Aquaculture 277 (2008) 164-173

Contents lists available at ScienceDirect

Aquaculture

journal homepage: www.elsevier.com/locate/aqua-online

An online operational alert system for the early detection of shrimp epidemics at the regional level based on real-time production

Bonny Bayot [a,b,*], Stanislaus Sonnenholzner [a], Xavier Ochoa [c], Johanna Guerrerro [c], Teresa Vera [d], Jorge Calderón [a], Ignacio de Blas [e], María del Pilar Cornejo-Grunauer [f], Sam Stern [a], Frans Ollevier [b]

[a] Fundación CENAIM-ESPOL, P.O. Box 09-01-4519 Guayaquil, Ecuador
[b] Laboratory of Aquatic Ecology, Catholic University of Leuven, Ch. de Bériotstraat 32, B-3000 Leuven, Belgium
[c] Centro de Tecnologías de la Información, Escuela Superior Politécnica del Litoral, Campus Prosperina, edificio Tecnológicas, Ecuador
[d] Centro de Estudios Ambientales, Escuela Superior Politécnica del Litoral, Campus Prosperina, edificio CEMA, Ecuador
[e] Facultad de Veterinaria, Universidad de Zaragoza, c/Miguel Servet 177-50013 Zaragoza, Spain
[f] Facultad de Ingeniería Marítima y Ciencias del Mar, Escuela Superior Politécnica del Litoral, Campus Prosperina, edificio FIMCM, Ecuador

ARTICLE INFO

Article history:
Received 1 February 2007
Received in revised form 17 February 2008
Accepted 22 February 2008

Keywords:
Early detection system
Veterinary disease surveillance
Online alert system
Shrimp epidemics
Ecuador
Aquatic epidemiology

ABSTRACT

Diseases are among the greatest threats affecting the sustainability of shrimp aquaculture. In Ecuador, diseases of cultured shrimp have been quickly transmitted from one region to another. Therefore, an early detection system of impending epidemics could serve as an important management tool for the aquaculture sector. We developed a system for the early detection of shrimp epidemics for the largest shrimp zone of Ecuador based on production surveillance. The system, called Epidemiological Alert System and Aquaculture Management (SAEMA), uses a geographical information system (GIS) with an imaginary grid cartography (12,860 ha per grid) dividing the study area. A production and management index is calculated with the harvest data of each pond. A standardized deviation around the historical averages and an alert level is calculated per grid and month. Normal conditions of production and therefore the absence of disease are depicted in green and yellow. While, orange and red colours express a disease warning manifested through suboptimal production levels. As a result, a map of the study area with grid divisions is displayed, with a specific alert colour for each grid where information is available. SAEMA was developed as a Web application (http://www.saema.espol.edu.ec) that enables producers to record data via a worksheet format using any web browser. Instantaneously, the applications perform a calculation of the alert index and provide feedback to the alert levels displayed in an interactive map. A feedback process was initiated in May 2006 with 19 participating shrimp farms. The objective of this research is to develop a platform for an early detection of shrimp epidemics on a regional scale. The detection of an epidemic, expressed as suboptimal production in a specific region, can provide producers from other zones and government authorities to engage in time preventive and control measures in order to reduce the spread of diseases.

1. Introduction

Spatial distribution of diseases can be studied using geographical information systems (GIS) (Carpenter, 2001), which are computerized systems with geographically referenced information. GIS advantages include the incorporation of layers of geographically referenced information to maps, cluster analysis, modelling disease spread and planning control strategies, among others. While GIS and information systems are widely used in public health and epidemiology (Glass et al., 1995; Clarke et al., 1996, among several other studies), applications have been relatively less common in veterinary epidemiology (Sanson et al., 1991; Yilma and Malone, 1998; Tum et al., 2004). Moreover, very few studies have been directed towards aquatic animal health. Most studies in aquaculture using GIS have mainly focused on site selection in aquatic farming operations (Aguilar-Manjarrez and Ross, 1995; Nath et al., 2000) and studies of relationship between mangroves and farms (Shahid and Pramanik, 1986). Smith (1999) applied GIS to study patterns of production costs and disease problems in Thai shrimp farms. Recently, a shrimp disease monitoring system using GIS in the Philippines has been reported (Lavilla-Pitogo et al., 2006). However, there are no additional reports of systematic surveillance systems in the shrimp industry using GIS. There are even fewer veterinary disease surveillance systems combining Web-based map services and GIS (Gai, 2003; Staubach et al., 2003; Cameron, 2004; Conte et al., 2005).

Over the past 15 years, the *Penaeus* (*Litopenaeus*) *vannamei* shrimp culture industry in Ecuador has been challenged by a number of serious epidemics quickly transmitted from one region to another (Alday de Graindorge and Griffith, 2001). The most recent disease

* Corresponding author. Fundación CENAIM-ESPOL, P. O. Box 09-01-4519 Guayaquil, Ecuador. Tel.: +593 4 2269494; fax: +593 4 2269492.
E-mail address: bbayot@cenaim.espol.edu.ec, bonny-bayot@yahoo.com (B. Bayot).

0044-8486/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.aquaculture.2008.02.035

occurred in 1999 when white spot disease (WSD) was detected in northern Ecuador (Esmeraldas) and subsequently spread to the entire shrimp farming industry (Calderón et al., 1999). The economic impact was huge and production dropped from 160,000 tonnes in 1999 to 40,000 tonnes in 2000 (Hill, 2002).

Infectious diseases propagate in a population through spatial–temporal contagious patterns exhibiting clusters. Based on the contagious nature of infectious diseases, we hypothesize that detection of production drops in farms sharing a similar geographic zone could be a cost-effective control system for detecting the onset of an epidemic on a regional level. The detection of an epidemic, expressed as suboptimal production, in a specific region could provide producers from other zones as well as government authorities to engage in timely preventive and control measures.

We developed an online, automated and interactive alert system, called Epidemiological Alert System and Aquaculture Management (SAEMA) for the detection of an epidemic on a regional level (for the largest shrimp producing zone of Ecuador), based on real-time information of production drops, using GIS and novel technology for information systems. The aim of this paper is to describe the structure and contents of SAEMA and to present preliminary results. This is the first report for an automated disease outbreak detection system based on production data for shrimp epidemics at a regional level.

2. Materials and methods

2.1. Study area

The Gulf of Guayaquil (Ecuador), located on the Pacific coast, between latitudes 2°13′S and 4°07′S (Fig. 1), is the largest estuary on the western coast of South America (Cucalón, 1996). SAEMA was developed for Ecuadorian shrimp farms in these zones. The total area of shrimp farms in the region is about 140,000 ha, representing 83% of the Ecuadorian production area.

The climate is tropical and subtropical with two climatic seasons. The wet/warm and dry/cold seasons occur from January to May and from June to December, respectively (Cucalón, 1996). The climatic pattern governs shrimp production, with the highest levels reported during the wet/warm season (Regueira, 2001). Shrimp production also shows variability in space with some zones presenting higher levels than others (Regueira, 2001).

The study area was divided into imaginary rectangular grids, covering approximately 12,860 ha, overlapping with the cartographic grid of the Ecuadorian National Chart (scale 1:25,000; IGM, 1999).

2.2. General methodology

There were three chronological steps involved in the SAEMA development (Fig. 2). In the first step, the tools to identify the alert levels were created. In step 2, the SAEMA platform was implemented building a desktop based GIS that was converted into an online GIS. The Web application enables producers to record data via a defined worksheet format to the SAEMA website using a web browser. The SAEMA website automatically calculates the alert index and provides feedback for the alert levels. Finally, in step 3, the SAEMA feedback at real time was started on May 2006 with data from shrimp farms of the study area.

