Agriculture, *fisheries and forestry*

As population growth, climate change and the impact of human activities on ecosystems increase, sustainable management of our environment and its renewable resources–especially food–is crucial. This requires being able to describe the past and current state of the environment, understand the underlying processes and simulate management scenarios by predicting how it could evolve under the impact of human pressure.

Continental surfaces form a spatially complex system resulting from a combination of features, including the geology, topography, soils, climate, fauna, flora and human land-use patterns. This extremely high spatial variability occurs on all scales: plant, farm plot, small region, country and continent. Besides this spatial structure, temporal changes also take place on different scales: daily cycle, meteorological event, season, and longer term climate change. This trend also applies to oceans, seas and continental waters, whose characteristics vary markedly on spatial and temporal levels.

It is essential to have access to methods for spatial description of the environment and also for organizing spatial information of different types and origins. Remote sensing techniques, geographic information systems (GIS) and spatial modelling techniques are favoured tools for this. Moreover, it is necessary to describe and gain insight into the evolution of these spatial variables–this is the focus of dynamic modelling studies supported by remote sensing data.

In the renewable resources field presented in this chapter–agriculture, forestry, ecosystems and fisheries resources–variables that characterize studied environments must first be determined spatially: topography, soils (mineralogy, humidity, surface state), vegetation (type, status, growth and development, height, solar radiation interception and albedo), landscape spatial organization (plot patterns, ditch networks), cropping practices (management strategies, tillage operations, pesticide treatments), water temperature, nutrients and plankton for fisheries resources. Furthermore, it is essential to gain insight into temporal changes that most of these variables undergo. In a number of these cases, this spatial information is used directly for management purposes (precise agricultural techniques, harvest management in cropping areas, controlling nonpoint source pollution). Moreover, this information is often used as parameters or inputs for models describing processes under way in target environments (crop models, hydrological models, surface-atmosphere exchange models).

Due to the complexity in the spatial organization of terrestrial environments–especially cultivated landscapes–there is an urgent need for spatial information representation and processing methods. GIS technology is widely implemented to combine spatial information of different types and origins in the fields of agriculture and ecosystem characterization. In addition to this conventional use, there are more specific needs, such as the application of spatial modelling to simulate an entire area based on information acquired in just a small part of this area, especially when other parts of the area are hard to monitor, for mapping purposes (spatial interpolation techniques, spatial stochastic simulations). Finally, substantial lateral flows run through these highly heterogeneous environments: water transfers via runoff, stream flow, groundwater movements, atmospheric gas and particle transport (pollen, pesticides, etc.). Spatial characterization of these environments and flow modelling are required to represent these flows–which is a current focus of active research.

Laurent Prévot (UMR LISAH)
& Jean-Baptiste Laurent (UPR SCA)

