Title: Exploring *feasible*, *functional* and *usable* **Open Source Geo Spatial Information Systems (GIS)** and **Remote Sensing Technologies** in the context of protecting elephants.

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Abstract:

Elephants are fast disappearing in Africa. Geo Spatial Information Systems based on GPS and remotely sensed data are increasingly used to study African elephants in an effort to protect the species from poaching and Human Elephant Conflict (HEC). Although advances in GIS technology have made the visualization of biospatial data based on GPS and remote-sensing increasingly easier to achieve, there remains a need for *seamlessly* integrated *feasible*, *functional* and *usable* GIS capable of rich statistical analysis *as well as* location-based visualization.

In this study, *open source* GIS are evaluated with reference to *feasibility*, *functionality* and *usability*; a software prototype is developed using *BoundlessGeo,* a state-of-the-art full-stack Geo Spatial platform. The prototype is based on GPS data and is representative of a real-time monitoring system capable of the rapid assimilation and analysis of GPS and remotely sensed biospatial data. The prototype is -seamlessly- integrated with the R-statistical package; R offers a functionality-rich statistical-analysis platform absent in the native *BoundlessGeo* stack.

The *feasibility*, *functionality* and *usability* of the prototype is discussed in the context of benefiting conservationists working to a budget and interested in affordable, state-of-the-art "GIS" processing of GPS and remotely sensed data. The prototype demonstrates *proof of concept* by managing, visualizing and analyzing spatial and biospatial data; it was tested using data points from GPS collared elephants in Cameroon

The study revealed problems inherent in installing, maintaining and enhancing Open Source GIS; the overriding difficulties stemmed from the deficiency of reliable and complete documentation specific to Apple's OS X operating system(s). The absence of dependable documentation forced meticulous and time-consuming research prior to installing software components required by the prototype; the procedure resulted in a sub-optimal, trial-and-error implementation process impacting feasibility. Once a successful installation was realized the prototype functioned as expected, lending itself readily to enhancements and scaling. Optimal functionality, usability and feasibility may be better achieved by opting for *Commercial* or *Supported* Open Sources GIS over *free* Open Sources GIS. The creative "chaos" persistent in the evolution of Open Source software often renders it a laissez-faire enterprise, making the installation and use of *free* Open Source software a non-trivial initiative.

The study will consider future enhancement and scaling of the prototype for use on Cloud based, mobile, Unmanned Aerial Vehicle (UAV) and stand-alone platforms. These and other GIS-friendly technologies are critical in understanding and predicting the behavior of elephants in the context of ensuring their survival.

Open Source technologies can be excellent alternatives to their proprietary counterparts in developing GIS-based solutions for the protection elephants, however, careful consideration must be given to maintainability, retaining skill and on-going support.

Introduction

Elephants are fast disappearing throughout the planet. In 1979, Africa was home to more than 1.3 million elephants; those populations have now dwindled to roughly 400,000 individuals occupying increasingly smaller and fragmented Home Ranges throughout the continent (Douglas-Hamilton 2012c, Wasser, Clark and Laurie 2009a), as illustrated in **Figure 1** (Scriber 2014). Poaching (Wasser et al. 2010), human-elephant-conflict (Sitati et al. 2003) and global warming induced climate change (Holdo et al. 2010) qualify as major contributing factors to the rapid demise of elephants in the wild. The ecological impact from the loss of elephants is predicted to be serious. It is well established that elephants are a keystone species, dispersing seeds far and wide, excavating water wells and architecting the nature of forests, savannas and desert (Blake et al. 2009, Gaston and Fuller 2007, Wasser et al. 2010). A myriad species of endemic fauna and flora depend on the survival of elephants (Campos-Arceiz and Blake 2011).

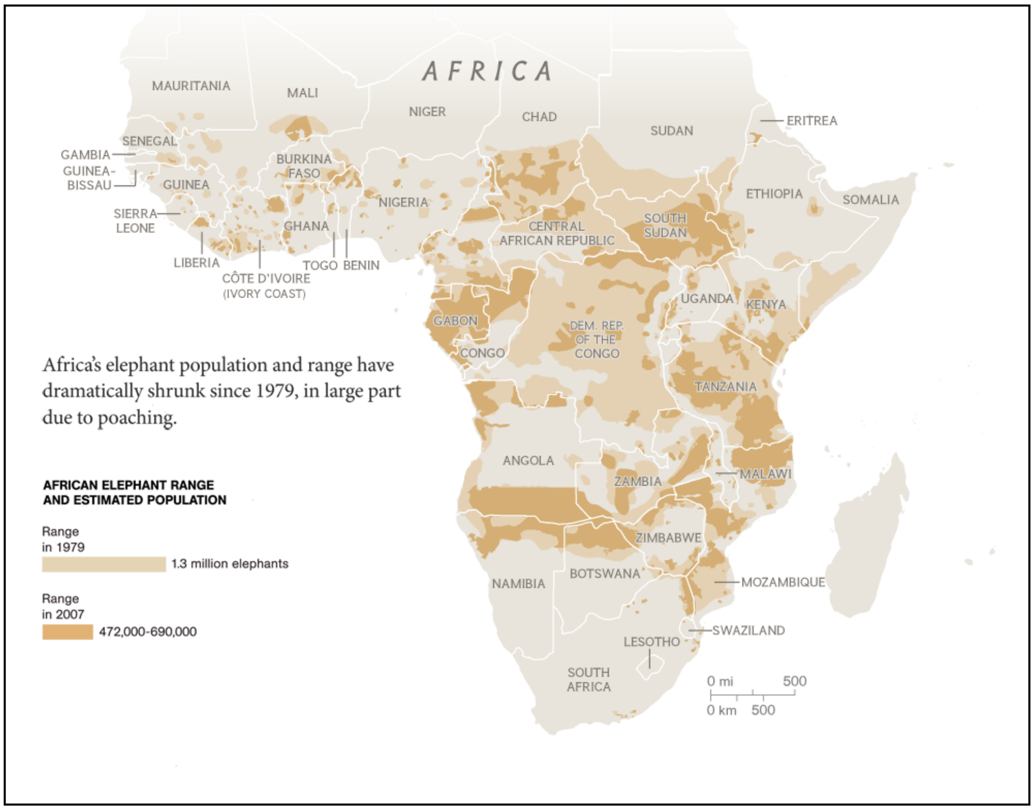


Figure 1: Africa's elephant population and range have dramatically shrunk since 1979, in large part due to poaching (National Geographic, 2012)

Poaching

Of the many factors contributing to the loss of elephants, none is as dramatic and as direct as poaching. In Africa, elephants are being killed in the thousands for their tusks (Wasser, Clark and Laurie 2009b) (Douglas-Hamilton 2012a, TheNewYorkTimes 2012); in 2011 alone more than 35,000 elephants were slaughtered to meet a growing demand for ivory in East Asia, primarily China (Fay and Nichols 2007, Gwin and Stirton 2012, Shoumatoff 2011). Much of the ivory is used ornamentally, carved into statuettes depicting a range of cultural and religious icons, deities and the like. In China, Asia and other regions where the ivory market thrives, owning ivory or ivory carvings engenders a "favored" or elevated social status (Fay and Nichols 2007, Gwin and Stirton 2012, Shoumatoff 2011).

Despite the persistent links between poaching and poverty (Duffy and St John 2013, Hickey and Magrath 2015, Joseph 2014), the recent escalation in poaching is largely influenced by the presence of heavily armed mercenaries operating within a context of well-organized black markets and major crime syndicates with international reach (Wasser et al. 2009a, Wasser et al. 2010). Administrative corruption in local agencies and African governments lacking the resources to provide an appropriate counter response compounds the problem (Vira and Ewing 2014). Over the span of just three years, poachers have killed 100,000 African elephants for their ivory, primarily for the trinket market in China and Asia (Fay and Nichols 2007, Gwin and Stirton 2012, Shoumatoff 2011). Elephant populations have reached a tipping point with more elephants being killed each year, than are being born (Morelle 2014). Lead author George Wittemyer (Wittemyer et al. 2014) from Colorado State University, said: "We are shredding the fabric of elephant society and exterminating populations across the continent" (Morelle 2014). In localized regions in Africa, elephants may be extinct within the decade (Maisels et al. 2013).

CITES (the Convention on International Trade in Endangered Species of Wild Fauna and Flora) was established in 1973 to manage the international trade in wild animals and plants and to ensure trade agreements did not jeopardize the survival of vulnerable species. In 1989, CITES imposed a ban on the international trade of ivory to combat the poaching frenzy of the 1980's (Anon 2007, Perlez 1989). At the time, Africa's elephant populations decreased by 50% from the demand imposed by international ivory markets (Anon 2015d, Anon 2015a, Lowery 1997, Douglas-Hamilton 2012b). The 1989 ban resulted in a mitigation of poaching and elephant numbers increased. Contrary to expectations, the price of ivory plummeted and the markets for ivory in Europe and Asia virtually died (Douglas-Hamilton 1992). Despite historical evidence of the efficacy of the ban, CITES temporarily lifted the ivory trade ban in 1999 and again in 2008 to permit "one-off-sales" of ivory to Japan and China. These sales ignited the "market" price, precipitating the current upsurge in poaching throughout the African continent (Anon 2015c, Christy 2012, Safina 2013).

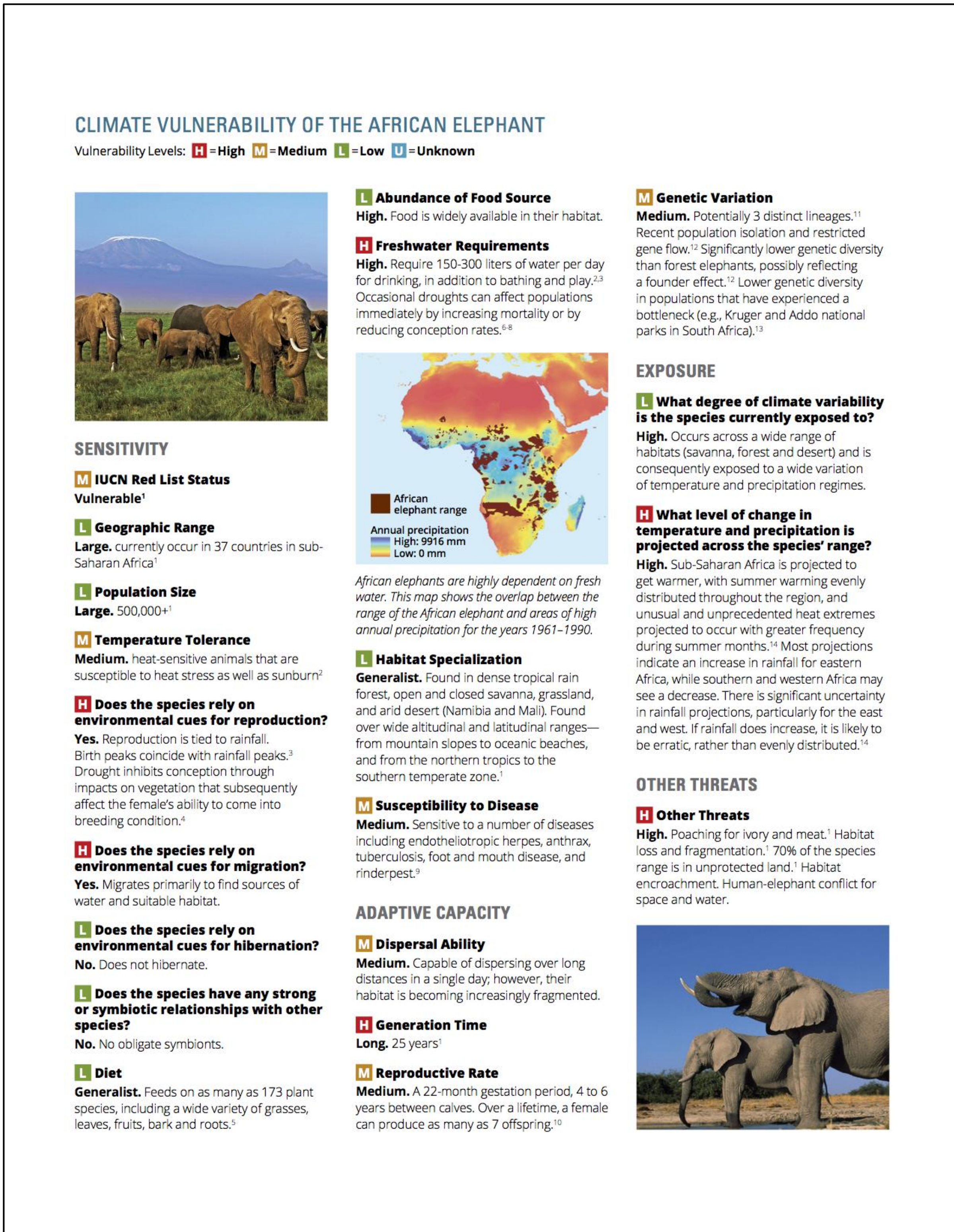
DNA fingerprinting of confiscated ivory stockpiles delivers a guaranteed mechanism to correlate areas of demand with source locations where ivory is poached (Wasser et al. 2009a, Wasser et al. 2010, Wasser et al. 2004). DNA signatures are derived at destination markets and cross-matched with DNA signatures from dung samples gathered throughout the African continent. Through the 'fingerprinting' process, geographic locations previously considered safe for elephants (e.g. Gabon and Tanzania) have been identified as "hot spots" for poaching (Wasser et al. 2009a, Wasser et al. 2010, Wasser et al. 2004). Gabon, Cameroon, the Central African Republic and adjacent nations represent a historical stronghold for forest elephants. These nations have lost more than 62% of their elephant population within the last decade (Maisels et al. 2013). It follows that forest elephants will disappear within the next ten years if poaching continues unabated in these regions (Maisels et al. 2013, Stiles 2015).

Human-elephant conflict (HEC)

Encroaching human populations pose a serious threat to elephants (Anon 2015f, Anon. 2015, Naughton, Rose and A. 1999). Unfettered human development abutting or within traditional elephant habitat leads to compromised elephant populations (Anon 2015f, Anon. 2015, Naughton et al. 1999). The loss of foraging terrain, migratory corridors and access to water are consequences of human infringement. The search for water and food may draw elephants away from impaired habitat and toward human settlements harboring water wells and attractive food crops. This behavior can lead to friction and increased rates of mortality from HEC (Anon 2015f, Anon. 2015, Naughton et al. 1999).