2.3. Step 1: development of the alert index and alert levels

2.3.1. Alert index

Production and management data were collected from ponds of fifteen large shrimp (*P. vannamei*) farms from the study area for the period 1996–2002. The objective was to build a production variable indicative of farm/pond performance that could be used as an alert variable for the detection of suboptimal production. In order to standardize the information of production among ponds with different management, an index composed of production and management variables was elaborated in the framework of this study (Sonnenholzner et al., 2004). The index, called Production and Management Index (IPM) (Eq. (1)) contains two terms: (1) a standardization of the production, dividing the yield by the stocking density and (2) the shrimp growth rate during the production cycle. The final units were g^2 shrimp^{-1} day^{-1}.

$$\mathrm{IPM} = \left[\frac{\text{Production}}{\text{Pond area}} \times \left(\frac{\text{Number of stocked shrimp}}{\text{Pond area}}\right)^{-1}\right] \times \left[\frac{\text{shrimp weight at harvest}}{\text{duration of the production cycle}}\right]. \quad (1)$$

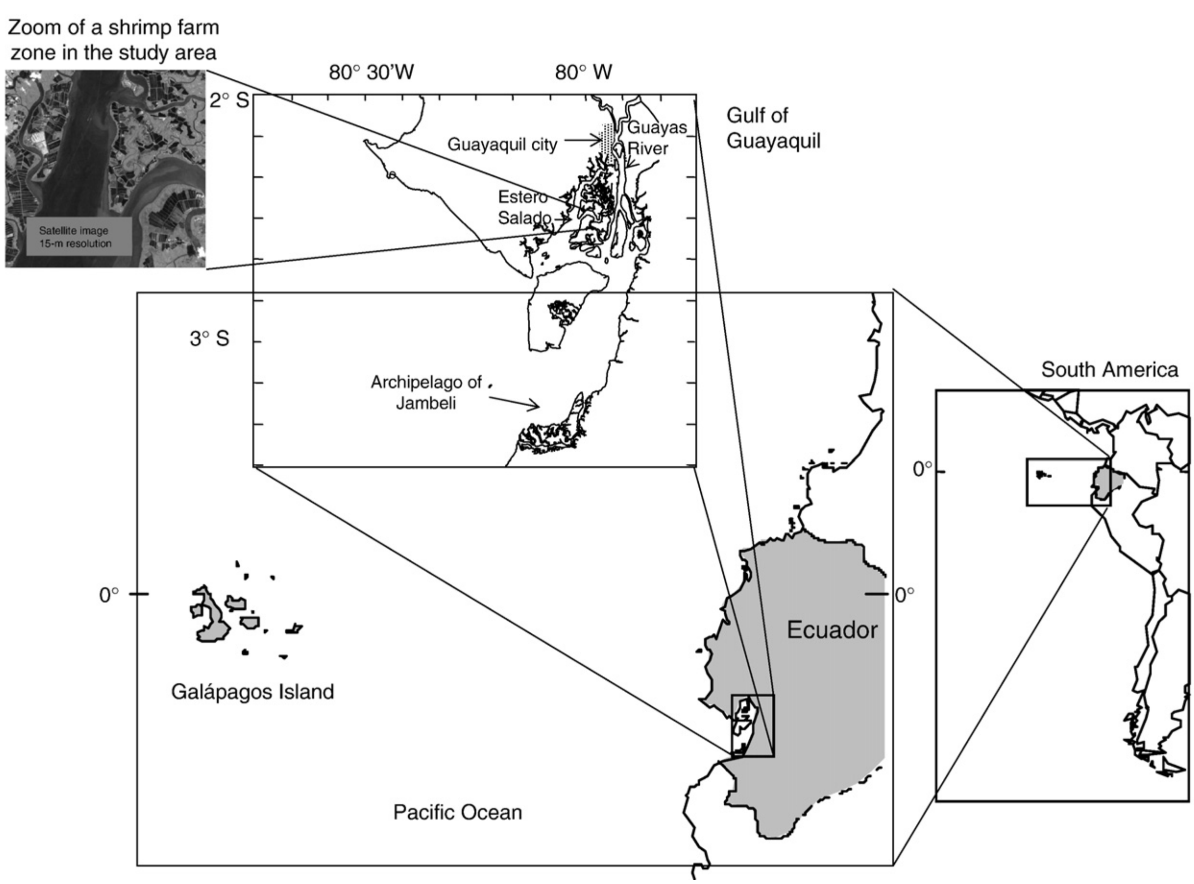


Fig. 1. Study area: shrimp farms located in the Gulf of Guayaquil (Ecuador).

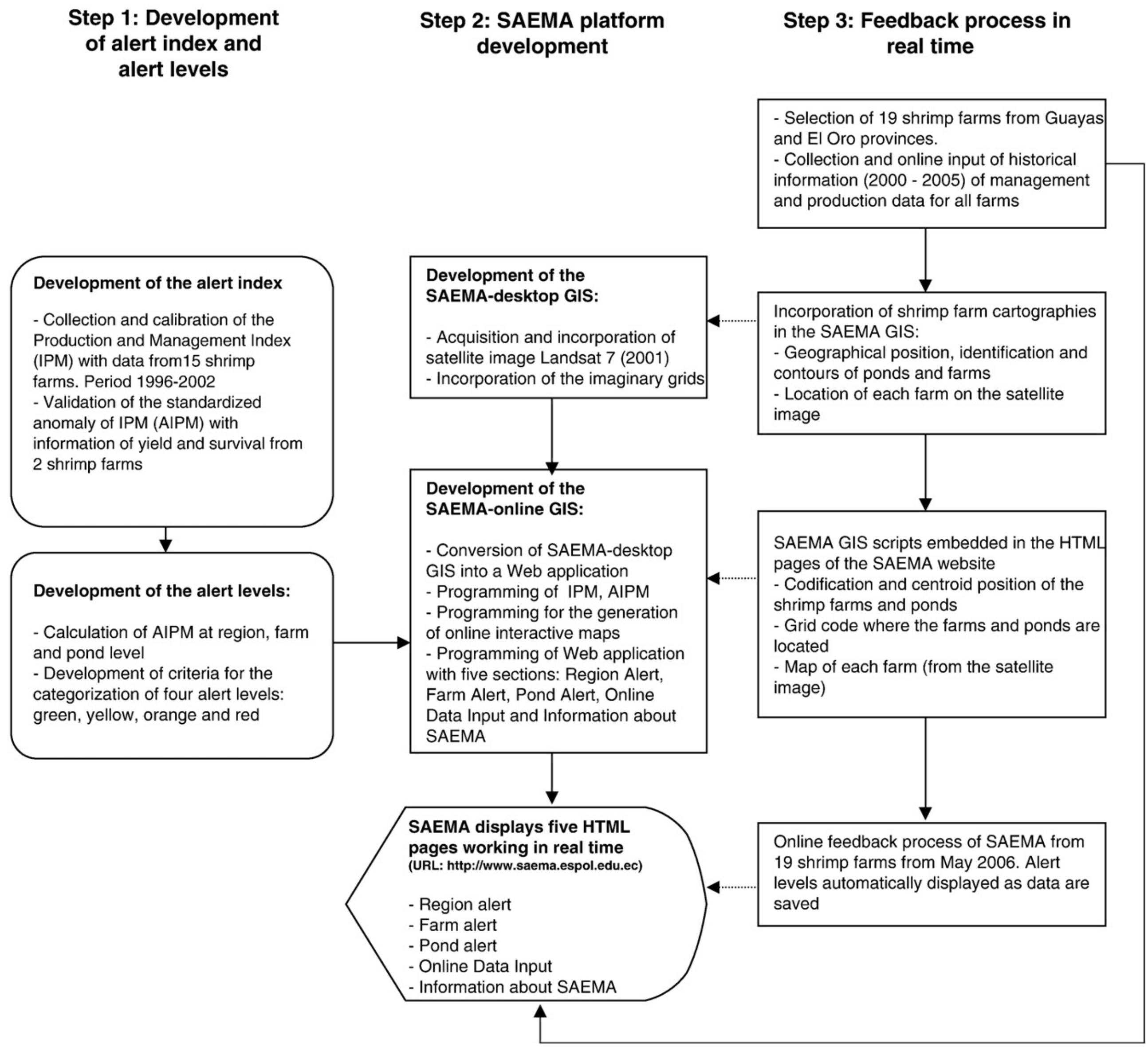


Fig. 2. Schematic diagram of the steps involved in the SAEMA development.

