Ecology is the study of the interactions between living organisms and their environment. Ecologies, in the plural, would however be more appropriate as shown by the various facets of this interdisciplinary science that are being explored by researchers from four UPS laboratories. Topics being studied include the mechanisms involved in biodiversity dynamics to the regulation of organic matter fluxes in landscapes. Such collaboration between research teams together with their well-recognized expertise in evolution and functional ecology make the Toulouse campus one of the prime research centres in France.

This issue of the magazine provides details of the research being carried out on the dynamics of biodiversity in the context of a changing environment on various temporal scales and under the influence of strong biological interactions (such as for example, mycorrhizal symbiosis). In other studies, the impact of climatic change and invading species on the diversity of aquatic communities is being modelled, allowing us to establish how certain species will spread and diversify in the near future. Moreover, biodiversity per se also controls the rate at which ecosystems function, which may for instance, be altered and become much less predictable should some species disappear.

Although, originally a basic science, ecology has not long since been confined to naturalism. It is based on continual interactions between observations, hypotheses, experiments, modelling and predictions. It has thus become a certain vision of our world with clear political stakes. As well as exposing the effects of industrialization and agriculture over the last decades, ecology has also put forward a number of useful applications and original solutions to environmental issues. As an example, ecological engineering exploits the ability of organisms and natural processes to remedy habitat degradation. This magazine also outlines the importance of research in Toulouse on biologically controlling agricultural pests. Finally, our laboratories have demonstrated their ability to transfer technology and forge industrial partnerships in the areas of environmental biogeochemistry and ecotoxicology. A recent example of such a partnership is the creation of the Nautile Joint Laboratory in 2010.

This special issue on ecology also brings with it the news that the laboratories EDB, EcoLab and part of the CESBIO are being assembled in a renovated building dedicated to ecology. The labs should be ready by the end of 2010. This major venture required important efforts from the institutions, especially the UPS, which covered almost half of the works costs. In addition, the ecological research station in Moulis (a CNRS lab) will soon offer a variety of experimental sites that are unique in Europe and will allow scientists from Toulouse to test original research hypotheses. Such positive initiatives also include the recent submission of a project by the Observatory of Biodiversity and Ecosystems in south-west France by Toulouse scientists. All these achievements will contribute to reinforce existing collaborations and develop new ones, thus making ecology, especially at the university of Toulouse, a key science increasingly responsive to society’s expectations.

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How fungi adapt to their environment

Fungi are omnipresent and play a fundamental role in the function of ecosystems. The key to their success: an intimate relationship with other organisms.

Fungi are heavily influenced by modifications in their habitat and by human activity. This is particularly true for fungi that are in symbiosis with plants, be they mutualistic or parasites. Historical agricultural practices have led to a loss in fungal diversity and species migration, as well as a state of imbalance leading to rapid speciation and radiation. Nearly 80,000 species of fungi have been described up to now. However, taxonomists agree on a total of 1.5 million estimated species in present-day flora. This reservoir of diversity plays a critical role in the function and sustainability of ecosystems and anthroposystems, through a variety of ways, such as mineral nutrient cycling, soil fixation, or resistance to pathogens. Behind this abundant biodiversity, there is a goldmine of bioproducts and biotransformations that have applications in domains as diverse as forest management, agronomy and biofertilizers, green chemistry and biofuels, or the synthesis of novel molecules for the agro-food and pharmaceutical industries. It is now urgent to gain a better understanding of evolutionary and ecological mechanisms that are involved in the origin and maintenance of this biodiversity, and therefore contribute to its preservation.

Symbiosis

Our research group is interested in the rules of community and population assembly, and in particular to study how species of fungi are spreading and specializing in relation to plants and their biotic and abiotic environment.

Our main study models are the ectomycorrhizal (ECM) fungi that form symbioses with tree roots. Tools and methods of molecular fingerprinting are being developed and utilized for identifying species in plant roots at various spatial scales. Phylogenetic and biogeographic data sets then allow us to validate or reject hypotheses for fungal diversity evolution.

