IAC-11-B5.1.10

Mapping habitats for vectors of infectious disease: VECMAP

Dr. Michiel Kruijff
SERCO/ESA, Noordwijk, The Netherlands, michiel.kruijff@esa.int

Dr. Guy Hendrickx
Avia-GIS, Zoersel, Belgium, ghendrickx@avia-gis.be

Dr. William Wint
Envirnmental Research Group (ERGO), Oxford, UK, william.wint@zoo.ox.ac.uk

Prof. Amnon Ginati
European Space Agency (ESA), Noordwijk, The Netherlands, amnon.ginati@esa.int

Vector-borne diseases such as Malaria, Chikungunya, Dengue and West Nile are a persistent public health concern. International trade and travel. as well as changing environmental conditions favours colonisation of new areas by foreign (especially arthropod) species. Some of these species transmit diseases to human, and so their spread represents a significant health risk which needs to be quantified and mapped to facilitate strategic preparedness. VECMAP is a project of the European Space Agency's Integrated Application Promotion program (IAP). Based on needs expressed by national public health agencies and regional mosquito controllers a consortium led by Avia-GIS is developing a service for predicting potential mosquito-related health risks (early warning) and for reducing nuisance (targeted control effort). VECMAP enhances and simplifies traditional mathematical distribution modelling, field and laboratory work with the help of Satellite Navigation and Earth Observation.). Though VECMAP's focus has so far been on mosquitoes, other vectors such as ticks, midges and rodents are now being considered

Prediction of vector distributions and associated risks is a challenge. It requires elaborate statistical simulations to be steadily fed with observations. To this end mosquito vectors are first sampled to make preliminary maps of vector presence. Using geo-referencing techniques and mobile communication technologies, the field data are automatically fed into the VECMAP distribution modelling tools, which use space imagery (processed to extract vegetation, weather data, proximity of water bodies, land use) to predict the presence of the vector throughout a project area, which may then be related to health risk or nuisance levels..

The VECMAP system optimises the sampling regime, ensures that state of the art modelling tools are used, and provides updated EO imagery to support the modelling. The system also provides expert assistance to clients where needed and acts as a secure data archive for the inputs and outputs.

Using VECMAP's integrated systems and services significantly reduces the resources needed to implement existing programmes, and with its automated methodologies and comprehensive supporting services makes advanced techniques more widely available than has hitherto been the case.

The results of the VECMAP feasibility study and prototype demonstration system indicate that the amount of field work can be greatly reduced by exploiting capabilities of satellites. A pre-operational service will therefore now be developed and implemented.

I. VECMAP AND ESA'S INTEGRATED APPLICATIONS PROGRAMME

I.1 ESA and IAP (ARTES 20)

The European Space Agency (ESA)'s Agenda 2011 contains a key objective: "*Development and Promotion of integrated applications (space & non-space) and integration of security in the European Space Policy. New concepts, new capabilities and a new culture have to be developed in order to respond to a multitude of needs from users who are not yet familiar with space systems*." Responding to this objective are the Integrated Applications Programme (IAP), also known as ESA's ARTES 20 element (user-driven applications), as well as the ARTES 3-4 Telecommunications Applications element (product-driven applications). These elements are dedicated to development, implementation and pilot operations, utilising not only Telecommunications satellites, but also combining the use of different types of space assets, including Earth Observation and Navigation, as well as Human Spaceflight technologies.

The overall goal of the IAP program is the *"the development of operational services for a wide range of users through the combination of different systems"*. The goal is to incubate sustainable services to the benefit of society that obtain their added value from the innovative integration of existing terrestrial technologies with space assets, such as Telecommunications, Earth Observation, Navigation, and Human Spaceflight technologies. "*Sustainable*" here means: triggered by, responsive to and sustained by real user demand, while taking into account financial (e.g. commercial) and non-financial (e.g. environmental, legal, adoptability) constraints. The provision of commercial *services* (rather than of mere products) is seen as a key outcome - one that offers flexibility and increases sustainability of demand, supply, and indirectly, up the value chain, also of space assets. In this way, "our satellites help to do better the daily work of society".

Such services are to be incubated through two steps or levels of ESA IAP activities:

1. Basic activities, which aim at generating, assessing and studying ideas for projects. Feasibility Studies provide the preparatory framework to identify, analyse and define new potentially sustainable activities.

2. Demonstration activities which aim at development and demonstration of the novel services identified in the first element, until an operational maturity is achieved that is satisfactory to the users.

IAP activities cover a wide range of themes, including Health, Transport, Energy, Development, Safety, Environment, Agriculture and Fisheries.

I.2 Space for Health

Typical Space for Health activities fall within the IAP Health Theme and use Earth Observation, Satellite Navigation, Satellite Communication assets as well as Human Space Flight technologies derived from astronaut health and telemedicine aspects and technologies related to autonomous habitat operations (Figure 1, http://iap.esa.int), for example in the context of:

- Field data collection
- Vector and disease risk mapping
- Early warning & emergency response
- eHealth and Telemedicine
- Integration/centralized data & analysis

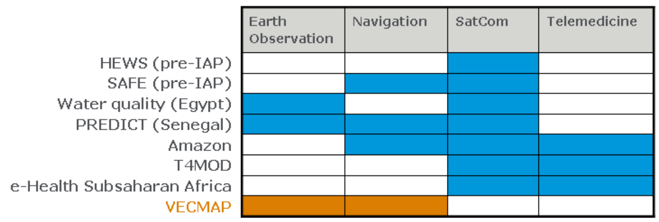

Figure 1. Some Space for Health projects of IAP and the involved space assets. Telemedicine here is referring to the relevant Human Space Flight technologies.

HEWS (Health Early Warning System) focused on the use of SatCom to deal with acute disease outbreaks (Anthrax attack, hemorrhagic (Marburg) fever outbreak), to Connect local health professionals with provincial authorities using satellite phones in the field, and VSAT/BGAN terminals in coordination centers.

SAFE (SAtellites For Epidemiology) demonstrated the use of SatCom (VSAT) for internet & tele-conferencing (local Wifi), and included electronic surveillance & GIS integration, as well as on-site biological analysis. An operational service has been established in Georgia for tuberculosis surveillance.

A water quality monitoring pilot study has been performed for Lake Manzalah, Egypt, combining in-situ measurements and EO data, with the aim to improved resource management.

PREDICT (Prevent and Respond to Epidemics and Demonstrate Information and Communication Technologies) is an ongoing study with Direction des services vétérinaires (DSV) in Senegal to monitor and collect data of a network of veterinary stations, including inspection teams with mobile SatCom. Vegetation and water bodies are also monitored via Earth Observation and all data is collected and represented in a central dBase plus GIS.

Amazon is a high-end terminal developed for remote diagnosis and first aid application, now commercially available.

T4MOD (Telemedicine for Ministries of Defense) is a SatCom based telemedicine solution providing teleconferencing capability in support of life-saving and other critical medical procedures.

eHealth in Subsaharan Africa (eHSA) is a recently initiated program of 4 studies in 4 thematic areas (Governance, Regulations, Interoperability, Sustainability) across the themes of eCare, eLearning, eSurveillance, eGovernance, funded by Lux Development (European Investment Bank) and run by ESA IAP.

The VECMAP project focuses on the use of space assets to quantify and map disease vector distributions as an important determinant of disease risk. It has completed the Feasibility Study and has now entered the Demonstration Project phase.

