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The Open Data Kit suite, Mobile Data Collection technology as an opportunity for forest mensuration practices

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Abstract - This paper examines the potential for using Mobile Data Collection (MDC) as an effective database supported technology to substantially improve forest mensuration practices. Open source Open Data Kit (ODK) procedures and tools were used during a survey campaign that initiated a local forest monitoring process in the Marganai forest (Sardinia). The ODK suite is practical to use and its procedures allow authoring and use of digital survey forms without users needing software development expertise. Form design enables a high degree of customization to be achieved by means of specifying a wide range of data flow control mechanisms. ODK has proved to be a valid tool for data coherence and completeness improvements. As forestry's contribution to regional Gross Domestic Product has dramatically decreased, forest mensuration practices have been reduced. Meeting the increased need to monitor environmental assets such as forests requires these practices to be re-evaluated. If regional public institutions took an active part in the process of enhancing forest mensuration, by contributing with open database systems acting as repositories and knowledge engines, support for MDC tools like ODK would potentially be a great opportunity to disseminate the use of the system and boost its development.

Keywords - forest monitoring, Mobile Data Collection, Open Data Kit, shared database.

Introduction

Monitoring the effects of silvicultural activities is an established essential operation enabling us to learn from experience (Corona and Scotti 2011, Lorenz and Fischer 2013, Rasmussen and Jepsen 2018). Forest mensuration techniques are rapidly evolving. Through remote and proximal sensing, foresters have found more effective ways of obtaining accurate estimates at low cost. The motivational framework has also radically changed: environmental and ecological aspects (e.g. responses to climate change, biodiversity protection, etc.) require accurate monitoring procedures, at least comparable to traditional wood and timber production requirements (O'Hara 2016).

The paradigm is currently slowly shifting (Fardusi et al. 2017) and implementation varies from region to region. In Mediterranean environments such as Sardinia, forests have been extensively shaped by historical human intervention and hence forestry's role in shaping the landscape is an important one. Nowadays forestry's contribution to the regional gross domestic product (GDP) is negligible and the relevance of forest assets in environmental monitoring does not generate action. A single example will suffice: the regional administration attempted a forest inventory in 1994 (IFRAS 1994) to no effect and no subsequent attempts have been made. Another sign of this lack of interest and activity is the fact that regionally calibrated forest mensuration tools and models have not been developed and there is very little work available, the most recent dating to the last century (Brandini and Tabacchi 1996).

It is a vicious cycle. In the absence of effective tools, forest mensuration results are approximate and of limited value. Since forest tally operations are expensive, they are progressively downgraded. No development is activated and the limitations multiply.

Residual forest mensuration activities are still carried out, for very specific purposes (national forest inventory, wood or more often cork trade, damages estimates, etc.) by specialized public institutions (rangers, forest management agencies and municipalities) or individual professionals. Data collected in such situations is not considered valuable. Data for national inventory purposes is entered directly into portable devices under the supervision of very specific proprietary closed-source applications and sent out to national aggregation centres. Otherwise, simple aggregated results are obtained, with minimal effort, by entering data onto loosely structured spreadsheets allowing for rapid processing, with practically no control of the processing flow and no potential for accumulating tally data in

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order to feed tool development (Murgia et al. 2019).

Building on an increased need to monitor environmental assets such as forests, this paper is an attempt to break this vicious cycle. The fundamental step is recognizing that forest tally data is valuable since it is indispensable to monitoring. Hence, once data has been collected, proper data archival and conservation is worth investing in. Relational Database Management Systems (RDBMS) are the tools that serve such purposes today and our foresters must thus extend their software skills beyond spreadsheets to include basic knowledge of relational databases, SQL and processing languages such as Python or R. To boost efforts, regional public institutions must take an active part in this process, contributing with open database systems for use as repositories, collectors and knowledge development engines.

Currently mensuration data is annotated in the forest using paper forms designed ad hoc and subsequently digitized or it is directly entered, using tablets, onto spreadsheet tables replicating paper form design. Taking advantage of Mobile Data Collection (MDC) technology to record, manage and use data collected in the forest would be a step in the direction of reactivating forest mensuration practices. The expected effects are twofold. Firstly, data coherence and completeness would be dramatically improved and, secondly, foresters would be forced to interact with database structures.

