A Necessary Pre-Analytical Vision

Resilience is one of the main ecosystems’ properties. A property that enables them to resist to negative impacts without losing their systemic integrity. Thanks to this property the impacts resulting from human interventions can partially be absorbed by the ecosystems which results in non-linear paths of degradation. So, this property translates into a service, the absorption capacity service. The conjoint absorption capacities of all ecosystems on earth are the most important ecosystem service offered by nature to human beings. Pollution occurs when the absorption capacity of the ecosystems is overloaded.

In this sense, understanding ecosystem dynamics is crucial for devising a set of environmental parameters and indicators. However this understanding effort can be time consuming and/or biased by wrong insights. In the case in point, the agro-ecosystems, after Liebig’s discovery in many main-stream agronomical circles the soil came to be viewed as a simple nutrients reservoir, which could be substituted by chemical fertilizers. Based on such an ‘ecological model’ of the soil, an environmental parameter like soil losses tolerance would have its meaning almost lost too, largely replaced by the fertilization cost.

As the soil science progressed, however, a more realistic view of the soil as a complex ecosystem has evolved. Based on this new vision soil erosion not only depletes its nutrients content but also threats other ecosystem services such as capacity of water storage, adequate mineral/organic structure favoring plant development, capacity of

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nutrients mobilization, prevention of fertilizers leaching/runoff, among others less known. So, an indicator such as the rate of soil erosion referred to the parameter soil losses tolerance would acquire new meanings. By the same token the parametric values for indicators like nitrogen or phosphorus surplus would have to be revised.

Other ecosystem services can be expected to be in offer by the adoption of complementary practices to the agro-ecological management of the soil, such as crop associations or crop rotations (which are temporal crop associations) which provide diseases/pest control services, and recovery/protection of natural vegetation areas as part of the agro-ecosystem which provide pollination, pest control and other services.

The key point is the vision of the agricultural production itself as an ecosystem service – the provision service, to be provided by a resilient agro-ecosystem. The farmer is a crucial part of this agro-ecosystem as he can manage it as to have a sustainable agricultural production in the very long run. The guiding rule for sustainable agro-ecosystems is the search for enhancing their biodiversity while keeping a high level of labor productivity. So, the share of the area under more or less sustainable agro-ecosystems in the utilized agricultural area – UAA would be a good agro-environmental indicator. In Europe different indicators based on good agricultural practices have been proposed but mostly not yet stemming from clearly defined agro-ecological models.

**Agro-Environmental Indicators: a comparative analysis**

*Biodiversity Indicator*

High Nature Value (HNV) farmland is a new indicator still being developed in Europe, which is based upon clearly defined agro-ecological models. It is viewed as a key indicator for the assessment of the impact of policy interventions with respect to the preservation and enhancement of biodiversity, habitats and ecosystems dependent on agriculture and of traditional rural landscapes. Its concept refers to the causality between certain types of farming activity and corresponding environmental outcomes, including high levels of biodiversity, the presence of environmentally valuable habitats and species. The main indicator is the share of estimated HNV farmland in utilized agricultural area, which is relatively easy to have if its quality is not taken into account. The most important HNV is the low intensity cattle breeding on unimproved vegetation. Considering that the pristine landscape has long ago disappeared, the share of the estimated HNV farmland is a good biodiversity indicator for the region.

In Brazil the scenario is altogether different. Although there exist some situations where traditional extensive cattle breeding on unimproved vegetation, as in Pantanal region, fits

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the HNV concept, for most of the country it contributes to land erosion and deforestation, so to biodiversity losses. Protecting and/or recovering biodiversity in the country means primarily protecting and/or recovering the original vegetation cover. In this respect there are clearly two broadly distinct situations: on one side the regions with vast areas still covered by the original vegetation, as the Amazon, where the agro-environmental policies should be aimed primarily at stopping the expansion of the agricultural frontier; on the other side, the regions where the original land cover has almost disappeared and should be recovered into a minimum of biodiversity resilience threshold as is mandated by the Forest Code.