II. VECTOR MAPPING

II.1 Background

Vector-borne diseases (i.e. diseases carried by vectors such as mosquitoes, ticks or birds and transmitted to humans by biting or physical contact) are an increasing concern to public health bodies in many European countries. Amongst others, West Nile Fever, Chikungunya, Dengue and Tick-Borne Encephalitis are examples of vector-borne diseases that are now present in Europe and whose health related and economic impact is or could be significant. Vectors and vector borne diseases are usually only prevalent in certain specific environments. However, the combination of increased travel and trade with the ongoing global environmental change creates suitable conditions for the spread or (re-)emergence of vector-borne diseases in areas where the risk is or was low. Europe must anticipate, prevent and control new emergences to avoid major societal and economical crises such as the recent outbreaks of SARS (Severe Acute Respiratory Syndrome) in Asia and West Nile Fever in the USA.

A recent study of the European Centre for Disease Prevention and Control (ECDC)[1] observes: "*Every year millions of people around the world including in Europe are affected by vector-borne diseases, the symptoms and severity of which are variable. For example, Chikungunya virus is transmitted from human to human by Aedes mosquitoes, such as the Aedes albopictus (Asian Tiger mosquito). While Chikungunya fever is usually non-fatal, a small number of patients may develop serious complications or chronic conditions. A huge epidemic has been striking Africa, the Indian Ocean and India over the last 3 years, with millions of cases. The 2007 outbreak of Chikungunya fever in Ravenna district, Italy was the first documented transmission of the virus on the European continent*".

It comes to the conclusion that "*The climate and environmental changes being predicted by experts will alter the risk to Europe from vector borne diseases. We are likely to see the spread of diseases such as tick-borne encephalitis, or even Chikungunya fever, to places where they have not been seen before. […] We need to better understand how these changes will alter the risk of vector-borne diseases, to better target surveillance and control, and improve preparedness in European countries.*

II.2 Epidemiological community and technological heritage in vector mapping

The European epidemiological community consists of approximately 300 public health and academic entities, that are connected through participation in a number of research, development and epidemiology network activities (2).

These networks operate so far on a mostly European scale to map the presence and absence of vectors, integrating a wide variety of high level data sources providing datapoints at the resolution of municipalities and regions. A prediction map for Europe based on this rather limited, unstandardized and often inaccessible set of entomological data has been produced within the ECDC TigerMaps project[2] for the *Aedes albopictus* or tiger mosquito (responsible for e.g. spread of Chikungunya). A similar activity has been completed for the European risk mapping of Dengue.

In contrast to this European-wide low-resolution mapping for strategic purposes, the Belgian national research project Modirisk[3] is an R&D project that has laid the ground work for a methodology to create a presence/distribution map at regional/national level (Figure 3) based on land use analysis and in-situ sampling of mosquitoes, covering Belgium and the Netherlands.

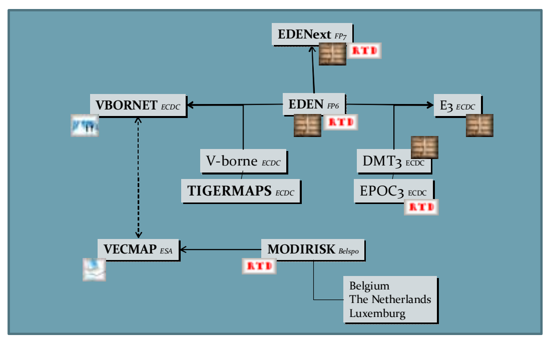

Figure 2. Vector Mapping activities in Europe

Figure 3. Examples of elements for vector mapping: Modirisk result in Belgium, field data collection via smart phone and a mosquito trap for sampling.

In a more operational sense, a surveillance network is being maintained in Emilia-Romagna (Italy) to keep the population of vectors below critical thresholds (see e.g. 9).

The predictive mosquito distribution models that have been developed in these projects need to be periodically validated by field-data because mosquito populations are dynamic and because land use and land cover change over time, which may cause shifts in high risk areas. The risks of introductions and/or spread of vectors and/or vector-borne pathogens may also change with time. Therefore, long-term monitoring of mosquito populations is required for a sustainable use of the methodology.

These projects are however so far mostly one-off exercises, relying on institutional funding and using tools and methodologies only available on an ad hoc basis. An integrated, consistent and standardized end-to-end map production chain covering a broad range of geographical areas does not yet exist.

II.3 Space assets for vector mapping

Space assets have proven to be useful to understand the dynamics of vectors and vector borne diseases (i.e. how they emerge and spread) and ultimately to help forecast the areas at risk for infections today and in the future.

ESA already carried out a preliminary study on the use of EO data for epidemiology concerns between 2003 and 2006 within the Epidemio project (ESA contract number 17809/03/I-LG[4]) of the Data User Element (DUE) of ESA's Earth Observation Envelope Programme.

Based on the above, ESA, in collaboration with the European Commission (EC) Directorate General for Health and Consumers (DG SANCO), CNES and the partners of the EC FP6 project EDEN organised in October 2007 a workshop on 'Operational Risk Maps for Communicable Diseases using Integrated Space and Non space Assets'[5]. Several key stakeholders and potential users attended the event and acknowledged the interest of space for developing disease risk maps and disease vector maps. It was recommended to further investigate the area and to pursue the development of operational services for diseases (especially tick-borne encephalitis and bluetongue) and disease vectors (especially mosquitoes).

Following this recommendation, ESA organized a workshop dedicated to space and mosquito as a vector of diseases in October 2008[6] mainly aimed at:

- understanding the need related to mosquitoes mapping in Europe
- federating users that can contribute to maps and end users that need the maps
- understanding which solutions can be envisaged using space elements for developing these maps and the added value of space
- establishing with users and potential providers of these solutions the feasibility and sustainability of a service providing an end-to-end solution

Overall, several potential end users from 6 European countries (UK, F, I, CH, NL, B) attended and clearly acknowledged the need for:

- Predictive mapping: to determine (1) the distribution of mosquito species in Europe especially in areas where surveillance does not exist, and (2) the risk for establishment/presence of these species to help anticipate potential outbreaks or to identify new risk areas.
- GIS: to optimize the sampling strategy and the work of field inspectors and therefore contribute to improve current surveillance networks or help developing those networks where they are needed.

The role of space assets to answer the above needs was discussed and recognised. R&D projects like Modirisk and TigerMaps as well as the surveillance network in Emilia-Romagna (Italy) are good examples of activities where space tools are already used (satellite navigation/ positioning and earth observation):

- **Satellite navigation/positioning** is used in some of these activities (e.g. in Emilia-Romagna) for geo-localising in situ data, e.g. mosquito traps or location of disease cases, as well as for field inspectors/teams to locate/control the areas at risk and for accurate follow-up of control operations.
- **Earth observation** provides data on the environmental factors that influence the emergence or the spread of the vectors or diseases (e.g. soil moisture, surface temperature, vegetation, land use) to be used in distribution models (Low-Resolution Remote Sensing for eco-climatic envelope, High-Resolution Remote-Sensing for landscape and habitat).

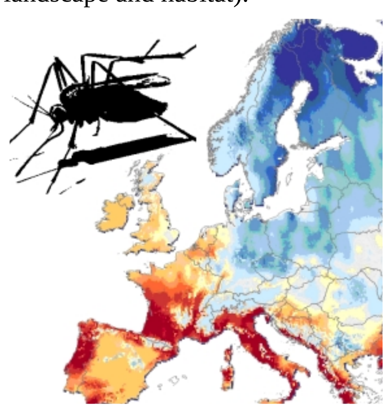

Figure 4. Prediction for habitat suitability for *Ae. albopictus,* the tiger mosquito.