Over recent years, adoption of the database supported MDC framework has been increasingly globally (Jung 2014, Satterlee et al. 2015) providing for innovative use of smartphones and tablets (hardware) and dedicated programs (software) to replace traditional data collection on paper and store retrieved information on shared databases. If properly applied, these tools are capable of facilitating data collection, knowledge accumulation sharing and reuse in the forestry sector. Given their inherent characteristics, a further potentially relevant strength of these technologies is their implementation in community-based observations for forest monitoring which implies devolving monitoring actions directly to local community groups or institutions, to varying degrees (Danielsen et al. 2011, Bowler et al. 2012).

This paper promotes use of the open source Open Data Kit (ODK) platform, having evaluated its procedures and tools during a survey campaign that initiated a local forest monitoring process (https://opendatakit.org/).

Material and methods

The Open Data Kit suite

Since its creation in 2008 (Borriello 2011), ODK has been a benchmark of MDC solutions (CartONG 2017) and inspired a series of research (Heunis et al. 2014., Tom-Aba et al. 2015, Macharia et al. 2015, Kipf et al. 2016, Maduka et al. 2017, Narayan et al. 2017), initiatives (FAO 2017) and services, both non-profit and for-profit. The ODK platform consists of three basic components (Fig. 1):

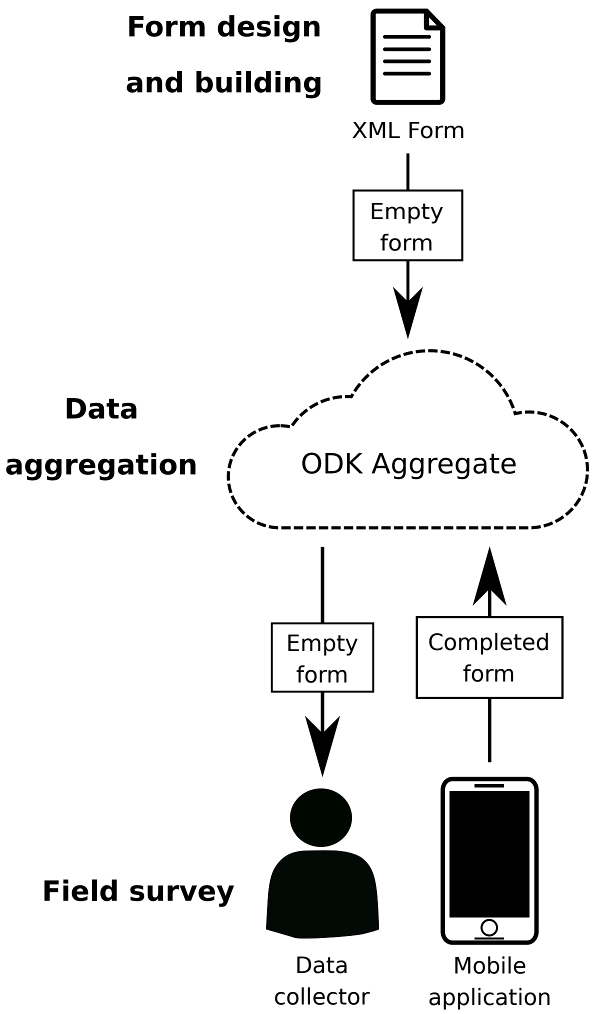

Figure 1 - Schematic demonstrating the flow of data through the ODK system.

a) XML forms - digital structures defining data collection forms' aspects and functions. These structures follow the ODK XForms specification, a subset of the W3C XForms specification (Boyer et al. 2009). XML forms allow for the use of a large variety of question types (multiple choices, checkboxes, text, acquisition of media and position, etc.) and the definition of logical rules and constraints with which to manage information and control inputs.

b) ODK Collect for Android - a mobile data collection application. Having downloaded the required

Table 1 - Attributes to be measured via stand dynamics and soil erosion monitoring protocol.