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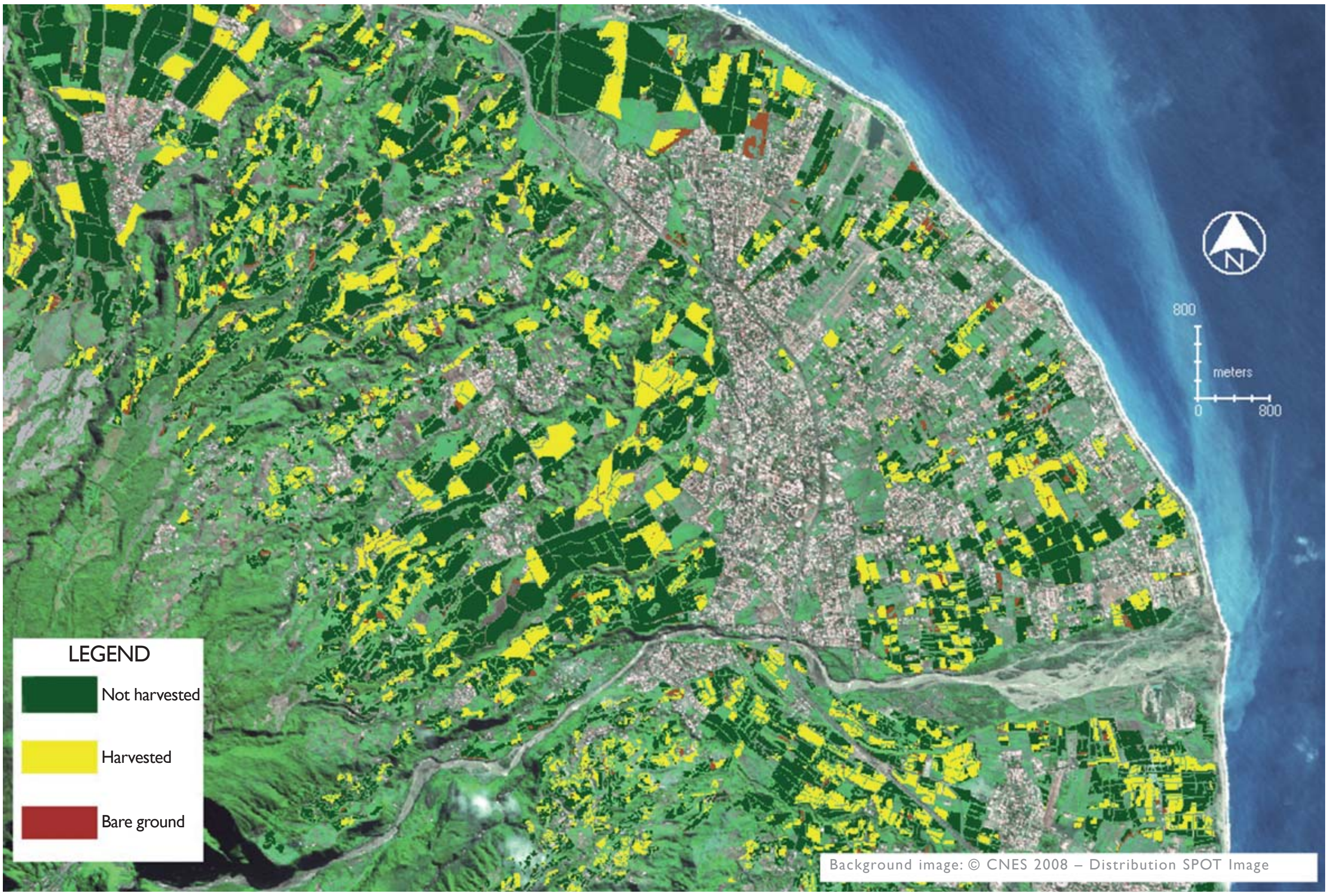


▲ *Sugarcane harvesting progress in the Pente Sassy region, Réunion (21/08/2008).*

Main teams

FRE MTE - Mutations des Territoires en Europe
(see page 55)

UMR CEFE - Centre of Evolutionary and Functional Ecology
(see page 43)

UMR EME CRH - Écosystèmes Marins Exploités, Centre de Recherche Halieutique méditerranéenne et tropicale
(see page 43)

UMR G-EAU - Water Resource Management, Actors and Uses
(see page 43)

UMR ITAP - Information and Technologies for AgroProcesses
(see page 8)

UMR LISAH - Laboratoire d'étude des Interactions Sol - Agrosystème – Hydrosystème
(see page 18)

UMR SYSTEM - Tropical and Mediterranean Cropping System Functioning and Management
(CIRAD, INRA, Montpellier SupAgro)
20 scientists, with 3 involved in the topic
Director: Jacques Wery,
wery@supagro.inra.fr
http://umr-system.cirad.fr/accueil

UMR TETIS - Geoinformation and Earth Observation for Environment and Land Management
(see page 8)

...continued on page 38

Monitoring sugarcane harvests in Réunion via satellite images

The regional productivity of the sugar industry is dependent on the sugarcane harvesting efficiency, i.e. regular supplies of sugarcane to sugar factories and effective geographical distribution of harvesting equipment and resources. In French overseas departments and many producing countries (South Africa, Vietnam, etc.), a large portion of sugarcane-growing areas is managed by thousands of small-scale farmers growing cane on barely a hectare of land. In such conditions, it is hard to obtain reliable and thorough information on harvestable sugarcane areas, their geographical distribution and harvesting progress rates.