After these two workshops and several consultations with users and experts, the idea of an end-to-end system and associated service aimed at mapping and surveillance of mosquitoes was selected as a candidate for an IAP feasibility study, in order to resolve some remaining open issues:

- The feasibility of providing the right information that users (i.e. public health authorities and epidemiologists) require had to be proven.
- The viability of the system and associated service had to be assessed.
- The added value of space assets had to be clearly demonstrated.

II.4 The VECMAP Project

The objective of IAP's VECMAP Feasibility Study (completed May 2011) has thus been the assessment of the technical and economic feasibility of the utilisation of space assets (so far primarily Earth Observation and Satellite Navigation) in a landscape and regional/national mapping service for presence and abundance of disease vectors, by seamlessly integrating data from terrestrial (in-situ) and space-based sources, and providing a more efficient, more effective and more standardized mapping methodology.

VECMAP is so far the only development aiming at a sustainable service provision in the domain of disease vector mapping in Europe. The sustainability is to be achieved through a self-supportive, commercially viable scheme.

As the VECMAP Feasibility Study has held a local, regional and national application target, it inherits its sampling methodology know-how mostly from the Modirisk project, whereas mapping and geospatial prediction technologies have been based on a broader heritage employing well established, if complex, modelling techniques and including the TigerMaps experience and Avia-GIS Vet-geotools GIS system).

The Feasibility Study has resulted in:

- a concept of a system and its associated service, providing predictive risk maps and GIS for mosquito surveillance, control and study in the European Union for industrial, public health and academic users, integrating space assets (Earth Observation data and Satellite Navigation) and tailored to the users selected in the frame of this study,

- a prototyping of all critical technologies and an assessment of the system and its associated service, including its added value with the users and the added value of the space assets,

- an assessment of the viability and commercialisation of the system and its associated service,

- the ingredients required to plan a demonstration project including the involvement and co-funding of a significant, diverse and representative group of users for the development phase.

A Demonstration Project has now been initiated (Sept. 2011) that aims to develop and demonstrate, to the involved users, a sustainable service in a pre-operational setting (i.e. finally achieving an operational and commercial service offering). This Demo is to cover three subsequent vector seasons. Although the Feasibility Study has focussed on the mapping of mosquito species presence in Europe, the Demo Project extends the topical scope beyond Europe and includes other vectors such as ticks. Also the range of services is extended, to include hi-res (landscape) mapping.

II.5 The VECMAP Study Team

The Feasibility Study team (Figure 5) consisted of:

- **Avia-GIS (B),** a company (SME) that specializes in the collection, processing and analysis of spatial information and the development of data driven space-time information systems with particular reference to animal health, agriculture, public health and the environment. Avia-GIS will lead the project and is in charge of the development, integration and commercialisation of the solution as the future service provider. They are also responsible for the VECMAP database, sampling tools and information system components.
- **ERGO (UK)**, an SME in collaboration with the **TALA (UK)** research group from the Zoology Department of Oxford University, responsible for the area-wide distribution modelling components and the Earth-Observation time series processing. This group have been involved in developing and deploying statistical distribution modelling research and for more than twenty years.
- **MEDES (F),** responsible for developing smart phone utilities (palm-to-web), including the use of Satellite Navigation systems. They carry out activities in the field of telemedicine, epidemiology, clinical research and activities or research.
- Processed Earth Observation data suppliers: EARS (NL) and VITO (B).
- User coordinator: RIVM (NL).

Figure 5. VECMAP team at Mid Term Review at the site of user EID Mediterranee.

Ten European user organizations were involved in the VECMAP study, broadly spanning three categories (Figure 6):

- **Industrial (pest control)**: CAA (I), EID Mediterranee (F), CMV (NL);
- **Public health (advice and decision making)**: RIVM (NL), IPH (B), and
- **Academic (R&D)**: ITM (B), UZH (CH), CIRAD (F), CVI (NL) and CEH (UK).

Most of these users are participating in the Demo Project as well. Five additional users have joined (Figure 7). Together they will cover the demonstration of the VECMAP services in a pre-operational setting, covering applications such as distribution (for planning) and landscape mapping (for control) of a variety of mosquito species, incl. vectors and nuisance species, (*Aedes albopictus*, *Ae. vexans*, *Ae. caspius*, *Ae. detritus*, *culex pipiens*), ticks and other vectors (such as rodents), as well as surveillance of diseases (veterinary diseases, West Nile virus, Chikungunya), see **Error! Reference source not found.** & Figure 8.

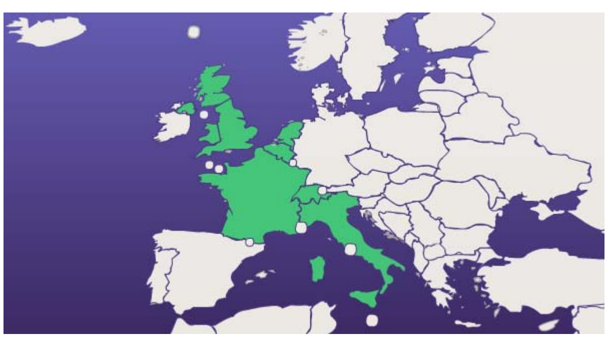

Figure 6. Geographical spread of VECMAP Feasibility Study users

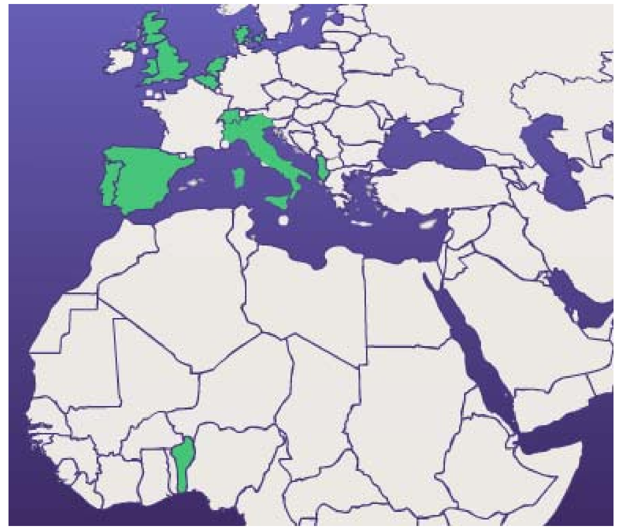

Figure 7. Geographical spread of VECMAP Demo Projects.

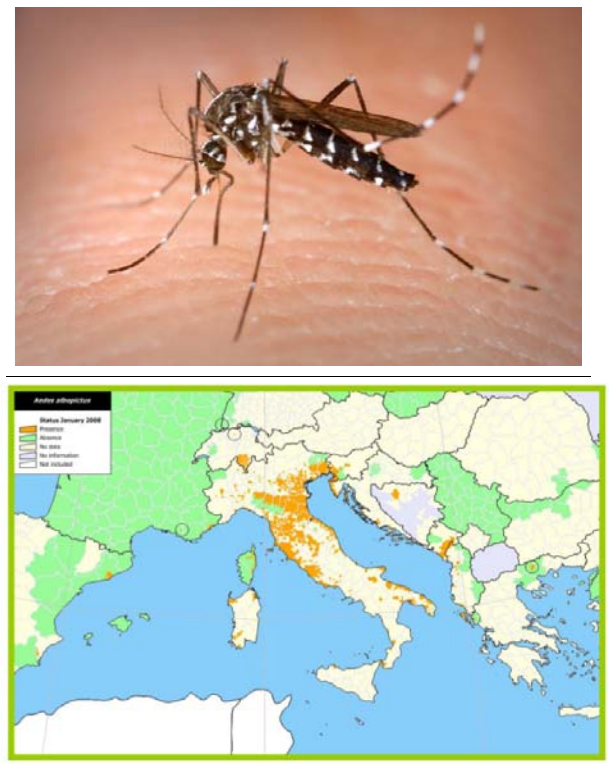

Figure 8. Tiger mosquito (*Aedes albopictus*) and geographical spread (orange)

III. VECMAP STUDY RESULTS

III.1 User groups

During the VECMAP Feasibility Study, three major user communities have been identified and characterized with respect to a potential VECMAP service.