Actually in this last case one find in many regions a situation where the forest recovering should be stimulated beyond the low limits established by the Forest Code. They are regions where the soils have been severely degraded by previous inadequate agricultural activities, the extensive cattle breeding being what was left as the only economic sound land using. In these regions, however, cattle breeding not only prevent forest recovery but also continue to degrade the soil as the grass cover in the existing conditions offer little protection against heavy tropical rains. Only natural forest offers enough protection beyond a certain slope degree. For intermediate ramp inclination levels forestry could offer a good soil protection. Cattle breeding could be sustainable, however, if based on improved grass cover in the more favorable areas of the region. So, it is possible to apply a HNV concept of a kind in these regions based on an agro-ecological model composed by tree different land covers: a natural and recovering forest in the more vulnerable areas, protected by a buffering forestry, followed by a more intensive but sustainable cattle breeding in the more favorable ones. This model could be labeled as “Forest and Milk”.

**Pressure Indicators: Nutrients Excess**

Inputs of nutrients to agricultural land across Europe are generally in excess of what is required by crops and grassland, resulting in nutrient surpluses, the nitrogen being the most problematic. The magnitude of these surpluses reflects their potential for detrimental impacts on the environment since they are available for gaseous loss to the atmosphere as ammonia, build-up in soil pools over time, or transport to the nearest receiving water body.

Excessive emissions of nutrients to freshwater cause eutrophication, characterized by the proliferation of algal blooms that are toxic, aesthetically unappealing and reduce the clarity of water, giving it the appearance of ‘green soup’, often accompanied by unpleasant smells. This proliferation is also associated with the loss of ‘desirable’ plant and animal species. The process of dissolved oxygen concentrations fall can be compounded when the aquatic plant life dies, generating huge amounts of organic matter and further diminishing oxygen levels. Impacts of eutrophication on freshwater ecosystems are documented throughout Europe. However, excessive levels of nitrogen have greatest
significance with respect to the eutrophication of estuarine and coastal waters, which remains widespread throughout Europe.

Toxic cyanobacteria associated with algal blooms pose a threat to public health. Direct skin contact with water containing these cyanotoxins, for example through freshwater and marine recreation, can cause allergic reactions similar to hay fever and asthma. Skin, eye and ear irritations can also occur, and ingestion of the toxins may result in gastrointestinal illness and liver damage. Cyanotoxins can also affect the nervous system. A recent assessment of European waters indicates that mass populations of bloom-, scum-, mat- and biofilm-forming cyanobacteria with cyanotoxin potential are relatively widespread and occur in water resources used for drinking water supply, aquaculture, recreation and tourism and moreover, health incidents involving cyanotoxins have been reported in some European countries. While excessive nutrient levels are strongly linked to cyanobacteria blooms, understanding of the impact of human activities on their occurrence remains incomplete. Municipal drinking water supply systems supply treated water under quality controlled conditions ensuring that nitrate concentrations do not exceed the threshold. However, in some rural areas of Europe, drinking water is taken from wells and consumed without purification. Excessive levels of nitrate in groundwater in the vicinity of such wells could, therefore, pose a threat to public health.

As for ammonia emissions (a harmful greenhouse gas), in 2010 the EU-27 agricultural sector was responsible for 94 % of total emissions across the region. The ammonia emissions mainly occur as a result of volatilization from livestock excreta. A smaller fraction of NH₃ emissions result from the volatilization of NH₃ from nitrogenous fertilizers and from fertilized crops. So the production of NH₃ is closely related to livestock production levels. However, the amount of emissions by livestock is a function of many variables, such as the properties of the animal manure, the animal type, the manure management system, the soil properties, and the method of application of manure into agricultural land. The magnitude of NH₃ emissions that occur as a result of the application of mineral nitrogenous fertilizers will similarly depend on many factors such as the type of fertilizer used, meteorological conditions and the time of fertilizer application in relation to the stage of crop canopy, the soil type and pH. Ammonia emissions emitted from the foliage of growing fertilized plants are generally related to the level of nitrogen fertilizer applied. However, NH₃ emissions from decomposing plants are uncertain, and are difficult to calculate due to the variable emissions that occur from this source.