Climate Change

Changes in weather patterns stemming from global climate change can lead to localized droughts and erratic rainfall (Anon 2015e). Reproduction in elephants correlates to rainfall; birth and rainfall peaks coincide; droughts affect vegetation and correspondingly the capacity to breed (WWF 2015). As the planet continues to warm, temperature and rainfall projections for the African continent remain uncertain. Sub-Saharan Africa is projected to be warmer with occurrences of extreme heat in the summers, eastern Africa is likely to experience more rainfall and southern and west Africa is expected to see less (WWF 2015). Changes in weather are more likely to be inconsistent than predictably even (WWF 2015).



CLIMATE VULNERABILITY OF THE AFRICAN ELEPHANT

Vulnerability Levels: H =High M =Medium L =Low U =Unknown

SENSITIVITY

M **IUCN Red List Status**
Vulnerable[1]

L **Geographic Range**
Large. currently occur in 37 countries in sub-Saharan Africa[1]

L **Population Size**
Large. 500,000+[1]

M **Temperature Tolerance**
Medium. heat-sensitive animals that are susceptible to heat stress as well as sunburn[2]

H **Does the species rely on environmental cues for reproduction?**
Yes. Reproduction is tied to rainfall. Birth peaks coincide with rainfall peaks.[3] Drought inhibits conception through impacts on vegetation that subsequently affect the female's ability to come into breeding condition.[4]

H **Does the species rely on environmental cues for migration?**
Yes. Migrates primarily to find sources of water and suitable habitat.

L **Does the species rely on environmental cues for hibernation?**
No. Does not hibernate.

L **Does the species have any strong or symbiotic relationships with other species?**
No. No obligate symbionts.

L **Diet**
Generalist. Feeds on as many as 173 plant species, including a wide variety of grasses, leaves, fruits, bark and roots.[5]

L **Abundance of Food Source**
High. Food is widely available in their habitat.

H **Freshwater Requirements**
High. Require 150-300 liters of water per day for drinking, in addition to bathing and play.[2,3] Occasional droughts can affect populations immediately by increasing mortality or by reducing conception rates.[6-8]

African elephant range
Annual precipitation
High: 9916 mm
Low: 0 mm

African elephants are highly dependent on fresh water. This map shows the overlap between the range of the African elephant and areas of high annual precipitation for the years 1961–1990.

L **Habitat Specialization**
Generalist. Found in dense tropical rain forest, open and closed savanna, grassland, and arid desert (Namibia and Mali). Found over wide altitudinal and latitudinal ranges—from mountain slopes to oceanic beaches, and from the northern tropics to the southern temperate zone.[1]

M **Susceptibility to Disease**
Medium. Sensitive to a number of diseases including endotheliotropic herpes, anthrax, tuberculosis, foot and mouth disease, and rinderpest.[9]

ADAPTIVE CAPACITY

M **Dispersal Ability**
Medium. Capable of dispersing over long distances in a single day; however, their habitat is becoming increasingly fragmented.

H **Generation Time**
Long. 25 years[1]

M **Reproductive Rate**
Medium. A 22-month gestation period, 4 to 6 years between calves. Over a lifetime, a female can produce as many as 7 offspring.[10]

M **Genetic Variation**
Medium. Potentially 3 distinct lineages.[11] Recent population isolation and restricted gene flow.[12] Significantly lower genetic diversity than forest elephants, possibly reflecting a founder effect.[12] Lower genetic diversity in populations that have experienced a bottleneck (e.g., Kruger and Addo national parks in South Africa).[13]

EXPOSURE

L **What degree of climate variability is the species currently exposed to?**
High. Occurs across a wide range of habitats (savanna, forest and desert) and is consequently exposed to a wide variation of temperature and precipitation regimes.

H **What level of change in temperature and precipitation is projected across the species' range?**
High. Sub-Saharan Africa is projected to get warmer, with summer warming evenly distributed throughout the region, and unusual and unprecedented heat extremes projected to occur with greater frequency during summer months.[14] Most projections indicate an increase in rainfall for eastern Africa, while southern and western Africa may see a decrease. There is significant uncertainty in rainfall projections, particularly for the east and west. If rainfall does increase, it is likely to be erratic, rather than evenly distributed.[14]

OTHER THREATS

H **Other Threats**
High. Poaching for ivory and meat.[1] Habitat loss and fragmentation.[1] 70% of the species range is in unprotected land.[1] Habitat encroachment. Human-elephant conflict for space and water.

Figure 2: Climate Vulnerability of the African Elephant (WWF 2015)

Remotely Sensed Data

The best use of remotely sensed data in protecting elephants is derived from advances made in UAV

(Unmanned Aerial Vehicle) surveillance technologies integrated with satellite monitoring and predictive analytics. UAVs capable of processing infrared data streams with the capacity to fly at night can work in tandem with law enforcement units deploying rangers to poaching hot spots - in time to prevent incidents (Anon 2015g).

The institute for Advanced Computer Studies at the University of Maryland, working with stakeholders in South Africa has devised models to predict "potential poaching incidents" based on analytics that combine UAV data streams, satellite imagery and movement patterns governing rangers, poachers and animals with local weather, phases of the moon, previous incidents, proximity to roads and other pertinent variables effecting poaching (Anon 2015b).

An enhanced, fleshed out version of the full-stack Open Source GIS prototype described in this paper can be mounted on UAVs and housed in mobile ranger-units for the rapid assimilation of real-time data and real-time analytics contingent on trigger functions similar in concept to those described in **Figure 25**.

Geo Spatial Information Systems (GIS) for Elephants

The use of Geo Spatial Information Systems in elephant conservation is well established; GIS have been extensively used to monitor and study African elephants (Birkett et al. 2012, Douglas-Hamilton et al. 2006, Douglas-Hamilton and Ihwagi 2010, Leggett 2010, Thomas 2010). GIS have been useful in mapping Home Ranges (Ngene et al. 2010, Thomas, Holland and Minot 2012), analyzing movement patterns (Graham et al. 2009), identifying poaching hotspots (Maingi et al. 2012, Watson et al. 2013) and understanding human-elephant-conflict (Sitati and Walpole 2006, Sitati et al. 2003) . The efficacy of Geo Spatial Information Systems based on GPS and remotely sensed data have proved beneficial in numerous conservation applications; creating corridors between habitat fragments, establishing safer landscapes for elephants, increasing protection, influencing policy on behalf of safeguards and establishing more meaningful enforcement (Maingi et al. 2012, Wall et al. 2014). The study of elephants through GIS permit an evolving understanding and knowledge of remaining African elephant populations, particularly in the context of a "landscape of fear" (Henley and Henley 2015, Laundre, Hernandez and Ripple 2010) induced by poaching; an understanding that will be necessary to ensure the protection and survival of earth's largest terrestrial mammal (Maingi et al. 2012, Wall et al. 2014).

The case for Open Source GIS

In the not too distant past, visualization (mapping) using GIS was a complex task requiring specialized software and knowledge. This reality led to a gap in understanding between a GIS specialist's concept of a "map" and the average consumer's concept of a "map". Given that specialists where the first clients (or the "first market") for mapping tools, most GIS apps served the needs of the specialists; the ability to work with multiple layers, the ability to combine layers, the ability to manipulate data, add data and analyze data were all standard requirements demanded by the specialist. The average consumer represented a very different market; often it was just a single layer that needed visualization. Given the discrepancy in requirements, it became increasingly impractical for the average consumer to purchase, understand and use the same GIS software used by the "specialist"; the specialists' software imposed a steep learning curve, and was expensive. Even for the specialist, the overhead imposed by proprietary GIS packages was often cumbersome and daunting (Boundless 2015)

The requirements-gap was "solved" for the average consumer by Google Maps, Bing Maps and other similar apps, all of which delivered a plug-and-play *online* GIS platform unencumbered by of much of the functionality required by the specialists. These disruptive online mapping technologies revolutionized the GIS mapping market, causing the non-specialist to rapidly colonize the online mapping space. As this evolution progressed two interesting phenomena occurred: (a) the specialists using proprietary GIS packages recognized the inflexible and cumbersome nature of the software they relied on and began the search for elegance and simplicity, while (b): the average consumer began demanding richer functionality of their providers; the demand for simplicity and the demand for richer functionality converged. This fertile middle ground became an incubation center for the birth and growth of numerous online and standalone open source GIS packages serving the evolving needs of both the average consumer and the specialist (Boundless 2015).

Current Open Source GIS

Rapid advances in software technologies have made Open Source Geo Spatial Information Systems increasingly feasible (see for overview (Scharl et al. 2007)). These advances provide conservationists, scientists and interested non-specialists with a viable arsenal of sophisticated tools to map the current state of the African elephant with the intent of furthering its survival (Maingi et al. 2012, Wall et al. 2014). The rapidly evolving landscape of Open Source GIS is not easy to track (Brandt 2013); the matrix of available options is dynamic and large. Live.osgeo.org provides a mechanism to test a wide variety of Open Source GIS Software on a virtual machine (Brandt 2013, OSGeoLive 2015).

Table 1: Matrix of Open Source GIS (OSGeoLive 2015). The listing is non-exhaustive.

Type of OS GIS	Current Open Source GIS Packages Satisfying "Type"
Desktop GIS: *General GIS viewing, editing and analysis on the desktop*	http://live.osgeo.org/en/presentation/index.html#/3 QGIS, GRASS GIS, gvSIG, uDig, Kosmo, OpenJump, SAGA.
Brower facing GIS: *General GIS viewing, editing and analysis in the Browser*	http://live.osgeo.org/en/presentation/index.html#/4 **OpenLayers**, Leftlet, Cesium, GeoMajas, Mapbender3, GeoMOOSE, Cartaro, GeoNode.
Web Services: *Publishing spatial data to the internet*	http://live.osgeo.org/en/presentation/index.html#/5 **Geoserver**, MapServer, degree, ncWMS, EOxServer, GeoNetwork, pycsw, MapProxy, QGIS Server, 52 North WPS/SOS, TinyOWS, Zoo Project
Data Stores: *Storing special data*	http://live.osgeo.org/en/presentation/index.html#/6 **PostGIS** SpatialLite, rasdaman, pgRouting
Navigation and Maps	http://live.osgeo.org/en/presentation/index.html#/7 GpsDrive, GpsPrune, Marble, OpenCPN, **Open Street Map**, Viking, zyGrib
Spatial Tools: *Specific analysis tools*	http://live.osgeo.org/en/presentation/index.html#/8 GeoKettle, GMT, IPython Notebook, Mapnik, TileMill, MapSlicer, OSSIM, ORFEO Toolbox, **R**
Domain Specific GIS *Applications targeted at a specific domain*	http://live.osgeo.org/en/presentation/index.html#/9 Sahana, Ushahidi, osgEarth, MB-System
Data *Spatial data sets*	http://live.osgeo.org/en/presentation/index.html#/10 Natural Earth, Open Street Map, North Carolina, netCDF
Geospatial Libraries	http://live.osgeo.org/en/presentation/index.html#/11 **GDAL/OGR**, GeoTools, GEOS, MetCRS Proj4, libLAS, Iris, JTS

Type of OS GIS	Current Open Source GIS Packages Satisfying "Type"
Other Applications *Installers only*	http://live.osgeo.org/en/presentation/index.html#/12 MapWindow, MapGuide Open Source

Feasibility, functionality and usability in GIS

An analysis of a spectrum of conservation-ready GIS packages suitable for the study and protection of elephant populations reveal that proprietary GIS are not only expensive, but also challenging to scale on demand (Boundless 2015). *Plug and play* open Source GIS packages (e.g. QGIS, MapWindow, gvSig and others - see **Table 1**) represent an evolution in this regard. However, they too are constrained by legitimate handicaps in the context of functionality, feasibility and usability. In an illuminating presentation, Shane Brandt, a geospatial extensions specialists at the University of New Hampshire, evaluated the relative merits of various *plug and play* Open Source GIS packages. They all fare extremely well on the *feasibility* scale (Brandt 2013) and most are satisfactory on the *functionality* scale, however, they remain constrained with respect to usability (Boundless 2015). Consider, for example, enhancing the functionality of a plug and play Open Source GIS to include specific types of statistical analyses such as the determination of home-ranges using Minimum Convex Polygon, or Kernel methods over a preferred range of parameters. The search for a solution leaves the user at the mercy of the open source community, incompatible plugins and assorted web resources. Often the search for an optimal solution is time consuming and yields unsatisfactory results.

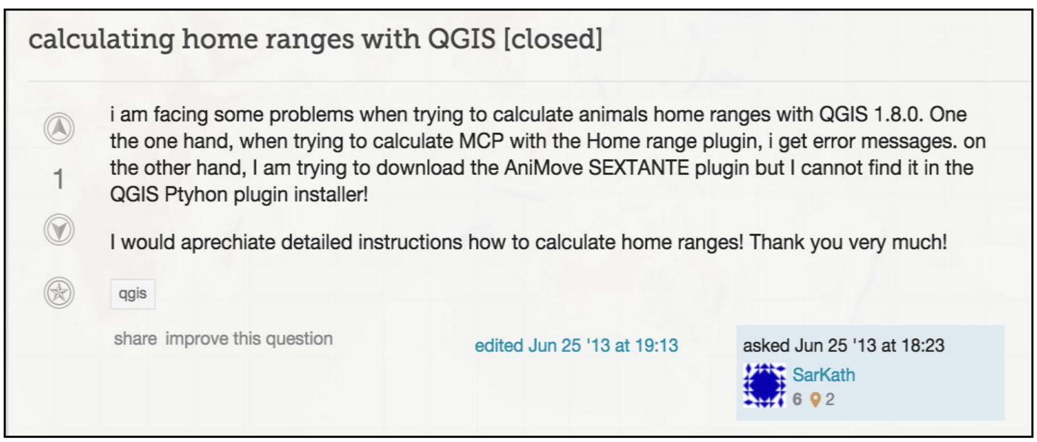


Figure 3: Searching for a compatible QGIS plugin to calculate MCP Home Ranges; often the search for an optimal solution is time consuming and yields unsatisfactory results (Stackexchange, http://gis.stackexchange.com/questions/64405/calculating-home-ranges-with-qgis, 2013).

The performance of Open Source Geospatial Information Systems with reference to feasibility, functionality and usability depends on the particular type of Open Source GIS (Boundless 2015). Referencing its own GIS package, the *OpenGeo Suite* as a case study, (a popular Open Source GIS startup, *Boundless)* (http://boundlessgeo.com/) evaluated three categories of Open Source Geospatial Information Systems: (a) *Closed Source* (b) *Unsupported Open Source* and (c) *Commercial Open Source.* The evaluation was done with reference to *Functionality* (F), *Feasibility* (O) and *Usability* (C). See **Figures 4** and **5**.