In the validation phase a normalization was done through calculation of the standardized anomaly (standardized deviations from the normal values) of IPM (AIPM). For each farm, historical averages and standardized deviation of IPM for each month (12 historical averages and 12 standardized deviations) were calculated. In this phase, AIPM was validated with the standardized survival for two (Farms A and B) of the fifteen shrimp farms in order to verify whether the index could be linked to disease problems in ponds and farms. Such validation was performed through a distributed lag analysis between monthly time series of AIPM (independent variable) and standardized survival (dependent variable) looking for significant cross correlations between both time series at different month lags. The statistical analyses were performed using Statistica 6.0 (1994–2001, StatSoft, Oklahoma, USA). AIPM was used as the SAEMA alert index.

2.3.2. Alert levels

In order to compare the production levels at different scales, namely at regional, farm and pond level, appropriate AIPMs were calculated. For the alert at regional level, AIPM was calculated for each grid and month using Eq. (2). For the alert at the farm level, AIPM was calculated for each farm and month similar to (2) but grid values were replaced by farm values. For the alert at pond level AIPM was calculated using Eq. (2) and replacing grid and month values by pond and production cycle, respectively. Also, at that level, month in the $\overline{\overline{\mathrm{IPM}}}_{\mathrm{historical}}$ and $S_{\mathrm{IPM\ historical}}$ terms of Eq. (2) were replaced by season. In this way, each grid or farm had one historical average for each month (IPM). At pond level, only two historical averages of IPM were obtained for each pond: wet/warm and dry/cold season (for ponds harvested between January to May and June to December, respectively). The historical period covered the years 2000–2005 for all cases.

$$\mathrm{AIPM}_{\mathrm{grid,\ month}} = \frac{\overline{\mathrm{IPM}}_{\mathrm{grid,\ month}} - \overline{\overline{\mathrm{IPM}}}_{\mathrm{historical\ (grid,\ month)}}}{S_{\mathrm{IPM\ historical\ (grid,\ month)}}}. \tag{2}$$

Where,

$\mathrm{AIPM}_{\mathrm{grid,month}}$ = standardized anomaly of IPM for a particular grid and for the current month

$\overline{\mathrm{IPM}}_{\mathrm{grid,\ month}}$ = average of IPM for all ponds harvested in the same grid during the current month

$\overline{\overline{\mathrm{IPM}}}_{\mathrm{historical\ (grid,\ month)}}$ = average of IPM for all ponds harvested in the same grid and month during the historical period

$S_{\mathrm{IPM\ historical\ (grid,\ month)}}$ = standard deviation of IPM for all ponds harvested in a same grid and month during the historical period.

AIPMs were used to categorize the alert levels. The mathematical criteria for their categorization were based on: (1) the sign and value of the AIPM for a particular point in time (AIPM_t) and (2) the sign and absolute value of the difference between AIPM_t and its previous value (AIPM_{t-1}). Four alert levels were delineated, which were identified with colours (green, yellow, orange and red) using the criteria showed in Table 1.

Table 1
Alert levels and mathematical criteria for their categorization

Alert level	Mathematical criterion for the categorization			Interpretation in terms of production
	Sign and value of $AIPM_t$	Slope sign ($AIPM_t - AIPM_{t-1}$)	Absolute value of the slope $\lvert AIPM_t - AIPM_{t-1} \rvert$	
Green**	$AIPM_t \geq 0$	*	*	Production above the historical averages
Yellow	$AIPM_t \geq 0$	<0	≥0.25	Production above the historical averages with (strong) decreasing trend
Orange	$-0.5 < AIPM_t < 0$	*	*	Production below the historical averages. Standard deviation up to 0.5
Red	$AIPM_t \leq -0.5$	*	*	Production far below the historical averages. Standard deviation higher than 0.5

Alert interpretation in terms of production.
*: criterion not applied.
**: The alert colour is green if $AIPM_t \geq 0$ and if both two other criteria of the alert level yellow are not fulfilled.

2.4. Step 2: development of the SAEMA platform

2.4.1. Development of the SAEMA-desktop GIS

The SAEMA geographical information system (SAEMA-GIS) contains a Landsat 7 (2001) satellite image (15-meter resolution), with ponds as the smallest unit of the geographical database. The satellite image and cartographic grid were integrated into a desktop geographical database of the SAEMA-GIS using MapInfo 5.0 (MapInfo Corporation, Troy, NY, USA).

2.4.2. Development of the SAEMA-online GIS

A Web application was developed using open source tools: i) UMN MapServer, was used for converting vector maps into images, ii) PostGIS, was used to store geographical information, iii) JavaServer pages (JSP) served as programming platform and iv) Apache Tomcat as a Web Server. The Web application is available at a website (URL: http://www.saema.espol.edu.ec) with three main sections containing each of the alerts at the regional, farm and pond level. For the alert at the regional level, the geographical information of the SAEMA-GIS is embedded in an interactive map into the web page. The map includes the satellite image of the Gulf of Guayaquil and the grids are coloured according to the alert level. For the alert at farm level, the map with the contour of the farm is placed on the page, while for the alert at pond level the map with the contours of the previous farm and also its ponds is presented. The first three sections are connected to a fourth section, called *Online Data Input*. The Web application allows online data input from any personal computer with access to Internet. Data are sent online and saved in the PostGIS database. The application links the data according to the codes and respective section, calculates the equations and updates the alert levels for each section. The system uses Spanish as the communication language.

JSP programming for the calculations of IPMs and AIPMs variables was done according to Eqs. (1) and (2) using the data contained in the PostGIS database and presented in the respective section.

The interactive maps of the first three sections present the alert level with colours limited by grid, farm and pond contours using the criteria explained in Table 1. The Web application allows for automatic interactive changes as data are obtained from the producers.

2.5. Step 3: SAEMA feedback process with real-time data from shrimp farms

2.5.1. Collection of historical data from shrimp farms

In May 2006, information of production and management of 19 shrimp farms from the study area was collected from 2000 until April 2006. According to the programming described above, the system recognizes as historical data only information from the 2000–2005 period. Data editing, reviewing of consistency, outliers, and validity of the data were performed for each pond.

2.5.2. Incorporation of shrimp farm cartographies to the SAEMA-desktop GIS and conversion to the SAEMA-online GIS

The cartography (geographical position of the farm contour and ponds, and codes for the farm and ponds) of each farm was collected. Each farm was located on the satellite image, already installed in the SAEMA-desktop GIS. A map of each shrimp farm (obtained by the satellite image) with the farm and pond contours was created and grid codes where the farm and ponds are located were determined. The cartography was also incorporated onto the SAEMA-desktop GIS and then was embedded in the maps of the first three sections of the Web application, according to the programming described in item *Development of the SAEMA-online GIS*.

2.5.3. Feedback process of SAEMA at real time

From May to July 2006, an online SAEMA feedback process in real time with data from 19 shrimp farms was performed. They recorded monthly harvest data via a worksheet file through the third section *Online Data Input* using a web browser, a username and a password. Data were automatically recorded at the SAEMA database.

