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VERSION 1

Principles for the assessment of livestock impacts on biodiversity

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AUTHORSHIP AND DEVELOPMENT PROCESS

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The Technical Advisory Group (TAG) on biodiversity developed the core technical content of the guidelines. The TAG was led by John Finn (Teagasc, Ireland) and Mohammed Said (ILRI, Kenya) who coordinated the activities of the TAG. The TAG leaders were supported by Félix Teillard (FAO) who, as technical secretary of the biodiversity TAG, conducted background research and processed input from TAG members and reviewers.

The biodiversity TAG was composed of: Rob Alkemade (PBL, Netherlands – TAG member until March 2014); Assumpció Anton (IRTA, Spain); Bertrand Dumont (INRA, France); Fernando R. Funes Monzote (Sociedad Cientifica Latinoamericana de Agroecologia, Cuba – TAG member until August 2014); Beverley Henry (Queensland University of Technology, Australia); Danielle Maia de Souza (Swedish University of Agricultural Sciences, Sweden); Pablo Manzano (IUCN CEM, Kenya & UAM, Spain); Llorenç Milà i Canals (UNEP, France); Catherine Phelps (Dairy Australia, Australia); Sandra Vijn (WWF, USA); Shannon R. White (Government of Alberta, and Alberta Biodiversity Monitoring Institute, Canada); and Hans-Peter Zerfas (World Vision, Germany – TAG member until March 2014).

Members of the biodiversity TAG developed the case studies presented in this document. In addition, Steven A. Osofsky (IUCN SSC) assisted Pablo Manzano in the development of Case Study 12 and Caste Study 11 was developed by Sheila Barry (University of California, Agriculture and Natural Resources).

The LEAP Secretariat coordinated and facilitated the work of the TAG, guided and contributed to content development and ensured coherence between the various guidelines. The LEAP secretariat, hosted at FAO, was composed of: Pierre Gerber (Coordinator until January 2015); Camillo De Camillis (LEAP manager); Carolyn Opio (Technical officer and Coordinator since February 2015); Félix Teillard (Technical officer); and Aimable Uwizeye (Technical officer).

The LEAP Steering Committee provided overall guidance for the activities of the Partnership, helped review and cleared the principles for public release. During development of the principles the LEAP Steering Committee consisted of:

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The initial draft guidelines developed by the TAG over 2014 went through an external peer-review before being revised and submitted for public review.

Three external experts reviewed the draft guidelines: Leslie Firbank (University of Leeds); Jeremy Radachowski (Wildlife Conservation Society); and Serenella Sala (European Commission, Joint Research Centre).

Before being submitted for both external peer review and public review, the guidelines were reviewed by the LEAP Secretariat. The LEAP Steering Committee also reviewed them at various stages of their development and provided additional feedback before clearing and releasing them for public review.

The public review – announced to the public through an article published on the FAO website – was launched at the 2nd Annual Meeting of the LEAP Partnership on 23 April 2015 and lasted until 15 September 2015.

Scholars in LCA were informed through announcements and reminders circulated via the mailing list on LCA held by PRé Consultants. The public review period was also advertised in two sessions of the 25th Annual Meeting of SETAC Europe. Experts in ecology were reached through various channels by LEAP partners such as IUCN and WWF. The following bodies were also asked for their input: FAO Collaborative Partnership on Sustainable Wildlife Management; Global Research Alliance – Livestock Research Group (GRA); Global Alliance for Sustainable Livestock; Global Alliance for Climate-Smart Agriculture (GACSA); Mitigation of Climate Change in Agriculture (MICCA) Programme; Standing Committee on Agricultural Research (SCAR); Joint Programming Initiative on Agriculture Food Security and Climate Change (FACCE-JPI); European Food Sustainable Consumption and Production Round Table; European Commission's Cattle Model Working Group members. Comments were also sought from relevant FAO technical officers.

The following participated in the public review and hence contributed to improving the quality of this technical document: Sheila Barry (University of California, Agriculture and Natural Resources); Anne Marie Boulay (WULCA–CIRAIG); K.E. Kenward (IUCN).

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Abbreviations

BAP	Biodiversity Action Plan
BDP	Biodiversity Damage Potential
CBD	Convention on Biological Diversity
CF	Characterization Factor
EC	European Commission
EDP	Ecological Damage Potential
EEA	European Environment Agency
FAO	Food and Agriculture Organization of the United Nations
GAP	Good Agricultural Practices
GHG	Greenhouse Gas
GRI	Global Reporting Initiative
ISO	International Organization for Standardization
IUCN	International Union for Conservation of Nature
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LEAP	Livestock Environmental Assessment and Performance Partnership
LPI	Living Planet Index
LU	Land Use
LUC	Land Use Change
LULUC	Land Use and Land Use Change
MEA	Millennium Ecosystem Assessment
NGO	Non-Governmental Organization
OECD	Organization for Economic Cooperation and Development
PDF	Potentially Disappeared Fraction (of species)
PNV	Potential Natural Vegetation
PSR	Pressure-State-Response
SETAC	Society for Environmental Toxicology and Chemistry
TAG	Technical Advisory Group
UN	United Nations
UNEP	United Nations Environment Programme
WWF	World Wide Fund for Nature

Glossary

Terms relating to biodiversity

Biodiversity	Variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic systems and the ecological complexes of which they are part, including diversity within species, between species and of ecosystems. [Article 2 of the CBD]
Biome	The world's major communities, classified according to the predominant vegetation and characterized by adaptations of organisms to that particular environment. For instance, tropical rainforest, grassland, tundra. [Campbell 1996]
Ecosystem	A dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit. [Article 2 of the CBD]
Ecosystem services	The benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual and recreational benefits; and supporting services such as nutrient cycling that maintain the conditions for life on Earth. [MEA 2005]
Endemism	Association of a biological taxon with a unique and well-defined geographic area. [The Encyclopedia of Earth, http://www.eoearth.org]
Endemic species	See **Endemism**
Habitat	The place or type of site where an organism or population naturally occurs. [Article 2 of the CBD]
Hotspot analysis	Hotspot analysis aims to define areas of high occurrence versus areas of low occurrence of a feature of interest. Here, it refers to an assessment of the relative contribution of different pressures and threats, with the aim of identifying those that make the strongest contribution to biodiversity loss. [LEAP Biodiversity TAG]
Hotspot, biodiversity	A hotspot for biodiversity represents a geographical area where there is a coincidence of high biodiversity and high level of biodiversity threats. [LEAP Biodiversity TAG]

Pressure-State-Response (PSR) framework The PSR framework describes the environmental cause effect chain and has been widely used to develop and structure biodiversity indicators. Indicators evaluate the *pressures* of human activities that lead to changes in environmental *states*, causing *responses* (decision and actions) of the stakeholders (political, socio-economic), undertaken to reach a more sustainable state. [Adapted from OECD 1993]

Rangeland Land on which the indigenous vegetation (climax or natural potential) is predominantly grasses, grass-like plants, forbs, or shrubs and is managed as a natural ecosystem. If plants are introduced, they are managed similarly. Rangelands include natural grasslands, savannas, shrublands, many deserts, tundras, alpine communities, marshes and meadows. [International Society for Range Management]

Terms relating to life cycle assessment and environmental assessment

Acidification Impact category that addresses impacts due to acidifying substances in the environment. Emissions of NOx, NH_3 and SOx lead to releases of hydrogen ions (H^+) when the gases are mineralized. The protons contribute to the acidification of soils and water when they are released in areas where the buffering capacity is low. Acidification may result in forest decline and lake acidification. [Adapted from Product Environmental Footprint Guide, European Commission, 2013]

Allocation Apportioning the input or output flows of a process or a product system between the product system under study and one or more other product systems. [ISO 14044:2006, 3.17]

Characterization Calculation of the magnitude of the contribution of each classified input/output to their respective impact categories, and aggregation of contributions within each category. This requires a linear multiplication of the inventory data with characterization factors for each substance and impact category of concern. For example, with respect to the impact category "climate change", CO2 is chosen as the reference substance and kg CO2-equivalents as the reference unit. [Adapted from Product Environmental Footprint Guide, European Commission, 2013]

Characterization factor Factor derived from a characterization model which is applied to convert an assigned life cycle inventory analysis result to the common unit of the category indicator. [ISO 14044:2006, 3.37]

Data quality Characteristics of data that relate to their ability to satisfy stated requirements. [ISO 14044:2006, 3.19]

Ecotoxicity	Environmental impact category that addresses the toxic impacts on an ecosystem which damage individual species and change the structure and function of the ecosystem. Eco-toxicity is a result of a variety of different toxicological mechanisms caused by the release of substances with a direct effect on the health of the ecosystem. [Adapted from Product Environmental Footprint Guide, European Commission, 2013]
Elementary flow	Material or energy entering the system being studied that has been drawn from the environment without previous human transformation, or material or energy leaving the system being studied that is released into the environment without subsequent human transformation. [ISO 14044:2006, 3.12]
Emissions	Release of substance to air and discharges to water and land.
Endpoint impact category	Damage-oriented approach translating environmental impacts into issues of concerns such as biodiversity. [Adapted from Guinée *et al.* (2002)]
Environmental impact	Any change to the environment, whether adverse or beneficial, wholly or partially resulting from an organization's activities, products or services. [ISO/TR 14062:2002, 3.6]
Eutrophication	Excess of nutrients (mainly nitrogen and phosphorus) in water or soil, from sewage outfalls and fertilized farmland. In water, eutrophication accelerates the growth of algae and other vegetation in water. The degradation of organic material consumes oxygen, resulting in oxygen deficiency and, in some cases, fish death. Eutrophication translates the quantity of substances emitted into a common measure expressed as the oxygen required for the degradation of dead biomass. In soil, eutrophication favors nitrophilous plant species and modifies the composition of plant communities. [Adapted from Product Environmental Footprint Guide, European Commission, 2013]
Functional unit	Quantified performance of a product system for use as a reference unit. [ISO 14044:2006, 3.20] It is essential that the functional unit allows comparisons that are valid where the compared objects (or time series data on the same object, for benchmarking) are comparable.

Greenhouse gases (GHGs)	Gaseous constituent of the atmosphere, both natural and anthropogenic, that absorbs and emits radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere, and clouds. [ISO 14064-1:2006, 2.1]
Impact category	Class representing environmental issues of concern to which life cycle inventory analysis results may be assigned. [ISO 14044:2006, 3.39]
Land occupation	Impact category related to use (occupation) of land area by activities such as agriculture, roads, housing, mining, etc. [Adapted from Product Environmental Footprint Guide, European Commission, 2013]
Land use change	Change in the purpose for which land is used by humans (e.g. between cropland, grassland, forestland, wetland, industrial land). [PAS 2050:2011, 3.27]
Life cycle	Consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal. [ISO 14044:2006, 3.1]
Life Cycle Assessment	Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle. [ISO 14044:2006, 3.2]
Life Cycle Impact Assessment (LCIA)	Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential impacts for a product system throughout the life cycle of the product. [Adapted from: ISO 14044:2006, 3.4]
Life Cycle Inventory (LCI)	Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle. [ISO 14046:2014, 3.3.6]
Midpoint impact category	Problem-oriented aproach translating impacts into environmental themes such as global warming, acidification, ecotoxicity. [Adapted from Guinée *et al.* (2002)]

Normalization	After characterization, normalization is an optional step in which the impact assessment results are multiplied by normalization factors that represent the overall inventory of a reference unit (e.g. a whole country or an average citizen). Normalized impact assessment results express the relative shares of the impacts of the analysed system in terms of the total contributions to each impact category per reference unit. When displaying the normalised impact assessment results of the different impact topics next to each other, it becomes evident which impact categories are affected most and least by the analysed system. Normalised impact assessment results reflect only the contribution of the analysed system to the total impact potential, not the severity/relevance of the respective total impacts. Normalised results are dimensionless, but not additive. [Product Environmental Footprint Guide, European Commission, 2013]
Primary data	Quantified value of a unit process or activity obtained from a direct measurement or a calculation based on direct measurements at its original source. [ISO 14046:2014, 3.6.1]
Product(s)	Any goods or service. [ISO 14044:2006, 3.9]
Product system	Collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product. [ISO 14044:2006, 3.28]
Raw material	Primary or secondary material that is used to produce a product. [ISO 14044:2006, 3.1.5]
Reference flow	Measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit. [ISO 14044:2006, 3.29]
Reporting	Presenting data to internal management and external users such as regulators, shareholders, the general public or specific stakeholder groups. [ENVIFOOD Protocol: 2013]
Secondary data	Data obtained from sources other than a direct measurement or a calculation based on direct measurements at the original source [ISO 14046:2014, 3.6.2]. Secondary data are used when primary data are not available or it is impractical to obtain primary data. Some emissions, such as methane from litter management, are calculated from a model, and are therefore considered secondary data.
Sensitivity analysis	Systematic procedures for estimating the effects of the choices made regarding methods and data on the outcome of a study. [ISO 14044:2006, 3.31]

System boundary	Set of criteria specifying which unit processes are part of a product system. [ISO 14044:2006, 3.32]
Uncertainty analysis	Systematic procedure to quantify the uncertainty introduced in the results of a life cycle inventory analysis due to the cumulative effects of model imprecision, input uncertainty and data variability. [ISO 14044:2006, 3.33]
Unit process	Smallest element considered in the life cycle inventory analysis for which input and output data are quantified. [ISO 14044:2006, 3.34]
Water use	Use of water by human activity. Note 1 to entry: use includes, but is not limited to, any water withdrawal, water release or other human activities within the drainage basin impacting water flows and/or quality, including in-stream uses such as fishing, recreation, transportation. Note 2 to entry: the term "water consumption" is often used to describe water removed from, but not returned to, the same drainage basin. Water consumption can be because of evaporation, transpiration, integration into a product, or release into a different drainage basin or the sea. Change in evaporation caused by land use change is considered water consumption (e.g. reservoir). The temporal and geographical coverage of the water footprint assessment should be defined in the goal and scope. [ISO 14046:2014, 3.2.1]
Weighting	Weighting is an additional, but not mandatory, step that may support the interpretation and communication of the results of the analysis. Impact assessment results are multiplied by a set of weighting factors, which reflect the perceived relative importance of the impact categories considered. Weighted impact assessment results can be directly compared across impact categories, and also summed across impact categories to obtain a single-value overall impact indicator. Weighting requires making value judgements as to the respective importance of the impact categories considered. These judgements may be based on expert opinion, social science methods, cultural/political viewpoints, or economic considerations. [Adapted from Product Environmental Footprint Guide, European Commission, 2013]

Summary and key principles

Livestock production is widespread around the world, with up to 26 percent of terrestrial areas dedicated to rangelands and 33 percent of cropland dedicated to fodder production. Demand for livestock products is projected to grow by 1.3 percent *per annum* until 2050 (although estimates vary), driven by a combination of global population growth and changes in patterns of food consumption due to increasing wealth and urbanization (Alexandratos and Bruinsma, 2012). The influence of livestock production on biodiversity is therefore obvious, although the exact effects are diverse. Whether livestock has a positive or negative impact on biodiversity very much depends on the intensity of production, the nature of specific practices, the livestock species used, and local ecological conditions. Livestock can put pressure on biodiversity through, for example, conversion of natural habitats and land use change. It can impact on water quality and quantity and contribute to climate change. The quantitative assessment of the impacts of livestock systems and other sectors on biodiversity is an emerging area of work that meets a growing demand for expanding sustainability assessments to include biodiversity. This document, in which international experts shared their views on biodiversity assessment, represents a first step. It should be considered as paving the way for future and more detailed guidance on biodiversity assessment within livestock systems.

This document identifies a number of broad principles intended to assist stakeholders in the assessment of livestock impacts on biodiversity. Part I provides a general introduction to the aims of this document and its overall framework. Part II contains a state-of-the-art introduction to Life Cycle Assessment approaches for biodiversity, with a major emphasis on the land use impacts associated with livestock systems. Part III addresses the use of the Pressure-State-Response (PSR) indicator approach to assess biodiversity within livestock systems. An overview of these two approaches is presented in Section 2.2.

The key principles from this report are presented here. Throughout this document, key principles are highlighted in the text where they apply (sometimes in more than one place).

OVERARCHING PRINCIPLES

The following principles are overarching in nature, in that they should be considered as applying equally to the contents of the LCA and PSR sections:

- Biodiversity is complex and multivariate by nature. The assessment of biodiversity is complicated by the lack of a common 'currency' for biodiversity, and by it being extremely context-dependent. For example, in greenhouse gas (GHG) assessments, a molecule of CO_2 has the same radiative forcing no matter how or where it is produced, impacts are potentially global (although severity may differ locally) and all GHG emissions can be expressed in carbon equivalents. In contrast, due to societal value judgements, there is great variation in the conservation value of different species and habitats, which complicates decision-making about conservation objectives and priorities – and ultimately complicates the assessment of impacts on biodiversity.

- The objectives of a biodiversity assessment and the objectives of any related initiatives should be clearly stated, and appropriate indicators and methodologies chosen to reflect these objectives.
- For all geographical areas within the system boundary, assessments of livestock systems should identify and recognize designation frameworks for biodiversity at both habitat level (e.g. protected habitats) and species level (e.g. protected species, IUCN Red List, and equivalent frameworks at national and sub-national scales). These and related (e.g. WWF) frameworks provide important guidance on the relative conservation value and status of habitats and species.
- Livestock production can have both negative and positive impacts. To increase their relevance to the livestock sector, assessment methodologies must be capable of reflecting livestock's beneficial as well as detrimental effects.
- As a priority issue, processes such as feed production, especially off-farm production, should be included in the system boundaries of livestock systems. This is due to feed's substantial and increasing contribution to overall impacts on biodiversity.
- The choice of reference state (the level of biodiversity that is used as a baseline for comparisons) has a strong influence on the interpretation of results; thus, it is important to clearly describe the situation that is being used as a reference level, and to interpret the results accordingly.

COMPLEMENTARITY BETWEEN LCA AND PSR APPROACHES

We provide principles that address two main approaches for biodiversity assessment, the LCA and PSR indicators. These principles are presented separately but the two approaches can be used complementarily in assessing biodiversity impacts. Complementarity in scope allows the two approaches to address different types of questions.

- Complementarity in quantification between the LCA and PSR approaches means that one approach can be used to fill the quantification gaps of the other.

Below are specific examples illustrating this important point:

- Livestock systems have multiple important impacts on biodiversity, including land use and land use change, acidification, eutrophication, climate change and ecotoxicity. Biodiversity assessments that focuses on a limited number of impacts (e.g. because of limited data or available methods) should also evaluate the relative importance of other impact categories and evaluate it at least qualitatively. For instance, there is consensus on LCA methodologies for LULUC; however, PSR approaches could be used to broaden this scope to include other categories of impact.
- LCA can be used to identify supply chain or spatial hotspots for further investigation with more detailed and complementary assessment methods, including Pressure-State-Response indicators (see below) to fill the gaps of current LCA methodologies. PSR indicators can, for instance, be applied to differentiate the effect of higher-resolution land use categories or livestock farming practices.

KEY PRINCIPLES FOR THE LCA APPROACH

Key principles regarding LCA for biodiversity include:

- The comprehensive scope of LCA is important and useful in order to avoid problem-shifting, e.g. from one phase of the life cycle to another, from one region to another, or from one environmental problem to another.

- For the impact category of land use, there is broad consensus on the impact assessment framework, and several methods are already available to quantify biodiversity impacts through land use. They are especially useful for assessment of the biodiversity impacts of globally traded products. Currently, impacts on biodiversity in LCA are mainly modelled as a result of land use and land use change interventions. Other impact categories can also be incorporated, although further methodological development is needed.
- Existing LCA methods describe land use through relatively coarse categories, which makes LCA more adapted to assessments at large spatial scales. For small-scale assessments aimed at discriminating between the relative impact of different practices on biodiversity, indicators are likely to need further adaptation and development.
- There will be continued development of methods for the identification and calculation of reference states and consequent characterization factors, and users should keep up-to-date with such developments.

KEY PRINCIPLES FOR THE PSR APPROACH

Key principles in using Pressure-State-Response indicators for biodiversity assessments include:

- Pressure, state and response (PSR) indicators are complementary and the PSR approach provides a way of articulating them to facilitate interpretation and decision-making. Combining several categories of indicators is strongly encouraged.
- The system boundaries should be defined to include off-farm feed cultivation when selecting and calculating pressure indicators. As a minimum, off-farm land use pressure should be quantified (Case Study 1 provides a simple example of how to do so with national yield data) and other categories should also be addressed if possible.
- The following ten major issues should be referred to when conducting an assessment of biodiversity impacts. They provide overarching guidance that is relevant to indicator-based approaches in general. Note especially that they introduce a life-cycle perspective to the selection of PSR indicators.
    1. goal definition
    2. scoping and hotspot analyses
    3. setting the boundaries
    4. identifying the scope of P, S and / or R
    5. engagement with stakeholders and experts
    6. identifying and prioritizing indicators
    7. identifying relevant information
    8. analysing data
    9. understanding and managing the impacts
    10. developing effective communications.

Pressure indicators

Principles applying to Pressure indicators include:

- The scoping and hotspot analyses should aim to define a shortlist of pressures and benefits to be quantified because of their importance in the user's livestock system and its context. At least one indicator should be computed for each

pressure and benefit category within the shortlist identified in the scoping analysis.
- Pressure and benefit are often two sides of the same gradient – both should be considered when conducting the hotspot analysis and, when relevant, the same indicator should reflect the whole gradient. Examples include grazing level (e.g. measured in livestock units/ha or residual plant biomass, height or cover) which results in different impacts from low to high grazing levels (see Case Study 4, 5 and 11).

State indicators

Principles applying to State indicators include:
- Species richness can be an important state indicator; however, where possible, state indicators should also include information that reflects the species composition and conservation value of species (see Case Studies 3, 4, 5 and 11).
- In assessments that rely on species richness, care should be taken to use information on species composition to measure the occurrence and distribution of undesirable species e.g. non-native invasive species, native invasive species, pest species, and indicators of low habitat quality. These should constitute a separate state indicator of biodiversity, and reflect a negative contribution (threat) to biodiversity (e.g. see Case Studies 4 and 5).
- When choosing state indicators, the contribution of species or species' groups to ecosystem functions and services should be considered, e.g. pollination, carbon sequestration, hydrological services.
- Integrity of data collection should be ensured, including a range of state indicators representing both those negatively and positively affected by livestock production.
- Assessing habitat area/semi-natural land cover is generally straightforward. It can be an informative state indicator for farmland biodiversity.

Response indicators

Principles applying to Response indicators include:
- Response indicators should be based on scientifically sound and verifiable evidence that details a clear link between adoption of the response indicator and the expected biodiversity outcome.
- Response indicators may be general, e.g. whether a biodiversity action plan is in place, or more specific, e.g. the level of expenditure on conservation of native grasslands or the decision to preserve an endangered species. Such specific indicators are determined by the scoping review and hotspot analysis.

FUTURE DIRECTIONS

More remains to be done to guide the quantitative assessment of impacts on biodiversity due to livestock systems. To this end, Life Cycle Assessment and PSR indicators will be key approaches. The following are a number of priority issues to improve the applicability of LCA and PSR to the assessment of biodiversity impacts from livestock systems:
- There is a need to identify and disseminate examples of best practice in biodiversity assessment in the livestock sector. These should include examples

of the effective use of LCA of biodiversity impacts for improved decision-making about livestock systems and supply chains. There is also a need for examples of the effective inclusion of life-cycle perspectives into Biodiversity Action Plans and related methods (e.g. certification standards) that rely on PSR indicators.

- A key outcome of this document is recognition of the complementarity that can be achieved through a combination of LCA and PSR approaches. LCA can be used to reveal supply chain or spatial hotspots for further investigation. Once that is done, a more detailed assessment can be achieved through PSR indicators. It would be highly desirable to identify further examples of where such complementarity is, or can be, achieved.
- Examples of completed, quantitative Life Cycle Assessments in livestock systems are needed to provide both further guidance and examples for developing and critiquing the state of the art in LCA for biodiversity. In particular, there is a need for:
    - development of local characterization factors for different livestock systems;
    - inclusion and recognition of positive and negative impacts;
    - incorporation of impacts on landscape-scale processes;
    - inclusion of several different midpoint impacts, e.g. the biodiversity impacts of acidification and eutrophication covering large geographic areas, as well as land use impacts;
    - improvement of the assessment of ecosystem services in LCA;
    - methods and examples of characterization for a wide variety of taxa and of the use of weighting approaches to recognise the differences in the conservation value of habitats and species (e.g. IUCN designation).

Looking to the future, it is clear that more remains to be done to guide the assessment of livestock impact on biodiversity. There are several opportunities for additional work by LEAP in this area. A number of priority issues could be addressed, as follows:

- ensure links between LEAP and other biodiversity initiatives;
- identify examples of the complementarity between LCA and PSR approaches;
- identify best practices in Biodiversity Action Plans;
- improve identification of biodiversity indicators for livestock systems;
- progress towards comprehensive environmental assessments in LEAP.

The ultimate goal of comprehensive environmental assessments is challenging, but it is necessary if we are to obtain more complete guidance on the environmental consequences of choices and decisions about the design and management of livestock systems.

LEAP and the preparation process

LEAP is a multi-stakeholder initiative launched in July 2012 with the goal of improving the environmental performance of livestock supply chains. Hosted by the Food and Agriculture Organization of the United Nations, LEAP brings together the private sector, governments, civil society representatives and leading experts who have a direct interest in the development of science-based, transparent and pragmatic guidance to measure and improve the environmental performance of livestock products.

In the context of climate change, increasing competition for natural resources, and the growth projected demand for animal products, there is significant pressure on the livestock sector to perform more sustainably. The identification and promotion of ways in which the sector can contribute to more efficient use of resource and better environmental outcomes is also important.

Currently, many different methods are used to assess the environmental impacts and performance of livestock products. This causes confusion and makes it difficult to compare results and set priorities for continuing improvement. With increasing market demand for more sustainable products, there is also the risk that debates about how sustainability is measured will distract people from driving real improvement in environmental performance. An added danger is that either labelling or private standards based on poorly developed metrics could lead to erroneous claims and comparisons.

The LEAP Partnership addresses the urgent need for a coordinated approach to developing clear guidelines for environmental performance assessment based on international best practices. The scope of LEAP is not to propose new standards but to produce detailed guidelines that are specifically relevant to the livestock sector, and refine guidance as to existing standards. LEAP is a multi-stakeholder partnership bringing together the private sector, governments and civil society. These three groups have an equal say in deciding work plans and approving outputs, thus ensuring that the guidelines produced are relevant to all stakeholders, widely accepted and supported by scientific evidence.

The work of LEAP is challenging but vitally important to the livestock sector. The diversity and complexity of livestock farming systems, products, stakeholders and environmental impacts can only be matched by the willingness of the sector's practitioners to work together to improve performance. LEAP provides the essential backbone of robust measurement methods to enable assessment, understanding and improvement in practice. More background information on the LEAP Partnership can be found at www.fao.org/partnerships/leap/en/.

DEVELOPMENT OF PRINCIPLES FOR BIODIVERSITY ASSESSMENT

Within LEAP, Technical Advisory Groups (TAGs) focused mainly on greenhouse gas (GHG) emissions and on specific livestock sub-sectors (feed, small ruminants, poultry, and large ruminants). They produced guidelines taking into account the specific nature of the livestock supply chain under investigation and aimed to provide sufficient definition of calculation methods and data requirements to enable consistent application of LCA across differing large ruminant supply chains.

The environmental impacts of livestock production are not restricted to GHG emissions. In particular, livestock influence biodiversity, both positively and negatively (LEAP Biodiversity Review, Teillard *et al.*, 2016a). The objective of LEAP was to gather experts from different background and to provide a forum for discussing biodiversity assessment in the livestock sector. Because of the early stage of the discussions on the subject, this document provides general principles rather than the detailed quantitative guidelines such as those focusing on GHG emissions within specific livestock sub-sectors.

BIODIVERSITY TAG AND PREPARATION PROCESS

The Biodiversity TAG of the LEAP Partnership was formed at the beginning of 2014. The core group included 12 experts in ecology, biodiversity assessment in LCA, and livestock production systems. Their backgrounds, complementary between systems and regions, allowed them to understand and address different perspectives. The TAG was led by Dr John Finn (Teagasc, Ireland) and Dr Mohammed Said (ILRI, Kenya) who were assisted by Dr Félix Teillard (FAO, Rome), Technical Secretary of the TAG.

The role of the TAG was to:

- identify biodiversity assessment approaches applicable to livestock production;
- develop principles for the sound use of these approaches; and
- describe future work needed to include meaningful biodiversity quantification in livestock environmental assessments and their related guidelines.

The TAG met for three workshops on 12-14 March 2014, Rome; 2-3 July 2014, Madrid; and 15-16 October 2014, Tivoli, Italy. Between the workshops, the TAG worked via email and teleconferences.

THE LEAP REVIEW OF INDICATORS AND METHODS TO ASSESS BIODIVERSITY

Prior to the first workshop of the LEAP biodiversity TAG, the Technical Secretary prepared a review on biodiversity indicators and assessment methods to serve as a common basis for work (Teillard *et al.*, 2016a). This review was revised by the TAG before publication.

The review presents a large number of scientific articles, reports and initiatives and a variety of biodiversity indicators and methods relevant to biodiversity assessment in the livestock sector. They are structured according to two main assessment methods – PSR indicators and LCA – which are also the two methods addressed by the present document. The part on PSR indicators provides details of multiple categories of pressures and benefits specific to the impact of livestock on biodiversity, and describes their environmental mechanisms, their relative importance across geographical regions and production systems and the indicators that can be used to describe them. Examples of state indicators are provided for different levels and dimensions of biodiversity and a particular focus is put on global indicators of the biodiversity state. Response indicators cover both public and private actions and finally, the relative strengths and limitations of the three categories of indicators are discussed. The part on LCA provides an overview of the main features of the method and of its application to the livestock sector. It then describes several methods for assessing biodiversity impacts from the main midpoint impact categories: land use, acidification and eutrophication, climate change, water use and ecotoxicity. Limitations of these current methods are discussed as well as complementarities between the PSR and LCA methods.

PERIOD OF VALIDITY

It is intended that these guidelines should be periodically reviewed to ensure the validity of the information and methodologies on which they rely. At the time of development, no mechanism was in place to ensure such review. The user is invited to visit the LEAP website (www.fao.org/partnerships/leap) to obtain the latest version.

Structure of the document

Part I provides a general introduction to the aims of this document and its overall framework. Major ecoregions and global hotspots of biodiversity are introduced while some of the major global patterns in the distribution of livestock are outlined. A major outcome of this work is the identification of complementarities between the methodological development of biodiversity assessment through Life Cycle Assessment (LCA), and the well-established Pressure-State-Response indicator approach for assessing environmental impact. Each of these is first introduced separately.

Part II contains a state-of-the-art introduction to Life Cycle Impact Assessment (LCIA) for biodiversity, with an emphasis on the land use impacts associated with livestock systems. LCA is typically a rigorous and demanding form of assessment (with several distinct features and advantages), as reflected here. This introduction to LCA helps describe and understand the current state of LCA for biodiversity and, importantly, points to how this can currently address assessment challenges for the livestock sector.

Part III addresses the use of the Pressure-State-Response indicator approach to assess biodiversity within livestock systems. We begin by providing ten overarching principles for the use of indicators, and then discuss in further detail the three widely used categories of indicators: Pressure indicators, State indicators and Response indicators. We discuss these different approaches, with reference to specific examples of indicators, and with reference to several case studies conducted as part of this work.

In **Part IV**, the final section, concludes with guidance on future directions. This addresses some of the things the livestock sector needs in the medium-term to improve its methodology for assessing biodiversity. To provide leadership, there is a need to identify and disseminate examples of good practices in conducting biodiversity assessments in the livestock industry. The development of relevant LCA methods is a fast-developing area, and LEAP can make a significant contribution by being part of it, and ensuring that progress is compatible with the needs of livestock systems.

Throughout the document, we refer to a number of case studies (**Part V**). These are not intended to be representative of the global distribution of livestock systems, nor are they necessarily representative of the global challenges to biodiversity in global livestock systems. Nevertheless, they do provide useful and practical examples of the interaction between livestock and biodiversity. Most importantly, they serve to highlight quantitative and qualitative indicators and methods that have been used to assess livestock impacts on biodiversity (within both the LCA and PSR approaches). The case studies also illustrate some of the various challenges and solutions and, in some cases, actions to mitigate these challenges.

PART 1

OVERVIEW AND GENERAL INFORMATION

1. Goal and scope

1.1 AN INITIAL STEP FOR BIODIVERSITY ASSESSMENT IN LEAP

The provision of guidance for the quantitative assessment of biodiversity in livestock and other sectors is an emerging area of work. This document represents an initial step in which international experts with various backgrounds – ecologists, LCA experts, members of NGOs and the private sector – shared their views on biodiversity assessment. Because of the early stage of development of the topic, we did not recommend a specific methodology nor provide the associated, detailed quantitative guidelines on how to use it to conduct a biodiversity assessment.

This document provides principles that can assist best practice in biodiversity assessment in livestock systems. Specific principles applying to two main approaches are provided: (i) LCA which is important for the link with the other LEAP guidelines and with the assessment of other environmental impacts (Section 2.2.1 and Part II); and (ii) an approach based on PSR indicators which is intuitive and covers a wide range of indicators and methods currently used by many stakeholders (Section 2.2.2 and Part III). This document also assesses the strengths and weaknesses of the two approaches, and potential complementarities between them.

This document is clearly a first step but it paves the way for future work on how to conduct biodiversity assessments in the livestock sector. Identifying priorities and challenges for this future work is another important contribution, addressed in Part IV. We identify research directions to make biodiversity assessment in LCA more ecologically relevant and more adapted to the specificities of the livestock sector. We also detail priorities for future developments within LEAP. They include strengthening links within LEAP and between LEAP and other initiatives; capitalizing on the link between the LCA and PSR approaches; identifying best practices and key performance indicators; and progressing towards comprehensive environmental assessments of the livestock sector.

1.2 OBJECTIVES AND INTENDED USERS

This document provides a number of broad principles for the assessment of livestock impacts on biodiversity. The general objective of this document was to develop principles applicable to different assessment methods in order to guarantee a minimum level of soundness, transparency, scientific relevance, and completeness. The level of generality of these principles means that they are not well adapted for making comparisons between different systems and assessments. These principles can be used to identify crucial elements of livestock systems that affect biodiversity, to monitor changes and make improvements, and to produce assessment results for internal or external communication.

This document is intended to be used by stakeholders at different scales, including:

- local spatial scales (e.g. farm, landscape, agro-ecosystems);
- intermediate scales (e.g. territory, supply chain, region);
- large spatial scales (national to global).

It was assumed that the primary users of this document would be individuals or organizations with a certain level of expertise in sustainability and/or biodiversity expertise, such as sustainability or LCA practitioners, people involved in research or education, and environmental NGOs. This document can be used by stakeholders in all countries and across a wide range of livestock production systems.

Different users may have different goals and biodiversity assessment methods may also differ as they are adapted to their goals (Table 1). The LCA approach (Part II) is adapted to identify hotspots along a product's life cycle, or spatial hotspots across large areas. It is also adapted to users conducting an LCA on other environmental criteria (e.g. GHG emissions) and wanting to expand its scope to include biodiversity. Current LCA methodologies have limitations: the most elaborate methods focus on impacts on biodiversity through land use, and only a few land use classes are differentiated (e.g. *cropland, grassland,* without considering differences in practices or intensity within land use classes). At the current state of development in LCA, pressure, state or response indicators are likely to be more suitable for small-scale assessments aimed at determining the relative impact of different practices on biodiversity.

1.3 SCOPE

1.3.1 Assessment approaches

This document addresses two main approaches for the assessment of livestock impacts on biodiversity: LCA, and PSR indicators. Both of these approaches are widely used in the scientific literature and they were selected in order to ensure the maximum objectivity. More specific reasons for their selection are detailed below.

The rationale for selecting the LCA approach was based on three related points. (i) LCA is the only formal and standardized tool to quantitatively measure

Table 1: Types of users at different scales along with their possible goals for conducting a biodiversity assessment. Different assessment tools that are adapted to these goals are suggested

	Spatial dimension		Supply chain dimension
	Small scale (farm, landscape, agro-ecosystem)	Large scale (national to global)	Product scale
Users	Farmers Land managers Communities Processors and multinationals	Policy makers Import/export companies	Sector and sub-sector sustainability managers Processors Other companies
Goals Across scales: monitor biodiversity performances	Reveal positive and negative practices for biodiversity Identify cost-effective practices to mitigate the impact Identify local and regional programmes that support appropriate responses	Identify hotspots of positive/negative impact along the supply chains, among different systems, or spatially Identify cost-effective practices to mitigate the average (e.g. national) impact Analyse the impact from a constraint perspective	Identify hotspots of impact along the supply chain Identify cost-effective practices to mitigate the average impact
Tools	Pressure, state, response indicators Life-cycle perspective	LCA Indicators for biodiversity trends at large scales	LCA Indicators for biodiversity trends at large scales Specific tools for the supply chain/region

environmental performance: it is governed by ISO and other standards. It could thus be used for overseeing different environmental certification at various levels (e.g. individual farms, companies, supply chains). (ii) LCA is increasingly used for decision-making, including in policies and environmental accreditation schemes for food products. There is therefore a risk for environmental impact categories not addressed by LCA to be left out of such policies and labelling schemes. (iii) The other LEAP documents address livestock sub-sectors (animal feed, poultry, small and large ruminants, pigs) and provide specific LCA guidelines to quantify one main impact category: GHG emissions. LCA is widely recognized as the predominant tool to quantify this impact. Covering the LCA approach in this document increases consistency with the other LEAP activities and can facilitate broadening the scope of the sectoral LEAP guidelines to include other environmental impacts such as biodiversity.

The rationale for selecting the PSR approach was also based on three main points. (i) The PSR approach is widely used and its relative simplicity and intuitiveness makes it easy to grasp by users and stakeholders, including those with less biodiversity expertise. This also explains why we used the PSR approach rather than one if its several elaborations (e.g. the DPSIR, EEA 2007). (ii) The PSR approach is a way of structuring indicators and it can cover a very wide range of methods. For instance, state indicators cover all direct measures of biodiversity while response indicators can apply to environmental policies, farming practices or private certifications. (iii) The PSR approach follows the same environmental cause-effect chain as the LCA, which facilitates identification of complementarities between the two approaches (Section 2.3).

1.3.2 Categories of impact

This document recognizes that livestock production can have both negative effects (pressures) and positive ones (benefits) on biodiversity (Section 3.5, Figure 6).

Part III on pressure, state and response indicators can apply to the whole range of pressure and benefit categories presented in Figure 6.

Part II on Life Cycle Assessment largely focuses on a single impact category: impact on biodiversity through land use. This focus is justified because land use is the category for which scientific methodology is most developed and for which consensus on assessment methods seems reachable in the relatively short term. LCA methodologies exist for other midpoint impact categories, acidification, eutrophication, ecotoxicity, water use and climate change in particular; however, these tend to be implemented at very coarse spatial scales; there are relatively few alternatives available; there is relatively little consensus on their use and applicability to agricultural systems. The most important methodologies are mentioned in Table 2 and presented in more details in the LEAP Biodiversity Review (Teillard *et al.*, 2016a).

Land use is likely to be an important category of impact, as livestock systems are a major user of land resources. However, impacts of livestock on biodiversity are not restricted to land use, and other impact categories can have a comparable effect. Consequently, LCA focusing on the impact of livestock systems through land use alone will underestimate the total impact on biodiversity. Focusing on land use also limits the comparability of impacts on biodiversity because the relative importance of impact categories will vary among regions and systems. For instance, intensive livestock systems, by definition, use less land by unit of product; however, they are often associated with higher use of inputs and higher concentrations of animals, which can lead to nutrient pollution. For these systems, the relative impact on biodiversity through land use may be lower than the impact through pollution (this highlights the need for comprehensive environmental assessment, Section 7.4). When focusing on impacts on biodiversity through land use, the relative impact of other categories should be discussed and, if possible, assessed quantitatively or qualitatively. As emphasized in the key principles Section and in Section 2.3, PSR indicators allow one to address additional impact categories and can thus be used to broaden the scope of LCA.

1.3.3 Livestock species and production systems

These principles are intended to be relevant to all varieties of livestock species and production systems.

1.3.4 Biodiversity

This document is intended to be relevant to assessments addressing biodiversity at the ecosystem level (terrestrial or aquatic) or at the species level (plants or animals). Biodiversity at the genetic level is beyond the scope of this document.

Table 2: Summary of LCA methods for assessing the impact of several midpoint categories on biodiversity. More details can be found in the LEAP Biodiversity Review (Teillard *et al.*, 2016)

Midpoint category & method	Biodiversity indicator	Geographic coverage
Land use		
Alkemade *et al.* (2009, 2012)	Mean Species Abundance	Global
deBaan *et al.* (2013a, b)	Species richness (PDF)	Global
Chaudhary *et al.* (2015)	Global species equivalent lost	Global
Koellner (2003), Koellner & Scholz (2008)	Species richness, number of threatened species (EDP)	Central Europe, SE Asia (Schmidt 2008)
Schmidt (2008)		
Michelsen (2008)	Ecosystem scarcity and vulnerability	Norway
Souza *et al.* (2013)	Functional diversity of species	Global
Acidification		
Azevedo *et al.* (2013c)	Species richness (PNOF)	Global
Van Zelm *et al.* (2007)	Species richness (PDF)	Europe
Eutrophication		Global
Azevedo *et al.* (2013a, 2013b)	Species richness (PNOF)	Global, Europe
Struijs *et al.* (2011)	Species richness (PDF)	Netherlands
Ecotoxicity		
Rosenbaum *et al.* (2008)	Species richness (PAF)	Global
Water availability		
Pfister *et al.* (2009)	Ecosystem quality (NPP used as a proxy for PDF)	Global
Verones *et al.* (2013)	Species richness (species equivalent)	Global
Hanafiah *et al.* (2011)	Species richness (PDF)	Global
Tendall *et al.* (2014)	Species richness (SDR)	Europe
Climate change	Net Primary Productivity	
De Schryver (2009)	Species richness (PDF)	Global

The case studies tend to focus on terrestrial ecosystems and on vegetation. This reflects the general focus of existing biodiversity assessments in the context of agriculture.