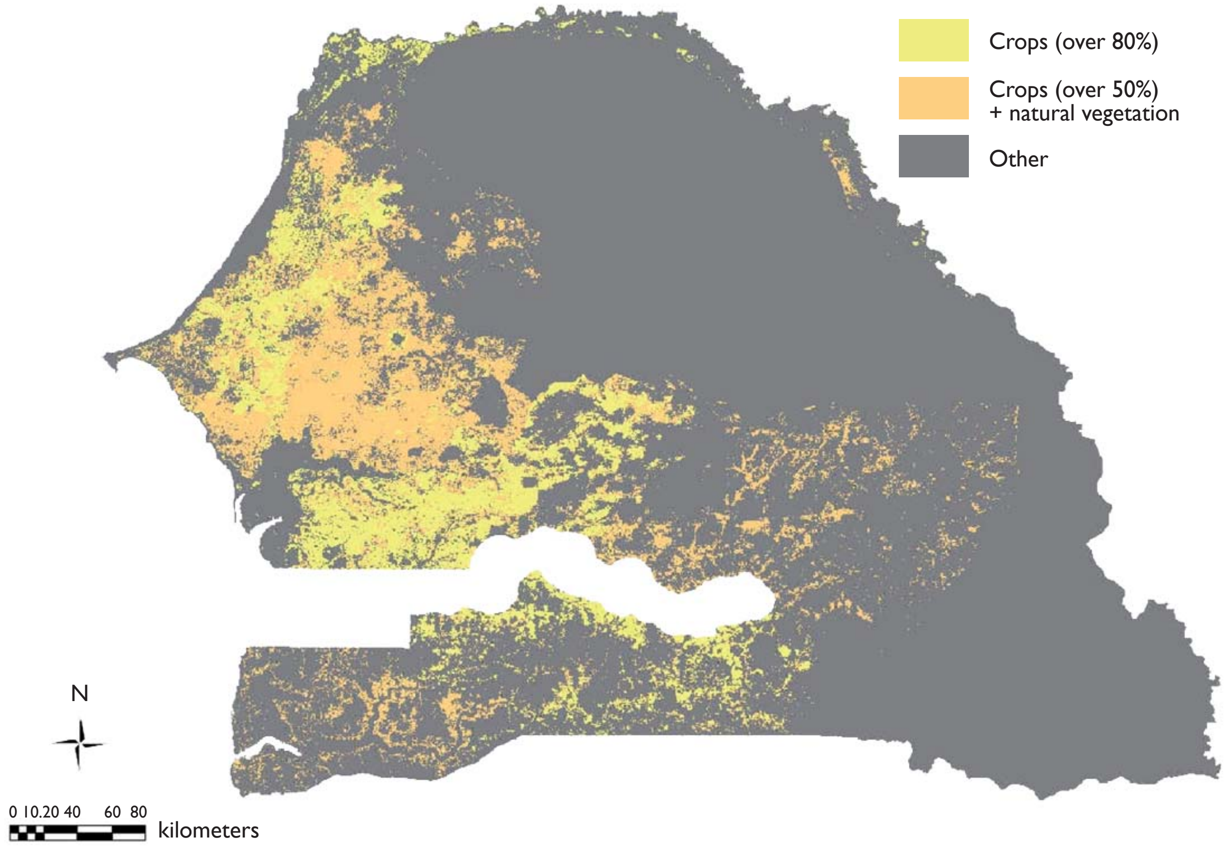
To address this concern, the SUCRETTE *(SUivi de la Canne à sucRE par TélédéTEction)* project, coordinated by CIRAD and SPOT Image, has developed a method for processing SPOT 4 and 5 images to generate maps of harvests in near-real time during harvesting periods.

The classification of sugarcane plots extracted from satellite images is based on the high spectral contrast between the standing plant cover, the crop-residue covered ground (after sugarcane harvesting) and bare soil (crop residue burnt, soil tilled for replanting). Statistical indicators of harvest areas and rates are thus calculated at different geographical scales (delivery centre, sugarcane-growing area, factory, region) in order to provide decisionmakers with elements that they require to adjust their production forecasts and harvest logistics.

In Réunion, CIRAD supplies its partners with four sugarcane monitoring maps per harvest season: a month after the beginning of harvesting, at mid-season, a month prior to the end of the season and postharvest. This enables them to estimate the annual unharvested sugarcane area.

An online information system (see TSIGANE system, p. 31) is being developed to support this type of tool, to automate treatments and to provide all stakeholders in this subsector with access to the results.

