ECOSYSTEM SERVICES ASSESSMENT IN THE EXTRACTIVE SECTOR LESSONS FROM THE LIFE IN QUARRIES PROJECT

Life in Quarries Project

LIFE14 NAT/BE/000364

Action D.3
Monitoring of Ecosystem Services
Final Report

DECEMBER 20TH 2021

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Context

Extractive sites are profoundly interlinked with their territory. Through their life cycle, quarries modify the landscape with extraction progressing through mineral deposits and constantly creating a large diversity of ecosystems, from temporary habitats to more permanent ones. In many cases, the biological role and ecosystem services provision of quarries are neglected, though they potentially play a significant role as core habitat or stepping-stones for patrimonial species and ecosystems services provisioning for Green Infrastructure in landscapes. In highly urbanized and controlled landscapes, quarries are an exceptional opportunity to maintain rare and threatened transient habitats hosting fugitive species. Biodiversity challenges for quarries should be aligned with ecosystems management to maximize ecosystem services (ES).

This report[1] is a deliverable of the Life in Quarries project (LIFE14 NAT/BE/000364) action D3 – *Monitoring of Ecosystem Services* – following the implementation of the project between 2015 and 2021. It synthetizes the results of the assessment of ecosystem services provided by quarries in 2016 (action A6) and 2020 to assess the diversity of ecosystem services delivered by quarries, the evolution of the provision of these ecosystem services resulting from the implementation of biodiversity conservations actions (actions C) and the development of dynamic biodiversity management plans (action D5).

According to the objective of action D3, it must thus allow to:

"Evaluate Ecosystem Services dynamic in quarries during the realization of temporary management actions (C2) and permanent nature management (C3).

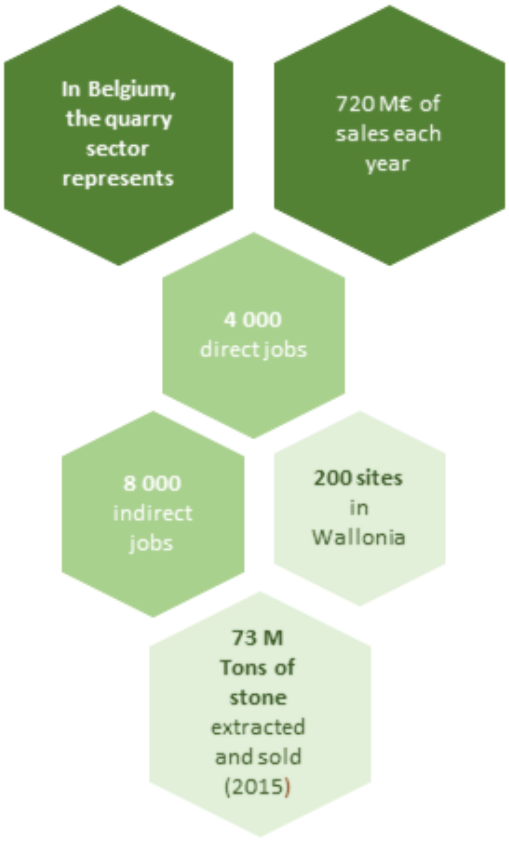
Besides, this report delivers a synthesis of key points to consider when evaluating Ecosystem Services in dynamic systems such as quarries and an adapted methodology for this evaluation that considers the multiple values of ecosystems for human society."

[1] Citation suggestion: Maebe L., Gillet K., Mercken K., Séleck M., Dufrêne M., Boeraeve F. & Mahy G. Ecosystem services assessment in the extractive sector - Lessons from the Life in Quarries project. University of Liège.

Concepts

Extractive industry and EU biodiversity strategy

The extractive industry includes economic activities aiming at extracting soil aggregates and, sometimes, subject them to transformation. The European aggregates industry represents 15 000 companies producing 3 billion tons of aggregates per year with an annual turnover of € 15 to 20 billion. Throughout Europe, a network of some 26 000 sites distributed throughout all biogeographical regions and employing 200 000 persons is a unique opportunity to reconcile biodiversity and economic development.



The large number of extraction sites across Europe combined with the specific characteristics of this industry – working directly on the earth crust, extracting raw materials, supplying a huge flow of heavy goods to the society … - makes it a major player in the economic and the environmental challenges of the European Union. Sustainable management of resources is one of the challenges facing the extractive sector. By implementing innovative practices, the industry intends to reduce its environmental impact and contribute to the European Green Deal.

Biodiversity is at the heart of the EU environmental policies. The European Commission has adopted the new EU Biodiversity Strategy for 2030 and an associated Action Plan - a comprehensive, ambitious, long-term plan for protecting nature and reversing the degradation of ecosystems. The EU Habitats and Birds Directives are the cornerstones of the Europe's biodiversity policy. At their heart, lies the creation of a network of sites designed to safeguard Europe's rarest and most endangered species and habitat types – the Natura 2000 Network. In order to recognize the central role of biodiversity in human well-being, the Millenniums Ecosystem Assessment (2005) has also popularized the term "ecosystem service", the contributions from nature to people, and changed society's view of ecosystems.

Biodiversity - including ordinary biodiversity - and Ecosystems Services are both integrated in the EU Green Infrastructure Strategy, part of the European Green Deal. The Green Deal aims at developing a strategically planned network of natural and semi-natural areas comprising other environmental features designed and managed to deliver a wide range of ecosystem services such as water purification, air quality, space for recreation and climate mitigation and adaptation.

Today, the European extractive industry considers that biodiversity and its proactive management, is an intrinsic part of the productive process. There are a number of important synergies between the industry and nature conservation, as shown by the many case studies in which new ecosystems allowing

the settlement of new species and an increase in environmental diversity have been generated. Extractive sites can thus be part of the EU Biodiversity and Green Infrastructure strategies with a significant potential for positive contributions to biodiversity conservation and landscape ecosystem services provisioning through passive restoration processes (Prach and Pyšek, 2001), through sound rehabilitation of extractive sites but also by implementing biodiversity management measures during the extractive phase[2]. By developing regional biodiversity and ecosystem services management schemes, quarries could demonstrate their benefit as stepping-stones between natural areas, as core populations of endangered species, but also as ecosystem services producers.

The extractive activity is also strongly anchored in the history of Wallonia, Southern Belgium, where a large network of quarries is to be found. Due to the diversity of rocks present in the Belgian subsoil, a multiplicity of products is produced each year: ornamental rock, rubble and paving stones, lime, cement, aggregates, sand and clays.

In Wallonia, FEDIEX (the federation of extractive industry) has integrated biodiversity in its focus for years. In 2012, the signature of a charter on Quarries and Biodiversity with the Walloon minister in charge of nature resulted in the development of active collaborations and to the production of good practices for the sector. These initiatives highlighted the need for a biodiversity project in quarries. The submission of the Life in Quarries falls within this approach.

FEDIEX
FÉDÉRATION DE L'INDUSTRIE EXTRACTIVE
VERBOND VAN ONTGINNINGSBEDRIJVEN

[2] See: Extractive Sector Species Protection Code of Conduct - A manageable approach for planning and permitting procedures respecting EU legislation and fostering biodiversity https://uepg.eu/mediatheque/media/Code_of_conduct_With_signatures_Digital_low_res.pdf

Active quarries: an opportunity for biodiversity

The extractive industry, through its activity, causes significant disruption to the landscape (Figure 1). The topography and occupation of the ground change to the benefit of mineral-looking habitats. At first glance, these constantly changing areas seem unwelcoming to flora and fauna. However, a growing number of research projects and field studies are showing that the proper management of extractive sites throughout their entire life cycles allows for the creation of protected species habitats. The biological role and ecosystem services provision of quarries are often neglected though they can play a significant stepping-stones role for species while developing Green Infrastructure in landscapes.

Figure 1. Simulated evolution of a quarry in its landscape.

Specifically, throughout the life of quarries, a large diversity of temporary habitats is generated, sometimes left to evolve to ones that are more permanent. In urbanized landscapes, this represents an exceptional opportunity to maintain rare and threatened transient habitats hosting fugitive species otherwise impacted by canalizations of rivers and flood controls, stabilizations and reforestations of screes and cliffs and eutrophication of waters.

Through their daily exploitation, quarries constantly initiate a succession process generating abiotic conditions for the installation of a diverse flora and fauna through a combination of factors such as recurrent perturbations and the oligotrophic status of soils and water. In a simple exploitation front, with its berms and slopes, a diversity of biotopes benefiting a variety of amphibians, reptiles, insects, birds or rare plants can coexist. Such ephemeral biodiversity cannot be managed by a site legal protection status. As exploitation progresses, more permanent, biodiverse habitats settle/are restored in abandoned areas but the biological potential could also be maximized by optimized groundwork through the whole exploitation process (Figure 2).

Irreversibly impacting production areas (food and feed biomass production, trees …), generating perturbations on water supply or emitting dusts during production and transports, active quarries are rarely seen as a source of ecosystem services diversity. By promoting pioneer biodiversity management and adequate and optimized biodiversity restoration during the exploitation, exploitations could limit impacts on ecosystem services delivery and could contribute to their restoration. In the post-exploitation phase, multiple restoration case studies have demonstrated that this contribution can be enhanced.

Generally situated in highly populated areas, these large Green Infrastructure components can contribute to more resilient landscapes as they can shape restoration plans that will allow for biomass (trees, fallows …) and livestock production (by grazing semi-natural grasslands, wetlands ...), carbon

sequestration restoring vegetation and soils, water regulation and retention (wetlands, lakes …), the capture of air particles through plantations … Through the development of local residents' nature experience, public access to green spaces for leisure activities or protected areas for nature discovery, they can also provide valuable cultural services.