The scope of a biodiversity assessment is also influenced by the scope in terms of impact categories (Section 1.3.2). Certain categories of impact are only relevant to terrestrial biodiversity, such as those related to land use and other habitat changes. Thus, in an LCA focusing on impact through land use, only terrestrial biodiversity will be considered. Table 2 provides examples of methods for addressing other impact categories, including categories that are relevant to aquatic biodiversity, eutrophication and ecotoxicity in particular. However, Table 2 also shows that most of the LCA methods that are currently available to include biodiversity assessment do not cover all levels and dimensions of biodiversity. Most of them focus on species richness.

2. Assessment methods

2.1 GENERIC FRAMEWORK AND TWO MAIN APPROACHES

The generic framework underlying these principles is the environmental cause-effect chain presented in Figure 1. Livestock production generates various kinds of pressures and benefits that lead to changes in the state of biodiversity, causing *responses* (decision and actions) from stakeholders (political, socio-economic) intended to improve the state of biodiversity.

Under this generic framework, these principles address two main types of assessment methods:

- Life cycle assessment, which follows the cause-effect chain, models the components and links between them. A first step of LCA aims to model the links between inventory items along the product's life cycle and midpoint impact categories (pressures). Optionally, a second step translates midpoint impacts into endpoint impacts such as changes in the state of biodiversity (ISO 14044:2006).
- Indicators, i.e. metrics describing one of the three following components of the cause-effect chain: pressures/benefits, state or response. The PSR structure permits identification of indicators which facilitate interpretation and decision-making.

This document addresses separately the two assessment approaches (LCA and PSR indicators). These two approaches rely on contrasting assessment methods which require specific principles. Principles for the LCA approach are described in Part II while those for PSR indicators are described in Part III. Part III also gives specific principles for the different categories of indicators: pressure, state and response. For all three, it recommends the adoption of a life-cycle perspective. The choice of the assessment method will mostly depend on the goal of the assessment (Section 1.2).

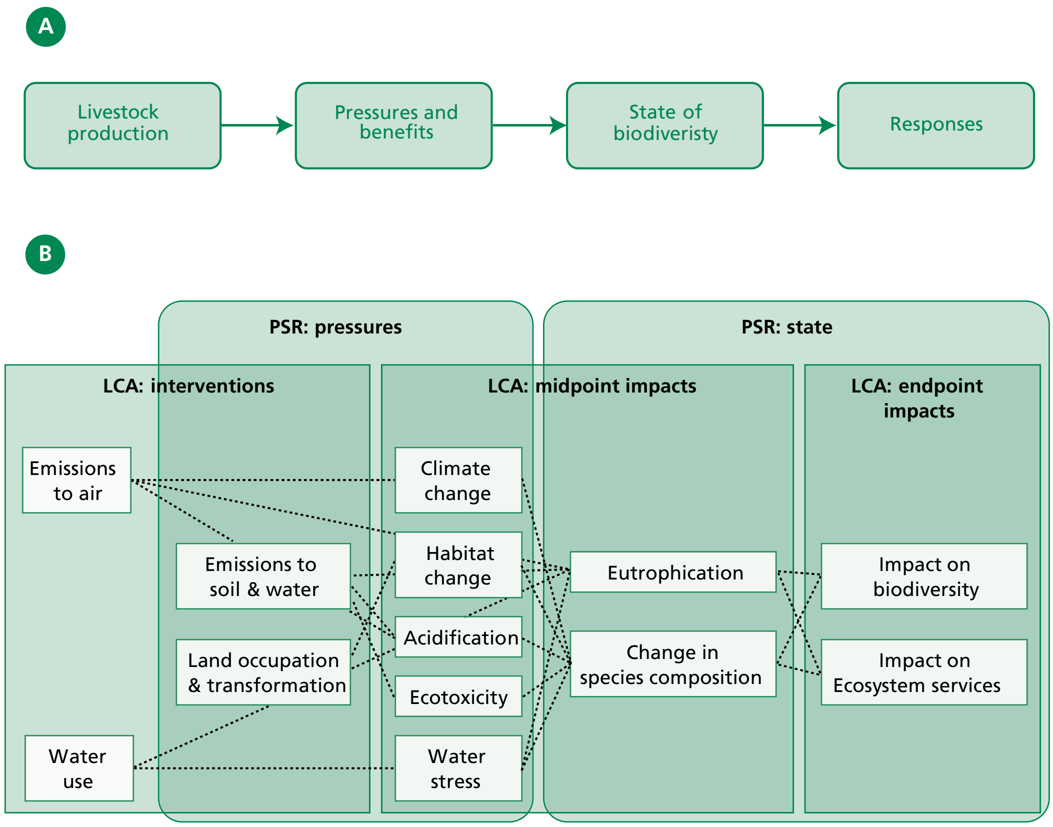
2.2 GENERAL INFORMATION ON THE ASSESSMENT METHODS

2.2.1 The LCA approach

Life Cycle Assessment is a tool for assessing the potential environmental impacts and resources used throughout a product's life cycle, i.e. from raw material acquisition, via production and use phases, to end-of-life treatment, i.e. from cradle to grave[1] (ISO, 2006a). In the case of livestock, such primary animal products as milk, meat, eggs, fibre and other by-products are included. The end-of-life treatment covers product and waste management practices such as disposal, recycling and incineration. The term 'product' includes goods, services and processes (ISO, 2006a). LCA is intended to be a comprehensive assessment and considers all attributes or aspects of natural environment, human health, and resources (ISO, 2006a). The comprehensive scope of LCA is useful in order to avoid problem-shifting, for example, from one phase of the life cycle to another, from one region to another, or from one environmental problem to another (Finnveden *et al.*, 2009).

[1] The term "cradle-to-grave" refers to the assessment of impacts from raw-materials extraction to end-of-life treatments, such as recycling or landfilling.

Figure 1
Environmental cause-effect chain linking livestock to impacts on biodiversity: (a) generic framework, (b) main environmental categories and their specific position on the cause-effect chain according to the PSR and LCA framework



Impacts can be characterized anywhere along the environmental cause-effect chain, either at the midpoint or endpoint level (Figure 1b). The midpoint impact categories can be defined as part of a problem-oriented approach, translating impacts into environmental themes such as global warming, land use, acidification or human toxicity. Endpoint impact categories provide a damage-oriented approach (ISO, 2006b). Traditional characterization methods are examples of midpoint modelling while nowadays it is increasingly accepted that inventory results should translate into their potential damage on endpoint impact categories (such as biodiversity loss) and areas of protections (human health, natural environment and natural resources). The goal of this damage modelling is to aid in understanding and interpreting midpoints by computing endpoint categories corresponding to areas of protection that form the basis of decisions in policy and sustainable development.

2.2.2 The PSR approach

Indicators are a crucial tool used to monitor either biodiversity impacts or improvement in biodiversity performance. Making a selection among the many existing biodiversity indicators (EEA, 2003 identified more than 600 of them at the European scale) should be based on logical frameworks (EEA, 2007). The Pressure-State-Response framework (OECD, 1993) has been widely used to develop and structure biodiversity indicators. The PSR framework is based on causality. Indicators evaluate the pressures of human activities that lead to changes in environmental states, causing responses (decision and actions) from the stakeholders (political, socio-economic), undertaken to reach a sustainable state. Focusing on livestock production among other human activities and on biodiversity among other environmental components is a straightforward application of the PSR framework to this specific context (Figure 2).

The PSR framework helps to inform policy-makers by providing indicators that are structured and easy to interpret (Smeets *et al.*, 1999). At the global and European levels, the CBD (CBD, 2006) and the European Environmental Agency (EEA, 2007) propose headline biodiversity indicators following the PSR structure.

2.3 COMPLEMENTARITIES BETWEEN THE LCA AND PSR APPROACHES

Key principles

- *Complementarity in quantification between the LCA and PSR approaches means that one approach can be used to fill quantification gaps in the other.*
- *Livestock systems have many important impacts on biodiversity, including land use and land use change, acidification, eutrophication, climate change and ecotoxicity. Biodiversity assessments that focus on a limited number of impacts (e.g. because of scarce data or method availability) should discuss the relative importance of other impact categories and evaluate them at least qualitatively. For instance, there is consensus on LCA methodologies for LULUC; however, PSR approaches can be used to broaden this scope to include other categories of impact.*
- *LCA can be used to identify supply chain or spatial hotspots for further investigation with more detailed and complementary assessment methods. These complementary assessments can use pressure-state-response indicators (see below) to fill the gaps of current LCA methodologies. For instance, PSR indicators can be applied to differentiate the effect of higher-resolution land use categories or livestock farming practices.*

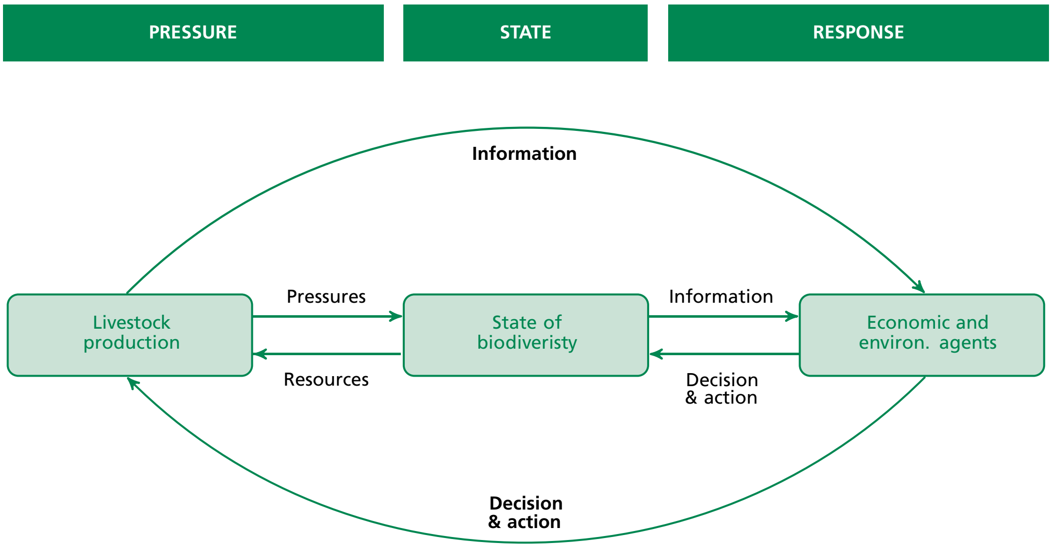
Principles for the PSR indicators and the LCA approaches are presented separately in this document (Parts II and III). Indeed, until now, they have generally been studied separately in different scientific disciplines. However, they are complementary in various aspects and follow the same environmental cause-effect chain. This complementarity allows them to be combined within the same assessment, as explored here.

2.3.1 Complementarity in scope

The methods currently available to characterize biodiversity in LCA rely on relatively coarse spatial scales and capture only part of the links between livestock and biodiversity. For instance:

- they rely on wide land use classes;
- they have a low level of biogeographical differentiation;

Figure 2
The Pressure-State-Response framework applied to livestock production and biodiversity



Source: adapted from OECD (1993).

- they include a limited number of midpoint impact categories, and;
- they focus on the species level of biodiversity and on certain taxa.

Given the current state of knowledge, LCA approaches are not well suited to answering some questions such as 'is livestock production practice A better than practice B for biodiversity?', when both A and B occur within one of the broad land use classes of the current LCA approaches. Approaches that are based on large geographical scales are much more suited to assessing land use changes impacts across bioregions, and not suited to assessing other more qualitative changes (such as the impacts of overgrazing or undergrazing) within a bioregion. However, LCA is a very useful for broad assessment of impacts on biodiversity at large spatial scales and for finding impact hotspots along the supply chain or among spatial entities. LCA can be used to reveal supply-chain or spatial hotspots for further investigation with more detailed assessment methods. PSR indicators are part of these more detailed assessment methods as they can differentiate between the effect of different practices or deal with other pressures and biodiversity levels and taxa.

2.3.2 Complementarity in perspective

LCA and PSR have orthogonal perspectives on the relationship between livestock production and biodiversity (Teillard *et al.* 2016b). LCAs address the environmental impact of a product and take into account all stages of production along its life cycle. In contrast, most PSR indicators focus on environmental impact within a bounded spatial area such as a farm, a landscape or a region.

These principles propose a first step towards bridging the gap between these two dimensions by adopting a life-cycle perspective when computing PSR indicators (Section 5.1). In particular, it is recommended that at least the impact of feed that is cultivated off-farm is included when selecting and calculating PSR indicators. This life cycle-perspective can also be extended to other production stages. Conversely, the spatial perspective of PSR indicators demonstrates the ecological importance of certain scales that are not necessarily those of the production units, such as the impact of landscape-scale processes on biodiversity. Adopting the spatial and landscape perspective could be an important step in improving the ecological relevance of LCA approaches, which can otherwise be insensitive to these issues.

As LCA focuses on products, impacts are often calculated on a 'per unit of production' basis. This approach could also be relevant to PSR indicators in order to tackle the issue of minimizing biodiversity impact while producing a certain amount of food. PSR indicators from the field of ecology and agricultural or animal sciences also show that livestock systems provide a much wider range of goods and services than just food production. For example, agricultural and livestock systems also provide environmental, social and economic services. There is a complex relationship between livestock production and ecosystem services. Livestock systems have an impact on a wide range of ecosystem services, that can be either positive, neutral or negative. A future challenge will be to incorporate the complexity of these relationships in LCA studies of livestock systems (Section 6).

2.3.3 Complementarities along the environmental cause-effect chain

Given their similarities in the environmental cause-and-effect chain, it is not surprising that there should also be several similarities between the LCA and PSR approaches. The LCA approach and the recommended PSR approach (Section 5.1) both highlight the need for: an assessment to define the goal; a scoping and hotspot analysis; definition of the system boundaries; reliance on relevant data to support analysis; and careful interpretation of the results. As might be expected, there are important differences in the nomenclature they use.

An important difference in the two approaches is that PSR describes the different points of the environmental cause-effect chain with certain metrics used as indicators, while the LCA approach models the links between them. At the different points of the environmental cause-effect chain, the two approaches can be combined.

- Many biodiversity pressures (e.g. GHG emissions, land use, eutrophication, water use) correspond to midpoint impact categories. Other pressures such as land use and land use change stand between inventory flows and midpoint impacts. At this level of the environmental cause-effect chain, combining the two approaches could provide mutual benefits to better quantify impacts. For example, widely accepted LCA models could be used to compute pressure indicators accounting for the whole life cycle of the livestock product. To date, such models mainly concern climate change and land use. In contrast, for other impact categories with less availability of LCIA models, PSR indicators could be used to complement the results. They would allow one to assess (qualitatively or quantitatively) additional midpoint impact categories and broaden the scope to include other categories of impact, e.g. acidification, eutrophication, climate change, ecotoxicity.
- At endpoint level, LCA describes the impact on biodiversity using a specific indicator, most often based on species richness and plants (see LEAP Biodiversity Review, Teillard *et al.*, 2016a). This focus on species richness is constrained by data availability at large scale, which is needed to calculate characterisation factors. But in addition to the biodiversity impact assessed by LCA,

state indicators can also be computed, allowing one to (i) address biodiversity levels, taxa and dimensions not covered by existing LCA methods or (ii) validate the LCA estimations by comparison with locally-calculated indicators. Moreover, state indicators can also be used to derive characterization factors for LCIA methods (Section 5.3.3).

Response indicators are closely linked to management decisions but their relationship with the state of biodiversity can be indirect. Some LCA models (consequential LCA in particular) make it possible to explore different scenarios or mitigation options and their effect on midpoint and endpoint impacts. Such LCA models can thus be used to estimate the effect of various response indicators and to select the most relevant.

Several elaborations of the PSR approach have been developed, such as the EEA (2007) Driver-Pressure-State-Impact-Response (DPSIR). The main difference with PSR is the distinction between pressures (resources use and emissions), state (state of the habitats and ecosystems) and impact (biodiversity loss or ecosystem collapse). The environmental cause-effect chain proposed by the DPSIR approach also allows complementarily with LCA. In particular, there is a good match between DPSIR pressures and LCA interventions. The DPSIR state and impacts are often equivalent to LCA midpoints and endpoints, respectively.

3. Background information on biodiversity and livestock

Key principles

- *Biodiversity is complex and multivariate by nature. The assessment of biodiversity is complicated by the lack of a common 'currency' for biodiversity, and by it being extremely context-dependent. For example, in greenhouse gas (GHG) assessments, a molecule of CO2 has the same radiative forcing no matter how or where it is produced, impacts are potentially global (although severity may differ locally) and all GHG emissions can be expressed in carbon equivalents. In contrast, due to societal value judgements, there is great variation in the conservation value of different species and habitats, which complicates decision-making about conservation objectives and priorities – and ultimately complicates the assessment of impacts on biodiversity.*
- *For all geographical areas within the system boundary, assessments of livestock systems should identify and recognize designation frameworks for biodiversity at both habitat level (e.g. protected habitats) and species level (e.g. protected species, IUCN Red List, and equivalent frameworks at national and sub-national scales). These and related (e.g. WWF) designation frameworks provide important guidance on the relative conservation value and status of habitats and species.*

3.1 BIODIVERSITY AND ITS COMPLEXITY

Biodiversity is a multivariate entity, which complicates its measurement considerably (for an accessible introduction, see Section 2 of OECD, 2002). Among the many units of measurement for biodiversity, common ones include: species richness (the number of species); evenness (the relative abundance of different species); community composition (the group of particular species present); functional group richness (the number of different groups of species in which each group performs a specific ecosystem function); genetic similarity; and community similarity. Unfortunately, there are often cases when the use of any one of these measures alone can lead to counter-intuitive situations that do not necessarily optimize the measurement (and conservation) of biodiversity (e.g. Solow *et al.*. 1993). A flavour of the complexity involved in measuring biodiversity at the species level is indicated in Table 3. Site 1 and Site 2 have the same richness, but very different evenness. Site 2 and Site 3 have the same richness and evenness, but differ in composition (with two of the four occurring in both sites). Site 4 has the highest species richness and Site 5 the lowest, and they have one species in common. A simple measure of diversity (Simpson's index of diversity) is also shown, in which higher values indicate lower diversity (the probability that two randomly selected individuals belong to the same species).

As mentioned above, the composition of the community (the particular species that are present) is another important dimension. Added complication stems from

Table 3: Example of the distribution of different species across different sites, illustrating differences in richness, evenness, species composition and Simpson's diversity (1-D). See main text for further discussion

	Site 1	Site 2	Site 3	Site 4	Site 5
Species 1	91	25	-	30	-
Species 2	3	25	-	20	-
Species 3	3	25	25	15	
Species 4	3	25	25	15	
Species 5	-	-	25	10	99
Species 6	-	-	25	10	-
Species 7	-	-	-	-	1
Simpson's diversity (1-D)	0.17	0.75	0.75	0.81	0.02
Richness	4	4	4	6	2

several conventions that assign importance weights to species, habitats and ecosystems, resulting in some being considered more important than others.

Implicitly, such conventions place a higher value on ecosystems that reflect the pristine state before human-dominated interventions. Thus, species that reflect the composition of the pristine, or historic state are considered to be more important, and other species such as non-native species are considered to be less so. Endemic species (which only occur within a defined geographical region or area) are considered to be of very high importance. (For an example of the importance of species composition, see Case Study 4 for an example of 'positive' and 'negative' species that indicate favourable and bad conservation status, respectively.) Simple measurements of species richness alone cannot incorporate such categories and importance levels (see below). Thus, the relative conservation value of Site 5 in Table 3 can very much depend on the identity of Species 7, and whether it is a common and widespread species in that region or a rare endemic species with a very restricted distribution. The latter would make this an 'irreplaceable' site. As one environmental dimension of environmental sustainability, such issues result in the assessment of biodiversity and its conservation being exceptionally context-dependent. It is worth noting that this is likely to become more complex, rather than less complex, as biodiversity conservation and assessments increasingly pay attention to the functional traits of biodiversity, the health of ecosystems, and the degree of provision of ecosystem services, all of which are related to biodiversity.

These and other value judgements pervade priority-setting and objectives for the conservation of biodiversity. It is beyond the scope of this document to detail the factors that contribute to determining such priorities, but a thorough assessment of the impacts of livestock on biodiversity must necessarily address whether they have been adequately taken into account (for an accessible introduction to some of these issues, see Section 2 of OECD, 2002; IFC, 2012). Any system of biodiversity conservation, no matter how much it claims to be science-based and objective, ultimately reflects value judgements about what features of biodiversity are important, and how they are weighted. As noted by Ladle and Whittaker (2011) "…decisions about where, what and how to conserve may be based on hard data and scientific principles, but are ultimately a reflection of different values within society or the global conservation community". The use of multi-stakeholder consultations that includes environmental NGOs is one way to incorporate relevant expertise on these issues, and can be extremely effective in improving understanding of local biodiversity priorities and features.

Further aspects of biodiversity and its conservation are discussed in the following section, which also introduces some conventional conservation priorities for global biodiversity.

3.2 GLOBAL PATTERNS IN BIODIVERSITY

Biodiversity is not uniformly distributed but there are several global initiatives that can assist an assessment of biodiversity impacts. For example, global patterns (at 10 km x 10 km scale) of terrestrial diversity and conservation are available for selected major taxonomic groups at: www.biodiversitymapping.org and there are other similar resources available (e.g., http://www.worldwildlife.org/pages/wildfinder or https://www.ibat-alliance.org/ibat-conservation/login). Such maps typically indicate pronounced differences in the global distribution of biodiversity based on species richness for birds, mammals and amphibians, for example (Figure 3). There is further variation in the distribution of species categorized according to their conservation status (vulnerable, endangered, or critically endangered in the IUCN Red List in Figure 3).

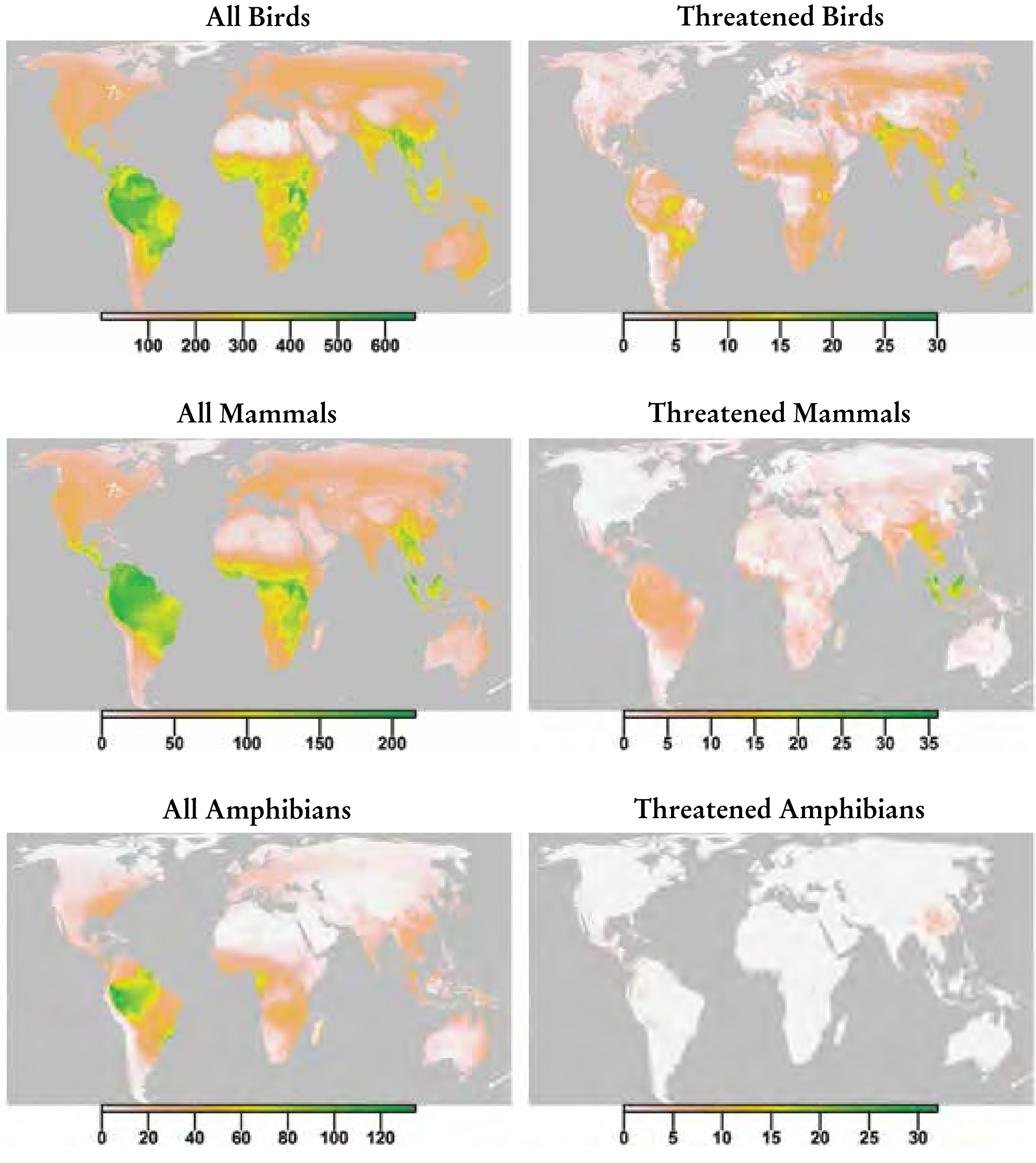
More generally, this variation in patterns of diversity has a number of consequences affecting the assessment of the impacts of livestock systems on biodiversity:

- Different conservation priorities and goals mean that different actions for biodiversity conservation may be more or less appropriate at a given site.
- The same pressure can have different consequences for biodiversity in different locations. This means that assessments need to incorporate the geographical variations in biodiversity, and the relative conservation of different species and ecosystems (this challenge for assessments is discussed in Parts II and III).
- Biodiversity conservation cannot be effectively achieved by confining conservation actions to biodiversity hotspots, prioritized areas and protected areas. Even a quick comparison of Figure 3 and Figure 4 (diversity patterns and ecoregions) indicates that there can be quite high diversity in many areas lying outside the Global Ecoregions and biodiversity hotspots (see Section 3.3). Even in countries and areas with relatively low diversity on a global scale, there can also be local, national or international priorities for biodiversity conservation.
- The geographical variation in biodiversity can result in trade-offs between local and global biodiversity goals. For example, the control or restriction of arable land conversion to protect local farmland diversity in temperate areas may result in disproportionate effects on biodiversity if the consequence is to shift arable production for livestock consumption to areas of higher biodiversity, e.g. tropical or subtropical areas.

3.3 GLOBAL-SCALE PRIORITIES FOR BIODIVERSITY CONSERVATION

As mentioned, priorities for biodiversity conservation tend to translate into value judgements. While this can introduce subjectivity and complexity in goal-setting (especially at the regional scale), there has also been considerable progress in achieving international consensus on the prioritization of global geographical areas for biodiversity conservation.

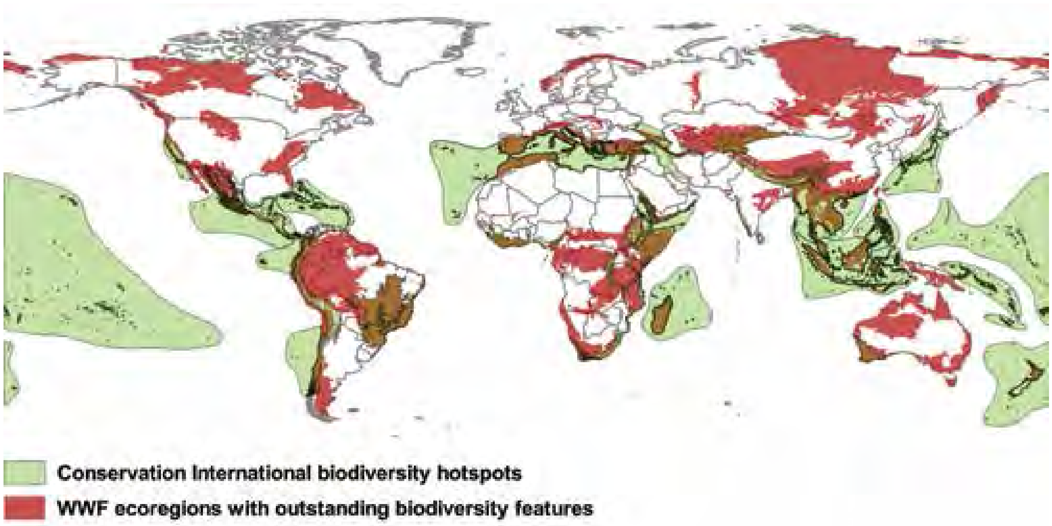
Figure 3
Illustration of the variation in the global distribution of biodiversity using global maps of species richness for different categories of species (birds, mammals and amphibians). The left column shows the richness of all species in the taxon. The right column shows the richness of threatened species (vulnerable, endangered, or critically endangered in the IUCN Red List)



Source: www.biodiversitymapping.org (Jenkins *et al.*, 2013).

An initiative led by WWF, the Global Ecoregions analysis is a criteria-based global ranking of the Earth's most biologically outstanding terrestrial, freshwater and marine habitats (Olson *et al.*, 2002). The Ecoregions are defined as relatively large units of land or water containing a distinct assemblage of natural communities sharing a large majority of species, dynamics, and environmental conditions

Figure 4
Global distribution of biodiversity hostpots
and of terrestrial Ecoregions with outstanding biodiversity features



Source: Conservation International 2011 and Olson *et al.* (2002), WWF (http://www.worldwildlife.org/publications/global-200).

(Olson *et al.*, 2002). They are chosen for their species richness, endemism, taxonomic uniqueness, unusual ecological or evolutionary phenomena, and global rarity. Each of the Ecoregions is assigned a conservation status and the three classes used are 1) critical or endangered; 2) vulnerable; and 3) relatively stable or intact. Over half of the Global Ecoregions are rated as endangered (Figure 4).

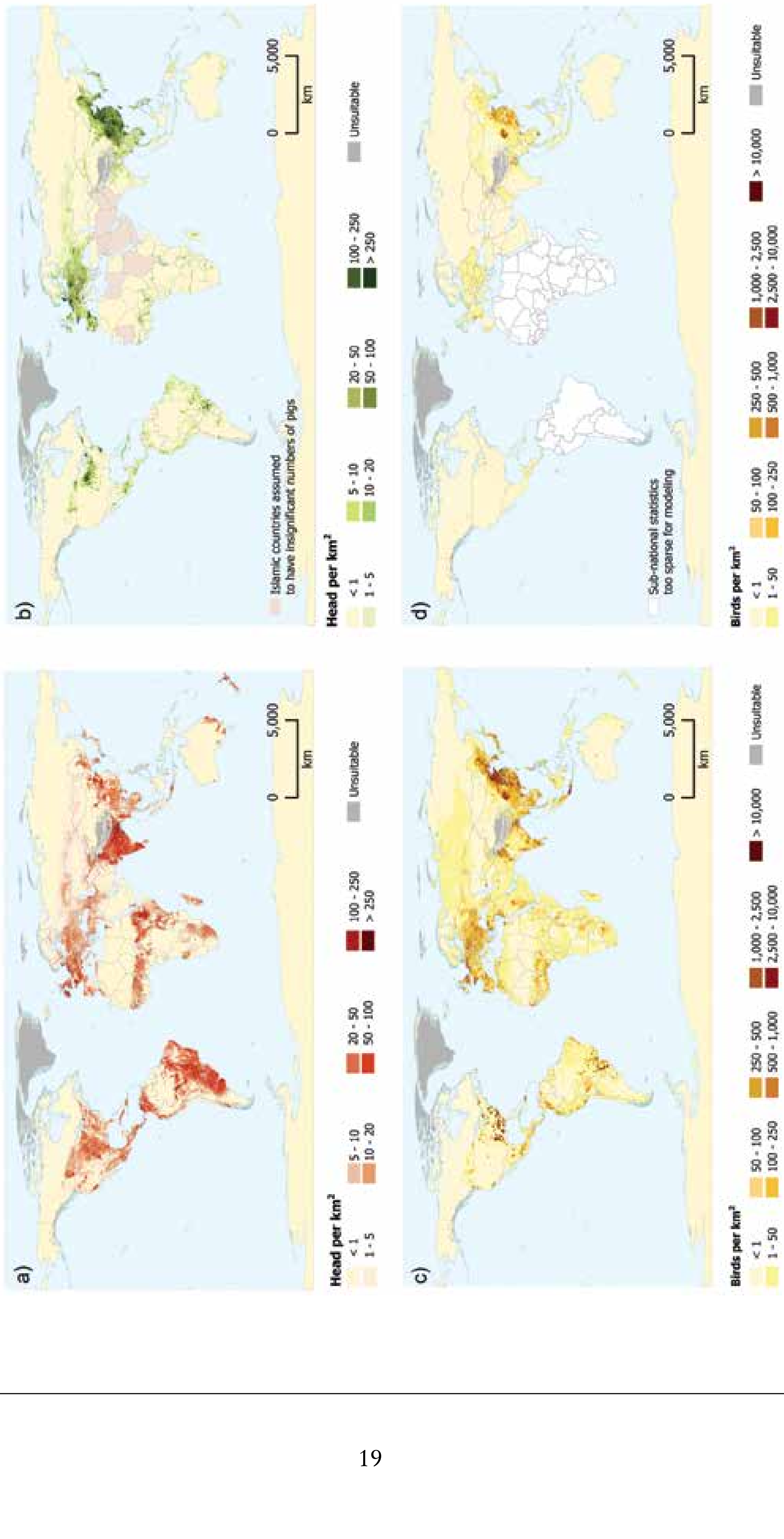
Based on the Global Ecoregion maps, Conservation International further derived biodiversity hotspot regions. They defined a biodiversity hotspot as an area having, at least, about 1,500 endemic vascular plants as endemics – implying a high percentage of plant life found nowhere else on the planet. As a second criterion, a hotspot is required to have 30 percent or more of its original natural vegetation showing high threat levels (Conservation International 2011). Thus, biodiversity hotspots represent areas of exceptionally high biodiversity that are also highly threatened.

Around the world, 35 areas qualify as biodiversity hotspots (Figure 4). They represent 2.3 percent of Earth's land surface, but they support more than half of the world's endemic plant species – i.e., species found nowhere else – and nearly 43 percent of endemic bird, mammal, reptile and amphibian species (Conservation International, 2011).

Standard tools exist to identify endangered species and their distribution areas, the most popular being the IUCN Red List. The IUCN Red List of Threatened Species is widely recognized as the most comprehensive, objective global approach for evaluating the conservation status of plant and animal species (www.iucnredlist.org). The IUCN has also initiated a complementary and standardised approach to identify the conservation status of global ecosystems (www.iucnredlistofecosystems.org). The IUCN Red List of Ecosystems will assign categories of risk to ecosystems and is intended to help inform conservation, land use and investment priorities.

Figure 5

Global distributions of (a) cattle; (b) pigs; (c) chickens; and (d) distribution of ducks, excluding South America and Africa



Source: Robinson *et al*. 2014).

Other sources of global diversity data include the Global Biodiversity Information Facility, an organization set up to share and access biodiversity data online. It encourages and helps hundreds of institutions worldwide to publish data according to common standards, making it the biggest biodiversity database on the Internet. Developed by WWF, the Living Planet Index is a measure of the state of the world's biological diversity based on population trends of vertebrate species. The LPI has been adopted by the Convention on Biological Biodiversity (CBD) as an indicator of progress towards its 2011-2020 target to 'take effective and urgent action to halt the loss of biodiversity'. Data on 14 971 populations from 3 204 species from around the world can be accessed via the Living Planet Index data portal[2].

3.4 GLOBAL PATTERNS OF LIVESTOCK DISTRIBUTION

The world's human population is predicted to increase from 7.3 billion in 2015 to 9.7 billion by 2050 (UN 2015). During that time, driven by economic growth and urbanisation, the demand for livestock products is expected to increase even more rapidly. In a business-as-usual scenario, the livestock sector would impact heavily on the global environment, including biodiversity.

Livestock distribution varies globally and for the different species. The highest cattle densities are found in India, the East African highlands (particularly in Ethiopia), Northern Europe and South America (Robinson *et al.*, 2014; Figure 5a). The highest concentrations of pigs are found in China, Eastern Pacific countries, and, with lower densities, in Europe and Africa (Figure 5b). The distribution of chickens closely follows that of humans, with the highest concentrations found in eastern China, Pakistan, India, and in Western Europe (Robinson *et al*., 2014; Figure 5c). Ducks are far less common than chickens worldwide with high densities in Southeast Asia and China, where duck production is often integrated with rice cropping and fish farming (Robinson *et al*., 2014; Figure 5d). Coincidently, the areas of high livestock densities coincide with ecoregions that are critically endangered or vulnerable.

3.5 SUMMARY OF THE INFLUENCES OF LIVESTOCK ON BIODIVERSITY

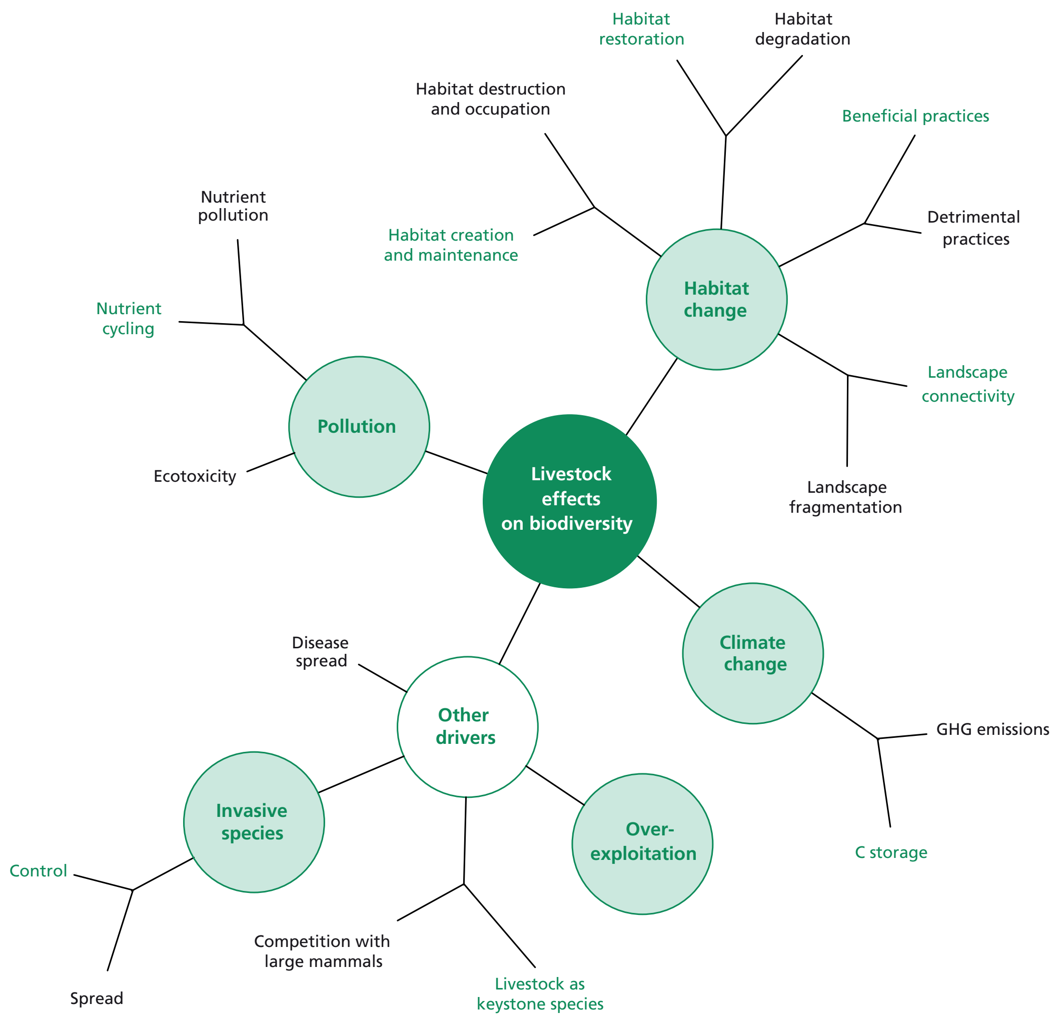
Key principles

Livestock production can have both negative and positive impacts. In order to increase their relevance to the livestock sector, assessment methodologies must be capable of reflecting the sector's beneficial as well as detrimental impacts.

The Millennium Ecosystem Assessment (2005) recognizes five main direct drivers of biodiversity loss: habitat change, climate change, pollution, overexploitation and invasive species. Steinfeld *et al*. (2006) showed how livestock contributes directly or indirectly to each of these drivers. Figure 6 identifies the specific categories of pressure relevant to livestock systems. It also emphasizes that the link between livestock and biodiversity is not restricted to pressures, and specific categories of benefits

[2] http://www.livingplanetindex.org/home/index

Figure 6
Overview of the categories of influences that livestock have on biodiversity.
The five main drivers of biodiversity loss recognized by the MEA (2005) appear in grey circles.
However, for most of these drivers, livestock can either exert negative pressure (brown) on, or provide benefits (green) to, biodiversity. See source for a detailed description of all categories



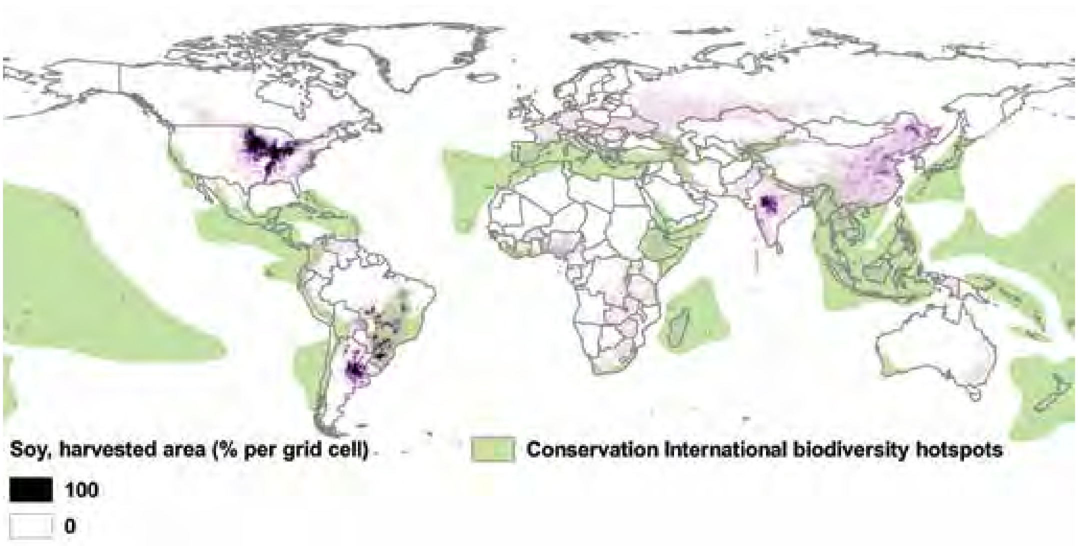
Source: LEAP Biodiversity Review (Teillard *et al.*, 2016a).

are also identified. Pressure and benefits are often two sides of the same coin. For instance, livestock systems destroy biodiversity habitats when forest is converted to pasture or feed crops, but grazing is the only way to maintain semi-natural grasslands that have existed for hundreds of years and host a rich and unique biodiversity. For more information about the different categories of pressures and benefits, see the LEAP Biodiversity Review (Teillard *et al.*, 2016a).

