Spatial information applications in different fields

Environment

Environment management and biodiversity conservation are universally considered as priorities in the current setting of accelerating global changes affecting physical and biological resources on Earth. It is important to think before acting, but also to understand before managing. Understanding the functioning of continental and aquatic ecosystems is, however, an uneasy task. It requires substantial time, many observations, and experts from different scientific fields to explain the underlying phenomena as accurately as possible. Geoinformation is a keystone of this approach.

Several research teams based in Montpellier (France) are working on formalizing knowledge on all physical, biological and socioeconomic processes required for sustainable natural resource management. They are developing databases and models that bring together acquired knowledge and facilitate hypothesis testing. These have been initially designed as knowledge tools that reflect specific aspects of studied systems, but they can also guide resource managers in their initiatives. To an increasing extent, these tools are based on geoinformation acquisition and processing methods, including remote sensing and geographic information systems (GIS), in order to mobilize a diverse range of data and account for their spatial and temporal relationships. Remote sensing and GIS are thus widely used in environmental sciences as they provide efficient support for integrating information and cartographic analysis.

The examples presented in this chapter illustrate the close links between environmental data acquisition, management and representation techniques, as well as thematic research domains as broad ranging as water, forestry and plant and animal biodiversity in terrestrial and aquatic environments. Satellite image (low or high resolution, optical or radar) processing is widely used to characterize the distribution of research subjects at different spatial and temporal scales. For instance, this is the case in monitoring Andean glaciers, African plant covers, toxic algal blooms in the Mediterranean, environmental niches of disease-vector rodents in Asia, coral ecosystems and oceanic eddies in association with marine predator populations. Most of these studies are also based on geographical database management systems that enable mapping and analysis of spatial interactions between the physical environment, the living environment and climatic or human forcings. This meshing of environmental data gives rise to a different enhanced view of the underlying mechanisms by promoting an interdisciplinary approach via spatial dialogue. Researchers can thus gain insight into processes and their spatial and temporal distribution, and more effective explanatory models can be developed to guide management, restoration and conservation strategies to be implemented.

Nicole Pasteur (IFR *Biodiversité*),
Denis Ruelland *(HydroSciences Montpellier)*
& Nicolas Arnaud *(Géosciences Montpellier)*

From Agropolis International thematic directory n° 9 - "Geoinformation and Earth Observation for environment and territories" (February 2010 - 68 p.)

Main teams

BRGM - Service Géologique Régional, Operational services « Eau » et « Aménagement et risques naturels »
(see page 49)

EMPA - Locust Ecology and Control
(see page 50)

EA GESTER - Gestion des Sociétés, des Territoires et des Risques
(see page 49)

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

UMR CBGP – Center for Biology and Management of Populations
(INRA, Montpellier SupAgro, CIRAD, IRD)
46 scientists, with 5 involved in the topic
Director: Denis Bourguet,
bourguet@supagro.inra.fr
www1.montpellier.inra.fr/CBGP

UMR CEFE - Centre of Evolutionary and Functional Ecology
(CNRS, UM1, UM2, UM3, CIRAD, Montpellier SupAgro, EPHE)
74 scientists, with 3 involved in the topic
Director: Jean-Dominique Lebreton,
jean-dominique.lebreton@cefe.cnrs.fr
www.cefe.cnrs.fr

UMR ECOLAG - Laboratoire Écosystèmes Lagunaires
(CNRS, IFREMER, UM2)
80 scientists, with 2 involved in the topic
Director: Marc Troussellier,
marc.troussellier@univ-montp2.fr
www.ecolag.univ-montp2.fr

UMR EME CRH - Écosystèmes Marins Exploités, Centre de Recherche Halieutique méditerranéenne et tropicale
(IRD, IFREMER, UM2)
52 scientists, with 12 involved in the topic
Director: Philippe Cury,
philippe.cury@ird.fr
www.crh-sete.org

UMR G-EAU - Water Resource Management, Actors and Uses
(Cemagref, CIHEAM-IAMM, CIRAD, AgroParisTech/ ENGREF, IRD, Montpellier SupAgro)
88 scientists, with 2 involved in the topic
Director: Patrice Garin,
patrice.garin@cemagref.fr
www.g-eau.net

UMR HydroSciences Montpellier
(see page 18)