The ectomycorrhizal symbiosis between Alnus and fungi

Our research on the molecular ecology of ECM fungi have confirmed that the mutual interaction between alders and their ectomycorrhizal symbionts is one of the best models to understand how certain species of ectomycorrhizal fungi have a restricted host range (“specialists”), whereas others associate with a broad range of plants (“generalists”). Thus, the alders associate with a small number of ECM fungal species (probably less than one hundred) that are highly specific. In the mushroom-forming genus Alnicola, we have found that specialization towards the host plant has appeared independently at least twice in the evolutionary history of the genus. The situation is even more puzzling for fungi in the ECM genus Alpova. Thus, field studies and phylogenetic analyses have shown that fungi which develop entirely in soil have adapted to certain species of alders, but not to others. However, fungal host switches are also observed among phylogenetically-related alder species or alder species in close proximity, within particular environmental contexts. Several mechanisms may explain the observed diversity and patterns of plant-fungus interactions, for instance limits in species dispersal or competition among the fungal symbionts. Within our research framework, we are also exploring the functional role of the ectomycorrhizal fungi, particularly in the nitrogen cycle, with the aim of revealing the biological traits that drive the specificity of the plant-fungus interaction.

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Climate change and biodiversity along river ecosystems

In the context of biodiversity crises on the global scale, freshwater ecosystems could be among the most threatened ecological systems following recent climatic and anthropogenic changes.

Biodiversity is increasingly being altered on the global scale. Such changes heavily impact river ecosystems, which have already been modified by human activities. Such ecosystems are known as habitat and biodiversity hotspots. However, their biodiversity is changing much faster than 'normal' evolution rate, since freshwater ecological communities are being more and more modified by the introduction of new species. How will these ecosystems react to recent climate changes?

Fewer brown trouts

This is the question addressed by the Evolution et Diversité Biologique (EDB) Laboratory. Part of this laboratory’s research is devoted to understanding the impact of climate change on the geographic distribution of stream fish species. Based on statistical modelling, these investigations aim to predict suitable habitats in the future under several climatic scenarios. While cold water species (like brown trout or common sculpin) would decrease in number, other species like European chub would significantly spread. Also, the number of species richness is expected to increase thanks to a dominant positive response of many different types of fish. This increase is especially expected along mountain streams. However, we predict a decrease in spatial diversity along French rivers. Therefore, upstream river stretches are of major ecological interest, as a refuge for cold water species or as new habitats for other species.

More invasive species

The research team ‘Communautés végétales aux interfaces terre-eau’ (plant communities at the water-inland interface) of the ECOLAB laboratory is studying the relationships between ecological disturbance and plant diversity at the frontier between a river and its floodplain (the “riparian” zone). Here, the hydrological regime of the river stimulates biogeochemical processes (such as nutrient cycling) and enhance species turn-over within the changing habitat mosaic of the riparian corridor. These properties explain why species diversity is exceptionally high within most temperate riparian zones (for example, more than 2000 plant species can be found along the 350 km long Adour River, and up to 100 species on parts of the river Garonne). Whereas human-induced habitat fragmentation and river regulation can reduce the abundance of species or make them disappear altogether, such anthropogenic changes can also favour the arrival of new species that come from surrounding ecosystems. This is the case for introduced and/or “ruderal” species (those growing in wastelands, agricultural or urban areas). Therefore, riparian corridors constitute not only a refuge for these alien species, but they are also efficient vectors for the spread of species on the regional scale. On average, 25% of the plant species found along river systems are non-native ones. Predictions for the ecological and physiological responses of these potentially invasive species facing climate change therefore represent a core issue for scientists and managers. Early modelling on this topic gave diverse results. Of the 54 invasive plant species studied, eight would not change their former distribution and 10 are expected to decrease in number while 36 species would increase and become more invasive. The next step for our team is to improve the models by including human and native species activity to efficiently predict the impact of these increasing invasions on future river ecosystems.