Attribute	Parameter to be recorded	Sampling unit
Ground surface level change	Distance between soil surface and its initial level	metallic stake
Deadwood	Diameter	transect line
Tree canopy cover	Proportion of floor covered by tree crowns projection	transect sectors
Shrub canopy cover	Proportion of floor covered by shrub crowns projection	transect sectors
Grass cover	Surface covered with grass	transect sectors
Litter cover	Surface covered with litter	transect sectors
Stoniness	Surface covered with stones or rock stoniness	transect sectors
Seedling regeneration	Species, height, type, damage	transect sectors
Shoot regrowth	Number of shoots, height of shoots	quadrants, transect sectors
Roughness at ground level	Basal tree section, tree stumps and shrubs	transect sectors
Tree density	Distance between trees and centre of quadrants	quadrants
Species frequency	Tree species	quadrants
Tree basal area	DBH	quadrants

XML forms, the application uses them both on- and off-line during surveying, reading and displaying the requested information on the basis of rules and constraints established during XML form definition. Finally, when an internet connection is available, data is uploaded to the aggregator.

c) Data storage server - the server runs the Java ODK Aggregate software acting as forms repository, survey collector and data retrieval system.

ODK Aggregate can be used on cloud services such as Digital Ocean, Amazon Web Services (AWS), Google development tools and services or any platform using a back-end DBMS, such as PostgreSql or MySQL. For the purposes of this study, given the need for a reliable and readily available server, we deployed ODK Aggregate to Google App Engine (GAE).

The case study

An opportunity to test the ODK suite in the context of forest monitoring came with the Environmental and Socio-Economic Sustainability of Forest Utilization in Margani Coppices project (https://www.progettomarganai.it), one of a number of projects funded by Sardinia's regional administration under the Piano Sulcis program (http://www.regione.sardegna.it/pianosulcis/).

The Marganai mountain range is in south west Sardinia and its highest peaks are over 900 m. The area is rich in minerals and has been exploited for mining since prehistoric times. The forest around it covers a surface of about 3,500 ha, made up of Mediterranean shrubland and woodlands dominated by *Quercus ilex* L., often accompanied by sclerophyllous trees and shrubs such as *Arbutus unedo* L., *Phillyrea latifolia* L. and *Erica arborea* L.

For several centuries forest management was based on coppicing and closely bound up with mining. When these came to an end, in the 1960s-70s, coppicing was abandoned. Currently the forest is homogeneously aging, losing diversity at various levels and resilience is decreasing. Prospecting to recover structural diversity and forest socio-economic value while preserving the majority of its natural aging and transformation processes, to increase the ecosystem service standards it provides (e.g. regulating and provisioning services through biodiversity, feeding wild ungulates and harvesting firewood, as well as cultural services in promoting the history and knowledge which shaped these mountains) led to a new forest management plan being adopted in 2010, reactivating coppicing practices in a limited area, less than 10% of the forest as a whole (Airi et al. 2010).

Setting up a series of areas for forest stand dynamics and soil erosion monitoring is one of the Marganai project's activities as part of a wider network whose purpose is to monitor the effects of silvicultural work. 52 points were thus marked in the forest for field measurement purposes both in a recently coppiced stand and in a stand coppiced half a century ago with each of these being a reference point for the establishment of a 5 by 2 meter transect divided into ten square (1 m side) sectors. In each sector vegetation cover, litter cover and stoniness were recorded along with tree regeneration and the basal section of standing trees and shrubs which affect ground level roughness. Deadwood was recorded using the Line Intersect Sampling method (LIS) while forest stand structure and density were assessed using the Point Centered Quarter method (PCQ) (Cottam and Curtis 1956, Lindsey et al. 1958).

For the purposes of tidying up information demands, the data collected was distributed between the following tables or table-sets in line with general data model design (Fig. 2).

a) General survey unit information. This is the master set which contains general sampling unit in-