UMR ISEM - Institute of Evolutionary Sciences
(CNRS, UM2)
107 scientists, with 10 involved in the topic
Director: Jean-Christophe Auffray,
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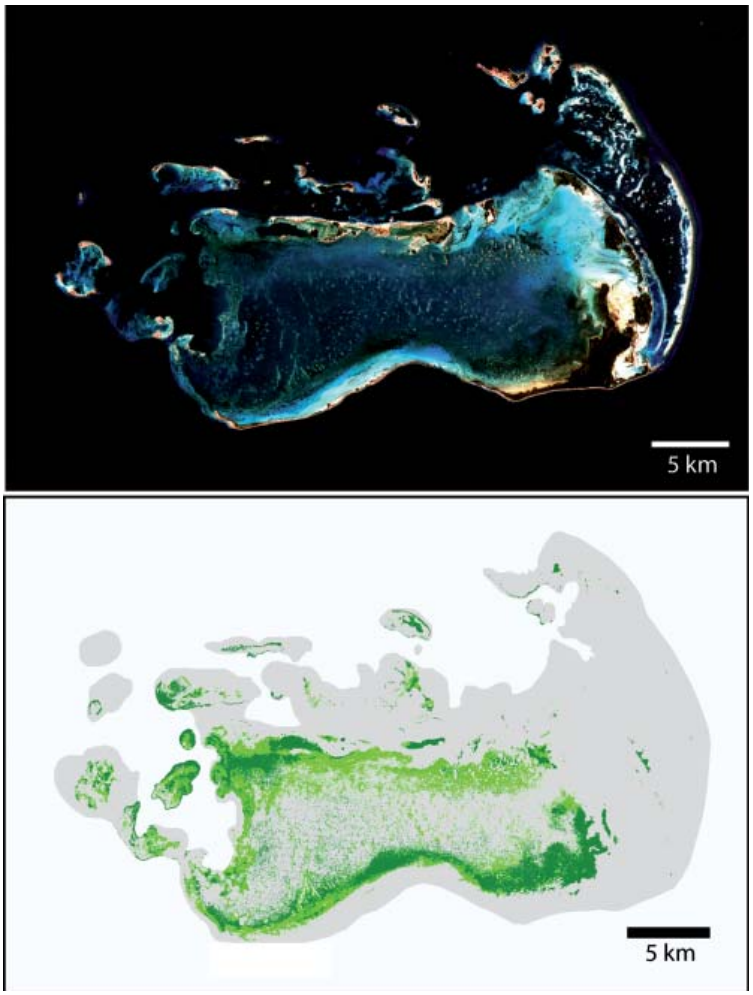
www.isem.cnrs.fr

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

UPR AGIRs - Animal and Integrated Risk Management
(see page 55)

...continued on page 44



▲ *Example of habitat maps drawn up within the framework of a regional study on marine turtles and seagrass beds in the Caribbean (extracted from Landsat images).*

Remote sensing andthe biocomplexity of coral ecosystems

Remote sensing applied to coral reef ecosystem biocomplexity focuses on biodiversity quantification specifically using a habitat-based approach. The aim is also to gain insight into processes that control and depend on this diversity, and its interaction with human communities. This latter aspect includes sustainable use of biological resources and their conservation.

Passive optical remote sensing is an effective observation tool for coral reef ecosystems that are often located in tropical, shallow, hard to reach, clear-water coastal environments. Spatial and airborne imagery, often combined with field observations, can be used to develop multidisciplinary products and applications such as field sampling designs, multi-thematic habitat maps, geomorphological atlases, bathymetric maps, water quality maps, multisensor temporal monitoring, etc. This first line of descriptive products provides decision support tools for managing communities of living organisms, delineating marine protected areas, assessing fisheries stocks, modelling hydrodynamic processes, monitoring reef systems impacted by high human pressure and global warming.

The research unit (UR) CoRéUs conducts research on several Indo-Pacific sites. The main sites are located in New Caledonia, French Polynesia, Wallis and Futuna, Réunion, Fiji, Vanuatu, Maldives and Madagascar. This research is carried out in close collaboration with local and international operators. In addition, as spatial data is routinely available for any site worldwide, the unit is a partner in scientific international research initiatives (Australia, USA) and for marine resource management programmes, with a regional (e.g. the Secretariat of the Pacific Community) and global scope (via the Millennium Coral Reef Mapping Project, Mora *et al.,* 2006).