Since 1990, however, following the general trend of nutrients surpluses reduction, these emissions have decreased by 30 %. Besides the reduction in livestock numbers, the decrease in emissions was mainly due to a change in agricultural practices aiming at a better management of organic manures and at a decreasing in the use of nitrogenous fertilizers. Regarding the former, specifically, manure spreading by broadcasting on the soil surface has been phased out, and has instead been replaced by application of slurries by injection or band spreading and rapid incorporation of manure into the soil. However,
the side effect of this measure can be to increase the amount of mineral nitrogen retained in the soil that, under anaerobic conditions, could be emitted as N\textsubscript{2}O. Incorporation of manure can also lead to increased nitrate leaching and subsequent pollution of water resources.

In Brazil most of meat production comes from extensive cattle breeding. In some regions, however, where poultry and pig production concentrates there are similar problems but the environmental concern is direct rather toward water pollution. The case of Ariranha Valley in the State of Santa Catarina is representative. There the river has been polluted by nitrates run off due to incorrect manure spreading on the soil: too much manure per hectare. The reason for that is the cost of manure spreading. The producers are being pressed by the authorities to find a solution for their “ecological footprint”. That could be achieved either by enlarging the manure spreading area or by reducing the manure content in nitrogen. The last one has proved to be the less expensive; different techniques of composting have been tried to this aim.

As for the nitrogenous fertilizers, a technological breakthrough on atmospheric nitrogen fixation more than two decades ago has enormously reduced its use in the main crops. Technologies of atmospheric nitrogen fixation and zero tillage practices, developed and/or improved in the country, are agricultural practices that manage the agro-ecosystem as to benefit from ecosystem services: nonvolatile N, leaching retention and erosion resistance, among others services that are provided by soils agro-ecologically managed. So, just the share of the crops based on these agro-ecologically integrated technologies in the total of UAA (utilized agricultural area) would be an adequate agro-environmental indicator for nitrogen associate environmental problems.

After the Nitrogen, the risk of Phosphorus (P) leaching/run-off follows as a matter of concern. However, the phosphorus cycle is very different from the Nitrogen cycle. Depending on the soil P capacity, excessive P can be stored in the soil. Not all of P in fertilizers and manure are directly available to the plant, a part is converted from active P (active P pool is the main source of available P for crops) to fixed P (The fixed P pool of phosphate will contain inorganic phosphate compounds that are very insoluble and organic compounds that are resistant to mineralization by microorganisms in the soil. Phosphate in this pool may remain in soils for years without being made available to plants and may have very little impact on the fertility of a soil). Depleting the active pool through crop uptake may cause some of the fixed P to slowly become active. The storage capacity of the soil is however depending on soil characteristics like soil texture. However, an important aspect of the ability of a soil to hold phosphate is that a soil cannot hold increasing amounts of phosphate in the solid phase without also increasing soil solution phosphate.

In turn, increased amounts of phosphate in solution will potentially cause more phosphate to be lost to water running over the soil surface or leaching through the soil. Loading soils with very high levels of phosphate will generally not hurt crops but may result in increased phosphate movement to nearby bodies of water. It has been estimated that 25 % or less of P applied annually is actually taken up by the growing crop, the remaining 75 % becomes bond in the soil profile or is lost to the water. The crop uptake of P is in sharp contrast to the crop use of N and K fertilizers, where the recovery in the season of application can be as high as 80 %. Yield and therefore the uptake of P by crops is not only determined by inputs but also by uncontrollable factors like climate.

So, the estimated P surplus represents the potential risks to water and soil. However, the actual P loss from agricultural land to surface waters is a complex function of climate, topography, soil type, soil P status, P fertilization, and land management. These factors vary greatly in space and over the year, and the hydrological pathways for P losses also vary greatly in space and time. The effects of these individual factors on P loss from agricultural land to surface waters are rather well understood, but in combination the understanding is less well developed. As a consequence, current simulation models do not simulate the actual P loss from agricultural land to surface waters very accurately yet. Further, the ecological effect of P from agricultural land in surface waters depends on the 'bio-availability' of the P. A significant fraction of the P from agricultural land that is lost to surface waters is particulate P and the availability of this P to growing organisms in surface waters is much less than dissolved reactive P, at least in the short term. Hence, 'the pollution effect' of P lost from agricultural land to surface waters does not depend on the total P loss but on the fraction 'reactive P'.