3. Results

3.1. Alert index

AIPM drops presented a 2-month forward warning concerning reduction in survival (strongest significant cross correlation at 2-month lag, $r=0.70$, $t=4.06$, $P<0.0001$). In order to smooth the data and observe a periodic trend a 3-month moving average of the AIPM, the yield and survival for farm A was performed (data of farm B are not shown) (Fig. 3). The trend was stronger at the end of 1998 and early 1999, the months prior to the onset of the WSD epidemic (Fig. 3). These results suggest that AIPM could be used as an indicator of the health status at the farm level. In addition, the range for the historical period was chosen from 2000 to 2005 to discard the period prior to the WSD epidemic (before 1999).

3.2. SAEMA feedback process at real time

From May to July 2006, 19 farmers sent their data online from their personal computers to the SAEMA server. The alerts at regional, farm and pond level were automatically updated as data were entered. The nineteen farms were distributed on fifteen grids. Not all fifteen grids were activated at the same time due to the fact that the

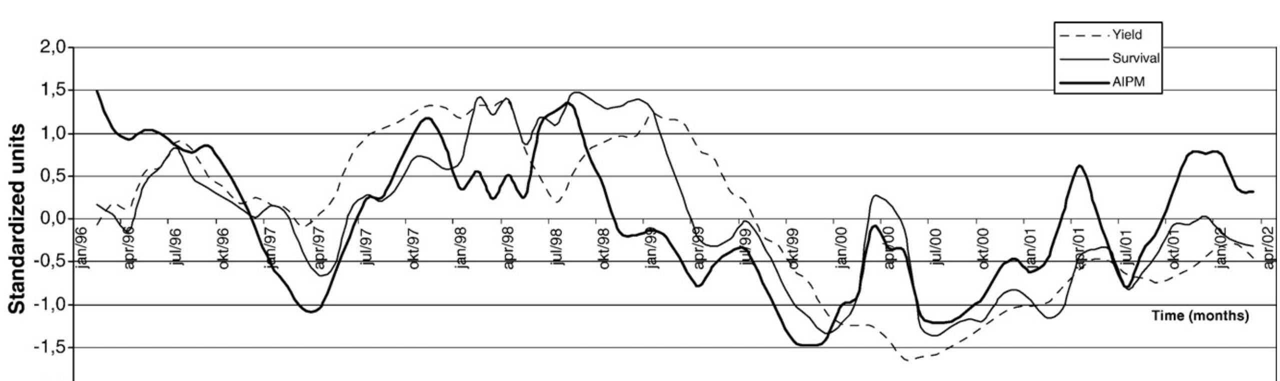


Fig. 3. Time series (3-month moving average) of yield (kg ha^{-1}), survival (%) and AIPM (g^2 $shrimp^{-1}$ day^{-1}) for farm A during 1996 to 2002. All three variables are standardized.

alert levels are updated when the producers enter their data in the system. When the producers began with the SAEMA feedback process, the system was placed in a URL address. From May to July 2006, 1137 hits were registered.

3.3. Regional, farm and pond alerts

Fig. 4 presents, as an example, the alert at the regional level for the Gulf of Guayaquil from April 2006. The figure shows 14 grids with information of IPM, with two grids showing a red alert level and the remaining green and yellow alerts. For May 2006 (figure not shown) one of the red grids changed to green and grids with red colour were therefore no longer observed, although four new orange grids were reported. In June and July 2006 (figure not shown), almost all grids showed production levels above the historical levels with green and yellow grids indicating a recovery of the production level status.

Time series of AIPM and alert levels for a 1-year cycle can be consulted for each grid by clicking on the grid of interest. The time series of AIPM for grid No. 178 Puerto Bolívar, located in the study area, showed in April and May 2006 a decreasing trend of production levels below the historical averages (Fig. 5). Such a trend was also observed for some zones of the Gulf of Guayaquil. Thus, an orange alert was displayed in May 2006 and a recovery was reported in June 2006. For the case of Fig. 5, a decrease of production was observed in April and May 2006 with a recovery for June 2006. Also in this figure, the alert level for each month, the number of ponds used to calculate the IPM average for each month ($\overline{IPM}_{grid,\ month}$) and the number of ponds used to calculate the monthly historical average of IPM ($\overline{IPM}_{historical\ grid,\ month}$) are displayed.

The alert output at the farm level is shown for one of the nineteen farms for April 2006 (Fig. 6). The farm area is filled with one of the four possible alert colours, according to the criteria described in the section material and methods. In addition, as in Fig. 5, by clicking on the farm map, time-series graphs for the 1-year AIPM and a table with the monthly alert levels for a 1-year cycle, the number of ponds used to calculate the IPM average for each month ($\overline{IPM}_{farm,\ month}$) and the monthly historical averages ($\overline{IPM}_{historical\ (farm,\ month)}$) are generated at the farm level.

The output for the pond alert follows the same scheme as presented for the previous alert scales (Fig. 7). A click on the pond of interest opens the time-series graphs for 1-year AIPM and a table with the monthly alert level for the 1-year cycle, the

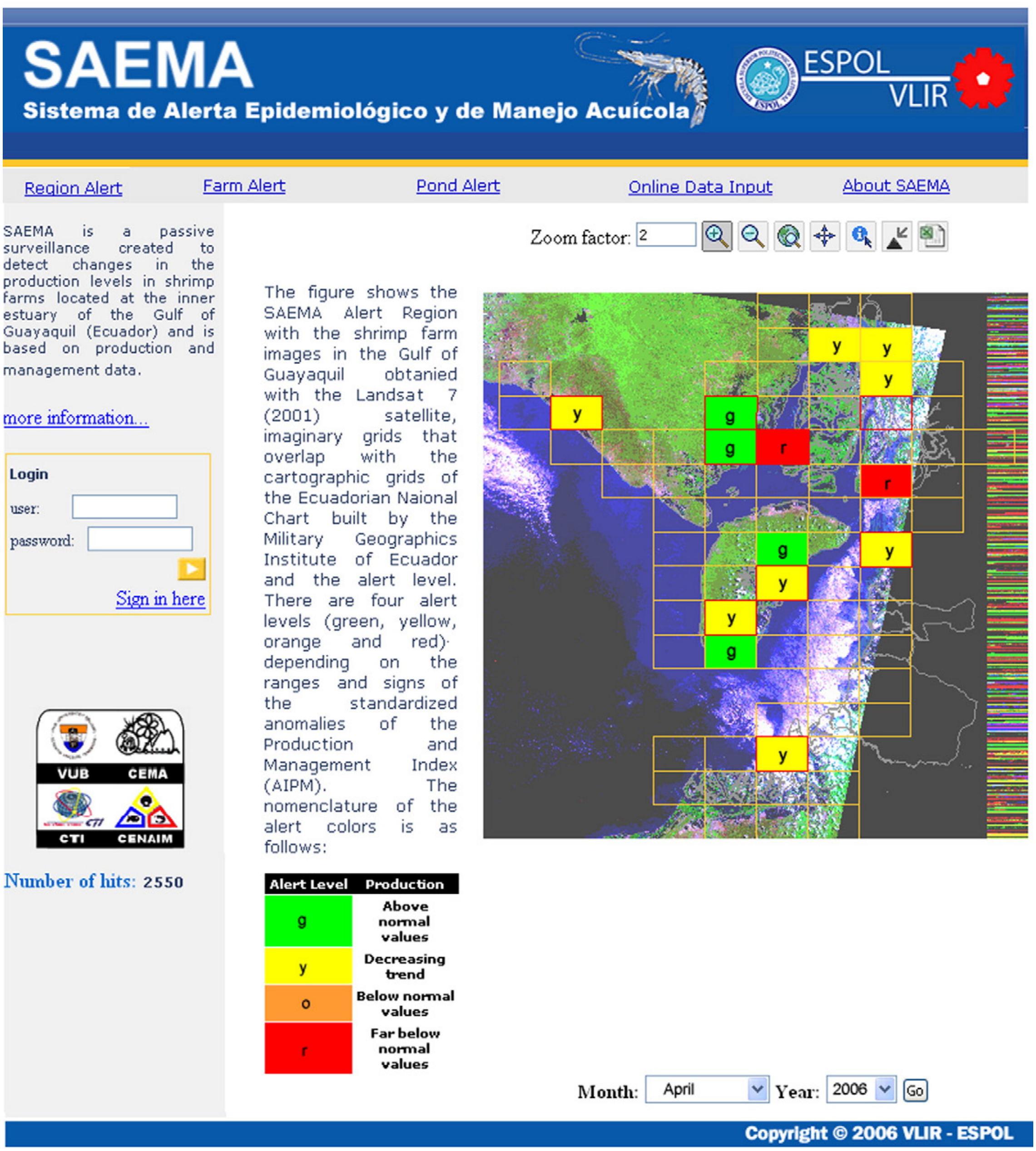
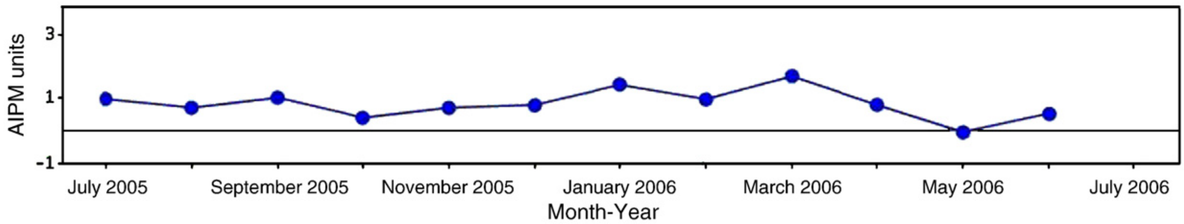