Unstable Cliffs

Pioneer vegetation

Riparian sand banks

Screens and gravel beds

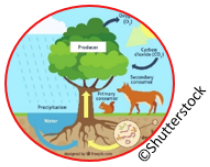
Temporary ponds

Muddy banks

Figure 2. Extractive activities create ecological conditions (bare soil, oligotrophic conditions …) similar to that of threatened natural habitats in human dominated landscapes. Such habitats frequently host endangered and protected species.

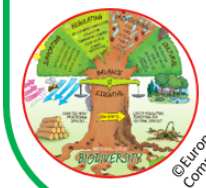
The Ecosystem Services concept - Definition and classification

KEY CONCEPTS



Ecosystem : A dynamic complex of plant, animal and micro-organism communities and the non-living environment, interacting as a functional unit.

Biodiversity : Variability of living organisms from all sources. This includes diversity within species, between species and in ecosystems.



Ecosystem services (ES) : Contribution of ecosystems to human well-being

Our everyday life depends on **ecosystems** and **biodiversity**. The functioning of ecosystems affects our well-being as they provide basic materials for life like food, water or wood. They can protect us from flooding, purify water or ensure pollination, while providing opportunities for recreation or enjoyment of nature. Protecting, managing, restoring our ecosystems and biodiversity, both for their intrinsic and utilitarian value, is key to human well-being (Haines-Young & Potschin, 2012; Sandifer et al., 2015). A global recognition of ecosystems benefits to human society has led to the development of the **ecosystem services** concept (hereafter 'ES').

The Convention for Biological Diversity (CBD) specifies that the ES approach aims to put human well-being at the center of biodiversity management (Figure 3). A focus is therefore set on the management and protection of key ecosystem components responsible for the provision of services to humans. It targets the long-term health of ecosystems allowing a continued delivery of services essential to the survival of other species (Sandifer et al., 2015).

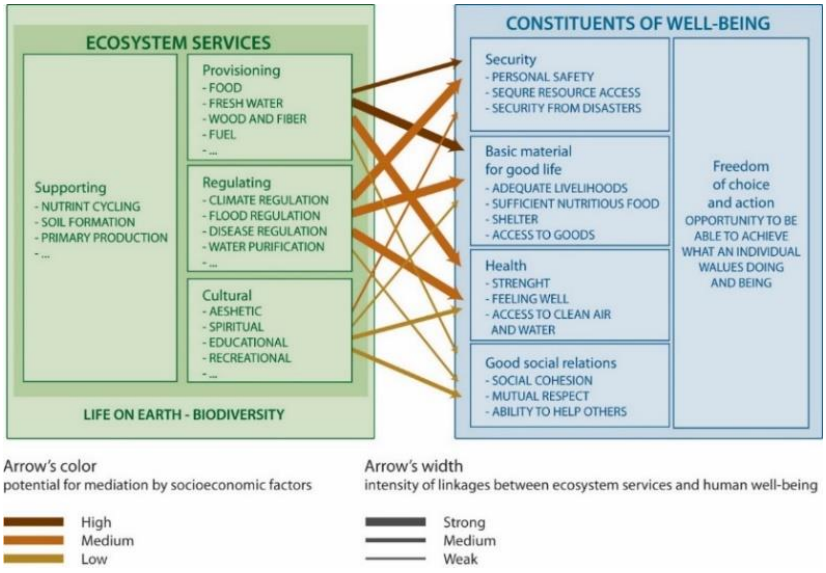


Figure 3. The links between ecosystem services and human well-being as described by MEA classification system (Source: Millenium Ecosytem Assesment, 2005).

Ecosystem services are classified into three categories: Provisioning, Regulating and Cultural services; all depending on Supporting services (Figure 4)[3]. They are dependent on the identity of ecosystems as well as on their quality: the presence of more diverse ecosystems providing a greater ES diversity while healthy ecosystems, supporting a high biological biodiversity, provide a larger ES panel.

[3] Ecosystem services do not include mineral resources (rocks, sands, etc.), fossil fuels (coals, hydrocarbons, etc.) or solar and wind energy because these do not depend on biological processes taking place on human time scale.

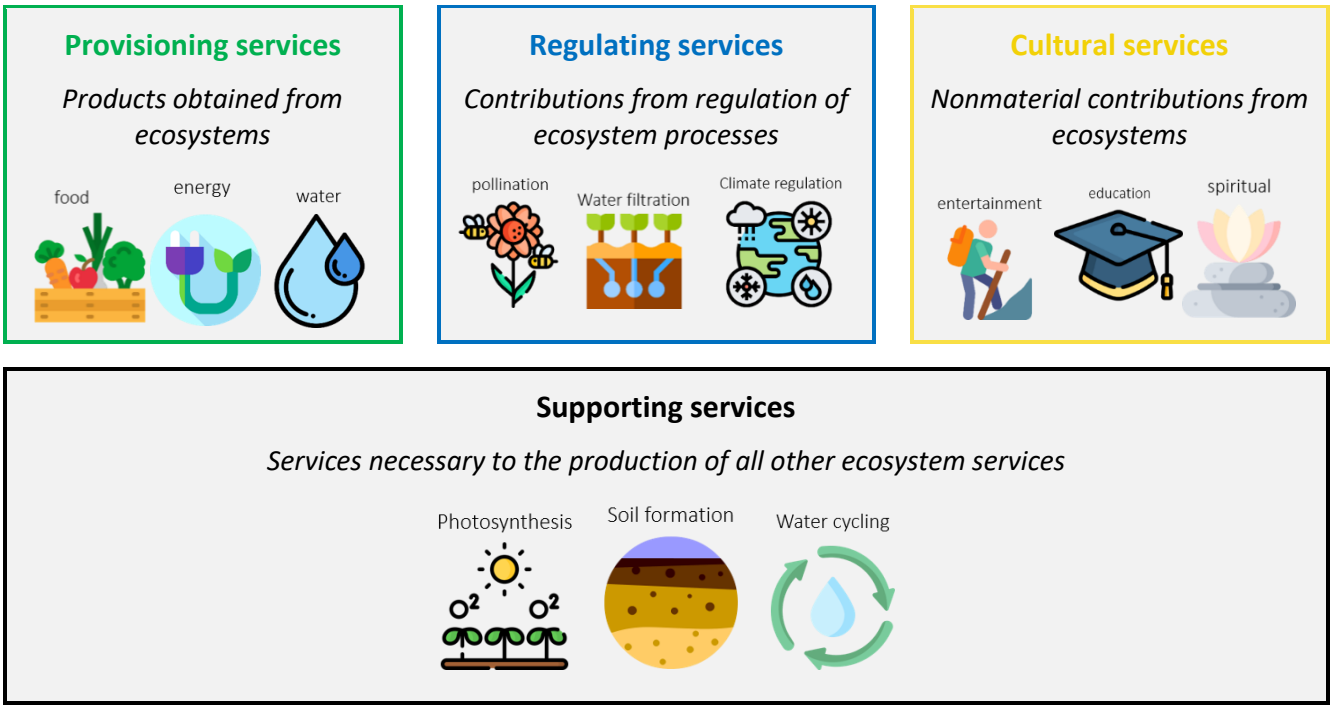


Figure 4. MEA classification of ecosystem services (Inspired from Millennium Ecosystem Assessment, 2005).

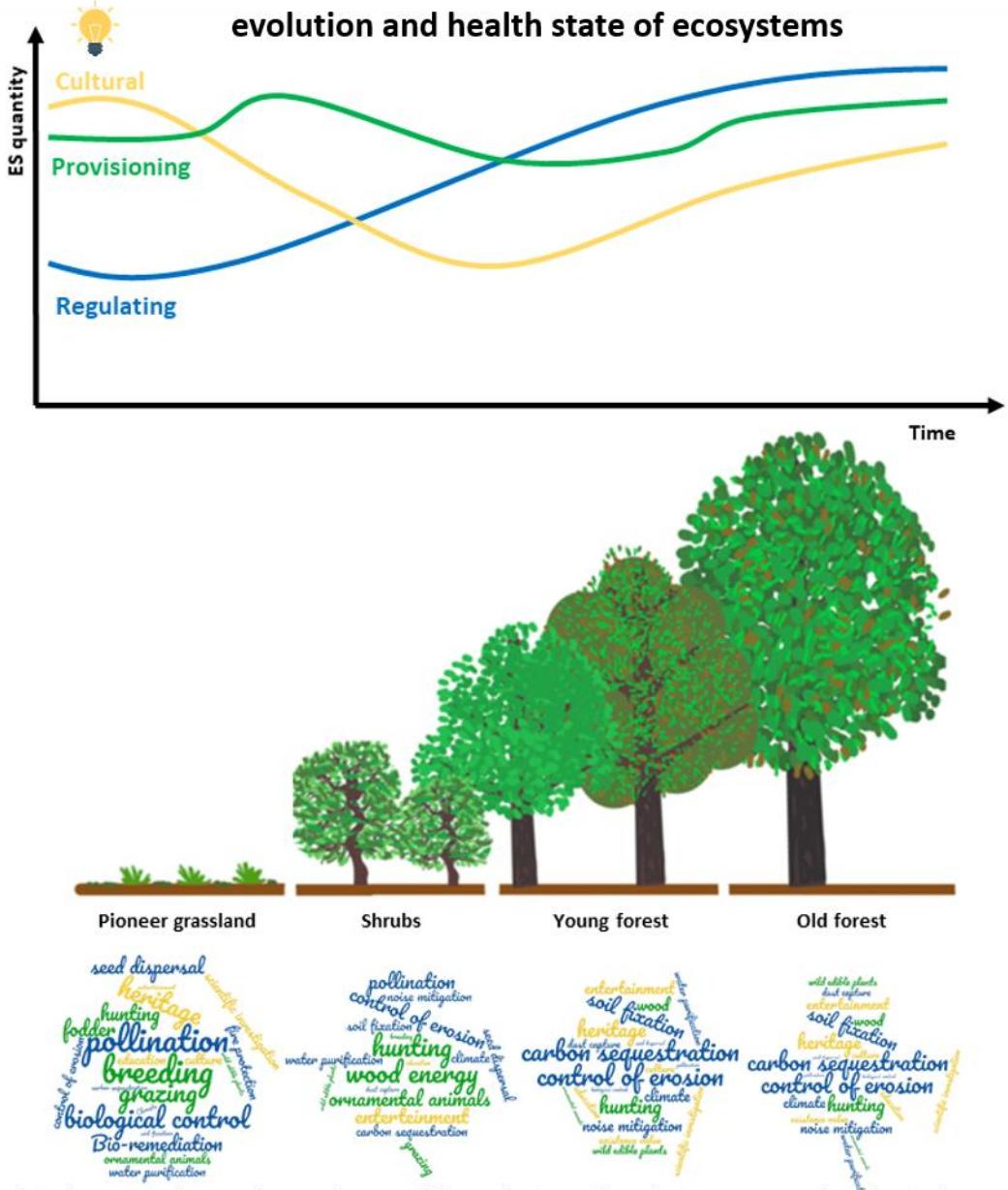
Ecosystem services are dynamic

Ecosystem services are not fixed in time. Changes in ecosystems over time and evolution of health state lead to variations in the types of provided ES and their proportion.