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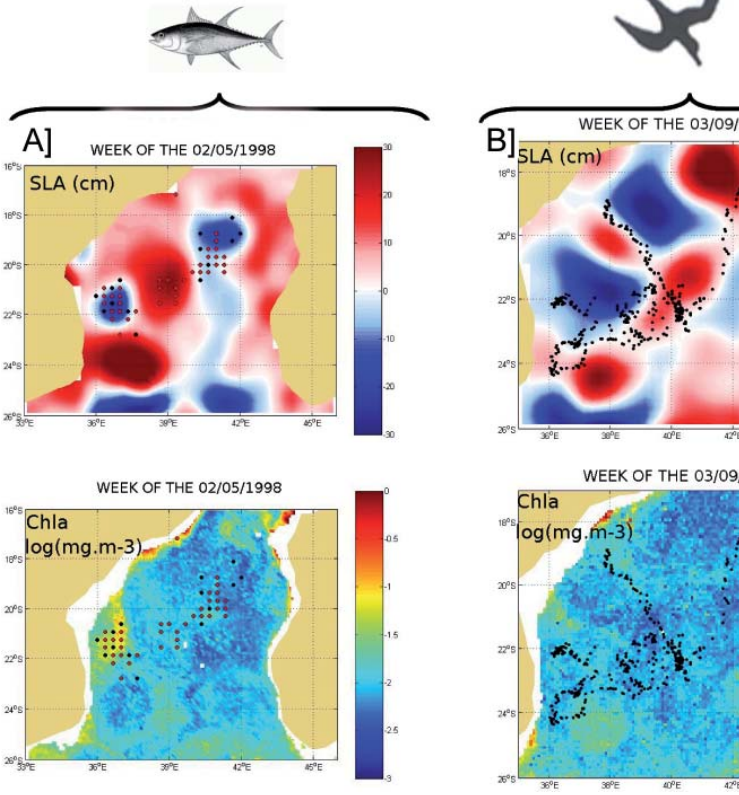

From Tew Kai E. and Marsac F., 2008.

▲ *Overlays (top) of sea level anomalies (SLA in cm, AVISO data) and (bottom) surface chlorophyll levels (in log [mg.m^{-3}], SeaWiFS data) with (dots) the positions of tuna catches (A) and frigatebirds (B).*

Red structures correspond to warm water anticyclonic eddies (converging at the surface), chlorophyll-rich along their edges, and blue structures correspond to cold water cyclonic eddies (divergent at the surface), chlorophyll-rich at the cores; the interface between two eddies is also highly productive.

Mesoscale eddies and top predator communities in the Mozambique Channel

The Mozambique Channel (10-30°S/30-50°E) is a natural laboratory for research on oceanic mesoscale eddies (50-300 km dia., lasting from one week to several months) and their impact on top predator populations. Four to seven eddies (alternation of cyclonic to anticyclonic) pass through the Channel each year. These eddies are detected mainly by satellite radar altimetry (satellite measurement of local sea level heights). Spatial descriptors of eddies and associated structures (fronts, filaments) have been used to study their impact on tuna distributions.

Two types of tuna school indicators were used: tuna catch data and georeferencing of frigatebirds fitted with transmitters. Frigatebirds, which are unable to dive, follow tuna schools to feed on small animals hunted by these large marine predators, essentially on the edges of eddies: their feeding strategy is tailored to small-sized habitats where the probability of finding prey is high. These birds thus have a role as "sentinels enabling greater insight into the evolution of marine ecosystem health" (F. Marsac).

Direct tuna catch observations (associated with the location of fishing boats) are obtained at the periphery or core of eddies, where phytoplankton production is high. Analysis of the spatial distribution of tuna schools based on these two types of indicator revealed that these fish, just like other top predators (turtles, sea lions, etc.), can benefit from eddies (core and periphery) for hunting. Mesoscale eddies can thus serve as transient habitats for these large pelagic fish.

This example highlights the importance of detecting and characterizing oceanic eddy structures in order to improve knowledge on offshore marine habitats and, finally, to enhance the management of exploited fisheries resources.