Fig. 4. Epidemiological alert at regional level for the Gulf of Guayaquil at April 2006. The figure contents have been translated into English for this article. Alert colour: g: green, y: yellow, o: orange and r: red. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)



AIPM Date	n	Historical period n	Alert colour
July 2005	11	56	g
August 2005	11	53	y
September 2005	13	38	g
October 2005	7	40	y
November 2005	12	52	g
December 2005	8	47	g
January 2006	18	50	g
February 2006	7	45	y
March 2006	16	52	g
April 2006	14	52	y
May 2006	5	47	o
June 2006	10	40	g
July 2006	-	0	

Fig. 5. Time series of AIPM and alert levels from July 2005 to July 2006 for grid No. 178 Puerto Bolívar, located in the study area. Historical period is from 2000 to 2005. Alert colour: g: green, y: yellow, o: orange and r: red. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

number of ponds used to calculate the IPM average for each month and the monthly historical average. The user can also “zoom” into a pond group or into a farm zone of interest to consult more details.

4. Discussion

A disease has a risk of introduction and likelihood of becoming established in a country. Such risk can be split into two components: “the hazard” is the likelihood of pathogen occurrence, and “the vulnerability” of the exposed elements being the likelihood of internal risk as consequence of their intrinsic predisposition to be affected. In Ecuador, as in other shrimp producing countries, the hazard risk of introduction is high, mainly as a result of the movement of infected live animals. Highly contagious diseases of significant economic importance have been propagated between hemispheres. Although, the government of Ecuador is increasing its control and implementing restrictions on movement of live animals and products, the risk continues to be high. Moreover, the vulnerability of the Ecuadorian aquatic production systems is high considering that *P. vannamei* is highly susceptible to infectious pathogens at low water temperatures (Vidal et al., 2001; Rodríguez et al., 2003). In addition, evidence relates cold climatic events such as La Niña with production losses and diseases (Bayot and Chavarría, 2004). After each La Niña event, a shrimp epidemic appeared in the Ecuadorian aquatic production systems. The last La Niña event occurred in 1999 and months later WSD was reported in Ecuador (Calderón et al., 1999).

There is no formal study of risk analysis for shrimp diseases in Ecuador, but we are convinced that the risk of a new epidemic continues to be high, as both risk components (hazard and vulnerability) are high. At the moment there are indications that new diseases infecting cultured shrimp being detected on the South American continent. Venezuela has been struck with a variant of the Taura syndrome virus (TSV) (OIE, 2005). In Brazil, a new viral disease, infectious myonecrosis virus (IMNV), is generating major losses (Lightner et al., 2004). Recently, *Penaeus vannamei* nodavirus has been reported in Belize (Tang et al., 2007). Therefore, the possibility of a quick spread of a disease in Ecuador, as was the case with WSD, needs to be taken into account (Calderón et al., 1999; Rodríguez et al., 2003). In the livestock sector, early detection of diseases is the most important factor to handle animal disease epidemics. If a disease is detected early in its development, there is a possibility to eliminate it before inflicting major damage (Paskin, 1999). This is equally applicable in shrimp aquaculture. An early detection can create an important advantage by creating physical or management related barriers. Consequently, it is critical that each tool providing an early warning is implemented to provide an additional layer of “protection” for shrimp producers.

The perceived risk for new shrimp epidemics has increased the interest in surveillance systems for the early detection of diseases. The word “surveillance” is commonly used interchangeably with “monitoring”. It is nevertheless important to differentiate between them. Surveillance is a mechanism applied to collect and interpret data on the health status of animal populations, with the aim of early detection and control of animal diseases of economic importance (Paskin, 1999; Salman et al., 2003; Subasinghe et al., 2004). Monitoring follows when surveillance indicates an early detection of disease and it is part of an early reaction after detection. Monitoring is related to the activities, which quantify changes in prevalence of a specific disease and determines the rate and direction of its spread (Paskin, 1999; Salman et al., 2003).

In accordance to the above definitions SAEMA falls in the surveillance category. Surveillance systems are extensively used in animal populations (Salman et al., 2003; Gibbens et al., 2003). However, we identified just one report of the systematic application of such a system in the shrimp industry at the regional or national level, namely in the Asia-Pacific region (NACA/FAO, 2006). Our system covers a specific region of Ecuador, while the surveillance system of NACA/FAO covers a wider region of several countries. Our system also differentiates from the NACA/FAO system in that the surveillance of production levels is used as indicator of health problems. Several reasons can be suggested to explain the scarcity of surveillance systems. They require among other items costly investments for veterinary service networks, sample analysis by certified reference laboratories, a legal framework, complex sampling systems (sample design, sampling and data analysis), and organized information channels and information analysis. The SAEMA platform functions as the first phase for the early detection of epidemics and may establish criteria to start into a second phase of early response.

In spite of the fact that SAEMA is not a traditional surveillance system, it fulfils a number of criteria: usefulness, simplicity for the