Evolutions in ecosystems result from natural modifications (ecological succession, disturbances) or from management choices. Depending on the nature of the ecosystem, the provided ES differ. Just as ecosystems evolve, ES change in quantity, nature and diversity depending on the evolution of ecosystems that provide them.

An ecosystem is said to be 'healthy' when the ecological structures and processes that should compose it are found and allow the ecosystem to perform its functions optimally. Healthy ecosystems are sustainable over time, capable to maintain their structures and functions in the face of external stresses (Costanza & Mageau, 1999). These functioning ecosystems allow for a maximal provision of ES linked to them. On the other hand, unhealthy ecosystems – being more or less degraded – provide a fluctuating amount of ES.

Key concept : Ecosystem services are dynamic and linked to the evolution and health state of ecosystems



This theoretical case shows the possible evolution of ES during a natural ecological succession from a grassland to a forest. The possible evolution of ES in terms of quantity is represented in the graph at the top of the figure, while the evolution of the nature and diversity of ES is represented at the bottom. The representation is only one the multiple potential SE evolution.

Assessment of Ecosystem Services: tipping points

Ecosystem services assessment is nowadays widely used as a tool to support more sustainable resources development and biodiversity management. In scientific and policy documents, ES are still often valued mainly based on their monetary value (Boeraeve et al., 2015), but the range of values linked to ES is far more multidimensional. The ecosystem services cascade of Potschin & Haines-Young (2011, 2016) shows that there are potentially a series of intermediate steps to link ecological and biophysical structures and processes to human well-being (Figure 5).

Different habitats (forests, grasslands, crops, etc.) present their own structures and functions. Ecosystems offer a potential of services depending on harbored ecological functions. These services can be provided naturally by the ecosystem or linked to human interventions (labor, intelligence, energy, technology, etc.). The benefits provided, *i.e.* welfare-enhancing advantages, are therefore multiple and different values can be attributed to variable components (Figure 6). For a same ES, several values can coexist, sometimes conflicting, but all equally "valid". This is called '**value pluralism'.** These different values for a same ES cannot be reduced to a single value or a single dimension that would have allowed them to be summed up and compared arithmetically (Gómez-Baggethun *et al*., 2014).

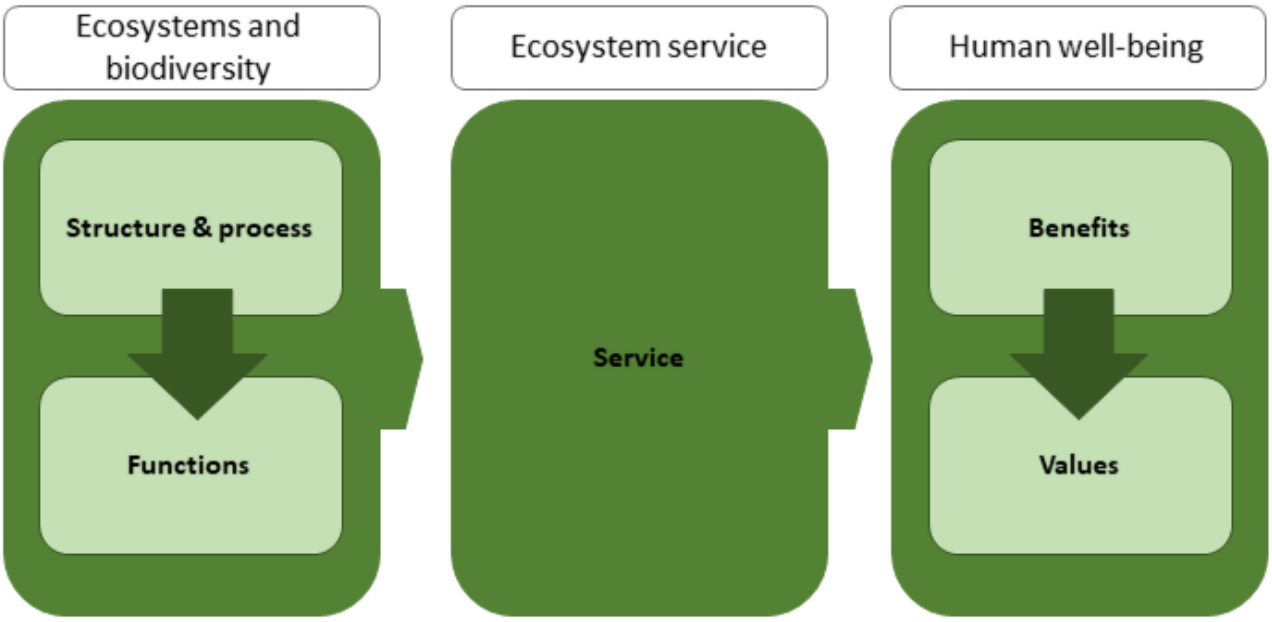
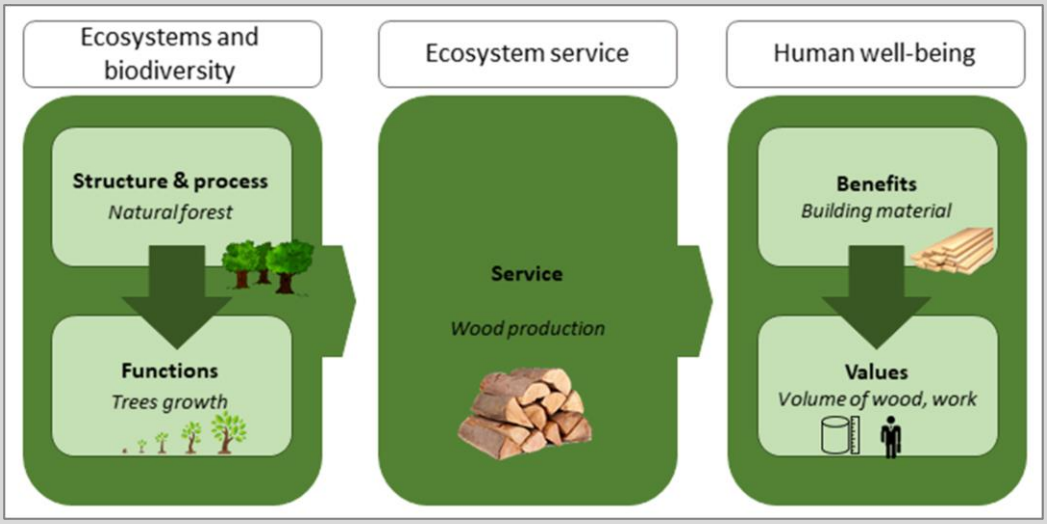


Figure 5. Schematic representation of the concept of ecosystem services based on Potschin and Haines-Young cascade model.

Example 1

*In a forest ecosystem, different ecological processes enable the growth of trees. As a result, the forest provides a wood production service from which one of the benefits to society is the provision of building material. The **generated income** and the **number of jobs** created are two possible indicators for the value of this benefit.*



Example 2

*Within forest ecosystems, through photosynthesis and carbon cycle atmospheric carbon is stored in the vegetation, which benefits human society by reducing CO2 concentrations in the air and provides clean air. The value of this service can be estimated by the **amount of carbon stored** or by its monetary v**alue on the carbon market**.*

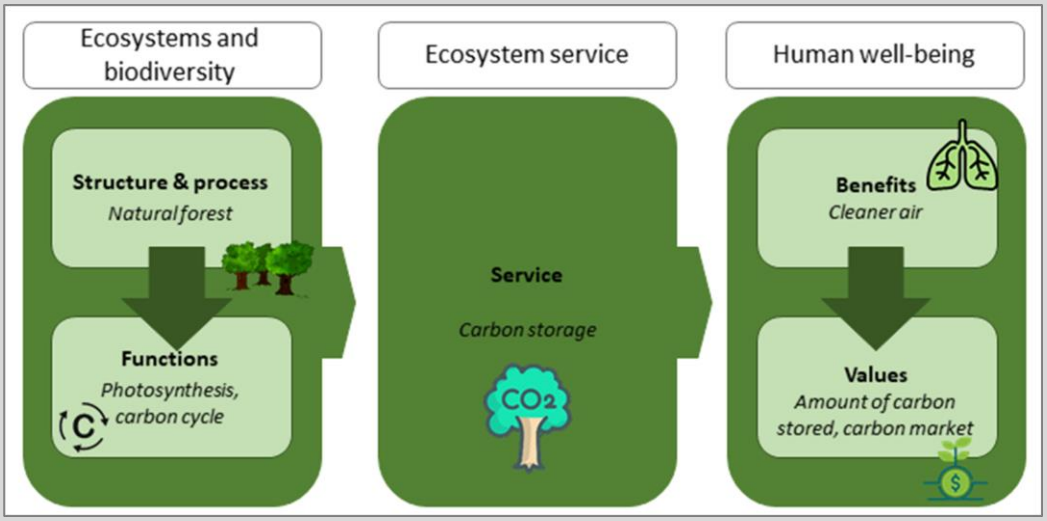


Figure 6. Two examples illustrating the multidimensionality of ecosystem services assessment for a forest ecosystem.