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Main teams

UPR Dynamics of Natural Forests
(CIRAD)
11 scientists, with 3 involved in the topic
Director: Sylvie Gourlet-Fleury,
sylvie.gourlet-fleury@cirad.fr
www.cirad.fr/en

UPR Functioning and Management of Tree-Based Planted Ecosystems
(see page 38)

UPR GREEN - Management of Renewable Resources and Environment
(see page 18)

UPR Management of Renewable Resources and Environment
(see page 28)

UR CoRéUs - Biocomplexité des écosystèmes coralliens de l'Indo-Pacifique
(IRD)
14 scientists, with 4 involved in the topic
Director: Jocelyne Ferraris,
jocelyne.ferraris@ird.fr
www.coreus.ird.fr

UR Great Ice - Glaciers et Ressources en Eau d'Altitude - Indicateurs Climatiques et Environnementaux
(IRD)
19 scientists, with 4 involved in the topic
Director: Marie-Pierre Ledru,
marie-pierre.ledru@ird.fr
www.ird.fr/ur032
This research unit became part of *HydroSciences Montpellier* in January 2009

URP Pastoralism
(see page 38)

US ESPACE - Expertise et SPatialisation des Connaissances en Environnement
(see page 8)

Other teams focused on this topic

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

UMR Géosciences Montpellier
(see page 28)

UMR LIRMM - Montpellier Laboratory of Informatics, Robotics and Microelectronics
(see page 28)

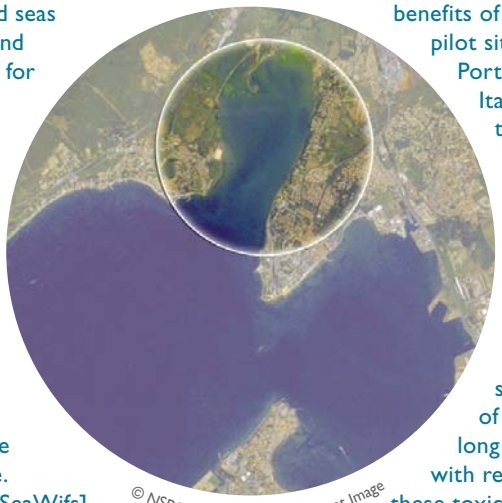
UMR LISAH - Laboratoire d'étude des Interactions Sol – Agrosystème – Hydrosystème
(see page 18)

UR Dynamiques socio-environnementales et gouvernance des ressources
(see page 55)

Monitoring blooms of the toxic alga *Alexandrium catenella* by satellite imagery at three Mediterranean sites (Thau, Tarragona, Olbia)

Toxic algal blooms occur in all oceans and seas worldwide, having major environmental and socioeconononomic impacts (often adverse for aquaculture and recreational activities).

A project was thus set up to analyse the dynamics of these algal blooms and links with human activities, within the framework of integrated environmental management policies. Satellite imagery, which provides a synoptic spatial view of the phenomenon, is also used to effectively support current *in situ* measurement methods (water sampling and analysis). However, the spatial resolution of satellite sensors designed for such monitoring (i.e. Sea-viewing Wide Field-of-view Sensors [SeaWifs], with around 1 km resolution) is not sufficient to obtain accurate descriptions of local or regional bloom phenomena, especially on basin or lagoon scales.



The aim of the project under way, carried out by the joint research unit (UMR) ECOLAG in collaboration with IFREMER and the Nev@ntropic company, in partnership with SPOT Image's collaborative Planet Action network, is to assess the benefits of high resolution satellite imagery at three pilot sites: Thau Lagoon (France), Tarragona Port (Spain) the Gulf of Olbia (Sardinia, Italy). These are sites where blooms of a toxic alga *(Alexandrium catenella)* occur regularly, and sometimes simultaneously, with a marked environmental impact. As a complement to *in situ* measurements, high resolution satellite imagery is used to specify and understand the factors determining bloom development through analysis of their spatiotemporal distributions and characterization of the species' lifecycles. The patchy distribution of algal blooms (typically around 100 m long and wide) is a substantial challenge with respect to evaluating the total biomass of these toxic algae. Satellite imagery–which provides an integrated synoptic view of the phenomenon–is thus used to monitor the development of such blooms and their dissipation over time.

