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Early warning epidemic surveillance in the Pacific island nations: an evaluation of the Pacific syndromic surveillance system

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Abstract

OBJECTIVE The Pacific Syndromic Surveillance System (PSSS), launched in 2010, provides a simple mechanism by which 121 sentinel surveillance sites in 21 Pacific island countries and areas perform routine indicator- and event-based surveillance for the early detection of infectious disease outbreaks. This evaluation aims to assess whether the PSSS is meeting its objectives, what progress has been made since a formative evaluation of the system was conducted in 2011, and provides recommendations to enhance the PSSS's performance in the future.

METHODS Twenty-one informant interviews were conducted with national operators of the system and regional public health agencies that use information generated by it. Historic PSSS data were analysed to assess timeliness and completeness of reporting.

RESULTS The system is simple, acceptable and useful for public health decision-makers. The PSSS has greatly enhanced Pacific island countries' ability to undertake early warning surveillance and has contributed to efforts to meet national surveillance-related International Health Regulation (2005) capacity development obligations. Despite this, issues with timeliness and completeness of reporting, data quality and system stability persist.

CONCLUSION A balance between maintaining the system's simplicity and technical advances will need to be found to ensure its long-term sustainability, given the low-resource context for which it is designed.

keywords communicable diseases, surveillance, Pacific islands, syndromic, early warning, evaluation

Introduction

The Pacific region covers one-third of the earth and is home to approximately 11.4 million people (excluding Australia and New Zealand). Of these, 8.2 million reside in Papua New Guinea with the remainder dispersed over the many thousands of islands and atolls that make up the other 20 Pacific countries and areas (PICs). Several of the world's smallest, least developed and most isolated populations are in the Pacific. Fourteen Pacific island countries are States Parties to the International Health Regulations (2005) (IHR 2005), and seven are territories or administrative areas for which IHR (2005) responsibilities are delegated to their metropolitan country [1–3].

Rates of infectious diseases are high in the Pacific [4], as are the number of new and re-emerging disease threats [5, 6]. The ability to respond to outbreaks is often hampered by poor health infrastructure, insufficient human resources, geographical isolation, infrequent and expensive transportation and logistics; poor access to response resources; lack of advanced diagnostic capacities in most countries; and inadequate communication infrastructure.

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Some populations are immunologically naive to important outbreak-prone diseases, leading to explosive outbreaks with high attack rates [1].

In 2010, recognising the challenge of conducting early warning outbreak surveillance in low-resource small population islands and heeding a call to strengthen outbreak early warning systems as a requirement under the IHR (2005) PICs, with support from the Pacific Public Health Surveillance Network (PPHSN), implemented a region-wide outbreak early warning syndromic surveillance system, the Pacific Syndromic Surveillance System (PSSS) [1, 7]. The utility of syndromic surveillance for early outbreak detection is well documented and is particularly relevant to resource poor settings, as is the case for most Pacific nations [8, 9].

The PSSS reports early warning disease surveillance data from 21 PICs1 weekly, all of whom collect data on four syndromes: acute fever and rash, influenza-like illness, diarrhoea and prolonged fever. As part of the PSSS, PICs are also encouraged to report any unusual events. The number of sentinel sites routinely participating has grown to 121 (Figure 1). The core syndromes under surveillance were determined taking into account PICs' capacity to conduct early warning outbreak surveillance, the outbreak-prone disease profiles of PICs, States' surveillance obligations under the IHR (2005) and the need to find a balance between simplicity (and hence ability to implement and sustain the system) and functionality [10, 11].

This evaluation builds on a formative evaluation conducted in 2011 [7], 1 year after the PSSS was launched and aims to assess performance against the system's objectives (see below), report progress since the formative evaluation and provide recommendations to enhance the PSSS's performance in the future.

Methods

The evaluation was conducted from July to December 2015. Qualitative data were collected through key informant interviews using a semi-structured questionnaire. The questionnaire was based on that used by American Samoa, Cook Islands, Federal States of Micronesia, Fiji, French Polynesia, Guam, Kiribati, Marshall Islands, Nauru, New Caledonia, Niue, Northern Marianas Islands, Palau, Pitcairn Island, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, Vanuatu, Wallis and Futuna. Papua New Guinea and New Zealand also contribute to the PSSS, however, not routinely and hence have not been included in this evaluation [7].