Grazed ecosystems naturally accommodate livestock, or even need livestock grazing for the maintenance of key ecosystem functions. But ecosystems converted to cropland for livestock feed have the greatest negative impacts on biodiversity. Lands of marginal plant productivity such as drylands, mountains or cold areas usually rely on grazing animals for many key ecosystem functions such as

Figure 7

Global biodiversity hotspots and main soy production areas. This map also includes areas where soy is harvested for purposes other than feed. While most soybean production in North and Latin America is used as feed, the soy from production hotspots in India and East Asia is mainly used for direct human consumption



Source: Monfreda *et al.*(2008) Conservation International (2011).

seed dispersal, nutrient cycling, preclusion of plant competition and mediation of climate change impacts (FAO, 2013). There, grazing abandonment can have very negative consequences on biodiversity (see Case Studies 4, 6 and 11). Also, biodiversity can be threatened when socio-economic as well as ecological factors increase pressures on biodiversity hotspots, especially when land use is changed and forest or biodiversity-rich pastures are converted into croplands.

While often far-reaching, the impacts of livestock systems on biodiversity may not be immediately obvious. Under the 'habitat destruction and occupation' category of pressure, a striking example is the global demand for soybean. Soy is a globally traded commodity produced in both temperate and tropical regions, and serves as a key source of protein and vegetable oils (Dros, 2004). Since the 1950s, global soybean production has increased fifteenfold, with the United States, Brazil, and Argentina together producing about 80 percent of the world's soy (Shurtleff and Akiko, 2004). Global soy production in 2012 was 270 million tonnes from an area of 100 million ha, which is projected to increase to 514 tonnes from 141 million ha by 2050 (WWF, 2014). China is the leading importer of soy (about 60 million tonnes in 2012), and a significant increase is projected.

As more land is allocated to soy production, important natural ecosystems come under greater pressure. An overlay of biodiversity hotspots and main areas of soybean production indicates high coincidence of biodiversity hotspots and soybean production areas, with the main endangered areas in Brazil, Argentina, India and China (Figure 7).

PART 2

THE LCA APPROACH

4. Principles applying to biodiversity assessment in LCA

This section focuses on Life Cycle Assessment of impacts on biodiversity through land use. Livestock systems are a major user of land resources; however, we clearly recognise that the impact of livestock on biodiversity is not restricted to land use. We also recognise that the relative importance of impact categories varies among regions and systems. Nevertheless, we focus on land use as this is an increasingly important category of impact, while the topic currently enjoys a quite advanced level of methodological development and consensus. PSR indicators are presented in Part III of this report with a wider scope in terms of impact category so that they can be used to complement LCA studies. In this Part, we introduce LCA and the main steps required to undertake an LCA, we present the conceptual framework that underpins how LCA treats the impacts on biodiversity of land use and land use change, and we provide a brief overview of a number of quantitative biodiversity indicators that have been used in LCA. Some of the limitations to current LCA methodologies, especially in relation to livestock systems, are discussed in Section 6.

Key principles

- *The comprehensive scope of LCA is important and useful in order to avoid problem-shifting, e.g. from one phase of the life cycle to another, from one region to another, or from one environmental problem to another.*
- *For the impact category of land use, there is broad consensus on the impact assessment framework, and several methods are already available to quantify biodiversity impacts through land use. They are especially useful for assessment of the biodiversity impacts of globally traded products. Currently, impacts on biodiversity in LCA are mainly modelled as a result of land use and land use change interventions. Other impact categories can also be incorporated, although further methodological development is needed.*
- *Existing LCA methods describe land use through relatively coarse categories, which makes LCA more adapted to assessments at large spatial scales. For small-scale assessments aimed at discriminating between the relative impact of different practices on biodiversity, indicators are likely to need further adaptation and development.*
- *There will be continued development of methods for the identification and calculation of reference states and consequent characterization factors, and users should keep up-to-date with such developments.*

4.1 OVERVIEW OF THE MAIN STEPS OF AN LCA

Key principles

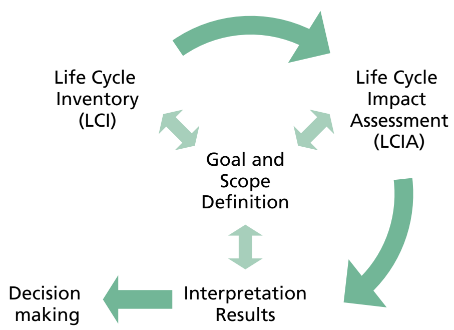
The objectives of a biodiversity assessment and the objectives of any related initiatives should be clearly stated, and appropriate indicators and methodologies chosen to reflect these objectives.

Procedures for conducting an LCA are governed by the ISO 14000 environmental management standards (ISO, 2006a, b). The procedure consists of four main steps: (1) definition of the goal and scope of the study; (2) life cycle inventory (LCI) of the system's inputs and outputs; (3) life cycle impact assessment (LCIA), and (4) interpretation of the results (Figure 8). Here, we discuss the general nature of each of these four steps in turn, and make specific references to the application of these steps to livestock systems.

Goal and scope definition – In the first step, the aims and extent of the life cycle study are defined, including the reasons for carrying out the study, the intended application, and the intended audience (ISO, 2006a). It is also the stage at which the *system boundaries* of the study are described and the *functional unit* is defined. The functional unit is a quantitative measure of the functions that the goods (process or service) provide. For recommended functional units at the farm gate and the primary processor gate, refer to the sectoral LEAP guidelines (on Feed, Poultry, Small Ruminants, Pigs or Large Ruminants). A clear definition of the goal and scope allows the baseline levels of system flows (inputs and outputs) to be determined, and facilitates comparisons among different options.

Life cycle inventory – The Life Cycle Inventory consists of an analysis (inventory) of input flows (raw-materials, water and energy) and output flows (releases to land, air and water e.g. wastes and emissions), associated with the defined functional unit.

Figure 8
Schematic representation of the four steps of LCA:
(1) definition of goal and scope; (2) life cycle inventory;
(3) life cycle impact assessment; and (4) interpretation of results



At this stage, *allocation procedures* are defined and data sources and quality are identified. Data on the various input and output flows is collected according to the system boundaries defined by the scope of the study. For the impact of livestock production on biodiversity through land use, processes such as feed production (including off-farm) should be included in the system boundaries, due to its potentially substantial contribution to overall impacts. The definition of the study system's boundaries will also depend on whether the scope of the study is attributional or consequential.

Life cycle impact assessment – In the third step, LCIA, aims to evaluate the significance of potential environmental impacts. Life cycle impact assessment typically consists of the following elements:

- selection of impact categories, category indicators, and characterization models;
- classification, where the inventory results are sorted and assigned to specific impact categories; and
- characterization, where potential impacts associated with a specific impact category are calculated by using characterization models based on the category indicator, i.e. the quantified representation of an impact associated with a specific impact category (ISO 2006b).

Optional elements in LCIA consist of normalization, grouping and weighting.

Thus, in the characterization step, flows identified in the inventory (e.g. greenhouse gas emissions, extent of occupied land) are associated with potential environmental impacts (e.g. global warming, habitat loss) caused during the life cycle. Characterization models are used to derive the so-called *characterization factors* (CFs), which are the values used to convert emissions and resources from inventory to *common impact units* to make them comparable (Curran, 1996). Impacts can be characterized anywhere along the environmental cause-effect chain, either at the midpoint or endpoint level (Figure 1). The midpoint impact category can be defined as a problem-oriented approach, translating impacts into environmental themes such as global warming, land use, acidification or human toxicity. Endpoint impact categories provide a damage-oriented approach (ISO, 2006b), which should be of direct relevance and understanding to decision-makers (Bare *et al.*, 2000). Traditional characterization methods are examples of midpoint modelling; more recently, there is growing acceptance that results from inventory results should be translated into their potential damage on endpoints (such as biodiversity loss) and areas of protection (human health, natural environment and natural resources).

Interpretation – Results are then finally interpreted and evaluated, based on the assumptions made during the definition of goal and scope and LCIA model used. Specific attention is given to the need and opportunities to reduce the impact of the product/ service on the environment. According to ISO standards, the interpretation should include:

- identification of significant issues based on the results of the LCI and LCIA steps;
- completeness, sensitivity and consistency checks; and
- conclusions, limitations and recommendations.

4.2 CONCEPTUAL FRAMEWORK: LAND USE CHANGE IN LCA

The current land use model recognizes two main interventions causing a change in the state of ecosystem quality: land use and land use change (Milà i Canals *et al.*, 2007). The environmental impact pathway linking these two interventions to biodiversity has been detailed by Milà i Canals *et al.,* 2014. Active restoration can also be considered as a third intervention, replacing the natural recovery of land. Figure 9 displays the current conceptual framework for land use impacts on biodiversity. Land use change (LUC), or land transformation, is assumed to be a sudden (instant in time) process during which human activities convert the current land use/cover to a new use. In this process, land quality may drop (land degradation) or increase (land restoration), from Q_o (in the case where the previous land cover was a natural area) to Q_i Examples of land transformation include deforestation to establish pastures, or conversion of natural grassland to cropland. Land use (LU), or land occupation lasts for a time t_o to t_f, during which the new land use takes place. During this time, land quality gradually evolves from Q_i, at the beginning of the occupation, to Q_f, when current land use ceases. These processes can lead to a loss (or a gain) of biological diversity but also to important changes in community or ecosystem composition. If the area is no longer used and land is set aside, land recovery (natural ecological succession) or active restoration (led by human intervention) processes may take place. The duration of this process, before reaching a new steady land quality Q_{PNV} (if the land remains undisturbed), can vary.

Key principles

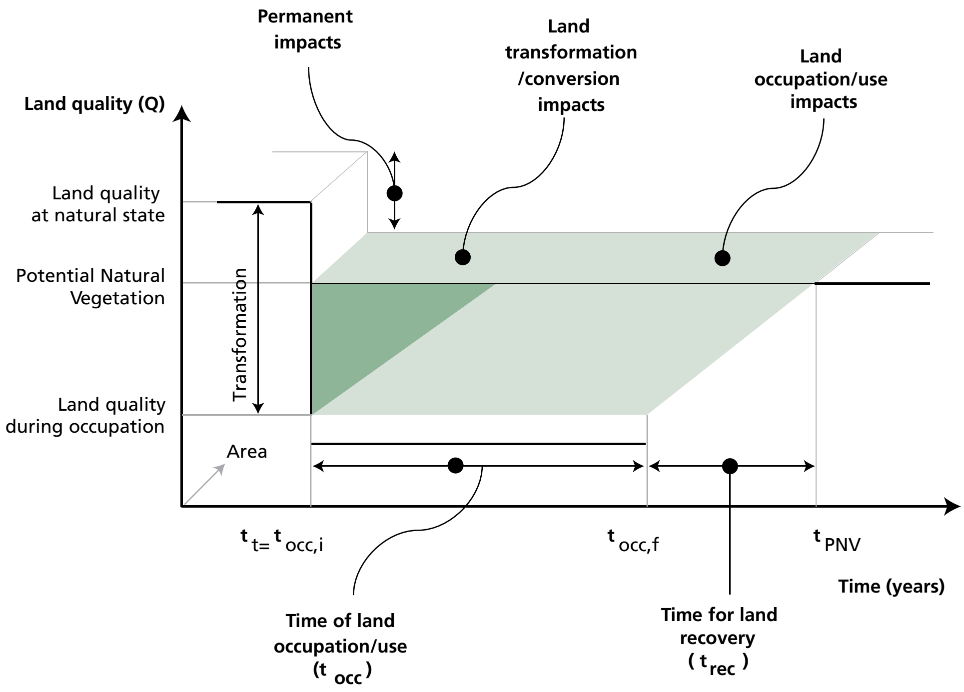
The choice of reference state (the level of biodiversity that is used as a baseline for comparisons) has a strong influence on the interpretation of results; thus, it is important to clearly describe the situation being used as a reference level, and to interpret the results accordingly.

At this point it is important to mention the importance of the choice of the reference state for the calculation of impacts from LULUC. The concept of Potential Natural Vegetation (PNV) is usually applied in current developed methods and corresponds to the vegetation that would develop if human activities ceased at once, excluding changes in climatic conditions. However, PNV may not be the most appropriate reference in the context of livestock production. Certain rangelands, including semi-natural grasslands that are extensively managed for livestock production, may host higher biodiversity levels and be a more suitable reference than the PNV. Other alternative reference states exist, such as the use of the current land cover or the global land cover types in a reference year. The choice of the baseline is not obvious, involves value choices and should be carefully considered, explained and discussed as it may have substantial influence on the final results and their interpretation. We discuss this further in Section 6.4.4.

In general, current land use models mainly compute the impacts of occupation, since little or no information exists on the dynamics and time of natural recovery of land quality. Impacts of occupation (I_{occ}) are calculated as the product of the land area occupied (A_{occ}), the time of land occupation (t_{occ}) and the difference in land quality between the potential quality state (e.g. Potential Natural Vegetation, Q_{PNV}) and the quality state during land occupation (Q_f).

$$I_{occ} = A_{occ} * t_{occ} * (Q_{PNV} - Q_f) \quad (1)$$

Figure 9
Scheme of the conceptual framework for impact assessment in LCA, depicting two land interventions (occupation and transformation) and land recovery. tPNV: time after which land reaches the PNV state



Source: Adapted from Souza *et al.* (2015).

One problem with this approach is that land quality is supposed to remain constant during occupation, and impacts are calculated as an integration of the overall impacts due to the drop in quality during transformation. Impacts resulting from management practices are not explicitly taken into account. Soil biodiversity, for example, is particularly sensitive to chemical use and changes in soil quality (chemistry and structure), which not only occur during land conversion, but can also occur during land occupation. However, the current framework is unable to take these impacts into account, and land quality is assumed to remain constant as a general effect of land management practices.

The calculation of land transformation impacts (I_{trans}) take into account the time of land recovery (t_{rec}).

$$I_{trans} = A_{occ} * t_{rec} * ½ (Q_{PNV} – Q_f) \quad (2)$$

Resulting occupation or transformation impacts can be classified as reversible or irreversible. For biodiversity, for example, Souza (2010) calculated as irreversible the loss of local/regional endemic species, classified as "extinct in the wild" and "extinct", according to the IUCN Red List. Irreversible or permanent impacts (I_{perm}) are calculated as:

$$I_{perm} = A_{occ} * t_{occ} * (Q_N - Q_{PNV}) \quad (3)$$

where Q_N represents the land quality of natural state. The results of land use impact assessment modelling will depend on the scale of reach and spatial resolution unit chosen for the calculation of characterization factors.

4.3 CURRENT DEVELOPMENT OF BIODIVERSITY INDICATORS AND MODELLING IN LCA

In the LCA approach, biodiversity indicators have been used in some impact categories in order to express potential damage to ecosystem quality. Research on biodiversity indicators for the assessment of land use impacts in LCA has been going on for more than 15 years, with some reviews on the topic (e.g. Souza *et al.,* 2015). Modelling efforts have yielded significant progress in this period; no consensus, however, has yet been reached on the use of a specific method for biodiversity. This lack of consensus could limit the inclusion of biodiversity as an important impact pathway in LCA, and hamper its relevance and applicability as a decision-making tool.

The complex dynamics of natural ecosystems and their spatio-temporal variability makes it difficult to simplify potential damage with practical biodiversity indicators: this is a distinct challenge to be overcome in LCA. First of all, biodiversity is a complex entity with multiple aspects that cannot be fully understood by one single indicator. Second, some assumptions of the land use model represent a linearization of dynamic processes in nature and lead to an oversimplification of the model (Souza *et al.,* 2015). Finally, LCA studies require globally-available characterization factors and this makes accurate modelling very data-hungry.

4.3.1 Towards a consensus on LCA for biodiversity

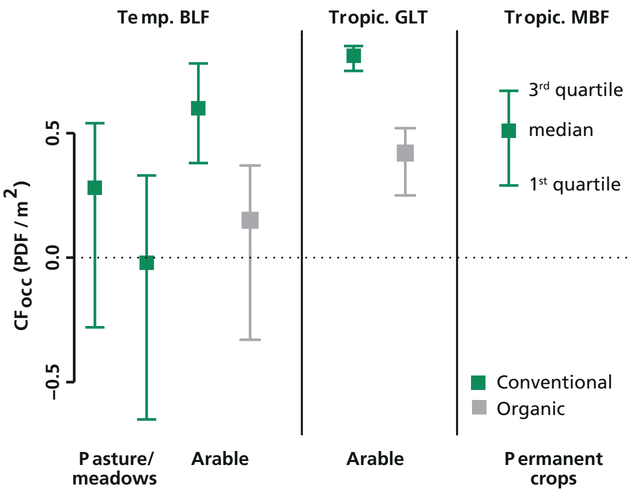
The UNEP-SETAC Life Cycle Initiative has launched a new flagship project to run a global process aiming at global guidance and consensus building on a limited number of environmental indicators, including indicators for impacts from land use on biodiversity (Milà i Canals *et al.,* 2014). A multi-year process engaging international experts and global stakeholders has been launched to carry out this programme, with the intent of developing guidance on Environmental Life Cycle Impact Assessment Indicators based on a consistently applied set of selection criteria and rigorous analysis of different methods for assessing biodiversity damage produced by land use. The UNEP-SETAC Life Cycle Initiative recommend a framework (Koellner *et al.*, 2013a, b) and characterization factors (Chaudhary *et al.* 2015) to estimate the impacts on biodiversity related to land use. These characterization factors have a number of limitations when applied to livestock production but they provide values that are relevant at global scale with a high level of spatial differentiation. They should be used as default when conducting an LCA of the impact of livestock on biodiversity through land use.

4.4 APPLYING BIODIVERSITY LCA TO LIVESTOCK PRODUCTION

Performing an LCI analysis of the land use elementary flows associated with a livestock supply chain, applying an LCIA framework (as the one presented in Section 4.2) and using existing biodiversity characterization factors (see Section 4.3 and the LEAP Biodiversity Review, Teillard *et al.*, 2016a) are reasonably straightforward

Figure 10

Value of the characterization factors of occupation (CFocc) for each land use type, farming practice and biome. Temp. BMF = temperate broadleaf and mixed forests; Tropic. GL = sub-/tropical grass-/shrublands and savannahs; Trop. MBF = sub-/tropical moist broadleaf forests. PDF = Potentially Disappeared Fraction of species



Source: Mueller *et al.* (2014).

steps in conducting a biodiversity LCA in the context of livestock production. Case Study 9 describes a published study detailing how these LCA steps can be applied to livestock (Figure 10). Existing LCA methods also have some limitations for their application to livestock: these limitations are discussed in Section 6.

PART 3

THE PSR INDICATOR APPROACH

5. Principles applying to biodiversity assessment within the Pressure-State-Response indicator approach

Part II of this report introduced the potential role of Life Cycle Assessment as a tool for use in the assessment of biodiversity within livestock systems. To date, however, there has been substantial focus on the use of indicators for this same goal. Given the likely continued prominence of indicator-based approaches within the livestock sector, Part III of this report addresses the use of indicators to assess biodiversity within livestock systems. We begin by providing broad guidance on the use of indictors, and then focus in turn on three widely used categories of indicators: Pressure indicators, State indicators and Response indicators (PSR indicators). Note that the LCA-based and indicator-based approaches are not mutually exclusive, and we addressed this further in Section 2.3. In particular, we propose that PSR indicators should adopt a life-cycle perspective. The PSR indicators could also be used to complement the results of an LCA study, by addressing additional pressure categories, for instance.

Key principles

- *Pressure, state and response (PSR) indicators are complementary and the PSR approach provides a way of articulating them to facilitate interpretation and decision-making. Combining several categories of indicators is strongly encouraged.*
- *The system boundaries should be defined to include off-farm feed cultivation when selecting and calculating pressure indicators. As a minimum, off-farm land use pressure should be quantified (Case Study 1 provides a simple example of how to estimate it with national yield data) and other categories should also be addressed if possible.*

5.1 COMMON ISSUES FOR BIODIVERSITY ASSESSMENT USING PSR APPROACH

The issues included in this section provide the foundation for a biodiversity assessment process based on the PSR approach. These broad issues should be referred to when undertaking an assessment of biodiversity impacts as they provide overarching guidance that is relevant to indicator-based approaches in general. Reflecting the complementarity in perspectives discussed in Section 2.3.2, note in particular that the following principles introduce a life-cycle perspective to the selection of PSR indicators. This is an important point, and is especially reflected in the use of scoping and hotspot analysis (the third principle), and in setting the boundaries to include off-farm impacts (the fourth principle).

We identify ten major issues below. Each of one is subsequently discussed in further further detail.

The following ten major issues should be referred to when conducting an assessment of biodiversity impacts. They provide overarching guidance that is relevant to indicator-based approaches in general. Note especially that they introduce a life-cycle perspective to the selection of PSR indicators.

1. *goal definition*
2. *scoping and hotspot analyses*
3. *setting the boundaries*
4. *identifying the scope of P, S and / or R*
5. *engagement with stakeholders and experts*
6. *identifying and prioritizing indicators*
7. *identifying relevant information*
8. *analysing data*
9. *understanding and managing the impacts*
10. *developing effective communications*

1. Goal definition

Key principles

The objectives of a biodiversity assessment and the objectives of any related initiatives should be clearly stated, and appropriate indicators and methodologies chosen to reflect these objectives.

The first step should be to set the goal of the assessment and to describe the intended use of the results. Given the context-dependency and role of value judgements associated with biodiversity and its conservation, definition of the goals of an assessment is an especially important issue (see below). Engagement with multiple stakeholders at this stage can be extremely useful in helping define goals that are relevant to the specific livestock system, the prominent biodiversity issues, and the spatial scales under consideration (see also point 5, below). All steps of the assessment should reflect the defined goal, i.e. goal, scope, data, methods, results and conclusions should all be aligned. Several aspects should be addressed and documented during the goal definition phase (e.g. European Commission, 2010):

- subject of the analysis;
- key properties of the assessed system: organization, location(s), dimension, sector, products, and position in the value chain;
- purpose of performing the study and decision context;
- intended use of the results: will they be used internally for decision-making or shared externally with third parties?

- target audience for the results;
- commissioner of the study and other relevant stakeholders.

These steps are highlighted in the case studies presented in this document.

In addition to clarifying and assessing the stated biodiversity goals of a sustainability initiative or of a livestock systems, the goals of the assessment should include consideration of over-arching priority issues such as: the extent to which Critically Endangered species are affected; the extent to which key ecosystems are affected (e.g. Global Ecoregions, biodiversity hotspots, IUCN Red List of Ecosystems); how far ecosystem services are maintained in areas of high conservation value; how far other priority goals in the study boundary are affected, etc. See Case Study 2 for the goals of the Reef Water Quality Protection Plan for grazing management to reduce off-site biodiversity impact on the Great Barrier Reef in northeastern Australia.

2. Scoping and hotspot analyses

Key principles

An initial step should be to perform scoping and hotspot analyses. A scoping analysis aims to identify the important biodiversity issues in the user's context, with specific inclusion of off-farm inputs and off-farm impacts on biodiversity. A hotspot analysis aims to provide a qualitative evaluation of the relative contribution of the livestock system to different biodiversity issues, and to identify the most prominent positive and negative impacts.

In performing a scoping analysis, context should be addressed at the local, regional, national and up to the global scale, where relevant to the user's activities. The scoping analysis will, for example, clarify what features of biodiversity are of concern (see Section 3) and whether ecosystem services are to be included. Important biodiversity issues will be identified, for example, through the review of information from the scientific literature, reports from environmental NGOs – local or international (e.g. WWF, IUCN) – laws, international frameworks, and consultations with stakeholders (see Section 3.2). At the local scale, important biodiversity issues could include the presence of endemic, protected or threatened species, and of protected habitats or habitats with high conservation value. It could also include any local legislation regulating certain practices such as habitat conversion or the use of pesticides/fertilizers. Similar regulations for species and habitat protection also exist at regional to national scale. Many countries have agro-environmental programmes offering subsidies for the voluntary adoption of certain environmentally sound practices. These practices can also indicate important local biodiversity issues and objectives. At the global scale, the Convention on Biological Diversity (CBD) is a multilateral treaty with the goal of the conservation of biodiversity and the sustainable use of its components. It includes the Aichi targets, established to help reach this objective. These internationally agreed targets can be relevant to the user and may be included in the scoping analysis. See Case Studies 2, 4, 8 and 11 for examples in which locally important aspects of biodiversity were assessed and prioritized. The case studies all focus on sites of high conservation value and pay particular attention to land use on, or close to them. The studies include the Great Barrier Reef; traditional livestock systems on the Aran Islands, Ireland; and large herbivores in the Serengeti National Park.

A hotspot analysis aims to provide a qualitative evaluation of the relative contribution of the livestock system to different biodiversity issues, and to identify the most prominent ones. Both local and delocalized contributions should be considered, and several examples of delocalized contributions are provided in the case studies. Delocalized contribution occurs when local pressures have an impact on biodiversity outside of the user's system, such as water pollution (Case Study 2) and GHG emissions, or when local management action disrupts migratory routes (Case Study 12). They also occur when the product's supply chain encompasses more than one area. The hotspot analysis should include this life-cycle perspective and qualitatively evaluate the relative contribution of the different steps of the supply chain. These concepts are illustrated in Case Studies 1, 5 and 9, which use the LCA approach. They consist of a global-scale analysis of off-farm livestock feed production; and two studies of the land use impacts of different dairy systems on biodiversity.

3. Setting the boundaries

Key principles

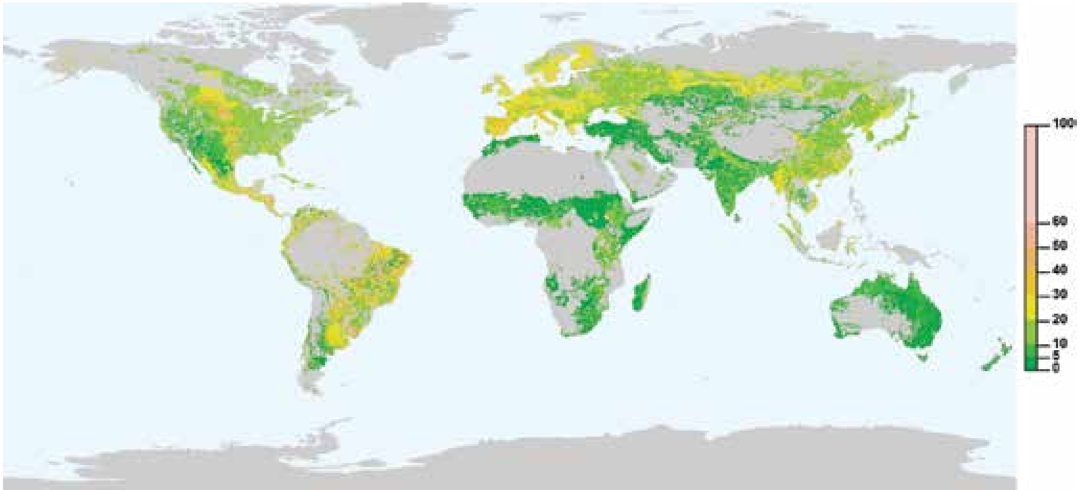
As a priority issue, processes such as feed production, especially off-farm feed production, should be included in the system boundaries of livestock systems. This is due to feed's substantial and increasing contribution to the overall impacts on biodiversity.

When the appropriate goals have been identified, the boundaries of the assessment should be clearly defined. Boundaries should include the geographical scope of the areas to be included in the assessment of the impacts of livestock operations, as in the case of the study in eastern Australia, in which the boundaries were defined as the coastal catchment area (and included 2 900 reefs as well as extensive seagrass meadows, mangrove forests and soft-bottom habitats) (refer to case Study 2). A life-cycle perspective should also be adopted since the supply chain in which the user is included often covers different geographical areas. In particular, if the livestock operations are using feed that is purchased off-farm, then the off-farm biodiversity impacts of feed production should be included where possible (see Case Studies 1, 5 and 9). Figure 7 shows how important areas for feed production can overlap with biodiversity hotspots. This suggests that even if a farm uses a small share of feed coming from a given hotspot, it could have a high relative impact on biodiversity.

Case Study 1 analysed the impact of livestock on biodiversity through land use for feed. The objective was to estimate the relative shares of such impact occurring on-farm (grassland, feed crops cultivated on the farm) and off-farm (imported feed). The output was a global map showing the impact of dairy cattle production on biodiversity occurring off-farm vs. on farm, and evidencing that the off-farm impacts are very significant (Figure 11).

Livestock sectors and commodity grain sectors could be encouraged to work together to measure and assess biodiversity throughout the supply chain. In this way,

Figure 11
Percentage of the estimated impact of dairy cattle production on biodiversity (MSA) through land use occurring off-farm, i.e. from imported feed. See Case Study 1 for details



livestock farmers who buy (off-farm) feed from the market can be more informed about, and better understand the biodiversity impacts of the products that they buy.

4. Identifying the scope of Pressure, State and/or Response indicators
It is important to identify the scope and needs of an assessment. Depending on the assessment, it will be necessary to select specific pressure, state and/or response indicators.

Pressure indicators stand at an intermediate point between management decisions and biodiversity. There is often a strong body of literature to evidence the link between pressure categories and biodiversity. Because they are closely related to management decisions, data required to calculate pressure indicators may be readily available. Pressure indicators should be used when there is a significant contribution of the user to pressure categories and good scientific evidence of the link between these categories and biodiversity (see Case Studies 1, 7, 8 and 11 where a scientific approach informed the choice of indicators). They could also be used when the user does not have the capacity to collect data and calculate indicators of the state of biodiversity. The relative importance of the different pressure categories to the overall impact on biodiversity is difficult to quantify and this limitation should be discussed when using pressure indicators.

State indicators provide a direct measure of biodiversity, which is ultimately what the user should act upon and improve. State indicators should be used when the user has the capacity to compute them and collect adequate data, which often requires a significant amount of time, financial resources and expertise. State indicators describing habitats rather than species may be computed more easily. The user should also identify a specific target regarding the state of biodiversity, e.g. reversing the decline of bird populations (Figure 13), or ensuring the conservation of certain species or habitats (see the case studies for several examples). Although state indicators can be a proxy for wider biodiversity, they cannot be comprehensive and this limitation in scope should be discussed. A very broad diversity of state indicators can be used and their values will often be uncorrelated. The choice of state indicators will have a huge influence on the outcome of the study; stakeholder engagement will therefore be very valuable in defining key biodiversity issues and selecting the corresponding state indicators (see point #5).

Response indicators are directly related to management decisions; therefore, the data required to compute them are often already available. Response indicators should be used to measure and monitor impacts on biodiversity. (See Case Study 7 which used information from a large-scale biodiversity monitoring programme to link multi-taxa biodiversity to land use supporting livestock production in western North America.) The link between the different response indicators and the positive influence on biodiversity should be strongly supported by the scientific literature, legal frameworks or private audit or certification. There is no guarantee that responses will actually lead to biodiversity improvement: other factors may have a more important effect, responses may be taken at inadequate scale, or coordination could be lacking between the responses of different stakeholders.

Pressure, state and response indicators are complementary and the PSR approach provides a way to articulate them to facilitate interpretation and decision-making. Combining several categories of indicators is strongly encouraged. Using response indicators in combination with pressure and state indicators allows one to show the changes adopted to improve biodiversity performance. Conversely, it also allows one to monitor whether responses actually result in lower pressures, higher benefits, or improvement of the state of biodiversity (Case Studies 4, 5 and 6 use indicators to show the importance of traditional practices in maintaining heterogeneous landscapes and biodiversity). It is also useful to combine pressure and state indicators in order to show the relative importance of the different categories of pressure and to prioritize action (e.g. Plantureux *et al.*, 2014).

5. Engagement with stakeholders and experts

Given the context-dependency of biodiversity conservation and priority-setting, engagement with multiple stakeholders (anyone who may be impacted by, or have an impact on, an issue) can improve several facets of an assessment. The role of stakeholders may include, but is not limited to:

- contributing to more effective goal definition (see point 1, above);
- improving awareness of traditional knowledge and practices about biodiversity;
- contributing to the selection of indicators;
- informing about the availability of other studies and existing data;
- providing feedback on the goal, methods and outcomes of an assessment;
- providing feedback on the acceptability and feasibility of recommended actions.

It is important to engage stakeholders, consult experts and access relevant information from other resources to identify the current or past biodiversity state within the system boundaries, and whether any plans or projects might be in place or in development to improve the state of biodiversity. Stakeholders can also support the selection of assessment methods and tools, as well as the identification of solutions for the mitigation of impacts. Experts can also provide such information, and have a more important role in providing specialized skills that can assist the validity, efficiency and effectiveness of an assessment. Depending on the goal of an assessment, there may be a need to employ experts to conduct part of the initiative (e.g. measuring population trends in a threatened species, conducting habitat surveys, analysing ecological data). If it is to be effective and credible, engagement with stakeholders and experts should be continuous, with regular interaction at key points in the planning, implementation and interpretation of a biodiversity assessment.

Where an assessment results in recommended actions, stakeholder engagement is necessary to achieve 'buy-in', especially if there is need for a coordinated response, which is often required to improve the state of biodiversity. For instance, coordination of several farmers or groups of farmers can provide a response at the landscape level, and coordination along the supply chain can ensure that both on-farm and off-farm feed cultivation lead to biodiversity improvements. Stakeholders are also able to provide a good indication of the wider response to an assessment, and whether it has sufficient content and clarity of communication to be trustworthy and likely to be accepted.

6. Identifying and prioritizing indicators

Based on expert input and consulted resources, identify the indicators and prioritize these for the assessment. Selected indicators should be SMART (Specific, Measurable, Actionable, Relevant and Timely), and measuring them should be economically feasible. The selected response indicators should be used to identify opportunities to address impacts. They can provide recommendations for practices that enhance biodiversity in livestock operation or feed crop areas. State indicators can be used to assess whether those practices have led to the desired outcomes. Each category of impact should be considered, and effort made to identify an appropriate pressure, state and/or response indicator for each of the major impact categories identified in the scoping and hotspot analysis (See Section 5.2 on pressure indicators for further discussion of this general approach).

Note that the desired outcomes may not be apparent because of long delays (and sometimes distances) between change in practices and measureable change in state indicators. Therefore, lack of apparent response in state indicators cannot always determine whether the response practices have been successful or not. An understanding of the underlying cause-and-effect relationships can help guide expectations on the temporal scale over which responses should be evident.

Various initiatives have developed indicators and guidance for these different levels of assessment as described in Sections 5.2 to 5.4, and we give an overview of some relevant initiatives/organizations/frameworks. Users can identify which ones are most relevant for the desired assessment based on location, sector, or other criteria.

Users can select the indicators that are most relevant to the circumstances of the livestock production operations that regard them. If such operations are located in an area of low biodiversity conservation value (e.g. no forests, wetlands or grasslands are directly and/or indirectly impacted by the livestock operation) then users can choose what indicators to adopt. When indicators are relevant to the livestock system, but there is no information to quantify the indicator, then a reason should be provided for its non-communication, and possible ways to collect the relevant information should be identified.

7. Identifying relevant information

Indicators are only useful if they address the goals of the assessment, and if there are data to quantify trends in the indicator. Existing information available to assess biodiversity impacts should be identified. If data are not available, it may be possible to collect them through a new monitoring campaign. Limited data availability should not be used as a reason for excluding important pressure/benefit categories if users have the capacity and financial resources to collect additional data. In some cases, there may be options for structured and organized self-reporting by farmers, although more specialized biodiversity monitoring will probably require the use of specialist expertise. The willingness of an organisation to commit resources to an effective monitoring programme that collects quantitative information is viewed by many stakeholders as a strong test of commitment to a sustainability programme. See also Case Studies 2-8 and 10-11 for examples of monitoring programmes). In any event, it is imperative that the data are collected in a way that is fit for purpose

The design of a monitoring programme and data collection protocols is a key activity that should be undertaken by personnel with the appropriate specialist expertise in this area. Thus, for example, there should be a stratification of the sample of farms and randomised selection of farms from the relevant suite of farms. (Stratification based on sensitivity of habitat, connectivity, capacity to monitor or implement practice change and/or location relevant to off-site impacts may provide more information and greater improvement.) Many universities, NGOs and other local conservation groups concerned with biodiversity have relevant expertise that can contribute to the valid design of a monitoring programme.

8. Analysis of data

The impacts on biodiversity can be identified through analysis and interpretation of data collected for the chosen indicators. Data analysis and interpretation is another key activity that should be undertaken by personnel with the appropriate expertise in this area.

Users should assess that the following aspects in data collection have been taken into consideration when carrying out an assessment (adapted from ISO 14044:2006):

- representativeness: qualitative assessment of the degree to which the data set reflects the true population of interest. Representativeness covers the three following dimensions:
  - temporal representativeness: age of data and the length of time over which data was collected;
  - geographical representativeness: geographical area from which data for unit processes was collected to satisfy the goal of the study;
  - technology representativeness: specific technology or technology mix.
- precision: measure of the variability of the data values for each data expressed (e.g. standard deviation);
- completeness: percentage of flow that is measured or estimated;
- consistency: qualitative assessment of whether the study methodology is applied uniformly to the various components of the analysis;
- reproducibility: qualitative assessment of the extent to which information about the methodology and data values would allow an independent practitioner to reproduce the results reported in the study;
- sources of the data;
- uncertainty of the information (e.g. data, models and assumptions).

Two types of data can be collected:

- primary data: defined as directly measured or collected data representative of processes at a specific facility or for specific processes within the product supply chain.
- secondary data: defined as information obtained from sources other than direct measurement. Secondary data are used when primary data are not available or it is impractical to obtain them. Some data are calculated from a model, and are therefore considered secondary data.

Primary data should preferably be used to describe foreground processes, i.e. those that are under the direct control of the user. Secondary data can be used for background processes. In that case, they should be as specific as possible, i.e. specific for the supplier of a given input and communicated by that supplier, as well as product-specific or country-specific. Case Study 5 gives an example where primary data are combined with country-specific secondary data to assess the land use pressure related to the cultivation of off-farm feed included in the composition of feed concentrates used on the farm.

Biodiversity data collection can be very demanding in terms of time, cost and expertise so that users are more likely to use secondary data. Such data are often collected for other purposes and can greatly vary in quality. But even with secondary data, quality should be ensured according to the ISO 14044:2006 criteria. Coherence between the purpose of the collection of the secondary data and the purpose of the assessment using them should also be addressed.

Two important criteria should be considered when using primary data: sensitivity and uncertainty. Sensitivity reflects how data and methodological choices such as the choice of indicators or system boundaries influence the results. Sensitivity should be assessed qualitatively and a quantitative sensitivity analysis should be conducted if relevant and possible. Uncertainty is important, especially if pressure indicators are computed on sample data or if secondary data are used. Average values of pressure indicators should always be provided with a measure of variability, such as the standard deviation.

9. Understanding and managing the impacts

Ultimately, the aim of data collection and analysis is to inform understanding and evaluation. The interpretation of the data for this purpose is an important activity that can improve knowledge of the relative impact of different activities in the life cycle of a product, assist judgement on the extent to which goals are being attained, and inform the degree to which corrective actions are required.

Within LCA, there are clear guidelines for the interpretation of results, as in Section 4.1:

- identification of significant issues based on the results of the LCI and LCIA steps;
- completeness, sensitivity and consistency checks; and
- conclusions, limitations and recommendations.

For both LCA- and PSR-based approaches, this phase of a study should directly address the goal of the assessment. It should deliver answers to the question(s) raised in the goal definition stage and recommend appropriate actions to the intended audience, within the context of the goal and scope. The study should explicitly discuss the limitations to robustness, uncertainty and applicability. For instance, if the goal is improvement over time and to mitigate pressures, then action plans and a plan to monitor (possibly context-specific) progress should be detailed. Thus, the Discussion phase of a study should not just set goals to be attained, but also to provide clear guidance on how to measure and monitor specific, stated indicators over time in order to understand whether policies or practices have led to improved biodiversity in livestock or feed crop operations.

For example, in Case Study 2, monitoring confirmed reductions in sediment, pesticide and nitrogen loads to the Great Barrier Reef system. Case Study 7 provided a clear link between the Biodiversity Intactness Index and different land uses. In Case Study 8 in the Serengeti-Mara ecosystem, large herbivores and carnivores were surveyed to assess human impacts on the system. In Case Study 11, research recognized that management of grazing to reduce vegetation height and residual dry plant matter and to increase bare ground favoured some listed vertebrates, invertebrates and endemic plants.

10. Developing effective communications

A major success factor in maintaining and improving sustainability (including biodiversity) is the successful transfer of information, and the achievement of cultural awareness and appreciation of biodiversity. As part of a wider set of activities to foster such awareness and appreciation, the results of monitoring programmes should also be communicated externally. This can help to illustrate successes where they occur, and help motivate farmers, consumers and other stakeholders. Where appropriate, the wider public should be kept informed of progress in biodiversity initiatives. Where monitoring indicates a lack of success, such quantitative information should also be useful in guiding and justifying the introduction of management actions that are more likely to be successful.

Information provided should be transparent about the aims and methods of an assessment. This should include: the methods chosen, the outcomes, the action plans following the assessment and any limitations related to the assessment or information. In particular, information should be communicated in a clear and understandable form, be complete, reliable, comparable (over time) and accurate. Communication should include information about boundaries, timelines, assumptions, resources consulted and stakeholders engaged. Tools may include guidance about communication of biodiversity assessment outcomes. For more guidance on communication regarding biodiversity, see the G4 Sustainability Reporting Guidelines of the Global Reporting Initiative (GRI[1]).