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François Marques, fm.nev@ntropic.fr
Annie Pastoureaud, annie.pastoureaud@ifremer.fr
& André Vaquer, vaquer@univ-montp2.fr

▲ *Toxic algal blooms in Angle Creek, located on the northeastern side of the Thau Lagoon (Hérault, France). This creek is the site of bloom onset, followed by propagation into the main part of the lagoon.*

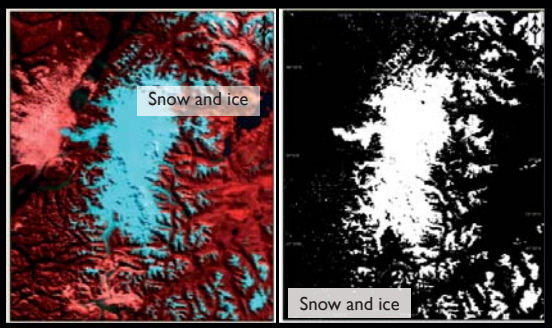
Monitoring snow cover on Campo de Hielo Norte, Patagonia (Chile) from MODIS satellite images

Many members of the scientific community are now focusing on gaining greater insight into the impact of climate change on our planet. Melting of glaciers is one of the most obvious consequences. Information acquisition is, unfortunately, complicated by problems of access (steep reliefs) and the vastness of glaciated areas.

Satellite and airborne remote sensing is very effective for overcoming these complications since it enables remote monitoring and analysis of huge surface areas. The research advantages of these technologies are multiplying with the regular improvements being achieved in spatial and temporal resolutions.

South America hosts many glaciers in the Andes Cordillera, stretching from Colombia to Patagonia. In line with the global trend, these glaciers are retreating, especially in the Patagonian region of Campo de Hielo Norte (CHN), i.e. a 4 200 km² ice field, whose surface area is diminishing in conjunction with the accelerated retreat of glaciers that prevail in this region.

To get a clearer picture of the local climatic factors influencing CHN glacier variations, the evolution of snow-covered areas in this ice field was monitored over the 2000-2006 period based on the normalized difference snow index (NDSI) applied to MODIS satellite images.



The study highlighted the seasonality of the intra-annual evolution in the snow-covered area: in summer (December-March), this surface area retracted to 3 600 km² (corresponding to the accumulation zone), with very few inter-annual variations during this season, whereas the snow extension was much greater in winter (up to 11 700 km²), with high inter-annual variations.

This study suggested that snow cover on the western part of CHN could melt more rapidly in response to the milder temperatures, but the area could be quickly covered again with more frequent and abundant snow falls.

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▲ *Example of an application of the NDSI index on a MODIS image.*

GIS tools are essential for tropical forest management

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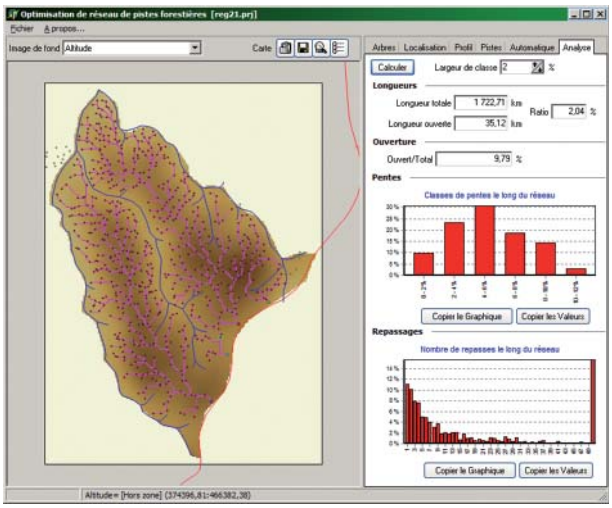

▲ *Map interface of a support tool for forest trail network planning.*

Since the Earth Summit (Rio, 1992), principles that promote ecologically sustainable management of tropical forest ecosystems are widely recognized. In Central Africa, sustainable forest management has become a key element of new forestry policies. Over the last 10 years, geographic information processing tools (GPS, image processing software and GIS) are widely used by professional stakeholders and GIS has become an essential tool for African forest managers.

Within the framework of companion research, CIRAD has been involved for over 15 years in the development of remote sensing methods to monitor forest cover and of GIS-based decision support tools.

Because of the complexity of the objectives (especially reconciling multiple uses), forest managers are hampered to an increasing extent by the problem of translating their objectives and potential management scenarios into a set of mathematical equations. This difficulty is partly due to the fact that foresters are unable to determine the state of a target system at any given time, and to the imprecise or even intuitive nature of the decisionmaking elements.

The research under way is geared towards the development of tools to support decisionmaking on planning forest trail networks, on creating plot layouts, on designing 'reduced impact' logging and on predicting stand growth. Because of the contextual limits (acceptance and adoption by stakeholders) of automated and mathematical optimization approaches, CIRAD aims to develop interactive and semiautomated management support tools. GIS software is a key tool for facilitating information integration and cartographic analysis, while also serving as an interface between users and automatic computation procedures.