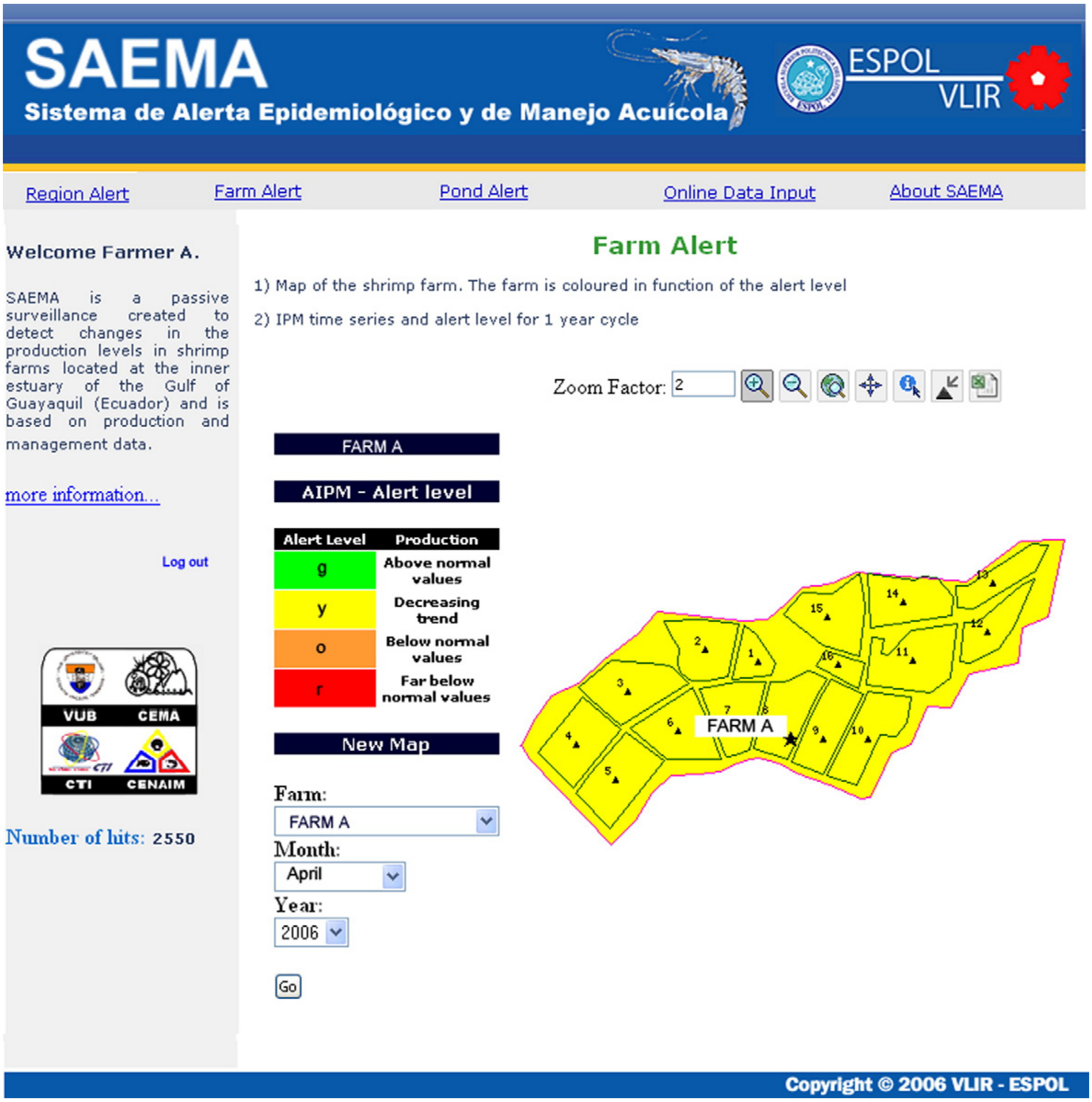


Fig. 6. Alert at the farm level for April 2006. Representation for farm A, located in the Gulf of Guayaquil. Farm A exhibits a yellow alert for that month. *: farm centroid. Alert colour: g: green, y: yellow, o: orange and r: red. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

operational phase, flexibility, quality of data, acceptability and timeliness (Table 2). While, this surveillance system has only been operational for a short time period, it will be necessary to evaluate the system over a longer period in order to determine sensitivity and predictive values. This aspect is also related with the inclusion of a high number of participants in the system. Even though the inclusion of all producers as members of the network could be a difficult task, nevertheless, the number of those wishing to participate is growing. With time, the system will also grow in popularity to the extent that those participating in the system will achieve a higher degree of proficiency as users. Another important consideration, for the present and near future, the service is being provided at no cost. This will hopefully facilitate the recruitment of new users to the network. For the present, the system is focused on providing the service in the most densely populated areas in terms of shrimp farms and hectares. The next task will be to implement the system on a national grid expanding it to include other regions of the country (north). Consequently, as an epidemiological tool the system can work, albeit at a limited scale, in the early stages operating on a regional or provincial basis, with the intention over time, to go beyond the regional as well as national borders by including Peru and Colombia.

Suboptimal production can be provoked by environmental problems, diseases or by inadequate management. If SAEMA is used by many producers the regional alert will dilute the effect produced by suboptimal production because of poor management practices. Our efforts are currently focused on covering as many grids as possible. In this process, we have the ability to select, if necessary, producers with a higher degree of operational sophistication. Notwithstanding this logical preference, we are selecting representative operations with lower levels of expertise. In these instances we provide tutorials and support so that these operations comply with the standard data collection necessary for the data base. The measures that a farm may take to mitigate the causes affecting its grid colour are dependent on the prevailing circumstances; is the problem located only in one grid or do we see that there is a tendency of other grids reflecting similar changes in colour. One may be the result of locally related circumstances of management and seed stock quality etc.; while the later may reflect a potential problem which needs to be attended to by all parties in the grid area or beyond. In this case special measures may be called upon such as, destocking, quarantine, biosecurity, etc.

For example, in April and May 2006, SAEMA reported orange and red alerts at the grid level. This result does not necessarily mean that