To sum up, the accumulated amount of P represents a larger actual risk for the environment than the amount of P which is applied yearly, or the surplus on today’s balance. However, the future risk is strongly influenced by the P balance of today and the near future, in combination with the capacity of a soil to bind P. This contrasts with nitrogen, for which the cumulative N balance of the past is much less relevant since N hardly accumulates in soils. This is why the main indicator – the estimated P surplus, on its own is not sufficient to indicate areas at risk of phosphorus pollution. For these reasons the results of this indicator should be interpreted in relation to a sub-indicator still to be developed - an alternative could be to resort to modeling.

Currently only limited data are available, for instance, on mapping the capacity of the soil to retain phosphorus by sorption and by resistance to erosion. 'Sorption of P' in the soil is defined in the study as a process whereby readily soluble phosphate is changed to less soluble forms by reacting with inorganic or organic compound of the soil so that P becomes immobilized. So the level of P-Sorption combined with the erosion risk of a soil translates into an indicator - 'P-sensitivity', of potential phosphorus pollution. Its level will depend on the soil type/slop and conditions and the agricultural practices which, in turn, influence soil conditions.
In Brazil the diffusion of zero tillage practices in the main crops, the most phosphorus demanding crops, have contributed for reducing the risk of P pollution. Also the fertilizers cost contributed to a change in fertilization practices which, in the Cerrado region, consisted in loading the soils with very high levels of phosphorus as to saturate the high cations exchange capacity typical of the soils there, which strongly bind P. Advanced scientific research in the role of mycorrhiza in plant nutrition has raised hope in the development of engineered mycorrhiza able to make important amounts of immobilized phosphorus available for the plants. Independently, however, of having engineered mycorrhiza a living soil carefully managed usually has a high level of enzymatic activity as so to provide the ecosystem service of nutrient mobilization, including a macro nutrient such as P, which is usually found strongly immobilized in the soil.

**Pressure Indicators: Pesticides Pollution**

The intense use of pesticides in agricultural production is emblematic of what is considered environmentally wrong with modern agricultural practices. It can have negative environmental impacts on water quality, terrestrial and aquatic biodiversity (persistence and toxic effects on non-target species, etc.). Pesticide residues in food can also pose a risk for human health. In EU the pesticides use has more or less stabilized and many residues in excess of the established maximum residue limits (MRLs) observed during the annual monitoring activities are ascribed to pesticides used during production of food imported from outside the EU. The risks of pesticide use to the environment vary considerably from one pesticide to another, depending on the intrinsic characteristics of their active ingredients (toxicity, persistence, etc.) and use patterns (applied volumes, application period and method, crop and soil type, etc.). However, most of statistics on these factors are not available yet, some of them probably will not be available for long.

Statistically what is readily available is the amount of total active ingredient. As pesticide indicator it does provide a broad indication of loading, but it overlooks factors governing pesticide fate – decaying into another substances (some often more harmful), which are often key parameters for determining long-term environmental impact. In Brazil, the second largest pesticide market in the world, an experiment\(^4\) designed to follow the decaying pattern of the active ingredients of two pesticides much in use in sugar cane crops in the State. It has shown decaying patterns which explain why the expected residues were not found by the State agency in charge of pollution control.

Contamination of the environment from pesticides may result from spray drift, volatilization, surface run-off, and subsurface loss via leaching/drain flow. Pesticide fate (and hence environmental risk) is primarily governed by vapor pressure, sorption characteristics, solubility in water, and environmental persistence. Vapor pressure governs the tendency for pesticides to volatilize and be lost to the atmosphere in gaseous form, while sorption properties govern bonding to organic and inorganic soil surfaces. Sorption properties limit

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the mobility of pesticides in the environment, and are influenced by factors including soil organic matter, clay content, and soil pH. Pesticides with greater water solubility often have lower sorption behavior, which makes them more mobile in the environment and hence more prone to leaching to water bodies.

The persistence of pesticides in the environment differs greatly and is dependent on factors such as their susceptibility to attack by micro-organisms and enzymes, soil temperature and water content. So, there is no absolute relationship between the loading of active ingredients and the potential threat to the environment and human and animal health. Indicators of the intensity of pesticide use, however, are a necessary step towards risk evaluation, despite the fact that total active ingredient values also do not discriminate between pesticides with transitory effects and those with characteristically longer residence times in the environment which may pose a greater risk to environmental and ecological quality objectives.