For transparent communication, the limitations of an assessment should be clearly described and discussed. First, a completeness check should ensure consistency between the goals of the assessment, its scope, its system boundaries and the assessment methods selected. Secondly, sensitivity checks should assess the extent to which the study outcomes are affected by methodological choices such as system boundaries, data sources, and the choice of indicators. If relevant, a quantitative sensitivity analysis can be performed. Biodiversity is a complex issue and its assessment will always involve simplifications and assumptions: the consequences of these should be discussed. Examples of simplification include instances when a limited number of pressure categories or biodiversity levels, dimensions or taxa are considered.

[1] https://www.globalreporting.org/reporting/g4/Pages/default.aspx

5.2 PRESSURE INDICATORS

Key principles

- *The scoping and hotspot analyses should aim to define a shortlist of pressures and benefits to be quantified because of their importance to the user's livestock system and its context. At least one indicator should be computed for each pressure and benefit category within the shortlist identified in the scoping analysis.*
- *Pressure and benefits are often two sides of the same gradient – both should be considered when conducting the hotspot analysis and, when relevant, the same indicator should reflect the whole gradient. An example includes grazing level (livestock units/ha, plant biomass/height, percentage of bare ground) which results in different impacts from low to high grazing levels (e.g. see Case Study 4, 5 and 11).*

Figure 6 identifies the categories of pressures and benefits that link livestock production to biodiversity. These categories are detailed in Table 4, which provides a summary of the broad mechanism of their effect on biodiversity, their relative importance among regions and production systems as well examples of key indicators to describe them.

5.2.1 Scoping and hotspot analysis

A scoping analysis should be conducted. This analysis will evaluate the relative importance of the different pressure and benefit categories (Table 4), based on two main criteria: (i) the contribution of the user's livestock system to the category and (ii) the contribution of the category to biodiversity changes. Based on this evaluation, a shortlist of pressure and benefit categories selected for quantitative assessment should be defined.

- Conduct a qualitative hotspot analysis of the relative contribution of the user to the different pressure and benefit categories. All the categories that are under the control of the user should be included in this analysis. A life cycle perspective should be adopted for this hotspot analysis and for each pressure/benefit category, and the relative contribution of the different stages of the supply chain should also be assessed qualitatively. Certain categories, while under the direct control of the user, lead to biodiversity changes outside of the user's system (e.g. imported feed, climate change, nutrient pollution in water). For example, this qualitative analysis could reveal that the most important pressure categories for a given extensive system are GHG emissions from enteric fermentation and, on the benefit side, habitat creation/maintenance; similarly, it could show that nutrient pollution and habitat destruction from off-farm feed cultivation are the major pressure categories for an intensive system.
- Conduct a scoping review to identify the most important drivers of biodiversity changes and pressure/benefits categories in the wider context of the user's system. For instance, does habitat destruction driven by livestock occur in the region (e.g. conversion of forest to pasture) or does the area suffer important nutrient pollution from livestock farms? This review should include scientific

literature, reports and legal frameworks aimed at mitigating certain pressures or at promoting certain benefits. For instance, laws banning deforestation or setting maximum thresholds for the spreading of manure/slurry on fields, voluntary schemes offering payments for the adoption of biodiversity-friendly practices at the field or landscape level.

The pressure/benefit categories presented in Table 4 (and Figure 6) remain relatively broad and can include several more specific mechanisms of impact. For instance, habitat destruction includes the conversion of primary forest to either grassland or cropland, as well as conversion of grassland to cropland; nutrient pollution includes atmospheric, soil, terrestrial and coastal water pollution. The shortlist of pressure/benefit categories should also detail these specific mechanisms.

Certain pressure/benefit categories presented in Table 4 (and Figure 6) have not been given sufficient attention in previous biodiversity assessment and their importance should be carefully examined. They include the spatial configuration at landscape scale (e.g. fragmentation, simplification, connectivity), the livestock/wildlife conflicts (competition for resources with wild herbivores, retaliatory kill of predators) and the wildlife/health issues. A detailed description of these pressure/benefit categories can be found in the LEAP Biodiversity Review (Teillard *et al.*, 2016a)

Table 4: Overview of the categories of pressures and benefits for the effects of livestock production on biodiversity. For the detailed description of all categories, refer to the LEAP Biodiversity Review (Teillard *et al.*, 2016a)

Main drivers and Subcategories	Mechanisms	Relative importance among regions and systems	Examples of indicators
		Pressures	
1. Habitat change			
Habitat destruction/ fragmentation	Deforestation and fragmentation	Tropical forests converted to pastures (in majority) and feed crops	Rate of conversion Extent of the original habitat Patch size/isolation to describe fragmentation
	Grassland to cropland conversion	Grassland in temperate countries	
	Land abandonment (see also the "Habitat creation/maintenance" category below)	Grassland systems in temperate countries	
Habitat degradation	Overgrazing	Overgrazing is always one factor	Normalized Difference Vegetation Index Rain use efficiency Overgrazing
	Desertification	In semi-arid rangeland	
	Woody encroachment	In arid climate and grazed woodland. In grasslands and shrublands with reduced grazing pressure or grazing exclusion	
	Soil degradation	All regions but humid/arid systems more fragile	

Cont.

Table 4: *(Cont)*

Main drivers and Subcategories	Mechanisms	Relative importance among regions and systems	Examples of indicators
	Pressures		
Detrimental practices	Higher use of inputs in feed crops (including pesticides, herbicides, fertilizers, irrigation) Grassland improvement, fertilization, higher stocking rates Mechanization	Intensive systems in developed countries that do not have nutrient recapture and recycling systems, and where animals spend time on pasture.	Output oriented (yield) Input oriented (inputs/area) Stocking rate
Landscape simplification	Composition (loss of semi natural habitats and habitat diversity) Configuration (loss of connectivity)	Different meaning in grasslands which are historically homogeneous at landscape scale but can be heterogeneous at smaller scale (e.g. species diversity, heterogeneity in the vegetation structure)	Percentage of semi natural habitats Habitat diversity (e.g. Shannon index) Spatial configuration indicators
2. Pollution			
Nutrient pollution	Soil and water pollution (acidification and eutrophication)	Heavily fertilized feed crops Livestock concentration (in intensive systems) can increase the risk of nutrient pollution if the system does not incorporate nutrient capture and recycling technologies	Fertilization Nitrogen/Phosphorus balance Nutrients in transition in water Increase in vegetation of high nutrient status
	Atmospheric pollution		Emissions of N gases Nutrient load exceedance
Ecotoxicity	Ecotoxic products such as pesticides and veterinary products (including hormones, antibiotics, anthelmintics)	Level of intensity of the system	Number/quantity of application of pesticides Molecule concentration in the environment
3. Climate change GHG emissions	GHG emissions originating from livestock and causing climate change	Concerns all species/ systems but ruminants with low productivity have the highest emission intensities	GHG emissions in CO_2-eq Climate change itself (but does not isolate the effect of livestock)
4. Other drivers			
Over-exploitation	Mainly overfishing for livestock fishmeal	Mainly intensive pig and poultry systems	
Competition	Competition with other herbivores	Extensive systems in all regions	Intensity indicators combined with presence of wild herbivores
	Predator kill by farmers		Number of kills
Invasive species	Degradations by livestock can favour invasions	Africa, India and Australia seem more at risk than Europe and China All systems leading to degradation could increase the risk	Presence/number of invasive species Other indicators reflecting degradation
Disease emergence	Disease outbreaks in livestock spreading to wild animals	Emerging countries with newly industrial systems lacking disease control	Outbreak events Factors favouring emergence

Cont.

Table 4: *(Cont)*

Main drivers and Subcategories	Mechanisms	Relative importance among regions and systems	Examples of indicators
	Benefits		
1. Habitat change			
Habitat creation, maintenance and improvement, beneficial practices	Extensively managed livestock can maintain species-rich rangelands Livestock abandonment leads to biodiversity loss	Extensive grazing systems In all ecoregions where grassland and other rangeland types naturally occur, and in Europe because of the long history of livestock grazing	Area of rangelands, including semi natural grasslands Vegetation structure (height, biomass, amount of thatch), percent of bare ground Practices (moderate livestock density, no fertilization, water developments)
Habitat restoration	Restoration of abandoned grassland	Extensive grazing	See indicators for habitat maintenance benefit
	Restoration of degraded grassland	Extensive/rotational grazing	See indicators for the habitat degradation pressure
Landscape connectivity	Semi-natural habitats and habitat diversity maintenance Spatial connectivity maintenance Plant dispersal by mobile herds	Extensive systems with management measures favouring landscape elements/connectivity or mosaic systems containing a mixture of intensive systems and extensive systems managed for biodiversity	See indicators for the landscape simplification pressure Enhancement of wildlife/ biodiversity corridors
2. Pollution Nutrient cycling	Nutrient supply from livestock dung/urine Excess nutrients removed from ecosystems	Extensive systems	Amount of inorganic fertilizer spared Animal excreta
3. Climate change C sequestration	Grassland managements enhancing C sequestration in grassland	Grassland systems but management practices have a strong effect	C storage quantity Practices favouring sequestration
4. Other drivers			
Food web maintenance	Resources for scavengers Resources for arthropods (e.g. dung beetles, crane fly larvae) which in turn provide benefits to plants and birds	Extensive grazing systems	Biodiversity state indicators are more adapted
Invasive species control	Maintenance of system stability and resistance to invasions When invasive species are selectively grazed	Extensive grazing systems	See indicators for the invasive species pressure

5.2.2 Principles for application of pressure indicators to analysis of livestock impacts

Minimum requirement. As a minimum requirement, there should be at least one pressure indicator for each category of pressure/benefit in the shortlist. Within each pressure/benefit category, several indicators should be computed if more than one mechanism of impact on biodiversity has been identified.

Choice of indicators. Pressure indicators should follow the SMART properties detailed in Section 5.1. In addition, they should be derived from the scientific literature or from technical reports that are cited by the user. In the event that a user chooses to develop a new indicator, a critical discussion of the strengths and limitation of the new indicator and a comparison with existing indicators should be provided. The LEAP Biodiversity Review (Teillard *et al.*, 2016a) gives several examples of pressure indicators (summarized in Table 4). Ideally, pressure indicators should include those that affect different dimension of impact on biodiversity, e.g. habitat area, configuration, quality, benefits for different species traits, risk of invasive species.

System boundaries and off-farm pressures. As outlined in Section 5.1, a life-cycle perspective should be adopted when calculating indicators. The scope of the analysis in terms of system boundaries should at least be extended to feed cultivation, especially if this stage occurs off-farm. The qualitative hotspot analysis should also give an idea of the relative contribution of the different life cycle stages to the different pressures and benefit categories. This information should also be considered when defining the system boundaries.

Pressure indicators related to the habitat change driver should always consider both the feed that is grown on farm and the feed that is grown off-farm and imported onto the farm. Case Study 1 compares the relative impact of on-farm and off-farm feed on biodiversity on a global scale and shows a very significant contribution from off-farm feed. For instance, a simple pressure indicator of habitat change is the area of land used for feed cultivation. This pressure indicator should detail the type of feed, include both on-farm areas and off-farm areas along with their origin. Information about the geographical origin of off-farm feed (e.g. concentrates) is often not directly available but the user should try to request it if possible. However, the composition of off-farm feed is known in most cases. If more precise information is not available, country-level or regional average yields (e.g. accessible through FAOSTAT) could be used to estimate areas from the amount of the different feed components. Case Study 5 illustrates an example of this approach and compares it with on-farm indicators for two different systems that contrast in their relative use of off-farm feed.

Ideally, pressure indicators related to drivers other than habitat change should also consider the stage of off-farm feed cultivation e.g. fertilizer use or GHG emissions associated with the cultivation of off-farm crops for feed. For assessing GHG emissions associated with feed cultivation, including off-farm feed, the user can refer to the LEAP guidelines for feed. Various databases (e.g. LEAP feed database) also provide the value of GHG emissions associated with feed cultivation. It is recognized that data availability may be an important limiting factor for addressing pressures other than habitat changes associated with off-farm feed cultivation.

Off-farm impacts also correspond to pressures originating on the farm but having an impact outside of it, such as biodiversity, climate change or atmospheric and water nutrient pollution. The user should make sure that the pressure indicator computed at farm level adequately reflects these impacts occurring off-farm. Case Studies, 1, 2 and 9 shows that these off-farm impacts can be very significant and also give examples of indicators able to capture them.

The pressure-benefit gradient. It is recognized that the effects of livestock production on biodiversity can be both positive and negative (Table 4, Figure 6). The switch between pressures and benefits can depend on the region (e.g. grasslands recently converted from forest in tropical regions vs. species-rich grasslands maintained by livestock in temperate regions) or there can be a continuous gradient between negative and positive effects (e.g., within the same production system and regions, different management practices leading to either degradation or restoration). Case Study 4 shows how differences in management practices within the same livestock system can lead to either the maintenance or the degradation of farmland with high conservation value. When pressures and benefits are part of the same gradient, indicators should capture this and reflect both negative and positive effects. When pressures and benefits are not part of the same gradient, the scoping analyses should have determined whether the pressure category, the benefit category or both should be described by a specific indicator. Case Study 3 presents the interaction between historical and current farm management and biodiversity values across a range of New Zealand High Country sheep farms producing fine Merino and mid-micro wool. The Case Study illustrates how balancing the capabilities of each land type to meet the nutritional requirements of animals will maximize grazing opportunities, identify areas for resting and recovery, prevent overgrazing and maintain native species. If the balance is not right, vigorous introduced species can take over and native plant species can disappear.

Reference value. The absolute value of a pressure indicator is not necessarily very informative, and it should therefore be provided along with a reference value. In the case of pressure indicators, the "natural state" (without human activities) corresponds to an absence of pressure and is therefore not necessarily an informative reference. Three main types of references can be used, and the choice of the reference mainly depends on the goal of the study (Table 5).

Spatial and temporal scale. The user should consider the spatial and temporal scales of the ecological mechanisms linking the pressure to its impacts on biodiversity. If the pressure has a delayed effect on biodiversity (e.g. climate change, pollution), the pressure indicator should be computed as an average of the past years. An average should also be used if the level of the pressure is likely to have significantly changed in recent years.

There can also be a mismatch in scale between the area controlled by the user and the ecological mechanism underlying the pressure that is measured. The principles in Section 5.1 and the example of catchment effects on the Great Barrier Reef (Case Study 2) show how pressure indicators should reflect off-farm impacts (see also Case Study 1). Potential scale mismatches can also occur with the landscape scale processes and wildlife/livestock interactions pressure categories (Case Study 12). The most relevant scales to address these pressure categories are small to intermediate (e.g. landscape, municipal, departmental, national, regional). Although pressure indicators could be measured at farm level (e.g. tree or shrub hedges, semi-natural habitats to describe the landscape structure), their effect on biodiversity will also depend on a wider scale. In this case, if possible, the pressure indicator should be measured both within the farm (Case Study 11) and in the surrounding relevant scale. Land use planning and zoning are key aspects of biodiversity conservation that are not well captured when restricting the assessment at farm scale, even when considering off-farm impacts from a global perspective.

Limitations. The study should include a discussion of the limitations of the results. In particular, this should include discussion of how pressure indicators can underestimate the impacts on biodiversity because (i) a limited number of pressure/benefits categories are considered, (ii) a limited number of indicators is used within each pressure/benefits category.

Table 5: Type of reference for pressure indicators and associated assessment goal

Reference type	Example of goal	Case studies
Temporal reference (value at a specific type)	Repeated measure of the pressure indicator to improve the system over time	Historical and current farm management practices such as stock type, stocking rate, timing of grazing, fertilizer and seed inputs can be monitored over time to help assess pressures on indigenous grasslands (Case Study 3). See Fig. 11 for temporal trends in different groups of farmland birds.
Average system reference (average value for system, e.g. in the region)	Communicate about the relative performance of the system	In areas of the Aran Islands without livestock grazing, the species-rich vegetation reverts to species-poor scrub that shades out grassland species. This represents a negative effect on biodiversity when livestock grazing is removed (Case Study 4)
Specific system reference (value for one key system or performance level, e.g. a system performing particularly well)	Transform the system towards the best-performing examples	The case of transhumance in Spain illustrates how the reference state without livestock is more homogenous and has lower biodiversity than states under moderate livestock use (Case Study 6). The Biodiversity Intactness Index in Case Study 7 uses native grassland, including rangeland, as a reference state.
Current system with low biodiversity performance	Ensure the transition towards a better system for conservation and monitor the improvement	The case of veterinary fencing in Southern Africa (Caste Study 12) illustrates how the current state prevents transboundary diseases but has poor conservation value. An alternative is proposed to maintain the benefits for animal health while improving conservation.

Note that the different pressures may have different relative effects on biodiversity. For instance, the low value of one specific pressure indicator can ultimately have more effects on biodiversity than the high value of another pressure indicator. The results should include a qualitative discussion of how the different pressures are expected to influence the state of biodiversity itself (species vs. ecosystem level, what species in particular, see Table 6 and Part1).

5.3 STATE INDICATORS

Key principles

- *Species richness can be an important state indicator; however, where possible, state indicators should also include information that reflects the species composition and conservation value of species. (e.g. Case Studies 3, 4 and 5).*
- *In assessments that rely on species richness, care should be taken to use information on species composition to measure the occurrence and distribution of undesirable species, e.g. non-native invasive species, native invasive species, pest species, and indicators of low habitat quality. These should constitute a separate state indicator of biodiversity, and reflect a negative contribution (threat) to biodiversity (e.g. Case Studies 4 and 5).*
- *When choosing state indicators, the contribution of species or species' groups to ecosystem functions and services should be considered, e.g. pollination, carbon sequestration, hydrological services.*
- *Integrity of data collection should be ensured, including a breadth of state indicators of both negative and positive effects of livestock production*
- *Habitat area/semi-natural land cover is generally straightforward to assess, and can be an informative state indicator for farmland biodiversity*

5.3.1 General information

State indicators can be used to describe the three dimensions of biodiversity – composition, structure and function: apply across these hierarchical levels (Table 6).

5.3.2 Scoping and hotspot analysis

An important part of any biodiversity assessment is to delineate the physical boundaries of the scope of interest, which should correspond to the main geographical areas where biodiversity is influenced by the livestock system being assessed. This generally refers to the geographic scope, and includes indicators for the immediate farm(s), as well as those associated with off-farm feed production, and end impacts which extend past the livestock production boundary (see Case Studies 1, 2, 5, 9 and 12). In some systems where land use changes inter- or intra-annually, it may also be necessary to define a temporal scope as well. For example, if the use of a land parcel varies from year to year between feed for cattle and other land use types that are

Table 6: Overview of levels and dimensions of biodiversity, and potential state indicators

Level and dimension	Description	Example of indicators
Species		
Composition	Describes the identity and variety of species	Abundance (number of individuals), richness (number of species) and diversity (combining abundance and richness) Can be computed for specific groups of species, i.e. taxa (e.g. birds, arthropods, vascular plants) or groups with particular conservation value (e.g. European farmland birds, see Figure 13) Abundance/richness/diversity can be computed over time or at a specific instant only
Structure	Spatial structure in the landscape Structure in age classes	Information on age structure of the population, especially for species of high conservation value, to ensure that there are individuals of breeding age, and to ensure that progeny are being produced and surviving Vegetation height, biomass, heterogeneity
Function	Functional groups (i.e. groups of species sharing the same function)	Information on trophic level for fauna Description of functional groups for flora (e.g. legumes, grasses, herbs)
Ecosystem		
Composition	Describes the identity and variety of ecosystems	As for species, the abundance (extent), richness and diversity can also be computed at the ecosystem level, either over time or as a snapshot Can focus on ecosystems and habitats with special designations that reflect a higher level of conservation value At smaller spatial scales (e.g. farm scale), the area, type and quality of habitats/native land cover is an important state indicator Formal keys exist for different vegetation types in some parts of the world
Structure	Vegetation structure Soil structure Structure is closely related to function at the ecosystem level	Architecture of the vegetation Dominant species of trees Habitat fragmentation across landscape
Function	Ecosystem processes, functions, which may translate into ecosystem services from the human point of view	Quantification of ecosystem function or services (e.g. biomass production, pollination etc.). This quantification can be done in specific units (e.g. t ha–1 yr–1 of carbon sequestration) or monetized in order to sum the different types of ecosystem services

not related to livestock production, biodiversity indicators for livestock production should be derived from years when cattle feed is produced.

The scale of the analysis should also be detailed and defined, whether it is local, regional, global, or multi-scale. The final indicator list should consist of indicators which can be directly controlled by the user, at the scale of consideration. For example, in a farm-scale investigation, if a wetland species is a patrimonial species[2] in the region, but there is no current or historical aquatic land cover on the farm, this will lie outside the scope of the assessment.

Table 6 provides an overview of the levels and dimensions of biodiversity that can be considered in an assessment; see also the LEAP Biodiversity Review (Teillard *et al.*, 2106) for additional biodiversity indicators. With these potential indicators in mind, the user should conduct a scoping analysis to identify relevant biodiversity indicators in these categories at the scale of interest. This analysis should also include a scan of existing biodiversity survey or monitoring programmes or data, as in many cases data availability will drive indicator selection. Of the potential indicators listed in Table 6 (and these are not exhaustive), it is likely that the composition indicators will be most widely relevant.

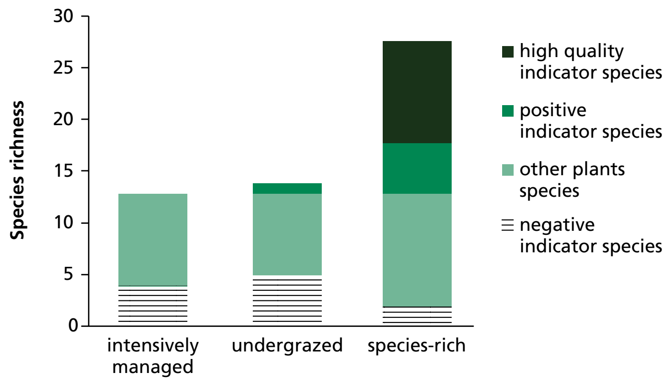
Particular attention should be paid to the ecosystem level, which was often neglected in previous assessments. Maintaining healthy ecosystems is key to ensuring their function and their ability to provide ecosystem services crucial for economic and human well-being (MEA, 2005).

At species level, the scoping analysis will also aim to determine on what taxa (group of species) the assessment should focus. For grassland or rangeland production systems, it is likely that the focus will be on plants as livestock grazing has a direct effect on the state of vegetation and on its biomass, composition and structure. Under adequate management, this direct effect on vegetation can be positive by supporting native species and species diversity (see Case Studies 4 and 11). When grazing modifies the vegetation composition and structure it modifies the habitat and affects other taxa such as grassland birds. Therefore, selecting those species for computing state indicators can also be relevant.

Some species and ecosystems are accorded higher conservation priority than others, and it is fundamental to any biodiversity assessment that these are adequately recognised. It is important, in other words, to distinguish between habitats and species that are not designated, or are not of high conservation priority, and species and habitats that are considered to be of high conservation value and of higher priority. This is not to say that native, undesignated habitats are unimportant, but simply highlights conventional recognition that not all habitats are of equal conservation value. For example, in a discussion of how a greater differentiation of farmland biodiversity can be achieved to help guide the prioritization and development of agri-environment measures, Finn & Ó hUallacháin (2012) described broad categories of farmland wildlife and habitats that varied from highest to lower levels of conservation value. These different categories represented a broad spectrum of conservation value of species and habitats (which are not necessarily mutually exclusive), as follows:

[2] Pervanchon (2004) proposed a definition of a patrimonial species which covers the concepts of both flagship and threatened species. A patrimonial species is "a rare or threatened species which needs local management and which may be a flagship species and may have cultural importance".

Figure 12
Example of the impact of intensive management and undergrazing on the species richness and nature conservation value of calcareous species-rich grasslands on the Aran Islands. The 'high-quality indicator species' include orchids and other plant species that are rare on an Irish and European scale. Data from 2m x 2m quadrat samples.
See Case Study 4 for details



- protection (including restoration) of priority habitats/species on Natura 2000 sites;
- protection of priority habitats/species that occur outside of Natura 2000 sites;
- protection of rare and threatened species (e.g. those associated with Red Data Lists, Species Action Plans, Flora Protection Orders etc.);
- protection of other species and habitats (neither rare nor threatened) of high conservation value;
- protection of species that are declining, but are not yet rare;
- protection of other common farmland habitats and species;
- creation of farmland habitat to support named species;
- creation of common farmland habitats.

Although this specific list was developed in Ireland, and strongly reflects conservation values derived from European conservation policy and designations, a primary lesson is that the nature and extent of wildlife designations can be used to infer greater or lesser conservation value.

Case Study 4 provides an example of assessment of high-conservation-status species and ecosystem state indicators: for example, number of species and habitats on national and European priority list (Figure 12). Importantly, the scoping analysis should go beyond conservation status. The lack of a designated conservation status should not be used to conclude that there is less need for biodiversity management, e.g. two areas of species-rich grassland may have the same species composition, but one may be designated and the other may not.

To identify threatened species and ecosystems in the area of interest, global sources of potential indicators should be scanned, for example the IUCN Red List of Threatened Species, the IUCN Red List of Threatened Ecosystems and the Living Planet Index (see also Section 3.2). The scoping analysis should also review corresponding lists compiled at the regional or local scale, such as national or sub-national endangered species frameworks. Due to elevated conservation value, a greater amount of data is also likely to be available concerning these species at the national or sub-national scale.

Local sources of knowledge will likely have to be utilized for identification of other potential species of interest such as culturally important (patrimonial) species and ecologically important (keystone, umbrella) ones. Potential sources of information include local extension documents as well as regionally relevant research. See Case Study 5 for an example of research which has produced a tool that can be used to guide assessment of state indicators, specifically ecosystem composition. Other indicators, such as functional groups, are descriptive in nature and as such require less guidance.

5.3.3 Principles

Indicator selection. From the indicators identified in the scoping analysis, the user will choose those to be included in the assessment. The user should specify which aspects of biodiversity the chosen indicators correspond to, both in terms of level (genetic[3], species, ecosystems) and dimension (composition, structure, function). Note that information on intermediate levels of biodiversity, such as community or population, can also be included. Most assessments will focus on the composition level for species and ecosystems as the most basic and pertinent level of information. However, the assessment can acquire further information if resources or data exist to survey the additional components. The indicators chosen can be influenced by the objectives of the assessment. For example, if the assessment was motivated by the goal of maintaining native land cover, the indicators can focus on this aspect. Case Study 10 provides an example of application of state indicators to specific objectives, in this case to use management practices to stabilize sand dunes in Botswana. The state indicators included: area of bare sand dunes, and percent of land area covered in thorn bush and poor-quality grazing grasses.

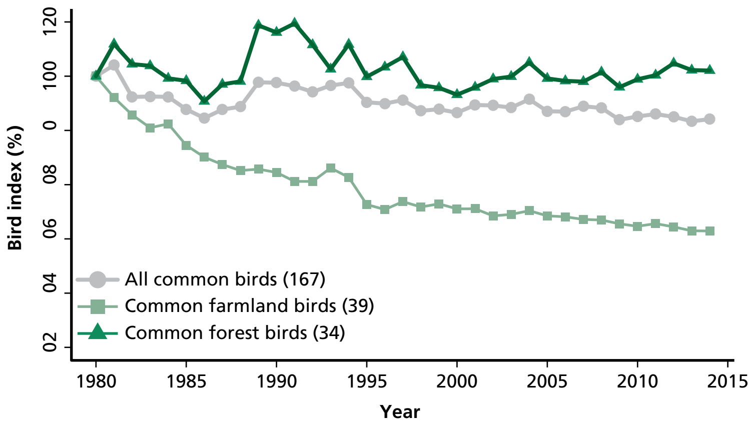
Minimum guidelines. Ideally, indicators that reflect both species and ecosystem composition should be included. Information should be comprehensive rather than redundant – i.e. species-level indicators should encompass varying taxa levels, and indicators should be chosen that are not known to be congruent in their response to livestock pressures on biodiversity. In Case Study 7, a wide range of state indicators are surveyed, including richness and abundance of vascular plant, lichen, moss, mite, mammal and bird species, comparable information for ecosystems, and a composite Range Health indicator. Case Study 2 provides another example of a broad, complementary suite of state indicators, including area and connectivity of reserves, density of invasive animals and plants, fire regime, and area protected from invasive predators. Further, species that are known to be sensitive to livestock pressures should be included preferentially. For example, species that are known to increase or decrease with grazing would be valuable components of a biodiversity assessment in rangeland (Case Studies 3, 4, and 6).

Different types of species can be monitored, such as common or rare species, or generalist or specialist species. Rare species have a higher conservation value and their maintenance typically requires specific attention while common species make a higher contribution to the overall ecosystem function, and their wide distribution

[3] This document does not cover the genetic level of biodiversity

Figure 13

Wild bird index for 27 European countries, with separate indicators for common farmland, common forest and common bird species. Numbers in parentheses show the number of species in each indicator. This index uses 1980 as a reference year (value = 100)



Source: European Bird Census Council, http://www.ebcc.info/index.php?ID=613

allows one to calculate large-scale biodiversity trends; both type of species are therefore relevant to monitoring programmes. Specialist species may be more important to monitor than generalist species because generalists are less sensitive or even benefit from disturbance (see Case Studies 4 and 5). Indeed, human disturbance may cause biotic homogenization, where a few generalist species replace many specialist species.

Considerations. Data sources should be appropriate to the scale of interest. For example, if discussing species composition at the local level, data should be derived from local field studies, rather than extrapolated from similar habitat in the region. For other indicators, local information may not exist, but proxy from similar habitats might be used. The ramifications of these decisions should be discussed as study limitations.

Methods should also be appropriate to the scale. For example, locally developed ecosystem health measures are appropriate at local scale, but not at global scale. An example of this would be the Range Health Index described in Case Study 7, which would not be directly applicable in other locations.

Robust data may not exist for a suite of indicators, or at multiple scales. When deciding whether to include or omit data, err on the side of inclusivity. However, data of poor or unknown quality should be flagged as qualitative or exploratory.

Reference conditions. A reference state for biodiversity should be established, where possible. For example, a specific livestock system may support five bird species, and there is value in knowing the extent to which this level of bird diversity changes over time. Without information on how this level compares to a reference state, however, (e.g. the number and types of bird species on an area of native land cover, or representative wildlife habitat), the interpretation of such information is more limited. Either quantitative or qualitative information on a reference state can help set objectives and track progress. Reference conditions are especially important for index indicators such as species richness. Care needs to be taken when using these composite indices as important information may be lost in aggregation. For example, invasive species may contribute to a measure of species diversity, but they contribute negatively to diversity when viewed in the context of a reference area, and should be interpreted as such (see use of negative indicator species in Case Study 4).

Reference conditions will further vary according to historical and geographical context. For example, in Europe reference conditions may be based on culturally important habitats and semi-natural habitats shaped by historical human activities. But historical reference conditions may be ecologically unfeasible and not provide a desirable and sustainable outcome. Increasingly, conservation land managers in the western United States are using ecological sites as a reference. They are defined as a distinct kind of land with specific soil and physical characteristics that differ from other kinds of land being able to produce a specific type and amount of vegetation and to respond similarly to management actions and natural disturbances. In this context, care should be taken to include both negative and positive impacts of livestock production on biodiversity. For further information, see also Section 6.4.

When possible, enumeration-type indicators should be accompanied by further information on condition. For example, information on species richness can be combined with data on species population trends to provide insight on condition (See Figure 13). Case Study 8 provides an example of comprehensive monitoring of wildlife as a state indicator. In this case study, wildlife and livestock density were monitored for over 40 years in both pastoral and protected areas. Similarly, beyond a survey of ecosystem services provided by the ecosystems of interest, how does the provision of the services compare to what is expected of a healthy ecosystem? Case Study 5 provides an example of quantification of ecosystem services, by combining information on biodiversity state with information on the effect of management practices for individual grassland typologies.

Monitoring. Monitoring typically involves surveying over time with the intention of collecting data to assess the extent to which a quantitative management objective is being achieved (Case Study 7 and 8 show the need for long-term monitoring of biodiversity in many ecoregions of the world). It is likely that monitoring for biodiversity purposes will include a number of indicators that reflect appropriate biodiversity goals. (The assessment of appropriateness is partly addressed in Section 5.2.1 on scoping and hotspot analysis.) Note that many monitoring programmes for biodiversity have clearly defined target levels for species richness, species abundance, species composition, as well as numbers and abundances of species that are designated and/or are of high conservation value (see the various case studies). Some programmes can also indicate threshold values of indicators that trigger corrective actions if the thresholds are crossed (see use of negative indicator species in Case Study 4).

Components such as species population size will vary over time due to influences independent of livestock production. There should be a consideration of what these influences are, how to account for them, and whether thresholds can be identified.

Discussing limitations. Discussion of the limitations should include ramifications of the selected indicators. For example, there may be poor data availability for the most sensitive species and thus the state of biodiversity may be overestimated. If not all scales have been included in the analysis, discuss the ramifications of omitting certain scales. For example, if the assessment is conducted at a regional scale, biodiversity may vary considerably and be at risk at the local scales comprising the region.

Links to other indicators. If the monitoring results from state indicators suggest mitigating actions are necessary, then information from pressure or response indicators can be used to guide and target the mitigating actions. Responses may include species recovery or ecosystem conservation/rehabilitation programmes. Combining response and state indicators makes it possible to monitor how actions lead to the expected biodiversity goals.

Using state indicators to derive LCIA characterization factors. State indicators may be used to derive characterization factors for LCIA methods. Several elements should be considered. LCIA methods generally strive for a broad geographical scope. State indicators computed at a very local scale may not be adapted to derive characterization factors. However, a quantitative meta-analysis of such local studies to compute an average-size effect would be a way to broaden the geographical scope and to derive characterization factors. Another approach would be to use data on the state of biodiversity already available on a large scale (e.g. on birds in Europe, Figure 13). In any case, the state indicators would have to be clearly linked to a midpoint impact category and use a defined LCIA framework. For land use, this LCIA framework should be the one detailed in Section 4.2. A standardized classification for land use and biogeographical differentiation (e.g. as in Koellner *et al*., 2013b) should also be used in order to ensure the generality of the characterization factors. Finally, careful attention should be paid to the choice of the reference state as it will have a strong influence on the results of the assessment and their interpretation. Section 6.4 describes different options for this reference state and includes a discussion of which reference is better adapted in the context of livestock production.

5.4 RESPONSE INDICATORS

Key principles

- *Response indicators should be based on scientifically sound and verifiable evidence that details a clear link between adoption of the response indicator and the expected biodiversity outcome.*
- *Response indicators may be general, e.g. whether a biodiversity action plan is in place, or more specific e.g. the level of expenditure on conservation of native grasslands or the decision to preserve an endangered species. Such specific indicators are determined by the scoping review and hotspot analysis.*

5.4.1 Scoping and hotspot analysis

Response indicators describe the decisions and actions that can be undertaken by stakeholders to mitigate pressures and improve the state of biodiversity. The stakeholders will vary with the scale and the farming system and may include policy makers, sustainability managers and farmers/livestock managers (users). Decisions and actions cover laws, incentives, certifications, biodiversity management plans or practices. A strength of response indicators is that they can describe decisions and actions that target improvement in both pressure indicators and state indicators.

Scoping review. The purpose of the scoping review is to identify the most important drivers of biodiversity change in the area under consideration. The main drivers of biodiversity change are outlined in Figure 6 and include habitat change, nutrient pollution, over-exploitation, climate change and invasive species. The boundary should include habitat areas adjacent to, or potentially impacted by the livestock operation, for example waterways and wildlife corridors. The biodiversity impacts of off-farm feed production should also be included within the boundary.

Hotspot analysis. Qualitative hotspot analysis identifies the relative importance of the different drivers of biodiversity change, and should prioritize those drivers that can be controlled or influenced by the land manager (or user). Categories or drivers under the control of the land manager are not confined to the selected area but include pressures that impact surrounding or connected areas. For example, an extensive grazing system may exert very low nutrient pressure in its own area but may exert greater nutrient pressure on aquatic biodiversity in adjacent water ways through nutrient and sediment runoff (Case Study 2). When conducting hotspot analysis, particular attention should be paid to pressures potentially affecting protected areas and species.

An example of using hotspot analysis to identify the most critical driver is provided in Case Study 4. In this example the driver of biodiversity change is traditional livestock grazing, and removal of livestock reduces biodiversity, whereas in other areas removal of livestock can enhance biodiversity (e.g. in semi-arid areas or in landscapes with a short grazing history: Milchunas *et al.*, 1988). For a fully housed, intensive livestock enterprise with full nutrient capture and water recycling, the critical drivers for biodiversity change are likely to be located where feed is sourced and produced.

5.4.2 Principles

Minimal requirement. Response indicators should be based on scientifically sound, verifiable evidence detailing a clear link between adoption of the response indicator and the expected biodiversity outcome. There is a significant body of research available to aid the identification of context-relevant response indicators for livestock systems in Europe, North America and Oceania. In regions where these data may be lacking, or have significant gaps, selection of response indicators should be informed by an adaptive, outcome-based management approach founded on regular monitoring of changes in pressure and state indicators in response to actions taken by stakeholders.

Indicator selection. Selection of effective response indicators requires a good understanding of (i) the baseline conditions and (ii) the drivers of biodiversity change, both positive and negative.

Baseline conditions. When selecting response indicators, the baseline condition encompasses more than just the current state of biodiversity. As response indicators reflect actions and decisions implemented by stakeholders, an understanding of the social, cultural and economic and biophysical assets is also required. For example, a key economic barrier is security of land tenure; nomadic graziers with no land tenure have limited potential to implement biodiversity response indicators, in contrast to corporate-owned, intensive livestock systems.

An understanding of the effectiveness of existing biodiversity regulations and policies is essential when prioritizing non-regulated response indicators in comparison to regulated response indicators. Although many countries have regulated biodiversity response indicators (such as banning deforestation and protection of threatened species habitat), they are not always effectively implemented. Some countries may have minimal regulation but have effective stakeholder-initiated programmes e.g. Dairying for Tomorrow (Australia), and increased recognition of the value of permanent grasslands for providing ecosystem services (Case Study 5, France).

The level of biodiversity management knowledge and skills among livestock enterprise managers and their advisers is also an important consideration as is access to biodiversity education programmes and financial support to help implement biodiversity response actions.

Drivers of biodiversity change. At the farm scale, the most important drivers can either be listed/organized based on Figure 6, or based on the framework for Good Agricultural Practices (GAP) formalized by the FAO Committee on Agriculture in 2003 (http://www.fao.org/docrep/meeting/006/y8704e.htm).

5.4.3 Farm-scale response indictors

These are actions or management practices implemented on the farm to limit its negative effects on biodiversity, for example minimizing the impact of operations such as tillage and agrochemical use on wildlife; establishing protected areas on river banks and around ponds to reduce the runoff of agrochemicals and of erosion, which can cause sediment loads in waterways and coastal lagoons; prohibiting wildlife habitat destruction and hunting; and controlling weed and animal pest invasions. Depending on the system, farm-scale planning as part of sustainability initiatives can also pose questions regarding the existence of actions on the farm to: promote biodiversity-friendly practices such as planting of wildlife/connectivity corridors; preserve field margins that constitute habitats for insects providing pest control and pollination; promote different cropping patterns, and; reduce invasive and predatory species. Selected farm response indicators may include both qualitative and quantitative indicators. Qualitative response indicators may include: developing a biodiversity action plan; existence of (counter-active) compensation for wildlife habitat destruction, or; participation in industry and/or public community biodiversity initiatives, including biodiversity education programmes. Examples of quantitative indicators include the proportion of farm area managed according to biodiversity-friendly practices; metres of riparian zone fenced to exclude livestock; trends in measures such as species numbers; ground cover or reduction in animal pests as identified in monitoring activities.

In summary, farm-scale response indicators must:

- respect FAO's Good Agricultural Practice Framework or any equivalent recommendations:
- be consistent with proposed pressure and state indicators;
- be supported by education actions conducted on the farm or with the community to inform people about local biodiversity, preservation priorities, and the effects of agricultural practices and landscape features on biodiversity, and;
- aim to overcome the financial barriers to adoption of biodiversity-friendly practices. For instance, in Colombia a recent rural capital incentive aims to promote the planting of trees. As it does not depend on farm size or farmer's capital, this incentive is available to all farmers (Murgeitio *et al*., 2011). More globally, the amount of funding for sustainable development can be seen as a response indicator.

Education actions can be included as response indicators (i.e. *Agricultural education and extension*, and *Agricultural research intensity ratio*) in the UN working list of sustainable development indicators (UN, 1996) together with more classical indicators based on land use and percentage of protected areas. In the UN (2001) core indicators, the response indicator associated with biodiversity preservation was also the *Extent of protected area as a percent of total area*. It focussed on ecosystem preservation and combined with two state indicators: *Area of selected key ecosystems* and *Abundance of selected key species*. Interestingly, it also combined with institutional response indicators – National sustainable development strategy, Implementation of ratified global agreements, and Expenditure on Research and Development as a percent of Gross Domestic Product.

5.4.4 Sector Response Indicators

Sector-specific biodiversity response indicators are developed by livestock-sector organizations, corporate sustainability consortia (e.g. Sustainable Agricultural Initiative - SAI Platform, Global Roundtable for Sustainable Beef[4]) and other initiatives (e.g. Unilever Sustainable Agriculture Code, Dairy Implementation Guide,[5] SAI Platform Farmer Self-Assessment 2.0).

Biodiversity response indicators developed by the sector tend to be qualitative as opposed to quantitative, to allow for multiple regional approaches to achieving biodiversity outcomes. The rationale is that the broad range of ecosystems in which livestock production occurs makes it unrealistic to develop a 'one-size-fits-all' global standard for pressure and state indicators. The majority of sector sustainability guidelines recommend the development of a farm- or enterprise-scale Biodiversity Action Plan as a key response indicator. For example, the Global Roundtable for Sustainable Beef considers context-specific elements, including metrics, that are only applicable in a narrow range of environments and systems and therefore need to be developed at the regional or local level.

Some examples of sector initiatives and response indicators are included here, but there are many others.

SAI Platform Farmer Self-Assessment 2.0

The Sustainable Agriculture Initiative (SAI) Platform is a global food industry initiative for sustainable agriculture (http://www.saiplatform.org/). SAI Platform is involved in developing tools and guidance to support global and local sustainable sourcing and agriculture practices. One of these tools is the Farm Sustainability Assessment, which assesses environmental, social and economic aspects on individual farms. The biodiversity questions in the Farm Sustainability Assessment (FSA 2.0) of the SAI Platform can be found at (http://www.fsatool.com/). Questions are classified as Essential, Basic, or Advanced, e.g.:

[4] http://grsbeef.org
[5] http://www.growingforthefuture.com/unileverimpguid/

FSA 63: Have you assessed biodiversity and identified priority actions to preserve biodiversity on your farm? (Basic)

An assessment includes:

1. Identification of on-farm rare and endangered species (plant and animal)
2. Identification of priority actions that promote biodiversity on farm
3. Take part in a biodiversity plan at landscape level if available and practical.