Interviews were conducted until 'saturation' (when collection of new data did not shed new light on the issues discussed) was reached. Data were recorded in 'Web questionnaires for epidemiologists and health professionals' v1.0 (www.wepi.org). Data were then thematically analysed. Key informants were chosen based on their knowledge of, participation in, and experience with the PSSS. Interviews took between 30 min and an hour to complete. Aggregated national syndromic surveillance data from November 2010 to December 2015 were collected and analysed in Excel 2010 and STATA v13 for timeliness, completeness and stability of reporting.

In recent years, the United States Centres for Disease Control and Prevention (USCDC) has issued several guidelines for the evaluation of public health surveillance systems [12–14], with the latest focusing on surveillance for the early detection of epidemics. The USCDC guidelines identify a range of system attributes for evaluation. Attributes appraised in this evaluation include system timeliness; data quality; representativeness; usefulness; acceptability; flexibility, portability and stability. It was not possible to evaluate the sensitivity of the PSSS, as measures of sensitivity require both an operational definition of an outbreak and a gold standard against which to compare system performance [8, 12], neither of which were available in the context.

Results

Interviews were completed with 21 informants (six face-to-face and 15 by telephone) including: a deputy director public health and National surveillance manager (from Fiji and from Kiribati); a public health surveillance manager (from the Solomon Islands); 11 PIC national syndromic surveillance coordinators (one from each of the Cook Islands, Fiji, Guam, Kiribati, Niue, Palau, Pitcairn Island, Solomon Islands, Vanuatu and two from Tuvalu); four WHO staff responsible for PSSS implementation or support; and three regional public health agencies (one from each of Queensland Department of Health (Australia), New Zealand Ministry of Health and the Secretariat of the Pacific Community) that use information generated by the PSSS. The mean time informants had been involved in the system was 2.4 years (SD 0.62).

System objectives and description

The objectives of the PSSS are 'to provide a simple, sustainable system that allows local health authorities to detect unusual cases and clusters of disease early, in order to respond rapidly and limit the impact of outbreaks' and 'to assist PICs meet their obligations under the IHR (2005)' these being: to build national capacity for early