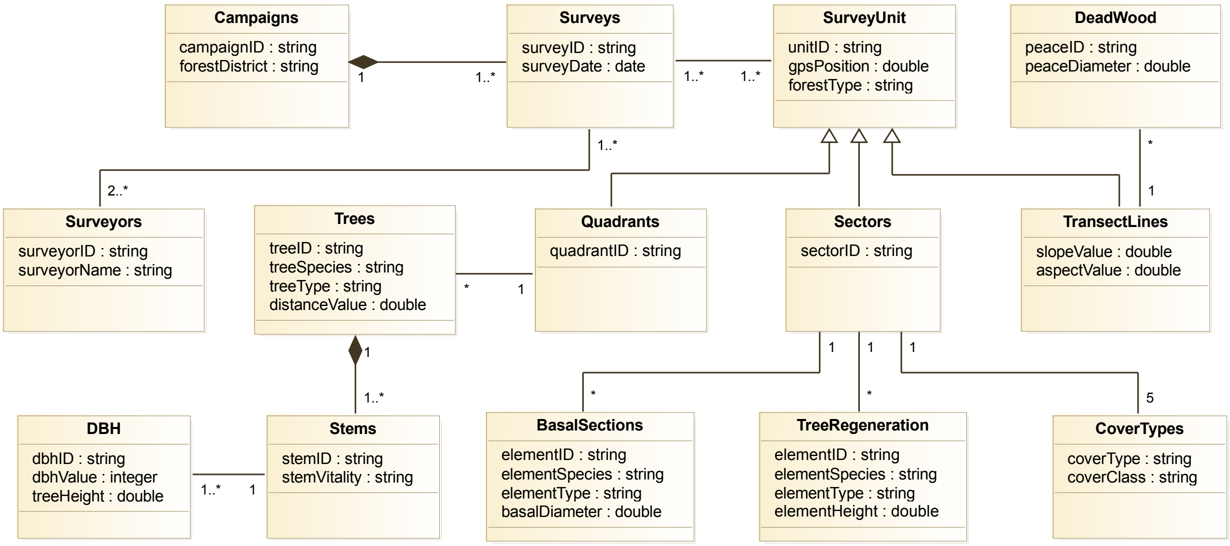

Figure 2 - UML data modelling of the information requested by the evaluated monitoring protocol.

formation (such as survey date, surveyors' names, forest district, etc.). The campaign, survey and sampling unit identifiers are key attributes in this set.

b) Line Intersect Sampling. This table contains diameter values for deadwood at the section crossed by the transect line.

c) Sector cover - estimates of vegetation (tree, shrub and grass layers), litter and stone cover inside each sector are shown in this table.

d) Tree regeneration and basal sections - a table-set containing data on tree regeneration and standing tree and shrub basal sections.

e) Point Centered Quarter. This is the table-set containing all the information on the trees selected in each quadrant on the basis of the PCQ method (tree species, DBH, tree height, etc.).

The data was used to calculate a set of indicators monitoring the effects of silvicultural work on stand dynamics and ecology factors considered important in water behaviour terms (Tab. 1). All XForm survey data collected in Marganai can be openly visualized and exported using the web-accessible application ODK Aggregate on https://marganai.mooo.com.

XML form authoring tool

XLSForm is the ODK authoring tool designed to simplify form creation (Marder and Dorey 2008). The tool is practical to use and allows complex form authoring even for users with no specific software development expertise.

It consists in a spreadsheet workbook (saved as MS Excel file) containing two main sheets: 'survey' and 'choices' (Fig. 3). The survey sheet defines the general structure of the form and contains a complete list of entries together with information on how these will appear in the form. An entry can be a single unit (such as a date, sampling unit ID, etc.) or it can be repeated, forming a 'repeat group'. For example, section ID, DBH and tree height entries are all required and can be grouped together so users can repeat groups as many times as required. Repeat groups can also be nested. A high degree of customization can be achieved on survey sheets, specifying entry constraints, defining conditional instructions based on previous entries, adding calculated values, creating spatial geometries, including recording media (audio, video and pictures) and GPS position. The choices sheet is used to specify which values a multiple choices input can accept or incorporate nomenclatures adopted from verified glossaries into a form.

XML form specifications

In response to data model demands, the original lengthy paper form used for surveys was split into five XML forms on the basis of the different XLSForm constructs available (Tab. 2).

a) The general survey unit information is recorded with a master XML form (SurveyInfo.xml).

As well as general survey data (e.g. identifiers, forest type, surveyor names, etc.) this form uses a XLS form construct to record GPS location and take pictures (e.g. pictures of the forest stand and the sampling unit after it has been marked on the ground). The form includes two pre-loaded nomenclature files (as comma separated values) to produce state-owned regional forest choice lists and regional forest types codes.

b) The LIS data collection form (LIS.xml) uses a repeat group construct to record the diameter of deadwood at the section crossed by the transect line. The repeat group manually ends when there are no more pieces to be recorded.

c) The sector coverage information is recorded by the SectorCover.xml form. This form displays