The Public Health Users: including public health agencies, international and non-governmental organizations. Geared to develop Public Health intervention plans, they are mainly interested in vector distribution mapping, to monitor current and future vector species distributions at a country level or above, for strategic planning, prioritization and decision making. They have a firm biological background but need support to plan field operations, maintain the database, conduct data analysis, and represent results.

The Industrial Users: private or public pest control companies and companies interested in spatial risk maps such as commercial Public Health websites, insurance and the real estate sector. They are primarily interested in vector control to reduce nuisance or disease risk and wish keep species causing nuisance or health risks below critical thresholds. They are in regular need of risk assessment and abundance maps that can be directly applied to plan control activities or for other commercial purposes. They need to concentrate their efforts on the right places at the right time to optimise control efforts.

The Academic Users: These research-oriented users are, like the Public Health users, mainly interested in vector distribution mapping. The Academic User community is also regarded as well-connected and a key channel for obtaining broad acceptance of the VECMAP services being developed. They are typically well-informed and broadly capable. They currently often use dedicated ad-hoc tools to perform the full range of described activities, based on in-house expertise in biology, geographic information systems (GIS) and ICT.

Several representatives of each these three communities has been involved in the VECMAP Feasibility Study in form of two user-workshops, a technical proof of concept of the VECMAP system prototype, various review meetings and a number of questionnaires addressing user needs and requirements, concept validation, market and pricing aspects (e.g. Figure 5, Figure 9).

III.2 General challenges to vector mapping

The two main applications for vector mapping are driven by the public health authorities and the pest controllers user groups. In practice, both authorities and controllers need predictive maps, to know the type of mosquitoes, their current and future location, and when their population will peak. To develop mosquito presence/distribution and prediction maps, historical and spatial entomological data are required (i.e. information on mosquito populations: how many and which mosquito species are occurring when and where) to feed suitable predictive models. Neither of these two components are readily available or trivial to obtain:

1. Mosquito sampling related challenges

Mosquito sampling is typically needed in a large number of field locations. Each disease is associated with specific vectors, and each vector with its particular environmental and meteorological conditions. Initially a nationwide or regional cross-sectional sampling should be performed, and followed by sustained monitoring using longitudinal sampling in a reduced set of specifically selected sites. In-situ field sampling activities are labour intensive and therefore expensive. Such information is therefore scarce and scattered: indeed some European countries have no vector surveillance systems and no history of systematic surveys, or are only beginning to put them in place.

This type of field work is typically held on an ad-hoc basis and with an arbitrary number of sample sites, often resulting in excessive cost or results that are not representative. The results may also be biased because sampling only takes place in sites with known presence. and due to inaccurate geo-referencing, proper correlation with land use at the sample site may be lost.

Such sampling programmes can be optimised by significantly reducing the number of sampling point while retaining a statistically representative coverage. This can be achieved if sample sites are selected taking into account environmental and climatic conditions, and if the actual sampling locations are accurately recorded. A formal, standardized optimisation process is required, firstly to ensure the sample site selection includes a sufficient number of sites with a likely absence of vectors, and secondly, to allow results from different research groups or sampling epochs to be compared with each other.

In summary, the amount of field work and the associated cost can be reduced, with increased representativeness, by a combination of proper, automated site selection and a modelling, based on static land use and geographical data, as well as dynamic data from satellites. The work can be made more efficient with support to data entry procedures, data archiving and data sharing.

2. Modelling related challenges

Distribution modelling is necessary to map the specific potential emergence and spread of particular mosquito species, as sampling can never be complete and ubiquitous. The introduction, abundance and spread of mosquitoes are linked to eco-climatic factors (such as winter temperatures, annual rainfall, summer rainfall and summer temperatures for *Aedes albopictus*, for example) and anthropogenic factors (such as land use or urbanisation). Using the entomological survey data as inputs, current modelling tools can produce predicted distribution maps, but they are only used by few highly specialised practitioners, and are not accessible to most mainstream health professionals.

III.3 Use cases and derived technical needs

Use cases, describing the current operational setting and procedures in more detail, have been constructed in consultation with users, independent experts and practitioners, in workshops and in individual consultations. Two major Use cases are considered, one representing the typical activities of a user focussing on Distribution Modelling; the other of a user focussing on Mosquito Control. Requirements and needs are derived by a systematic evaluation of the use case.

1. Distribution Modelling Use Case

Research institutions and governmental health organisations aim at mapping a baseline distribution map of mostly endemic species. In addition they are interested in longitudinal sampling (same location over the course of time) and monitoring of species in order to determine entomological parameters such as a vector-free period, start of vector season, peak of vector activity etc. Lastly these users are interested in assessing whether changes in environmental (e.g. human, climatic) can influence the distribution of both endemic and invasive species e.g. *Aedes albopictus*. The steps that the user currently takes to achieve its goal are described in Table 1.

2. Mosquito Control Use Case

Mosquito control operators aim to maintain target insect population levels below certain thresholds above which there is a danger for nuisance or even potential for spread of disease. Control should preferably be applied in an environmentally friendly manner on the larvae, shortly after hatching. The conditions, location and timing of hatching vary widely between species however. Highly detailed and frequent information is required on the local environment and weather conditions that the mosquito populations are exposed to. By combination of various Earth Observation data sets (radar, optical, infra-red) with data from sensors installed in the field an adequate model may be developed. Also distributed sensor networks were suggested for this purpose, e.g. to monitor the controlled flooding of rice fields by their owners, an event that affects the hatching of certain species.

EID Méditerranée and CAA are currently active in the mosquito control of nuisance mosquitoes (*Aedes caspius*), potential vectors of disease (*Culex pipiens*) and invasive mosquitoes (*Aedes albopictus*), each of which has its own particular environmental preferences, according to which control measures need to be adapted (Table 2).

The steps that these users currently take to achieve its goal are described in Table 3.

Step1.1 – Mosquito sampling

- *Definition of key sampling strata*

Broad key sampling strata (e.g. urban, agricultural, forests, mountains, wetlands) are defined in relation to the insect species and the insect stadium, which are (for baseline mapping) usually adults. On top of these, high-risk of introduction environments are selected depending to the species: second hand tyres companies, ports, airports, natural wetland areas and protected areas. Representative sites are selected within these environments for a cost-efficient survey.

- *Cross-sectional survey*

Is applied for defining the presence of insect species in defined areas. The most general approach consists to place traps in environments and time-periods chosen as the most favorable by expert advice. However, a more objective approach can also be used, based on random-selected sites and dates according to a GIS.

- *Longitudinal survey*

Is generally applied throughout the mosquito development season (which depends to the species and the local climate), but can be reduced to a shorter time frame in case of time-limited transmission risk. The frequency of field data collection is dependent to the insect species, the larval habitat functioning (temporary or permanent, flooding rhythm) and the risk level. However, a routine weekly base is generally appropriate.

