thailand varies so greatly by focus that we could not quantify the expected cost of implementation for an 'average' instance of PACD. We hope that the provided Excel-based calculator will provide readers the ability to understand the drivers of differences in PACD costs. This calculator may also be helpful for complex settings where supplemental costs, such as security for public health workers, may be needed to provide malaria services, or for locations that use a varying mix of microscopy and RDTs for diagnosis. For RACD, which is implemented following a reasonably set structure, the costs we calculate in this paper are lower than in the few other ACD studies. However, those studies included treatment costs in their analyses, which we excluded from consideration.[16 19 35]

Challenges with ACD implementation

A consistent success factor in Thailand's malaria elimination programming is decentralisation of financing and decision-making.[3] This flexibility uplifts local experts, allows for diverse capacities and approaches, and gives the DVBD an opportunity to practice mutuality with subnational officers. This localisation, however, also makes it difficult to distinguish and assess how each ACD method is implemented and performing. Although there

are strict protocols for RACD implementation as part of Thailand's 1-3-7 strategy, there is not a specific protocol for PACD implementation that clearly differentiates the three methods.

Another challenge with PACD implementation is the limited flexibility in funding streams. Budgeting generally occurs in an annual cycle and can be difficult to reprogram quickly enough to respond to an epidemiological change identified by Thailand's real-time surveillance system. The DVBD budgets for two rounds of PACD per province each year, and it can be difficult to develop new plans and distribute adequate per diems for overnight work in remote areas during special ACD deployment.

Next steps to optimising ACD for elimination

The results of this study suggest that the utility of current ACD strategies is diminishing as burden reduces in Thailand, warranting a new strategic plan to accelerate towards elimination. Further analyses could shed light on how to optimise the mix of PACD and RACD, accounting for the variation in methods, subnational epidemiological contexts and costs.

Several tambons recorded PACD yield under 0.01%, indicating poor return on investment. Waning PACD yield could be an indication that this strategy is no longer relevant for Thailand's epidemiology, but it more likely indicates an opportunity for better targeting PACD methods and more responsive implementation. Local teams are tasked with planning their own PACD sites and implementation. A protocol containing specific guidance about which surveillance data to review to generate subsequent evidence-based and systematic decisions to sharpen the targeting, timing and implementation of PACD could renew utility in this elimination strategy. The protocol development process could also be an opportunity to streamline redundancies among the three PACD methods, which are distinct on paper but overlap in real-world settings.

PACD is most likely to remain useful only in specific microcontexts in Thailand. Rather than a national policy, PACD could be alternatively implemented to maximise yield and reduce wastage, with individuals targeted based on identifying the networks to which they are affiliated. For example, imported cases could trigger screening of fellow travellers from malaria-endemic areas using snowball sampling or a variation on time-location sampling that would be safe and appropriate for this context.[5 36] Using Thailand's extensive VHV network could support higher quality PACD implementation by offering more flexible times and locations to reach potential patients per their convenience.

Moving forward, RACD could be adjusted where resources are scarce by limiting inclusion criteria to more narrowly defined high-risk populations. In very low transmission settings such as eastern Thailand, for example, risk may be related to demographic or behavioural characteristics (ie, military members or forest goers). In such situations, deploying RACD using demographics-based screening criteria, rather than geographical criteria, could increase efficient use of resources while maintaining a very low risk of missed cases.[37] This future risk analysis could also consider key vector control interventions coverage, as gaps would indicate higher potential for onward transmission. Reactive drug administration is unlikely to be part of Thailand's future elimination programming due to the complexities of radical cure for *P. vivax*, which is responsible for nearly all infections.

Ultimately, ACD can continue to contribute to Thailand's malaria elimination programme but with more deliberate targeting, guided by the country's high-quality surveillance data to balance known operational costs.

Limitations of the study

This study used Thailand's national routine surveillance data as the main data source. Data completeness is very high for this type of data source; however, as reported in the results section, completeness is less than 100%.