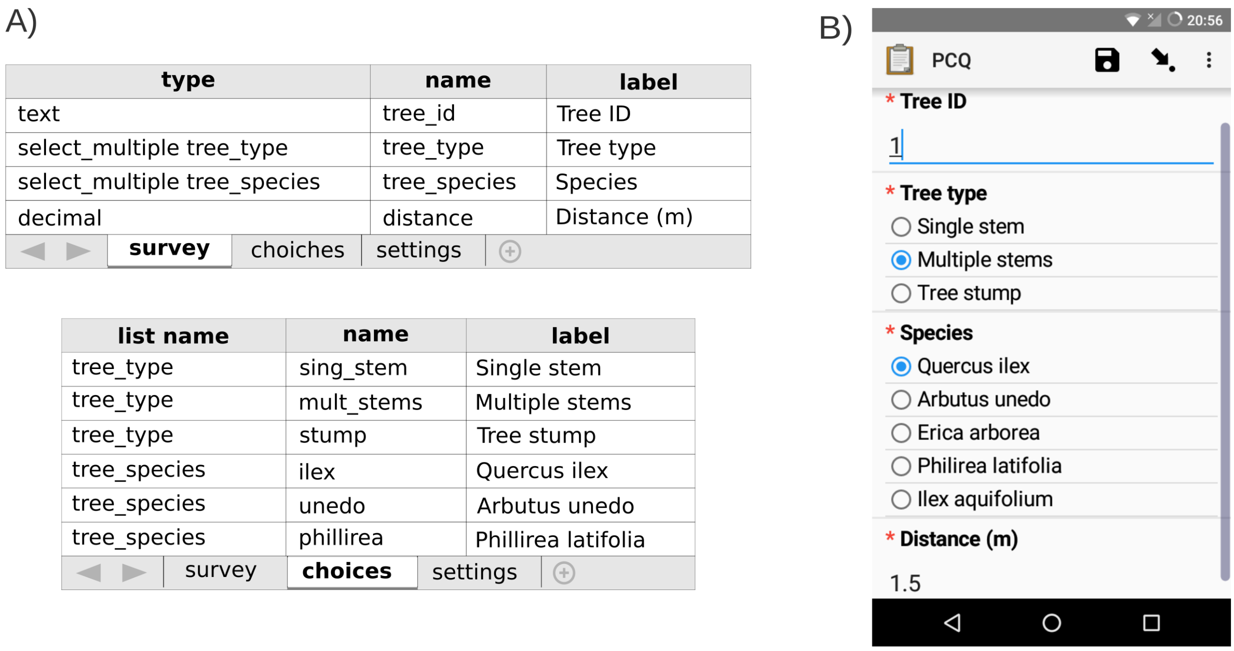

Figure 3 - Example of the authoring process using XLSForm (A) and the corresponding section of the form displayed by the mobile application (B).

sector IDs and cover classes for each cover type (e.g. vegetation cover, litter cover and stoniness) as choice lists. These entries are grouped together through a repeat construct that requires all entries for all sectors to be completed. A logical constraint is used to prevent the same sector from being (unwittingly) selected more than once. The form requires two pictures per sector to be taken: one of forest floor coverage (camera oriented at nadir) and one of tree canopy cover (camera oriented at the zenith).

d) The RegAndBasalSection.xml form displays tree regeneration and basal section element information demands for each of the ten sectors. This information is arranged into two repeat groups and a filter logic makes these visible in the form depending on the presence or non-presence of the element concerned in the sector. As with the previous form, a logical constraint avoids duplicate sectors. As well as the sector choice list, the form also displays regeneration method (by seed or sprouts), element type (e.g. multiple shoots, single stem, tree stump) and species code lists. The latter can also be pushed from a pre-loaded file.

e) The PCQ.xml form is used to record information on the trees selected in the PCQ quadrants. It contains four nested repeat groups: quadrants, trees, stems and DBH. In order to double check that all required measurements have been taken and avoid a question after each measurement, the form requires surveyors to count elements before measurement begins and closes the repeat group after the last input. Filter logic and conditional constraint are used to control entry flow and data integrity.

XML form export and database structure

Once forms have been designed and coded in XLSForm they are converted into XForm to be read with the mobile application and used in the forest. More than one operator can simultaneously use the forms, in the same or a distinct survey unit. With an internet connection the completed forms are submitted to the server where the ODK Aggregate software runs.

This software uses mechanisms for writing data

Table 2 - Main features of the XML forms designed on the basis of the monitoring protocol.