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>>> Predicting the increase in the number of invasive plant species along the elevation gradient, assuming successive increases in mean annual air temperature. The grey area shows the location of the mountain-lowland transition.
Biodiversity for ecosystems

All organisms on Earth, be they big or small, play a role in the ecosystem. Current ecological research seeks to predict the consequences of ongoing biodiversity changes caused by man-made perturbations in the environment.

Charles Darwin’s final book entitled “The formation of vegetable mould, through the action of worms, with observations on their habits” (1881) reported on how earthworms affect the properties of soils. Since then, empirical research has provided confirmation for the idea that microbes, plants and animals play crucial roles in the ecosystem. Living organisms influence the amount of material in their environment and the rate at which it is processed.

Growing evidence for the unprecedented rate of biodiversity loss worldwide has led to considerable research that is looking at the consequences on ecosystems. Ecologists have designed experiments in which ecological communities are assembled using fewer species. A vast majority of these studies focus on seeded grassland plots. Based on these findings, it should be expected that plant species loss negatively affects a range of important properties of grasslands, such as productivity, protection of soil against erosion, or community resistance against biological invasions. Such biodiversity effects are very different for different species living in the same habitat.

Biodiversity and the carbon cycle

In our research lab, we aim at evaluating the consequences of losing microbial, plant and animal communities on the dynamics of carbon in aquatic ecosystems. Experiments using laboratory and field microcosms have revealed that fewer tree or fungal decomposer species lead to less predictable rates of how plant detritus is broken down. Furthermore, we have shown that invertebrate detritivores are more efficient at recycling plant detritus when colonized by species-rich colonies of fungal decomposers than by species-poor colonies. Both these results highlight a close relationship between the carbon cycle and biodiversity dynamics.

Towards realistic experimental systems

A major challenge for ecologists is to determine if lessons from microcosm experiments can be extrapolated to the real world, where systems are far more complex and dynamic. We are currently designing semi-natural experimental systems, namely a network of ponds and artificial streams, which will allow us to manipulate biodiversity and other ecological factors in real-world conditions. This scaling-up effort is made in collaboration with the CNRS Station d’Ecologie Expérimentale at Moulis (in Ariège, France) which is becoming a central research platform in France.

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>>> Antoine LECERF, assistant professor at UPS, member of the laboratoire d’écologie fonctionnelle (EcoLab), joint UPS/CNRS/INPT lab.

>>> Experimental data showing that variations in the rate of plant detritus breakdown increase as the diversity of trees (left) and fungal decomposers (right) declines. This process illustrates how biodiversity can lead to ecosystem stability.
In the IVth Century, Chinese farmers used ants to protect citrus orchards from various species of caterpillars. They were in fact practicing what is now called biological control, which is the control of pests with other beneficial organisms. In Europe, the biologist René-Antoine de Réaumur and Erasmus Darwin, Charles' grandfather, rediscovered this means of pest control in the XVIIIth century. They independently observed aggregations of predatory insects on plants infested by aphids. Therefore, they suggested that gardeners employed by aristocrats and other nobles should introduce predators into their greenhouses in order to protect their collection of plants.

A ladybird from Oceania

The first modern application of biological control dates from the end of the XIXth Century. A ladybird from Oceania, Rodolia cardina, was introduced into California to control an exotic mealybug, inadvertently introduced from Oceania. Mealybugs were proliferating in citrus orchards and threatening the production of fruit. 100 ladybirds were collected in Australia and brought back to California. They gave birth to about 10 000 offspring that were then scattered in the most infested orchards. These ladybirds became acclimatized, bred and colonized all the orchards. Two years later, mealybugs had nearly disappeared altogether and were just a bad memory. This outstanding but unexpected success triggered a flurry of enthusiasm for biological control using ladybird beetles in particular. However, R. Cardinalis’ success story is still a rare event today. According to available data, only 0.6% of attempts at controlling aphids meet with success and 8.6% in the case of coccids. Why?