The costing analysis presented in this paper has two key limitations. First, we relied on budget data and expert opinion for costing data. Although these are less reliable sources of funding, the DVBD has been implementing ACD for several years, and so we find it reasonable to assume that their budgets and experience track with actual expenditures. Second, although travel and lodging costs vary by geography, the DVBD does not keep records of actual travel expenditures; instead, all we could gather were the flat rates budgeted for travel. We hope that the provision of the spreadsheet used to generate expected costs given different inputs will allow programme designers, both within and outside of Thailand, to adjust our example estimates to better reflect their own context.

CONCLUSIONS

The DVBD has successfully implemented a broad and detailed ACD portfolio as part of its comprehensive transition from a malaria control to a malaria elimination setting. ACD yields are declining alongside decreasing malaria incidence, with a noticeably higher yield for RACD compared with PACD and significant geographical differences by tambon. This documentation of ACD implementation helps identify opportunities to simplify the complexity of Thailand's various ACD methods and to sharpen targeting and implementation. A PACD protocol could outline a method to systematically identify specific microcontexts where PACD could meaningfully curb transmission in lieu of the current national policy. Similarly, further analyses could offer details on how to shift from geographical-based screening criteria to demographic or behavioural criteria for RACD. This work will support optimising the mix of PACD and RACD, accounting for the variation in ACD methods, subnational epidemiological contexts and costs.

Author affiliations
[1]Division of Vector-Borne Diseases, Department of Disease Control, Ministry of Public Health, Nonthaburi, Thailand

[2]Inform Asia: USAID's Health Research Program, RTI International, Bangkok, Thailand
[3]London School of Hygiene and Tropical Medicine, London, UK
[4]Brighton and Sussex Medical School, Brighton, UK
[5]RTI International, Research Triangle Park, North Carolina, USA
[6]Sa Kaeo Provincial Health Office, Ministry of Public Health, Sa Kaeo, Thailand
[7]Mukdahan Vector-Borne Disease Control Center 10.2, Ministry of Public Health, Mukdahan, Thailand
[8]World Health Organization, Nonthaburi, Thailand
[9]U.S. President's Malaria Initiative, United States Agency for International Development (USAID), Regional Development Mission for Asia, Bangkok, Thailand
[10]Division of Epidemiology and Public Health, School of Medicine, University of Nottingham, Nottingham, UK

Acknowledgements The authors recognise all local public health teams and partners who have contributed to planning and implementing active case detectionunder the leadership of Thailand's Division of Vector Borne Diseases, Department of Disease Control, Ministry of Public Health. A special thank you is reserved for the Sa Kaeo Provincial Health Office and Mukdahan Vector-Borne Disease Control Center for sharing specific experiences in their jurisdictions.

Contributors SK, SN, PS and JAS conceptualised the manuscript. SN, HS and RS analysed the quantitative results, and HS and DB analysed the spatial results. SN and JAS led the writing of the manuscript. All authors, including CS, SP, WC, DG, JK, RT, NP and DS provided input and review. All authors read and approved the final manuscript. JAS is responsible for the overall content as guarantor.

Funding This study was made possible by the generous support of the American people through the US President's Malaria Initiative (PMI) and United States Agency for International Development (USAID), under the terms of Cooperative Agreement AID-486-LA-15-00002 for Inform Asia: USAID's Health Research Program.

Disclaimer The contents of this article are the responsibility of the authors and do not necessarily reflect the views of USAID, PMI, or the U.S. Government. DG is a staff member of the WHO and is responsible for the views expressed in this publication, which do not necessarily reflect the decisions or policies of WHO.

Map disclaimer The inclusion of any map (including the depiction of any boundaries therein), or of any geographic or locational reference, does not imply the expression of any opinion whatsoever on the part of BMJ concerning the legal status of any country, territory, jurisdiction or area or of its authorities. Any such expression remains solely that of the relevant source and is not endorsed by BMJ. Maps are provided without any warranty of any kind, either express or implied.

Competing interests The authors declare that they have no competing interests.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available in a public, open access repository. The data supporting the conclusions of this article are available in the Malaria Online repository, http://malaria.ddc.moph.go.th/.