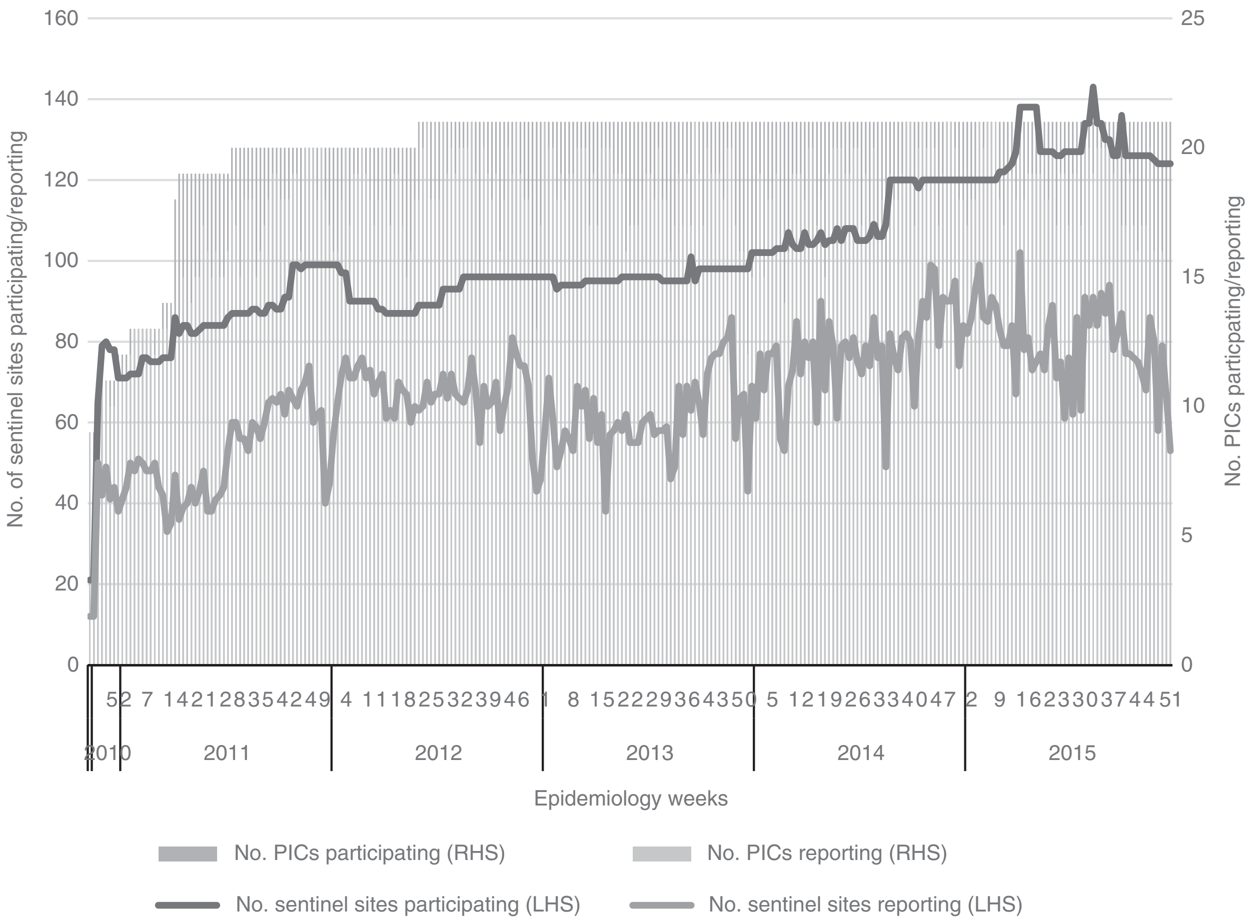


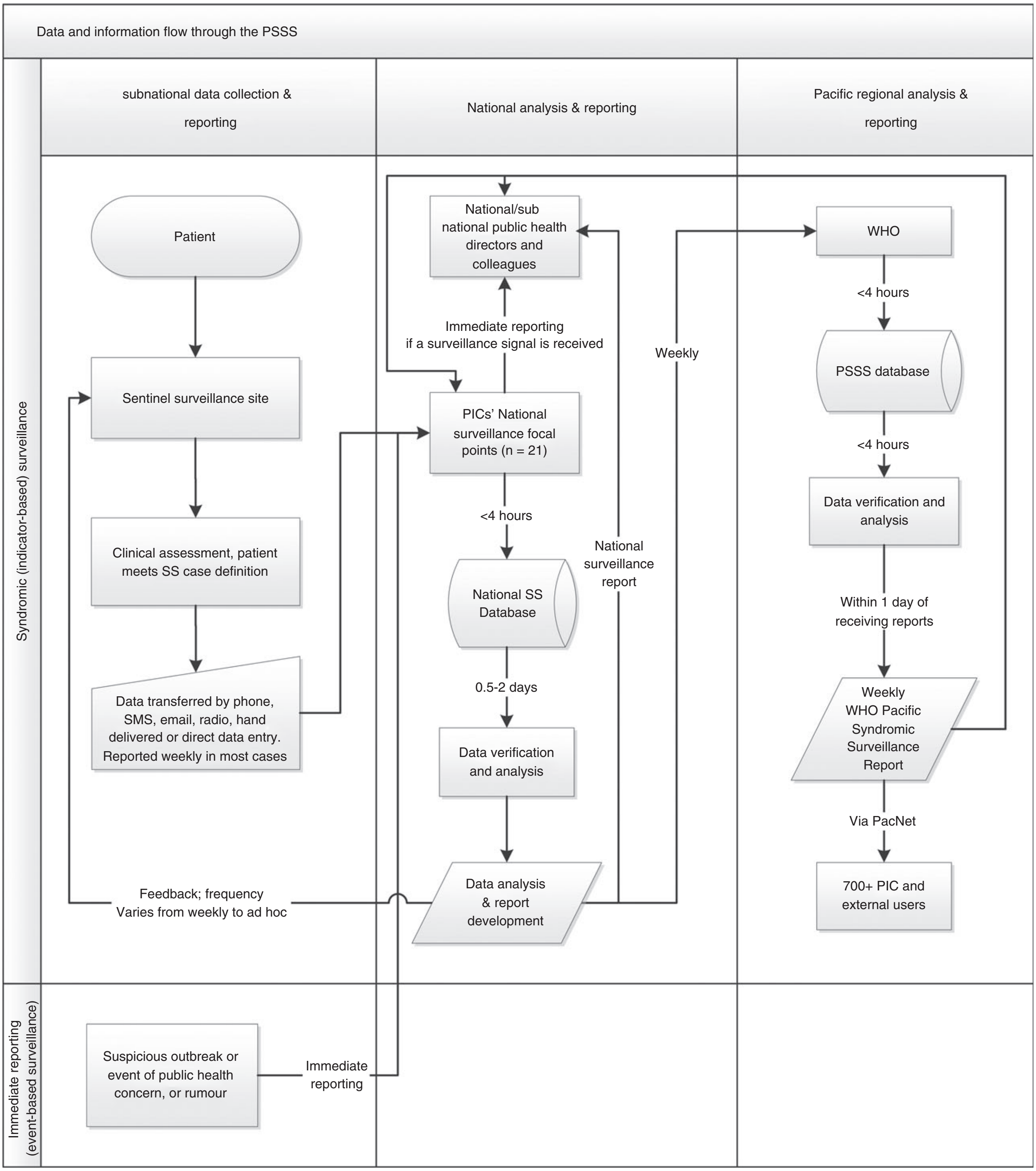
Figure 1 Number of sentinel surveillance sites (LHS) and PICs (LHS) participating in the PSSS and reporting to WHO, by epidemiology week, November 2010–December 2015.