In Brazil integrated pest control methods are in use in some of the main crops of the country, where some agro-ecological practices are adopted as to minimize the use of pesticides. It is worth notice the development of a very effective method for controlling a worm that is very damaging for soya beans crops. The method is based upon the spreading of what is popularly called a 'worm juice', made of naturally virus infected worms. Also an agro-ecological technique such as crop rotations is considered as very effective in controlling nematodes infestations. However, the amount of total active ingredient in use per hectare/year is still very high for most of the main crops.

**Soil Erosion**

Approximately 15 % of the EU territory is estimated to be affected by a significant soil erosion rate (moderate – high level or more than 5 tons per ha per year), especially in southern countries. It has cost an enormous amount of money to the countries. On-site effects of water soil are particularly important on agricultural areas resulting in a reduction of cultivable soil depth and a decline in soil fertility. The loss of soil productivity following erosion may be significant. Topsoil, which is the most fertile layer of the soil, is the most exposed to erosion; also the mechanisms of soil erosion preferentially remove soil organic matter, clay, and fine silt material. Soil erosion also reduces the volume of soil available for plants roots and degrades soil physical properties (such as water holding capacity). Off-site effects of soil water erosion arise from sedimentation, which causes infrastructure burial, changes in watercourses shape and obstruction of drainage networks enhancing the risk of flooding and shortening the life of reservoirs. Many irrigation or hydroelectricity projects have been damaged by soil water erosion.

There has been much discussion in the literature about thresholds above which soil erosion should be regarded as a serious problem. This has given rise to the concept of
‘tolerable’ rates of soil erosion that should be based on reliable estimates of natural rates of soil formation. In general, losses above 1 tons per hectare per year are generally considered as irreversible. But erosion not only threats to deplete a non-renewable natural resource, but also damage soil functions which are responsible for many ecosystem services as described above.

However, it is impractical and technically difficult to measure soil loss across whole landscapes and thus research is urgently needed to improve methods of estimating soil erosion using modeling, upon which mitigation can be implemented. A wide variety of models are available for soil water erosion estimation. The selection of a model depends mainly on the purpose for which it is intended and the available dataset. Some models are designed to predict soil erosion from single storms while others predict long-term effects. Models such as the Universal Soil Loss Equation and derived versions are developed to predict only sheet and rill soil erosion and do not take into account other processes like gully erosion.

Two soil erosion indicators have been produced on the basis of empirical computer model. The main indicator represents estimated soil erosion levels for territorial units; the second indicator is a cell-based map that estimates the rate of soil erosion by water in Europe in tons per hectare per year for cells of 1 km x 1 km for the EU.

These indicators are derived from an enhanced version of the Revised Universal Soil Loss Equation (RUSLE) model. The model was developed primarily to guide conservation planning, inventory erosion rates and estimate sediment delivery on the basis of accepted scientific knowledge and technical judgment. Due to the scale of the input data it offers an overview of the soil erosion susceptibility in the landscape rather than a real estimation for a specific location. In this assessment, the basic RUSLE model has been adapted through the addition of a new factor that improves the estimation of the effect of stoniness on soil erosion.

The revised version of the RUSLE is an empirical model that calculates soil loss due to sheet and rill erosion. The model considers seven main factors controlling soil erosion: the erosivity of the eroding agents (water), the erodibility of the soil, the slope steepness and the slope length of the land, the land cover, the stoniness and the human practices designed to control erosion.

The model estimates erosion by means of an empirical equation: $Er = R \times K \times L \times S \times C \times P$

Where:

$Er = (annual) \ soil \ loss \ (tons \ per \ hectare \ per \ year)$.
$R = rainfall \ erosivity \ factor$
$K = soil \ erodibility \ factor$
$L = slope \ length \ factor$
$S = slope \ steepness \ factor$
$C = cover \ management \ factor$
St = stoniness correction factor
P = human practices aimed at erosion control

Among the limitations of this model are the lack of high-resolution pan-Europe environmental datasets, the non-linearity present within the climatic-based ensemble model and the underlying principles of the RUSLE model that considers only some categories of soil erosion. There are also great difficulties in gathering enough information to drive an adequate validation of the model results, but this aspect applies to the output from any large area erosion-prediction model. The validation of erosion estimates at continental scale is not technically and financially feasible. One validation option is through the upscaling of local monitoring studies of large-scale modeling assessments. However, the RUSLE model has been used due to its flexibility in relation to input data requirements and despite its limitations it is a scientifically valid method that renders operationally feasible a systematic follow up of an important land degradation factor.