Pesticides

This major issue at the beginning of the XXth century gradually dwindled at the same time as pesticides became the ideal weapon again pests. However, today’s society is worried by the detrimental effects of pesticides on the environment and human health. Sustainable agriculture, which has a lower impact on the environment and uses less fossil energy, is becoming more and more important. In accordance with European policy, France launched the Ecophyto 2018 plan, whose objective is a 50 % reduction in pesticide consumption by 2018. Biological control is therefore coming back into the limelight.

Our laboratory is interested in this topic. Why are predators not able to wipe out populations of pests such as aphids or coccids? Biological control is based on a widely accepted idea that predators regulate pest abundance because they eat pests. Therefore, the more they eat the better they should be at regulating the pests. This is true in some cases, such as the Californian case study described above, but not in all. On the contrary, ladybirds feeding on aphids only have a marginal influence on their prey. The reason for this lies in the reproduction behaviour of the predators. Observing ladybird females, we have discovered that they only lay eggs at the beginning of the development of aphid colonies. In addition, females avoid colonies in which co-specific larvae hunt prey. Our team showed that larvae deposit a smear of hydrocarbons while moving on leaves and stems. It is likely that these substances improve the grip of larvae to waxy cuticles of plants. Females recognize the track left by larvae and avoid colonies that are so marked. Female behaviour is adaptive because it reduces the risk of egg cannibalism by larvae born from earlier batches of eggs. Can this behaviour explain the failure of ladybird predators or is it the reason why coccids are better? Would it be possible to exploit this behaviour to design biological control strategies? These are the questions driving our research.

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Looking for a new biological control agent against a maize pest

Macrocentrus cingulum, a small wasp, could protect maize against one of its worst enemies, the corn borer. Good news for advocates of biological control.

Maize is the third most widely cultivated cereal around the world with 694 million tons grown every year on 144 million hectares, of which 56 million tons in Europe and 13 in France. One of its worst pests is a moth belonging to the genus Ostrinia, which includes two closely related species, O. nubilalis, the European corn borer which was accidentally introduced into North America a century ago, and O. furnacalis, the Asian corn borer which is present in Asia and Oceania. These pests are responsible for the loss of around 10% of crop.

The most common way of getting rid of corn borers is to use chemical insecticides, which are bad for human health and the environment. Alternatives include using genetically modified (Bt) maize, and also biological control. This consists of releasing natural enemies - parasites or predators - of the target pest, which are usually less harmful for producers, consumers, and the environment. The method has proved quite successful so far in the case of maize, as shown by the company Biotop selling a small hymenopteran parasite, the trichogramma, for the last twenty years to maize growers. However, trichograms exclusively attack the egg stage: if a larva manages to hatch in time, it is not affected by trichogram. A second, natural enemy would thus be useful here.

Larval parasite

We set out to evaluate the potential of a second hymenoptera, Macrocentrus cingulum, a larval parasite. The little we know about it is intriguing. It was first studied in the US in the 1920s, just after the European corn borer arrived in North America. The first idea was to search for natural enemies in the pest’s area of origin in order to control it. Releasing M. cingulum collected in France mostly failed, despite an impressive number of predators. Surprisingly, predators from Asia seemed to be more successful, even in much smaller numbers.

Part of this mystery was solved when we, together with a team from INRA, showed that there were in fact not one, but two European borer species: one species feeding not on maize but on mugwort, strongly infested by M. cingulum, and from which the individuals unsuccessfully released in the US probably originated, and another, feeding on maize, and little or not infested by M. cingulum. Our current hypothesis is that there are also two Macrocentrus “species”: one European, unable to prey on corn borers, and the other, Asian, with encouraging results in the US suggesting that it may be a promising candidate for biological control in Europe.

Our goal is now to more carefully assess the taxonomy of Macrocentrus to better understand why certain populations or species are more efficient at preying on the maize corn borer, and to assess the feasibility and the effects on the environment of introducing a more efficient parasitoid into Europe. Taxonomists from the National Museum of Natural History, geneticists from INRA, immunologists from INRA and from Guangzhou (China), an entomologist from the University of Kentucky and Biotop are working together on this interdisciplinary project.