detection, assessment, response and reporting of public health events of potential international concern [11].

The operation of the PSSS, presented in Figure 2, has been described elsewhere [1]. In brief, the PSSS model includes both indicator- and event-based surveillance components. The indicator-based component involves the collection of pre-confirmed diagnosis syndrome-based data about case presentations from 121 sentinel surveillance sites (median = 3; range 1–30 sites per PIC) located across 21 PICs. Surveillance sites (hospitals and community-based clinics) collect and report aggregated data on four core syndromes that are indicator presentations for infectious diseases of concern. Standard case definitions are used. The event-based surveillance component of the PSSS encourages sites to report suspicion of outbreaks to a central authority immediately. Typically, indicator-based surveillance sites' data are reported to a national surveillance coordinator on a weekly basis. Each week national surveillance coordinators transmit aggregated national data to WHO's Division of Pacific Technical Support in Fiji, where Pacific regional analysis is undertaken. WHO produces a weekly surveillance report (http://goo.gl/evAHB3) that is disseminated to a network of 700+ PIC and external stakeholders through the Pacific Public Health Surveillance Network's 'PacNet2' Listserv (http://goo.gl/03cctM) (Figure 2).

System attributes

'Timeliness' refers to the time taken to transmit information between each step of the surveillance system [12, 13]. Under ideal circumstances, a syndromic surveillance system should collect, report and interpret data in near real time; however, due to logistical and capacity constraints, most PICs' systems aimed for weekly reporting to a national coordinator. Those interviewed noted that



SS – syndromic surveillance
PSSS – Pacific Syndromic Surveillance System

Figure 2 Usual steps, data flow and data/information transfer time through the Pacific Syndromic Surveillance System.

in most instances reports were received within the 7-day reporting time frame, however, if a surveillance site was very busy or the officer responsible not available data reporting was often delayed.

Once data are received, they are processed and interpreted quickly (usually within 4 h) and, if required, senior decision-makers are verbally alerted of suspected outbreaks. Nine (82%) national surveillance coordinators interviewed reported producing and disseminating weekly national surveillance reports; one (9%) – from a country with a very small public health workforce (n = 3) – reported providing a verbal report to senior staff on a weekly basis and one (9%) reported not routinely producing a report. The time spent in developing written reports varied from 0.5 to 2 days with the variance related to the amount of follow-up required, access to computers to analyse data, the internal clearance process required to release reports and the degree to which surveillance data collection and handling was systematised. Core syndromic surveillance steps and typical data transfer time frames are presented in Figure 2.

'Data quality' refers to the completeness and validity of data entered into a system. Data quality varies between PICs. Analysis of reporting completeness found that weekly subnational surveillance sites' reporting completeness ranged from 40% to 87.8% (mean 65.8%; IQR = 59.4–73.5%) (Figure 1; Table 1). Reporting of national data to WHO has, however, been consistently high with a mean of 88% (IQR = 81–95.2%) of PICs reporting weekly; 71.5% (IQR = 63.6–83.3%) of reports were received by WHO before the recommended deadline (Figure 1; Table 1). PacNet is an email Listserv that serves as an outbreak alert communication tool between PICs and regional public health agencies.

Analysis of data validity (i.e. data sensitivity and specificity) was not possible due to lack of standard methods for detection and recording outbreak events, or a gold standard comparison against which to assess each national systems' performance.

Data captured are simple weekly case presentation count and variance in number of sentinel sites participating in the system; changes in catchment population size or seasonality are not taken into account, nor are population-based incidence rates routinely calculated.

'Representativeness' refers to the ability of a surveillance system to accurately describe the occurrence of events over time and their distribution in the population by place and person [13]. Across all PICs, there is approximately one sentinel site for every 25 000 people, but the range is large (1:~57 in Pitcairn Island to 1: ~245 500 for New Caledonia). Typically, participating surveillance sites are larger health facilities in urban centres and hence have large catchment populations relative to population size. Table 2 presents the surveillance site coverage by PIC, and Figure 1 presents the increase in the number of sites participating in the PSSS over time.