Contact: Pierre Todoroff, pierre.todoroff@cirad.fr



▲ *Cultivated area in Senegal in 2005.*

Mapping agricultural intensification patterns in Senegal and production modelling

Agricultural production forecasting is a keystone of early drought warning systems in Sudanian-Sahelian regions where climate change has a heavy impact. The aim of this project is to improve the production forecasting capacity by characterizing agricultural landscape variability via remote sensing. It addresses two questions:

- How can this variability be expressed on different scales?
- How can it be taken into account to improve yield estimations?

Agricultural landscape descriptions are based on the characterization of land-use patterns through the analysis of spectral, spatial and temporal information derived from remote sensing images. The data and methods should be tailored to semiarid environments and to their heterogeneous mosaic patterns (rangelands, crops, wooded savannas, etc.), while also being adapted to the economic conditions in these regions (low-cost monitoring). MODIS and SPOT VEGETATION images were used for this study.

Initial results have been obtained for Senegal (African Monsoon Multidisciplinary Analysis [AMMA] European Integrated Project, 2005-2009) by combining thematic information from different sources with time-series SPOT VEGETATION and MODIS satellite images. A first 'stratification' phase involves delimitation of homogenous agroecological zones by visual analysis of thematic maps (heterogeneous in terms of dates, media, etc.) describing the soil, relief, vegetation and climatic features. A second 'classification' phase is focused within each of these zones, and then photointerpretation of each class is done using SPOT set images (high resolution) and monitoring the normalized difference vegetation index (NDVI) on MODIS time series (NDVI is used to monitor plant phenology). Finally the crop land-use rates are mapped (classification at three levels: absence, >50%, >80%) by analysing, per pixel, decadal NDVI time series datasets derived from the satellite images.

Temporal changes in types of land use will be the focus of further studies.

Contacts: Christian Baron, christian.baron@cirad.fr
Agnès Bégué, begue@teledetection.fr
& Danny Lo Seen, loseen@teledetection.fr

Main teams

UPR AIVA - Agro-ecological Adaptation and Varietal Innovation
(CIRAD)
28 scientists, with 1 involved in the topic
Director: Michael Dingkuhn, michael.dingkuhn@cirad.fr
www.cirad.fr/en/research-operations/research-units/aiva

UPR Functioning and Management of Tree-Based Planted Ecosystems
(CIRAD)
17 scientists, with 2 involved in the topic
Director: Jean-Pierre Bouillet, jean-pierre.bouillet@cirad.fr
www.cirad.fr/en/research-operations/research-units/functioning-and-management-of-tree-based-planted-ecosystems

URP Pastoralism
(CIRAD)
5 scientists, with 3 involved in the topic
Director: Amadou Tamsir Diop, amtadiop@sentoo.sn

UPR SCA - Annual Cropping Systems
(CIRAD)
51 scientists, with 6 involved in the topic
Director: Florent Maraux, florent.maraux@cirad.fr
www.cirad.fr/en/research-operations/research-units/annual-cropping-systems

Other team focused on this topic

UMR AMAP - Botany and Computational Plant Architecture
(see page 18)

How geomatics information enhances knowledge on complex cropping systems

Many specific methodological problems arise when characterizing and assessing complex cropping systems established on smallholders' plots and based on various crop associations, e.g. fruit trees (coconut, papaya, cocoa, banana, etc.) and vegetable gardens. Agronomists are thus adopting new tools, such as geomatics, to enable them to gain insight into these systems on different scales. Moderate spatial resolution studies facilitate quantification of structures and their temporal evolution on a regional level, whereas very high resolution imagery can be used to refocus studies on a cultivated crop level.

A preliminary study was carried out by a CIRAD team from the joint research units UMR SYSTEM and UMR TETIS on coconut-based Melanesian agroforestry systems. This involved the combined use of field data and very high spatial resolution satellite image information to gain further insight into the intra-plot structure of these systems. A QuickBird satellite image (processed at 0.65 m/pixel resolution, multispectral [green, red, NIR bands]) covering a 64 km² area on Malo Island (Vanuatu Archipelago) was thus acquired in 2003.

The results revealed that coconut plantations could be clearly identified on the images and classified according to age. The main agroforestry types were recognized and mapped using a texture-based classification, thus enabling preliminary analysis of their layouts and densities. A remote-sensing index was also developed to quantify the canopy closure of the vegetation cover in relation to the complexity of the associations present. However, this method was not suitable for assessing all agroforestry systems encountered in the field, especially highly complex structures in which associated plants were invisible under the main cover.