Results from the evaluation by Boundless suggest that commercial Open Source Geospatial Information Systems offer the most optimal solutions for conservation organizations on constrained budgets (Boundless 2015).

Many commercial Open Source GIS offerings also provide an unsupported (zero cost) option; if chosen, the user must be willing and capable of installing, enhancing, scaling and managing the GIS herself (Boundless 2015). Save the Elephants (http://savetheelephants.org/), Elephants Alive (http://elephantsalive.org/) and the Atlas of Living Australia (http://www.ala.org.au/, https://youtu.be/3GBqeEXII4U,) are amongst the many conservation organizations using free, Open Source GIS successful (Henley and Henley 2015, Jackson 2011, Wall et al. 2014).

The Value of the OpenGeo Suite Versus Alternatives

The formula [**V = (F/O) * C**] provides a mechanism to assess the value of commercial open source (the OpenGeo Suite) versus closed and unsupported open source alternatives. As the equation must stay in balance, increasing **F** (Functional Power) or **C** (Control and Choice) or decreasing **O** (Operational Costs) will result in greater **V** (Value). Table 1 (below) outlines the relative position of closed source, (unsupported) open source and commercial open source (the OpenGeo Suite) on the value elements outlined above.

Table 1	Closed Source	Unsupported Open Source	Commercial Open Source: OpenGeo Suite
Functional Power, F	*Medium high* Strong functionality offset by lower reliability and scalability.	*Medium* Reliable and scalable.	*Medium high* High reliability and scalability. Expanding functionality.
Operational Costs, O	*High* Software license costs + maintenance costs + high infrastructure costs due to poor scalability.	*Medium* No software license costs, but all maintenance costs are left to users. Good scalability resulting in lower scalability costs.	*Low* No software license costs. Expert support lowers maintenance costs, and strong scalability lowers infrastructure costs.
Control, C	*Low* Closed source leads to asymmetrical relations with customers and lowers customer control and choice	*Medium* Offers a solid alternative to closed source. Do it yourself, or hire as needed.	*High* Adds to control and choice by creating an excellent third option for enterprises, the ability to modify on your own and/or have access to OpenGeo resources.

Figure 4: An evaluation of functionality (F), feasibility (O) and usability (C) with reference to Closed, Open and Commercial Open Source GIS (Boundless 2015).

Comparing Value for Software Alternatives

Based on the relative positions outlined in Table 1(above) for factors, **F**, **O** and **C**, the relative values of Closed Source, unsupported open source and commercial open source (the OpenGeo Suite) can be determined (see Table 2, below).

Table 2	Closed Source	Unsupported Open Source	Commercial Open Source: OpenGeo Suite
Functional Power, F	*Medium high*	*Medium*	*Medium high*
Operational Costs, O	*High*	*Medium*	*Low*
Control, C	*Low*	*Medium*	*High*
Relative Position on V = F/O * C	Medium Low	Medium	*High*

For Closed Source the ratio of **F/O** works out to be fairly poor, as medium high *Functional Power* is diminished by high *Organizational Costs*. Then that is compounded by the poor score on *Control* (no choice, a lot of unhackability/vendor lock-in, etc.) to end up at a Value position estimated at Medium Low. For unsupported open source all factors are Medium, for an overall Value of Medium. And for the the commercial open source alternative, the OpenGeo Suite the added **F** *(Functional Power)* provided by OpenGeo combines with reduced **O** *(Organizational Costs)* from expert, enterprise-class support to create an outstanding **F/O** ratio.

Figure 5: An evaluation of functionality (F), feasibility (O) and usability (C) with reference to Closed, Open and Commercial Open Source GIS (Boundless 2015).

An Open Source, Seamless GIS Prototype Capable of Rich Analysis

Boundless offers an OGC (Open Geospatial Consortium, http://www.opengeospatial.org/) compliant, Open Source, seamlessly combined, full stack GIS through its OpenGeo suite (Boundless 2015) the package is offered under the Creative Commons license (https://creativecommons.org/licenses/).

A functional disadvantage of the OpenGeo suite is the absence of an integrated and robust analysis package. The R Project for Statistical Computing offers the potential for comprehensive spatial and statistical analysis (R-Project 2015); R can be integrated with the spatial database layer of the OpenGeo stack. The *adehabitat* suite of libraries forming part of the R tool-set delivers rich functionality to analyze the behavior of migratory wildlife (Calenge 2015).

- *adehabitatHR* package provides classes and methods for dealing with Home Range analysis in R.
- *adehabitatHS* package provides classes and methods for dealing with habitat selection analysis in R
- *adehabitatLT* package provides classes and methods for dealing with animal trajectory analysis in R.
- *adehabitatMA* package provides classes and methods for dealing with maps in R.

By integrating R with the OpenGeo's database layer, we developed an Open Source GIS prototype, specifically tuned to monitor, study and visualize the behavior of elephants in the context of a "landscape of fear". The prototype is based on GPS derived location data (and meta data) from collared elephants.

The OpenGeo Suite Architecture

The OpenGeo Suite architecture is modularized. Any component of the stack can be replaced with any other OGC compliant GIS module that is functionally analogous; e.g. GeoServer can be replaced with MapServer; see **Table 1** and **Figure 6** (Boundless 2015).

- **Storage:** Raw data needs to be managed in a consistent read/write data store, a relational database. OpenGeo Suite uses the PostGIS spatial database. Other options include SQL Server, Oracle Spatial and DB2.
- **Application server:** The raw data needs to be accessed using web services, and rendered into cartographic products. OpenGeo Suite uses the GeoServer map/feature server. Other options include ArcGIS Server, MapGuide, and MapServer.
- **Application cache:** Performance requires the caching of intermediate results, such as map files. OpenGeo Suite uses the GeoWebCache tile cache. Other options include TileCache, ArcGIS Server and MapGuide.
- **User interface framework:** Targeted vertical applications serve one operational need and serve it well. OpenGeo Suite uses GeoExt/ExtJS as a platform independent user interface toolkit. Other options include FLEX and Silverlight.
- **User interface map component:** Mapping applications need a map component that understands spatial features and map layers. OpenGeo Suite uses OpenLayers. Other options include Google Maps API and Bing Maps API.

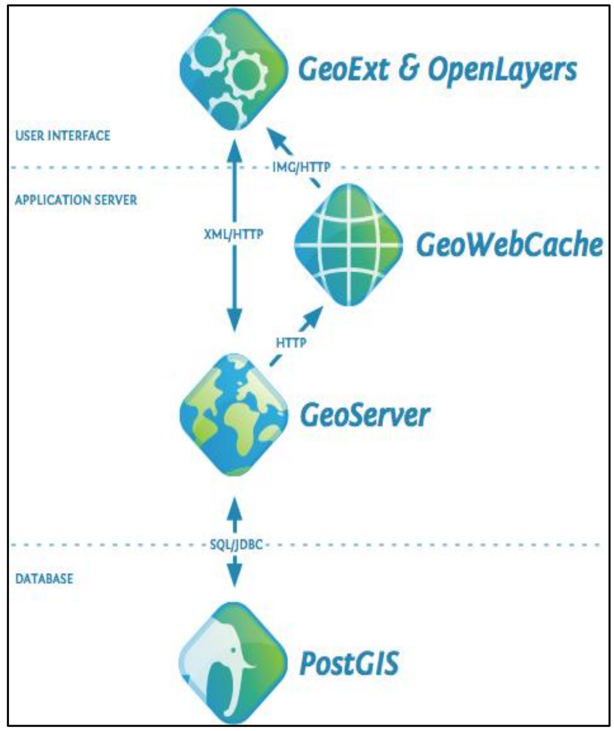


Figure 6: The OpenGeo Suite Architecture; any component of the geo stack can be replaced with any other OGC compliant GIS module that is functionally analogous (Boundless 2015).

Methods

The prototype used ***PostGIS*** (***PostgreSQL***) integrated with the ***R*** statistical package at the Database level, ***GeoServer*** at the Application Server level, and ***GeoExt*** with ***OpenLayers*** at the User Interface level; by running the webserver (GeoServer) on port 8080 at localhost:8080, it is possible to run the prototype as an off-line application in the event of a loss of connectivity.

Installation

The installation process, in general, held to the following:

1. Install Boundless' OpenGeo Suite (boundlessgeo.com/); a seamlessly integrated configuration of PostGIS/PostgreSQL spatial database, GeoServer, GeoWebCache, OpenLayers and GeoExt (Boundless 2015).

Figure 7: OpenGeo Suite (Boundless, 2015)

2. Using *Homebrew,* (https://github.com/Homebrew/homebrew) install the GDAL/OGR library (Geospatial Data Abstraction Library, see **Table 1**). GDAL/OGR is used by the R statistical package.
3. Using Homebrew, install the R library (The R Project for Statistical Computing, https://www.r-project.org/). R is integrated with PostGIS/PostgreSQL in #4.
4. Install PL/R (The Procedural Language for R, http://www.joeconway.com/plr/doc/) ensuring it is configured correctly to interface with the PostGIS/PostgreSQL installation in #1. PL/R is a language that supports writing PostgreSQL functions and triggers. It is the interface between the R library installed in #3 and the PostGIS/PostgreSQL installation in #1. PL/R offers access to most of the functional capabilities found in the R language (Conway 2015).
5. Install PgAdmin (http://www.pgadmin.org/). PgAdmin serves as a secondary means of managing the data and the database.
6. *Optionally install QGIS (http://qgis.org/en/site/) for visualizing the data in the database.*

Data

The location based readings (i.e. longitude and latitude) and derived from GPS collared elephants in Cameroon (Park 2015); all data sets are obsolete, ensuring the safety of the animals. The data are in CSV, XML and JSON formats and include the *Names* (of the elephants), *Level of Confidence Codes* (specifying the integrity of the GPS readings), the *GPS-readings* (longitude, latitude), *Times (of the reading)* and in some cases the *GPS Collar IDs*. A *Level of Confidence Code* (LC) value of "3" represents the most accurate data, with "2" and "1" being less accurate. An LC measure of "A" or " B" is generally less accurate than "1," though either can be acceptably accurate (Park 2015).

Table 2: Base map data (layers) are from *Open Street Map* (https://www.openstreetmap.org). Cameroon data (layers) were sourced as shown:

SHAPEFILE (DATA SET)	DESCRIPTION	SOURCE
CMR_adm0.shp	Cameroon’s boundary	http://www.gadm.org/country
CMR_adm2.shp	Cameroon’s administrative regions	http://www.gadm.org/country
TCD_adm0.shp	Chad’s boundary	http://www.gadm.org/country
NGA_adm0.shp	Nigeria’s boundary	http://www.gadm.org/country
COG_adm0.shp	Congo’s boundary	http://www.gadm.org/country
CAF_adm0.shp	Central African Republic’s boundary	http://www.gadm.org/country
GAB_adm0.shp	Gabon’s boundary	http://www.gadm.org/country
forest.shp	Cameroon’s forests and protected areas	http://cameroun-foret.com/
zics.shp	Cameroon’s hunting areas	http://cameroun-foret.com/
cameroon_highway.shp	Cameroon’s roads	http://downloads.cloudmade.com/
cameroon_water.shp	Cameroon’s hydrology	http://downloads.cloudmade.com/
cameroon_poi.shp	Cameroon’s points of interest (airports, govt. agencies etc.)	http://downloads.cloudmade.com/

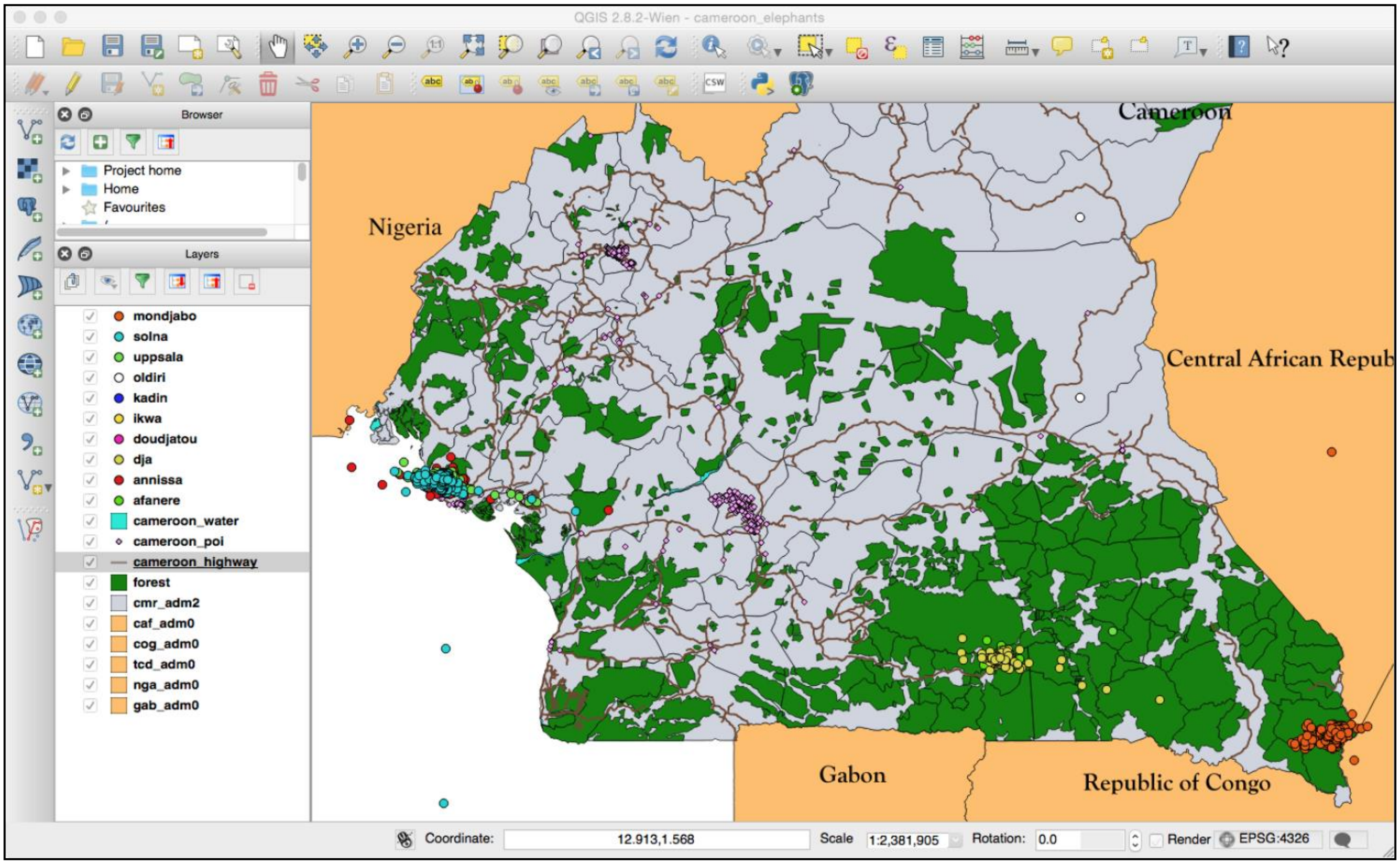


Figure 8: Cameroon is politically unstable and home to rampant poaching. The green patches represent fragmented forests, and the variously colored "dots" are the GPS derived locations of collared elephants whose names appear in the QGIS legend on the left. Some of the GPS readings are (obviously) invalid; e.g. Solna, Uppsala and Anissa are (sometimes) in the Ocean! In these cases the Level of Confidence (LC) Code representing the location will indicate a GPS reading lacking integrity.