Form name	Form description	Main features
SurveyInfo.xml	General survey unit information	picture and GPS acquisition, choice lists based on common standards
LIS.xml	Deadwood diameter	repeat constructs, entry constraints
SectorCover.xml	Ground cover information	picture acquisition, entry constraint, repeat constructs, choice lists based on common standards
RegAndBasalSection.xml	Tree regeneration and basal sections	entry constraint, repeat constructs, choice lists based on common standards
PCQ.xml	Forest stand structure and composition	entry constraint, repeat constructs, choice lists based on common standards

into tables that are defined on the basis of the principles inspiring the Aggregate 1.0 data model (Sundt 2017) and are the same for all deployment solutions. On the basis of these mechanisms submitted forms are split into table-sets. Repeat group nesting results in relations represented using external keys. Repeat group nesting levels influence the complexity of the table-set produced. For instance, in the case of the PCQ form, the four repeat groups are split into four tables linked by a hierarchical relationship: a Quadrant table, a Tree table, a Stems table and a DBH table.

Items containing binary files such as audio and video images are stored in a separate table-set. Together with tables generated by the XML forms submitted by users there are system tables specifying associated metadata.

Discussion

This section will analyse the key aspects characterizing the MDC procedures adopted by the Marganai Project based on the open source ODK platform.

Monitoring process initiation

On the strength of the new ad hoc protocol and the ODK suite the project took the opportunity to initiate silvicultural practice monitoring in the Marganai forest. The evaluated protocol provides a wide

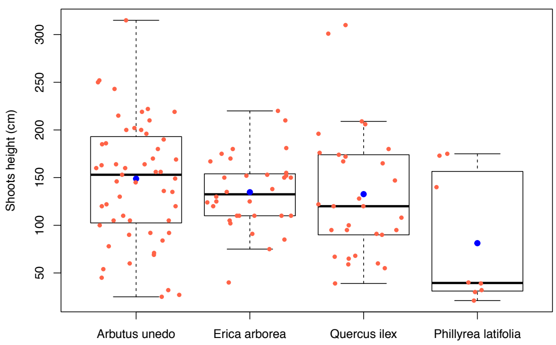

Figure 4 - Growth in height of shoots after 5 years from coppicing.

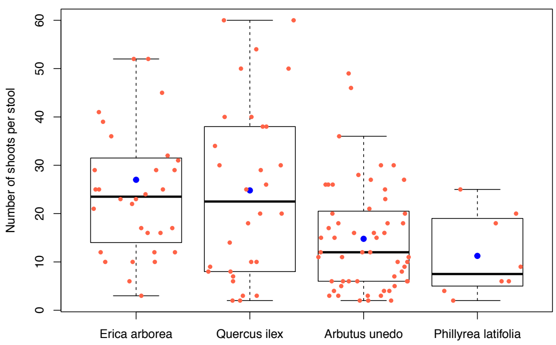

Figure 5 - Number of shoots per stool after 5 years from coppicing.

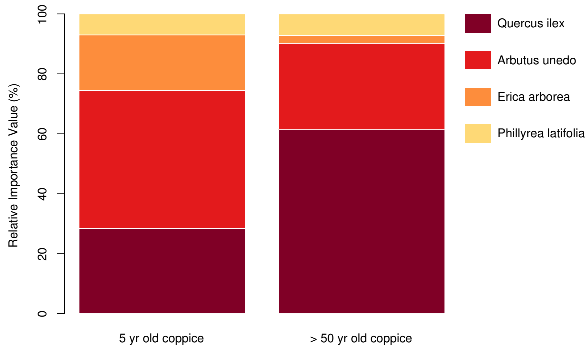

Figure 6 - Differences in species relative importance between the two investigated forest stands.

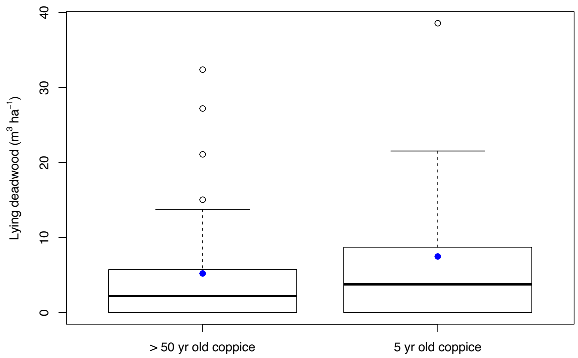

Figure 7 - Differences in lying deadwood volume between the two investigated forest stands.