1. Monocropped coconut plantation
2. Coconut plantation including associations with forest tree species and cocoa trees
3. & 4. Coconut plantations in relatively intensive rangelands
5. Coconut trees planted in a forest stand
6. Old abandoned coconut plantation (rangeland)

▲ *Multispectral NIR-red-green colour composite extracted from a QuickBird satellite image merged at 0.65 m/pixel highlighting several types of coconut-based agroforestry systems on Malo Island (Vanuatu).*

Contacts: Nathalie Lamanda, nathalie.lamanda@cirad.fr
Dominique Nicolas, dominique.nicolas@cirad.fr
& Camille Lelong, camille.lelong@cirad.fr

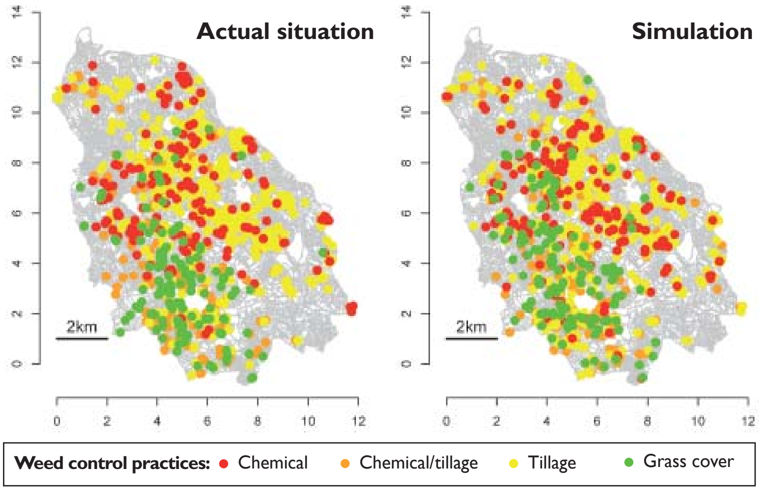
Spatialization of vineyard weed control practices in Languedoc (France)

Vineyard weed control practices represent an important factor with respect to variations in flooding, soil erosion and pesticide nonpoint source pollution hazards. These practices are the result of decisions made by farmers on the basis of various constraints and opportunities on different spatial scales–from the plot to the production area–and at different time steps. This results in a complex spatial and temporal organization on a catchment scale, which must be monitored to be able to assess the hazards.

On large spatial scales (several tens of km²), data required for these risk assessments cannot be obtained by field surveys or in-depth monitoring. The joint research unit (UMR) LISAH thus decided to adopt another approach to analyse the spatial organization of these agricultural practices in the Languedoc vineyard region (France) so as to be able to locate and quantify them.

Surveys of 65 wine growers in the lower Peyne Valley (80 km²), representing 1460 vineyard plots, enabled the researchers to draw up a typology of weed control practices that accounts for herbicide treatment ranges and variations in the soil surface states that determine the extent of runoff.

Multivariate analysis of the determinants of these practices and their locations revealed a high spatial structure of practices related with the communal locations of the plots.



▲ *Example of maps showing the distribution of vineyard maintenance practices in Peyne Valley, France (left), and a spatial stochastic simulation (right).*

The vineyard inter-row widths was the second influencing factor of soil maintenance practices.

Finally, stochastic spatial simulations based on methods for classifying these determinants, some of which could be extracted by remote sensing (UMR TETIS collaboration), generated realistic maps of weed control practices on a plot scale for the entire lower Peyne Valley. These maps could be used as inputs for distributed hydrological models to enable risk assessment.

Contacts: Anne Biarnes, biarnes@supagro.inra.fr
Jean-Stéphane Bailly, bailly@teledetection.fr
& Philippe Lagacherie, lagache@supagro.inra.fr

GIS-a tool to understand the dynamics of Mediterranean tree agroecosystems: fig and olive orchards in northern Morocco

© Y. Thomas

▲ *Agrarian landscape with a high prevalence of fig and olive trees in B'ni Ahmad region, northern Morocco.*

Trees and forest components are structuring elements of different types of Mediterranean agroecosystems, including chestnut orchards in the Cevennes (France), argan groves in southwestern Morocco, and orchards predominantly planted with fig and olive trees in northern Morocco. The extension and regression dynamics of these tree stands are associated with historical, socioeconomic and political factors. Spatial and temporal information analysis may be used to gain insight into these factors.