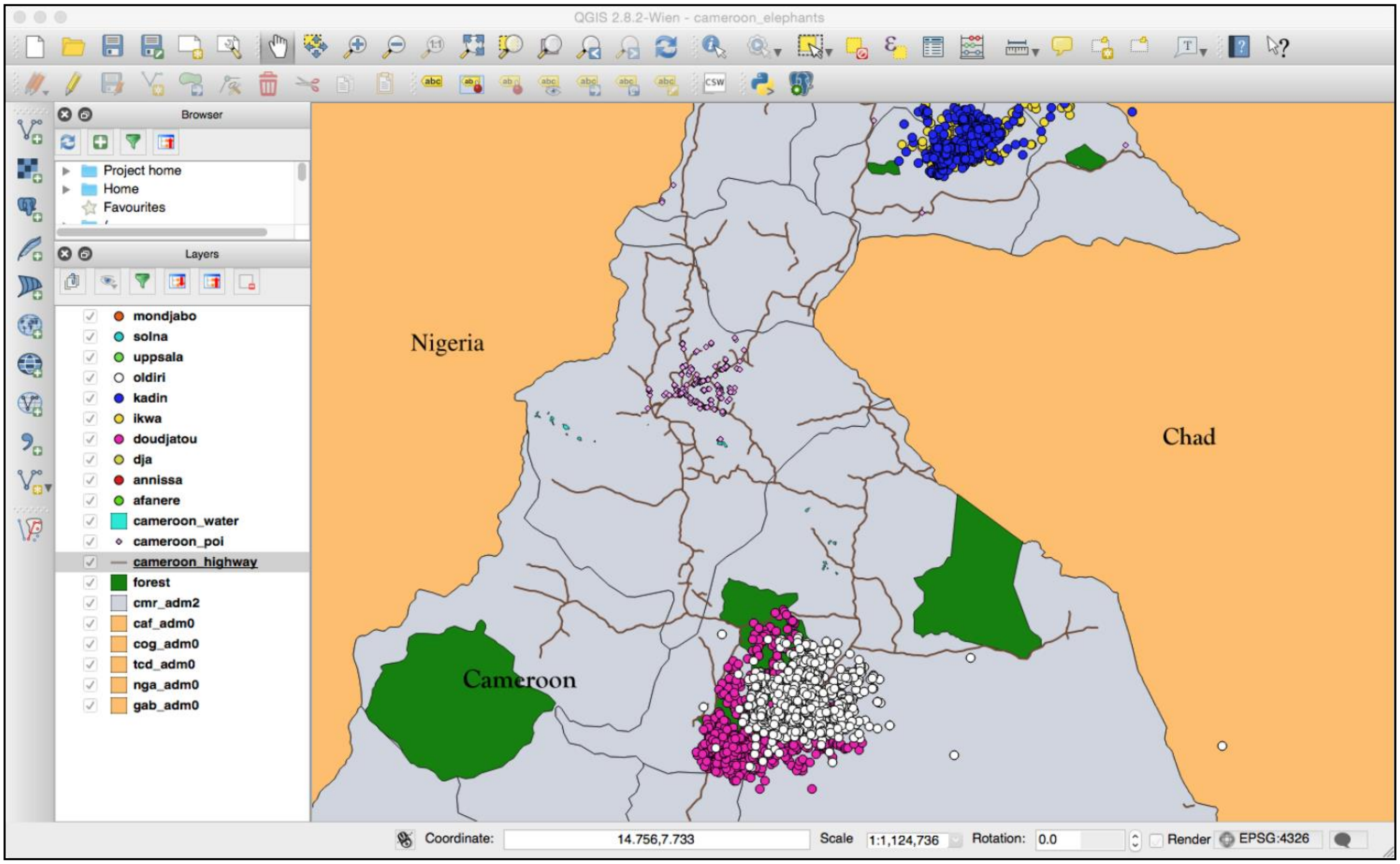


Figure 9: Bouba Ndjida National Park (on the far right) in Cameroon is the site of one of the most brutal elephant massacres in recent years. In 2012, over a span of three months, poachers slaughtered 650 elephants.

Configuring the database

The PostGIS/PostgreSQL database is configured as follows:

1. Create and configure the database; include the PostGIS extension which lends the database a *spatial dimension* "optimized to store and query data representing objects defined in geometric space" (wiki 2015). The 2 dimensional (longitude, latitude) or 3 dimensional (longitude, latitude, elevation) "point" returned by a GPS reading is an example of an object defined in geometric space.
2. Create and configure the database tables.
3. Load the data into the database tables.
4. Create and populate spatial/geometry columns representing the GPS readings, or "points" described in #1.
5. Create an R extension for the database using PL/R. The extension empowers the database with the capacity to deliver rich statistical analysis on demand.
6. Generate and add analysis functions to the database using PL/R; run these functions against the spatial database and create tables of results, such as, a table of MCP Home Ranges for all elephants.

The next series of images demonstrate points #1 through #6 using pgAdmin.

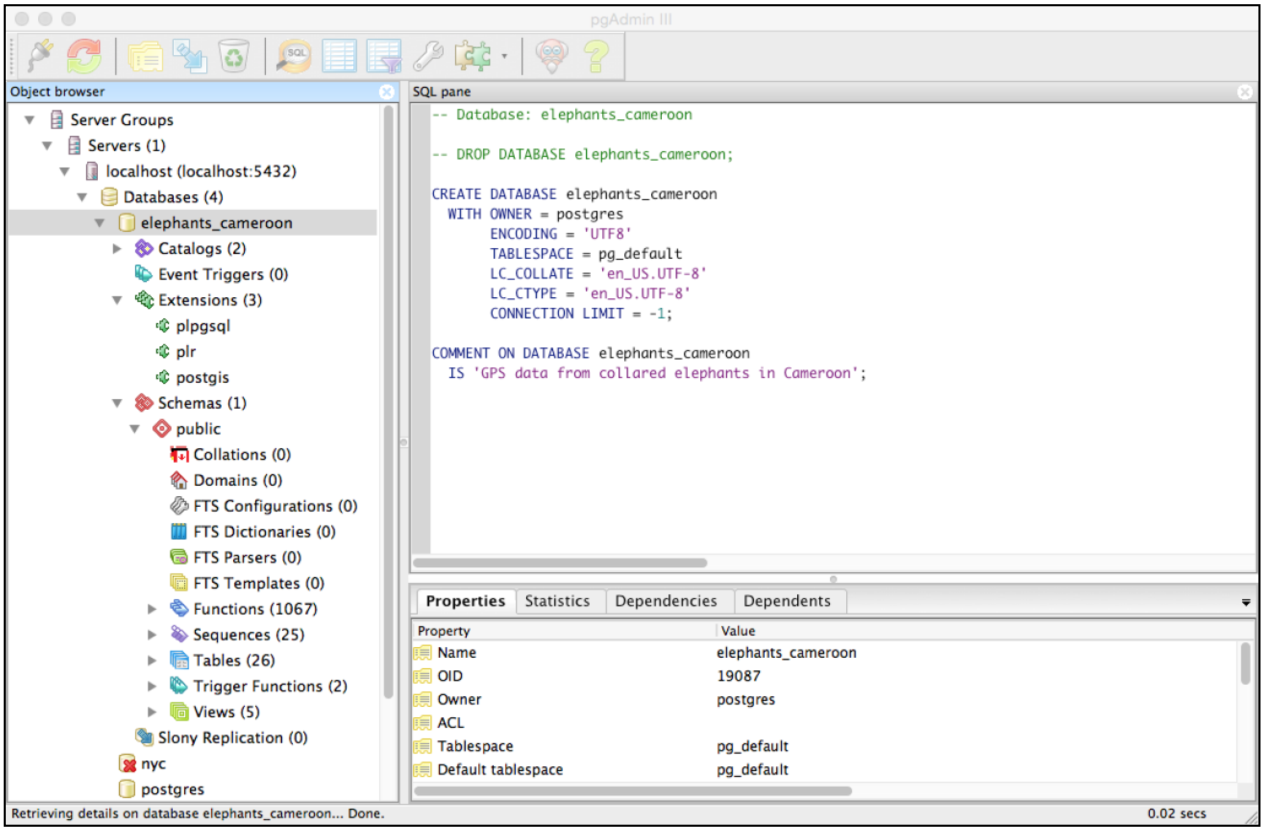


Figure 10: Database with PostGIS 'spatial' extension.

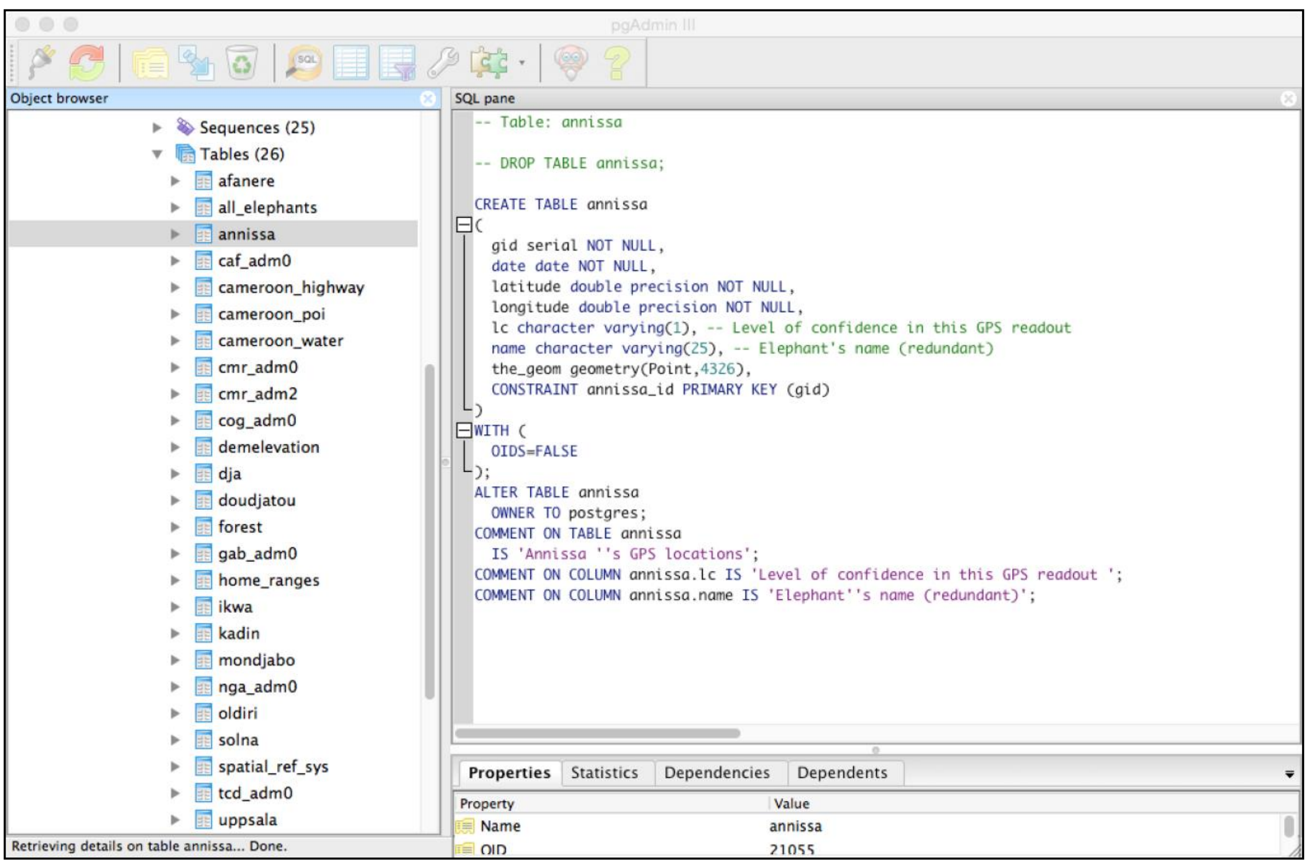


Figure 11: Tables in the spatial database; note the geometry columns representing the GPS readings, or "points".