Ecosystem services are also part of a socio-ecological system. If the supply of a service meets a demand from individuals or human communities, the service is effectively provided. Humans then use it and obtain benefits, to which a certain value can be attributed depending on the perceived contribution to human well-being. These values influence ecosystem management decisions and impact the governance processes governing human-nature linkages. Through these processes, ES demand by different stakeholders are converted into concrete human actions, modifying ecosystems, their management and/or functioning (Figure 7).

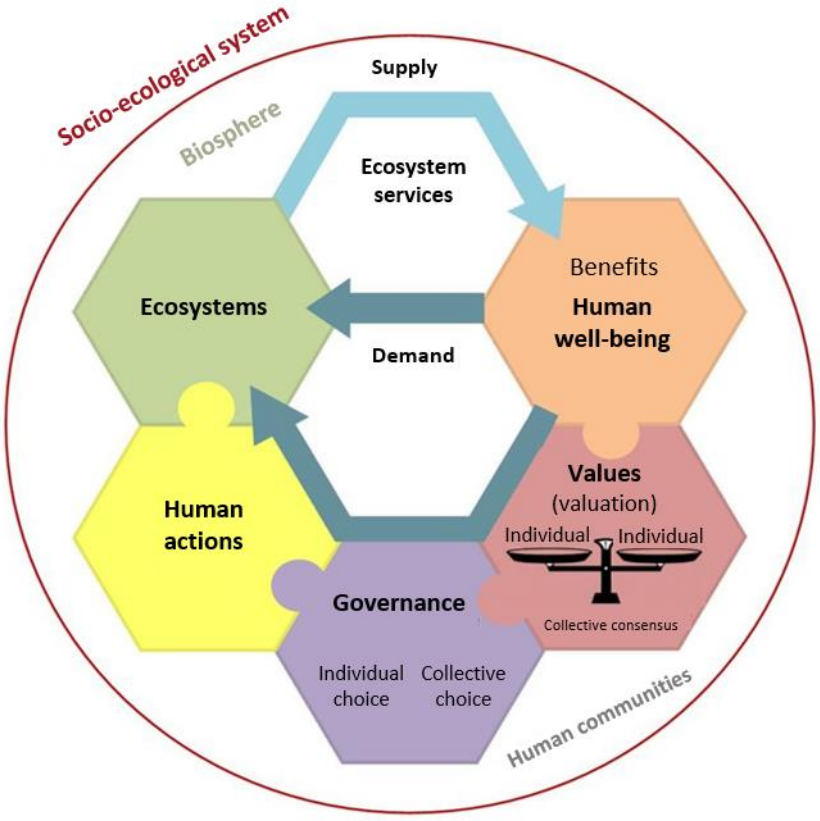


Figure 7. Schematic representation of the concept of ecosystem services and related concepts (Source: Wal-ES).

Life in Quarries and Ecosystem Services

Life in Quarries: a project for biodiversity including Ecosystem Services

The Life in Quarries (LIFE14 NAT/BE/000364)[4] is an EU LIFE funded project. Running from 2015 to 2021, it demonstrated that operational biodiversity solutions can be proposed and implemented through controlled investments benefiting nature protection as well as the private sector. The general idea of the project is to define measures acceptable to the private operator, legally and scientifically valid and favorable to biodiversity. The partnership forged on this basis includes the private sector, regional authorities, scientists and NGOs. The project is led by FEDIEX (Fédération des Entreprises Extractives) in partnership with the Walloon region (Department of Nature and Forests), University of Liège - Gembloux Agro-Bio Tech, Biodiversity and Landscape Unit, Natagora asbl and the Scheldt Plains Nature Park (Parc naturel des Plaines de l'Escaut).

Life in Quarries aims to develop and make sustainable the hosting capacity of biodiversity in active quarries in Wallonia. The originality of this project is based on the implementation of biodiversity management actions during the extractive phase and not only as part of rehabilitation, at the end of works. This integration during the operational phase requires the initiation of new biodiversity development approaches as well as an administrative and legal management. A dynamic management of biodiversity is intended to create a network of temporary habitats managed dynamically in time and space across the quarry in parallel with the extractive activity, ensuring a constant availability of suitable habitats for the development of pioneer species. For example, quarries commit to a fixed number of pioneer ponds on their site throughout the project. When the exploitation leads to the need to remove ponds, new water points are dug before the amphibian reproduction period in order to maintain a sufficient pool of pioneer ponds. Post-exploitation areas are also targeted by the projects actions. Permanent nature actions are implemented there with the aim to maintain the same habitat in an area permanently. The legal management goes through the definition of a management plan targeting species and habitats among which protected ones. The legal securing can go through a derogation under Article 16 of the EU Habitats Directive as proposed under the new *Guidance document on the strict protection of animal species of Community interest under the Habitats Directive*.[5]

Within the project, 26 quarries help create a regional network for an integrated development of biodiversity actions, taking into account the specificities and potentialities of individual sites. Fourteen are defined as phase I quarries, nine as phase II.1 quarries and three as phase II.2 quarries. The phase I quarries are extractive sites that joined the project at its initiation in 2016. Phase II.1 quarries were added to the project at a later stage, in 2018, and phase II.2 quarries in 2019.

[4] http://www.lifeinquarries.eu/en/

[5] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=PI_COM:C(2021)7301

The Life in Quarries is divided into 28 actions that aims to (Annex 1):

- Prepare actions and action plans (actions A);
- Implement concrete conservation actions (actions C);
- Monitor the impact of actions (actions D);
- Raise public awareness and disseminate results (actions E);
- Manage the project (actions F);

Through actions A6 and D3, this project offered the opportunity to study ES in active quarries. The objectives were to:

- Evaluate ES status in quarries at the beginning of the project (action A6);
- Provide valuable information in order to allow for the maximization of ES through temporary management actions (C2) and permanent nature management action (C3) (action A6);
- Evaluate ES dynamic in active quarries, resulting from the realization of actions C2 and C3 (action D3).

The integration of an ES approach allows developing them in the project's action and management plans thus favoring Walloon quarries integration into the regional Green Infrastructure. Expected impacts of implemented actions on quarries' ES provision was discussed and directly integrated into the project's action plans.

This anthropogenic or utilitarian approach to the roles of ordinary biodiversity is complementary to the other approaches of the project, such as the heritage or existential values of extraordinary biodiversity (action D2) and the socio-economic or consciousness aspects (action D6). It complements these approaches by bringing a new perspective allowing for informed decision-making without imposing a course of action.

A short description of Life in Quarries biodiversity actions (*see* Figure 8 for illustration)

Life in Quarries Temporary nature actions

Dynamic management of temporary ponds: The presence of temporary ponds is conducive to strengthen amphibian populations (Natterjack and Midwife toads) and dragonflies, linked to these habitat networks and stimulating the development of Stoneworts (Characeae), typical algae of nutrients poor (oligotrophic) ponds.

Dynamic management of pioneer grasslands: Often associated with temporary ponds but also occurring on drier substrates, pioneer grasslands house a large variety of annual plants and insects. In quarries, these grasslands encourage the reproduction cycles of birds, such as the woodlark and the Little-ringed plover. Multi-annual management allows the reopening of these pioneer environments and development of typical plant species.

Creation and refreshing of loose cliffs: In Wallonia, the scarcity of the natural habitat of the sand martin, following the stabilization of riverbanks, led it to colonize loose cliffs of quarries and other artificial sites. The creation and annual refreshing of soft sediment cliffs ensures the maintenance of a suitable habitat. These habitats may also encourage the development of solitary bee populations.

Installation of shelters: To host and develop biodiversity in smoothened areas of quarries, it is necessary to rebuild a favorable shelters and hides. This action includes the construction of shelters and hibernacula for reptiles, amphibians and insects.

Development of vascular plants: The seed lots development for patrimonial pioneer plant species allow developing new populations within areas presenting favorable conditions for their development.

Translocation of the Natterjack toad and the Great crested newt: The geographic isolation of quarries can act as a limiting factor in the recolonization of small wildlife, typical of pioneer environments. In order to benefit from the welcoming potential, the project strives to translocate new populations of Natterjack toads and great crested newts into active quarry sites.

Reintroduction of the yellow-bellied toad: In the Walloon region, the yellow-bellied toad is almost extinct following the disappearance of its habitat. Frequently observed in quarries abroad, this toad can flourish on operational sites. A project's objective is to reproduce and reintroduce a population of yellow-bellied toads on one site.

Life in Quarries Permanent nature actions:

Creation of permanent ponds: Through the creation of permanent waterbodies holding diverse habitats, the project ensures the subsistence – food and reproduction – of numerous plant and animal species, such as the Great crested newt and the Midwife toad.

Creation of gentle slopes for the installation of reed beds: Old quarrying pits are often flooded with exceptional quality water. However, the steep cliffs of the old operating fronts can limit the introduction of vegetation and associated wildlife. A goal of the project is to create gentle slopes favoring the installation of riparian vegetation.