In tropical countries soil erosion represents a much worse environmental problem as the heavy tropical rains translates into a very high value for the parameter R (rainfall erosivity factor) of the equation. In many tropical regions the top soil, the fertile one on which agricultural production depends, has vanished. In most there is a risk of suffering the same fate. In Brazil historically severe soil erosion has depleted large agricultural areas. Erosion rates up to 100 tons of soil per hectare/year have been registered. The growing awareness of the problem, followed by the spread of soil conservation practices, especially the diffusion of zero tillage practices, has mitigated the problem that remains however a serious one.

As for the assessment of the problem, the main agricultural research institutions have performed experiments designed to accurately measure erosion rates for different types of soil and in different conditions. The knowledge they provide enables the experts to make fairly accurate erosion estimates for the main agricultural regions of the country. Nevertheless, such estimates cannot provide an adequate basis for a systematic and regular set of erosion indicators regionally and/or cultures focused.

This knowledge however does provide the means for the use of a predicting model based on an adapted USLE such as that that has been developed by the Agronomical Institute of Campinas – IAC. In addition, and differently from the EU case where each country has its own specific information gathering system, in Brazil national institutions as EMBRAPA (Brazilian Enterprise of Agricultural Research) and IBGE (Brazilian Institute of Geography and Statistics) could provide the necessary information. In especial, it can be relatively easy to overcome the difficulties concerning the systematic information gathering about the C and the P parameters as well as to organize regional model validation panels as IBGE has a long tradition and a very good networking structure for gathering agricultural information at municipal level.
Final Remarks

In EU dozens of agro-environmental indicators are in use and/or being developed. There are pressure indicators such as nutrients surplus (N balance and risk of P pollution) related to mineral fertilizers consumption indicator; pesticide risk indicator related to consumption of pesticides indicator; soil erosion related to soil cover indicator; ammonia and other greenhouse gases emissions; water abstraction; and intensification/extensification.

However, there are not enough state indicators for as to cover all the degradation problems of the agro-ecosystem resulting from environmental pressures resulting from the predominant agricultural practices due to the difficulties (and cost) to produce the information for that. Nonlinear degradation paths explain much of these difficulties to have accurate degradation indicators.

There are state indicators of environmentally sound agricultural/livestock patterns and practices such as high nature value farmlands (HNV), specialization, livestock patterns and tillage practices. There is also a committing indicator that indicates the share of agricultural area enrolled in agro-environmental measures in the UAA (utilized agricultural area).

There also general landscape state indicators like cropping patterns (the respective shares of arable land, permanent grassland and land under permanent crops in the UAA), and landscape state and diversity.

This last one more or less encompasses the other state indicators. It assumes that farmers play a crucial role in transforming, managing and maintaining landscapes. It has three components, each describing a very different aspect of the agrarian landscape:

- the physical structure of the agricultural landscape, intended as land cover and its spatial organization as a product of land management;
- the hemeroby state as a proxy for the influence exerted by farming practices on land cover and state;
- the societal awareness of the landscape, as the society perceives, assesses and values landscape quality, plans, manages, and uses the landscape for productive or non-productive purposes.

Monitoring these three components will indicate if the trend in landscape structure leads to a higher homogeneity or diversity; how trends in farming practices influence the hemeroby index; if society is becoming more aware of the services the agrarian landscape provides.

Clearly the structure of this composed indicator reflects a pre-analytical vision that sees the agricultural production in a broader ecosystem context where biodiversity is the key value, implicitly seen as a proxy for ecosystem resilience.
In Brazil it would be feasible to build a simpler state indicator, a kind of an improved committing indicator, to taken into account a changing agricultural landscape scenario towards a more or less resilient agro-ecosystem. Instead of a committing indicator that monitor just changes in the share of agricultural area enrolled in agro-environmental measures in the UAA, it would monitor the respective shares the agricultural area under different agro-ecosystem models, which would be ranked accordingly to different resilience levels. The agro-environmental measures adopted would be evaluated accordingly to agro-ecological models.