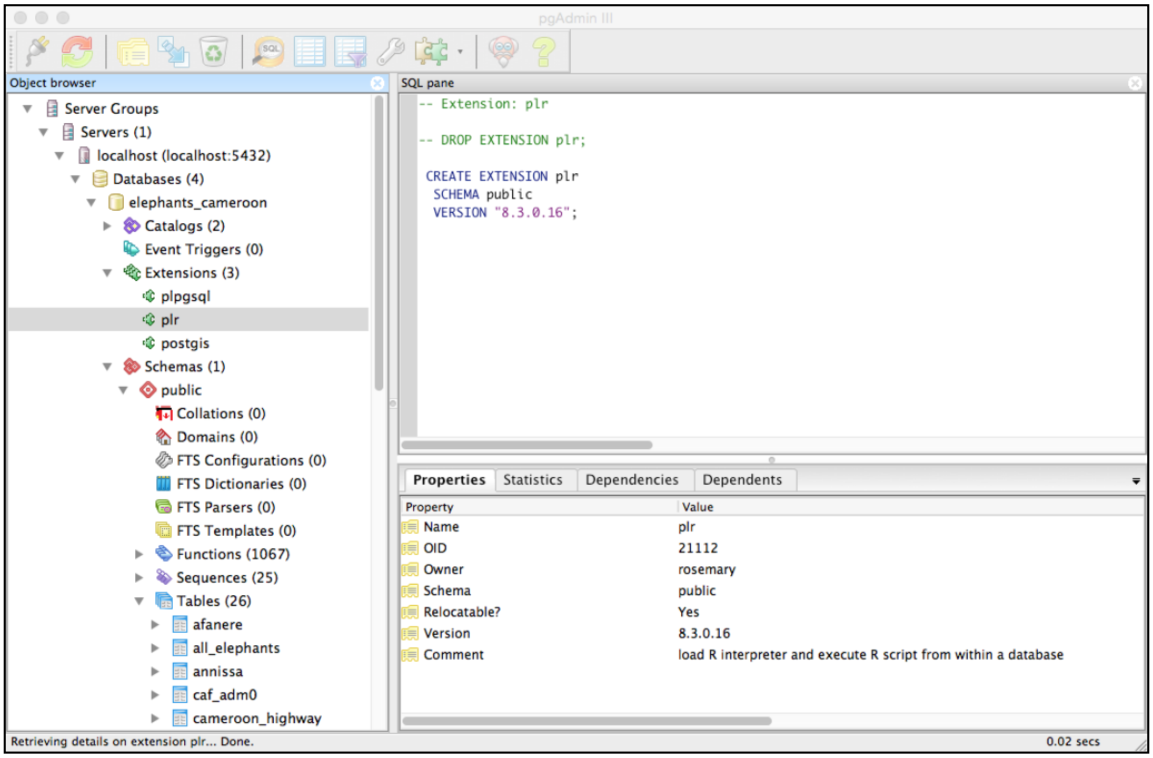


Figure 12: Database with the PL/R extension; PL/R interfaces with the R statistical package, providing access to its *adehabitat* suite of libraries. These libraries deliver rich functionality to analyze the behavior of migratory wildlife.

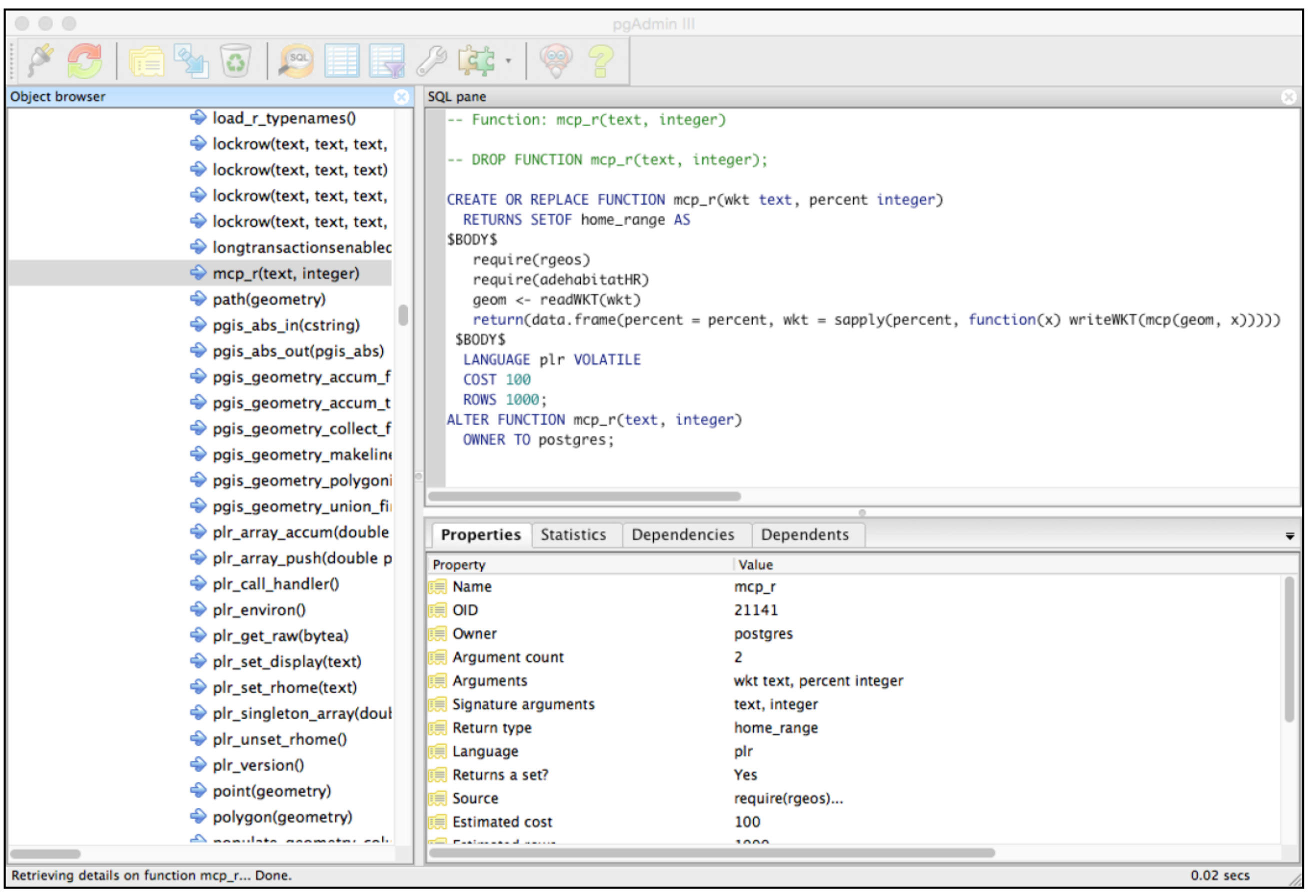


Figure 13: Create a series of functions (e.g. a Minimum Convex Polygon method for Home Ranges) in PL/R to access the rich statistical functionality offered by R (Urbano and Cagnacci 2014).

```
Create the function: (and see attached) - Minimum Convex Polygon

CREATE TYPE home_range AS (percent int, wkt text);


CREATE OR REPLACE FUNCTION mcp_r (wkt text, percent integer)
 RETURNS SETOF home_range AS
 $BODY$
   require(rgeos)
   require(adehabitatHR)
   geom <- readWKT(wkt)
   return(data.frame(percent = percent, wkt = sapply(percent,
function(x) writeWKT(mcp(geom, x)))))
 $BODY$
 LANGUAGE plr;

_______________________________________

-- Table: home_ranges

-- DROP TABLE home_ranges;

CREATE TABLE home_ranges AS
WITH
 mcpr AS (
 SELECT name, (mcp_r(ST_AsText(ST_Collect(the_geom)), 90)).*
 FROM all_elephants
 WHERE lc <> 'A' AND lc <> 'B'
 GROUP BY name)
 SELECT
  mcpr.name, mcpr.percent, mcpr.wkt
  FROM  mcpr;

[Then add a serial id, as PRIMARY key and the geometry field as a polygon]

select AddGeometryColumn('home_ranges', 'the_geom', 4326, 'POLYGON', 2);

UPDATE home_ranges SET the_geom = ST_GeomFromText(wkt,4326);
```

Figure 14: Generate and add analysis functions to the database using PL/R; run these functions against the spatial database and create tables of results, such as a table of MCP Home Ranges for all elephants.

Configuring GeoServer

GeoServer (see **Figure 6**) is a java based software server built on GeoTools (GeoTools 2015). The server responds to requests for accessing, viewing and editing geospatial data adhering to OGC (Open Geospatial Consortium) standards. It provides a highly flexible interface for visualizing and sharing data using the Web Map Services (WMS) and Web Feature Services (WFS) protocols (Boundless 2015, GeoTools 2015).

For the purpose of the prototype, GeosServer was configured as follows: (an in-depth exploration of each of these elements is beyond the scope of this document.)

The Server runs on *localhost* at port 8080. Visualization is rendered through a web browser.

1. Create a workspace(s); a workspace is a container which organizers other items, such as data stores (#2) and layers (#3).
2. Create data stores; these are handles used to access the spatial database.

3. Create the layers; these may incorporate SQL queries, functions and views which work to filter the data, returning data sets satisfying specific criteria requested by the user, such as GPS data satisfying the MCP Home Range filter for a specific elephant or a herd.
4. Create any relevant style sheets (using SDL) for the display of maps and features by way of the layers defined in #3.

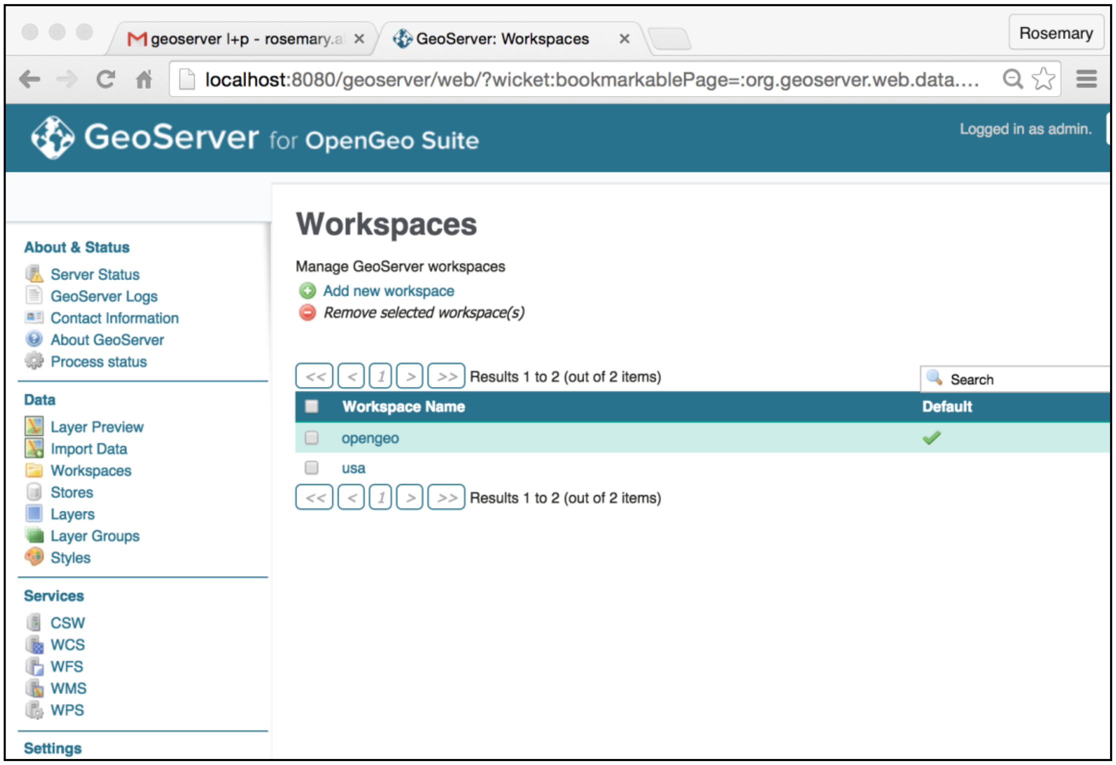


Figure 15: GeoServer: Workspaces; of interest is *opengeo*.

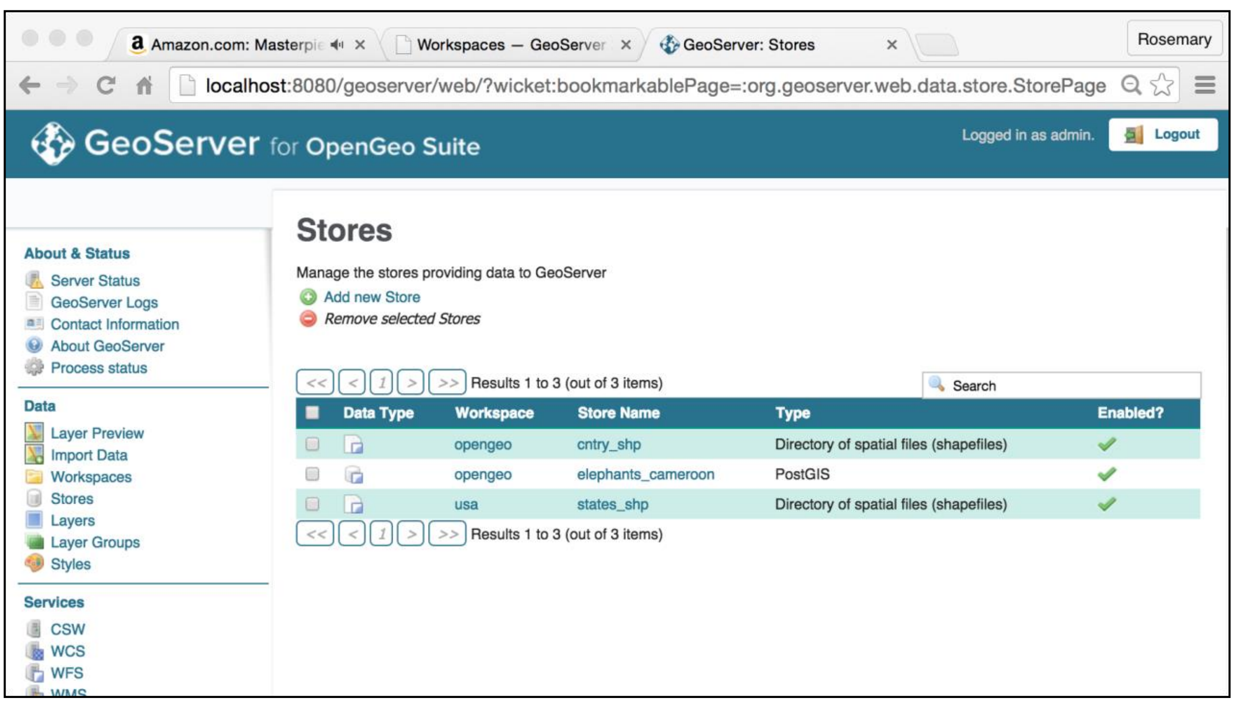


Figure 16: GeoServer: Stores; of interest is *elephants_cameroon* which is attached to the PostGIS spatial database.