Installation of floating platforms: Large lakes resulting from sites exploitation can be rapidly colonized by fishes. The lack of islets on these large bodies of water can limit the installation of ground nesting birds such as terns and the common gull. The aim of the project is to proceed with the installation of 16 nesting platforms.

Securing of bat galleries: The surroundings of quarries can host old limekilns, technical galleries, ancient houses or farms … that may, upon securing within the project, provide hibernating grounds for bats.

Restoration and management of grasslands: The hay meadows are becoming increasingly rare due to the intensification of agriculture. Through restoration, the project aims at developing new areas for these diverse grasslands.

Restoration and management of grazed meadows: Quarry sites are an important opportunity for the restoration of limestone or acid-loving grasslands depending on the type of rocks concerned. The restoration of these environments requires different types of work such as clearing, deforestation, planting or transfer of hay and the fight against invasive plants (e.g. buddleia, acacia). Fencing and transfer of the management to herders allows for the restoration of this potential on inclined spoil heaps.

Creation of linear screes: The establishment of linear rocky structures aims at ensuring connectivity between habitats suitable for reptiles.

Figure 8. Illustration of the biodiversity actions implemented in the active quarries of the Life in Quarries (Sources: http://www.lifeinquarries.eu; pictures: ©Maxime Séleck). 1. Dynamic management of temporary ponds, 2. Creation and refreshing of loose cliffs, 3. Installation of shelters, 4. Pioneer grasslands, 5. Creation of long-term water bodies, 6. Restoration and management of grazed meadows.

Quarries dynamic and Ecosystems Services assessment

An important aspect to take into account in quarries' ES assessment is that exploitation, over time, implies that a quarry at the beginning of its exploitation does not present the same ecological structure as at its end. The first step in opening a new site is the striping of the overburden material. The quarry is then shaped into an open-pit or set up on a hillside, and structured in benches up to 25 meters high. Its development is commonly accompanied by an expansion of the pit, both in terms of size and depth. Frequently, the pit floor falls below the water table leading to it being pumped out to allow for exploitation.

In Wallonia, quarries are now obliged to rehabilitate their sites after exploitation. Managing the rehabilitation throughout the exploitation phases allows the valorization of several ES:

- Mitigation of noise;
- Capture of dust;
- Mitigation of visual impacts at both long and short distances;
- Ensure the landscape and biological reconstruction of the site.

However, there is no standard procedure and rehabilitation is often adapted to the characteristics of the site and designed on a case-by-case basis. Through the succession of operational and rehabilitation phases, a quarry changes its facies and habitats (Figure 1). These modifications lead to evolution in ES as for their quantity, nature and diversity.

Life in Quarries method to assess Ecosystem Services in active quarries

An innovative method for Ecosystem Services assessment in quarries

The Life in Quarries ES-assessment methodology is based on the work of the Wal-ES platform[6], adapted to the extractive activities context and the Life in Quarries, notably through a literature review on ecosystem services approaches in quarries (Ameloot *et al*., s.d.; Herman & Blokland, s.d.; RESTORE, s.d.; Shrestha & Lal, 2006; Thompson & Birch, 2009; Feng *et al*., 2010; Olsen & Shannon, 2010; Thomspon *et al*., 2010; Grigg *et al*., 2011; Balez *et al.*, 2012; King *et al.*, 2013; Rusche *et al*., 2013; Benning *et al*., 2015; Blaen *et al*., 2015).

It is nevertheless unique and address for the first time specific topics of ES assessment in the extractive industry as:

- Most references use the ES approach to support decision-making on different rehabilitation orientations at the end of activity (RESTORE project; Olsen & Shannon, 2010; Thompson *et al.*, 2010; King, 2013; Blaen *et al.*, 2015), the Life in Quarries ES-assessment methodology is dedicated to a dynamic assessment in active quarries;
- Other authors (Feng *et al.*, 2010; Grigg *et al*., 2011; Balez *et al.*, 2012) use the ES approach to assess the impacts of dependencies and mining activity. The objectives of the project differ as the assessment aims at analyzing the initial and final status of ES in quarries and guide nature management actions;
- Most of the authors (RESTORE project; Feng *et al.*, 2010; Olsen & Shannon, 2010; Balez *et al.*, 2012) carry out a cost-benefit analysis of services through a monetary evaluation, while in the Life in Quarries methodology, the ecological and social importance of services are studied in addition to the economic.

The Life in Quarries methodology to evaluate ES in Quarries assumes their 'value pluralism'. The approach adopted in the project is based on three assessment dimensions in order to take into account the diversity of the components that link ecological structures and processes to human well-being as well as the beneficiaries of ES:

- Biophysical (e.g. volume, weight, area, etc.);
- Social (e.g. qualitative importance, perception, etc.);
- Economic (monetary value).

The methodology addresses these three values domains simultaneously and offers the possibility to establish links between them (synergies, oppositions, dependencies, etc.).

[6] https://services-ecosystemiques.wallonie.be/fr/le-projet-wal-es.html?IDC=5734

Such a multidimensional methodology enables the development of indicators for the estimation of:

- ES stock: the potential of services supply provided by ecosystems. Stock indicators provide a measure of the theoretical or maximum amount of ES that ecosystems can provide, but do not specify whether or not this supply meets a demand and /or is used;
- ES flow: the amount of ES that meets a demand;
- ES demand: demand for a service by individuals or a human community. These are the ES that society wants to see provided, but that are not necessarily delivered.

Conceptual framework of Ecosystem Services evaluation

An integrated valuation of ES requires considering simultaneously (Figure 9):

a) The **ecosystems** providing them;
b) The **management practices** applied on each ecosystem, which influence their flow and stock;
c) The ecosystem services;
d) **Stakeholders** benefiting from and/or negatively impacted by the ES;
e) The socio-economic, socio-cultural and decision-making/governance **context** in which the valuation takes place.

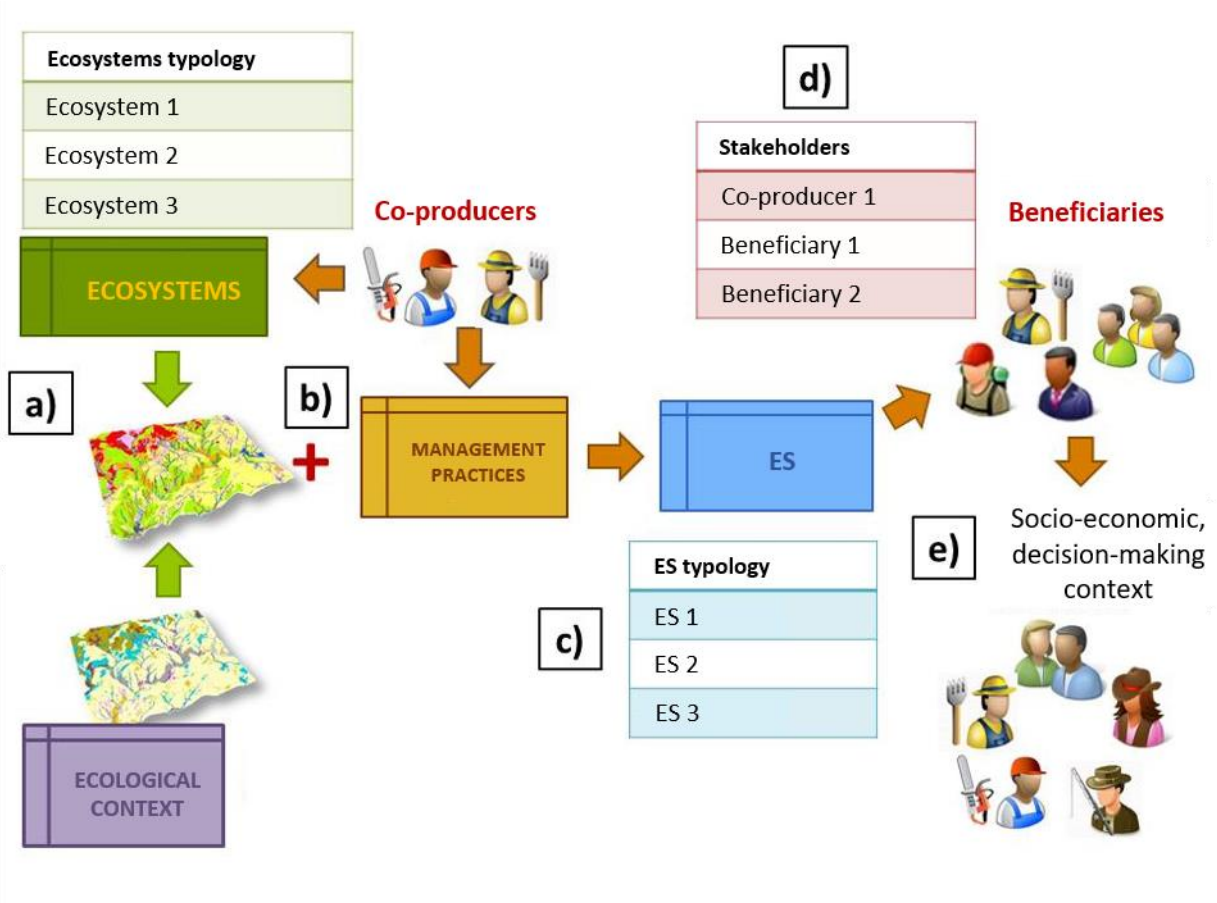


Figure 9. Specific objectives of ecosystem services valuation according to the Wal-ES conceptual framework.

Ecosystems

In the Life in Quarries methodology, ecosystems were identified using land use and ecological context. Habitat maps for each quarry (realized under Action A3) were used to define the land use according to the WalEunis typology, derived from the EUNIS typology. The EUNIS habitat classification is described by the European Environment Agency as "*a comprehensive pan-European system for habitat identification. The classification is hierarchical and covers all types of habitats from natural to artificial, from terrestrial to freshwater and marine*". The WalEunis typology is therefore a selection of Walloon habitats from the EUNIS typology and takes into account the specificities of Wallonia. This typology has become the reference in Wallonia. A list of all WalEunis habitats present in Life in Quarries' sites is presented in Annex 2.