ORCID iD
Jui A Shah http://orcid.org/0000-0001-5723-4738

REFERENCES

1 World Health Organisation. World malaria report 2020: 20 years of global progress and challenges. 2020.
2 Lertpiriyasuwat C, Sudathip P, Kitchakarn S, *et al*. Implementation and success factors from Thailand's 1-3-7 surveillance strategy for malaria elimination. *Malar J* 2021;20:201.
3 Sudathip P, Naowarat S, Kitchakarn S. Assessing Thailand's 1-3-7 surveillance strategy in accelerating malaria elimination. *Malar J* [Preprint] 2021.
4 World Health Organization. *World Malaria Day: WHO launches effort to stamp out malaria in 25 more countries by 2025*. Geneva: World Health Organisation, 2021. Available: https://www.who.int/news/item/21-04-2021-world-malaria-day-who-launches-effort-to-stamp-out-malaria-in-25-more-countries-by-2025
5 Prempree P, Bisanzio D, Sudathip P, *et al*. Environmental factors linked to reporting of active malaria foci in Thailand. *Trop Med Infect Dis* 2023;8:179.
6 Sturrock HJW, Hsiang MS, Cohen JM, *et al*. Targeting asymptomatic malaria infections: active surveillance in control and elimination. *PLoS Med* 2013;10:e1001467.
7 Deen J, Mukaka M, von Seidlein L. What is the yield of malaria reactive case detection in the greater Mekong sub-region? A review of published data and meta-analysis. *Malar J* 2021;20:131.
8 WHO SEARO. Mobile and migrant populations and malaria information systems 2015. 2021. Available: https://apps.who.int/iris/bitstream/handle/10665/204343/SEA-MAL-279.pdf;jsessionid=B89749B15B3AF36D0921C95AB3C7B5BD?sequence=1
9 World Health Organisation. A framework for malaria elimination. 2017 Available: https://apps.who.int/iris/rest/bitstreams/1081424/retrieve
10 Sudathip P, Kitchakarn S, Thimasarn K, *et al*. The evolution of the malaria clinic: the cornerstone of malaria elimination in Thailand. *Trop Med Infect Dis* 2019;4:143.
11 Division of Vector Borne Disease. *Malaria Online: The Digital Surveillance System for Thailand Malaria Elimination*. Department of Disease Control, MOPH2019.
12 Khamsiriwatchara A, Sudathip P, Sawang S, *et al*. Artemisinin resistance containment project in Thailand. (I): implementation of electronic-based malaria information system for early case detection and individual case management in provinces along the Thai-Cambodian border. *Malar J* 2012;11:247.
13 World Health Organization. A framework for malaria elimination. 2017. Available: https://www.who.int/malaria/publications/atoz/9789241511988/en/
14 Zhou S-S, Zhang S-S, Zhang L, *et al*. China's 1-3-7 surveillance and response strategy for malaria elimination: is case reporting, investigation and foci response happening according to plan. *Infect Dis Poverty* 2015;4:55.
15 Bureau of Vector Borne Disease. *Malaria Elimination Guideline for District and Sub-district Health Worker*. Ministry of Public Health, 2019.
16 Conteh L, Shuford K, Agboraw E, *et al*. Costs and cost-effectiveness of malaria control interventions: a systematic literature review. *Value Health* 2021;24:1213–22.
17 Zelman BW, Baral R, Zarlinda I, *et al*. Costs and cost-effectiveness of malaria reactive case detection using loop-mediated isothermal amplification compared to microscopy in the low transmission setting of Aceh province, Indonesia. *Malar J* 2018;17:220.
18 World Health Organization. Malaria surveillance, monitoring & evaluation: a reference manual. 2018. Available: https://apps.who.int/iris/bitstream/handle/10665/272284/9789241565578-eng.pdf?ua=1
19 Larson BA, Ngoma T, Silumbe K, *et al*. A framework for evaluating the costs of malaria elimination interventions: an application to reactive case detection in Southern province of Zambia, 2014. *Malar J* 2016;15:408.
20 Sudathip P, Kitchakarn S, Shah JA, *et al*. A foci cohort analysis to monitor successful and persistent foci under Thailand's malaria elimination strategy. *Malar J* 2021;20:118.
21 Merlo J, Chaix B, Yang M, *et al*. A brief conceptual tutorial of multilevel analysis in social epidemiology: linking the statistical concept of clustering to the idea of contextual phenomenon. *J Epidemiol Community Health* 2005;59:443–9.
22 Consumer Price Index [Internet]. Ministry of Commerce Thailand; 2022. Available: https://tradingeconomics.com/thailand/consumer-price-index-cpi [Accessed 8 Aug 2022].
23 Consumer Price Index [Internet]. Ministry of Commerce U.S.; 2022. Available: https://tradingeconomics.com/united-states/consumer-price-index-cpi [Accessed 8 Aug 2022].
24 XE.com.Inc. US dollar to Thai Baht exchange rate chart. 2022. Available: https://www.xe.com/currencycharts/?from=USD&to=THB