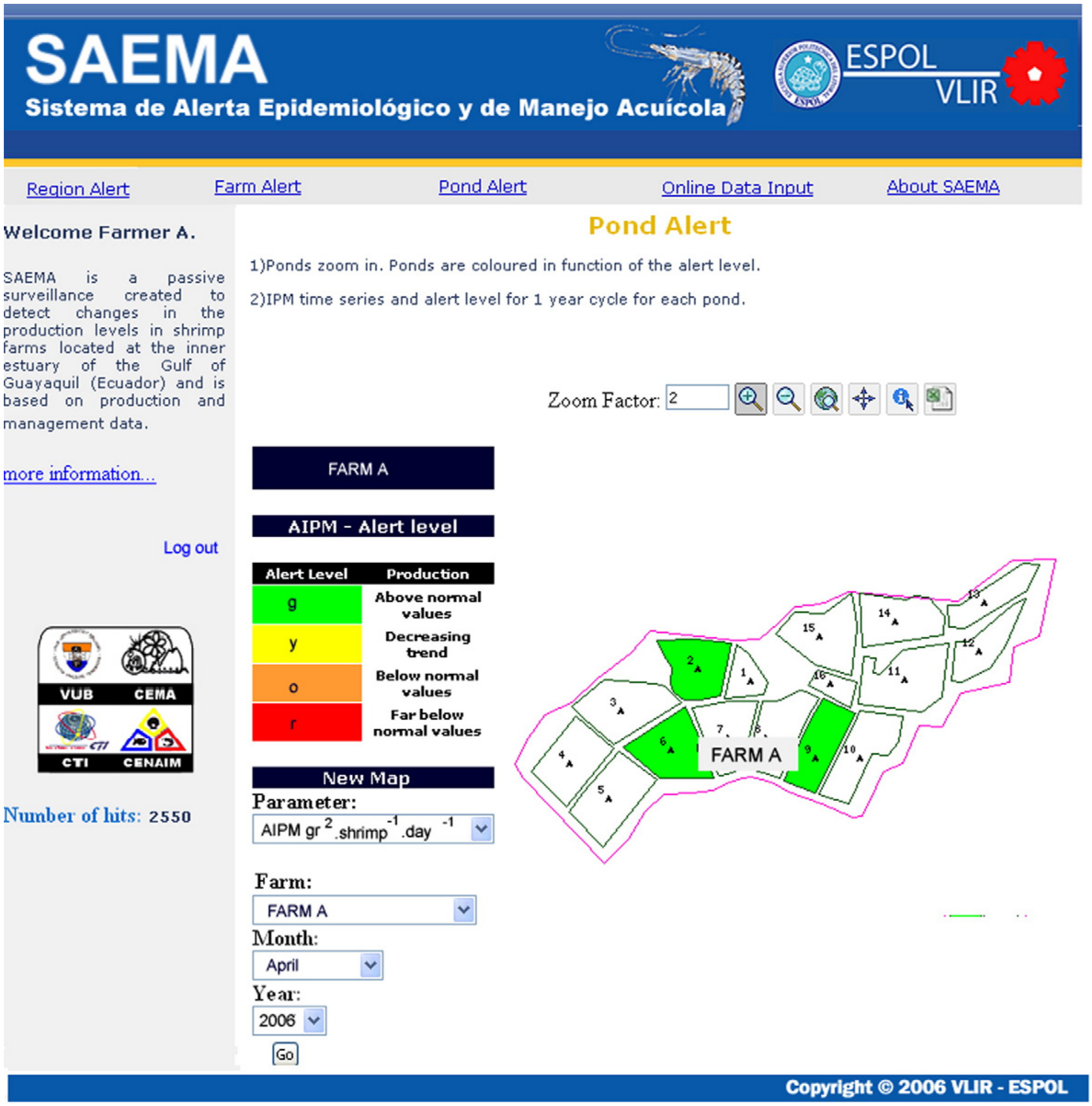


Fig. 7. Pond alert for farm A during April 2006. Farm A exhibits three ponds with green alert for that month. Alert colour: g: green, y: yellow, o: orange and r: red (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).

an epidemic started in these grids, as these colours were the result of AIPM averages of only 1 or 2 farms per grid. Such a small numbers of farms are explained by the fact that the system became operational at "real time" only three months previous. Several owners from farms located in these grids areas provided us with sanitary information. Most of those problems were generated by WSD and coincided with the transition from the wet/warm to the dry/cold season. Coincidently, other producers from these affected zones reported more disease problems compared to 2005. However, a recovery was observed from July to August 2006 (data of August not shown) as green and yellow colours were reported in all grids.

AIPM (per month and per grid) and the alert levels, as described in this article, are the result of temporal and spatial analysis of data from farms and can be used during early detection phases of diseases. If a disease outbreak or an epidemic is confirmed during the early reaction phase, SAEMA can be the operational framework for an overview of disease clustering in space and time. SAEMA was designed as an online alert system for the detection of shrimp diseases but has potential to be applied for other species. The SAEMA platform can be used among others for: geographical correlation studies in an epidmic; risk point studies; selecting grid parcels with problems; and locating farms with lowest AIPM. As research is still in progress, the next steps will be to: (1) further refine the calibrations of the criteria for each alert level (especially the orange and red alerts); (2) establish criteria for early reactions and (3) elaborate preparedness and action plans using the SAEMA as the operational framework.

SAEMA is one component of a Contingency Plan against shrimp diseases which consists of a Preparedness Plan and an Action Plan. In such a framework, SAEMA is the tool proposed by Academia for detecting the onset of an epidemic, with producer participation as a key component of the network. The Contingency Plan considers the statutory authorities participation as the competent authority for the control and execution of sanitary actions. The industry in Ecuador operates within the context of a tripartite of authorities of which Academia plays an important advisory role linking itself with the Aquaculture Chamber of Commerce as the industry representative and finally the Subsecretariat of Aquaculture in representation of the Government. Thus, decisions are not unilateral but multilateral which should reduce friction among potential interest groups. This issue is potentially sensitive and admittedly will take time and coo-peration, however we do believe that it is feasible once having

Table 2
Evaluation of the performance of the SAEMA system using the criteria (taken from Salman et al., 2003) for assessing a surveillance system

Criterion	
Usefulness	The beneficiaries are all linked to the shrimp industry. It concerns mainly: (1) The shrimp industry itself, since a detection of an epidemic focus in a determined region, expressed as suboptimal production, could help to prevent its spreading, and eventually, gain interest from policy makers. Additionally, the system could act as a framework for preparedness and action plans to counteract shrimp diseases, (2) Producers, in supporting management decisions, (3) Research organizations: the system could serve as a platform for future epidemiological research studies (e.g. disease mapping, geographical correlation studies in an epidemic, risk point studies) and (4) Statutory authorities: SAEMA is one component of a Contingency Plan against shrimp diseases which contains a Preparedness Plan and an Action Plan. The Contingency Plan considers the statutory authorities participation as competent authority for the control and execution of sanitary actions for rapid detection.
Simplicity	The rather complex system needed to develop SAEMA has been created in order to simplify the operational phase. The SAEMA feedback is performed by the producer through online input of harvest data. The geographical position of the farms can be done, inclusive direct viewing on the GIS map, without GPS positioning.
Flexibility	Once the system has been installed on the Internet website it needs: one part-time operator for the inter-phase GIS-Web, one part-time operator for the GIS, one assistant for the visits and coordination with the farmers and one general coordinator between the disciplines. Funds needed for the operation of SAEMA are not high and can be shared by the participating farms.
Quality of data	The data fed into the SAEMA system are the same as those used by the producers in their daily management. Therefore, the risk to deal with bad data quality is low. The system presents restrictions (an online error message is displayed) if data entered are not logical (e.g. survival must be lower than 100%, duration of the production cycle cannot be negative, etc.). AIPM per grid dilutes wrong data, or extreme low values of a farm (provoked by inadequate management).
Acceptability	Private sector participation has been essential for the SAEMA development. Participants have expressed their satisfaction with the system. From May to July 2006 a counter installed on the website registered 1137 hits, which confirms that the system is been used by the producers. Producers feel safe to enter their data because the confidentiality level of their information is high (without a password there is no access to specific farm or pond information).
Sensitivity and positive predictive value	The system has run at real time only for three months (from May to July 2006). Sensitivity, specificity and predictive values cannot be calculated at the moment. If needed the mathematical criteria for the categorization of the alert levels can be changed during the operational phase through a re-calibration process. This applies especially for the cut offs of the orange and red levels.
Representativeness	As part of a Pilot Plan, producers from 19 farms of the study area have entered data to the alert system from May to July 2006. In implementing an early warning system at a national scale, the current SAEMA template could serve as the operational framework. In this context, it is the purpose to involve more shrimp farms from the study area and to create a similar framework for shrimp farms in the area not yet covered.
Timeliness	SAEMA provides quick information to the producers on a real-time basis with data provided by its users. The information is easily accessible via the Internet. During the feedback process, from May to July 2006, information was mainly updated at a monthly frequency. SAEMA displayed maps with data valid for the previous month as producers enter data to the system approximately one month after the harvest. Therefore the system gives information with a one-month delay. Such delay is not considered a problem as there is a 2-month lag between AIPM and survival, with drops of AIPM occurring two months before the survival drops. During a disease event, producers can be encouraged to decrease the delay between harvest and entering the data.
Stability	Efforts have been made to automate the system in order to avoid human errors. In this way, the system collects, manages and provides data properly without failures. The system is operational all day round.

demonstrated the benefits achieved through the SAEMA platform on a small scale.

Acknowledgements

This project was supported by the Project VLIR-ESPOL, subcomponent 4.3: Geographical Information Systems for Aquaculture Management and the Centro Nacional de Acuicultura e Investigaciones Marinas (CENAIM). The research is part of the doctoral thesis of Bonny Bayot, who was funded by the Belgian Technical Cooperation (BTC) in the framework of the Master of Science Marine Aquaculture Project (NI 17693/12). The authors wish to thank Dr. F. Volckaert for his comments on the original manuscript and Inge Vissers for English corrections. We would like to thank all participating shrimp farms, especially Bravito and ENACA.

References

Aguilar-Manjarrez, J.A., Ross, L.G., 1995. Geographical information system (GIS) environmental models for aquaculture development in Sinaloa State, Mexico. Aquacult. Int. 3, 103–115.