Ecosystem services

The ES typology developed by the Wal-ES platform proposes a classification of all the services provided by ecosystems in Wallonia. This typology was constructed based on existing typologies at the international (MEA[7], TEEB[8]), European (CICES[9] V4.3) and national (CICES-Belgium[10]) levels and adapted to the Walloon context. It is presented in Annex 3 and includes 63 ecosystem services: 26 Provisioning, 21 Regulating and 16 Cultural services.

An initial selection of relevant quarries services was realized based:

- Ecosystems present in the quarries during the field visits (according to the Wal-ES Ecosystems X ES matrix in Annex 4);
- Literature on ES in quarries (Thompson & Birch, 2009; IPEICA & OGP, 2011; King, 2013);
- Activities carried out in the quarries according to information provided by the operators (hunting, recreative walk, school visits, etc.);
- Potential influences of the project actions.

A second selection was made based on the feasibility of evaluation. Indeed, some services could not be measured due to a lack or unavailability of data.

As a result, 29 ecosystem services were studied for the 23 evaluated quarries of the project, including 7 Provisioning, 14 Regulating and 8 Cultural services.

All ES studied in this final report and their descriptions are found in section *Diversity of Ecosystem Services provided in Life in Quarries' sites.* The services of the Wal-ES typology not studied in this report are listed and described in Annex 5.

[7] Millenium Ecosystem Assessment, 2005
[8] The Economics of Ecosystems and Biodiversity, 2010
[9] The Common International Classification of Ecosytem Services: https://cices.eu/
[10] Turkelboom et al., 2013

Stakeholders

To ensure a fair sharing of the benefits from ES, it is important to identify all stakeholders. They can be distinguished based on two statuses:

- **Co-producers** of ES, who input labor, energy, technology, etc. to ecosystems to enhance the supply of services;
- **Beneficiaries** of ES, who obtain benefits improving their well-being.

Co-producers can also be beneficiaries of the service they contribute to provide. For example, a farmer is a co-producer of the "crops" ES as well as a beneficiary through the financial income generated by his activity. The ES x stakeholders matrix developed by Wal-ES (Annex 6) was adapted to the quarrying context according to the actors identified during the field visits and to the information given by operators. For each quarry, the matrix was used to identify co-producers and beneficiaries of the provided ES.

Context

The socio-economic, socio-cultural and decision-making context of the extractive sector must also be identified to define the issues faced by the sites. This also provides guidance for the social and economic valuations.

This context is studied within different actions of the project:

- Action A3 defining the biological context of quarries through biological inventories;
- Action A4 focusing on the legal framework associated to the concept of temporary nature;
- Action D6 studying the perception of the mining sector with regard to biodiversity.

Indicators for Ecosystem Services assessment

Indicators for assessment of ES retained for the study were selected based on five criteria (Church et al., 2014):

- Relevance to the objectives of the assessment;
- Representativeness of the services being evaluated;
- Scientific reliability;
- Adequacy with the resources available;
- Availability of data.

In addition, between the initial analysis of ecosystem services in quarries (A6 report) and this final analysis, some indicators were modified or abandoned. Some selected initially proved to vary greatly over time and therefore did not reflect the actual provision of the services. Data for some indicators finally appeared as unavailable.

Diversity of Ecosystem Services provided in Life in Quarries' sites

In this section, we describe the ES provided by the quarries network and their indicators. The extent of the different services is measured on the percentage of quarries providing the service and specific quantitative estimators measured at the level of the network.

Out of the 29 services evaluated, the quarries network provided 27.

Provisioning services

For this ES category, both stock and flow were assessed.

The stock of provisioning services was estimated based on surface of habitats found in the quarry providing the considered ES. Habitats maps for each quarry (action A3) were used to define the land use. To determine the area of crops and fodder in the quarries, SIGeC[11] data were used, data from 2013 to 2015 were considered for the initial assessment and from 2016 to 2018 for the final one.

The flow of provisioning services was estimated either by the annual production of goods when the data were available, or by the presence of activities enabling the production of goods (in cases when the value of the annual production was not available).

The flow was also assessed by the presence of a **market** for the good supplied (the monetary value was often missing or incomplete). A **market** was identified for provisioning services (except for non-commercial breeding): agriculture production market, wood market, hunting and fishing products. Quarries used these markets at different extents to generate incomes, but, in most cases, quarry managers were not able to identify the level of incomes generated in particular for services linked to hunting and fishing. Monetary valuation of provisioning services was limited by available data.

A more detailed description of the calculation methods for these ES indicators is provided in Annex 7.

Food

Food production services (all the goods provided by ecosystems that we consume directly or after transformation in the form of food) provided by quarries included '*Commercial cultivated crops*' and '*Commercial and non-commercial breeding*' (supported mainly by farming activities in non-active areas of the quarry) as well as, hunting and fishing. '*Wild terrestrial animals*' hunting presented the highest stock with 100% of quarries and about 1700 ha of areas supporting the ES, but the ES was only realized in 39% (2020) - 48% (2016) of the quarries (Table 1). Stock for '*Fresh water fishes and shellfishes*' was also present in 100% of quarries but was seldom realized with <5% of quarries hosting fishing activities. Stock of ES linked to agricultural production came second for food production but differed greatly in the extent of use. The service of '*Commercial cultivated crops*' production was frequently provided by quarries in unexploited/restored areas (>65% quarries with ES stock, ~235 ha crop production) and existing flow (100% quarries with existing stock used the ES, total ~3500 – 4700 T). In contrast,

[11] Système Intégré de Gestion et de Contrôle – Integrated management and control system. The SIGeC is a database managed by a department of Wallonia which allows the identification of farmers and the parcels they cultivate.

'*Commercial and non-commercial breeding*' had a high potential (>95% quarries with stock services, 187-245 ha), but was less often valued (low flow: 4-35% quarries with existing stock used the ES) (Table 1).

Raw materials & energy

Raw materials production services provided by quarries included '*Wood*' for materials or energy and '*Fodder*' for animal feed. It was not possible to distinguish raw materials (wood) used for energy purposes from those used for material purposes. The stock of wood production service was the second highest (after wild animals hunting) with 100% quarries and ~620 ha but was hardly realized due to low exploitation of the resources (30-35% quarries with existing stock used the ES). The stock for fodder production service was similar to the stock for '*Commercial cultivated crops*' and '*Commercial and non-commercial breeding*' (78-87%) but with smaller surfaces (93-95 ha), and was realized in all quarries with available stock (Table 1).

Drinking water

The volumes of surface water (dams, pumping, etc.) and groundwater depend largely on ecosystems present on the surface and the activities that take place there. Drinking water is mainly used for domestic and industrial purposes (cooling, agriculture …). The production of '*Drinking water*' was a service specific to a small percentage of quarries (13-17%), depending on the level of the water table and the demand for drinking water. The service was realized in almost all quarries with ES stock and provided high flow of drinking water production ($7.9*10^6$ - $8.5*10^6$ m^3/year) (Table 1), corresponding roughly to the annual consumption of 100,000 households.

Table 1. Assessment of provisioning services at the scale of the Life in Quarries network of quarries. List of assessed provisioning services, indicators for assessment, and ES delivered. Total number of quarries studied: 23.

	Description		Number of quarries providing the ES		ES quantification		
			2016	2020	Indicator	2016	2020
Commercial cultivated crops	All agricultural crop production to be marketed as food for human consumption.	Stock	16 (70%)	15 (65%)	Quarry area suitable for commercial food crop (ha)	241 ha	227 ha
		Flow	16 (70%)	15 (65%)	Production of farmland in the quarry (T)	4699 T	3486 T
Commercial and non-commercial breeding	Breeding set up by farmers or individuals/communities, with or without a marketing aim.	Stock	22 (96%)	22 (96%)	Quarry area suitable for grazing (ha)	187.4 ha	244 ha
		Flow	1 (4%)	8 (35%)	% quarries with domestic grazing activity (yes/no)	4%	35%
Wild terrestrial animals	Animals hunted for human consumption	Stock	23 (100%)	23 (100%)	Quarry area suitable for hunted wild terrestrial animals (ha)	1724 ha	1662 ha
		Flow	11 (48%)	9 (39%)	% quarries with hunting (yes/no)	48%	39%
Fresh water fishes and shellfishes	Wild fishes and shellfishes caught for human consumption.	Stock	23 (100%)	23 (100%)	Water surface in the quarry (ha)	88 ha	100 ha
		Flow	1 (4%)	1 (4%)	% quarries with fishing activities (yes/no)	4%	4%
Wood	Wood products used as material or for burning	Stock	23 (100%)	23 (100%)	Wooded area of the quarry (ha)	629 ha	615 ha
		Flow	8 (35%)	7 (30%)	% quarries with timber harvesting (yes/no)	35%	30%
Fodder	Raw materials used as fodder for animal feed.	Stock	18 (78%)	20 (87%)	Quarry areas of grassland and fodder crops (ha)	92.8 ha	95.3 ha
		Flow	18 (78%)	20 (87%)	Fodder production (T)	1419 T	1564 T
Drinking water	Freshwater from water bodies and wetlands of a drinking water source.	Stock	4 (17%)	3 (13%)	Drinking water surfaces in the quarry (ha)	6.7 ha	11.4 ha
		Flow	3 (13%)	3 (13%)	Volume of potable water (m^3)	$8.5*10^6$ m^3	$7.9*10^6$ m^3

Regulating services

All regulating services were assessed using the same method. Both stock and flow were assessed.