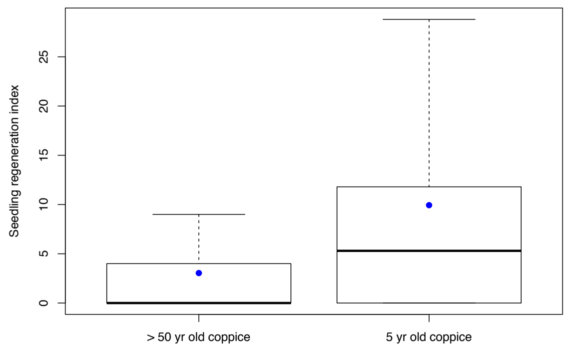

Figure 8 - Differences in seedling regeneration index between the two investigated forest stands.

set of parameters which were used to quantify the current state of the environmental system in two forest stands in which the monitoring network was set up.

One of the most important aspects is certainly regrowth dynamics five years after coppicing. Canopy cover has recovered well both vertically and horizontally and hydrological functionality control has been achieved. *Arbutus unedo* L. is growing higher (Fig. 4) while *Quercus ilex* L. and *Erica arborea* L. have the highest number of shoots per stool (Fig. 5).

Coppicing has been shown to play an important role in enhancing the intrinsic diversity levels of this type of community. By contrast the homogeneous aging observed in old coppices entails a decrease in the relative importance of evergreen shrubs (Fig. 6).

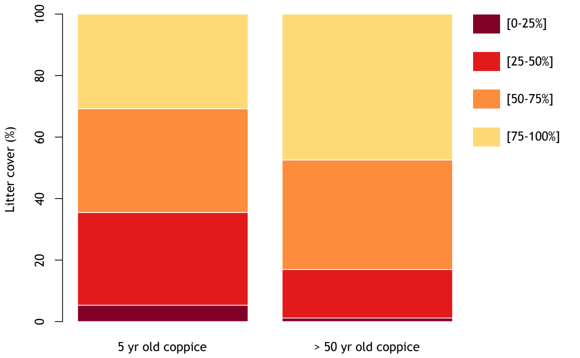

Figure 9 - Differences in class of litter cover frequency between the two investigated forest stands.

The deadwood data shows differences between the two stands with higher values in recently coppiced stands (Fig. 7), due to the release on site of woody residues from harvesting. Seedling regeneration, as is to be expected, is significantly higher in young coppices given the sudden increase in understory light level conditions (Fig. 8).

Litter cover is still in the process of recovering a few years after the removal of most photosynthetic phytomass through coppicing (Fig. 9). A more complex humic layer is expected to reconstitute in a more advanced stage of stand development and constant monitoring action will provide the elements necessary to ascertain the strength of this assumption.

Having analysed the information available after the first measurement protocol phase alone, it is crucial to underline that it is only after the second and subsequent phases that actual monitoring results will be produced. The process is designed to continue over time via a regular and systematic data collection program. The actual efficiency and scientific dimensions of the process as a whole can only be evaluated once an adequate data time series has been made available in line with monitoring objectives.

Operational efficiency and information quality

On the basis of MDC tool use, the data collection flow can be closely controlled, efficiently managed by verified processing chains and finally archived in database systems. Compared to paper form based methods, MDC tool savings also stem from the elimination of inefficient data transfer to a digital device and ex-post data checking processes. The greater the size and complexity of the survey, the more evident these savings will be.

Data quality improvement is achieved on the basis of the potential to control tally completeness and coherence directly in the forest. It is relatively easy to set up control mechanisms verifying whether required fields have been filled in with acceptable and non-contradictory values using XLS forms. Defining conditional instructions based on previous entries allows users to avoid duplications (e.g. the same transect sector cannot be entered twice) and respect coherence between interdependent information (e.g. the height of the basal part of the tree crown cannot be greater than the total height). The opportunity to add calculated values allows for automatic key field compilation.

Having shared open repositories, possibly maintained by regional institutions, common standards can be adopted by incorporating verified glossaries. This is of particular value in adopting standard codes by tree species, based on an EPPO database (EPPO 2014) for example, as well as forest type codes or any other common codification systems, with undoubted advantages in terms of coordination and synchronization between surveyors working in different survey campaigns or different areas simultaneously.