25 Thailand 10 year government bond [Internet]. *The Wall Street Journal* 2022. Available: https://www.wsj.com/market-data/quotes/bond/BX/AMBMKTH-10Y/historical-prices [Accessed 26 Jul 2022].
26 Attema AE, Brouwer WBF, Claxton K. Discounting in economic evaluations. *Pharmacoeconomics* 2018;36:745–58.
27 Thailand Governemnt holiday 2022 (in Thai): iTAX. n.d. Available: https://www.itax.in.th/media/%E0%B8%A7%E0%B8%B1%E0%B8%99%E0%B8%AB%E0%B8%A2%E0%B8%B8%E0%B8%94-2565-%E0%B8%9B%E0%B8%8F%E0%B8%B4%E0%B8%97%E0%B8%B4%E0%B8%99%E0%B8%A7%E0%B8%B1%E0%B8%99%E0%B8%AB%E0%B8%A2%E0%B8%B8%E0%B8%94/
28 Social Statistics Division. *Thailand muitiple indicator cluster survey 2019: summary of key indicators*. Thailand: National Statistical Office, 2020.
29 Premaratne R, Wickremasinghe R, Ranaweera D, *et al*. Technical and operational underpinnings of malaria elimination from Sri Lanka. *Malar J* 2019;18:256.
30 Rossi G, Vernaeve L, Van den Bergh R, *et al*. Closing in on the reservoir: proactive case detection in high-risk groups as a strategy to detect *Plasmodium falciparum* asymptomatic carriers in Cambodia. *Clin Infect Dis* 2018;66:1610–7.
31 Chhim S, Piola P, Housen T, *et al*. Malaria in Cambodia: a retrospective analysis of a changing epidemiology 2006-2019. *Int J Environ Res Public Health* 2021;18:1960.
32 Rogawski ET, Congpuong K, Sudathip P, *et al*. Active case detection with pooled real-time PCR to eliminate malaria in trat province, Thailand. *Am J Trop Med Hyg* 2012;86:789–91.
33 van Eijk AM, Ramanathapuram L, Sutton PL, *et al*. What is the value of reactive case detection in malaria control? A case-study in India and a systematic review. *Malar J* 2016;15:67.
34 Sudathip P, Saejeng A, Khantikul N, *et al*. Progress and challenges of integrated drug efficacy surveillance for uncomplicated malaria in Thailand. *Malar J* 2021;20:261.
35 Ntuku H, Smith-Gueye C, Scott V, *et al*. Cost and cost effectiveness of reactive case detection (RACD), reactive focal mass drug administration (RfMDA) and reactive focal vector control (RAVC) to reduce malaria in the low endemic setting of Namibia: an analysis alongside a 2×2 factorial design cluster randomised controlled trial. *BMJ Open* 2022;12:e049050.
36 Magnani R, Sabin K, Saidel T, *et al*. Review of sampling hard-to-reach and hidden populations for HIV surveillance. AIDS. *AIDS* 2005;19(Supplement 2):S67–72.
37 Smith Gueye C, Sanders KC, Galappaththy GNL, *et al*. Active case detection for malaria elimination: a survey among Asia Pacific countries. *Malar J* 2013;12:358.