Stock

The stock of regulating services is related to the quarries' ecosystem areas providing the different services weighted by a score of habitat capacity to deliver the services. A score from 0 to 5 representing the capacity to provide a given service was assigned to each habitat on expert consensus (0 = no capacity to 5 = very high capacity). A scoring matrix (habitat X regulating services) was created (Table 2). Habitats were defined based on the second level of the WalEunis classification; this level is, in general, precise enough to distinguish two habitats providing significantly different services. The only exception to this rule was for E5 – *Woodland fringes and clearings and tall forb* habitats split as Habitat E5.2 – *Thermophile woodland fringes* was considered to provide significantly different ES than habitat E5.4 – *Moist or wet tall-herb and fern fringes and meadows* and E5.6 – *Weed communities of recently abandoned urban and suburban constructions, rural constructions or extractive industrial sites.* These three habitats were therefore separated in the data analysis. Each score was weighted by the relative area (percentage) of each habitat in the quarry. Thus, a habitat with a large area scoring a low service capacity has the same impact as a habitat with a small area that provides a high service. The adjusted stock indicator for regulating services is therefore comprised between 0 and 5. Any change in this indicator is due solely to the change in the area of the habitat present in the quarry.

Table 2. Matrix of expert scores for the different WalEunis habitats in quarries reflecting the relative capacity to provide the different regulating services (from 0 = no capacity to 5 = very high capability).

	Control of erosion	Attenuation of sediment flows	Regulation of hydrological cycle	Flood protection	Surface water purification and oxygenation	Groundwater purification and oxygenation	Capture dust, chemicals and odors	Mitigation of noise and visual impacts	Pollination	Maintenance of habitats for species life cycles	Biological control	Regulation of invasive alien species	Regulation of the global climate by sequestrating greenhouse gases	Micro-climate regulation
C1 - Surface standing waters	0	3	2	3	2	2	1	0	0	5	5	0	3	3
C2 - Surface running waters	0	0	1	4	1	1	0	0	0	5	5	0	1	3
C3 - Littoral zone of inland surface waterbodies	0	2	2	3	4	2	0	0	0	5	5	1	2	2
D5 - Sedge and reedbeds, normally without free-standing water	3	3	4	3	4	2	2	2	3	4	3	3	3	2
E1 - Dry grasslands	2	1	2	0	2	2	1	1	4	5	5	0	1	0
E2 - Mesic grasslands	3	2	3	1	2	2	1	1	5	4	4	3	2	1
E3 - Seasonally wet and wet grasslands	3	2	4	2	3	2	2	1	5	5	4	3	3	2
E5.2 - Thermophile woodland fringes	3	3	3	2	2	3	2	2	5	5	5	3	3	3
E5.4 - Moist or wet tall-herb and fern fringes and meadows	4	5	3	4	4	2	3	2	4	5	5	4	3	3
E5.6 - Weed communities of recently abandoned urban and suburban constructions, rural constructions and extractive industrial sites	2	1	3	1	2	2	1	1	4	4	4	2	2	1
F3 - Temperate and mediterranean-montane scrub	4	3	3	2	2	3	3	3	3	5	5	4	3	3
F4 - Temperate shrub heathland	3	2	2	2	2	2	2	2	4	5	5	3	2	2
FA - Hedgerows	4	3	3	4	3	4	3	3	5	5	5	1	3	4
G1 - Broadleaved deciduous woodland	5	5	5	5	5	5	4	4	4	5	5	5	5	5
G3 - Coniferous woodland	3	2	2	3	2	2	5	5	0	2	1	5	4	5
G5 - Lines of trees, small anthropogenic woodlands, recently felled woodland, early-stage woodland and coppice	4	3	3	4	3	4	4	4	3	3	2	1	3	4
H1 - Terrestrial underground caves, cave systems, passages and waterbodies	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2 - Screes	1	0	1	0	0	0	1	1	1	5	5	0	0	1
H3 - Inland cliffs, rock pavements and outcrops	0	0	0	0	0	0	1	0	0	5	5	0	0	1
I1 - Arable land and market gardens	0	0	0	0	0	0	1	1	1	2	1	2	1	1
I2 - Cultivated areas of gardens and parks	2	0	1	0	1	1	2	2	3	2	2	0	2	2
Ia - Agriculturally-improved, re-seeded and heavily fertilized grassland, including sports fields and grass lawns	2	0	1	1	1	0	1	1	1	2	1	2	1	1
J1 - Buildings of cities, towns and villages	0	0	0	0	0	0	0	0	0	0	0	0	0	0
J2 - Low density buildings	0	0	0	0	0	0	0	0	0	0	0	0	0	0
J3 - Extractive industrial sites	0	0	0	0	0	0	0	0	0	0	0	0	0	0
J4 - Transport networks and other constructed hard-surfaced areas	0	0	0	0	0	0	0	0	0	0	0	0	0	0
J5 - Highly artificial man-made waters and associated structures	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Flow

The flow of regulating services was identified in 2016 and 2021 through question 8 of the action D6 survey – *Socio cultural monitoring of communication actions /consciousness of the sector for biodiversity.* This question was specifically intended to identify the use of regulating services by quarryman. The wording of the question was carefully designed to make it understandable by the entire quarrying sector: the term "ecosystem services" was not directly used as it is rarely understood and was rather replaced by "service" or "activity". 102 participants in 2016, and 99 participants in 2021, representing the project's quarries and all the professional positions in the management organigram of quarries, completed the questionnaire. Interviews were conducted face-to-face in 2016 and a mix of face-to-face and videoconference (due to the Covid-19 crisis) in 2021. This question also allowed informing on the flow of cultural services.

"In your opinion, besides raw materials production, what are the services supplied by the quarry among the following list?"

☐ Place to walk	☐ Living space for plants and animals	☐ Maintaining water quality
☐ Wood production	☐ Cultural /spiritual	☐ Water supply
☐ Food production	☐ Dust capture	☐ Climate control
☐ Place for recreation and leisure	☐ Flood protection	☐ Limitation of visual and noise impacts
☐ Scientific interest	☐ Landslide protection	☐ Nothing
	☐ Education	☐ I don't know
	☐ Other: …	

Based on the stock indicators, all the regulating services were provided by all quarries to a greater or lesser extent from one quarry to another. Individual scoring of ES across each quarries ranged from 0.40 ('*Flood protection*') to 3.47 ('*Maintenance of habitats for species life cycles*') on a scale from 0 to 5. When considered at the level of the quarry network (Table 3), the ES category **'*Control of biological processes*'** presented the highest stock weighted indicators (1.60 to 2.56), specifically for the '*Maintenance of habitats for species life cycles*' (2.45 – 2.46) and '*Biological control*' (2.32 to 2.43). This high scoring was due to the large areas of ecosystems supporting the services in quarries with high expert scoring (*Broadleaved deciduous woodland* – G1, *Woodland fringes and clearings and tall forb stands* - E5, *Temperate and Mediterranean-montane scrub* – F3, *Dry grasslands* – E1). **'*Climate regulation*'** came as the second scored category of regulation services, due to both the high expert scoring (Table 2) and large areas of forest habitats (Table 1). Other regulating services, included in **'*Regulation of extreme events*'** and **'*Regulation of various pollutions*'**, ranked at lower positions, specifically for '*Capture of dusts, chemicals and odors*', and '*Mitigation of noise and visual impacts*'.

Table 3. Assessment of regulating services at the scale of the Life in Quarries network. List of assessed regulating services, indicators for assessment, and ES delivered.

	Description	Stock Indicator Weighted Score (0-5)	
		2016	2020
Regulation of extreme events			
Control of erosion	Vegetation protects the soil from rainfall and wind, while the roots help to stabilize the soil, preventing sediments displacement.	1.65	1.59
Attenuation of sediment flows	Retention and storage of sediments by vegetation cover.	1.47	1.42
Regulation of hydrological cycle	Regulation of water flows (e.g. evapotranspiration, water storage, infiltration).	1.72	1.65
Flood protection	Reduction of flood risk and intensity by acting as a temporary reservoir for precipitation and runoff.	1.41	1.34
Regulation of various pollutions			
Surface water purification and oxygenation	Oxygenation, filtration, sequestration and degradation of surface water pollutants.	1.54	1.47
Groundwater purification and oxygenation	Oxygenation, filtration, sequestration and degradation of pollutants, contributing to the purification of groundwater.	1.61	1.54
Capture dust, chemicals and odors	Capture and sequestration of dust, pollutants and odors	1.38	1.32
Mitigation of noise and visual impacts	Reduction of noise and visual impacts from human activities and infrastructure. Plants alter sound by reflecting or absorbing it and act as visual barriers.	1.32	1.26
Control of biological processes			
Pollination	Pollination ensures the reproduction of many plants through the transfer of pollen between flowers by animals or wind.	1.78	1.73
Maintenance of habitats for species life cycles	Some species need several habitats to ensure their life cycle. These habitats meet different needs: reproduction, nutrition, protection, etc.	2.56	2.45
Biological control	A method of controlling pest such as crop pests, diseases or weeds, by using antagonistic living organisms (predators, parasitoids, pathogens or herbivores).	2.43	2.32
Regulation of invasive alien species	Ecosystems can be more or less resistant to the introduction of invasive species.	1.69	1.60
Climate regulation			
Regulation of the global climate by sequestrating greenhouse gases	This service helps to mitigate climate change. E.g.: Sequestration of carbon dioxide, degradation of methane and nitrous oxide by microbial activity.	1.69	1.61
Micro-climate regulation	Ecosystems create a microclimate by locally influencing climate variables.	1.61	1.52

When evaluating **the flow of regulating services,** respondents of the survey considered that the regulating services most provided in their quarries were the '*Maintenance of habitats for species life cycles*' (in accordance with evaluated stocks, Table 3), '*Mitigation of noise and visual impacts*', '*Groundwater purification and oxygenation*' and '*Capture dust, chemicals and odors*' (while those ES presented the lowest stocks, Table 3) (Figure 10). The operators therefore clearly identified ES promoted within the quarry to limit the impacts of the exploitation on the environment. In addition, 100% respondents cited the service '*Living place for plants and animals*' as a likely result of the Life in Quarries project reflecting the raised sector's awareness that quarries can play a role for biodiversity.