- *Logistic planning of survey*

Once the survey aim and method and the resulting field protocol are defined, trapping sites are most generally selected directly on the field in the defined areas, depending to the technical suitability for the trapping (accessibility, security for the expensive material, etc.). Spatial coordinates and physical addresses need to be collected during the first trap placement.

Step 1.2 – Field data collection

Adult trapping provide samples that are brought back to the laboratory for detailed analysis. During trap placement and/or trap removing, various field data could be collected reported on sheets for further analysis, depending to the request of each user.

Step 1.3 – Field data analysis and storage

Field collected samples are analyzed in the laboratory for identification and counting of the collected insects. Personal are usually trained for identifying the local most common species. However, specialized mosquito taxonomists are rare and identification of newly introduced species and deep research on mosquito fauna need good knowledge, which is not often available. Data are stored in databases for further analysis.

Step 1.4 – Spatial distribution modeling

Spatial distribution modeling is usually limited to a technique standard available in commercial software packages.

Table 1. Distribution Modelling Use Case

Aedes albopictus - nuisance and risk for Chikungunya and dengue fevers - found in urban environment showing man-made containers and catch basins. - Larval control teams operate on regular basis by treating permanent water collections (e.g. local drains) while adult control teams are activated after nuisance reports of local inhabitants. - This requires a service focused on rapid logistic deployment of control teams. Aedes caspius and Aedes detritus - nuisance - are largely breeding in temporary flooded coastal salt marshes as well as in inland fresh water (e.g. rice fields) with synchronous eggs eclosion and larval development following flooding of the areas. - This requires that the habitat setting can be correctly identified and that natural and artificial flooding can be monitored. Within the small water bodies, the number of larvae must be continuously monitored to enable fast control using larvicidal treatment. Aedes vexans - nuisance - found in natural areas showing fresh water flooding areas. Anopheles maculipennis s.l. - nuisance - natural areas showing permanent fresh water flooding marshes and canals and agricultural areas sowing rice paddles and pools. Coquillettidia richiardii - nuisance - natural areas showing permanent fresh water marshes. Culex modestus - risk for West Nile fever - natural areas showing marshes with red beds and agricultural areas showing rice paddies. Culex pipiens - urban nuisance and/or risk for West Nile fever - urban environment with small waterbodies, irrigation canals, man-made containers, catch basins, flooded cellars; agricultural areas showing ditches, pools and cesspits. - This requires that the rural habitat setting can be correctly identified and that natural and artificial flooding can be monitored. Within the small water bodies, the number of larvae must be continuously monitored to enable fast control using larvicidal treatment.

Table 2. Mosquito species control particularities

Requirements and needs are derived by a systematic evaluation of the use case. These two use cases have largely overlapping needs. The only exception is related to the type of maps, which for the industrial activity (vector control) has a requirement for medium resolution (<30 m) whereas for the public health and academic activities a low resolution (1 km) is sufficient. These two resolutions require a fundamentally different service approach. The low resolution maps can be generated in a standardized, highly automated manner, and with high temporal resolution, whereas the medium resolution maps are less available, more costly and cannot be processed fully automatically. The analysis needs to be custom-developed, in close interaction with the user.

The needs arising from this use case analysis are summarized in Table 2.

Step 2.1 – Mosquito sampling • *Definition of key sampling strata* Firstly, key sampling strata are defined in relation to the insect species responsible of nuisance or transmission risk, the insect stadium, which is chosen for the surveillance, as well as the insect stadium chosen to be controlled (larvae, pupae, adults, eggs). This last choice is dependent to the availability of adapted and efficient control methods (larviciding or adulticiding) and to their financial and environmental costs. Most insecticides for example have no effect on pupae. Environments are selected depending to the species responsible for the nuisance or the transmission risk, see e.g. Error! Reference source not found.. Representative sites are selected within these environments for a cost-efficient survey. • *Cross-sectional surveys* These are applied for defining the presence of insect species in defined areas. The most general approach consists to place traps in environments and time-periods chosen as the most favorable by expert advice. However, a more objective approach can also be used, based on random-selected sites and dates according to a GIS. • *Longitudinal surveys* Are generally applied throughout the mosquito development season (which depends to the species and the local climate), but can be reduced to a shorter time frame in case of time-limited transmission risk. The frequency of field data collection is dependent to the insect species, the larval habitat functioning (temporary or permanent, flooding rhythm) and the risk level. However, a routine weekly base is generally appropriate. • *Logistic planning of survey* Once the survey aim and method and the resulting field protocol are defined, trapping sites are most generally selected directly on the field in the defined areas, depending to the technical suitability for the trapping (accessibility, security for the expensive material, etc.). Spatial coordinates and physical addresses need to be collected during the first trap placement. Step 2.2 – Field data collection Larval or pupal surveys and adult or egg trapping provide samples that are brought back to the laboratory for detailed analysis. During trap placement and/or trap removing, various field data could be collected reported on sheets for further analysis, depending to the request of each user. Step 2.3 – Field data analysis and storage Field collected samples are analyzed in the laboratory for identification and counting of the collected insects. Personal are usually trained for identifying the local most common species. However, specialized mosquito taxonomists are rare and identification of newly introduced species and deep research on mosquito fauna need good knowledge, which is not often available. Data are stored in databases for further analysis.

Table 3. Mosquito Control Use Case

III.3 Users' constraints and needs for an integrated solution

At a higher, non-technical level, there are significant constraints and needs to be taken into account that link these defined needs.

Ad-hoc modelling techniques are currently available: the principles of biological sampling are well understood, the acquisition and processing of Earth Observation imagery is well established and supported by specialised software such as ERDAS Imagine and the ESRI suites; and spatial modelling techniques have been available for some time through software such as Idrisi and a number of specialist distribution modelling tools.

The problem is that the available techniques require staff with considerable technical expertise in biological sampling, statistics, spatial modelling, database management and satellite image processing to implement. Such skills are sometimes available in to Academic Users in research institutions, though not often the complete range needed, but are vanishingly rare in Public Health or Industrial Organisations. This means that very few organisations or institutions are capable of actually implementing the required vector mapping or the underlying processing and sampling needed.

Users currently therefore have two major alternatives if they wish to produce the vector distribution maps needed to understand disease risks: to develop the complete range of required skills themselves or to buy them in from established experts. Both courses of action are often too expensive of time or resources to be realistic options, which is why there is a real threat that vector mapping will not be done.

Public Health users require therefore:

- the possibility of obtaining results and maps for decision making, with less dependency on in-house expertise, e.g. through access to end-to-end solution or particular modules by outsourcing.

Academic Users need:

- to improve the quality of field sampling, spend less time collecting field samples (logistics) and as a result freeing time for analysis and research, hence significantly contributing to improve research outputs.
- to establish base-line entomological databases in a standardised format and which will allow them to follow-up vector distribution patterns over time - None of the research teams involved with VECMAP operates a centralized entomological data archive within their institutes;
- to have guaranteed access to a wide range of high quality specifically processed EO time series to produce comparable spatial distribution models over time – None of the research teams involved with VECMAP currently has such a guaranteed access;
- a system available to all relevant project teams in the Institute, to increase the integrative and standardising advantages, such that after completion of research projects and or departure of individual researchers data automatically remain available to the Institute – In addition to the fact that currently no integrated system is on the market, currently most the research teams operate using their own methods without streamlining methods with other teams;
- to strengthen research networks between Institutes without raising internal network accessibility and security issues, e.g. through real time data entry in a central database and secured access to the externally hosted DB platform to all authorised partners, – this will facilitate secured real time exchanges between teams, not only from the same institute but also from other institutes without internal IT issues being raised or fire-walls blocking exchanges.