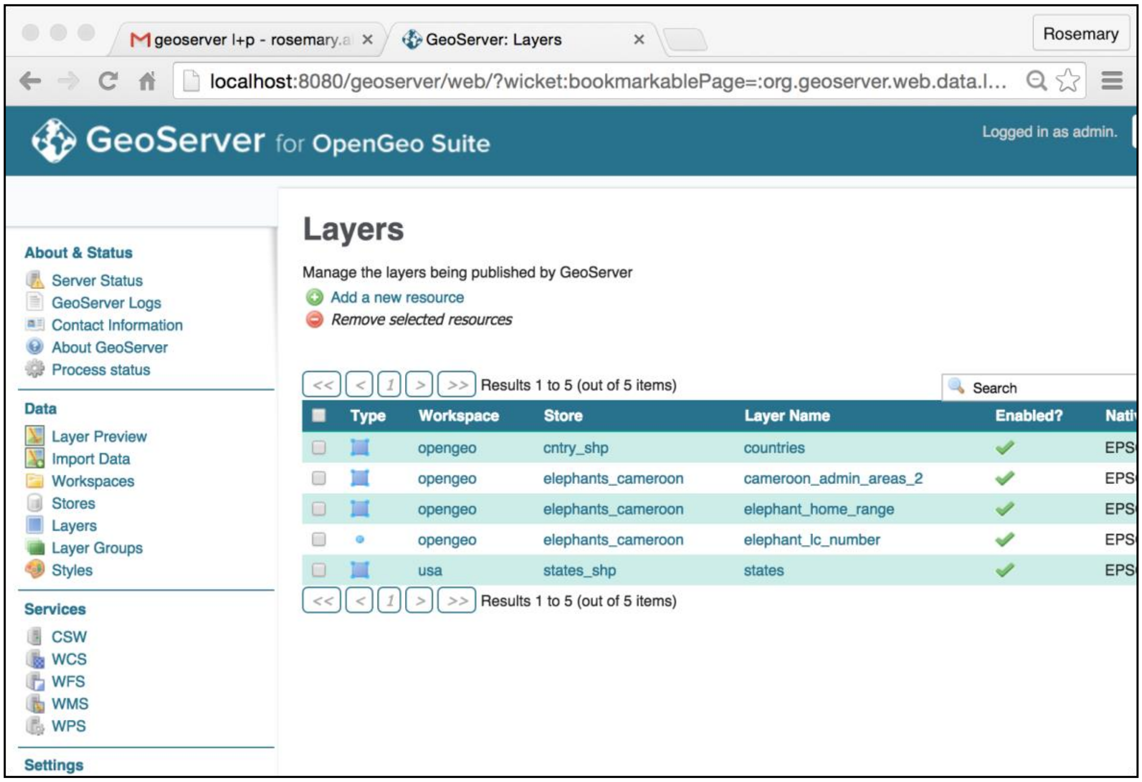


Figure 17: GeoServer: Layers; of interest are the *Cameroon_admin_areas2*, the *elephant_home_range* and the *elephant_lc_number* layers.

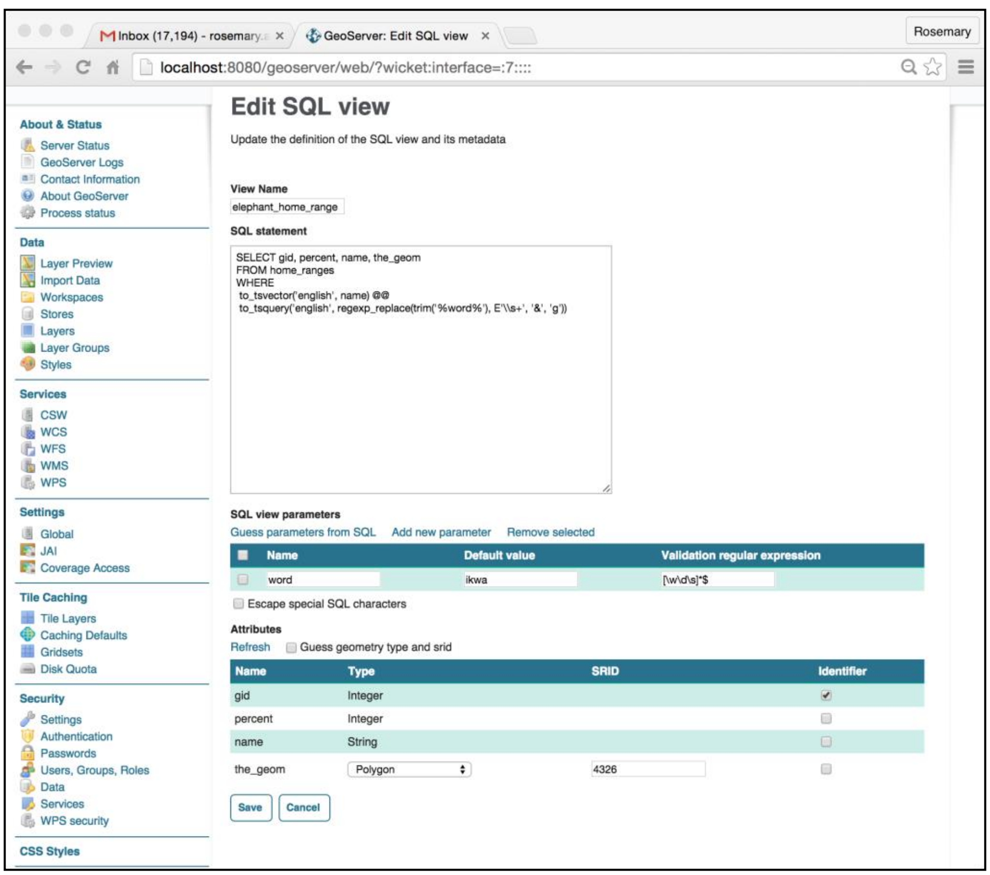


Figure 18: GeoServer: Layers; SQL view; the SQL view defines a SQL query that filers the data based on specific criteria. Note the reference to the *home_ranges* table populated in Figure 14.

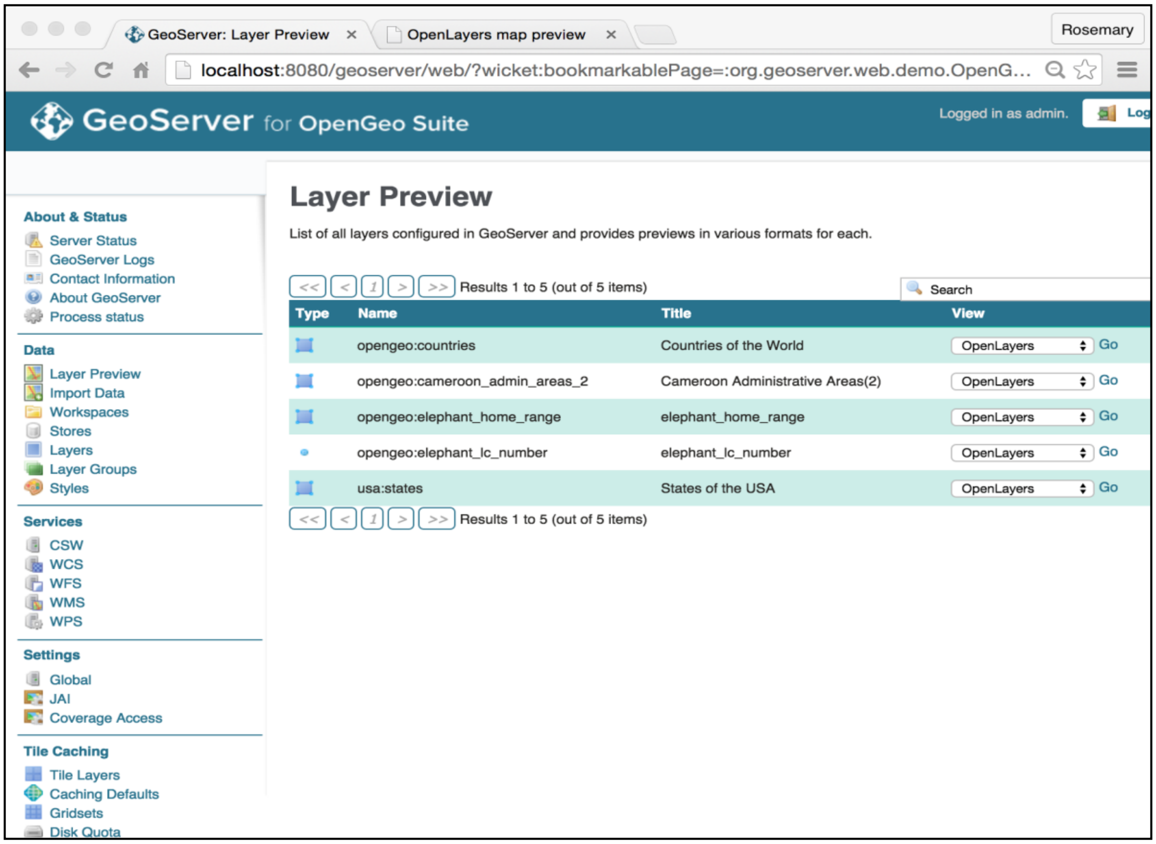


Figure 19: GeoServer: Layer Preview; GeoServer permits a rudimentary visualization of the layers via a *preview* mechanism.

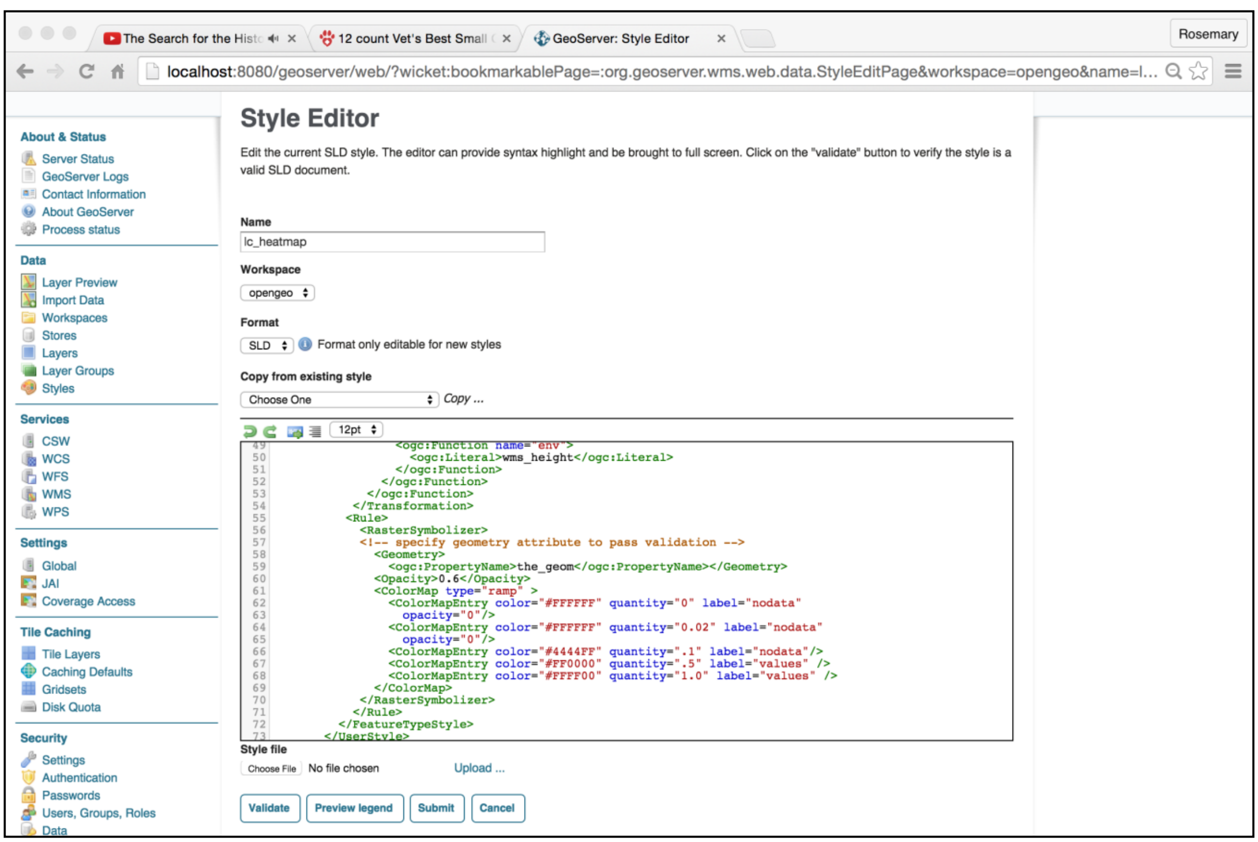


Figure 20: GeoServer: Style Sheet in SDL (Styled Descriptor Language).