'Usefulness' refers to the contribution of the system makes to the prevention and control of adverse events, including improved understanding of the implication of such events [13]. All PIC informants interviewed (n = 14) agreed that the PSSS has enhanced their jurisdiction's ability to detect and respond to outbreaks more rapidly. One senior manager commented, 'before we had the PSSS we relied on doctors reporting that something unusual was going on before we knew about it, now we have 'eyes' and 'ears' on the ground'. Another said 'without the PSSS we'd have nothing to go by, we'd only hear about outbreaks when someone bothered to tell us'.

The PSSS provides a mechanism to routinely monitor trends in syndromes over time and to identify deviations from those trends. With several years of syndromic surveillance, data collected algorithm-based alert thresholds have been developed for national data in all PICs and for some sentinel sites. All PIC informants interviewed noted that the establishment of response thresholds has built their ability and confidence to raise an alert when a signal is detected. 'Having a threshold helps us know when to react' a surveillance coordinator commented. One national surveillance officer recalled a time when their national syndromic surveillance system signalled higher than expected case presentations of diarrhoeal disease from a group of sentinel surveillance sites proximity to each other. Subsequently, the signal was investigated confirming an outbreak of acute and severe diarrhoea affecting young children; rotavirus was suspected (and later confirmed by an overseas laboratory) as being the causal pathogen. 'The surveillance system alerted us to the event and meant that we were able to take action faster than if we had of waited until the laboratory or a doctor raised an alarm' the senior public health officer said.

Information generated by one PICs' surveillance system is shared with others through the weekly WHO Pacific Syndromic Surveillance Report distributed by email to >700 PIC surveillance focal points, public health directors and external public health agencies through PPHSN's PacNet Listserv. Distribution of the weekly report has raised situational awareness, stimulated peer dialogue and has frequently initiated public health action. For example, in 2014, the Queensland Department of Health, Australia, was first alerted to an outbreak of Zika virus in New Caledonia after reading the weekly Pacific Syndromic Surveillance Report and subsequently raised awareness among clinicians and laboratories to be on the

Table 1 Interviewees' perception of system performance and system reporting compliance

	PIC users		WHO coordinators		Regional public health agencies	
	Count	Per cent	Count	Per cent	Count	Per cent
Interviewees						
Number of individuals interviewed	14	67%	4	19%	3	14%
Number of PICs interviewees drawn from	10	48%	–		–	
Sentinel site reporting frequency (by PIC)						
Near real time	1	10%	–		–	
Daily	2	20%	–		–	
Weekly	8	80%	–		–	
No. of sentinel sites per population						
Mean	1:25 000					
Range	1:57 (Pitcairn Is) to 1:245 500 (New Caledonia)					
Reporting compliance	PICs reporting to WHO	Reporting within the suggested time frame	Subnational sentinel site reporting			
2015	87%	66%	63%			
2014	88%	68%	70%			
2013	88%	74%	64%			
2012	89%	77%	72%			
2011	88%	76%	61%			
2010 (part year)	96%	52%	59%			
Users' self-reported perspectives of system performance, by evaluation component						
Acceptability						
Good / very good	8	57%	4	100%	3	100%
Acceptable	6	43%	0	0%	0	0%
Poor / very poor	0	0%	0	0%	0	0%
Simplicity						
Good / very good	9	64%	4	100%	3	100%
Acceptable	5	36%	0	0%	0	0%
Poor / very poor	0	0%	0	0%	0	0%
Representativeness						
Good / very good	4	29%	0	0%	0	0%
Acceptable	7	50%	3	75%	2	67%
Poor / very poor	3	21%	1	25%	1	33%
Usefulness						
Good / very good	5	36%	4	100%	3	100%
Acceptable	6	43%	0	0%	0	0%
Poor / very poor	3	21%	0	0%	0	0%
Stability						
Good / very good	1	7%	0	0%	0	0%
Acceptable	9	64%	0	0%	1	33%
Poor / very poor	4	29%	4	100%	1	33%
Adaptability						
Good / very good	4	29%	0	0%	0	0%
Acceptable	5	36%	4	100%	1	33%
Poor / very poor	5	36%	0	0%	0	0%
Portability						
Good / very good	6	43%	2	50%	1	33%
Acceptable	5	36%	2	50%	0	0%
Poor / very poor	3	21%	0	0%	0	0%
Data quality						
Good / very good	3	21%	0	0%	0	0%

Table 1 (*Continued*)