FSA 64: Do you have a biodiversity plan for your farm to maintain or improve biodiversity? (Advanced)

This biodiversity plan is reviewed annually, and if available and practical, is part of a biodiversity plan at landscape level.

Guidance: Farmers are encouraged to have a biodiversity action plan for their farm which includes:

- A map of the location of areas or features important to biodiversity on and around the farm.
- Details of how provision is made for wildlife habitats and food sources through hedges, field margins, extensive pasture, etc.
- Measures to avoid degradation and deforestation of High Conservation Value Areas (HCV) areas or other ecologically sensitive areas.
- Assessment of possible disruption of biological corridors because of farm activities and if required, based on the assessment mitigation measures.

This plan can be managed at landscape or group level and the review can be made by public or private bodies.

FSA 65: Have you left all primary forest, wetland, peatland, and protected grassland or other native eco-systems in its original condition within the last 5 years? (Essential)

This includes ensuring that no practices were used that could weaken or destroy primary forest, wetland, peatland, grassland or other native eco-systems. This question can only be not applicable if you did not have primary forest, wetland, peatland, grassland or other native eco-systems at your farm.

FSA 66: If you have deforested secondary forest or cleared grassland, did you ensure that you have acted legally and that you have the right permits? (Basic)

This includes all of the below:

1. Legal land title is available
2. The land is classified as agricultural and/or approved for agricultural use
3. Government permits are available (if required by law)

FSA 67: Do you practice habitat restoration and do you compensate for areas on your farm that have been prone to habitat/ biodiversity loss? (Advanced)

FSA 68: If you work next to or in protected areas, do you work with legal permits and ensure that your activities do not harm the ecosystem? (Basic)

Global Roundtable for Sustainable Beef

The Global Roundtable for Sustainable Beef (GRSB, http://grsbeef.org) is a multi-stakeholder initiative with broad beef industry, NGO and consumer representation. In late 2014, the GRSB published a set of high-level principles and criteria defining sustainability across the global beef value chain. Some of the criteria most relevant to biodiversity are listed here:

3. Environmental stewardship objectives are attained through adaptive management, with activities monitored to achieve continuous improvement of measurable natural resource management outcomes.

4. Native forests are protected from deforestation. Grasslands, other native ecosystems, and high-conservation-value areas are protected from land conversion and degradation.
5. Land management practices conserve and enhance the health of ecosystems and high- conservation-value areas throughout all sectors of the beef value chain.
6. Water resources (including quality and quantity attributes), are responsibly and efficiently managed to support ecological function and availability.
7. Soil health is maintained or improved through implementation of appropriate management practices.
8. The beef value chain contributes to the maintenance or enhancement of native plant and animal biological diversity.
9. Where available, feed sources are sustainably-produced.

Tropical Forest Alliance 2020

TFA (TFA 2020) is a public-private partnership in which partners take voluntary actions, individually and in combination, to reduce the tropical deforestation associated with the sourcing of commodities such as palm oil, soy, beef, and paper and pulp. It does so by tackling the drivers of tropical deforestation, using a range of market, policy, and communications approaches (for more information visit www.tfa2020.com). TFA 2020 is engaging with governments around the world, with civil society organizations active in both producer and consumer nations, and with multinational corporations.

Field to Market: The Alliance for Sustainable Agriculture

The Habitat Potential Index (HPI) for Biodiversity explores the potential impact of agricultural land use on habitat quality and quantity of production and non-production lands. It offers a qualitative estimate of the potential of a farm to provide habitat for biodiversity. Biodiversity under the HPI includes a variety of native species and ecosystems that may be found on or near the farm – for example, plants, invertebrates (such as pollinators and other insects), birds, mammals, reptiles and amphibians, or fish. The HPI considers current land cover types present at the farm scale – including production lands and non-production lands – as well as the producer's management activities (response indicators) for each land cover type. Land cover types included in the HPI are crop production areas, forest, grasslands and savannahs, wetlands, surface waters, and edge-of-field areas such as buffer strips. The approach is intended to promote practical protection and enhancement of existing on-farm habitat attributes, as opposed to the conversion of production areas back to pre-agricultural conditions. The HPI approach emphasizes the ecological benefits afforded by effective stewardship of non-agricultural and agricultural land cover types. By design, best management practices and sound environmental stewardship incorporate relevant ecosystem services, including biodiversity[6].

Here, we provide some examples of national and international quantitative response indicators taken from selected initiatives:

[6] https://www.fieldtomarket.org/fieldprint-calculator/

Seamless[7]

- protected area as a percentage of total land area;
- existence of national biodiversity regulations or guidelines;
- expenditure on biodiversity research in livestock systems;
- expenditure on agro-environmental education and extension relevant to biodiversity;
- amount of new or additional funding for sustainable development;
- technical cooperation grants;
- share of area under agro-environmental support.

Environmental Sustainability Index[8]

- percentage of country's territory in threatened ecoregions;
- threatened bird species as percentage of known breeding bird species in each country;
- threatened mammal species as percentage of known mammal species in each country;
- threatened amphibian species as percentage of known amphibian species in each country.

Eurostat list of Sustainable Development Indicators

- Level II: share of production from enterprises with a formal sustainable management system;
- Level II: enterprises with an environmental management system;
- Level III: eco-label awards, by country and by product group;
- Level II: land use change, by category;
- Level II: exceedance of critical loads of acidifying substances and nitrogen in nitrogen-sensitive areas.

5.4.5 Considerations

Response indicators may be general, for example the development of a Biodiversity Action Plan, or they may be more specific as determined by the scoping review or hotspot analysis. The decision to use more general response indicators as opposed to specific indicators will depend on the goal. If the goal is continuous improvement through the adoption of good practices, then a Biodiversity Action Plan is an appropriate response indicator.

Many sectoral sustainability tools and guidelines include biodiversity management as a component of a whole farm/enterprise sustainability assessment. This approach can make prioritization of biodiversity issues over other sustainability issues difficult from the perspective of an individual enterprise. There are some sector-specific biodiversity guidelines and these may be a more useful resource for identifying appropriate response indicators (see Table 7 for examples from Australia).

The potential impact of climate change on the effectiveness of response indicators over time should be considered when selecting response indicators. Some major livestock producing regions are already experiencing increased climate variability and climate extremes as documented in the IPCC Assessment Report: Climate Change 2014:

7 p. 105, http://ageconsearch.umn.edu/bitstream/57937/2/Report_49_PD2.2.1.pdf
8 http://envirocenter.yale.edu/programs/environmental-performance-management/environmental-sustainability-index

Impacts, Adaptation, and Vulnerability- Summary for policy makers https://ipcc-wg2.gov/AR5/images/uploads/IPCC_WG2AR5_SPM_Approved.pdf.

Possible climate change considerations when prioritizing response indicators are: *Will the response management practices be appropriate in 30 years' time, based on IPCC regional climate change predictions?* and, *Is the management practice likely to assist or hinder the target species/habitat to adapt to climate change*?

Resources to assess potential climate change impacts on biodiversity for many key livestock producing regions are available from the Convention on Biological Diversity website, http://adaptation.cbd.int/. National and local-level resources are also available, one example being *Climate Change Adaptation Plan for Australian Birds*, (Garnett & Franklin, 2014).

Monitoring. Response indicators are the decisions and actions taken by stakeholders to improve biodiversity. Where a scientifically validated link between adoption of the response indicator and the expected improvement in pressure and /or state indicators is known, monitoring of actions as opposed to monitoring of species and resource condition is appropriate. Where clear links do not exist, an adaptive management approach based on regular monitoring should be implemented, e.g. monitor changes in species and/or resource condition in response to the implementation of decisions and actions taken by stakeholders. Stakeholder actions can then be altered if they are not achieving the desired goal.

Monitoring of species and resource conditions can be expensive and impractical. In this situation selection of response indicators should be biased towards indicators where clear links between actions and biodiversity impacts are well validated. Emerging sensor and satellite technologies will likely enable cost-effective monitoring of response decisions and actions in the near future.

Limitations. A key role of response indicators is to monitor progress, both in pressure indicators and state indicators. Effective implementation of response indicators is generally dependent on the capacity of the livestock manager (or user) to monitor the effectiveness of their actions over time and adapt where necessary. Where appropriate management capacity is lacking, additional support for training and education may be required. Alternatively, other interested stakeholders may take on the responsibility for monitoring progress and providing advice on appropriate response actions. These stakeholders may include policy makers, conservation agencies, industry associations and private corporations.

General response indicators, such as biodiversity action plans, will be limited in their capacity to monitor progress against specific pressure and response indicators, e.g. the destruction of habitat supporting a red list species. In such a situation, a more specific response indicator may be appropriate.

Table 7: Recommended biodiversity management practices for the Australian dairy industry. (Australian Dairy Industry Biodiversity Action Plan template)

Improving aquatic biodiversity	Habitat restoration	Building ecosystem resilience	Building skills and capacity to manage biodiversity
Waterways (riparian zones) protected from nutrient runoff and stock access through fencing, buffer strips and off-stream watering points Groundcover maintained at 70 percent or higher Fert$mart[1] plan used to inform fertiliser application Precision irrigation technologies implemented (e.g. automation)	Remnant vegetation protected through fencing and removal of invasive (pest) species Riparian zones replanted with appropriate native species Connectivity corridors established between remnants where feasible Vegetative wind and shelter breaks established around pasture Locally threatened species have their habitat established/protected	Soil fertility enhanced through Fert$mart planning, conservation tillage, and precision irrigation. Fire- and climate- resilient species included in revegetation plantings	Participation in biodiversity stewardship programmes (e.g. 20 Million Trees)[2] Member of a local Landcare/industry NRM group[3] Species list of farm native flora and fauna maintained Experience and knowledge of local biodiversity issues and management

[1] http://fertsmart.dairyingfortomorrow.com.au/.

[2] http://www.nrm.gov.au/national/20-million-trees.

[3] Natural Resource Management group: http://nrmregionsaustralia.com.au/w.

PART 4

FUTURE DIRECTIONS

6. Future challenges for improved biodiversity assessment in LCA and its application to livestock production

Key principles

Examples of completed, quantitative Life Cycle Assessment in livestock systems are needed to provide both further guidance and examples for developing and critiquing the state of the art in LCA for biodiversity. In particular, there is a need for:

- *development of local characterization factors for different livestock systems;*
- *inclusion and recognition of positive and negative impacts;*
- *incorporation of impacts on landscape-scale processes;*
- *the inclusion of several different midpoint impacts, e.g. the biodiversity impacts of acidification and eutrophication covering a large geographic area, as well as land use impacts;*
- *improvement of the assessment of ecosystem services in LCA;*
- *methods and examples of characterization for a wide variety of taxa and of the use of weighting approaches to recognise the differences in conservation value of habitats and species, (e.g. IUCN designation).*

The development of LCA methodologies for biodiversity has clearly undergone rapid and sustained development since about 2000, and considerable progress has been achieved.

A specific limitation to date is the lack of application of such methods to livestock systems. Nevertheless, there are some examples of LCA for biodiversity from other systems that may serve to inform how LCA could be implemented in livestock systems. Some of these are described in the LEAP Biodiversity Review (Teillard *et al.*, 2016a).

Some methodological challenges remain, with some of the main ones presented here. A number of these challenges should be a priority in order to make LCA more adapted to livestock production. They include the need for:

- development of local characterization factors for different livestock systems (e.g. intensive, mixed, extensive, pastoralism);
- inclusion of a number of midpoint impacts, e.g. the biodiversity impacts of land use, nutrient pollution, acidification and eutrophication;
- further clarification of reference state and more guidance on how to make it operational. At the very least, the consequences deriving from the specific choice of reference need to be clearly explained. The choice of the reference state has key consequences on whether or not the LCA approach allows consideration of the positive effects of livestock production on biodiversity. Failing to consider such positive aspects is a weakness shown by some current LCA methods in their application to the livestock sector.

Other developments are needed to make LCA methodologies more ecologically relevant:

- improved inclusion and assessment of ecosystem services in LCA;
- improved inclusion of landscape-scale and spatial processes;
- methods and examples of the use of weighting approaches to recognise the differences in conservation value of habitats and species, e.g. IUCN designation.

Several of these challenges are discussed in more details in the next subsections.

6.1 INCLUSION OF SEVERAL MIDPOINT IMPACTS ON BIODIVERSITY

The highest level of methodological development and consensus for including biodiversity impacts in LCA concerns impacts through land use. However, livestock production affects biodiversity through other midpoint impact categories. Further methodological developments will be needed to include these other categories of biodiversity impacts. For instance, climate change is the second most important driver of biodiversity loss after habitat change and it is increasingly influential. Livestock production has a significant impact on climate change – Gerber *et al.* (2013) estimated that GHG emissions related to livestock production represented 14.5 percent of human-induced emissions. To date, a single operational method exists to assess the impact of GHG emissions and climate change on biodiversity in LCA (de Shryver *et al.*, 2009). A single global method also exists for assessing the impact of the use of water (Pfister *et al.*, 2009), which is another resource extensively used by livestock (e.g. 112 m^3 of water is necessary to produce 1kg of beef protein as estimated by Mekonnen & Hoekstra, 2012). Accounting for the impact of acidification and eutrophication on biodiversity would also be very important in the context of livestock production. First, because some livestock systems cause significant nutrient concentrations that can give rise to pollution, which contributes to these midpoint impacts, and also because this contribution varies greatly between production systems. Secondly, because considering eutrophication is key in accounting for impact on aquatic biodiversity while the other midpoint categories tend to focus on terrestrial biodiversity. A few characterization factors are available to link acidification and eutrophication to species richness, both at the regional level (Van Zelm *et al.*, 2007, for acidification in Europe; Struijs *et al.*, 2011 for eutrophication in the Netherlands), and at global scales (Azevedo, *et al.*, 2013a; Azevedo, *et al.*, 2013b; Azevedo, *et al.*, 2013c). Accurate and broadly agreed methods to address the impacts of other midpoint categories on biodiversity are needed to avoid underestimating the total impact of livestock on biodiversity (see Section 7.4) and to ensure that the relative impacts of different livestock systems are reflected accurately.

6.2 BIODIVERSITY REPRESENTATION

6.2.1 Cross-representation of taxonomic groups

The assumption that vascular plant diversity is reasonably well correlated with other terrestrial species (Weidema & Lindeijer, 2001), together with their data availability, has generally resulted in vascular plants being chosen as representative biodiversity indicators for other taxonomic groups. However, other studies question the extent to which vascular plants can serve as a predictor for all other groups (Souza *et al.*, 2015). Recent studies include other taxonomic groups such as arthropods, other invertebrates and vertebrates (de Baan *et al.*, 2013a) mammals, birds, amphibians and reptiles (de Baan *et al.*, 2013b). Elshout *et al.* (2014) recommended that species of multiple groups should be included whenever possible. Vascular plants and arthropods should at least be well represented for agricultural studies.

6.2.2 Inclusion of ecosystem services

The activities of species in ecosystems result in the provision of services that can be environmentally, socially and economically important. Such services include soil fertility, production of food and fibre, nutrient cycling, supply of freshwater of sufficient quality, erosion control, pollution attenuation and degradation, pollination, pest and disease control, and many others including biodiversity conservation, and cultural or spiritual values associated with ecosystems. There is increased scientific understanding about how biodiversity regulates the delivery of ecosystem services, and there is considerable concern about the knock-on effects of biodiversity loss on their delivery. Given the importance of these services to human welfare and to the integrity of many livestock systems, LCA methods will be increasingly challenged to develop methodologies to account for impact on ecosystem services. In the context of livestock, these methodologies should be able to consider the range of positive and negative impacts of livestock systems on ecosystem services.

6.3 LAND USE REPRESENTATION

6.3.1 Land use cover and geographic scope

Existing LCA methods describe land use through relatively coarse categories, which makes LCA more adapted to assessments at intermediate to large spatial scales. For small-scale assessments aimed at discriminating the relative impact of different practices on biodiversity, methods are likely to need further adaptation and development. For instance, within one coarse land use class such as rangelands, methods should be able to differentiate between various land use intensity levels and vegetation compositions/structures.

In terms of land use cover and geographic scope, the approach developed by Koellner *et al*. (2013b) consists of four levels of detail ranging from very general global land cover classes to more refined categories and very specific categories indicating land use intensities. Regionalisation is built on five levels, first distinguishing between terrestrial, freshwater, and marine biomes and further specifying climatic regions, specific biomes, eco-regions and finally indicating the exact geo-referenced information of land use. Unfortunately, there are not yet characterization factors for every scenario, but this seems a promising approach to advance their development.

6.3.2 Incorporation of landscape-scale processes

A limitation of LCA for biodiversity is that it may underestimate biodiversity impacts through low ability to measure the disruption of landscape-scale processes that support species' populations. Land use occupation can not only alter the species richness in the local area that is occupied, but may also have impacts across the wider region. These different scales of damage are known as local and regional. The local damage describes the change in species richness on the occupied area compared with the species richness on the baseline state of land use. The regional damage describes the species change in the surrounding area (de Schryver *et al*., 2009).

6.4 REFERENCE STATES FOR BIODIVERSITY

6.4.1 Choice of reference state in LCAs for biodiversity

As mentioned above, the use of a reference state is a common feature of LCA approaches that aim to assess the impact of LULUC on biodiversity. The reference state serves as a baseline that generally reflects the situation that would occur after the cessation of human influence, and can be used as a comparison for the biodiversity effects of alternative land classes/covers and as a measure of biodiversity impacts resulting from LULUC (Figure 9). The choice of a reference state reflects value judgements and the goal of the assessment. It is a critical issue because it has an important influence on the results of the assessment. Natural vegetation is often considered as the reference state, and reflects the biodiversity level of vegetation that would have occurred in the absence of human influence. Through comparison of the biodiversity state of different land uses/covers, LCA aims to develop characterization factors that reflect the impact of land transformation and occupation on biodiversity. The UNEP/SETAC Life Cycle Initiative is currently (2014-2015) hosting a platform to build consensus on existing methodologies to assess the impacts of land use on biodiversity in LCA, taking into account different aspects, including the choice of baseline for comparison of impacts.

6.4.2 What is currently done?

The LEAP Biodiversity Review (Teillard *et al.*, 2016a) refers to a number of different approaches to assess the impacts of land use on biodiversity, including the Ecological Damage Potential; the ReCiPe methodology; and the Mean Species Abundance.

The UNEP/SETAC Life Cycle Initiative recommends the use of the potential natural vegetation (PNV) as a reference when assessing land use impact on a global scale (Koellner, 2013a. However, it also acknowledges that the definition of the reference state requires further exploration: depending on the goal and scope of a study, a different choice of reference state might be more appropriate (see below for further discussion).

As mentioned in Section 6.4.1, the choice of the reference state is not obvious, and can involve value choices that have considerable consequences on the assessment of impacts and interpretation. This is an area in which there is likely to be continuing need for discussion, and development of guidance on best practices. A number of different considerations and caveats occur about the choice of reference state and the consequent development of characterization factors (reviewed in Souza *et al*., 2015; see also Milà i Canals, 2014).

6.4.3 Geographical scale of the metrics for PNV

Recent years have seen an impressive increase in the data that is available to develop quantitative estimates of the reference state of biodiversity associated with a range of biomes and eco-regions (e.g. Mueller-Wenk, 1997; Weidema & Lindeijer, 2001; Koellner & Scholz, 2008; Alkemade *et al.,* 2009). These approaches allow LCA practitioners to achieve assessments on a geographical scale broad enough to reflect the global interlinkages of supply chains associated with livestock systems, e.g. de Baan *et al.* (2014); Geyer *et al.* (2010a, b). These general approaches can facilitate assessments that do not have enough detailed local information available on how biodiversity is affected by livestock systems. In addition to these large-scale assessments, however, there is also a recognised need for more locally adapted LCAs that use more locally relevant data for the development of characterization factors.

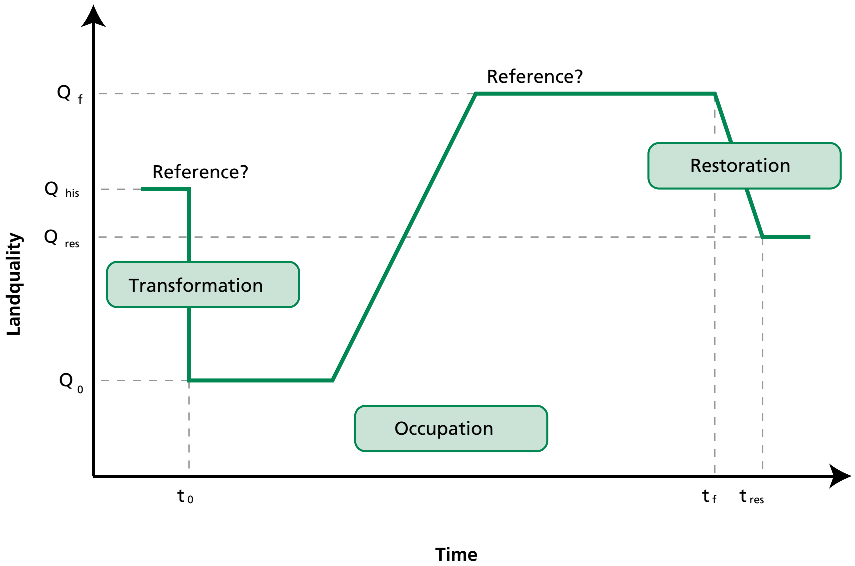
The use of local data has some advantages: in principle, there may be excellent local availability of data on the state of biodiversity across different livestock systems and reference states. Such data can allow the calculation of characterization factors that better reflect the state of local biodiversity in different land use types/cover and allow them to be used in more locally specific LCA studies. This may allow the comparison between, for example, the different levels of grazing pressure that may exist, ranging from: undergrazed; extensively grazed on semi-natural pastures; intensively grazed on grass monocultures and/or imported feed, to: overgrazed. In addition, there may be data on biodiversity responses to the relaxation of grazing pressure, whether it be from overgrazed to intensively grazed, or from extensively grazed to no grazing. Where such examples can be used to develop local characterization factors, a strong advantage is the possibility of conducting very detailed LCAs with a high degree of precision to detail the relative impacts of different aspects of livestock systems at the local scale. Looking to future assessments, it is likely that there will be an increase in the incidence of LCAs taking into account impacts on biodiversity, requiring the use of more 'bottom-up' approaches. There may also be a benefit from hybrid approaches that combine the bottom-up and top-down avenues.

6.4.4 Choice of reference state and representation of positive influences of livestock systems

There are several alternatives for selection of a reference state. In addition to potential natural vegetation, these include the use of historical land cover types; the natural climax vegetation; the current land cover in the absence of human activity; and mosaics of land cover types at a specific time. In practice, the use of historical land cover types as reference states gives similar weights to land use impacts that are currently occurring (e.g. contemporary tropical deforestation) and land use impacts that occurred a long time ago (e.g. deforestation of European woodlands). Thus the historical land cover approach sees species-rich grasslands in Europe as deforested areas, and the impact on biodiversity appears to be mostly negative. Alternatively, the selection of recent land use states as the reference state (e.g. land cover in year 2000) results in a higher impact for current land use change processes, and historical land transformations are treated as a sunk cost. Under this approach, although there cannot be a positive effect of land use that continues to support livestock production, it can be neutral if no land use change has occurred since the reference year. To improve the quality of interpretation of impacts, Koellner (2013a) advised practitioners to compare the effects on the results of the potential natural vegetation *versus* the current land use mix.

An important caveat concerning existing LCA methodologies is that they may not necessarily consider all of the positive impacts of livestock on biodiversity (Section 6.4.1) Characterization factors are typically calculated on the basis of an undisturbed reference state that corresponds to the counterfactual situation that would occur in the absence of human activity, and informs the quantification of the full complement of species against which the effect of human activity can be compared. From this perspective, land uses that support livestock production are considered as a disturbed state involving a loss of biodiversity. Characterization factors are not adapted to more specific situations in the context of livestock production: e.g. when livestock maintains key biodiversity habitats and when the abandonment of

Figure 14
Evolution of land quality (Q) over time (t), as a result of land transformation and occupation. Idealized situation that could apply to the livestock context: occupation lasts for a very long time and biodiversity adapts to it. his = historical, 0 = initial (after land transformation and at the beginning of land occupation), f = final (at the end of land occupation), res = restoration (at the end of restoration)



Source: LEAP Biodiversity Review (Teillard *et al.*, 2016a).

production leads to biodiversity loss (LEAP Biodiversity Review, Teillard *et al.*, 2016a). Such specific situations would have to be added to existing biodiversity LCA methodologies in order to make them relevant to the livestock sector.

Many grazed semi-natural grasslands in Europe (and elsewhere) in fact illustrate such situations, idealized in Figure 14. Conversion from forest/woodland to pastures (land transformation) and the associated decrease in biodiversity took place hundreds of years ago. The very long duration and the extensive nature of land occupation for livestock farming has allowed time for a unique biodiversity to co-evolve with grazing. Today, when livestock farming is abandoned in these semi-natural grassland areas, the natural process of habitat succession to original forest results in a loss of biodiversity (See Case Studies 4 and 5).

6.4.5 Choice of attributional vs. consequential LCAs

Attributional LCA seeks to assess and attribute environmental burdens associated with a product while consequential LCA seeks to quantify environmental changes associated with a change in the system under study. While the principles presented in PART II and the other LEAP guidelines only address attributional LCAs, a consequential approach would be relevant to biodiversity assessment in the context of livestock and have important implications.

Because there is increasing pressure on land, land use changes related to livestock – conversion to pasture or feed crops, intensification, abandonment – are very likely to trigger other land use changes off-site and in other sectors such as agriculture (for human nourishment) or forestry. Identifying these changes and their impact on biodiversity, in addition to those directly related to livestock, is part of the consequential approach. It requires an understanding of agricultural production pathways likely to respond to marginal increases in demand. It also requires an understanding of socio-economic drivers linking livestock and other sectors to land use events such as land appropriation (sometimes associated with cattle and soy production), human displacements resulting in knock-on deforestation, intensification stimulating increased production and agricultural expansion. Consequential approaches also have implications for the relevant reference land use to be selected. For instance, while the natural state or PNV is often used in attributional LCA, the alternative land use and effects outside of the livestock sector may be a more appropriate reference state in consequential LCAs.

Thomassen *et al*. (2008), in providing a comparison of attributional and consequential LCA approaches in the context of milk production, address impacts on land use. However, to our knowledge consequential LCA has not been applied to biodiversity so far.

7. Future priorities for LEAP & Biodiversity

Key principles

More remains to be done to guide the quantitative assessment of impact on biodiversity due to livestock systems. To this end, Life Cycle Assessment and PSR indicators will be key approaches. We identify a number of priority issues to improve their applicability to the assessment of livestock systems' impact on biodiversity, as follows:

- *There is a need to identify and disseminate examples of best practices in biodiversity assessments in the livestock sector. These should include examples of the effective use of LCA of biodiversity impacts for improved decision-making about livestock systems and supply chains. There is also a need for examples of the effective inclusion of life-cycle perspectives into Biodiversity Action Plans and related methods (e.g. certification standards) that rely on PSR indicators.*
- *A key outcome of this document is a recognition of the complementarity that can be achieved through a combination of LCA and PSR approaches. LCA can be used to reveal supply chain or spatial hotspots for further investigation. Having broadly identified such hotspots, more detailed assessment can be achieved through PSR indicators. It would be highly desirable to identify examples where such complementarity is achieved.*

7.1 ENSURE LINKS BETWEEN LEAP AND OTHER BIODIVERSITY INITIATIVES

Many (but certainly not all) current initiatives in the livestock and food sector are indicated in Section 5.4, and these suggest a strong reliance on PSR indicators (response indicators in particular) as opposed to LCA. There is considerable opportunity for LEAP to continue to provide guidance to the sector, to learn from it about its most pressing needs for biodiversity assessment, and also to assist it in addressing these needs.

Future work can build on existing examples of guidance for biodiversity conservation for commercial sectors, which could be tailored for livestock systems. For example, the Open Standards for the Practice of Conservation provides tools and stepwise methodology for scoping (conceptual models), strategic planning, and monitoring impacts on conservation goals[1]. This is likely most useful for PSR-type assessment at the farm, landscape, national, or regional level. At the level of supply chains, the Business and Biodiversity Offsets Programme (BBOP[2]), and especially their standards and guidelines for companies, 'Standards on Biodiversity Offsets[3]'. Similarly, the International Finance Corporation has developed Sustainability Performance Standards

[1] http://cmp-openstandards.org/
[2] http://bbop.forest-trends.org/
[3] http://www.forest-trends.org/documents/files/doc_3078.pdf

that include 'Performance Standard 6: Biodiversity Conservation and Sustainable Management of Living Natural Resources[4]'.

The livestock and related industries have continued to develop approaches to guide the adoption of more sustainable production practices, and these include biodiversity to varying extents. Several of these are mentioned in Section 5, and there are other examples, e.g. the Round Table on Responsible Soy Certification, a scheme that includes reference to biodiversity (http://www.responsiblesoy.org/). There is obviously a demand for best practices in the design and assessment of the biodiversity standards in certification schemes, and this should feature in future LEAP initiatives.

For many years, NGOs have championed the awareness and practical development of biodiversity conservation, including programmes for livestock production. LEAP should continue to maintain professional links with NGOs, and ensure that their expertise is maintained in LEAP's future work of on biodiversity.

It has been recognized that the LCA approach for biodiversity assessment needs substantial improvements as it is unable to grasp the real and complex dynamics of ecosystem interactions (Milà i Canals *et al*., 2014; Souza *et al.,* 2015). Souza *et al.* (2015) discuss some of the issues to be improved, such as the choice of appropriate ecological models; the identification of adequate surrogate species and indicators; and the integration of the spatial and temporal variability of biodiversity and biological processes. Life cycle inventory flows need more refinement, in order to incorporate the differences between various management practices. These methodological constraints and the lack of agreement on the application of currently existing models led the UNEP/SETAC Life Cycle Initiative[5] to conduct a deeper analysis of the land use impact assessment framework, aiming to provide global guidance and consensus building on important aspects of impact categories such as land use (Jolliet *et al.,* 2014). According to Milà i Canals *et al.* (2014), the lack of consensus also imposes constraints on the comparison of land use impact results among two or more studies. There is an ongoing need for LEAP to maintain communication with UNEP-SETAC as it continues its work to develop LCA methods for biodiversity. There will also be a continuing need to articulate the more general UNEP-SETAC guidelines with the more specific needs of livestock systems. This ensures a role for LEAP to further contribute to the development of LCA approaches that recognise and incorporate the needs of livestock systems.

7.2 IDENTIFY BEST PRACTICES IN BIODIVERSITY ACTION PLANS

From this description, there is a clear overlap between the development of Biodiversity Action Plans for livestock systems and these LEAP Principles for Assessment of Biodiversity Impacts. Looking to the future, it would be highly desirable to identify examples of best practices in the development, implementation and assessment of BAPs in livestock systems, especially those that have a transparent process for qualitative and quantitative evaluation. The following list provides examples of elements of a Biodiversity Action Plan for livestock systems that largely relies on PSR indicators, and uses these to include a life cycle perspective (Sections 2.3.2 and 5.1). As well as corresponding with the principles in Section 5.1, specific features to exemplify would include the following:

[4] http://www.ifc.org
[5] http://www.lifecycleinitiative.org/

- identification of biodiversity goals;
- clear statement of the method and outcome of scoping and hotspot analyses;
- recognition of off-farm impacts;
- approaches that recognise and differentiate between habitats of high conservation value and more common farmland habitats;
- selection of quantitative indicators;
- practical management strategies undertaken by farmers;
- implementation of a well-designed monitoring programme;
- valid and objective analysis of data;
- use of data to confirm success or the need to further improve management;
- successful knowledge-transfer to farmers;
- wider communication of biodiversity benefits and achievements in agricultural sustainability;
- use of mitigation of biodiversity impacts to improve green labelling and business performance.

A key message from these LEAP principles is the complementarity between LCA and PSR approaches (Section 2.3). It is highly desirable to identify and disseminate examples of best practices that demonstrate the effective complementarity in scope, perspective and quantification between LCA and PSR indicators. As mentioned in Section 2.3.1, this might be in the form of an LCA assessment of impacts on biodiversity at large spatial scales and to reveal hotspots of impact along the supply chain or among spatial entities. Once supply chain or spatial hotspots are identified, PSR indicators can be used to conduct further investigation with more detailed assessment methods. The use of PSR indicators may be more readily adapted to differentiate between the effect of different livestock practices. Within an identified hotspot, PSR indicators might also be used to expand the assessment to provide, for example, more information on other pressures or other biodiversity levels and taxa, and to include impacts on ecosystem services.

7.3 IMPROVED IDENTIFICATION OF BIODIVERSITY INDICATORS FOR LIVESTOCK SYSTEMS

The LEAP Biodiversity Review (Teillard *et al.*, 2016a) provides several examples of indicators that can be used with these LEAP Principles for Assessment of Biodiversity Impacts, which make these two documents interdependent. A next step towards consistency and operationality should be to recommend specific indicators, i.e. key performance indicators (KPIs) for biodiversity in livestock systems. Potentially, different indicators would be recommended for different users, livestock production systems and regions, because the main biodiversity issues vary among these categories. Additional reviews of the literature and expert consultation would be necessary to identify these issues and corresponding KPIs. The final outcome would be a toolbox that details indicators for each system along with guidelines for their calculation. The development of such a toolbox would also be an opportunity to target an audience of users that are not biodiversity specialists, by providing ready-to-use indicators and simple guidelines on how to apply them. Such a toolbox should include a decision-support step that aims to recognise different goals, different ecological contexts, and different livestock systems, and provide guidance on the most relevant indicators. A specific challenge will be to define and address the needs of the 'audience of users', which may vary in nature to include individual farmers and producers, national governments, livestock processing companies, certification schemes, and those conducting regional- to global-scale assessments of livestock impacts.

7.4 PROGRESS TOWARDS COMPREHENSIVE ENVIRONMENTAL ASSESSMENTS IN LEAP

Because, ideally, livestock assessment relies on several environmental impact categories (including land use, climate change, water, nutrient pollution, biodiversity), there is a need for a more holistic assessment of the environmental performance of livestock supply chains.

With these principles for biodiversity assessment, there is a great opportunity to expand the scope of the LEAP sector guidelines (for feed, poultry, small and large ruminants, and pigs) to include the environmental category of biodiversity. This would require specific changes during the next revision of the LEAP sector guidelines. As part of future activity, a parallel review will identify what elements of the sector guidelines can be used as input for the biodiversity assessment, and where additional efforts will have to be invested. In particular, this will concern currently available data for inventory flows and midpoint impact categories that can be used as pressure indicators for biodiversity, or transformed into a biodiversity value using proper characterization factors. For instance, the LEAP Animal Feed Guidelines cover land occupation as a midpoint impact category. Limited additional effort would be needed to provide guidance on how to measure land use (in its various aspects), which is a crucial category in biodiversity LCIA. A parallel revision of the biodiversity guidelines will ensure that the link between these outputs of the sector guidelines and the biodiversity assessment is straightforward. The Biodiversity Principles will have to be properly cited along the sector guidelines, and specific elements could also be inserted into the main text of other LEAP sector guidelines.

As a future priority, a joint case study should be developed in order to illustrate how multiple impact categories – e.g. GHG emissions and biodiversity – can be assessed for the same livestock system. It will show which data and LCI elements are common for the two criteria and which are different. It will also indicate how to inform on the synergies and trade-offs between the two criteria, which can be a very important issue in multi-criteria assessment.

The LCA methodologies for assessing impacts of land use on biodiversity need further development (Section 6). Nevertheless, a focus on land use impacts alone will be insufficient to capture the full impacts of livestock systems on biodiversity and ecosystem services (Section 6.1). The full characterization of the livestock effects of the range of global livestock systems will not be properly reflected until LCA methods can incorporate multiple environmental dimensions, e.g. water use, biodiversity, carbon dynamics, soil quality. A first step toward meeting this challenge would be to conduct a joint LCA that assesses, for example, both the biodiversity and climate change effects associated with a specific livestock system. To our knowledge, this would be one of the first times that such a combined LCA approach is undertaken within a livestock system.

This is a challenging goal, but a necessary requirement if we are to have more complete guidance on the environmental consequences of choices and decisions about the design and management of livestock systems. In the absence of such more holistic approaches, the possibility will remain of pollution swapping and unrecognised trade-offs among different dimensions of agro-environmental sustainability.