Industrial users require:

- Improved quality and efficiency: e.g. less time spent to cover the same areas, the same areas covered in a better way, opportunity to expand areas under control without need to increase staff numbers.
- Access to outstanding expertise on demand with no need for hiring expensive specialized permanent staff. As was shown during the feasibility study, whilst pest control companies have a high level of ‘classical’ expertise in all technical aspects needed to control pests, they have little or no in-house expertise in cost effective sampling, using remote sensing (both low and high resolution) or modelling for improving the efficiency of their control activities;
- Opportunities to improve the development of environmentally friendly integrated pest management approaches based on evidence provided by advanced EO and modelling methods.

All the abovementioned needs are addressed by the VECMAP solution.

VECMAP Service		User Community			Current approach by users	Needs to be addressed by VECMAP service	Space Asset
		Public Health	Indus-trial	Aca-demic			
1	Key habitat delineation	X	X	X	Based on available maps and/or assumptions , general info on vectors & habitats	Automatic delineation of key habitats for a vector Tools for combining spatial layers	Static third party data (generated with EO, GNSS)
2	Cross-sectional stratified sampling strategy	X	X	X	Ad hoc determination type & number of traps (based on budget or manpower), and location, time & duration of placement, for native, indicator and/or invasive species, at various stages of life cycle	Rational/optimal determination of these parameters. Visualise sites. Automated document generation (for access requests) Automated team assignments	EO
3	Field data collection	X	X	X	Multiple teams distributed over season and area (to remove bias), find a proper location near preselected location (e.g. by talking to farmer in neighborhood), place traps in the field, return later to collect results	Automated routing and scheduling, filtering (for the assigned team). Mobile unit that includes a routing component (based on e.g. military maps). Field data entry on mobile unit with easy-to-use interface. Accurate location record. Predefined standardised set of field parameters, plus user-defined extension. Field data stored on the mobile unit until automatic upload to a centralised database.	EO, GNSS
4	Field database setup	X	X	X	Ad-hoc tools (e.g. Excel file)	Standard set of database field parameters, user defined parameters, all to be added to the central database.	-
5	Field data analysis	X	X	X	In laboratory, manual morphological identification of collected mosquitoes, data entry in laboratory system	Training, external validation, laboratory & web-based interface to central database	-
6a	Local habitat mapping		X		Ad-hoc tools, using existing maps and weather reports, in-situ inspections	Standardized, flexible and easy to use tools to develop a static map of local focal habitat. Seasonal map output is preferred. Validation.	EO, GNSS
6 b	Area-wide distribution mapping	X		X	Ad-hoc tools, using existing maps and weather reports.	Flexible and easy to use tools for countrywide distribution maps for presence / absence probability. Single out environmental parameters that correlate best to habitat suitability. Abundance maps can be a surplus. Validation.	EO, GNSS
7	Longitudinal sampling strategy/foll ow-up monitoring	X	X	X	Trial and error to determine type of traps, number of traps, and location, that can be used to monitor the current level of abundance for native, indicator and/or invasive species (at different development status).	Optimal selection based on medium resolution images of land use and results of cross-sectional analysis. Provision of home address close to site. Automated scheduling. Automated document generation (for access requests). Visualisation.	EO
8	Other	X	X	X	Recurring lack of accessible competence / organizational support	Access to historical data sets, web-training.	EO

Table 4: Services to be developed in the VECMAP Demo Project

III.4 The VECMAP solution

The VECMAP solution is defined by the system, the services and the service provisioning scheme, each described below.

VECMAP System

The VECMAP system is the technology that is to provide the foundation for the offering of services responding to the above user needs. The system has been prototyped during the Feasibility Study and validated by the involved users (Figure 9).

The VECMAP system consists of several integrated components (Figure 10).

- A means to design and execute **Field Sampling** campaigns using smart phone and GNSS technology linked to a **centralised database** for archiving and storage. In this manner the field work can be done remotely, effectively and independently.
- A user-friendly **Distribution Modelling** software package, fed by the field sample data and the necessary EO processed data provided as part of the System.
- The **Information System (IS)** which is the glue that integrates the other components and provides access to all the required supporting data as well as the means to display and analyse final mapped products. Depending on the user's needs a variety of graphical representations and interactive research is made possible through the engine for the Geographical Information System (GIS)-environment. The I.S. also takes care of distribution and secure archiving of user and system data, VECMAP utilities, dissemination of updates and supporting materials as well as product branding.

Figure 9. Second VECMAP user workshop at RIVM (NL), during validation of the VECMAP system components.

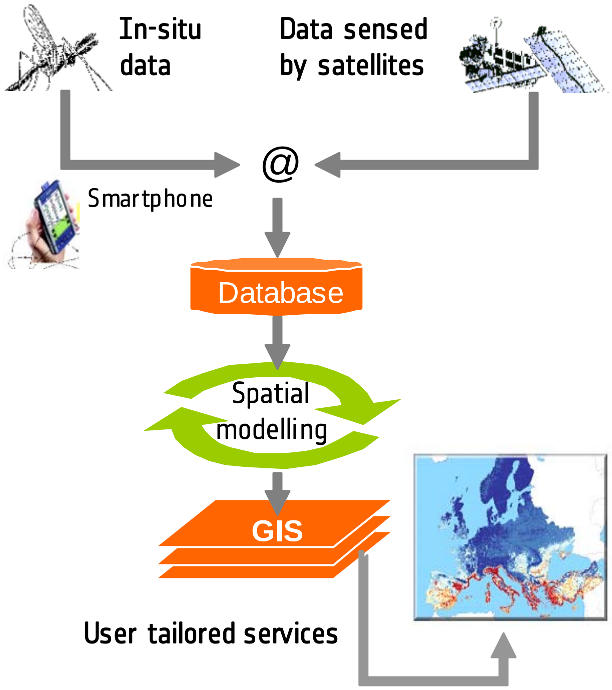

Figure 10: VECMAP - highlevel system overview

VECMAP Services

The VECMAP system makes it possible to support each user community according to the needs identified during the Feasibility Study. For each step in the use case, a service, or rather, a set of supporting services has been identified that utilises the VECMAP system. In this way, a highly modular service offering can be obtained (Figure 12). These services are to be developed during the next phase of the VECMAP project (IAP Demonstration Project).

The foreseen interaction of the user with the VECMAP components and services are described in the following steps of the vector mapping use case.

1. **Key habitat delineation (Service 1)**

   With the help of static geographical vector and raster data from third parties (administrative unit layers, Corine land use, elevation), the area to be studied is stratified into key habitat regions. A statistically representative number of sampling points is calulated and then the locations are generated randomly within each of the sampling strata.

2. **Cross-sectional stratified sampling strategy (Service 2)**

   As team members have been registered, schedules are produced for sampling teams to visit sites in such a way that possible regional or seasonal bias is removed. The VECMAP system identifies the owner of the land where a sampling site is planned and automatically generates the letter to request access to the land. A routing service is available, as well as a web-based map server for visualising terrain accessibility in advance. The strategy and sampling points are synchronized with a central database, also if the user runs his own version of the VECMAP software. This provides security, accessibility for all team members, the possibility to share and combine data of different campaigns managers via a web-interface, and the possibility to detect inconsistencies in the data. Progress of the sampling activity can also be monitored via this interface.