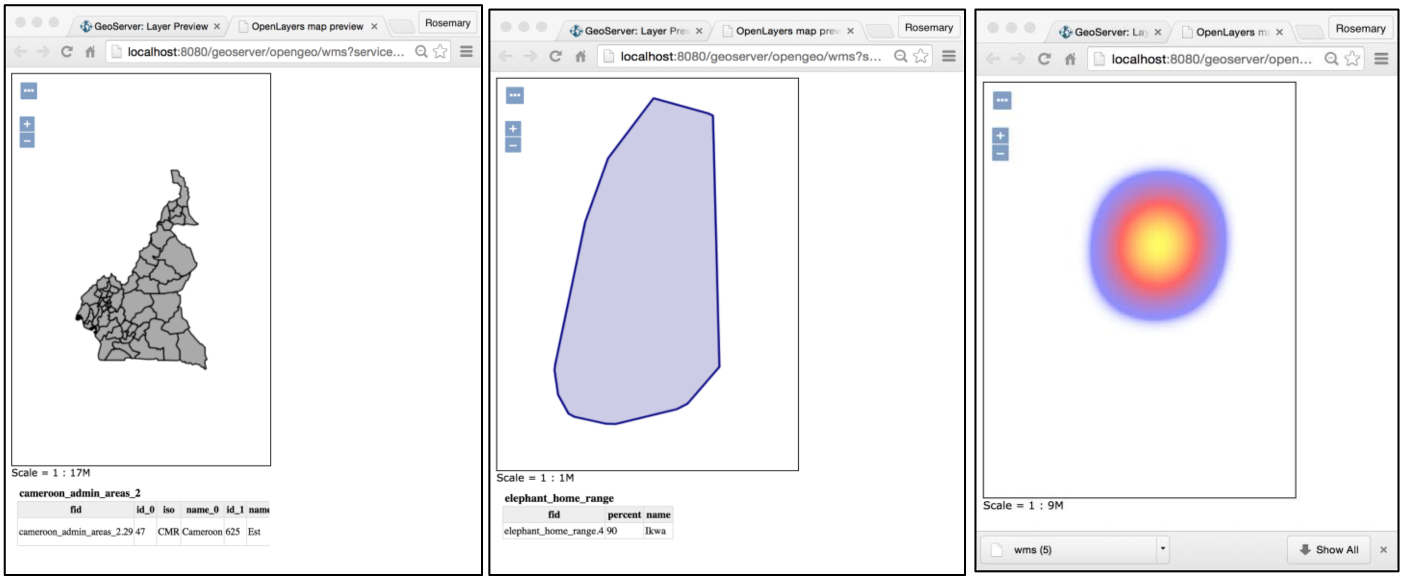
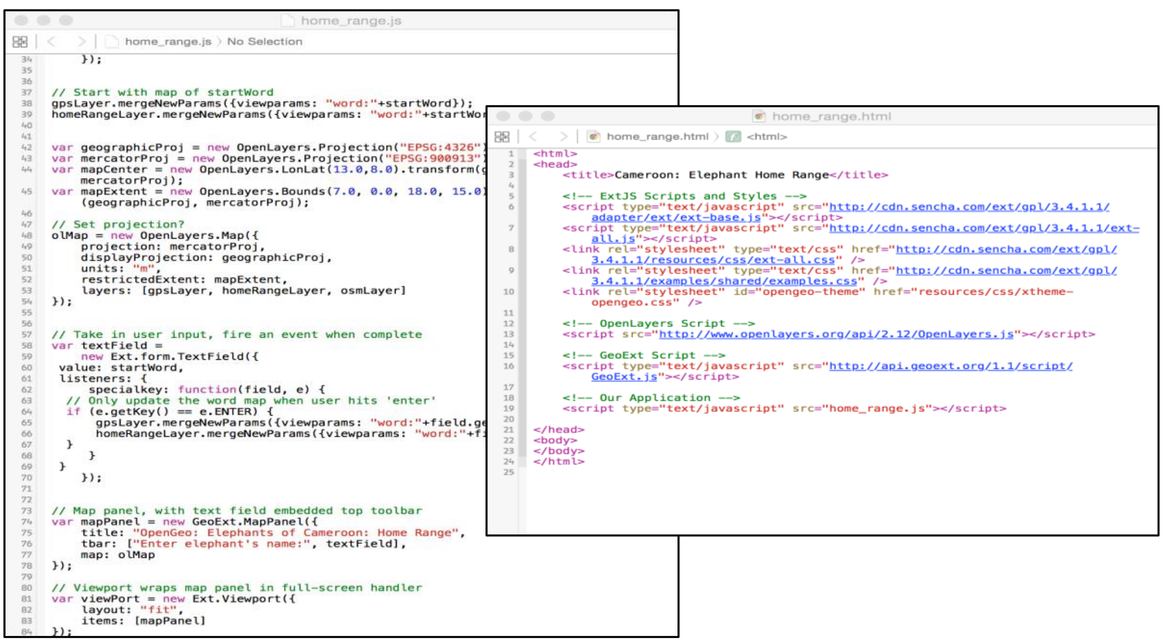


Figure 21: GeoServer: rudimentary visualization for layers defined in Figure 17. From left to right, *Cameroon_admin_areas2* layer, *elephant_home_range* layer (for the elephant Ikwa) and *elephant_lc_number* heat-map layer (lc = level of confidence in GPS points for the elephant Ikwa).

Generate the Web Interface with OpenLayers and GeoExt

The final step is to establish visualization of the layers configured in GeoServer via a web client/browser. For this, we use the OpenLayers and GeoExt java script libraries to program an interface (see **Figure 6**). For the purpose of establishing proof of concept and testing the prototype, the resulting HTML scripts are run on port 8080, at localhost:8080/apps/. Firebug (http://getfirebug.com/whatisfirebug) is used for debugging.



home_range.js

```
    });


// Start with map of startWord
gpsLayer.mergeNewParams({viewparams: "word:"+startWord});
homeRangeLayer.mergeNewParams({viewparams: "word:"+startWo


var geographicProj = new OpenLayers.Projection("EPSG:4326"
var mercatorProj = new OpenLayers.Projection("EPSG:900913"
var mapCenter = new OpenLayers.LonLat(13.0,8.0).transform(
    mercatorProj);
var mapExtent = new OpenLayers.Bounds(7.0, 0.0, 18.0, 15.0
    (geographicProj, mercatorProj);

// Set projection?
olMap = new OpenLayers.Map({
    projection: mercatorProj,
    displayProjection: geographicProj,
    units: "m",
    restrictedExtent: mapExtent,
    layers: [gpsLayer, homeRangeLayer, osmLayer]
});


// Take in user input, fire an event when complete
var textField =
    new Ext.form.TextField({
 value: startWord,
 listeners: {
     specialkey: function(field, e) {
  // Only update the word map when user hits 'enter'
  if (e.getKey() == e.ENTER) {
      gpsLayer.mergeNewParams({viewparams: "word:"+field.ge
      homeRangeLayer.mergeNewParams({viewparams: "word:"+f
  }
     }
 }
    });


// Map panel, with text field embedded top toolbar
var mapPanel = new GeoExt.MapPanel({
    title: "OpenGeo: Elephants of Cameroon: Home Range",
    tbar: ["Enter elephant's name:", textField],
    map: olMap
});

// Viewport wraps map panel in full-screen handler
var viewPort = new Ext.Viewport({
    layout: "fit",
    items: [mapPanel]
});
```

home_range.html

```
<html>
<head>
    <title>Cameroon: Elephant Home Range</title>

    <!-- ExtJS Scripts and Styles -->
    <script type="text/javascript" src="http://cdn.sencha.com/ext/gpl/3.4.1.1/
        adapter/ext/ext-base.js"></script>
    <script type="text/javascript" src="http://cdn.sencha.com/ext/gpl/3.4.1.1/ext-
        all.js"></script>
    <link rel="stylesheet" type="text/css" href="http://cdn.sencha.com/ext/gpl/
        3.4.1.1/resources/css/ext-all.css" />
    <link rel="stylesheet" type="text/css" href="http://cdn.sencha.com/ext/gpl/
        3.4.1.1/examples/shared/examples.css" />
    <link rel="stylesheet" id="opengeo-theme" href="resources/css/xtheme-
        opengeo.css" />

    <!-- OpenLayers Script -->
    <script src="http://www.openlayers.org/api/2.12/OpenLayers.js"></script>

    <!-- GeoExt Script -->
    <script type="text/javascript" src="http://api.geoext.org/1.1/script/
        GeoExt.js"></script>

    <!-- Our Application -->
    <script type="text/javascript" src="home_range.js"></script>

</head>
<body>
</body>
</html>
```

Figure 22: Code segments from the OpenLayers/GeoExt modules that run the prototype's web interface; by disabling connectivity and running the web client on the local host at port 8080, the prototype behaves as does a local application. Running 'locally' brings up interesting questions about where data/databases should reside; data is increasingly moving to the Cloud, given the context, running locally on a PDA-type device underlines the 'problem' of extracting critical segments of data in an optimized manner from the Cloud for on-demand use in, for example, the field.

Results

These results are a minimal subset of the broad spectrum of potential visualization and analyses achievable by an enhanced version of the prototype.

1. Visualization of the Level of Confidence (LC) Code. What is the LC code? "LC - a level of confidence index that represents the accuracy of the data. An LC value of "3" represents the most accurate data, with "2" and " 1" being less accurate. An LC measure of "A" or "B" is generally less accurate than "1," though either can be acceptably accurate. Ultimately, the only dependable way to judge the accuracy of location points is to the map them with a GIS system" (Park 2015). The LC code is also visualized using a heat map; for visualizing the LC code using a heat map, we designed a SDL (style descriptor language) style sheet; see **Figure 20**.
2. Using PL/R (procedural language for R) we defined statistical analysis procedures in our PostGIS database; these engage the R-statistical package (see **Figure 13**), referencing its libraries that provide

rich functionality to analyze the behavior of migratory wildlife. Using these functions we populate tables in our database, access them through GeoServer and visualize our results using OpenLayers/GeoExt.

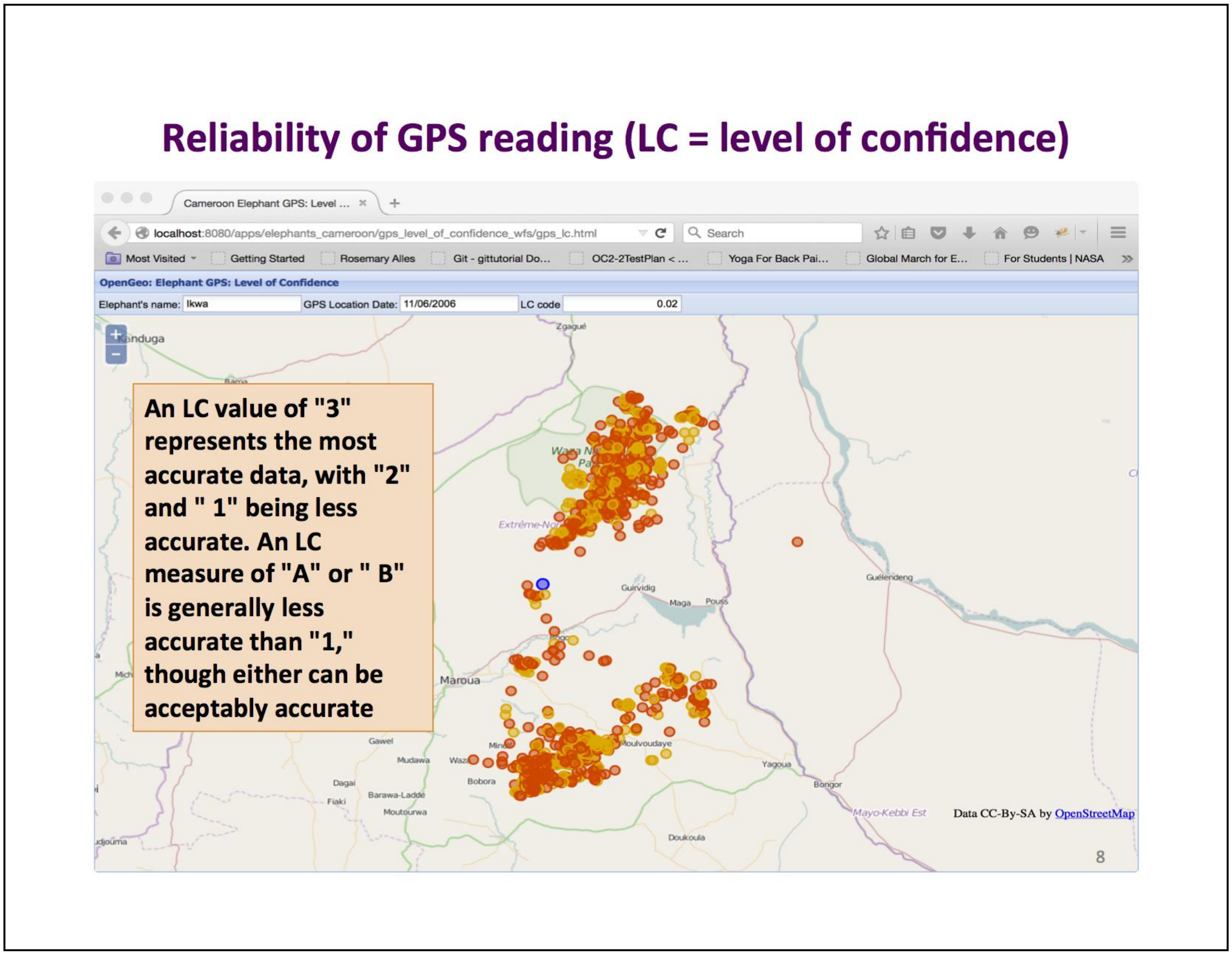


Figure 23: Results; colorized visualization of LC codes depicting the GPS coordinates for the elephant *Ikwa*; red depicts less reliable readings. Choosing a particular point (blue) displays the LC value of that point in a predefined field of the interface, in this case the value of 0.02 in the "LC code" field.

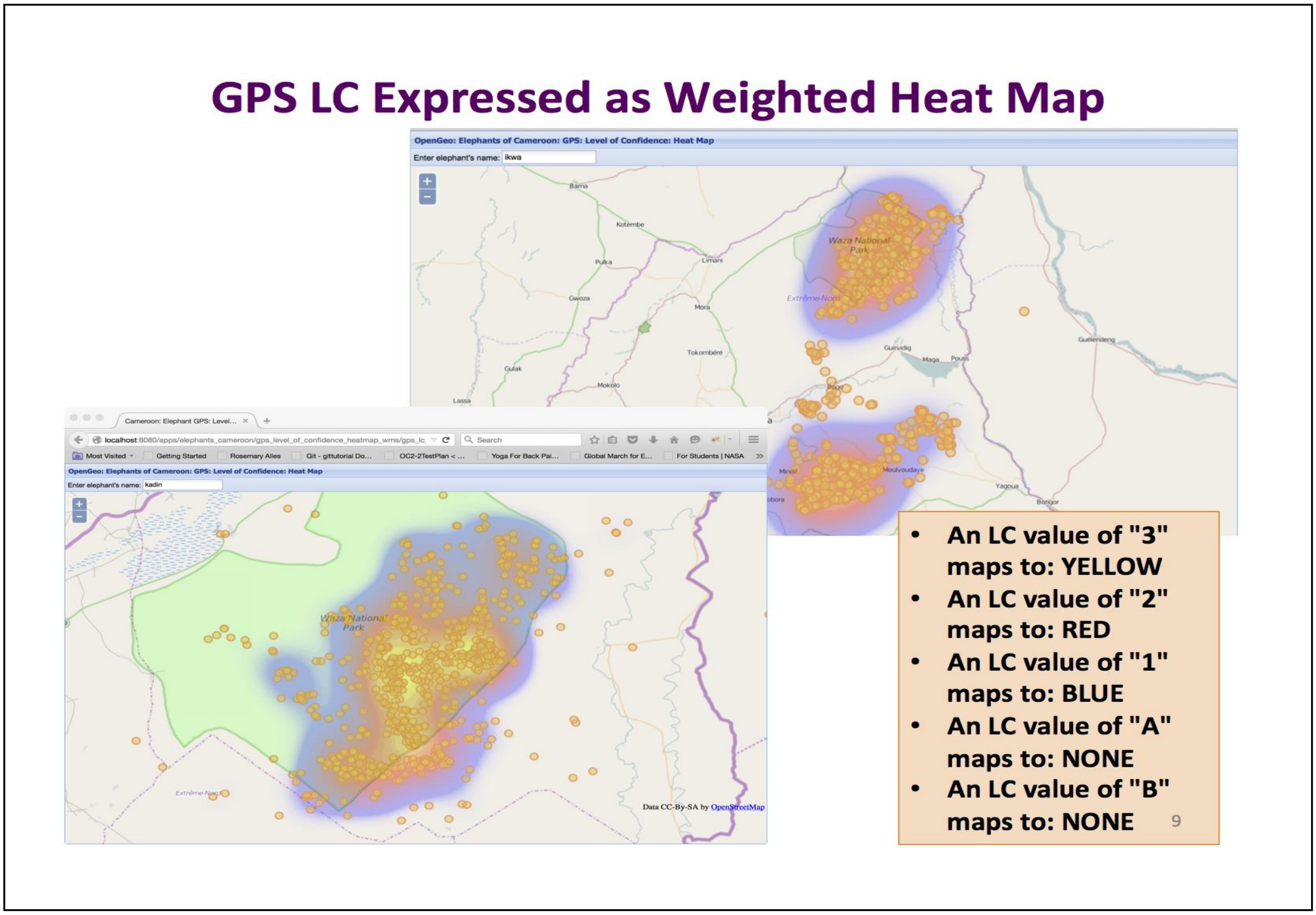


Figure 24: Results: The highest density of the "more" accurate GPS readings are within the polygon rendered by the heat map; albeit, we cannot conclude that GPS readings outside the heat map are, consequently, invalid. Other factors may need to be considered. For example: elephants can travel vast distances in any given period of time (and) if an LC code of "low confidence" is assigned to a GPS reading because it was "seen" as an outlier based on travel speed or distance/time, then meta data need to be factored prior to dismissing the reading as unreliable. Some GPS deliver biospatial data (such as the body temperature of the subject); these types of data must be considered to reach a more reasonable and intelligent conclusion about the reliability of a GPS reading. This heat map of LC codes is for the elephant *Ikwa*.