References

Alkemade, R., Oorschot, M., Miles, L., Nellemann, C., Bakkenes, M. & ten Brink, B. *(2009). GLOBIO3: A Framework to Investigate Options for Reducing Global Terrestrial Biodiversity Loss. Ecosystems, 12: 374–390.*

Alkemade, R., Reid, R.S., van den Berg, M., de Leeuw, J. & Jeuken, M. *(2012). Assessing the impacts of livestock production on biodiversity in rangeland ecosystems. Proceedings of the National Academy of Sciences of the United States of America, 2011.*

Andrén, H. *(1994) Effects of Habitat Fragmentation on Birds and Mammals in Landscapes with Different Proportions of Suitable Habitat: A Review. Oikos, 71: 355-366.*

Alexandratos, N. and Bruinsma, J. *(2012) World agriculture towards 2030/2050: the 2012 revision. ESA Working Paper 12-03. FAO, Rome.*

Archibald, E.E.A. *(1949). The specific character of plant communities: II. A quantitative approach. The Journal of Ecology, 37: 274–288.*

Arrhenius, O. *(1921). Species and area. Journal of Ecology, 9: 95–99.*

Azevedo, L.B., Henderson, A.D., *et al.*, *2013a. Assessing the importance of spatial variability versus model choices in life cycle impact assessment: the case of freshwater eutrophication in Europe. Environmental Science & Technology, 47(23): 13565–13570.*

Azevedo, L.B., van Zelm, R., *et al.*, *2013b. Global assessment of the effects of terrestrial acidification on plant species richness. Environmental Pollution, 174:10–15.*

Azevedo, L.B., Zelm, R., *et al.*, *2013c. Species richness – phosphorus relationships for lakes and streams worldwide. Global Ecology and Biogeography, 22(12):1304–1314.*

Bare J.C., Hofstetter P., Pennington D.W., Udo de Haes H.A. *2000. Life Cycle Impact Assessment Workshop Summary: Midpoints versus Endpoints: The Sacrifices and Benefits. The International Journal of Life Cycle Assessment 5(6): 319-326.*

Campbell, N.A. *1996. Biology, 4th Edition. Menlo Park, California. The Benjamin/Cummings Publishing Company, Inc.*

CBD *(2006). Global Biodiversity Outlook 2. Tech. rep., Montreal.*

Chaudhary, A., Verones, F., de Baan, L., & Hellweg, S. *(2015). Quantifying Land Use Impacts on Biodiversity: Combining Species–Area Models and Vulnerability Indicators. Environmental science & technology, 49(16), 9987-9995.*

Chytrý, M. *(1998) Potential replacement vegetation: an approach to vegetation mapping of cultural landscapes. Applied Vegetation Science, 1:177-188.*

Connor E.F. & Mccoy E.D. *2001. Species-area relationships. Encyclopaedia of Biodiversity. Volume 5.*

Conservation International *2011. Critical Ecosystem Partnership Fund, The biodiversity hotspots. http://www.cepf.net/resources/hotspots/Pages/default.aspx*

Curran, M. *(1996) Environmental Life-Cycle Assessment, pp. 432. New York. McGraw-Hill.*

Curran, M., de Baan, L., De Schryver, A.M., Van Zelm, R., Hellweg, S., Koellner, T., Sonnemann, G. & Huijbregts, M.a.J. *2011. Toward meaningful end points of biodiversity in life cycle assessment. Environmental Science & Technology, 45: 70–9.*

de Baan, L., Alkemade, R. & Koellner, T. *2013a. Land use impacts on biodiversity in LCA: a global approach. The International Journal of Life Cycle Assessment, 18: 1216–1230.*

de Baan L, Mutel CL, Curran M, Hellweg S, Koellner,T. *2013b. Land Use in Life Cycle Assessment: Global Characterization Factors Based on Regional and Global Potential Species Extinction. Environmental Science & Technology, 47: 9281–9290.*

de Schryver, A.M., Brakkee, K.W., Goedkoop, M.J. & Huijbregts, M.A.J. *2009. Characterization Factors for Global Warming in Life Cycle Assessment Based on Damages to Humans and Ecosystems. Environmental Science & Technology, 43: 1689-1695.*

Dros, M. *2004. Managing the soy boom: Two scenarios of soy production expansion in South America, AIDEnvironment, Amsterdam.*

EEA. *2003. An inventory of biodiversity indicators in Europe. Tech. rep., European Environment Agency, Copenhagen.*

EEA *2007. Halting the Loss of Biodiversity by 2010: Proposal for a First Set of Indicators to Monitor Progress in Europe. Tech. rep., European Environment Agency, Copenhagen.*

Elshout, P. M., van Zelm, R., Karuppiah, R., Laurenzi, I. J., & Huijbregts, M. A. *2014. A spatially explicit data-driven approach to assess the effect of agricultural land occupation on species groups. The International Journal of Life Cycle Assessment, 19(4): 758-769.*

European Commission. *2000. Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles - Commission Statements.*

European Commission. *2003. Communication from the Commission to the Council and the European Parliament. COM(2003) 302 Integrated Product Policy: Building on Environmental Life Cycle Thinking.*

European Commission. *2004 Directive 2004/12/EC of the European Parliament and of the Council of 11 February 2004 amending Directive 94/62/EC on packaging and packaging waste.*

European Commission. *2011. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the regions COM(2011) 571: Roadmap to a Resource Efficient Europe.*

European Commission. *2010. ILDC Handbook. Analysis of existing environmental impact assessment methodologies for use in life cycle assessment. Tech. rep.*

Food SCP RT. *2013. ENVIFOOD Protocol, Environmental Assessment of Food and Drink Protocol, European Food Sustainable Consumption and Production Round Table (SCP RT), Working Group 1, Brussels, Belgium.*

FAO. *2013. Roles of small-scale livestock keepers in the conservation and sustainable use of animal genetic resources. Fourteenth regular session of the Commission on Genetic Resources for Food and Agriculture.*

Finn, J.A. and Ó hUallacháin, D. *2012. A review of evidence for the environmental effectiveness of Ireland's Rural Environmental Protection Scheme. Biology and Environment 112B: 1-24.*

Finnveden, G., Hauschild, M.Z., Ekvall, T., Guinée, J., Heijungs, R., Hellweg, S., Koehler, A., Pennington, D. and Suh, S. *2009 Recent developments in life cycle assessment. Journal of Environmental Management, 91: 1-21.*

Frankl P., Rubik F. *(2000) Life Cycle Assessment in Industry and Business: adoption of patterns, applications and implications. Berlin. Springer.*

Garnett, S. and Franklin, D. *(eds) (2014). Climate change adaptation plan for Australian birds. Melbourne. CSIRO Publishing.*

Gerber, P.J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A., Tempio, G. *et al.*, *2013. Tackling climate change through livestock: a global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations (FAO).*

Geyer, R., Lindner, J., Stoms, D., Davis, F. & Wittstock, B. *2010a. Coupling GIS and LCA for biodiversity assessments of land use. Part 2: Impact assessment. The International Journal of Life Cycle Assessment,* **15***: 467692–703.*

Geyer, R., Stoms, D., Lindner, J., Davis, F., Wittstock, B. *2010b. Coupling GIS and LCA for biodiversity assessments of land use. Part 1: Inventory modeling. The International Journal of Life Cycle Assessment,* **15***: 454–467.*

Gleason, H.A. *1925. Species and area. Ecology, 6: 66–74.*

Goedkoop, M., Huijbregts M., Heijungs R., De Schryver A., Struijs J., van Zelm R. *2012. ReCiPe 2008. A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. First edition (revised). Tech. rep.*

Guerci, M., Knudsen M.T., Bava, L., Zucali M., Schönbach, P., Kristensen, T. *2013 Parameters affecting the environmental impact of a range of dairy farming systems in Denmark, Germany and Italy. Journal of Cleaner Production,* **54***: 133–141.*

Guinée, J.B., Gorrée, M., Heijungs, R., Huppes, G., Kleijn, R., De Koning, A., Van Oers, L., Wegener Sleeswijk, A., Suh, S., de Haes, H.A. & Others. *2002. Life cycle assessment; An operational guide to the ISO standards; Parts 1 and 2. Ministry of Housing, Spatial Planning and Environment (VROM) and Centre of Environmental Science (CML), Den Haag and Leiden, The Netherlands.*

Hanafiah, M.M., Xenopoulos, M.A., Pfister, S., *et al.*, *2011. Characterization Factors for Water Consumption and Greenhouse Gas Emissions Based on Freshwater Fish Species Extinction. Environ Sci Technol 45:5272–5278.*

Hauschild, M.Z. *2005 Assessing environmental impacts in a life cycle perspective. Environmental Science & Technology* **39***(4):81-88A.*

IFC. *2012. Performance Standard for Biodiversity Conservation and Sustainable Management of Living Natural Resources. Washington DC.*

ISO *2006a. ISO 14040. Environmental Management - Life Cycle Assessment – Principles and framework. Geneva. pp. 20.*

ISO*(2006b. ISO 14044. Environmental Management - Life Cycle Assessment – Requirements and Guidelines. Geneva. pp. 46.*

ISO *2006c. ISO 14064-1. Greenhouse gases - Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals. Geneva.*

ISO *2014. ISO 14046: 2014 Environmental management – Water footprint – Principles, requirements and guidelines. First edition. Geneva.*

Jenkins, C. N., Pimm, S. L., & Joppa, L. N. *2013. Global patterns of terrestrial vertebrate diversity and conservation. Proceedings of the National Academy of Sciences, 110(28): E2602-E2610.*

Jolliet, O., Frischknecht, R., Bare, J., Boulay, A.-M., Bulle, C., Fantke, P., Gheewala, S., Hauschild, M., Itsubo, N., Margni, M., McKone,T.E., Milà i Canals, L.,

Postuma L., Prado-Lopez, V., Ridoutt, B., Sonnemann, G., Rosenbaum, R.K., Seager, T., Struijs, J., van Zelm, R., Vigon, B., Weisbrod, A. *with contributions of the other workshop participants.2014. Global guidance on environmental life cycle impact assessment indicators: findings of the scoping phase. The International Journal of Life Cycle Assessment,* **19***: 962-967.*

Koellner, T., Baan, L., Beck, T., Brandão, M., Civit, B., Goedkoop, M., Margni, M., Milà I Canals, L., Müller-Wenk, R., Weidema, B., Wittstock, B. *2013a. Principles for life cycle inventories of land use on a global scale. The International Journal of Life Cycle Assessment, 18: 1203–1215.*

Koellner, T., de Baan, L., Beck, T., Brandão, M., Civit, B., Margni, M., Milà i Canals, L., Saad, R., Souza, D.M., Müller-Wenk, R. *2013b. UNEP-SETAC guideline on global land use impact assessment on biodiversity and ecosystem services in LCA. The International Journal of Life Cycle Assessment, 18: 1188-1202.*

Koellner, T., Scholz, R. *2008. Assessment of land use impacts on the natural environment-Part 2: Generic characterization factors for local species diversity in Central Europe. International Journal of Life Cycle Assessment, 13: 32–48.*

Koellner, T. *2003. Land use in product life cycles and ecosystem quality. European University Studies, Bruxelles.*

Ladle, R.J. and Whittaker, R.J. *(eds.) 2011. Conservation Biogeography. Hoboken, NJ. John Wiley & Sons.*

MEA. *2005. Millennium Ecosystem Assessment. Ecosystems and human well-being. Washington DC. Island Press.*

Mekonnen & Hoekstra *2012. A Global Assessment of the Water Footprint of Farm Animal Products, Ecosystems (2012) 15: 401–415*

Michelsen, O. *2008. Assessment of land use impact on biodiversity: proposal of a new methodology exemplified with forestry operations in Norway. The International Journal of Life Cycle Assessment,* **13***: 22-31.*

Milà i Canals, L., Bauer, C., Depestele, J., Dubreuil, A., Knuchel, R.F., Gaillard, G., Michelsen, O., Müller-Wenk, R., Rydgren, B. *2007. Key elements in a framework for land use impact assessment within LCA. The International Journal of Life Cycle Assessment,* **12***: 5–15.*

Milà i Canals, L., Michelsen O, Teixeira R.F.M., Souza D.M., Curran M., Assumpció, A. *2014 Building consensus for assessing land use impacts on biodiversity in LCA. In 9th International Conference LCA Food 2014, San Francisco, USA. Available at http://lcafood2014.org/papers/128.pdf.*

Milà i Canals, L., de Baan, L. *(in press) Land Use. In: Hauschild M. and Huijbregts M. Life Cycle Impact Assessment, Volume 4 in The Life Cycle Assessment Encyclopaedia. Berlin. Springer.*

Milchunas, D.G., Sala, O.E., Lauenroth, W.K. *1988. A generalized model of the effects of grazing by large herbivores on grassland community structure. American Naturalist, 132: 87-106.*

Monfreda, C., Ramankutty, N., Foley, J. A. *2008. Farming the planet: 2. Geographic distribution of crop areas, yields, physiological types and net primary production in the year 2000, Global Biogeochemical Cycles, 22, GB1022, doi:10.1029/2007/GB002947*

Mueller, C., Baan, L. & Koellner, T. *2014. Comparing direct land use impacts on biodiversity of conventional and organic milk—based on a Swedish case study. The International Journal of Life Cycle Assessment, 19(1): 52–68.*

Müller-Wenk, R. *1998. Land use the main threat to species: How to include land use in LCA. 64.IWÖ Diskussionsbeitrag, pp 45. Universität St. Gallen, St. Gallen, Switzerland.*

Murgueitio, Enrique, *et al.* *"Native trees and shrubs for the productive rehabilitation of tropical cattle ranching lands." Forest Ecology and Management 261.10 (2011): 1654-1663.*

OECD. *1993. OECD core set of indicators for environmental performance reviews. Environment Monographs. OECD Publishing, Paris.*

OECD. *2002. Handbook of Biodiversity Valuation. A guide for policy makers. OECD Publishing, Paris.*

Olson, D. M. & Dinerstein, E. *1998. The Global 200: A representation approach to conserving the Earth's most biologically valuable ecoregions. Conservation Biology. 12:502–515*

Olson, D. M., Dinerstein, E. *2002.The Global 2000: Priority ecoregions for global conservation. Annals of the Missouri Botanical Garden 89(2):199-224.*

Palmer, M.W., White, P.S. *1994. Scale dependence and the species-area relationship. The American Naturalist,* **144***: 717-740.*

British Standards Institution.*2011. PAS 2050:2011. BSI. 2011. Specification for the assessment of the life cycle greenhouse gas emissions of goods and services. London.*

Pervanchon, F. *2004. Modélisation de l'effet des pratiques agricoles sur la diversité végétale et la valeur agronomique des prairies permanents en vue de l'élaboration d'indicateurs agri-environnementaux, Ph.D. Thesis, Nancy, INPL.*

Pfister, S., Koehler, A. & Hellweg, S. *2009. Assessing the environmental impacts of freshwater consumption in LCA. Environmental science & technology, 43(11): 4098–104.*

Plantureux, S., Dumont, B., Rossignol, N., Taugourdeau, S. Huguenin-Elie, O. *2014 An indicator-based tool to assess environmental impacts of multi-specific swards. Grassland Science in Europe 19: 756-758.*

European Commission. *2013. Product Environmental Footprint Guide, Commission Recommendation of 9 April 2013 on the use of common methods to measure and communicate the life cycle environmental performance of products and organizations. Official Journal of the European Union L 124/1.*

Rosenbaum, R.K., Bachmann, T.M., Gold, L.S., Huijbregts, M.a.J., Jolliet, O., Juraske, R., Koehler, A., Larsen, H.F., MacLeod, M., Margni, M., McKone, T.E., Payet, J., Schuhmacher, M., Meent, D. & Hauschild, M.Z. *2008. USEtox — the UNEP-SETAC toxicity model: recommended characterization factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment. The International Journal of Life Cycle Assessment, 13: 532–546.*

Robinson, T. P., Wint, G. R. W., Conchedda, G., Van Boeckel, T. P. *2014. Mapping the Global Distribution of Livestock. PLoS ONE 9(5): e96084. doi:10.1371/journal.pone.0096084*

Rybicki, J., Hanski, I. *2013. Species-area relationships and extinctions caused by habitat loss and fragmentation. Ecology Letters, 16: 27-38.*

Schmidt, J.H. *2008. Development of LCIA characterization factors for land use impacts on biodiversity. Journal of Cleaner Production,* **16***: 1929–1942.*

Shurtleff, W. and Aoyagi, Akiko. *2004. History of world soyabean production and trade. A chapter from the unpublished manuscript, History of soyabeans and soyfoods, 1100 B.C. to the 1980s.*

Smeets, E., & Weterings, R. *1999. Environmental indicators: Typology and overview. pp. 19. Copenhagen: European Environment Agency.*

Solow, A., Polasky, S. and Broadus, J. *1993. On the measurement of biological diversity. Journal of Environmental Economics and Management 24: 60-68.*

Souza, D.M. *2010. Proposta de um modelo de caracterização de impactos do uso da terra, segundo indicadores de biodiversidade, em AICV: cálculo de fatores de caracterização para ecorregiões brasileiras. Universidade Federal de Santa Catarina. PhD Dissertation.*

Souza, D.M., Flynn, D.F.B., DeClerck, F., Rosenbaum, R.K., Lisboa, H.M., Koellner, T. *2013. Land use impacts on biodiversity in LCA: proposal of characterization factors based on functional diversity. The International Journal of Life Cycle Assessment,* **18***: 1231-1242.*

Souza, D.M., Teixeira,R.F.M., Ostermann, O.P. *(2015). Assessing biodiversity loss due to land use with Life Cycle Assessment: Are we there yet? Global Change Biology,* **21***(1), 32-47.*

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., & Haan, C. D. *2006. Livestock's long shadow: environmental issues and options. Rome. FAO.*

Struijs, J., Beusen, A., de Zwart, D. & Huijbregts, M. *2011. Characterization factors for inland water eutrophication at the damage level in life cycle impact assessment. The International Journal of Life Cycle Assessment, 16: 59–64.*

Teillard, F., Anton, A., Dumont, B., Finn, J., Henry, B., Souza, D.M., Manzano, P., Milà i Canals L., Phelps, C., Said, M., Vijn, S., White, S. *2016a. A review of indicators and methods to assess biodiversity – application to livestock production at global scale. Livestock Environmental Assessment and Performance Partnership (LEAP). FAO, Rome, Italy.*

Teillard, F., Maia de Souza, D., Thoma, G., Gerber, P. J., & Finn, J. A. *2016. What does Life- Cycle Assessment of agricultural products need for more meaningful inclusion of biodiversity?. Journal of Applied Ecology DOI: 10.1111/1365-2664.12683.*

Tendall, D.M., Hellweg, S., Pfister, S., ***et al.*** *2014. Impacts of river water consumption on aquatic biodiversity in life cycle assessment--a proposed method, and a case study for Europe. Environ Sci Technol 48:3236–44. doi: 10.1021/es4048686*

Thomassen, Marlies A., ***et al.*** *2008. "Attributional and consequential LCA of milk production." The International Journal of Life Cycle Assessment 13.4 (2008): 339-349.*

UN *1996. United Nations, Indicators of Sustainable Development Framework and Methodologies, United Nations Sales Publication No. E.96.II.A.16 New York.*

UN *2001. United Nations, Indicators of Sustainable Development: Guidelines and Methodologies, Second Edition, UN Sales Publication No. E.01.II.A.6 New York.*

UN *(2012). United Nations, Department of Economic and Social Affairs, Population Division. World Population Prospects: The 2015 Revision, Key Findings and Advance Tables. Working Paper No. ESA/P/WP.241. New York.*

Van Zelm, R., Huijbregts, M. A., Van Jaarsveld, H. A., Reinds, G. J., De Zwart, D., Struijs, J., & Van de Meent, D. *2007. Time horizon dependent characterization factors for acidification in life-cycle assessment based on forest plant species occurrence in Europe. Environmental Science & Technology, 41: 922-927.*

Verones, F., Saner, D., Pfister, S.. ***et al.*** *2013. Effects of Consumptive Water Use on Biodiversity in Wetlands of International Importance. Environmental Science & Technology 47:12248–12257.*

Weidema, B.P., Ekvall, T., Heijungs, R. *2009. Guidelines for applications of deepened and broadened LCA. Deliverable D18 of work package 5 of the CALCAS project. Available at http://www.leidenuniv.nl/cml/ssp/publications/calcas_report_d18.pdf*

Weidema, B.P., Lindeijer, E. *(2001). Physical impacts of land use in product life cycle assessment. Technical University of Denmark, pp. 52.*

WWF *2014. The Growth of Soy: Impacts and Solutions. WWF International, Gland, Switzerland*

Zerbe, S. *1998 Potential natural vegetation: validity and applicability in landscape planning and nature conservation. Applied Vegetation Science,* **1***: 165-172.*

PART 5

CASE STUDIES

CASE STUDY #1
ON-FARM VS. OFF-FARM IMPACT OF LIVESTOCK THROUGH LAND USE ON A GLOBAL SCALE

The case study focuses on the impact of livestock on biodiversity through land use for feed. The objective was to estimate the relative shares of this impact occurring on-farm (grassland, feed crops cultivated on the farm) and off-farm (imported feed) at a global scale.

CASE STUDY #2
GRAZING MANAGEMENT TO REDUCE OFF-SITE BIODIVERSITY IMPACTS IN NORTHEASTERN AUSTRALIA

The case study describes the implementation of a programme in the Great Barrier Reef lagoon to reduce impacts on biodiversity arising from management of land for livestock production in coastal catchments.

CASE STUDY #3
BIODIVERSITY CONSERVATION AND HIGH COUNTRY SHEEP PRODUCTION IN NEW ZEALAND

The case study shows the interaction between historical and current farm management and biodiversity values across a range of New Zealand High Country sheep properties producing fine merino and mid-micro wool.

CASE STUDY #4
PLANT DIVERSITY IN TRADITIONAL LIVESTOCK SYSTEMS ON THE ARAN ISLANDS, IRELAND

The case study demonstrates the dependence of biodiversity on traditional livestock systems in the Aran Islands, Ireland. The Aran Islands are an extremely important site for a number of priority terrestrial habitats under the European Habitats Directive.

CASE STUDY #5
DAIRY SYSTEMS IN UPLAND PDO CHEESE PRODUCTION AREAS, FRANCE

The assessment provides overview of grassland biodiversity and of the relative ability of each grassland type to provide services (agronomic, ecological and quality of dairy products) in the species-rich humid grasslands of Central France.

CASE STUDY #6
MOBILE AND SEDENTARY MODELS OF EXTENSIVE LIVESTOCK KEEPING COMPARED ALONG THE CONQUENSE DROVE ROAD IN EASTERN SPAIN

The study highlights the impact of drove-road-mediated seed dispersal on the genetic structure of plant populations, and the impacts of management type on tree regeneration in dehesa systems, comparing sedentary, motorized and walking transhumant sheep.

CASE STUDY #7
A LARGE-SCALE, WIDE-SCOPE BIODIVERSITY MONITORING PROGRAMME LINKS MULTI-TAXA BIODIVERSITY TO LAND USE SUPPORTING LIVESTOCK PRODUCTION IN WESTERN NORTH AMERICA

The case study demonstrates development of statistical models linking land cover and land use to species abundance to estimate an overall index of Biodiversity Intactness.

Biodiversity Intactness has been reported as 53 percent in Alberta's prairie region, where land use is largely dedicated to supporting livestock production.

CASE STUDY #8

DISTRIBUTION OF LARGE HERBIVORES IN RELATION TO ENVIRONMENTAL AND ANTHROPOGENIC FACTORS IN THE EAST AFRICA SAVANNAH ECOSYSTEM

The study demonstrates how competition with, and facilitation by, livestock, predation risk, forage quantity and quality and water interact with life history traits, seasons and land use in shaping the dynamics of herbivore hotspots in protected and human-dominated savannahs.

CASE STUDY #9

COMPARING DIRECT LAND USE IMPACTS ON BIODIVERSITY OF CONVENTIONAL AND ORGANIC MILK IN SWEDEN

The case study shows how to perform quantification of the direct land use impacts on biodiversity in a Life Cycle perspective. The main purpose was to compare land use in organic and conventional milk production and its effects on biodiversity in Sweden.

CASE STUDY #10

LAND MANAGEMENT FOR ARID GRAZING IN BOTSWANA

The case study demonstrates the importance of incorporating local/indigenous knowledge in developing strategies to manage or restore biodiversity values and ecosystems services. The holistic approach to biodiversity management is recommended to avoid perverse outcomes.

CASE STUDY #11

GRAZING AND RANCHER STEWARDSHIP TO CONSERVE THREATENED AND ENDANGERED SPECIES AND ASSOCIATED HABITATS ON CALIFORNIA'S RANGELANDS

This case study describes research findings regarding benefits of grazing and ranchers' stewardship for common and special-status species. The case study illustrates the importance of landscape- and pasture-level conservation efforts. It also recognizes that the benefits provided by livestock systems avoid environmental costs that would otherwise be incurred in creating, improving and maintaining habitats for numerous special-status species.

CASE STUDY #12

IMPROVEMENTS OF LIVESTOCK DISEASE MANAGEMENT THROUGH ENHANCED BEEF SUPPLY CHAIN HAZARD ANALYSIS PROCEDURES AROUND TRANSFRONTIER CONSERVATION AREAS IN SOUTHERN AFRICA.

This case study describes a large-scale effort to reduce the impacts of fence-based livestock disease management on biodiversity. The spatial area includes the transfrontier conservation areas (TFCAs) shared among Angola, Botswana, Namibia, Zambia and Zimbabwe.

Case Study #1

On-farm *vs.* off-farm impact of livestock through land use on a global scale

GENERAL PRINCIPLES ILLUSTRATED BY THIS CASE STUDY

System boundaries and off-farm impacts

This case study illustrates how the boundaries of the system can be extended beyond the boundaries of the farm, i.e. to off-farm feed cultivation. It also demonstrates the importance of this boundary extension since a significant share of the impact on biodiversity occurs off-farm.

LCA principles

This case study illustrates a global LCA approach and the use of characterization factors to link land use elementary flows to a biodiversity impact indicator.

Large scale and high resolution

This case study shows the advantages of addressing a large scale with a high resolution, which makes it possible to compute average, aggregated impacts across nested scales.

State indicator

This case study uses Mean Species Abundance (MSA) as a biodiversity indicator. The MSA indicator is a compound indicator combining the abundance of several species. Its computation follows a standardized methodology based on a meta-analysis of the scientific literature. Reliability, comprehensiveness and large-scale applicability are several advantages of the use of state indicators that have been published and widely used, such as the MSA.

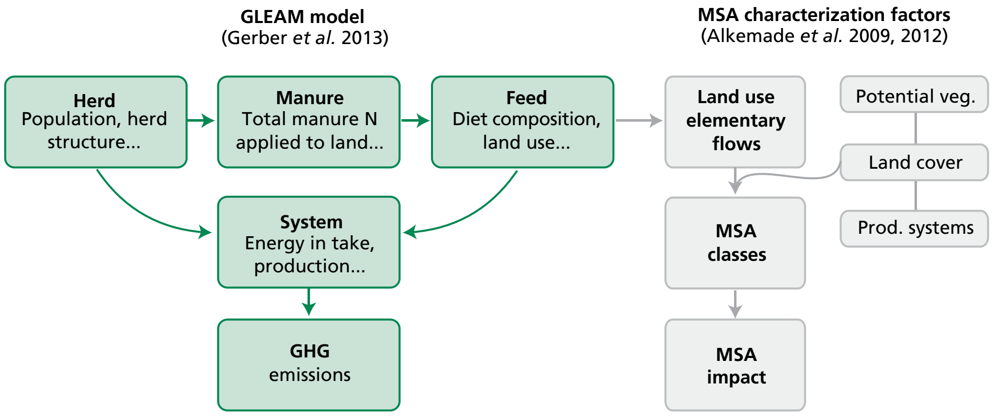
OVERALL OBJECTIVES

Most ecological studies assessing the impact of livestock on biodiversity have computed biodiversity indicators on a finite area such as the farm or the landscape. The Life Cycle Assessment (LCA) field offers a new perspective by computing impacts along the whole life cycle of a product. For livestock production, it draws attention to the fact that ecological indicators computed at farm level do not capture indirect impacts of the farm occurring elsewhere, from imported feed in particular. We focused on the impact of livestock on biodiversity through land use for feed. The objective was to estimate the relative share of this impact occurring on-farm (grassland, feed crops cultivated on the farm) and off-farm (imported feed).

SCALE, USERS AND GOAL

The case study used a GIS model at a global scale, with a resolution of 3 arc minutes (5kmx5km at the equator). Due to the coarse spatial scale at which global biodiversity indicators are available, such data are not suited to support management decisions at local scale (*e.g.* farmers' decisions on individual farms), although they

Figure CS1.1
Overview of the modelling procedure used to compute biodiversity impact, through the GLEAM model (Gerber *et al.*, 2013) and Mean Species Abundance methodology (MSA, Alkemade *et al.*, 2009; 2012). Prod. = production



Source: Adapted from Gerber *et al.*, 2013.

can inform decisions at sector, country or regional scale. In particular, we show the importance of not restricting biodiversity assessment to farm boundaries.

DESCRIPTION OF GEOGRAPHICAL AREA AND MAIN DRIVERS

The case study addresses the global scale and focuses on 'land use' as a driver. We used the GLEAM model which describes global livestock supply chains in details and computes the GHG emission (Gerber *et al.*, 2013). Computing the land use for feed is an intermediary output of the model (Figure CS1.1). We used this intermediary output to develop a new component of GLEAM, which estimated the impact of livestock on biodiversity through land use. For this biodiversity component, we relied on the MSA methodology which provides a biodiversity value (expressed as Mean Species Abundance) for several classes of land use and intensity (Alkemade *et al.*, 2009; 2012).

DESCRIPTION OF LIVESTOCK SYSTEM

The study focused on dairy cattle production.

DESCRIPTION OF PRIMARY BIODIVERSITY FEATURES

We describe biodiversity using the MSA indicator, which sums the abundance of species belonging to various taxa. Alkemade *et al.* (2009; 2012) provide an MSA value for different land use and intensity classes (Table CS1. 1), following a meta-analysis and selected articles that presented data on species composition in disturbed vs. undisturbed land uses. Studies in the meta-analysis addressed both plants and animals (mainly birds, mammals and insects). The MSA value of each land use class was derived from the ratio of the abundances of the different species

Figure CS1.2
Percentage of the impact of dairy cattle production on biodiversity (MSA) through land use occurring off -farm, i.e. from imported feed. Examples of country averages: Australia = 4%, Brazil = 26%, Canada = 15%, France = 23%, Ireland = 28%, Kenya = 6%, Spain = 31% USA = 17%

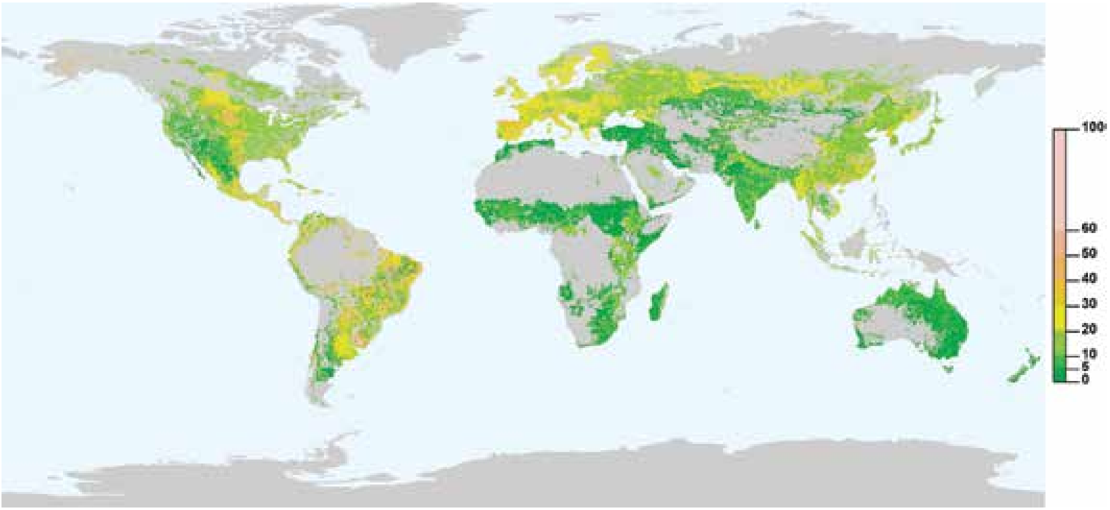


Table CS1.1: Mean Species Abundance (MSA) value of the different land use and intensity classes of rangelands/grasslands, and croplands (Alkemade *et al.*, 2009; 2012)

Land use and intensity classes	MSA value
Rangelands/grasslands	
Natural rangelands	1
Moderately used rangelands	0.6
Intensively used rangelands	0.5
Man-made grasslands	0.3
Croplands	
Low input agriculture	0.3
Intensive agriculture	0.1

in the occupied land use class compared to a reference land use. MSA values vary between 0 and 1. MSA = 1 in undisturbed ecosystems where 100 percent of the original species abundances remains, conversely, MSA = 0 in a destroyed ecosystem with no original species left.

MAIN FINDINGS AND IMPACTS

We computed the percentage of MSA impact from feed land use occurring off-farm (relative to the total on-farm + off-farm impact). Figure CS1.2 shows the global distribution of this percentage of off-farm impact. According to the model estimations it ranged from 0 to 100 percent. A significant percentage of the impact occurred off-farm, especially in America, Europe, East and Southeast Asia.

LIMITATIONS

The MSA indicator is one of the very few characterization factors linking land use to biodiversity that is available at the global scale. However it has certain limitations:

- The MSA indicator is based on a sum of the abundance of various species. It does not recognize that certain species have a higher conservation value than others, (e.g. IUCN Red List, patrimonial species).
- The MSA value of each land use and intensity class is global and does not account for regional differences. This means that the biodiversity value of undisturbed forest – or the biodiversity loss following its conversion to pasture – is the same in Siberia and Amazonia, for example.
- The land use and intensity classes of the MSA characterization factors are coarse. It is not possible to differentiate between the biodiversity impact of different grassland types or management practices associated with livestock production.
- Our approach was restricted to land use, which underestimates the impact on biodiversity because other categories of pressures (e.g. nutrient pollution, climate change, habitat fragmentation) are not addressed.

REFERENCES

Alkemade, R., M. van Oorschot, L. Miles, C. Nellemann, M. Bakkenes, and B. ten Brink. *2009. GLOBIO3: A Framework to Investigate Options for Reducing Global Terrestrial Biodiversity Loss. Ecosystems 12:374-390.*

Alkemade, R , Reid, R.S., Van den Berg, M., De Leeuw, J., Jeuken M. *2012. Assessing the impact of livestock production on biodiversity in rangeland ecosystems. Proceedings of the National Academy of Sciences of the United States of America (PNAS Early edition), doi: http://dx.doi.org/10.1073/pnas.1011013108*

Gerber, P.J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A., Tempio, G. *2013. Tackling climate change through livestock – A global assessment of emissions and mitigation opportunities. Rome: Food and Agriculture Organization of the United Nations.*

Case Study #2

Grazing management to reduce off-site biodiversity impacts in northeastern Australia

The Reef Rescue programme helped fund 130 off-stream watering points and over 160 km fencing of riparian and land types to assist in managing stock access to creeks and river systems on farms

Image: B. Henry.

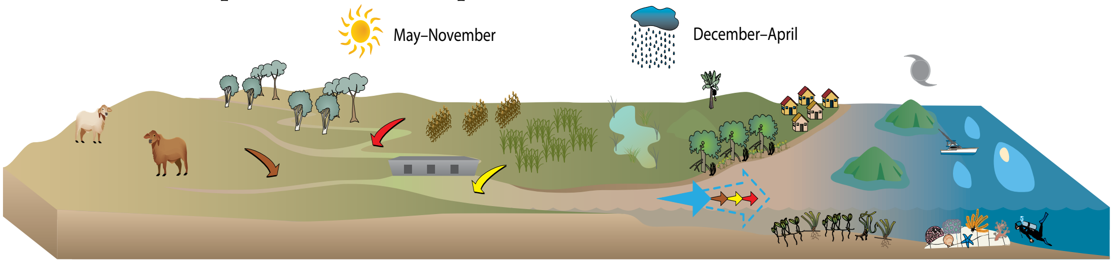
GENERAL PRINCIPLES ILLUSTRATED BY THIS CASE STUDY

System boundaries and off-site impacts

This case study illustrates an approach that integrates information and develops an action plan across management practices, regional/catchment indicators, catchment loads and ecosystem health for the Great Barrier Reef coastal lagoon. It highlights the importance of monitoring across scales and of considering off-site effects of land use for livestock production.

Figure CS2.1

Multiple land uses and impacts in the Great Barrier Reef catchments



The Great Barrier Reef catchments are largely rural and dominated by summer monsoonal rains and occasional cyclones delivering sediments, nutrients and pesticides to the inshore and sometimes offshore portions of the reef in pulsed flows, which can be affected by water reservoirs and dams. Grazing is the largest single land use, and sugarcane, horticulture and other cropping make up other agricultural land uses. Small urban centres are located on the coastal strip. Habitats include wetlands, reef, seagrass and mangrove habitats, and continental and coral islands are present. Reef-based tourism, as well as commercial and recreational fisheries, is an important part of the regional economy.

Source: Image from the Australia and Queensland government's Reef Water Quality Protection Plan First Report Card 2009 Baseline.

Indicators

State indicators for farm to catchment scale include wetland and riparian loss as well as groundcover and catchment loads. Off-site indicators include species change, (e.g. seagrass abundance), and ecosystem status, (e.g. coral cover and macroalgal richness). Response indicators include the percentage of cattle producers implementing the Grazing Best Management Practices as set out in technical information provided under the Reef Plan. Modelled average annual pollutant loads, with simulations over almost 30 years to reduce the influence of climate variability, are compared to baseline conditions of 2009 for reporting purposes on progress.

The case study also provides a practical example of how multiple land uses and natural (e.g. climate variability) and anthropogenic factors can be considered in a programme that aims to improve habitat conditions and ecosystem health for biodiversity values.

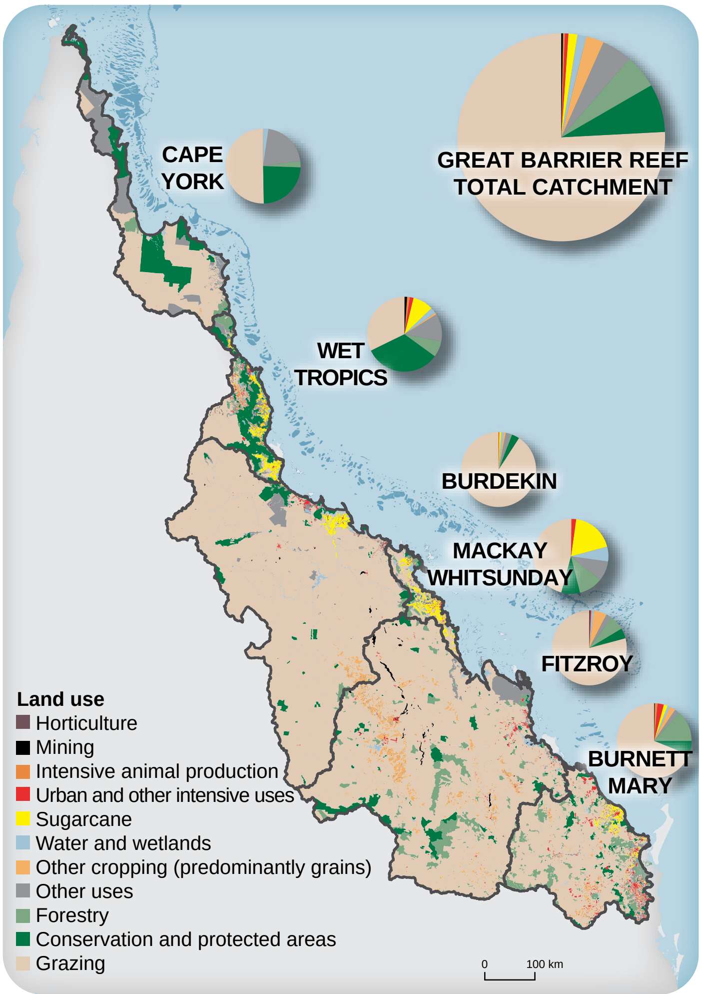
OVERALL OBJECTIVES

This case study demonstrates how management practices for extensively grazed beef cattle can have off-site as well as on-site biodiversity impacts. Biodiversity values in coastal catchments in northeastern Australia include endemic species of plants and animals on land, coastal wetlands and the iconic coral reef communities of the Great Barrier Reef. Complex interactions with natural ecosystems and climate, livestock production, intensive cropping and other human activities such as tourism must be considered in managing these sensitive biodiversity hotspots (Figure CS2.1). This case study describes the implementation of a programme in the Great Barrier Reef lagoon to reduce impacts on biodiversity arising from management of land for livestock production in coastal catchments.

SCALE, USERS AND GOAL

The goal of this case study is to demonstrate the importance of understanding off-site as well as on-site outcomes of livestock management for biodiversity in areas where runoff and water flows have the potential to affect water quality in terrestrial

Figure CS2.2
Land use in the Great Barrier Reef Catchments (http://www.reefplan.qld.gov.au)



Source: Image from the Australia and Queensland government's Reef Water Quality Protection Plan First Report Card 2009 Baseline.

and aquatic ecosystems. The Reef Water Quality Protection Plan was implemented in 2003 with a view to improving water quality and reducing sediment, nutrient and pesticide flows to the coastal lagoons of the Great Barrier Reef. This programme was developed on the basis of sound scientific research to provide guidance on good grazing and cropping practices in major catchments which affect the quality of run-off. Monitoring of outcomes has demonstrated progress and highlighted areas of ongoing concern where accelerated action is required.

DESCRIPTION OF GEOGRAPHICAL AREA AND MAIN DRIVERS

The area of the case study is the coastal catchments adjacent to the Great Barrier Reef lagoons of northeastern Australia (Figure CS2.2). The Great Barrier Reef is the largest coral reef ecosystem in the world and has been listed as a World Heritage site in recognition of the international importance of its ecology and beauty. It extends over 2 300 km along the Queensland coast, covering an area of 350 000 km^2 including over 2 900 reefs as well as extensive seagrass meadows, mangrove forests and soft-bottom habitats. Protecting the biodiversity of the region is important for the continued survival of many iconic and rare species.

DESCRIPTION OF LIVESTOCK SYSTEM

The major livestock system is low-input, extensively grazed beef cattle production. There is a smaller contribution from dairy cattle systems on the better land areas.

DESCRIPTION OF PRIMARY BIODIVERSITY FEATURES

The region has iconic biodiversity value due to the Great Barrier Reef, which represents about 10 percent of the world's total coral reef area. There are also unique terrestrial and wetland ecosystems in the coastal catchments.

MAIN INTERACTIONS BETWEEN LIVESTOCK AND BIODIVERSITY

The most sensitive impact of livestock on biodiversity in the case study region is through the quality of water flowing into the Great Barrier Reef lagoons.

MAIN FINDINGS AND IMPACTS

The Reef Catchments Grazing Programme provides financial assistance to graziers in the region to implement grazing Best Management Practices designed to benefit landscape conditions, including biodiversity, on-site and off-site, and improve the efficiency and long-term viability of cattle production. Periodic 'report cards' provide an estimate of the status of the key indicators in the Plan relative to assessments in 2003 and 2009 giving an historic baseline. Ongoing scientific research, monitoring of response and state indicators identifies progress and where accelerated action is needed. Modelled annual average sediment load, pesticide load and particulate nitrogen load to the GBR has declined by 12 percent, 30 percent and 11 percent respectively from 2009-2014.

FURTHER INFORMATION

http://reefcatchments.com.au/
http://www.reefplan.qld.gov.au

O'Reagain, P.J., Bushell, J.J. *2011. The Wambiana Grazing Trial: Key Learnings for Sustainable and Profitable Management in a Variable Environment. Department of Employment, Economic Development and Innovation.*

O'Reagain, P.J., Brodie, J., Fraser, G., Bushell, J.J., Holloway, C.H., Faithful, J.W., Haynes, D. *2005. Nutrient loss and water quality under extensive grazing in the upper Burdekin river catchment, North Queensland. Marine Pollution Bulletin, 51(1): 37-50.*

Queensland Government *2009. Reef Water Quality Protection Plan 2009. The State of Queensland, Brisbane.*

Case Study #3

Biodiversity conservation and High Country sheep production in New Zealand[1]

GENERAL PRINCIPLES ILLUSTRATED BY THIS CASE STUDY

The case study illustrates how balancing the capabilities of each land type to meet the nutritional requirements of animals maximizes grazing opportunities, identifies areas for resting and recovery, prevents overgrazing and maintains native species. If the balance is not right, vigorous introduced species can take over and native plant species can disappear.

Pressure Indicators. Historical and current farm management practices such as stock type, stocking rate, timing of grazing, fertilizer and seed inputs have reduced or modified indigenous grasslands.

State Indicators. This case study showed the value of a clear methodology for describing the baseline and developing terrestrial and aquatic state indicators for biodiversity on productive sheep pastoral properties.

Response Indicators. Response indicators for management of grazing regimes and subdivision of paddocks were developed based on understanding of sheep grazing behaviour obtained using GPS collars. Between 2005 and 2010, monitoring provided reassurance that, in general, the farming systems that have evolved in the High Country of the South Island are effectively balancing the need for agricultural production with the need to preserve indigenous biodiversity ecosystems. It also confirmed the very high quality of water in High Country waterways compared to streams draining more intensive land use catchments.

OVERALL OBJECTIVES

This case study shows the interaction between historical and current farm management and biodiversity values across a range of New Zealand High Country sheep properties producing fine merino and mid-micro wool. The overall objective was to provide farmers with information and tools to better manage both livestock and biodiversity values within the environments they farmed. Equally important was the provision of robust scientific data to validate claims in regard to sustainable merino production.

SCALE, USERS AND GOAL

The study considered eight High Country merino sheep stations. The properties covered a total of 139 000 ha, carrying 113 000 stock units. Property sizes range from 4 000 – 40 000 ha, averaging 19 720 ha. The properties have similar overarching farming strategies, in that their management is based on pastoral systems.

[1] Prepared by Ministry for Primary Industries, New Zealand, October 2014

The project looked at two spatial scales and provides information for farmers and policy makers, first across eight High Country farms, and second at the scale of individual grazing units within farms. At the farm scale, the project addressed the following questions:

- What are the trends in terrestrial and aquatic biodiversity?
- Are there patterns in biodiversity indices that can be related to management inputs?
- How can the monitoring information be used to develop more sustainable farm management practices?

At the grazing unit scale, specific questions related to the interaction between merino sheep and their environment:

- How do wethers and ewes utilise different parts of the landscape with respect to biodiversity?
- How do wethers and ewes respond in habitat use to different weather conditions?
- How is animal comfort correlated with habitat use and weather conditions?

DESCRIPTION OF GEOGRAPHICAL AREA AND MAIN DRIVERS

The study area spanned an altitudinal gradient of between 300 m and 2500 m in the rain-shadow region to the east of New Zealand's Southern Alps, from the Marlborough to Otago regions (i.e. spanning two-thirds of the South Island, approximately 600 km). This region was dominated in the pre-European period by indigenous, low to mid-altitude tussock grassland sitting below the climatic tree-line. The species are now mainly narrow-leaved snow tussock (*C. rigida*) with slim snow tussock (*C. macra*) at higher altitudes. Moister regions also contain red or copper tussock (*C. rubra* subsp. *cuprea*). These indigenous grasslands have been modified to varying degrees by the indirect or direct effect of human activity – in particular, the over-sowing of legume species (mostly white clover, *Trifolium repens*) and other exotic grass forage species.

DESCRIPTION OF LIVESTOCK SYSTEM

The eight High Country farms have a mix of cultivated flat land, medium slope terrain and high, steep terrain. Farmers face a challenge in balancing the capabilities of these land types to meet the nutritional needs of animals while maintaining indigenous biodiversity. Merino sheep were a substantial part of the management enterprise on all case-study farms.