Prototypes are currently being field tested in French Guiana, Central African Republic and Gabon.

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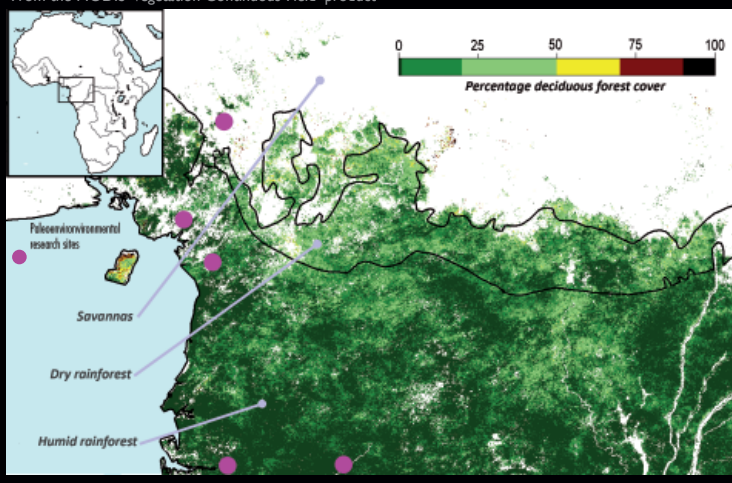
Satellite vegetation data as a tool for paleoecology research in Central Africa

From the MODIS 'Vegetation Continuous Field' product



▲ *Map of the dry and humid rainforest region based on floristic associations (phytogeographical domains identified by White, black lines) or on the percentage deciduous tree cover (evergreen forest in dark green, semideciduous in pale green).*

Climate change and human activities can trigger flora and vegetation structure modifications. In the Central African forest region, paleoenvironmental research sites, where the evolution of the vegetation cover and associated forcings over the last millenia can be traced, may be represented by a few scattered dots on a map. To reconstruct a regional history of the range and nature of the forest, this point information should be interpolated via spatialization of functional models that are able to deduce the features of plant formations according to the climatic and pedological characteristics.

In Central Africa, outputs of these models can be interpreted in terms of the vegetation structure, e.g. by assessing the total biomass, the grass-tree cover distribution in savannas and the proportion of deciduous tree cover in forest areas during the dry season. This information on the actual vegetation status, which was for a long time limited to small areas, is now available on a large scale via remote sensing tools. These data (generally open source) are highly useful for the task set out by ISEM (Institute of Evolutionary Sciences, CNRS, UM2) of integrating ecological and paleoecological knowledge on Central Africa: i) they compensate for the lack of field measurements to calibrate paleoenvironmental indices required to trace the history of the vegetation structure; ii) they enable a regional comparison between the vegetation patterns and phytogeographical domains, i.e. the distribution of floristic associations on which current vegetation maps are based; iii) they provide a reference source for validating vegetation models; these latter could thus more accurately represent the current situation before being used to reconstruct or predict past and future changes.

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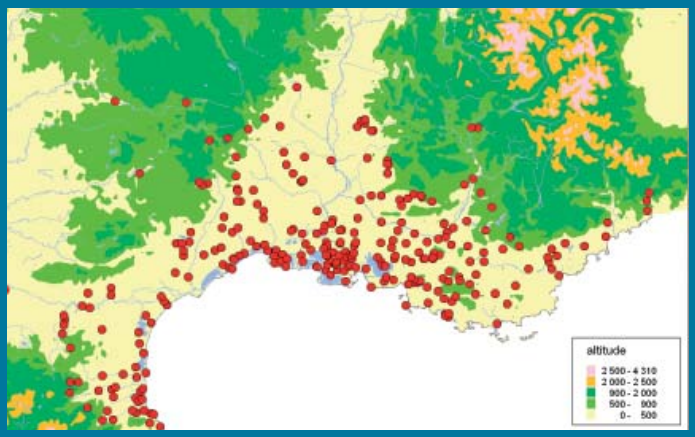
Georeferenced taxonomy databases on vertebrates (amphibians, reptiles, mammals) in the South of France

For three decades, the Ecology and Biogeography research team of the *École Pratique des Hautes Études* (CEFE-EPHE) has been centralizing information on vertebrates in southern France derived from point observations by professional and amateur naturalists. This information, which is now computerized and spatialized, can be used to answer many scientific and operational questions.