Northern Morocco (Tingitane Peninsula and Rif area) is a remarkable region with respect to the expansion of olive and fig orchards. An interdisciplinary research project involving geneticists and ethnobiologists from CEFE, the joint research unit (UMR) *Développement et Amélioration des Plantes* (INRA, Morocco) and Abdelmalek Essaadi University (Tetouan, Morocco), is focused on studying fig and olive tree domestication processes from two angles: the layout of wooded landscapes and the genetic structure of tree agrodiversity and associated ethnobiological knowledge.

GIS is an efficient analytical tool for comparing oral testimony (ethnohistorical data) with political and historical data and to gain insight into landscapes. The Spanish annexation of part of northern Morocco had a positive impact on the extension of these orchards (dissemination of new agricultural techniques, plants, etc.). Similarly, at independence in 1956, historical data suggests that inhabitants benefitted from a transition period to extend their land rights by planting fig and olive orchards on large tracts of land. Aerial photos taken at different periods (pre- and post-independence) and old georeferenced military maps are used for this analysis.

The project is currently pooling substantial georeferenced data from the Rif area on intravarietal genetic variability in fig and olive trees with the aim of gaining insight into the underlying genetic structure. GIS will be used to facilitate comparisons with ethnobiological data.

Contacts: Yildiz Aumeeruddy-Thomas, yildiz.thomas@cefe.cnrs.fr & Younes H'mimsa, hmimsa.younes@caramail.com

Modelling tools to understand and sustainably manage pastoral systems

Extensive nomadic livestock herding is a key economic factor in Sahelian countries and generally in other African countries south of the Sahara. This activity, which is practiced with a diverse range of livestock species, contributes to the food security of rural and urban households. There are many ambivalent interactions between herding and the environment. Herding has negative impacts such as extreme grazing pressure and health risks due to water pollution. It can also have positive impacts on ecosystems such as improving soil fertility through better organic matter recycling or increasing herbaceous biodiversity and landscape diversity through grazing pressure.

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A multidisciplinary approach using substantial georeferenced data is required to characterize the potential of pastoral systems and analyse their functioning and spatiotemporal dynamics. Moreover, accurate updated information on the state of natural resources, their dynamics, many functions and uses by human and animal populations is essential for decisionmaking on planning, local development and rangeland safeguarding initiatives.

There is growing demand from stakeholders, territorial authorities and technical services for spatial data, information systems, indicators and simulation models. This is a challenge for targeted research on knowledge building processes and the utilization of information in decisionmaking tools.

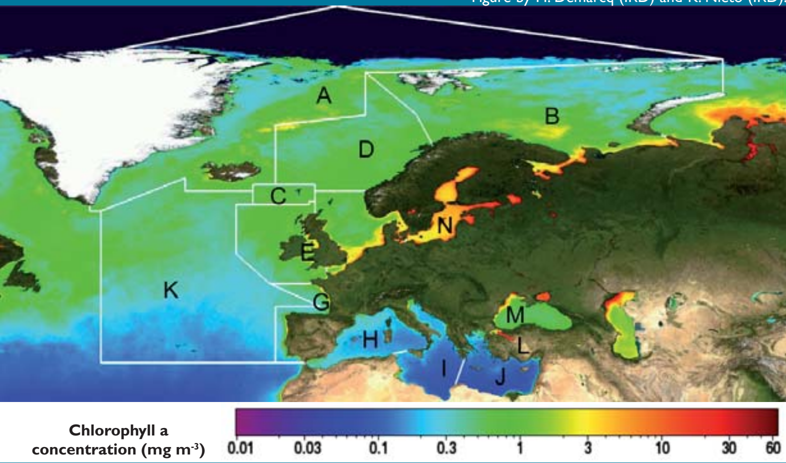
To address this challenge, some research lines of the scientific programme of the international research unit (URP) Pastoralism (CIRAD, Dry Zone Pastoral Research Pole) are focused on accounting for information and relevant baseline data needs to be used in decision support and resource management tools, as well as on the participative construction of indicators and shared use of information systems.

Contact: Ibra Touré, ibra.toure@cirad.fr

▲ *Participatory mapping workshop based on the interpretation of satellite images with herders.*

Primary production in marine environments regulates fisheries catch levels in European waters

Figure by H. Demarcq (IRD) and K. Nieto (IRD).