3. **Field data collection (Service 3)**

The sampling team members make use of a VECMAP Smartphone. EGNOS enabled satellite navigation guides the team members towards their daily sampling sites, both via main roads and rural paths. Via a user-friendly interface, the team member can complete a form to log the sample site observations. The form contains typically mandatory, standard and user-defined fields. The location is automatically added. Synchronization of the data with the central database takes place as soon as a link can be established via terrestrial communication links.

4. **Field database set-up (Service 4)**

Together with the user, the database for the user-collected data is set up. This may be shared with other users (e.g. within the same institute) under a variety of access levels. Modelling results as well as all Earth Observation data, raw and processed, are also maintained in the database.

5. **Field data analysis support (Service 5)**

The samples of vectors are typically analyzed by the user or a third party in a laboratory. VECMAP provides the option to enter the analysis results directly into the VECMAP system via the user interface. Alternatively, the laboratory data on the retrieved vectors can be ported from the laboratory data management system to VECMAP via an interface agent that is part of the VECMAP software.

6. **Distribution modelling and landscape mapping (Services 6a and 6b)**

Sample data or other geo-referenced data of vector presence/absence can be combined with geographical data in order to obtain maps of habitat suitability, distribution, risk or abundance, etc. Typically such maps require complex modelling and significant validation effort and follow-up work. VECMAP provides step-by-step, highly automated modelling according to the most-used techniques. A specifically powerful technique is the Non-Linear Discriminant Analysis, which identifies the geographical input parameters that provide the best correlation with sampling results. With the correlations known, a meaningful fit between sample results can be obtained, responsive to the local values of the relevant geographical parameters. Validation and indices of interpolation quality are then provided.

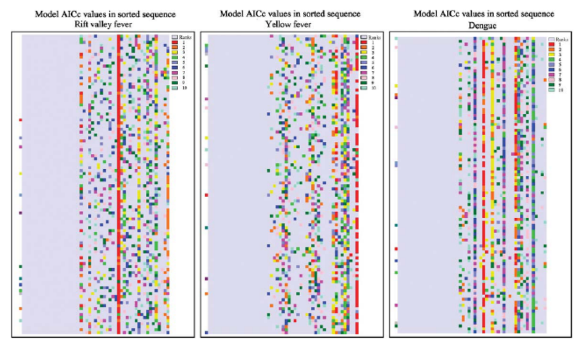

Figure 11. NLDA typical results (vertical: simulations, horizontal: parameters, strength of correlation indicated by color)

The input parameters required for the modelling can be any type of raster data, e.g. demographical, topographical or Earth Observation data. Typical Earth Observation derived parameters with relevance to epidemiology are vegetation indices (e.g. NDVI, fAPAR from SPOTp, Envisat-MERIS or Terra/Aqua-MODIS) or land surface temperatures (Terra/Aqua-MODIS) The VECMAP service provides a guaranteed record of recent as well as historical Earth Observation data. The data is taken at a time resolution of several weeks, and then expressed in a more compact way via Fourier transform, therewith exposing seasonal effects in particular.

For distribution modelling at national scale, a 1 km resolution typically suffices and this has been selected as the standard (Service 6b). Data from different sources must thus be geo-referenced and resampled to obtain the necessary standard input format.

Satellite/Sensor	Environmental data time series	Spatial resolution	Time Series Period
METEOSAT SEVIRI	Precipitation	3km	2004 onwards
	Net Radiation	3km	2004 onwards
	Sensible Heat Flux	3km	2004 onwards
	Actual Evapotranspiration	3km	2004 onwards
	Relative Evapotranspiration	3km	2004 onwards
MODIS TERRA AQUA	Day-time Land Surface Temperature	1km	2001 onwards
	Night-time Land Surface Temperature	1km	2001 onwards
	Middle Infrared	1km	2001 onwards
	Normalised Difference Vegetation Index	1km	2001 onwards
	Enhanced Vegetation Index	1km	2001 onwards
SPOT-VGT	fAPAR	1km	1998 onwards
	Normalised Difference Vegetation Index	1km	1998 onwards
ENVISAT MERIS	fAPAR	1km	2003 onwards
	LAI	1km	2003 onwards
	fCOVER	1km	2003 onwards
	MTCI	1km	2003 onwards
	Normalised Difference Vegetation Index	1km	2003 onwards

Table 5. Earth Observation data available for VECMAP Distribution Modeling service

Users active in vector control require typically medium or high resolution maps (better than 30 m) and a regular update (days) in the critical season when mosquito larvae hatch. The vector control needs are very specific to both vector species and region. The distribution modelling approach is not valid for these cases. The landscape mapping (Service 6a) must therefore be performed in two stages. First the needs are mapped by interaction with each user individually, then a tailored service is developed, as much as possible building on (or extending) the VECMAP system.

7. Longitudinal sampling strategy & follow-up monitoring (Service 7)

Following a baseline mapping activity, VECMAP can provide the best strategy to monitor and improve the situation on the long term. For this a much smaller number of well-selected samplings will suffice, that are regularly visited (e.g. every two weeks during the vector season).

8. VECMAP support services (Service 8).

In addition to these use-case related services, the VECMAP system shall provide a number of additional services, related to the Information System (I.S.) as well as those based on special requests from the users. This includes secure access and archiving for the different data sets produced via a web-interface, including Earth Observation data at its various stages of processing, access to spatial analysis tools and the provision of updates, web-based training etc.

This service supply scheme allows tailoring the service provision modes to the three user communities.