In our teams at UPS, we rear M. cingulum on its natural host to provide everybody with the organisms they need for their studies or experiments. We catch M. cingulum in various countries and check whether non-European strains are able to fully develop on European O. nubilalis. We also study the immune and behavioral processes involved. Finally, we intend to test non-European strains of M. cingulum for host specificity with the goal of possibly releasing these in Europe for biocontrol.

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Are carbon nanotubes dangerous for the environment?

One way to answer this crucial question is to ask researchers from different scientific disciplines like those working in the framework of a new structure called the NAUTILE laboratory.

Until recently, it was not very easy to demonstrate that there were pharmaceutical contaminants in the aquatic environment. Today, such contamination is well recognized and documented. The general aim of "prospective ecotoxicology" is to predict the potential effects of a new molecule or of new processes on the environment. The discipline relies on laboratory validated test-systems and on standardized procedures, like those used in the new European legislation on chemical substances (REACH: Registration, Evaluation and Authorization of Chemicals). But, in some cases, scientists and regulators run into difficulties, like in the case of new “emerging risks” - for example, in the case of nanoparticles in the biosphere.

Very little is known on the subject

Artificially synthesized carbon nanotubes are relatively well known by the general public and are often highlighted in the general press. However, little is known about their potential interactions with, and effects on, living systems. A few years ago at Paul Sabatier University, chemists specialized in making carbon nanoparticles, and biologists specialized in studying chemical contaminants in the environment (ecotoxicologists) developed joint research programs on the subject. This was the case of the “Ecotoxicology and environmental genotoxicity” team at the EcoLab laboratory (joint CNRS/UPS/INPT lab) and of the “Nanocomposites and Carbon nanotubes” team at the Cirimat laboratory (joint CNRS/UPS/INPT lab). This collaborative work was the first in France to deal with the potential risks of carbon nanotubes in the environment.

The NAUTILE Joint Laboratory

Working programs were developed in collaboration with the two laboratories from Toulouse, in close cooperation with a producer and supplier of carbon nanotubes, Arkema-France. In the framework of this collaborative program new methodologies for assessing the ecotoxicity and genotoxicity of carbon nanotubes in aquatic media will be developed as well as the physical-chemical characterization of carbon nanotubes (depending on how they are synthesized). Furthermore, this work will provide support to national and international standardization in the working group on “Nanotechnologies”. This new collaborative program between laboratories and industry will be housed at a new joint laboratory called NAUTILE (NAnotubes & écoToxIcoLogiE). This new structure will involve close cooperation between scientists working at the EcoLab, Cirimat and GRL-Arkema. The first results obtained from NAUTILE already demonstrate the importance of studying the effects of carbon nanoparticles and show that biological responses are highly varied, because of the physical-chemical properties of the studied nanoparticles.

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During the last century, like in most northern European countries, French forests were exposed to increasing amounts of sulphur, nitrogen and metals from the atmosphere as polluting emissions increased. In the mid-eighties, forest degradation increased even further, forcing scientists to investigate and understand the mechanisms involved. Coniferous forests absorb large amounts of atmospheric particles mainly during dry periods. Consequently atmospheric pollutants in soils increase even in areas not directly polluted. When such forests grow on soils with a weak buffering acid capacity, that is, soils unable to limit acidification, the nutrient pool is disturbed and forest health is indirectly affected. This may lead to forests dying as already observed in some eastern European countries.

International negotiations

The “critical load” concept was set up on the European scale to reduce long-range transboundary atmospheric acid pollutant emissions. It has been used for more than 15 years for international negotiations on pollutant emission reductions. The critical load is “the highest possible deposition of compounds that will not cause chemical changes in soil leading to long-term harmful effects on ecosystem structure and function”, according to present knowledge.