In addition to entries requiring users to input vales manually, the XML form can also be set to automatically collect metadata such as timestamps. This enables the timing of alternative survey protocol techniques to be compared and consequently overall work efficiency in future campaigns to be improved.

Real-time data sharing and advanced analysis

The proposed procedure makes forestry related data available for analysis. Achieving similar results using traditional methods requires significantly more time. As the information is entered directly into an electronic form exported to a data management system (such as ODK Aggregate), access is potentially instantaneous. ODK Aggregate offers a safe storage environment in which administrators can manage user permissions, visualize and browse data in a structured way and export them into the most common formats (e.g. .csv, .kml, etc.). The overall effectiveness of data processing and analysis can be significantly increased by exploiting the full potential of the DBMS on any web server running Apache Tomcat (http://tomcat.apache.org/) with MySQL or PostgreSQL. Simple as well as advanced products can be obtained performing even complex queries and using reporting and data processing tools such as R-project with its specific DBMS connection libraries (Ooms et al. 2016, Conway et al. 2017).

Information modelling

As the previous sections highlighted, there are intrinsic benefits to MDC technology use. In order to exploit their efficiency, before proceeding to XML form design, the information model underlying the data acquisition project must be formalized. The database's relational structure (schema) has therefore to be defined (using UML and ERD approaches, for e.g.). Data modelling is a critical step towards an explicit, documented and verified logic ensuring data completeness and consistency, increasing the internal coherence and usability of the data and the XML forms. The formalization of a coherent data model together with appropriate use of logic rules and conditional constraints in XML forms thus determines the overall integrity of data collection and database storage processes. In this study data modelling was limited to the information required by the protocol tested in Marganai forest and more work is undoubtedly needed in order to develop a modelling data process encompassing and integrating various forest monitoring approaches.

Feasibility

Profiting from MDC functionalities requires upfront investment, in both skill and financial terms. The use of hardware and software components and their maintenance involve some user skill (e.g. logical design and authoring of the forms to be converted into digital format) and perhaps external support. Software costs depend on the choice of service to be used. For the Marganai project we deployed ODK aggregate to GAE, with a relatively limited usage of instances and no charge. Tomcat deployments allow for more advanced usage together with more dynamic interaction with the DBMS but involve additional costs, a steep learning curve and technical aptitude. On top of that, the costs required for the recruitment and training of operators to use mobile devices is an additional element. However, such expertise is not difficult to build up as these tools are highly intuitive.

Within the MDC technology panorama there is a wide range of services beyond ODK, suiting various project requirements. One interesting option is open source project SMAP (https://www.smap.com.au/) which integrates ODK and provides hosting services via advanced software using PostgreSQL and PostGis for data management.

Conclusions

Implementation of Mobile Data Collection (MDC) technology in forest mensuration activities constitutes a stimulating opportunity. A combination of multiple factors is progressively reducing mensuration practices while, conversely, the need for environmental monitoring has increased. Introducing MDC can contribute to updating forest tally procedures providing valuable data for environmental as well as economic evaluations.

As part of the ongoing Environmental and socio-economic sustainability of coppice forest utilization in Marganai project, a forest monitoring system has been initiated and the first measurements taken. The work was implemented by testing Open Data Kit MDC tools. Using this example, the paper described and commented on the benefits and costs entailed by such tools.

Adopting MDC clearly involves taking a step forward in data management and processing competence. As regards the simple spreadsheet competence available in the professional forestry environment (at least in Sardinia), basic database management and programming skills are required. Rather than simply a cost, this should be considered a necessary investment required to reactivate forest mensuration practices.

Direct advantages encompass the potential for increasing data quality as the tools allow for in-depth monitoring of tally completeness and internal coherence in quite a straightforward manner.

However, putting this proposal into practice requires adopting these technologies in the context of a well-defined, shared strategy with the potential to rely on the support of a robust and long-term structure channelling skills and investments. In Sardinia this is constituted by the regional authorities which are capable of activating internal and outsourced services that will enable MDC procedures in support of the forestry sector to be used and maintained. Beyond conventional research and professional applications, the region can potentially be motivated to invest in this direction, also favouring the dissemination of community-based forestry monitoring.

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