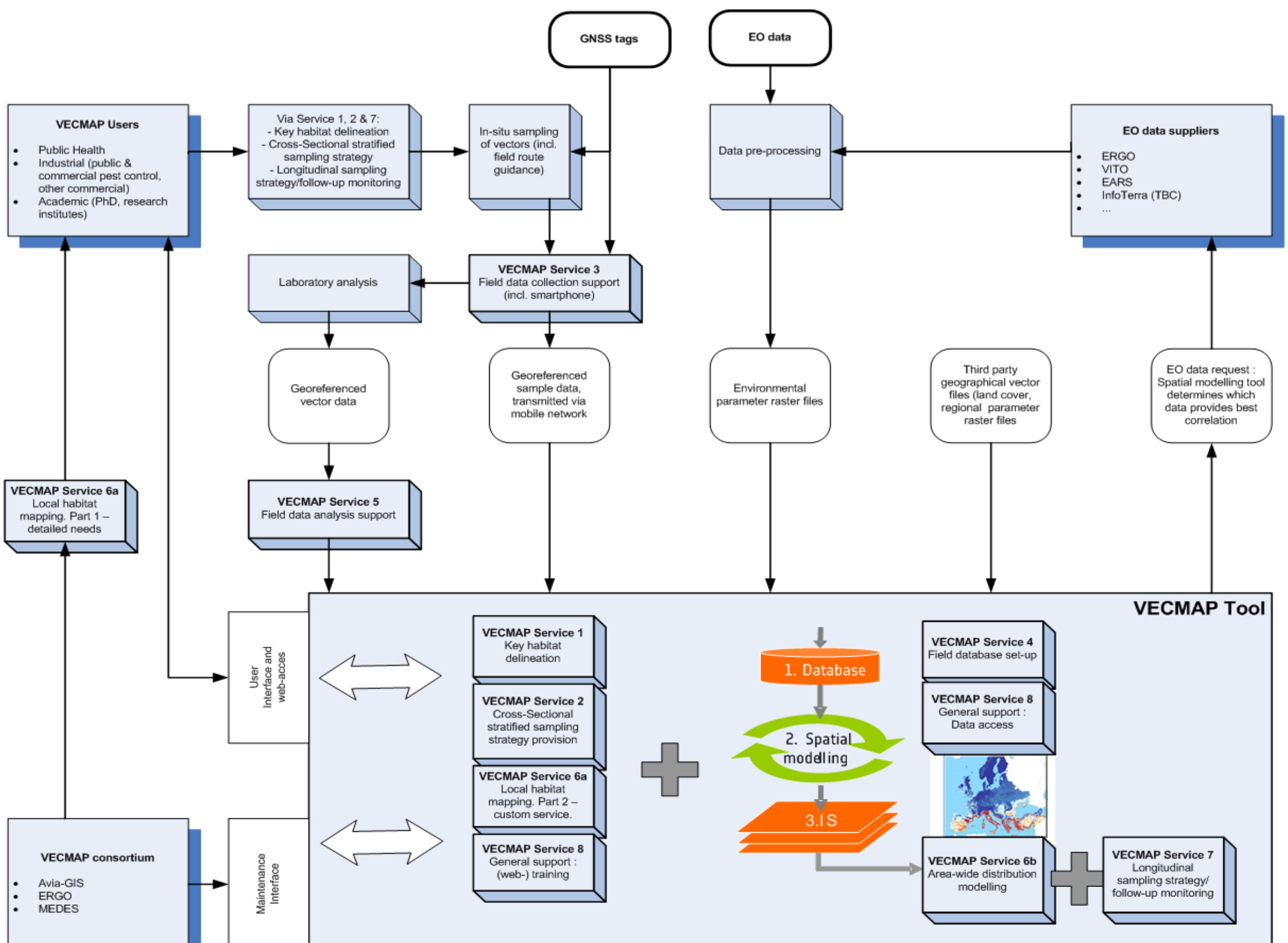

Figure 12. VECMAP system and service architecture, user interaction and space assets involvement

Service provision modes

Even if the services required by the various user groups are much alike, the manner in which they are to be offered depends on the distinct characteristics and available expertise that drive the manner in which these user groups are typically operating (Section III.1). VECMAP is therefore planned to be offered in three different service modes:

- **On-Premise Service Mode**
  Provided for advanced users who have all necessary expertise in-house and who wish to operate all VECMAP functionalities independently (primarily tailored to academics);

- **On-Demand Service Mode**
  For users who wish to operate part of the VECMAP functionalities in-house and require additional external expertise offered by the VECMAP consortium as a service (tailored to public health users);

- **Full-Service Service Mode**
  Provided for users who only require access to the final output: e.g. risk assessment maps. The VECMAP consortium acquires data, operates the system and generates customised outputs (tailored to industrial users).

III.4 Benefits and potential of VECMAP

VECMAP presents a 'One-Shop-Stop" that integrates the entire process of producing risk maps into a single enabling package that can be used by a much wider range of practitioners than is currently the case.

This integration into a single system of all stages required for sampling, modelling and risk mapping, and data archiving, ensures technical compatibility of all data sources, as well as the provision of regular updates where necessary, and specialised support. It demystifies the methodologies, guarantees continued access to state of the art techniques, and makes the outputs more transparent and thus more applicable. It also provides standardization for data sharing and efficient access to historical records.

VECMAP allows a reduction in field work and data retrieval and pre-processing. Sampling strategies for modelling or monitoring can be optimised to use the minimum resources needed to achieve a predefined level of reliability. Modelling implementation is streamlined and simplified with no loss of accuracy. Data pre-processing needs are largely removed, enabling clients to commit more resources to producing outputs rather than to processing overheads.

This allows the users to focus on data analysis.

VECMAP service can readily be used to map other targets than the mosquitoes for which the prototype is currently tailored. This includes the distribution of anything that is primarily determined by the environmental and demographic factors fed into the modelling process and is global in scope, e.g. other vectors such as ticks and Culicoides (biting midges), as well as a wide range animal or human diseases.

Future users may thus include private companies such as insurance companies, pharmaceutical companies and insecticide producers to quantify the risks and thus the potential markets they represent.

VECMAP thus is both 'enabling' – by making state of the art techniques available to non-specialists, and 'enhancing' – by improving efficiency and cost effectiveness for those who can use some of the methods and resources that currently exist.

Surveying and mapping vectors thus becomes affordable and resources are freed to conduct other related research activities, to improve scientific quality or to expand surveys to new areas and/ or other species.

IV. DEMONSTRATION PROJECT

During the Demonstration Project, started recently, the VECMAP system prototype will serve as a basis for services to be developed and matured up to an operational stage, and then demonstrated under field condition. The three types of service provision will be refined and deployed. In addition, dedicated services will be developed and validated for high resolution vector monitoring and control, in particular regarding resource optimization, presence/abundance mapping and prediction.

A number of available prototype systems will thus be improved. The prototype sampling strategy system elements will be further developed and its applicability extended to obtain meaningful results for disease vectors other than mosquitoes. The same holds true for the smart-phone-based field data collection system that provide field data entry functionalities. Furthermore, a single centralized, secure data archive will be created within the information system. The Earth Observation system data will require updating and maintenance to ensure time series are fully up to date when VECMAP is launched, and in addition to the other EO data sources, the MERIS imagery will be acquired, processed and evaluated. The distribution modelling system tool will be enhanced to include additional capabilities and will be fully integrated with the other systems.

A largely new development will be the habitat mapping service of the mosquito landscape mapping system, which will be designed, developed and validated. For this, a dedicated toolset will be built, including high-resolution geographical data processing and analysis algorithms and software.

Data representation tools and the necessary analysis environment will be further tailored to user needs. Furthermore, services will be developed that interact with the system and the user requiring development of software, service centre infrastructure, operational procedures, manuals and other documentation for the users.

V. CONCLUSION

The VECMAP IAP Feasibility Study prototyped a system that optimizes the required resources for mosquito mapping field and laboratory work, mosquito mapping and distribution modelling, tailored for public health, industrial (pest control) and academic users.

Using geo-referencing techniques and mobile communication technologies, field data are automatically fed into the prediction model. In addition, state-of-the-art space imagery is routinely processed to support the modelling, thereby alleviating field work. On a case-by-case basis, high resolution remote sensing data is used to assess critical issues more closely (e.g. weather data, state of water bodies). The system provides assistance to clients where needed and acts as a secure and consistent, web-accessible data archive for the inputs and outputs. It has been validated with the VECMAP users in a Proof of Concept, and will now be made operational through an IAP Demonstration Project.

Presence and abundance of disease vectors can be better predicted and controlled with the support of a range of available integrated elements: remote sensing data (Earth Observation), Satellite Navigation, handheld smart devices, terrestrial communication networks, a database, modelling tools and an information system.

---

[1] ECDC communication on vector-borne diseases, http://www.world-television.se/world_television.se/mnr_stat/mnr/ECDC/431/index.php#

[2] ECDC project TigerMaps, http://www.avia-gis.com

[3] Modirisk project, http://www.modirisk.be, http://modirisk.avia-gis.com

[4] ESA DUE project Epidemio Final Report to ESA contract 17809/03/I-LG, http://dup.esrin.esa.it/projects/summaryp60.asp

[5] DG SANCO – ESA workshop on “Initiative for Generating Operational Risk Maps for Communicable Diseases using Integrated Space and Non-space Assets” (Oct. 2007)

[6] ESA “Mosquitoes' habitat mapping” workshop (Oct. 2008)