	PIC users		WHO coordinators		Regional public health agencies	
	Count	Per cent	Count	Per cent	Count	Per cent
Acceptable	7	50%	0	0%	2	67%
Poor / very poor	4	29%	4	100%	1	33%

Table 2 Pacific islands' populations (various years) and number of sentinel syndromic surveillance sites per island

PIC	Last population census	Population count at last census	Percentage of all PIC population (%)	Number of sentinel syndromic surveillance sites (%)	Per cent of all surveillance sites participating in the PSSS
American Samoa	2010	55 519	1.9	1	0.8
Cook Islands	2011	14 974	0.50	13	10.7
Federated States of Micronesia	2010	102 843	3.4	4	3.3
Fiji	2007	837 271	28.0	12	9.9
French Polynesia	2012	268 270	9.0	30	24.8
Guam	2010	159 358	5.3	1	0.8
Kiribati	2010	103 058	3.5	14	11.6
Marshall Islands	2011	53 158	1.8	2	1.7
Nauru	2011	10 084	0.3	1	0.8
New Caledonia	2009	245 580	8.2	1	0.8
Niue	2011	1611	0.1	1	0.8
Northern Mariana Islands	2010	53 883	1.8	7	5.8
Palau	2012	17 445	0.6	1	0.8
Pitcairn Island	2012	57	<0.1	1	0.8
Samoa	2011	187 820	6.3	7	5.8
Solomon Islands	2009	515 870	17.3	9	7.4
Tokelau	2011	1205	<0.1	3	2.5
Tonga	2011	103 252	3.5	1	0.8
Tuvalu	2011	10 564	0.4	1	0.8
Vanuatu	2009	234 023	7.8	7	5.8
Wallis and Futuna	2008	13 445	0.5	4	3.3
TOTAL		2 989 290*	100*	121	100

Source: [3].
Note: all estimates refer to de facto population, except the Cook Islands where estimates refer to resident population only.
*Excluding Papua New Guinea and New Zealand. The population of Papua New Guinea was 7.06M (2011) and New Zealand 4.4M (2011).

lookout for disease in recently returned travellers from the Pacific. The warning raised awareness, which resulted in the detection of imported cases of Zika virus from the Pacific to Australia [15]. This information was fed back to PICs' health authorities through PacNet to enhanced region-wide disease transmission intelligence and associated risk assessment activity.

'Acceptability' refers to the willingness of users to contribute to, participate in, and use the system and its outputs [13]. All system users interviewed rated the system's acceptance by intended users as 'good /very good' (n = 15; 71%) or 'acceptable' (n = 6; 29%) (Table 1). All PIC interviewees (n = 14) reported that senior staff trusted the information produced.

The data collection function of the system is now well established and a routine part of surveillance sites' core activities. 'Nurses now see surveillance data collection as just another activity they do as part of their job' a surveillance officer reported. Senior staff with public health decision-making responsibilities report high levels of satisfaction with the system's function, particularly relating to evidence gathering for identification and monitoring of outbreak events. 'The system provides us with something to go on' a senior Ministry of Health official reported. 'When an outbreak happens we can easily ask our sites to report more frequently, like every day, this gives us good information to take to [outbreak response] meetings'.

The high degree of internal (within Ministries of Health) and external (from assistance partners) support for PSSS activities, and the demonstrated use of system-generated data for outbreak response decision-making purposes, were reported as key motivating factors for adoption and ongoing investment by PICs' Ministries of Health. Further, the simplicity (and hence implementability in low-resourced settings) of the surveillance case definitions and having at least one dedicated staff member to manage the day-to-day operation of national systems are factors cited as being critical for system sustainability.

Health officials from countries neighbouring the PICs reported using information generated by the PSSS for a variety of purposes including general awareness, as an input to health risk assessments and for global outbreak reporting and monitoring. Partner health agencies interviewed acknowledged the challenges in conducting early warning disease surveillance in the Pacific setting and reported appreciating the information generated by the PSSS.

'Flexibility' refers to a system's ability to adapt to changing information needs or operating conditions, 'portability' refers to how well a system can be duplicated in another setting, and 'stability' refers to a system's ability to operate when needed [12, 13]. The PSSS's ability to adapt to changing needs or operational environments has been repeatedly tested in the setting of disasters, mass gatherings and disease outbreaks. The Solomon Island's syndromic surveillance system was adapted to an Early Warning Alert and Response System Network after flash flooding in Honiara in 2014 where it successfully identified and monitored a widespread post-disaster diarrhoeal outbreak [16]. The French Polynesian syndromic surveillance system, a system with 30 sentinel sites, was adapted to monitor large dengue, Zika and chikungunya virus outbreaks in 2013–2014 [17, 18]. The Kiribati syndromic surveillance system was enhanced to monitor a large rotavirus outbreak in 2013 and 2014 [19]. With the emergence or re-emergence of multiple epidemic-prone arboviruses circulating in the Pacific [5], many PICs are considering adding dengue-like, chikungunya-like and/or Zika-like illness to their syndromic surveillance systems.