▲*Mean daily surface chlorophyll concentration calculated from MODIS images (2002-2007 period).*
A to M: ecoregions used for the calculation.

The productivity of the northeastern Atlantic, Mediterranean, Black Sea and Baltic Sea marine ecoregions was spatially characterized on the basis of primary production (biomass) data derived from a model based on satellite 'ocean colour' images and fisheries catch data for the 1998-2004 period. The relationship between marine productivity (phytoplankton, zooplankton, etc.) and marine fisheries production (actual catch volumes) in European seas was analysed in this study.

Positive linear and statistically significant relationships were documented between primary production and the small pelagic fish catch, as well as between primary production and the total catch. The results revealed that large-scale spatial variability in primary production determines the spatial gradients of fisheries production. This highlights the prevalence of a bottom-up trophic (nutrition) linkage in European seas, i.e. the consistent patterns (spatial structures) observed are associated with energy transfers from biomass–produced during phytoplankton photosynthesis activity–towards higher trophic levels by predation along the food chain.

The results are important with respect to promoting an ecosystem approach to fisheries, especially for estimating the capacity of ecoregions to support sustainable fisheries. Our findings are also relevant in the climate change framework as they facilitate the assessment of variations in high trophic level species and in fisheries as a function of potential modifications in plankton communities due to global warming.

Combining satellite information on biological production in oceans with global fisheries data was found to be especially useful for detecting large-scale ecological patterns and testing hypotheses on the structure and/or function of marine ecosystems.

Contact: Emmanuel Chassot, emmanuel.chassot@ird.fr

An information system to reduce pesticide pollution

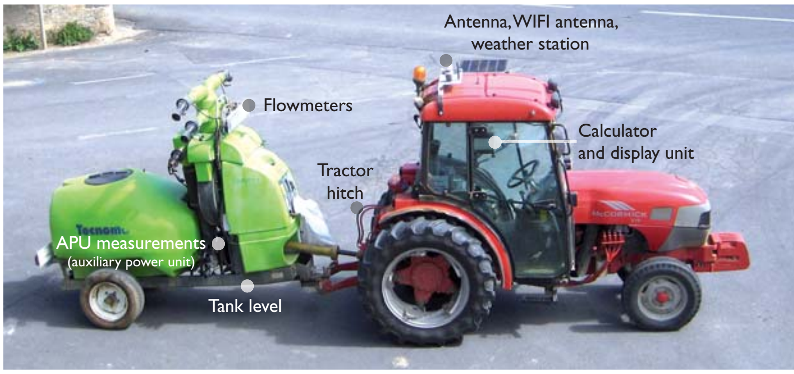
As part of the European LIFE project 'A Water Assessment to Respect the Environment' (AWARE), Cemagref has developed new onboard equipment technology for monitoring and recording pesticide application data. With this system, treatments can be accurately monitored since it measures and records application parameters every second with GPS georeferencing. Collected traceability data (flow rates, tank volumes, meteorological data, etc.) are analysed and compared to declarative data so as to be able to propose wine growers ways to improve their cropping practices.

With this tool, wine growers can calibrate their equipment daily and monitor the meteorological conditions. Moreover, they can detect malfunctions by viewing the equipment operation parameters in real time.

A GIS enables collection and display of all data: catchment delimitation, vineyard plots, river system, relief, pesticides applied, etc., in order to produce maps and spatial analyses on the concerned catchment. Rows in vineyard plots can be accurately differentiated by GPS.

The system produces a set of objective data for automatic treatment sheet printouts, including a graph of the plot on which one of the measured (flow rates in l/min) or calculated (e.g. vol/ha, wind speed and direction) parameters is displayed, along with a written summary of the different parameters: current sprayer settings, meteorological measurements, treated area, number of rows treated, dosages used, etc.

V. De Rudnicki © Cemagref



▲ *Prototype system mounted on sprayers to measure pesticide application parameters.*

Moreover, hardcopy declarative data are compared with automatically recorded data, thus enabling operational feedback and facilitating discussions with wine growers. Potential ways for improving spraying methods are thus highlighted. Streamlining the techniques could lead to a reduction in application losses and in applied pesticide quantities.

Contacts: Vincent de Rudnicki, vincent.derudnicki@cemagref.fr
Bernadette Ruelle, bernadette.ruelle@cemagref.fr
& Michaël Douchin, michael.douchin@cemagref.fr