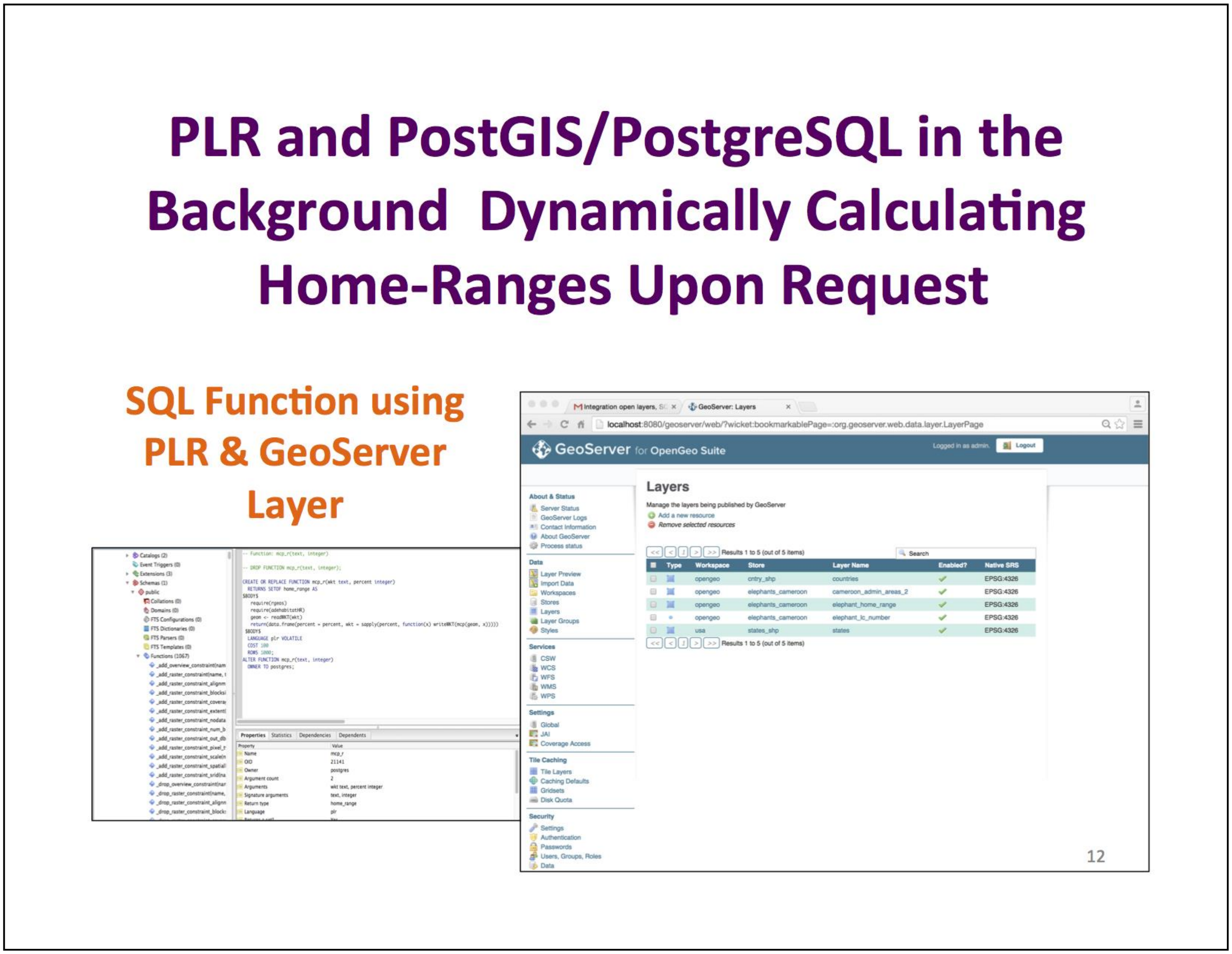


Figure 25: Results: SQL function using PL/R, accessing the R statistical package. Here, we define a function to return the Home Range of any given elephant base on the MCP (Minimum Convex Polygon) Method (Urbano and Cagnacci 2014).

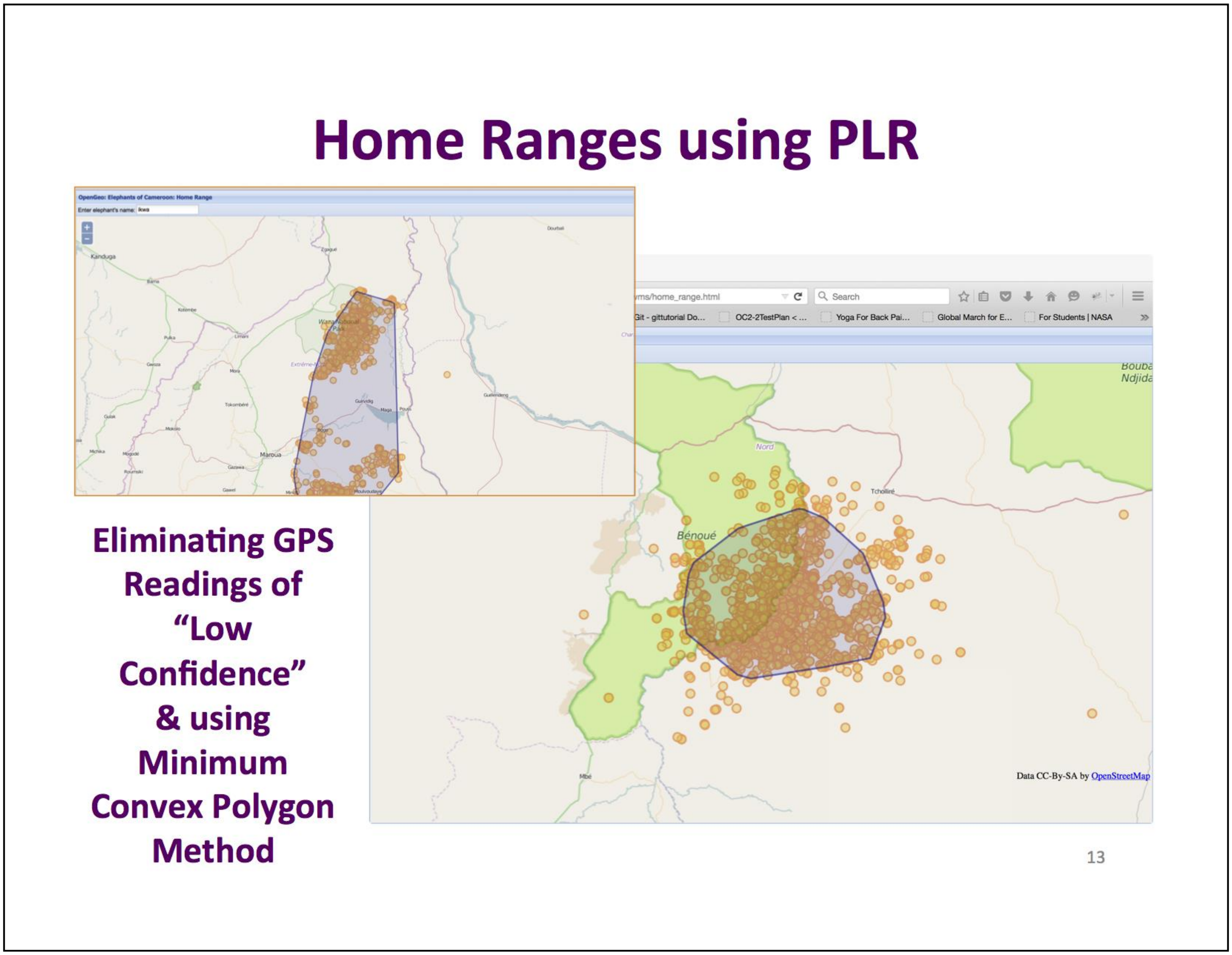


Figure 26: Results: After eliminating GPS readings whose LC values render them "suspect", we map the Home Ranges for the elephant *Ikwa*, using the PL/R procedure defined in Figure 14.

<u>Discussion and Conclusions</u>

Installing non-commercial Open Source Geo Spatial software components on mac OS X 10.10.3 (Yosemite) remain sub optimal. A great deal of trial and error, investigation, installing, uninstalling and re-installing was undertaken before components communicated with each other as intended and as necessary. A significant number of Open Source systems maintain poor documentation (Lester 2013). The documentation is not maintained at a frequency demanded by the rapid evolution inherent in the software they describe (Lester 2013). These inconsistencies lead to a great deal of time spent on experimentation; If Open Source GIS systems are to be adapted, used, enhanced and shared by Interested stakeholders, these failings need addressing in a non-frivolous manner.

Once installed, BoundlessGeo does work as advertised. It delivers a GIS platform with a seamlessly integrated geo stack offering countless opportunities for enhancement specific to the subject matter of interest (Boundless 2015). Support for BoundlessGeo is available if the commercial/supported option is chosen. Commercial and supported Open Source packages are a feasible alternative to proprietary and expensive GIS. Unsupported Open Source GIS established in production environments often "evolve" to render unwieldy systems whose maintenance represents significant hidden costs (Boundless 2015); see **Figure 27**.

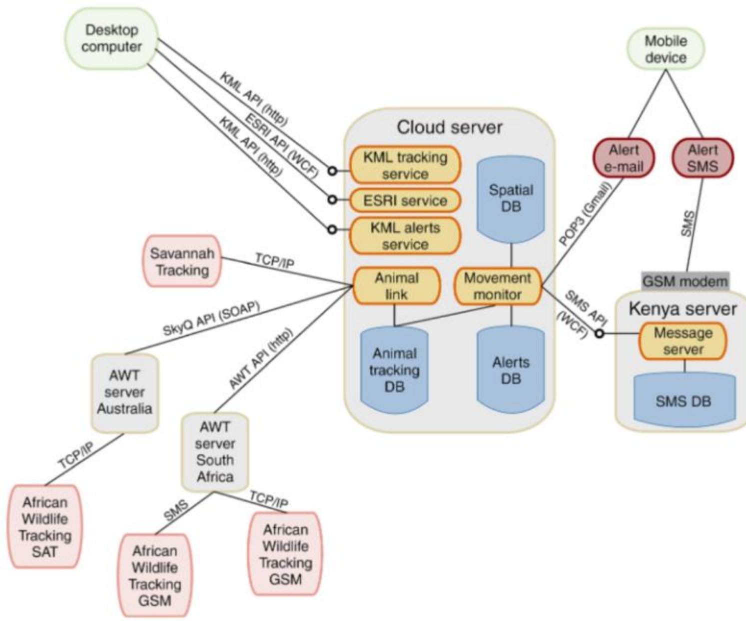


FIG. 1. Real-time monitoring (RTM) system to monitor the movement behavior of African elephants (*Loxodonta africana*). GPS tracking data are collected from four collar types deployed on 94 elephants and telemetered to a cloud-based server. Our *AnimalLink* software ingests the data and stores it in a PostgreSQL database (DB) (*AnimalTracking*). *MovementMonitor* software continuously monitors incoming data and implements four algorithms (proximity, geofencing, movement rate, immobility). If an alert condition is detected, both an SMS message (160-character limit) and e-mail are generated and issued to subscribed users. Application programming interfaces (APIs) make both alert and tracking data instantly available to desktop- and mobile-based clients including both Google (as Keyhole Markup Language, KML) and Environmental Systems Research Institute (ESRI) geographic information system (GIS) software. Full technical details of the implementation of our RTM system are provided in the Appendix. Acronyms are: AWT, African Wildlife Tracking (Praetoria, South Africa); GSM, global system for mobile communications based on telemetry; SAT, satellite-based telemetry; WCF, Windows Communication Foundation; POP-3, Post Office Protocol; and SOAP, Simple Object Access Protocol.

Figure 27: Open Source GIS maintained and used by Save the Elephants (http://savetheelephants.org/). The system in primarily a 'free' Open Source GIS with some components of the architecture commercially supported. The number of disparate modules in the system suggests sub-optimal *usability.* These "usability" issues may evolve to be unmanageable as technologies advance and versions become obsolete.

The GIS system envisioned by an enhanced, fleshed out version of the prototype can be scaled to incorporate Cloud based data, mobile devices and further integration with the rich analytical functionality offered by R. It can be used by scientists in the field, conservation organizations, interested citizenry and policy makers vested in the survival of earth's last elephants.

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