Since late 2011, there has been little expansion of the PSSS (Figure 1). Portability to new sites has proven difficult due to logistical hurdles including lack of reliable communication, inability (due to large distance and infrequent transportation) to support new sites, cost, limited human resources and a focus on ensuring sustainability of foundation sites prior to new site establishment. Opportunity costs associated with efforts to expand national surveillance systems are considered high. Nevertheless, interest and intent to expand the number of surveillance sites participating in national systems was high with 8 (73%) of the national surveillance coordinators interviewed indicating an intention to expand coverage within the next 2 years.

Pacific islander informants indicated that national systems' sustainability is typically reliant on a small number of individuals (usually the national surveillance focal points) and core function elements (data collection, analysis and reporting) are vulnerable to failure if these officers are absent. Highlighting this point, Figure 1 shows that while national reporting to the PSSS is largely consistent, there have been distinct and consistent periods (corresponding with the late December holiday period when staff are likely to be on leave) when reporting rates fall sharply.

Discussion

We report the findings of an evaluation of a 21-country infectious disease outbreak early warning surveillance system, the PSSS, 5 years after the system began operation. The PSSS is the largest integrated early warning surveillance system globally and is critical to PICs' meeting their national and global health protection aims and obligations.

The results of this evaluation indicate that the PSSS provides a functional mechanism through which PICs are able to undertake active early warning indicator-based surveillance of outbreak-prone diseases and to monitor the impact of outbreaks over time. Event-based surveillance is being conducted in all PICs; however, mechanisms are not routinely systematised and reporting often relies on opportunistic processes. Reflecting on performance against the system's objectives, we found the indicator-based component of the PSSS to be simple and – given ongoing support from national leaders, WHO and PPHSN development partners – to be sustainable. The event-based component needs to be strengthened. We were not able to quantify the system's ability to detect unusual cases or clusters of disease due to the lack of a standard (and 'true') measure against which to compare system performance. However, anecdotal evidence (collected through informant interviews) indicates that users believe that the system is effective at identifying 'explosive' events affecting a large number of people in a short time frame but has limited utility for rare or small outbreaks, or outbreaks on remote settings outside of the surveillance system's catchment. This observation, while not novel for syndrome-based early warning surveillance [9, 20, 21], highlights the challenge faced by PICs that are reliant on the indicator-based component of the PSSS of the early detection of public health events. Further, this finding underscores the need to supplement syndrome-based models of early warning surveillance with other surveillance methods, such as systematised event-based surveillance and outbreak-prone disease specific laboratory-based surveillance methods [22, 23], to improve system sensitivity, specificity and timeliness and hence usefulness. Such enhancements will contribute to PICs' efforts to meet the broad 'all-hazards' situational awareness objectives required under the IHR (2005).

To overcome barriers associated with evaluating sensitivity and specificity, others have applied somewhat complex statistical (and often untested) modelling techniques [8]. Modelling techniques, while potentially useful for the PSSS, should not be seen as a prerequisite for future assessment of the system's ability to detect true outbreaks. Defining and consistently applying a definition of what constitutes an 'outbreak'; meticulously recording events that meet this definition; and enhancing the use of appropriate field- or laboratory-based testing to verify clinical diagnosis will yield data with which to evaluate sensitivity and specificity. Such analysis will complement the findings of this evaluation. The evaluation identified several areas where the system could be improved. The operation of the PSSS is simple and highly accepted, valued and used by national authorities and external stakeholders. The utility of the PSSS pertains to the system as a whole in that it serves to not only fulfil core outbreak detection and monitoring functions (as per the stated system's objectives) but also raises the profile, understanding and value placed upon outbreak surveillance activities which in turn encourages user-directed quality improvement. The PSSS encourages collection and sharing of outbreak-related risk information between countries and with development agencies. This practice builds more timely and accurate awareness across the region. Further, the PSSS provides the basic structure for larger post-disaster response surveillance systems, as seen in the Solomon Islands in 2014 after flash flooding in Yap State (FSM) and a tropical cyclones in Vanuatu in 2015 [16, 23]. These, while not explicit objectives of the PSSS, are important contributions to note.