DESCRIPTION OF PRIMARY BIODIVERSITY FEATURES

The study found four major vegetation groups across all the monitoring sites:

- Vegetation Type 1 – Snow tussock/blue tussock/mouse-ear hawkweed grassland;
- Vegetation Type 2 – Hard tussock/brown-top-sweet verna/mouse-ear hawkweed grassland;
- Vegetation Type 3 – Brown-top-Kentucky blue grass/mouse-ear hawkweed grassland;
- Vegetation Type 4 – Brown-top/hare's-foot trefoil/mouse-ear hawkweed herbfield.

MAIN INTERACTIONS BETWEEN LIVESTOCK AND BIODIVERSITY

Assessment of the interaction between historical and current farm management and biodiversity values across the eight New Zealand High Country sheep properties found that pastoral farming, and in particular past management practices, have reduced or modified these indigenous grasslands.

MAIN FINDINGS AND IMPACTS

The monitoring network comprised 309 land-cover and 54 aquatic monitoring sites.

Land-cover monitoring identified changes in the overall abundance of the 20 most abundant species across the four major vegetation types. Aquatic monitoring collected and evaluated overall condition of High Country waterways and compared this to the overall condition of dairy and sheep/beef farms. Indicators of contamination such as nutrient concentrations and turbidity, recorded across the 40 High Country streams were 2-3 orders of magnitude lower than those recorded for dairy and less than a third of the average sheep/beef farm value. In addition, values for the percentage of total number of taxa and the macro invertebrate community index recorded from the High Country properties were high compared to those recorded in other New Zealand farming systems.

Over the five years covered by the monitoring programme in the study properties, land cover and aquatic systems changed relatively little overall.

FURTHER INFORMATION

NZ Merino Co. *2013. Biodiversity conservation and High Country sheep production. Summary Report. http://maxa.maf.govt.nz/sff/about-projects/search/09-125/biodiversity-conservation-and-high-country-sheep-production-Summary.pdf*

Fact Sheet Developed from the Case Study - http://maxa.maf.govt.nz/sff/about-projects/search/09-125/Biodiversity.pdf

Final Project Report - http://maxa.maf.govt.nz/sff/about-projects/search/09-125/09-125-Final-Report-Web-Update-2013.pdf

Norton, D.A. *2008. Guidelines for preparing whole property management plans for High Country farms (School of Forestry, University of Canterbury, Christchurch). http://maxa.maf.govt.nz/sff/about-projects/search/04-063/guidelines.pdf*

Case Study #4

Plant diversity in traditional livestock systems on the Aran Islands, Ireland

Source: AranLIFE project.

GENERAL PRINCIPLES ILLUSTRATED BY THIS CASE STUDY

State indicators

Designation status (IUCN, continental, national, regional); number of species and habitats on national and European priority list; size (km^2) of designated area; conservation status of habitats (favourable condition, not in favourable condition); species richness; presence of invasive species, area of scrub, change in area of scrub over time.

For priority habitats, the EU Habitats Directive (92/43/EEC) specifies that habitats protected by the Directive must be maintained in 'Favourable Conservation Status' within their range in the member states. The conservation status of a natural habitat is taken as being favourable when:

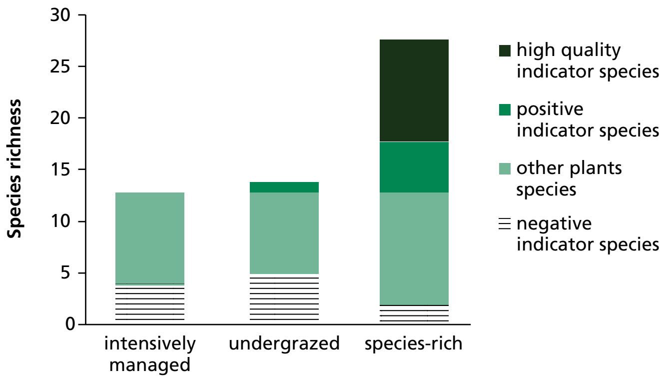
- its natural range and the area it covers within that range is stable or increasing, and;
- the specific structure and functions necessary for its long-term maintenance exist and are likely to remain in existence for the foreseeable future, and;
- the conservation status of its typical species is favourable.

Figure CS4.1
Fields along the grazing intensity gradient

Undergrazed | **Moderately grazed (species-rich)** | **Intensively managed**

Source: AranLIFE project.

Figure CS4.2
Example of the impact of intensive management and undergrazing on the species richness and nature conservation value of calcareous species-rich grasslands on the Aran Islands. The 'high-quality indicator species' include orchids and other plants that are rare in Ireland and Europe. Data from 2m x 2m quadrat samples



Source: AranLIFE project.

For further specific examples, species lists and quantitative indicators exist for vegetation structure for calcareous grasslands, which are important orchid sites. The lists of plant species include high-quality indicator species, positive indicator species, and negative indicator species (see Figure CS4.2). Vegetation characteristics for these grasslands require, for example, a broadleaf herb component of 40-90 percent, and for scrub encroachment by woody species ≤ 10 percent cover.

Midpoint indicators

Livestock density; change in livestock density over time; amounts of inorganic fertiliser applied (kg/ha/yr).

For further specific examples, species lists and quantitative indicators exist for vegetation structure for calcareous grasslands, which are important orchid sites. The lists of plant species include high-quality indicator species, positive indicator species, and negative indicator species (see Figure CS4.2). Vegetation characteristics for these grasslands require, for example, a broadleaf herb component of 40-90 percent, and for scrub encroachment by woody species ≤ 10 percent cover.

Midpoint indicators

Livestock density; change in livestock density over time; amounts of inorganic fertiliser applied (kg/ha/yr).

Response Indicators

Number of farmers participating in conservation programme; expenditure on conservation actions; number of awareness-raising events, workshops and demonstration activities.

Reference state

Without livestock grazing, the species-rich vegetation reverts to species-poor scrub dominated by brambles, blackthorn and hazel, which shade out grassland species. Removing livestock grazing thus has a negative effect on biodiversity.

OVERALL OBJECTIVES

The Aran Islands are a group of three islands located on the western seaboard of Ireland. The islands have long supported traditional, extensive livestock systems. This case study describes appropriate indicators for assessing the interaction between livestock and biodiversity.

SCALE, USERS AND GOAL

This case study demonstrates the dependence of biodiversity on traditional livestock systems in the Aran Islands.

DESCRIPTION OF GEOGRAPHICAL AREA AND MAIN DRIVERS

The Aran Islands exhibit a highly fragmented structure of small farms, with most herds numbering less than 10. Poor economic return from such small holdings is leading to a reduction of farming on the islands, where active farms have decreased by more than 30 percent in the last 15 years due to abandonment and consolidation. The agricultural landscape is traditional, with a rich mosaic of habitats that include a high density of stone walls, and rocky fields with pastures and meadows containing a high diversity of flora.

Since the 1970s the Aran Islands have come under a succession of national and European environmental designations. They have been varyingly classified as ASIs (Areas of Scientific Interest), NHAs (Natural Heritage Areas), SACs (Special Areas of Conservation) and SPAs (Special Protection Areas). Over 75 percent of the total land area of the Aran Islands is now designated as Natura 2000 sites.

DESCRIPTION OF LIVESTOCK SYSTEM

Livestock is traditionally reared in a very extensive beef production system. The High Nature Value farming systems found on the islands (and there are similar areas on the mainland) are dependent on regular grazing at a low stocking density. The main biodiversity features are thus reliant on extensive livestock systems.

DESCRIPTION OF PRIMARY BIODIVERSITY FEATURES

The Aran Islands are an extremely important site for a number of priority terrestrial habitats under the European Habitats Directive (Annex 1). Most of the land in the islands is now designated as EU Natura 2000 sites. Dominated by species-rich grasslands with many orchids and alpine flora, there are also machairs (characteristic dune grasslands), and many plant species of high conservation status.

MAIN INTERACTIONS BETWEEN LIVESTOCK AND BIODIVERSITY

The flora (and associated fauna) have co-evolved as part of a traditional grazing system that is characterized by low stocking density. Grazed areas are distinguished by high floral diversity and include habitats and species of high conservation priority in the European Union (Figure CS4.1 and CS4.2). The main threats deriving from changes to the traditional livestock systems include: land abandonment, undergrazing, inappropriate management practices, intensification, loss of traditional farm knowledge and skills, and lack of understanding and engagement among key stakeholders.

On semi-natural limestone habitats, undergrazing results in increased dominance by a limited number of species such as *Sesleria albicans*, *Molinia caerulea* and a range of bryophytes. Within a few years, plant species diversity is significantly reduced. On sheltered sites, undergrazing is leading to scrub encroachment, particularly *Rubus fruticosus*. Scrub encroachment is thus affecting the conservation status of priority habitats and is threatening future colonisation of new areas.

Some areas are also subject to intensification in the form of ploughing, reseeding and fertilizer application to increase forage production. Such actions can result in the rapid transformation of species-rich vegetation to a type dominated by e.g. *Lolium perenne* and other grasses that thrive on fertilizer applications. Recovery to the original vegetation state can take many decades.

Main findings and impacts

FURTHER INFORMATION

http://www.aranlife.ie/

Case Studies on High Nature Value Farming in Ireland: North Connemara and the Aran Islands. The Heritage Council. 2010

http://www.npws.ie/publications/irishwildlifemanuals/IWM73percent20Limestonepercent20pavement.pdf

Case Study #5

Dairy systems in upland PDO cheese production areas, France

GENERAL PRINCIPLES ILLUSTRATED BY THIS CASE STUDY

Definition of system boundaries

We compared two systems, one importing off-farm feed, the other not. We demonstrate that the area of off-farm land use for feed can be significant and should be measured. We also illustrate one way to estimate this area with easily accessible information.

Quantification of biodiversity state and of the effect of practices based on a regional grassland typology

For the user, using this typology to identify grassland types and to derive the associated biodiversity indicators requires a limited level of expertise. It relies on identification of the dominant grass species and flowering plant species used as indicators. The typology is user-friendly and, being underpinned by science (mainly plot-scale experiments), also allows quantification of biodiversity and various ecosystem services. Its use leads to consistency across hierarchical spatial scales: plot, farm and landscape (this last scale is not shown here).

Multiple state indicators

These cover both the species (plant species richness and rarity index) and ecosystem levels (pollination, carbon sequestration, patrimonial and landscape interest).

OVERALL OBJECTIVES

This case study emphasizes the multiple state indicators covering both species and ecosystem levels in species-rich humid grasslands in Central France. Community structure and species richness of plants and insects are recorded at plot scale under different management regimes, while a user-friendly grassland typology underpinned by science leads to consistency among hierarchical scales: plot, farm and landscape. This tool also allows analysis of multiple ecosystem functions in grassland and associated ecosystem services so that farmers know how to adapt management practices in order to preserve and benefit from grassland diversity.

SCALE, USERS AND GOALS

- To propose win-win strategies for pasture management that combine good production levels with biodiversity preservation. Research is conducted at the plot scale, and is based on either medium- or long-term surveys of biodiversity dynamics under contrasting management rules,
- To construct a science-based typology, which includes an in-depth description of the 23 main types of grasslands observed in the dairy systems of certified Protected Designation of Origin (PDO) geographical areas. This allows an overview of grassland biodiversity and of the relative ability of each grassland

type to provide services (agronomic, ecological and quality of dairy products). It thus offers a basis for discussion with livestock farmers when it comes to the question of adapting management practices (Carrère *et al.*, 2012).

- To design and evaluate innovative dairy systems that combine good economic performance and reduced environmental footprints. Interdisciplinary research is conducted in two contrasting systems (on an experimental farm) that differ according to grassland diversity, management rules, use of off-farm concentrate feed, etc. (Pomiès *et al.*, 2013; Farruggia *et al.*, 2014). Management is kept relatively constant for 4-5 years to allow systems to adapt before being modified to test for a new set of rules.

Users are farmers, agricultural advisers, Protected Designation of Origin (PDO) inter-branch organizations, NGOs involved in biodiversity conservation, and land managers. Our aim is to produce both references and tools.

DESCRIPTION OF GEOGRAPHICAL AREA AND MAIN DRIVERS

In the French Massif Central, a region dominated by semi-natural grasslands, PDO dairy production and tourism are the main drivers of the local economy. These semi-natural upland grasslands are usually species-rich and are important refuges for insect populations (including butterflies and bumblebees). The type of grass fed to cattle contributes to the typical flavour (and nutritional properties) of traditional cheese.

DESCRIPTION OF LIVESTOCK SYSTEM

Dairy farming systems are dominant in this area, with farmers engaged in the PDO cheese supply chain, including farmhouse cheese producers. The main sustainability challenge is to reconcile the agricultural and environmental performances of these systems in an environment with strong emphasis on biodiversity conservation. These are grassland-based systems with a stocking rate between 0.8 and 1.1 LU/ha. Technical challenges are related to an efficient use of grasslands to minimize feed and fertilizer inputs while complying with specifications of the PDO inter-branch organization.

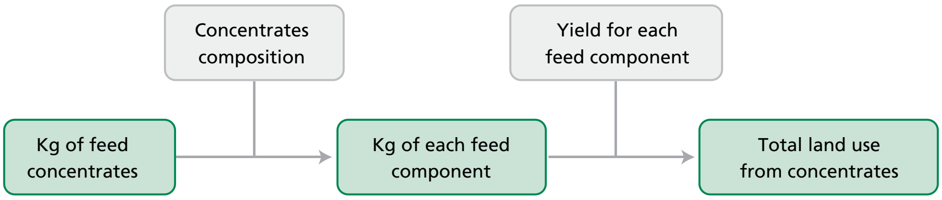
DESCRIPTION OF PRIMARY BIODIVERSITY FEATURES

Grassland diversity: 23 types of semi-natural upland grasslands are relevant regionally High species richness in grasslands for plants and insects (e.g. Dumont *et al.*, 2009), with some red-list species (e.g. butterfly *Maculinea arion*), iconic species (*Narcissus jonquilla*) or endangered habitats (peatlands)

MAIN INTERACTIONS BETWEEN LIVESTOCK AND BIODIVERSITY

In semi-natural grasslands, species diversity is known to decline as the result of grassland intensification (fertilization, stocking rate [Dumont *et al.*, 2009]). An alternative rotational grazing in which some of the plots are excluded from grazing at flowering peak can benefit flower-visiting insects, but presents risk for farmers in terms of providing livestock with sufficient forage under unfavourable grass growth during spring (Farruggia *et al.*, 2012). Biodiversity is also assumed to be higher at the farm/landscape levels when a wider range of grassland types is maintained.

Figure CS5.1
Main steps to compute land use from concentrates used in the two farms



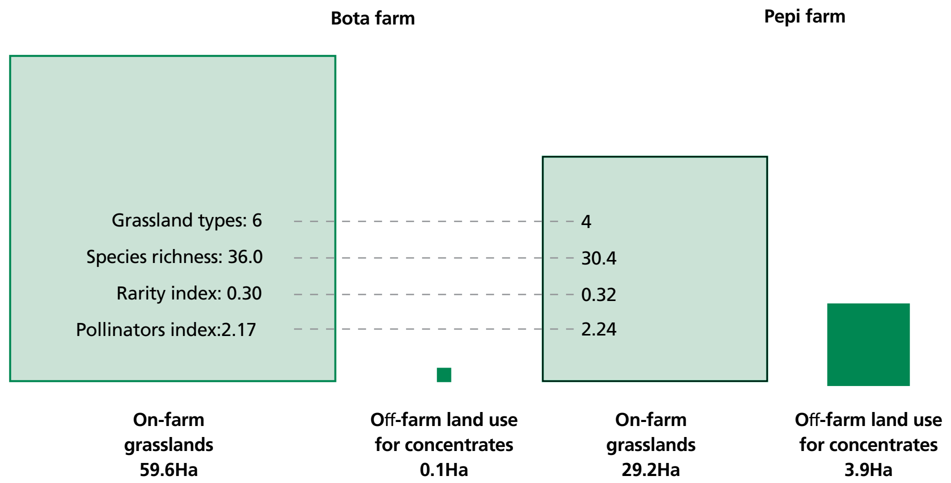
MAIN FINDINGS AND IMPACTS

We compared two dairy farms for biodiversity performance in their on-farm grassland area and for their use of off-farm feed. System 'Bota', used by one, was an almost exclusively grassland-based system while 'Pepi',used by the other, also relied on the use of concentrates. The grassland typology described in this case study gives the value of various production and sustainability indicators for different grassland types. We computed the mean value of four biodiversity indicators for each farm: the number of grassland types; the species richness (average number of species per plot); the rarity index of plant species (relative value varying between 0 and 0.65); and a pollinator index (relative score varying between 1 and 3).

The annual consumption and composition of the different types of concentrates used by the Pepi farm, i.e. the percentage of each feed components (e.g. barley, maize, triticale, rapeseed) was available so the equivalent consumption of each feed component in kg could be computed. FAOSTAT yield data were used to estimate the land use associated with this feed consumption (Figure CS5.1).

In the Bota farm, the estimated off-farm area corresponding to feed concentrates use was very low, at 0.1 ha, while the farm included 59.6 ha of grassland (Figure CS5.2). In the Pepi farm, the off-farm area for feed concentrates represented 3.9 ha, i.e. approximately 13 percent of the on-farm grassland area. Depending on the relative impact of grassland and feed crops on biodiversity, these 13 percent of off-farm feed could make a significant contribution to the total biodiversity impact of the farm. For instance, Case Study 1 estimated that on average, off-farm feed accounts for 23 percent of the total land use impact of French dairy farms. There was a higher diversity of grassland types within the Bota farm and higher plant species richness. Rarity and pollinator indices were similar for the grassland area of the two farms. There was no straightforward correlation between the biodiversity indicators computed on the farm and the use of off-farm feed. It showed the importance of not focusing solely on on-farm measures but estimating off-farm impacts as well.

Figure CS5.2
Land use and on-farm grassland characteristics in the two farms



FURTHER INFORMATION

Carrère, P., Seytre, L., Piquet, M. *et al., 2012. A multifunctional typology of grassland in AOP-certified dairy systems in the Massif Central combining and agronomic and ecological approach. Fourrages, 209: 9-21*

Dumont, B., Farruggia, A., Garel J.P., Bachelard, P., Boitier, E., Frain M., *2009. How does grazing intensity influence the diversity of plants and insects in a species-rich upland grassland on basalt soils? Grass For. Sci., 64: 92-105*

Farruggia, A., Dumont, B., Scohier, A., Leroy, T., Pradel, P., Garel J.P., *2012. An alternative rotational stocking management designed to favour butterflies in permanent grasslands. Grass For. Sci., 67: 136-149*

Farruggia, A., Pomiès, D., Coppa, M. *et al., 2014. Animal performances, pasture biodiversity and dairy product quality: How it works in contrasted mountain grazing systems. Agriculture, Ecosystems & Environment 185: 231-244*

Pomiès, D., Martin, B., Pradel, P. *et al., 2013. Design of low-input dairy farming systems in mountain areas: animal performance and cheese sensory properties. In: 17th Meeting of the FAO-CIHEAM Mountain Pasture Network, 5-7 June 2013, Trivero, Italy, pp. 22-26*

Case Study #6

Mobile and sedentary models of extensive livestock keeping compared along the Conquense Drove Road in Eastern Spain

The Conquense drove road crosses agricultural land and is therefore both a source of landscape heterogeneity and a vector for organism dispersal

Image: Raquel Casas Nogales.

GENERAL PRINCIPLES ILLUSTRATED BY THIS CASE STUDY

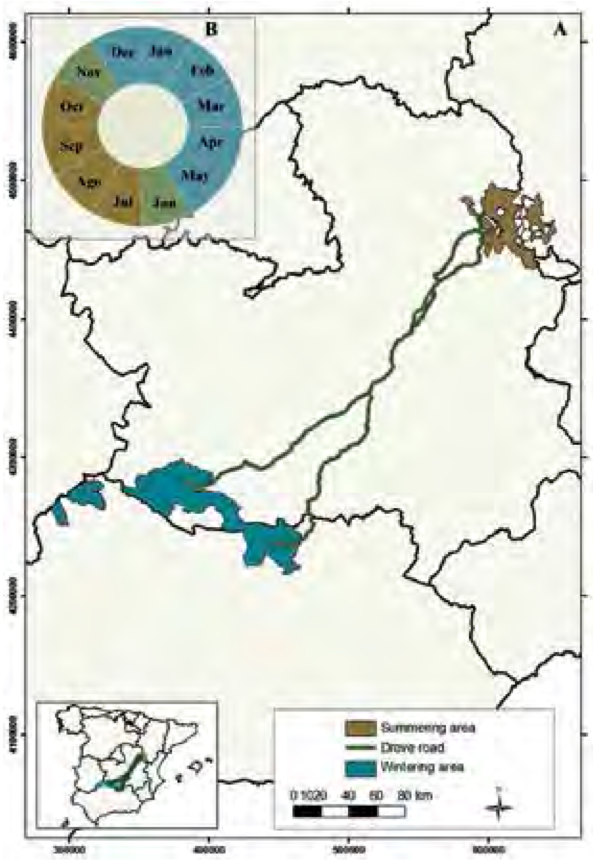
Pressure indicators

Management type, fossil fuel use.

State indicators

Measures of biodiversity and biodiversity loss, Red List Species indicators, tree regeneration rate, genetic structure of plant populations.

Figure CS6.1
Study area map, with summer and winter areas (A) and annual cycle of transhumant movements on the hoof. (B)



Source: Reproduced from: www.ecologyandsociety.org/vol18/iss3/art33/figure1.html.

Response indicators

Agro-environmental schemes supporting transhumance; contribution to resilience to climate change.

Reference state

This case illustrates how the reference state without livestock lacks drivers for heterogeneity, which actually leads to lower biodiversity than states under moderate use.

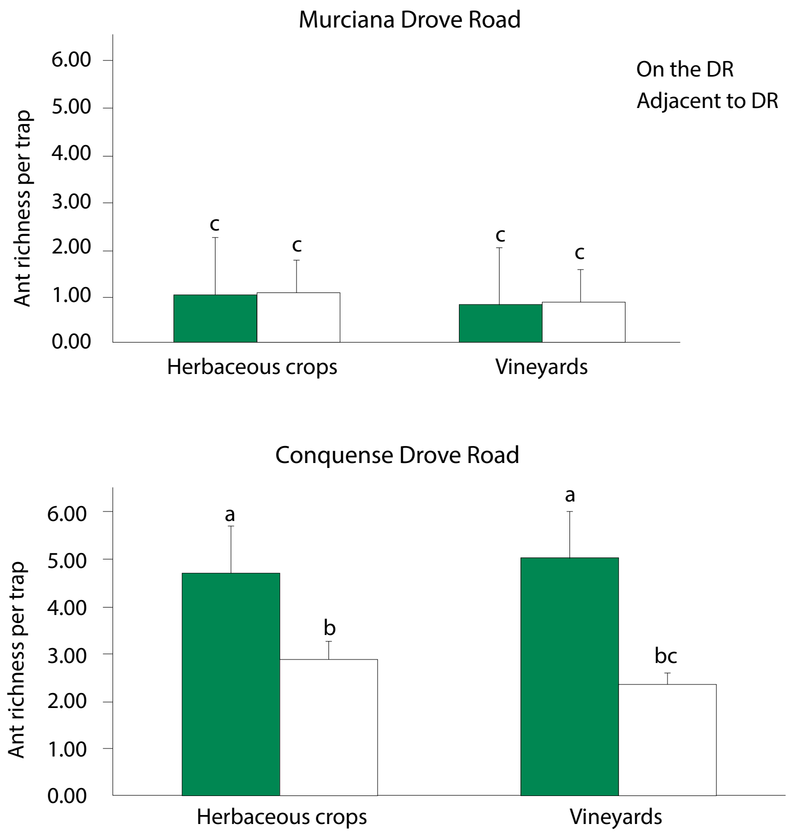
Setting the boundaries

In this case study, it is clear how boundaries are variable depending on the system considered. Mobile systems or intensive systems depending on external inputs have much wider boundaries than intermediate systems in the intensification gradient.

OVERALL OBJECTIVES

To compare the environmental impacts of sheep-grazed systems along an intensification gradient, including:

Figure CS6.2
Biodiversity indicators are consistently higher in drove roads under use than in abandoned drove roads



Source: Hevia *et al.* (2013).

- transhumant sheep performing semi-annual, 600-km-long displacements on the hoof;
- transhumant sheep performing the same displacements by lorry;
- sedentary sheep under extensive conditions, semi-intensive sedentary sheep, sheep on feedlots.

All of these systems occur in the same geographical area. This is exceptional as the most extensive practices are usually abandoned when countries become industrialized.

SCALE, USERS AND GOAL

The scale of the study encompasses a whole ecosystem bounded by summer and winter pastures. We aimed to know the effects on the environment of intensification vs. extensification in order to inform policy decisions in the livestock sector.

DESCRIPTION OF GEOGRAPHICAL AREA AND MAIN DRIVERS

Spain has a rich transhumance history dictated by the climatic and geographic configuration of the country. Wide areas are under a combination of ecosystems that include:

- lowland areas to the south with the typical Mediterranean summer droughts and winter rains
- highland areas to the north with orographic-related summer rains and heavy winter frosts
- connection areas that experience two semi-annual plant productivity peaks

The climatic conditions have promoted the practice of transhumance since ancient times. The Conquense drove road is the only one of the whole medieval drove road system that has remained in use in its full length up to the present day. It extends along 600 km and it has been conserved because of the presence and continuous use of bullfighting herds.

DESCRIPTION OF THE LIVESTOCK SYSTEM

About 10 000 head of the sheep in the study walk between their seasonal pastures. Additionally, some 20 000 sheep practice motorized transhumance, while there are extensive, sedentary sheep farms both in the summer and winter pastures. Meat industry located in the summer pastures area facilitates specialized, intensive farming.

DESCRIPTION OF PRIMARY BIODIVERSITY FEATURES

Spain is the major host of biodiversity in Europe, with some 5 000 plant species. Largely untouched by glaciation during the last ice age, the country's mostly rugged terrain multiplies ecological niches and causes frequent biogeographic island effects. The predominant semi-arid climate in the country further facilitates biodiversity.

MAIN INTERACTIONS BETWEEN LIVESTOCK AND BIODIVERSITY

Extensive livestock is found in most of the mountainous and dry areas found in the country. Its role as a biodiversity-maintaining force has been identified in ecosystems subjected to heavy perturbation following the end of the ice age. Many species are dependent on grazing: lack of it leads to shrub encroachment and the closing of landscapes. Dispersal mechanisms mediated by livestock have also been measured, and identified as very important.

PRINCIPLES, FRAMEWORK, DATA, TOOLS OR STATISTICAL APPROACHES USED

Comparative approaches were adopted to characterize the impact of the different livestock management types. LCA and fossil fuel analyses were performed along all the livestock intensification gradient. The impact of management type on tree regeneration in dehesas (savanna-like landscapes with live oaks scattered among pastures) was measured, and the effects of the various sheep management systems (sedentary, motorized and walking transhumance) compared. The contribution of drove roads to spatial heterogeneity and the creation of habitats for arthropods, especially harvester ants as a bioindicator and wild bees as providers of pollination services, was examined. The impact of drove-road-mediated seed dispersal on the genetic structure of plant populations was also investigated.

MAIN FINDINGS AND IMPACTS

A clear positive correlation between fossil fuel use, channelled water and fodder use, on the one side, and degree of intensification, on the other, can be observed. For example, fuel and fodder consumption in the sedentary extensive system is four times larger than at transhumance on the hoof. This has clear consequences for biodiversity both at the global scale (oil spills, infrastructure build-up, landscape transformation, climate change) and at the local scale (grazing abandonment). Tree regeneration was also observed to be negatively affected by intensification along the whole gradient. Drove roads decisively contribute to habitat heterogeneity in non-pasture landscapes and they act as a general species reservoir when crossing agricultural landscapes and a reservoir for species typical of open spaces when crossing forests. The collection of results on the genetic structure of populations is continuing.

FURTHER INFORMATION

Azcárate, F.M., Robleño, I., Seoane, J., Manzano, P., Peco, B. *2013. Drove roads as local biodiversity reservoirs: effects on landscape pattern and plant communities in a Mediterranean region. Applied Vegetation Science 16: 480-490.*

Carmona, C. P., Azcárate, F. M., Oteros-Rozas, E., González, J. A., Peco, B*. 2013. Assessing the effects of seasonal grazing on holm oak regeneration: Implications for the conservation of Mediterranean dehesas. Biological Conservation 159: 240–247.*

Casas Nogales, R., Manzano Baena, P. *2010. Hagamos bien las cuentas. Eficiencia y servicios de la trashuman-cia en la Cañada Real Conquense. II Congreso Nacional de Vías Pecuarias, Cáceres, Spain, 302-315.*

Hevia, V., Azcárate, F.M., Oteros-Rozas, E., González, J.A. *2013. Exploring the role of transhumance drove roads on the conservation of ant diversity in Mediterranean agroecosystems. Biodiversity and Conservation 22: 2567-2581.*

Hevia, V., Bosch, J., Azcárate, F.M., Fernández, E., Rodrigo, A., Barril-Graells, H., González, J.A. *2016. Bee diversity and abundance in a livestock drove road and its impact on pollination and seed set in adjacent sunflower fields. Agriculture, Ecosystems and Environment 232, 336–344.*

Manzano, P. & Casas, R. *2010. Past, present and future of trashumancia in Spain: nomadism in a developed country. Pastoralism: Research, Policy and Practice (Practical Action) 1: 72-90.*

Case Study #7

A large-scale, wide-scope biodiversity monitoring programme links multi-taxa biodiversity to land use supporting livestock production in western North America

GENERAL PRINCIPLES ILLUSTRATED BY THIS CASE STUDY

State indicators

Comprehensive, multi-taxa species occurrence and aggregated richness indices; habitat conversion, fragmentation, and degradation.

Data integrity

Data are publicly available and consistent data collection methods are used.

Scoping of system boundaries

The scope of the data extend from extensive rangeland to intensive crop production for feed, whether on-farm or off-farm.

Linking Pressure-State-Response Indicators

The index of Biodiversity Intactness links Pressure Indicators (e.g. land use) to biodiversity.

State Indicators

Reference state: in its calculation of Biodiversity Intactness, The Alberta Biodiversity Monitoring Institute (ABMI) uses all native grassland, including rangeland, as reference state. This is consistent with the premise that plant species in this region co-evolved with grazing pressure from bison, and that the pressure from cattle grazing can be largely analogous to that of bison.

Scale

This case study is most applicable at the intermediate scale (supply chain, territory), although there are applications of information at the small and large scales as well.

OVERALL OBJECTIVES

ABMI operates a large-scale monitoring programme producing publicly-available information on biodiversity and land use. Comprehensive land cover, land use, and multi-taxa species monitoring is performed at 1 656 permanent sampling sites arranged in a systematic grid across the Canadian province of Alberta.

SCALE, USERS, AND GOAL

ABMI operates at the provincial scale. The province of Alberta is 661 848 km^2, making it one of few biodiversity monitoring programmes of its depth and extent. ABMI operates at arms-length from government and industry, and is thus well-positioned to deliver on its goal of providing high-quality information on biodiversity to a host of users, including government, NGOs, academia, and industry.

DESCRIPTION OF GEOGRAPHICAL AREA AND MAIN DRIVERS

Livestock production occurs throughout much of Alberta, which is predominantly composed of grassland (prairie) in the south, transitioning to savannah and forest in the north, with livestock production occurring throughout, but less so in forested areas. Prior to the late 1800s, the area supported bison herds, and fire was a common natural disturbance. This region comprises the northernmost extent of the North American Great Plains, and the climate is continental with drought an important climatic driver. Soils are fertile, and much of the region, especially the prime agricultural soil, has been converted to cultivated annual cropland, although habitat conversion has not been as pronounced as in the rest of the Great Plains. As a major economic driver in the region, activities related to petroleum energy production, such as well sites, contribute to rangeland habitat conversion, degradation, and fragmentation.

DESCRIPTION OF LIVESTOCK SYSTEM

Alberta is home to 4.9 million beef cattle, generating approximately $3.1 billion farm income annually. Ranchers use a variety of grazing management practices ranging from high- intensity rotational grazing, to low-intensity continuous grazing. Cattle generally spend a portion of their lives in feedlots, where feed is derived from crops such as barley and oats. Most of the feed is sourced locally.

DESCRIPTION OF PRIMARY BIODIVERSITY FEATURES

Rare habitat: globally, temperate grassland is one of the most converted and least protected ecosystems. These species-rich grasslands are habitat for rare and endangered species, such as the burrowing owl, sage grouse, piping plover, and swift fox. A variety of native mammals including bears, pronghorn antelope, elk, wolves, and deer share use of the grassland with cattle. It also provides habitat for diverse pollinators.

MAIN INTERACTIONS BETWEEN LIVESTOCK AND BIODIVERSITY

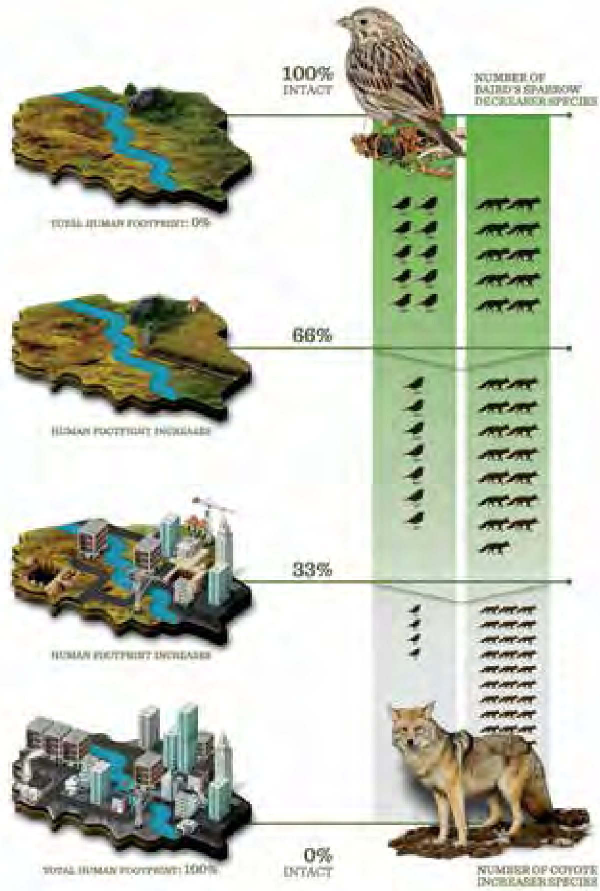
The data come from a variety of land uses associated with livestock production – from cropland with relatively low biodiversity value, to extensively grazed native grassland with high biodiversity value, and thus illustrate many of the possible relationships between livestock and biodiversity.

PRINCIPLES, FRAMEWORK, DATA, TOOLS OR STATISTICAL APPROACHES USED

ABMI uses site-level data to develop statistical models linking land cover and land use to species abundance. These models are coupled with remotely-sensed land use and land cover data and averaged across species to estimate an overall index of Biodiversity Intactness at the landscape scale (Figure CS7.1). Another tool employed at the monitored sites is the Range Health Assessment developed by the Government

Figure CS7.1

The Biodiversity Intactness Index ranges from 0 percent to 100 percent. At 100 percent intact, the abundance of both species is equal to the abundance expected in an undisturbed area with 0 percent human footprint. As the intactness index declines toward 0 percent, there is a change in the abundance of a species in response to human footprint. For the Baird's Sparrow, a grassland specialist species, a decrease in numbers is observed; for the Coyote, which thrives in disturbed habitat, an increase in numbers is found (ABMI, 2011)



Source: The Alberta Biodiversity Monitoring Institute. 2013. The ABMI Biodiversity Intactness Index. Alberta Monitoring Monitoring Institute, Alberta, Canada. Available at www.abmi.ca.

of Alberta (Adams, 2009). Grassland sites are scored on a variety of criteria including litter production, weed cover, and plant community composition, to provide information on grassland condition.

MAIN FINDINGS AND IMPACTS

Although the reporting of Biodiversity Intactness specifically for land uses associated with livestock production is in progress, Biodiversity Intactness has been reported as 53 percent in Alberta's prairie region (ABMI, 2015), where land use is largely dedicated to supporting livestock production.

FURTHER INFORMATION

Adams, B.W., Ehlert, G., Stone, C., Alexander, M., Lawrence, D., Willoughby, M., Moisey, D., Hincz, C., Burkinshaw, A., Carlson, J., and France, K., *2009. Range Health Assessment for Grassland, Forest, and Tame Pasture. Public Lands and Forests Division, Alberta Sustainable Resource Development. Pub. No. T/-44.*

Alberta Biodiversity Monitoring Institute*. 2015. The Status of Biodiversity in the South Saskatchewan Planning Region: Preliminary Assessment. Alberta Biodiversity Monitoring Institute, Alberta, Canada. Report available at www. abmi.ca.*

Alberta Biodiversity Monitoring Institute*, 2011. The Status of Biodiversity in the South Saskatchewan Planning Region: Preliminary Assessment. (00063) Version 2011-08-13. Alberta Biodiversity Monitoring Institute, Alberta, Canada. Report available at www. abmi.ca. Published August 2011.*

Case Study #8

Distribution of large herbivores in relation to environmental and anthropogenic factors in East African savannah ecosystem

GENERAL PRINCIPLES ILLUSTRATED BY THIS CASE STUDY

Illustration of possible indicators

Because of its biodiversity and ecological significance, Serengeti National park has been listed by the UNESCO as a World Heritage Site. As a national park, it is designated as a Category II protected area, which means that it should be managed either through a legal instrument or through other effective means so as to protect the ecosystem or ecological processes as a whole.

Midpoint indicators

Wildlife density and livestock density; long-term monitoring of both wildlife and livestock in protected and pastoral areas. Wildlife and livestock counts have been conducted in the Serengeti-Mara Ecosystem (SME) for the last 40 years, forming the benchmark. Human impacts on the system have also been studied.

Response Indicators

Since 2007, more than 100 conservancies have been developed and signs of improvement of biodiversity in these landscapes are increasing. In many of these conservancies livestock keeping is an integral part of land use.

OVERALL OBJECTIVES

In African savannahs, native wildlife and humans have coexisted for centuries under moderate traditional human activities. However, because of intensifying anthropogenic activities, strong gradients often emerge between protected areas and surrounding human-dominated pastoral ranches, creating spatial heterogeneity in predation risk, resource availability and quality. Consequently, locations with conditions that maximize the net effects of forage availability and quality and minimize predation risk will support above-average herbivore abundance.

SCALE, USERS AND GOAL

This case study demonstrates the dependence of large wildlife herbivores on traditional livestock systems in African savannah ecosystems.

DESCRIPTION OF GEOGRAPHICAL AREA AND MAIN DRIVERS

The Greater Serengeti-Mara Ecosystem (GSME) is undoubtedly one of Africa's most iconic regions with a long history of popular, human and scientific interest. It stretches across two countries, Kenya and Tanzania, and covers a total area of about 25 000 km^2.

The region is characterized by high spatial heterogeneity in human pressures, yielding a "natural experiment" for studying how drivers of change affect ecosystem services. The GSME is surrounded by pastoral and agro-pastoral communities.

DESCRIPTION OF LIVESTOCK SYSTEM AND PRIMARY BIODIVERSITY FEATURES

The livestock system in SME consists of both pastoral and agro-pastoral systems, with high densities of both wildlife and livestock but with increasing populations of livestock and people. The ecosystem hosts about 1.8 million migratory wildebeest, more than 600 000 plain zebras, more than 300 000 Thomson gazelles, more than 3 000 elephants, about 3 000 lions, about 9 000 spotted hyenas and many other antelope and carnivore species.

MAIN INTERACTIONS BETWEEN LIVESTOCK AND BIODIVERSITY

The dominant traditional conservation paradigm emphasizes the importance of national parks and reserves in protecting terrestrial biodiversity against human activities. This paradigm implicitly assumes that human activities such as agricultural and livestock production predominantly harm wildlife.

PRINCIPLES, FRAMEWORK, DATA, TOOLS OR STATISTICAL APPROACHES USED

Multivariate semi-parametric quantile regression analysis was adopted to relate herbivore density to a Normalized Difference Vegetation Index (NDVI) (considering seasonal, annual and lagged components); livestock density/mean density; distance to the nearest river; total wetness index (TWI); and human population density measured within each grid cell in each of the three landscapes (park, inner and outer group ranch) covering the entire Mara ecosystem, for each species and season. The model enabled exploration of how density responds to variation in the covariates near its upper limit, a region more relevant to understanding variation in hotspots of abundance than the median.

MAIN FINDINGS AND IMPACTS

These results reveal how competition with, and facilitation by, livestock, predation risk, forage quantity and quality and water interact with life history traits, seasons and land use in shaping the dynamics of herbivore hotspots in protected and human-dominated savannahs.

In response to the changes occurring in pastoral areas, wildlife conservancies have recently been formed as part of new initiatives aimed at enhancing wildlife conservation and improving the livelihoods of pastoralists through partnerships with private investors. Through the partnerships, both managers and communities are managing land in a way that benefits both conservation and pastoral livelihoods.

Our analytical approach may be used to assess the extent to which these conservation efforts are beneficial to wildlife by comparing changes in wildlife densities in grid cells located within the conservancies before and after their formation, against changes occurring in the same period in similar grid cells located deep within neighbouring, benchmark protected reserves.

FURTHER INFORMATION

Bhola, N., Ogutu, J.O., Said, M.Y., Hans-Peter Piepho, Olff, H. *2012. The distribution of large herbivore hotspots in relation to environmental and anthropogenic correlates in the Mara region of Kenya. Journal of Animal Ecology, 18: 1268-1287.*

Reid, R.S., Nkedianye, D., Said, M.Y., Kaelo, D., Neselle, M., Makui, O., Onetu, L., Kiruswa, S., Ole Kamuaro, N., Kristjanson, P., Dickson, N.M., Clark, W.C. *2009. Evolving models to support communities and policy makers with science: balancing pastoralism and wildlife conservation in East Africa. Proceedings of the National Academy of Science, www.pnas.org_cgi_doi_10.1073_pnas.0900313106.*

Case Study #9

Comparing direct land use impacts on biodiversity of conventional and organic milk in Sweden[2]

GENERAL PRINCIPLES ILLUSTRATED BY THIS CASE STUDY

LCA approach

This case study shows the possibility of adapting a clear LCA methodology for applying a biodiversity indicator and solving the drawbacks suggested due to the lack of data.

Characterization factors

The factor proposed by de Baan *et al.* (2013) is easy to apply and consistent over ecoregions on a global level. The inclusion of the biodiversity weighting factor makes it possible to compare varying intensity of agricultural practice and account for specific regions in more detail. Relative species richness can be a suitable indicator if regional differences in absolute species richness are included.