From a scientific standpoint, many issues can be addressed via these databases: How is biodiversity distributed in the Mediterranean area? What factors best explain the observed gradients? What changes have been under way in recent decades? Hence, it is possible to monitor the progression of invasive species (e.g. red-eared slider turtles, muskrats, painted frogs) and develop strategies to control them or, conversely, to monitor the fate of endangered heritage species that would warrant conservation initiatives: otter, ocellated lizard, European pond turtle, etc.

From a more applied standpoint, these databases can be utilized to fulfil many current biodiversity conservation requests: What areas would warrant biodiversity preservation initiatives? In what areas is there contention between economic development and environmental protection? These databases are therefore tapped by many French administrations and governmental agencies (*Direction Régionale de l'Environnement, Agence Régionale de l'Environnement,* general councils, etc.) responsible for the protection of natural environments: setting up the Natura 2000 network, inventories of natural areas of ecological, faunistic and floristic interest, acquisition policies for sensitive natural areas, development of a regional biodiversity preservation strategy, etc. They can also address wider scope requests such as monitoring biodiversity on a national or European basis. These databases should ultimately be merged with public databases that are being developed on a French *(Système d'Information sur la Nature et les Paysages)* and international (Global Biodiversity Information Facility) scale.



F. Poitevin © CEFE

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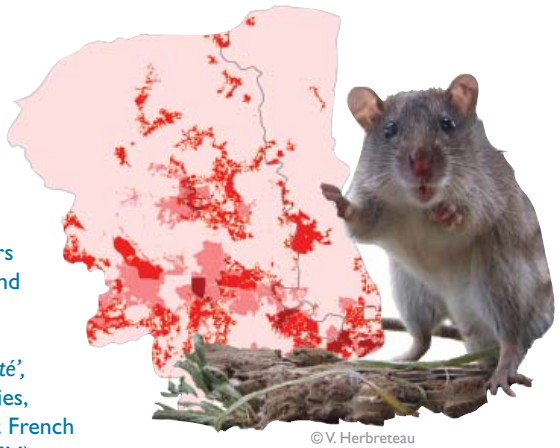
& Philippe Geniez, philippe.geniez@cefe.cnrs.fr

▲ *Distribution range of the Etruscan shrew* (Suncus etruscus) *in the French Mediterranean region (red dots).*

Ecology of rodent communities and their pathogens in Southeast Asia

The high biodiversity that is known to prevail in Southeast Asia is currently threatened by the rapid economic development and rising impact of human activities on ecosystems. In this setting of harsh and radical environmental change, rodent populations, which account for most of the vertebrate animal biomass present, are emerging as major vectors of diseases (some of which can be fatal for humans, e.g. leptospirosis and scrub typhus) and as crop pests.


© V. Herbreteau

The CEROPATH project, funded by the French *Agence Nationale de la Recherche 'Biodiversité',* is focused on the impacts of environmental change on the evolution of rodent communities, their parasites (helminths, arthropods) and pathogens (microparasites). It groups different French and foreign laboratories in complementary fields, including population genetics (CBGP, ISEM), morphometry (ISEM, *Muséum National d'Histoire Naturelle*), spatial analysis (TETIS and the Laotian National Agricultural and Forestry Institute), as well as molecular epidemiology for research on viruses (*Institut Pasteur,* Cambodia), bacteria (Siriraj Hospital, Mahidol University, Thailand), fungi (*Institut Pasteur,* Lille, France) and blood parasites (Kasetsart University, Thailand).

This project, which is under way at eight research sites located in Cambodia, Laos and Thailand, is aimed at characterizing processes that contribute to observed host-pathogen associations, while also considering the environment and evolutionary histories of the interacting species. One of the key issues concerns the identification of rodent species and estimation of their spatial distribution and spatiotemporal dynamics. The study is based on GIS software integrating field data on rodents. This GIS utilizes satellite images on different scales, from the regional scale (to compare study sites and place them in their geographical context), to the local scale (involving high spatial resolution characterization of environmental niches). The project is thus aimed at building models to assess the spatiotemporal dynamics of populations and to forecast changes in host-pathogen communities associated with potential ecological changes.

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▲ *Potential distribution range of* Rattus tanezumi *in Nakhon Pathom province (Thailand) estimated by combining field capture data and satellite image analysis.*