Timeliness of data capture and subnational-to-national level reporting are important and perhaps the attribute of the system most amenable to improvement. Given reporting timeliness is, to a large extent in most settings, due to adherence to procedures that were developed when the system was first established, and the overriding aim was to encourage adoption in sites not familiar with performing surveillance activities, there is opportunity to improve performance without undue cost or delay. Some PICs' syndromic surveillance systems (e.g. the Kiribati and Tuvalu systems that collect and report data on a daily basis) offer useful Pacific examples for how timeliness can be improved, while remaining cognisant that redistributing limited human resources to enhance surveillance activities has potential consequences and needs to be justified.

A surveillance system that is representative is able to observe health events across all populations and geographical areas [24]. Broad participation in the PSSS provides, at the macro level, the opportunity to identify outbreaks across the Pacific; however, given PICs' populations are distributed across many islands and atolls (many without the capacity to participate in routine early warning surveillance activities), there are population pockets that the system is not logistically able to reach. Further, as there is no direct comparative data source for the review of 'missed' cases, there may never be a satisfactory means to assess this factor in this setting.

Core to improving the integrity (and hence utility) of data quality is ensuring that data captured is accurate, reporting stable and analysis meaningful. Paterson *et al.* [7] noted that data quality checks had not yet been implemented in the sites that were assessed; our evaluation found the situation unchanged. To address this, a programme of quality assurance monitoring is suggested. Further, current analysis is PSSS-collected data, which is rudimentary (i.e. simple comparison of case presentation count data over time). An enhancement worth considering is a shift to the collection of sufficient data to allow the calculation (and subsequent analysis and reporting of) population-based case presentation rates, comparable over time and place. Paterson (2012) [7] found that the system's simplicity, high level of internal and external support, clearly defined operator roles and responsibilities, and clear user-friendly surveillance case definitions were key factors in the system's success. Based on our evaluation, these factors remain critical to the ongoing success of the PSSS and should continue to be central considerations as the system evolves. Paterson (2012) reported that, at the time, none of the PIC's interviewed ($n = 11$) had statistical algorithm-derived outbreak alert thresholds in place to trigger response activities. This evaluation found that thresholds are now established in all PICs participating in the PSSS. Informants report that having alert thresholds built into their systems enhanced their ministries' capacity to interpret data and provided a sense of assurance when taking action. High variability in the frequency of subnational reporting in some settings (Figure 1) has the potential to undermine the reliability, and hence usefulness, of threshold-based methods for signal generation.

Paterson (2012) found that the PSSS substantially contributed to improved communication of outbreak-related information within and across PICs' health systems. This finding was again reflected in this study with PICs' demonstrating a willingness to raise alerts, post-outbreak update and share situation reports with others through the weekly Pacific Surveillance Report and on the PacNet Listserv. The regular sharing of surveillance and outbreak-related information is seen as a motivating factor for participation in the PSSS.

Since the PSSS began, other initiatives have commenced that contribute to PSSS strengthening. These include the Australian-funded Response and Analysis for Pacific Infectious Diseases project (a response to the 2012 evaluation), and the delivery of an adapted version of the USCDC-developed 'Data for Decision Making' courses [25] by PPHSN partners. These initiatives build PSSS operators' competence that, in turn, is likely to improve the quality of information being produced by the PSSS. Further, to support early warning outbreak surveillance and response activity of PICs development, partners have produced the practical Pacific Outbreak Manual (http://goo.gl/DpzIIR) [26].

The success of a surveillance system depends on a correct mix of characteristics that balance users' needs with the geo-politico-economic context in which a system is operating. While the evaluation guidelines developed by the USCDC are useful, not all of the suggested criteria are of equal importance, and others (e.g. system sensitivity and specificity) cannot currently be assessed. These limitations, together with an IHR (2005)-driven shift in focus towards and all-hazards situational awareness approach to surveillance [27, 28], highlight a need to reconsider methods for evaluating the performance of early warning systems, particularly those designed and applied in challenging contexts where measures of success are likely to be less quantifiable.

Conclusion

This evaluation has identified attributes of the PSSS that are underperforming and highlighted areas for system development in the future. During the 5 years of operation, the PSSS has achieved a great deal and made a significant contribution to improving public health security in the Pacific and, through its link with WHO and the PPHSN, improved global health information. As the PSSS moves forward, a balance between the system's simplicity and technological advances to improve sensitivity, specificity, coverage and timeliness needs to be found to ensure its long-term sustainability.

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