Vegetation and collembola as indicators of critical limit

Today, the challenge is to model how sensitive forest ecosystems are to atmospheric pollution within the framework of global climate change. Indeed, sulphur pollution has been noticeably reduced but nitrogen not much so, and nitrogen transformation in soils leads to acidity. This contributes significantly - and more significantly than before - to soil acidification or eutrophication. Thanks to the way they reproduce, grow and their taxonomic diversity, collembola (small soil invertebrates) can be used as bio-indicators of critical limits for metals in forest ecosystems. (This work is being done in collaboration with Yves Crouau and Charles Gers from EcoLab). To model critical loads for nutrient nitrogen (in collaboration with Lund University, Sweden), we are investigating how vegetation diversity responds to nitrogen atmospheric deposition in the context of global change and the biogeochemical response of soils. For that purpose, the French vegetation maps from Henri Gaussen have been used. Databases combining those of soil and vegetation were used for calibration (in collaboration with Jean-Claude Gégout from Engref-Nancy, Jean-Luc Dupouey from Inra-Nancy and Thierry Gauquelin from Imep-Marseille). Another upcoming scientific project aims to determine the sensitivity of grassland ecosystems to nitrogen in the Pyrénées Mountains (in collaboration with André Pornon from the EDB laboratory and Thierry Lamaze at Cesbio).

The challenge in the next few years is to better understand how a large variety of ecosystems respond to anthropogenic or natural global change, to be able to protect them in the future.
Burning fossil fuels is not the only reason for the increase in atmospheric CO₂ concentrations that cause climate change. Cultivated soils may also contribute to this increase. Here, fast organic matter decomposition releases CO₂ and soil carbon stocks fall below certain levels, limiting soil fertility and increasing erosion risks. But could these soil organic and carbon stocks be increased? If yes, agricultural soils could help mitigate climate change.

**Inputs and outputs**

In order to quantify the amount of carbon that soils can store, different inputs and outputs from the field have to be considered. The main input at plot scale is plant photosynthesis using light and atmospheric CO₂ to allow cultivated crops to build organic matter that contains carbon. Eventually, organic fertilizers may be applied (solid or liquid manure) and they also represent a carbon input. Carbon outputs are decomposition (mineralization that produces CO₂) of organic matter by soil microbes, plant respiration (which continuously produces some CO₂) and finally the amount of carbon exported at harvest contained in the grains, straws and tubers.

**Different budgets for different crops**

The CESBIO laboratory in Toulouse analyses those different carbon fluxes on three different experimental plots representative of soils, management regimes and crop rotations in south-west France. Different results are found depending on crop and management regimes. The longer the growing vegetation period, the more the plot is able to store carbon because plants compensate for carbon losses from the field (plant respiration and soil organic matter decomposition) by photosynthesis. For instance, the annual carbon budget for winter wheat may be positive (carbon fixation) whereas sunflower generally has a negative carbon budget (losses) because its growing season is very short compared to that of winter wheat. Moreover when crops regrow after harvest (under favorable climatic conditions), they improve the plot carbon budget. On the other hand, carbon exports at harvest strongly reduce the potential for carbon storage. If carbon contained in winter wheat grains is only exported at harvest, all the carbon contained in the aboveground biomass will be exported when maize is grown for silaging. In this case, only a small fraction of the carbon that had been absorbed by the plant will remain on the plot and most of it will be decomposed.

**Impact of management operations**

In order to get a full greenhouse gas (GHG) budget, emissions of all GHG gases associated with agriculture practices and management also have to be accounted for and converted into carbon equivalents: CO₂, N₂O, CH₄ (methane) emissions caused by machinery use, pesticides, fertilizers and irrigation systems, for example. These emissions represent around 30% of the GHG budget. Most of the budget is driven by the carbon budget at plot scale. Our work aims to identify which practices and crop rotations have the best potential for reducing GHG emissions and storing carbon in soil (for example, practicing reduced tillage and carbon exports, and using intermediate cover crops. New legislation that encourages farmers to grow intermediate cover crops in the autumn (for example, mustard) before seeding summer crop (for example, sunflower and maize) in order to fix nitrates and prevent soil erosion will also be useful in the context of preserving organic content in soil.

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