Alday de Graindorge, V., Griffith, D., 2001. Ecuador: national review on management strategies for major diseases in shrimp aquaculture. In: Subasinghe, R., Phillips, A.R., Reantaso, M. (Eds.), Proceedings of the workshop on Thematic Review on Management Strategies for Major Diseases in Shrimp Aquaculture, 28–30 November 1999, Cebu, Philippines, pp. 17–19.

Bayot, B., Chavarría, J., 2004. Effect of the climatic variability on shrimp diseases and production in Ecuador. Aquaculture Europe 2004 Conference. European Aquaculture Society, Special publication No. 34, Barcelona, Spain, pp. 150–151.

Calderón, J., Bayot, B., Betancourt, I., Alday de Graindorge, V., 1999. Monitoreo del virus de la mancha blanca en Ecuador. El Mundo Acuícola 5, 211–214.

Cameron, A.R., 2004. Data management and analysis systems for bluetongue virus zoning in Australia. Vet. Ital. 40, 365–368.

Carpenter, T.M., 2001. Methods to investigate spatial and temporal clustering in veterinary epidemiology. Prev. Vet. Med. 48, 303–320.

Clarke, K.C., McLafferty, S.L., Tempalski, B.J., 1996. On epidemiology and geographic information systems: a review and discussion of future directions. Emerg. Infect. Dis. 2, 85–92.

Conte, A., Colangeli, P., Ippoliti, C., Paladini, C., Ambrosini, M., Savini, L., Dall'Acqua, F., Calistri, P., 2005. The use of a Web-based interactive Geographical Information system for the surveillance of bluetongue in Italy. Rev. Sci. Tech. OIE 24, 857–868.

Cucalón, E., 1996. Oceanografía y Sistemas Físicos. In: Comisión Asesora Ambiental de la Presidencia de la República (Ed.), Sistemas Biofísicos en el Golfo de Guayaquil, Guayaquil, Ecuador, 100–105.

Gai, H., 2003. China built national health information system. Electronic proceeding of the Tenth Symposium of the International Society for Veterinary Epidemiology and Economics (ISVEE 10), 17–21 November 2003, Viña del Mar, Chile.

Gibbens, J.C., Lysons, R.E., Smith, L.H., 2003. Veterinary surveillance in the UK: approaches to working in Partnership. Electronic proceeding of the Tenth Symposium of the International Society for Veterinary Epidemiology and Economics (ISVEE 10), 17–21 November 2003, Viña del Mar, Chile.

Glass, G.E., Schwartz, B.S., Morgan, J.M., Johnson, D.T., Noy, P.M., Israel, E., 1995. Environmental risk factors for Lyme disease identified with geographic information systems. Am. J. Public Health 85, 944–948.

Hill, B., 2002. National and international impacts of white spot disease of shrimp. B. Eur. Assoc. Fish P. 22, 58–65.

IGM, 1999. Ecuadorian National Chart 1:25000. Instituto Geográfico Militar.

Lavilla-Pitogo, C.R., de la Peña, L.D., Tendencia, E.A., 2006. Electronic Proceeding of the Tenth Symposium of the International Society for Veterinary Epidemiology and Economics (ISVEE 11), 6–11 August 2006, Cairns, Australia.

Lightner, D.V., Pantoja, C.R., Poulos, B.T., Tang, K.F.J., Redman, R.M., Andreas, T., Bonami, J.R., 2004. Infectious myonecrosis (IMN): a new virus disease of *Litopenaeus vannamei*. Book of Abstracts of World Aquaculture 2004, 2–5 March 2004, Honolulu, USA. World. Aquaculture Society, Baton Rouge, LA, USA.

NACA/FAO, 2006. Quaterly Aquatic Animal Disease Report (Asia and Pacific Region), January–March 2006. NACA, Bangkok, Thailand.

Nath, S.S., Bolte, J.P., Ross, L.G., Aguilar-Manjarrez, J., 2000. Applications of geographical information systems (GIS) for spatial decision support in aquaculture. Aquacult. Eng. 23, 233–278.

OIE, 2005. Disease Information 11 March 2005 18, No. 10.

Paskin, R., 1999. Manual on livestock disease surveillance and information systems. FAO Animal Health Manual, vol. 8. FAO, Rome, p. 71 pp.

Regueira, E., 2001. Patrones espaciales y temporales de la producción camaronera en el Golfo de Guayaquil. MSc. Thesis, Escuela Superior Politécnica del Litoral, Ecuador.

Rodríguez, J., Bayot, B., Amano, Y., Panchana, F., de Blas, I., Alday, V., Calderón, J., 2003. White spot syndrome virus infection in cultured *Penaeus vannamei* (Boone) in Ecuador with emphasis on histopathology and ultrastructure. J. Fish Dis. 26, 439–450.

Salman, M.D., Star, K.D.C., Zepeda, C., 2003. Quality assurance applied to animal disease surveillance systems. Rev. Sci. Tech. OIE 22, 689–696.

Sanson, R.L., Pfeiffer, D.U., Morris, R.S., 1991. Geographic information systems: their application in animal disease control. Rev. Sci. Tech. OIE 10, 179–195.

Shahid, M.A., Pramanik, M.A.H., 1986. The application of remote sensing techniques to study the relationship between the shrimp/fish farm and the mangrove ecosystem of the Bangladesh coastal region. Proceedings of the Regional Seminar on the Application of Remote Sensing Techniques to Coastal Zone Management and Environmental Monitoring, Dhaka, Bangladesh, SPARRSO-UNDP/ESCAP. United Nations Development Programme/Economic and Social Commission for Asia-Pacific, pp. 108–119.

Smith, P.T., 1999. Application of GIS to the Thai shrimp farm survey. In: Smith, P.T. (Ed.), Proceeding of the Workshop on Towards sustainable shrimp culture in Thailand and the region, 28 October–1 November 1996, Hai Yai, Songkhla, Thailand. ACIAR Proceeding No. 90. Canberra, Australia.

Sonnenholzner, S., Bayot, B., Apolo, I., Vera, T., Ochoa, X., Cisneros, Z., Van Biesen, L., Cornejo, M.P., Calderón, J., 2004. Development of a shrimp yield index for a geographic information system (GIS) assisted determination of production levels: implementation of an alert system for the shrimp farming industry of Ecuador. Aquaculture 2004 Meeting abstract 2004, Hawaii, USA.

Staubach, C., Klob, D., Kroschewski, K., Demel, W., Kramer, M., 2003. CSF of wild boar — a surveillance data base for Belgium, France, Germany, Luxembourg and The Netherlands. Electronic proceeding of the Tenth Symposium of the International Society for Veterinary Epidemiology and Economics (ISVEE 10), 17–21 November 2003, Viña del Mar, Chile.

Subasinghe, R.P., McGladdery, S.E., Hill, B.J. (Eds.), 2004. Surveillance and zoning for aquatic animals diseases. . FAO Fish. Tech. Pap., 451. FAO, Rome. 73 pp.

Tang, K.F.J., Pantoja, C.R., Redman, R.M., Lightner, D.V., 2007. Development of *in situ* hybridization and RT-PCR assay for the detection of a nodavirus (PvNV) that causes muscle necrosis in *Penaeus vannamei*. Dis. Aquat. Org. 75, 183–190.

Tum, S., Puotinen, M.L., Copeman, D.B., 2004. A geographic information systems model for mapping risk of fasciolosis in cattle and buffaloes in Cambodia. Vet. Parasitol. 122, 141–149.

Vidal, O.M., Granja, C.B., Aranguren, F., 2001. A profound effect of hyperthermia on survival of *Litopenaeus vannamei* juveniles infected with white spot syndrome virus. J. World Aquacult. Soc. 32, 364–372.

Yilma, J.M., Malone, J.B., 1998. A geographic information system forecast model for strategic control of fasciolosis in Ethiopia. Vet. Parasitol. 78, 103–127.