Although organic land requires about twice the area than that required for conventional milk production, the direct impacts on biodiversity were less than half. This illustrates the importance of differentiating land occupation characterization factors CF_{Occ} depending on the land use intensity (e.g. organic versus conventional).

This case study provides guidelines on how to adapt life cycle impact methods to assess and compare different livestock scenarios. Results show the importance of the inclusion of feed production as part of the whole life cycle of milk production.

OVERALL OBJECTIVES

This case study can be used as an example of how to quantify direct land use impacts on biodiversity in a Life Cycle perspective based on the methodology presented in de Baan *et al.* (2013) and Mueller *et al.* (2014). The main purpose of the study was to compare land use in organic and conventional milk production and its effects on biodiversity in Sweden. The overall objective of this case study was to provide guidelines to technicians regarding which data need to be collected for inventory as well as help with the development of specific characterization factors and the interpretation of the results.

SCALE, USERS AND GOAL

The study carried out by Mueller *et al*. (2014) was to assess direct land use impacts of 1kg of milk leaving the farm gate. The project looked at the whole life cycle of milk production, focusing on biodiversity impacts from land use based on livestock feed production. Following the framework of the United Nations Environment Programme/Society of Environmental Toxicology and Chemistry Life

2 Based on Mueller *et al.* (2014)

Table CS9.1: Bioma corresponding to the different crops and land cover

Bioma	Crop	Land cover
Temperate broadleaf and mixed forests	Legumes	Arable
	Grains	Arable
	Rapeseed	Arable
	Sugar beet	Arable
	Pastures/Meadows	Permanent
Tropical and subtropical grass-/shrublands and savannahs	Soy bean	Arable
Tropical and subtropical moist broadleaf forest	Oil Palm	Permanent

Cycle Initiative (Milà i Canals *et al*., 2013; Koellner *et al*., 2013a, b), the authors distinguished two land use impacts: land occupation (using land) and land transformation (changing the land use). The Biodiversity Damage Potential (BDP) of land use can be calculated as the sum of the transformation and of the occupation impacts.

DESCRIPTION OF GEOGRAPHICAL AREA AND MAIN DRIVERS

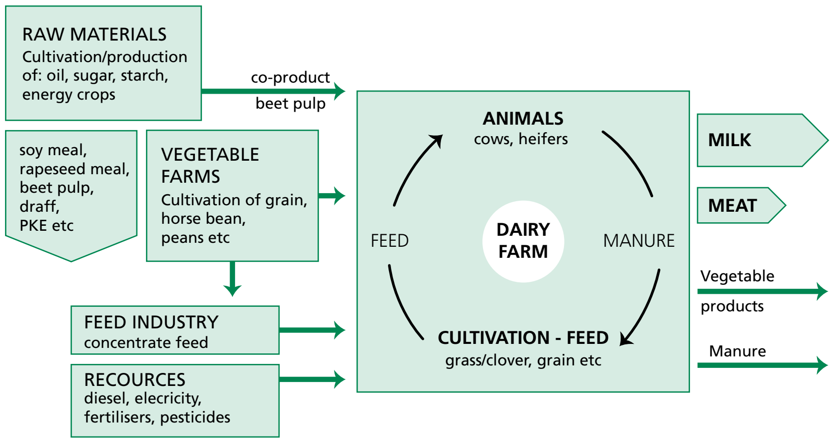
Livestock farms were located in western Sweden, in the Halland and Vastra Göteland regions. Direct land use impacts due to feed production were ascribed to the region in which the crop was most likely to be cultivated according to Cederberg and Flysjoe (2004) and, in the case of organic soy, according to the Research Institute of Organic Agriculture FiBL (2012), (Table CS9.1).

In this study, it was assumed that the land was occupied for one whole year for most crops, as in temperate latitudes only one fodder crop can be grown per year and oil palm fruit, meadows and pastures are cultivated permanently (Milà i Canals *et al*., 2013). For transformation impacts or land use change, the authors calculated the inventory data for transformed area as proposed by Milà i Canals *et al*. (2013). This approach only associates direct land transformation with a fodder crop if (i) in its country of origin the harvested area of that specific crop increased in the last 20 years and if, additionally (ii), the area of its land use type (i.e. arable land, permanent crops or meadows and pastures) increased. In case these two conditions applied, the transformed area for every occupied hectare and year was calculated by dividing the increase in land use type area over the last 20 years by the current area of this land use type (as proposed in Milà i Canals *et al*., 2013).

DESCRIPTION OF LIVESTOCK SYSTEM

Data for livestock feed assessment were collected from 15 dairy farms, nine high-intensity conventional farms and six organic ones. Conventional farms purchased more concentrated feed, 2 951 kg per cow/year, as they had more cows (65 cows per farm). In contrast, the average number of cows on organic farms was 39, with 1 457 kg of feed purchased per cow/ year. The functional unit (FU) of the study was "1 kg of energy-corrected milk per cow/ year" leaving the farm gate, i.e. transportation and processing of raw milk were excluded. Roughage feed in the diets of organic cows resulted in lower milk yields from organic, 9 400 kg compared to 10 100 kg from conventional cows.

Figure CS9.1
Flow diagram for a farm production of milk



Source: Cederberg and Flysjoe 2004.

DESCRIPTION OF PRIMARY BIODIVERSITY FEATURES

The Biodiversity Indicator used to express potential livestock damage was calculated as relative species richness, and a biodiversity weighting factor was applied to account for differences in absolute species numbers as well as conservation value between ecoregions, as recommended in de Baan *et al.* (2013). Analysis was restricted to vascular plants because data availability for organic land use types is relatively good for this taxon.

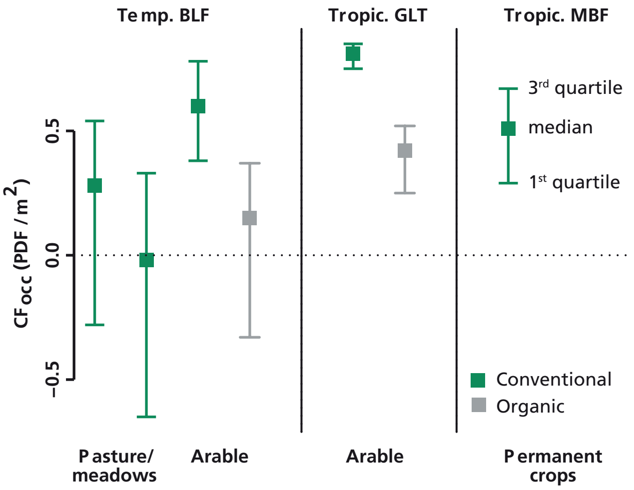
As sampling area varied strongly among studies, sampled species richness (S) was standardized to an area (A) of 100 m² using the transformed power model of the species–area relationship proposed in Kier *et al.* (2005), where z is the species accumulation factor:

$$S_{100\,m^2} = S_{sampled}\left(\frac{A_{100\,m^2}}{A_{sampled}}\right)^z$$

The biodiversity weighting factor was based on absolute species richness, irreplaceability and vulnerability:

- *Data*: to solve the lack of data on organic land uses or data from the biome sub-tropical grassland, shrubland and savannahs, the authors performed a search of the scientific database on the Web. Overall, this search resulted in 66 studies, providing 111 data points for the different land use types and 53 data points for the reference situations in three different biomes of feedstock production for Swedish milk.
- *Biodiversity weighting factor*: the three indices to quantify the biodiversity value of each ecoregion were calculated as follows:
  - Absolute species richness (S) was calculated as area-corrected total number of amphibian, reptile, mammal and bird species per ecoregion.

Figure CS9. 2
Box and whisker plot of characterization factors of a) occupation (CFOcc) for each land use type, farming practice and biome. b) transformation (CFTrans) for each farming practice, biome and land use type regenerating to after human abandonment. TempBMF temperate broadleaf and mixed forests; TropGL sub-/tropical grass-/shrublands and savannahs; TropMBF sub-/tropical moist broadleaf forests



Source: Mueller *et al.* (2014).

Table CS9. 2: Applied z-values by biome Results of normalisations of species richness (S), endemic species richness (EndS) and Conservation Risk Index (CRI) and their product, the BWF per ecoregion[a]

Biome	Ecoregion	z-value	S[c]	End S[c]	CRI[c]	BWF[c]
Sub-/tropical moist broadleaf forest	Peninsular Malaysian rain	0.26[b]	4.6	1.5	3.0	18.1
Temperate broadleaf &mixed forests	Atlantic mixed forests	0.17	2.4	1.0	7.8	18.6
	Baltic mixed forests	0.17	2.4	1.0	5.4	12.8
	Sarmatic mixed forests	0.17	2.1	1.0	1.6	3.4
Sub-/tropical grass-/shrublands and savannahs	Cerrado	0.18	3.3	1.8	5.4	31.7

[a] Results of normalisations for all ecoregions are provided in Mueller *et al.* (2014).
[b] Specifically for Asia as for this biome region-specific z-values were given.
[c] Results of normalisations.
Source: Mueller *et al.* (2014).

As sampling area varied strongly among studies, sampled species richness (S) was standardized to an area (A) of 100 m^2 using the transformed power model of the species–area relationship proposed in Kier *et al.* (2005).

- Irreplaceability was quantified as the area-corrected number of strict endemic species of amphibians, reptiles, mammals and birds (EndS). For endemism, these are the only taxonomic groups where data per ecoregion are available. For consistency, the same selection of taxonomic groups was also chosen for species richness, and data on plants were excluded.

- Vulnerability was expressed as the 'Conservation Risk Index' (CRI), which is calculated as the ratio of converted ecoregion area (percent) to protected ecoregion area (percent). The latter concept assumes that the more area is occupied, the more damaging an occupation or transformation will be for the remaining ecosystem (Koellner 2000). To prevent division by zero, all values below 1 percent were set to 1 percent.

MAIN FINDINGS AND IMPACTS

Although organic milk required about twice the amount of agricultural land to produce 1 kg of milk, the occupation impact of organic milk was only half that of conventional. CF_{Occ} of organic land use types were always considerably lower than conventional ones thus leading to smaller occupation impacts. In addition, the different composition of the feedstock, with larger shares of roughage feed and grazing for organic cows, and larger shares of concentrate feed for conventional cows, considerably influenced the result. Results found here also stress the importance of subsidies for organic agriculture as this type of farming makes an important contribution to the maintenance of species richness in the agricultural landscape. More details of the results including graphs and tables are available in Mueller *et al.* (2014).

FURTHER INFORMATION

Cederberg, C., Flysjoe, A. *2004. Life cycle inventory of 23 dairy farms in south-western Sweden. SIK-report Nr 728. The Swedish Institute for food and biotechnology, Goeteborg*

de Baan, L., Alkemade, R., Koellner. T. *2013. Land use impacts on biodiversity in LCA: a global approach. Int J Life Cycle Assess18(6):1216–1230*

FiBL *2012. Data tables from the FiBL-IFOAM survey on organic agriculture world-wide Research Institute of Organic Agriculture FiBL, Frick, Swiss. http://www.organic-world.net/statistics-data-tables.html (Accessed December 2014)*

Koellner, T., de Baan L., Beck, T., Brandão, M., Civit, B., Margni, M., Milà i Canals, L., Saad, R., de Souza, D.M., Mueller-Wenk, R. *2013a. UNEP SETAC guideline on global land use impact assessment on biodiversity and ecosystem services in LCA. Int J Life Cycle Assess18(6):1188–1202*

Koellner, T., de Baan, L., Beck, T., Brandão, M., Civit, B., Goedkoop, M., Margni, M., Milà i Canals, L., Mueller-Wenk, R., Weidema, B., Wittstock, B. *2013b. Principles for life cycle inventories of land use on a global scale. Int J Life Cycle Assess 18(6):1203–1215*

Milà i Canals L., Bauer, C., Depestele, J., Dubreuil, A., Freiermuth, K.R., Gaillard, G., Michelsen, O., Mueller-Wenk, R., Rydgren, B. *2007. Key elements in a framework for land use impact assessment within LCA. Int J Life Cycle Assess 12(1):5–15*

Milà i Canals, L., Rigarlsford, G., Sim, S. *2013. Land use impact assessment of margarine. Int J Life Cycle Assess 18(6):1265–1277*

Mueller, C., de Baan, L., Koellner, T. *2014. Comparing direct land use impacts on biodiversity of conventional and organic milk—based on a Swedish case study. Int J Life Cycle Assess 19:52–68*

Case Study #10

Land management for arid grazing in Botswana

GENERAL PRINCIPLES ILLUSTRATED BY THIS CASE STUDY

Pressure indicators

Livestock density and wildlife species status (including invasive species cover), adoption of appropriate grazing management practices, fire regime, extent of fencing.

State indicators

Area of bare sand dunes, percentage of land area covered in thorn bush and poor-quality grazing grasses, water table depth, invasive species prevalence, area of communal land use.

Response indicators

- planting of trees on sand dunes (*Eucalyptus* spp, Salt bush; *Prosopis* spp, etc.);
- fencing of sand dunes to protect them from livestock;
- establishment of beekeeping and horticultural projects within fenced sand dunes;
- participation in communal land use regulated by local authorities;
- capacity building and environmental awareness courses or seminars, including recording condition and comparing to 'old veld' or veld rarely grazed by cattle.

Reference State

Wildlife species status, percentage of stabilized sand dunes.

DESCRIPTION OF GEOGRAPHICAL AREA

Southern Kgalagadi District, southwest Botswana has an arid climate (annual av. rainfall 250 mm, summer temperatures of 20 – 38°C, winter temperatures of –2 – 12°C). It consists of 11 villages located along the Nosop-Molopo valley (Fossil River), close to the Kalahari. The area has a gently undulating, sand-covered plain topography and a diverse array of now fossil dune systems.

DESCRIPTION OF LIVESTOCK SYSTEM

The environment of the Southern Kgalagadi region has very low productivity and is highly susceptible to land degradation or desertification if subjected to ill-advised interventions. Grazing is based on smallholder or nomadic systems which rely on the utilization of communal lands and boreholes, particularly in times of drought. Livestock management is conditioned not only by the changing conditions of vegetation from one season to another but also by the absence of superficial water streams.

With the establishment and promotion of privatized, fenced cattle ranches, the area has become degraded. Poor management practices have exacerbated the impacts of naturally present environmental threats which include wild fires, wind erosion, loss of vegetation, sand dune movement and frequent droughts and heat waves. Poor practices have also translated into increases in the depth of the water table, with increased investment costs for livestock keepers.

DESCRIPTION OF PRIMARY BIODIVERSITY FEATURES

The region consists of poorly structured and infertile sandy soils of low moisture-retaining capacity. There is no permanent surface water and very little runoff. However, the area is home to well-conserved ecosystems hosting wildlife that boosts local tourism, and which triggered the creation of the Kgalagadi Transfrontier Park, a national park shared by Botswana and South Africa. The regional trends of wildlife abundance have been consistently declining.

There has been an increase in bare dunes and the amount of bush growing between dunes and an increase in thornbush over the last 20 years. At the same time, poor grasses are becoming more common in southwest Kgalagadi ranches and there has been an increase in invasive species, particularly the honey mesquite (*Prosopis glandulosa*).

MAIN INTERACTIONS BETWEEN LIVESTOCK AND BIODIVERSITY

Traditionally, interactions between livestock and biodiversity in the area have been both positive and negative. Customary land use and mobility patterns have guaranteed the sustainability of fodder resources and the maintenance of palatable species among the plant communities. Availability of groundwater for livestock has also played a role in favouring the presence of wild herbivores. At the same time, however, livestock have had to compete to some extent with wild herbivores and livestock keepers have traditionally fought with wild predators.

In line with “Tragedy of the Commons” thinking (individuals’ pursuit of self-interest runs counter to the common good in shared-resource systems), during the last decades the government has discouraged communal land tenure systems oriented towards local meat production. Instead, it has promoted private ranches producing beef for export to the European market. Extensive fencing has occurred throughout the country, including the Kgalagadi area, both for veterinary and for privatization reasons. This has had direct, pervasive consequences for wildlife by reducing wild animals’ capacity to cope with the environmental threats cited above. Given that much of the private land has been established on former communal areas, the poorest livestock keepers, with reduced investment capacity, have been forced to concentrate on the few communal areas left. This has added to the disruption of mobility and created a situation that has led to land degradation.

In early 1980s, the Ministry of Agriculture, through the Drought Relief Progarmme (supported by UNCCD), initiated Sand Dune Stabilization projects in the Kgalagadi South region. The projects covered nine villages in areas ranging from 2 ha to 10 ha. The objective was to stabilize sand dunes through effective sustainable land management practices, including grazing, and support to communities to implement their own management actions – hence contributing to improved livelihoods and maintenance of ecosystems integrity. The intervention failed, however, to tackle the underlying causes of reduced mobility or overuse of remaining communal lands. Instead, species such as the alien *Prosopis glandulosa* were used for sand dune stabilization. But given their high water demand, during the dry season they ended up deepening the water accessibility issues (an issue also known for other mesquites introduced in Africa), further displacing poorer livestock keepers and further promoting the ranching model.

Further policy development such as through the Community-Based Natural Resources Management approach, and later interventions such as the ones developed by IUCN through UNEP-GEF funding, have, however, concentrated on promoting local knowledge of ecosystems. Results are starting to be encouraging following the identification of some enthusiastic livestock keepers who are improving the biodiversity status of surrounding lands while also increasing their resilience and their livelihoods options. The reconnection of ecosystems through restoration of livestock mobility and communal land use is also a promising tool for improving the conservation of wildlife species.

MAIN FINDINGS

This case study shows the importance of incorporating local/indigenous knowledge in development strategies aimed at managing or restoring biodiversity values and ecosystems services.

It also shows the need to take a multi-category, holistic approach to biodiversity management and monitor progress to avoid perverse outcomes or trade-offs with other biological or ecological values.

FURTHER INFORMATION

Bartlam-Brooks, H.L.A., Bonyongo, M.C. & Harris, S. *2011. Will reconnecting ecosystems allow long-distance mammal migrations to resume? A case study of a zebra Equus burchelli migration in Botswana. Oryx, 45: 210–216. http://www.guidetrainingcourses.com/wp-content/uploads/2013/10/A-case-study-of-a-zebra-Equus-burchelli-migration-in-Botswana.pdf*

Buckham-Walsh, L. & Mutambirwa, C.C. *2014. Strengthening communal rangelands management in Botswana. Legal and policy opportunities and constraints. In: Herrera, P.M.; Davies, J. M.; Manzano Baena, P. (eds.), The Governance of Rangelands: Collective Action for Sustainable Pastoralism., London. Routleddge. pp. 214-235.*

Dougill, A.J., Perkins, J.S., Akanyang, L., Eckardt, F., Stringer, L.C., Favretto, N., Atlhopheng, J. & Mulale, K. *2014. Land Use, Rangeland Degradation and Ecosystem Service Provision: New Analyses from southern Kalahari, Botswana. Report for the Economics of Land Degradation Initiative. Leeds, UK, 18 pp. [online]. Available from: http://www.see.leeds.ac.uk/research/sri/eld/*

Mbaiwa, J.E. & Mbaiwa, O.I. *2006. The effects of veterinary fences on wildlife populations in Okavango Delta, Botswana. International Journal of Wilderness 12: 17–24. http://www.wilderness.net/library/documents/ijwdec06_mbaiwa.pdf*

McGahey, D. *2011. Livestock mobility and animal health policy in southern Africa: the impact of veterinary cordon fences on pastoralists. Pastoralism: Research, Policy and Practice 2011,* **1***:14. http://www.pastoralismjournal.com/content/1/1/14*

Mosalagae, D. & Mogotsi, K. *2013. Caught in a sandstorm: an assessment of pressures on communal pastoral livelihoods in the Kalahari Desert of Botswana. Pastoralism: Research, Policy and Practice 2011,* **3***:18. http://www.pastoralismjournal.com/content/3/1/18*

Case Study #11

Grazing and rancher stewardship to conserve threatened and endangered species, and associated habitats on California's rangelands

GENERAL PRINCIPLES ILLUSTRATED BY THIS CASE STUDY

Federal and state-listed plant and animal species and their critical habitat designations throughout California provide a public obligation and legal mechanism to require management and documentation of conservation and recovery efforts.

Pressure indicators

Plant biomass including thatch, vegetation density and height, and percentage of bare ground may all be assessed annually. Management of grazing to reduce biomass and vegetation height, and increase bare ground enhances habitat for some native species.

Spatial and temporal scale

Biodiversity related to livestock ranching is assessed both at the landscape and pasture levels in terms of habitat quality.

Response indicators

Hectares of public and private rangelands managed with livestock grazing; livestock water developments (created or maintained); intact livestock grazing infrastructure, e.g. working facilities, fences and livestock water, are indicators of the ability to sustain ranching and its benefits to biodiversity. Currently, more than 30 different public landowner agencies use grazing to manage their rangelands. Some public landowners have devoted conservation dollars to maintain livestock working facilities. Livestock water developments are hampered by regulatory requirements and high economic costs but conservation interests are working to streamline regulations and provide cost-share. Habitat conservation and mitigation funds are securing easements on private and public land to ensure ranching continues.

LCA consideration

Vegetation management methods other than livestock grazing are not only less reliable but also have environmental costs. Livestock grazing should be credited with avoiding impacts from alternative management methods, e.g. mowing, disking, scraping, pesticide application.

OVERALL OBJECTIVES

Conservation of biodiversity on California's rangelands is facilitated by livestock grazing and rancher stewardship associated with extensively grazed beef cattle, and to a lesser extent sheep and goat production. Livestock grazing and rancher stewardship on California's rangelands create, enhance and maintain habitat and support ecosystem health for biodiversity.

SCALE, USERS AND GOAL

This case study demonstrates the value of livestock grazing and other land stewardship practices associated with extensive livestock production to conserve biodiversity on California's rangelands at two scales: landscape and pasture. These rangelands include rich and varied landscapes of grasslands, oak woodlands, ephemeral wetlands, and riparian areas that are important aesthetically, while some conservation objectives also depend on extensive, natural landscapes provided by working ranches. Sustaining working ranches can minimize loss of diversity resulting from land use change. At the pasture level, grazing and rancher stewardship is effective at creating, enhancing and maintaining habitat for conserving both common and rare native species. Sustaining working ranches can mediate some impacts to biodiversity from climate change, including changes to water regimes and vegetation.

DESCRIPTION OF GEOGRAPHICAL AREA AND MAIN DRIVERS

There are 40 million ha of land in the state of California, of which 23 million ha can be considered as rangelands. Approximately 47 percent of these rangelands are owned by the federal government and another 12 percent by other state, regional and local public agencies. The diverse environments associated with these rangelands contribute to their status as an internationally recognized biodiversity hotspot, with more than 4 800 native plants, 29 percent of which are endemic to the state. Approximately 1 000 native vertebrates occur in the state, including 125 federally or state-listed species. The Central Valley is also home to the highest diversity and density of wintering raptors anywhere in North America.

Although California's rangelands are biologically rich, they have been impacted by the accidental and intentional introduction of non-native plant and animal species. Some 1 050 non-native plant species are known in California and with urbanization and climate change more are expected to arrive. Nearly half of these non-native plants are annuals that dominate much of the rangeland landscape. Unmanaged non-native annual plants alter water and nutrient regimes, and change vegetation composition and structure resulting in negative impacts on biodiversity.

DESCRIPTION OF LIVESTOCK SYSTEM

Livestock grazing, primarily by beef cattle, is California's most extensive land use. Much of the livestock forage, approximately 65 percent, is produced on privately-owned land in the Mediterranean climate zone from about 4.5 million ha of annual grass-dominated rangelands, 2.1 million ha of hardwood woodlands with annual grass understory, and 0.4 million ha of irrigated pasture.

MAIN INTERACTIONS BETWEEN LIVESTOCK AND BIODIVERSITY

At the landscape level, livestock ranching maintains extensive, open landscapes. Larger patches of open, grazed grassland support a more species-rich, abundant bird community. At the pasture level, livestock ranching supports biodiversity through grazing and associated rancher stewardship. Grazing reduces annual plant biomass, influences vegetation composition, impacts vegetation structure and provides bare ground. The endangered bay checkerspot butterfly (Euphydryas editha bayensis), kit fox (Vulpes macrotis mutica), kangaroo rats (Dipodomys stephensi), burrowing owls (Athene cunicularia), tiger beetle (Cicindela ohlone), wildflowers, and numerous rare flora and fauna associated with vernal pools benefit from livestock grazing managing vegetation. Grazing exclusion has resulted in extirpation of some populations of these species from "protected sites". Rancher stewardship includes development and maintenance of livestock water sources, pest management, debris clean-up, and forage improvement. Ponds developed for livestock water provide half of the available habitat for the endangered tiger salamander (Ambystoma californiense) in the San Francisco Bay Area. Similarly, more than half of the habitat for the rare California black rail (Laterallus jamaicensis) comes from leaky irrigation pipes associated with ranching in the foothills of the Central Valley.

MAIN FINDINGS AND IMPACT

Livestock grazing occurs throughout California on diverse rangelands with unique flora and fauna. The many synergistic opportunities for enhancing and maintaining biological diversity and producing food have led to a notable collaborative effort. In 2005, environmental groups, agricultural organizations, and federal, state and local land management agencies drafted and signed the California Rangeland Resolution and initiated the California Rangeland Conservation Coalition. The resolution, which has now been signed by 126 entities, pledges signatories to work collaboratively to protect and enhance California's rangelands. The resolution states that "rangelands, and the species that rely on these habitats, largely persist today due to the positive and experienced grazing and other land stewardship practices of [cattle and sheep] ranchers that have owned and managed these lands." Tools being promoted and considered to conserve California's working ranches include conservation easements, mitigation easements, cost-sharing for implementation of conservation practices, reduced or no-cost grazing leases, and payments for ecosystem services.

REFERENCES

Barry, S., Schohr, T, and K. Sweet. *2007. The California Rangeland Conservation Coalition. Rangelands 29(3): 31-34.*

Cornelisse, T.M. *2013. Conserving extirpated sites: using habitat quality to manage unoccupied patches for metapopulation persistence. Biodiversity and Conservation 22:3171-3184.*

Bartolome, J., Allen-Diaz, B., Barry, S., Ford, L., Hammond, M., Hopkinson, P., Ratcliff, F., Spiegal, S., & M. White. *2014. Grazing for Biodiversity in Californian Mediterranean Grasslands. Rangelands 36(5):36-43.*

Huntsinger, L., & Bartolome, J. *2014. Cows? In California? Rangelands and Livestock in the Golden State. Rangelands 36(5):4-10.*

Huntsinger, J., & Oviedo, J. 2014. Ecosystem services may be better termed social ecological services in a traditional pastoral system: the case in California Mediterranean rangelands at multiple scales. *Ecology and Society* 19(1):8

Marty, J. 2005. Effects of Cattle Grazing on Diversity in Ephemeral Wetlands. *Conservation Biology* 19(5):1626-1632.

Pandolfino, E.R., Herzog, M., Hooper, S. & Smith, Z. *2011. Winter habitat associations of diurnal raptors in California's Central Valley. Western Birds 42: p. 385-397.*

Stromberg, M.R., Corbin, J.D., & D'Antonio, C., *(Eds.) 2007. California Grasslands: Ecology and Management. Berkeley: University of California Press.*
Weiss, S. 1999. Cars, cows, and checkerspot butterflies: nitrogen deposition and management of nutrient-poor grasslands for a threatened species. Conservation Biology 13(6):1476-1486.

Case Study #12

Improvements of livestock disease management through enhanced beef supply chain hazard analysis procedures around Transfrontier Conservation Areas in Southern Africa

GENERAL PRINCIPLE ILLUSTRATED BY CASE STUDY

Pressure indicators

Management type, especially regarding the spread of veterinary cordon fences.

State indicators

Measures of biodiversity and biodiversity loss with a focus on large mammals both because of their high conservation value and because they are directly impacted by livestock management practices such as veterinary cordon fences.

Response indicators

Investment in safe supply chains; capacity building for enhanced livestock disease surveillance and management (and enhanced information-sharing).

Reference state

This case illustrates how the reference state with veterinary fences and without investment in livestock (beef) value chain improvement yields a poorer conservation state whose effects are cross-cutting.

Setting the boundaries

Although the scope of the conclusions encompasses the whole region, transboundary conservation areas can be used as study systems to evaluate the impacts of the approaches.

OVERALL OBJECTIVES

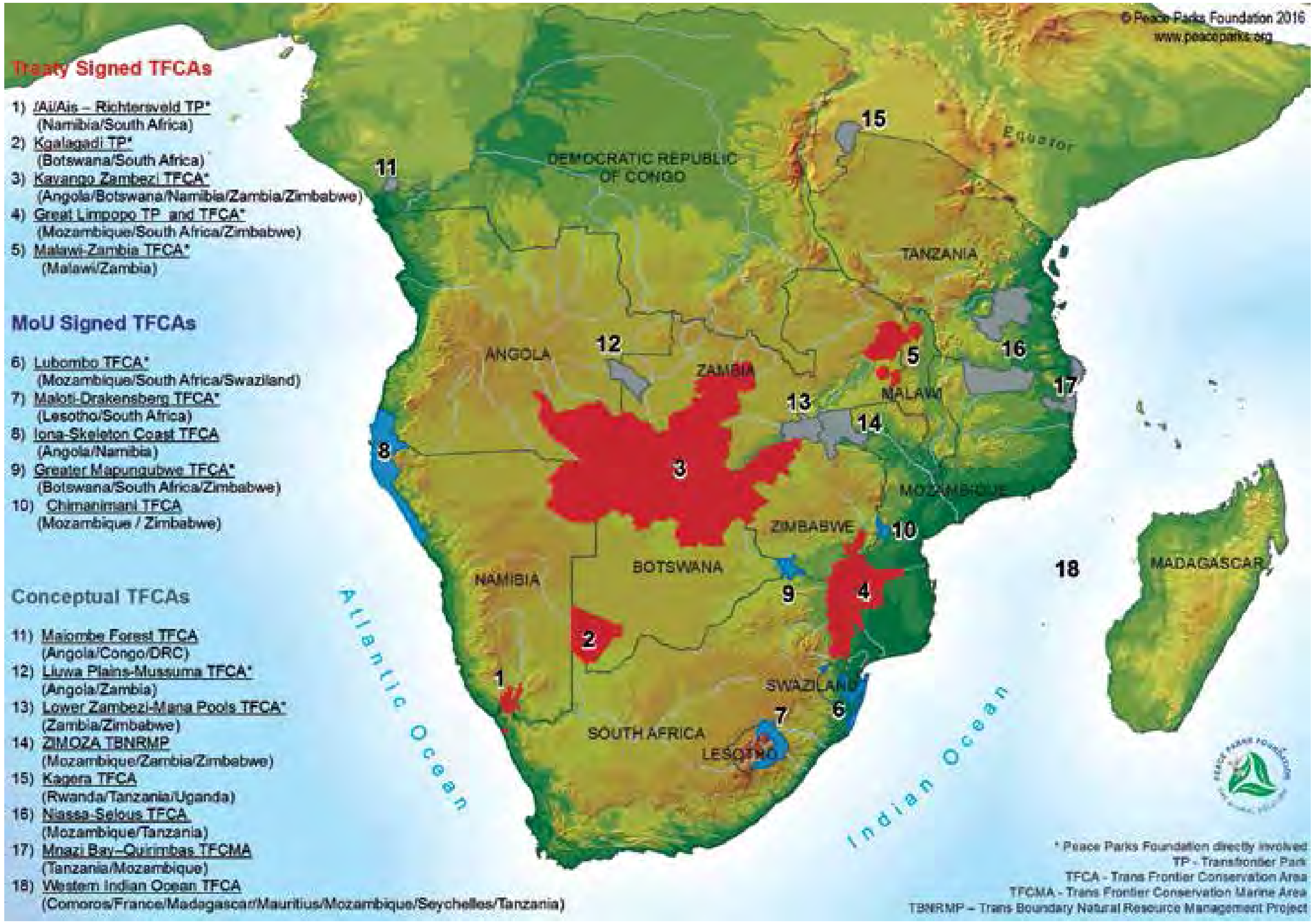
To reduce the impacts of fence-based livestock disease management on biodiversity in transfrontier conservation areas (TFCAs), very rich in wildlife, particularly the Kavango Zambezi TFCA shared among Angola, Botswana, Namibia, Zambia and Zimbabwe.

DESCRIPTION OF GEOGRAPHICAL AREA AND MAIN DRIVERS

The case study involves the Kavango-Zambezi Transfrontier Conservation Area (KAZA TFCA), a region of more than 450 000 km^2, as well as other Transfrontier

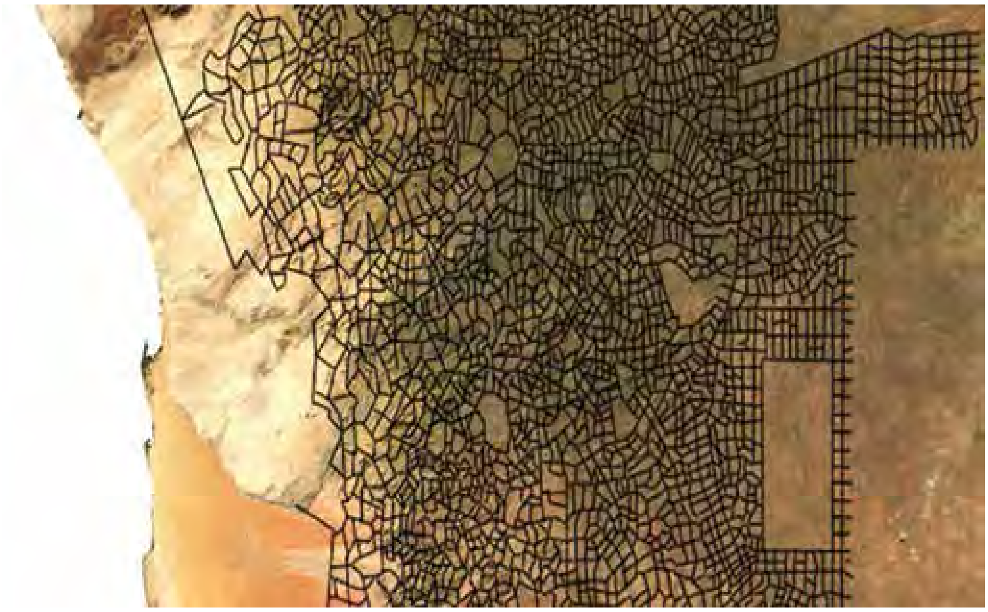
Figure CS12.1

Location of 18 established or planned transfrontier conservation areas (TFCAs) in Southern Africa



Source: courtesy of Peace Parks Foundation (www.peaceparks.org).

Figure CS12.2
Fences in central Namibia as an example of extreme habitat fragmentation in southern Africa (adapted from EC, 2015)



Source: adapted from EC (2013).

Conservation Areas in the region totalling at least 750 000 km^2. Largely dominated by miombo[3]-type trees, this landscape has an arid and semi-arid climate and is suited to extensive livestock husbandry. The considerations examined here also apply more broadly to southern Africa as a whole, especially in the context of sustainable development. An important driver is the abundance of wildlife and an extensive interface with livestock, across which diseases can move in either direction.

DESCRIPTION OF THE LIVESTOCK SYSTEM

In the SADC (Southern African Development Community) area, at least 10 million people are exclusively dependent on livestock, and the number of people depending at least partially on livestock may be as much as 100 million. The practice of livestock-keeping ranges from nomadic and pastoralist systems to capital-intensive ranches. A focus on regional / international beef exports continues to be important.

DESCRIPTION OF PRIMARY BIODIVERSITY FEATURES

The KAZA TFCA and other conservation areas in the region, as well as many areas without such formal protected status, host a very rich biodiversity, with the best-conserved guilds of large herbivores and predators in the world along with East Africa. As an example, the largest contiguous population of elephants (approximately 250 000 individuals) is found in the KAZA TFCA. The ecosystems present range from miombo savannahs and woodlands to sandy semi-deserts and deserts.

[3] Miombo is the Swahili word for *Brachystegia*, a tree genus

MAIN INTERACTIONS BETWEEN LIVESTOCK AND BIODIVERSITY

Historically, nomadic and pastoralist practices had been compatible with the local biodiversity. However, livestock economies in southern Africa have increasingly worked to expand trade to target export markets, and ideally the lucrative markets of the European Union, United States and Japan (although serving market demand within Africa itself is becoming a more pragmatic endeavour). The prevalence of some transboundary animal diseases in the area, especially foot-and-mouth disease (FMD), has triggered international trade rules that have required physically demarcated zones officially free from the disease. These zones are physically isolated through extensive cordon fencing that prevents unaffected livestock from contact not only other livestock but also with wildlife (Figure. CS12.2). The result is an extreme fragmentation of the landscape, which began more than half a century ago, with very negative consequences on the population dynamics of wildlife due to disruptions of important seasonal migratory routes. Besides the biodiversity considerations, this situation affects development opportunities in the area, because a) wildlife is a very promising local source of income, and b) the profitability and sustainability of local livestock practices can be ultimately damaged by fencing (see Case Study #10: *Land management for arid grazing in Botswana* as well as SADC's *Phakalane Declaration on Adoption of Non-Geographic Approaches for Management of Foot and Mouth Disease* – http://www.wcs-ahead.org/phakalane_declaration.html).

PRINCIPLES, FRAMEWORK, DATA, TOOLS OR STATISTICAL APPROACHES USED

The conventional approach of facilitating the export of livestock products has focused on containing livestock diseases through sanitary cordon fences (Figure CS12.2). A newer approach now successfully piloted has the potential to replace the "disease-free status of livestock's region of origin" principle by one focused on the "safety of the beef production process" principle, which targets all relevant steps along the value chain. In the latter, the safety of livestock products for export is provided by successful prevention of disease hazards all through the livestock management and product manufacturing process.

The removal, or at least strategic realignment of impenetrable veterinary fencing, would also help SADC realize its vision of regional transboundary conservation, where mobility of wildlife is a must for long-term ecological viability as well as for enhanced wildlife-based economic activities. Note that nature-based activities now contribute more to the region's GDP than the livestock sector.

MAIN FINDINGS AND IMPACTS

Value-chain oriented interventions (also known as commodity-based trade), as well as strengthening the capacities at national levels for more robust livestock disease surveillance and management programmes (and concomitant information-sharing), should manage to control the major transboundary diseases and create a safe environment for livestock exports from the region. Recent changes in international regulations along these lines, including changes made by the World Organisation for Animal Health, have created a constructive enabling environment for value chain-focused approaches for the first time in decades. Commodity-based beef value chain approaches would lessen the need for a conventional sanitary cordon fences approach, and thus improve wildlife-related activities while facilitating system resilience. Additionally, a bigger investment in product transformation at origin would also help create added value in the SADC countries and reduce poverty. Finally, the removal of barriers to movements of wildlife and livestock would also improve the chances of adaptive responses to climate change, given the ongoing dry-weather trends predicted for the subregion.

FURTHER INFORMATION

Atkinson, S. & Osofsky, S. *2014. "Tourism, Beef or Both? Rethinking Productivity in the Kavango Zambezi Transfrontier Conservation Area," Zambezi Traveller, Jun-Jul-Aug edition. P. 34. http://zambezitraveller.com/chobe/transfrontier-parks/tourism-beef-or-both*

Barnes, J. I. *2013 Economic Analysis of Land Use Policies for Livestock, Wildlife and Disease Management in Caprivi, Namibia, with Potential Wider Implications for Regional Transfrontier Conservation Areas. Technical Report to the Wildlife Conservation Society's AHEAD Programme and the World Wide Fund for Nature. 84pp. http://www.wcs-ahead.org/kaza/ahead_wwf_caprivi_analysis_final_030613.pdf*

Cassidy, D., Thomson, G. & Barnes, J. *2013. Establishing Priorities through Use of Multi-Criteria Decision Analysis for a Commodity Based Trade Approach to Beef Exports from the East Caprivi Region of Namibia. Technical Report to the United States Agency for International Development (USAID) / Southern Africa Sanitary and Phytosanitary Support (SPS) Programme for Regional Trade in Southern Africa. 109 pp. http://www.wcs-ahead.org/kaza/mcda_review_cbt_appendixes_final.pdf*

Cumming, D. H. M., Osofsky, S. A., Atkinson, S. J. & M. W. Atkinson. *2015. "Beyond Fences: Wildlife, Livestock and Land Use in Southern Africa," pp. 243-257, in Zinsstag, J., Schelling, E., Waltner-Toews, D., Whittaker, M., and Tanner, M. (eds.) One Health: The Theory and Practice of Integrated Health Approaches. C.A.B. International, Oxfordshire, United Kingdom.*

European Commission*. 2015. Larger than elephants. Inputs for an EU strategic approach to wildlife conservation in Africa. Directorate-General for International Cooperation and Development, Brussels, 112 pp. ISBN 978-92-79-49563-2 https://ec.europa.eu/europeaid/larger-elephants-inputs-eu-strategic-approach-wildlife-conservation-africa-synthesis-0_en*

SATOTO Livestock Projects, Meat Board of Namibia and TAD Scientific *(2014) Development of Export Opportunities for Beef Products from the Zambezi Region. Technical Report to the Millennium Challenge Account Namibia. 23pp. http://www.wcs-ahead.org/kaza/2014_zambezi_project_technical_booklet_final.pdf*

Thomson, G. R., Penrith, M.-L., Atkinson, M. W., Atkinson, S. J., Cassidy, D. & S. A. Osofsky*. 2013. "Balancing Livestock Production and Wildlife Conservation in and around Southern Africa's Transfrontier Conservation Areas," Transboundary and Emerging Diseases, vol. 60 (6): 492–506. http://dx.doi.org/10.1111/tbed.12175*

Thomson, G. R., Penrith, M.-L., Atkinson, M. W., Thalwitzer, S., Mancuso, A., Atkinson, S. J. & S. A. Osofsky*. 2013. International Trade Standards for Commodities and Products Derived from Animals: The Need for a System that Integrates Food Safety and Animal Disease Risk Management, Transboundary and Emerging Diseases, vol. 60 (6): 507–515. http://dx.doi.org/10.1111/tbed.12164*

Thomson, G. & Penrith, M.L., *2015. Guidelines for Implementation of a Value Chain Approach to Management of Foot and Mouth Disease Risk for Beef Exporting Enterprises in Southern Africa. Technical Report to the Wildlife Conservation Society's AHEAD Programme. 12 pp. http://www.wcs-ahead.org/kaza/150313_guidelines_report_value_chain_final.pdf*

Wildlife Conservation Society. *2015. Animal & Human Health for the Environment and Development. http://www.wcs-ahead.org/*

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