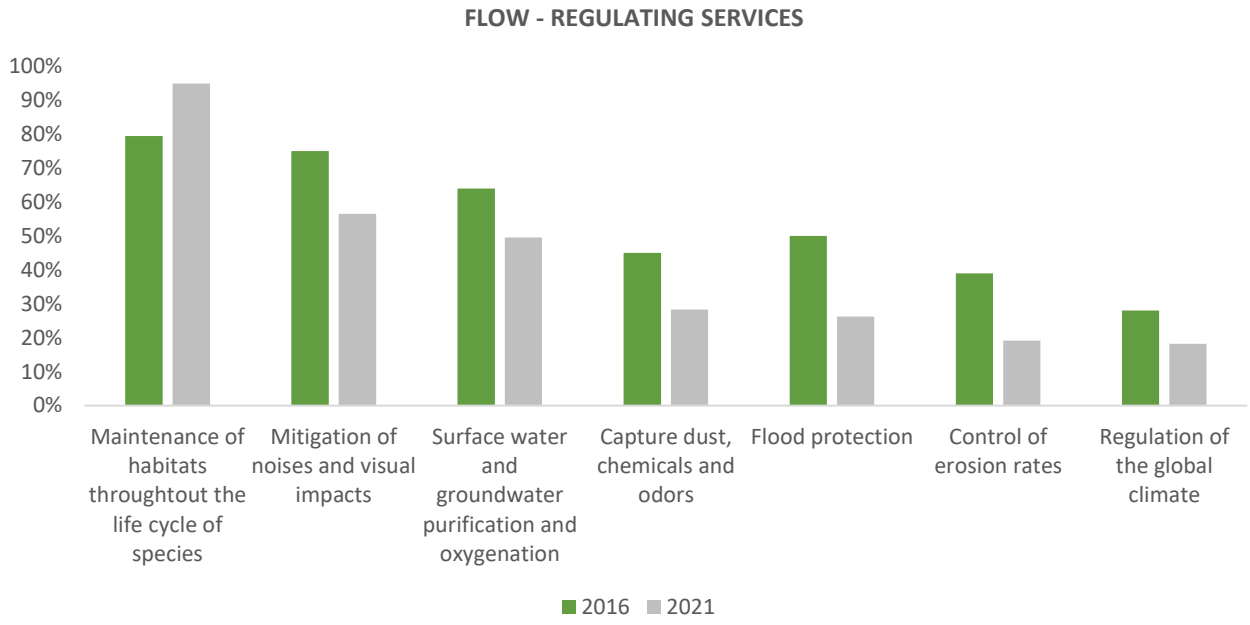


Figure 10. Percentages of operators who considered that the different regulating services are provided by quarries. This value reflects the flow of these services from quarryman perspective.

Cultural services

Stock of cultural services was assessed based on quarries areas (ha) potentiality supporting the different services. **The flow** of cultural services was assessed based on indicators reflecting the organization of activities related to the different cultural services and public participation to these activities: percentage of quarries organizing activities, number of activities organized, and number of participants. **The demand** indicator for these services was the proportion of people interested in further enjoying them in quarries.

The flow and demand for these services were determined using feedbacks from quarries on public activities organized and using a questionnaire filled in by participants to activities occurring in quarries (see Annex 8). The questions were based on scientific literature (Benning et al., 2015; Boll, T. et al., 2014; Cessford, 1995; Church et al., 2014; Clough, 2013; Cord et al., 2015; Dwyer & Gobster, 1992; Joris, 2015; Lindberg, s.d.; Lisberg Jensen & Ouis, 2008; Peh et al., 2013; Petrosillo et al., 2007; Schneider & Lorencova, 2015; Skår et al., 2008; Tarrant & Smith, 2002; Voigt et al., 2014). In addition to flow and demand, these questionnaires evaluated the degree of satisfaction for the ES. The availability of data therefore depends on the activities organized by the quarries in 2016 and 2018 for the initial report (for phase I and II quarries respectively) and in 2020 for the final analysis. While some quarries did not report

any activities, this does not mean that cultural services do not exist in these quarries. The attractiveness of a quarry to the public for cultural purposes is dependent of a large number of parameters such as its location, structure or dimension as well as its accessibility to the public. The lack of data for the year 2020 linked to the Covid-19 pandemic (cancelation of public activities) led us to consider all activities organized during the Life in Quarries to evaluate these services at the end of the project.

Stock

Relating the different areas of quarries to specific cultural services appeared difficult as activities in quarries used many different zones for different purposes. For example, an activity for outdoor recreation such as biking can use bikeable areas including exploitation tracks in the active pits and non-exploited zones covering the diversity of habitats. The service '*Natural space and biodiversity sources of inspiration and entertainment*' is more linked to the global quarry landscape than to specific areas. **Hence, the entire area of quarries was considered to deliver a stock for cultural services**.

An exception was made for, ***'Everyday environment'* services.** This category includes living and working environment as well as daily activities in ecosystems. Some nuisance can accompany extractive activities for the inhabitants of the surrounding area. These disturbances can linked to vibrations due to blasting causing damage to neighboring buildings or to dusts emissions and traffic related to quarries impacting daily lives of neighbors (CRAEC, 2010, Chaïb, 1998). These impacts of operations are felt at the local scale, but also influence significantly the landscape. During its activity, a quarry can be considered aesthetically intrusive, removing any impression of naturalness from the landscape (Mouflis et al., 2008). These elements affect negatively cultural services linked to ***'Everyday environment'***. Quarries can implement measures to reduce such nuisances, such as the promotion of vegetation screens limiting noise and dust (see *Regulating services*). On the other hand, at the end of its activity, a quarry can become a positive element if transformed into a shared space (green spaces, nature reserves, recreation areas, or their combination). Structured evaluation with neighbors were not possible in the framework of the project, so it was not possible to detail the flow and demand for this service. The '*Non-exclusive natural space suitable for daily outdoor activities*' service was thus evaluated according to its stock based on the presence or not of paths and non-exclusive viewpoints in the quarry's surrounding area. Its stock being evaluated as provided for quarries with viewpoints or paths accessible to everyone in their surroundings representing 70% of the project's sites (Table 4).

Flow

The quarries can welcome a wide audience, with all sites having a significant range of outdoor activities providing cultural services. The different activities that were organized in the project quarries during 2016 (phase I) and 2018 (phase II) (initial evaluation) are listed in Table 5. Links between organized activities and cultural services are multidimensional as some activities, such as school visits or secondary education visits, are mainly related to the service '*Natural space and biodiversity serving as a support for education*'. Other activities, like "nights of batrachians", visits of "youths from Nature" conservation NGOs, leisure for mineralogy club … can relate to several cultural services: '*Exclusive natural space for outdoor recreation*', *Natural space and biodiversity supporting the experience of nature*' and '*Natural space and biodiversity as a support for scientific research*'.

Table 4. Assessment of cultural services at the scale of the Life in Quarries network. List of assessed cultural services, indicators for assessment, and ES delivered (NA = no available data).

	Description	Indicator	Values	
			Up to 2016	Up to 2021
Everyday environment (STOCK)				
Non-exclusive natural space suitable for daily outdoor activities	Non-exclusive natural or semi-natural areas that provide an environment with conditions and characteristics that allow daily outdoor human activities to take place.	% quarries with presence of paths and non-exclusive viewpoints in the area surrounding the quarry (Q).	Q: 70%	Q: 70%
Environment for recreation (FLOW)				
Exclusive natural space for outdoor recreation	Exclusive natural and semi-natural areas which provide an environment with conditions and characteristics that allow the exercise of human leisure activities and outdoor tourism.	% quarries organizing the activity (Q), number of activities (A), number of participants in activity (P)	Q: 78% A: 15 P: 3126	Q: 91% A: NA P: NA
Exclusive natural space for productive leisure activities	Exclusive natural and semi-natural areas which allow activities that enable both the enjoyment of the area and the harvesting of productive goods.	% quarries organizing the activity (Q), number of activities (A), number of participants in activity (P)	Q: 43% A/P: NA	Q: 52% A/P: NA
Sources of experience and knowledge (FLOW)				
Natural space and biodiversity supporting the experience of nature	Natural or semi-natural areas where nature, plant, animal species or communities can be observed and interacted with.	% quarries organizing the activity (Q), number of activities (A), number of participants in activity (P)	Q: 48% A: 10 P: 1516	Q: 87% A: NA P: NA
Natural space and biodiversity serving as a support for education	Natural or semi-natural areas and elements of biodiversity used for nature discovery activities.	% quarries organizing the activity (Q), number of activities (A), number of participants in activity (P)	Q: 70% A: 20 P: 1526	Q: 100% A: NA P: NA
Natural space and biodiversity as a support for scientific research	Natural or semi-natural areas and elements of biodiversity used for scientific research, to better understand the functions and dynamics of species populations, ecosystems, landscapes, etc.	% quarries organizing the activity (Q), number of activities (A), number of participants in activity (P)	Q: 83% A/P: NA	Q: 91% A/P: NA
Sources of inspiration and values (FLOW)				
Natural space and biodiversity sources of inspiration and entertainment	Natural or semi-natural areas that inspire a representation or expression of feelings, beauty, … through painting, sculpture, cinematography, photography, etc.	% quarries organizing the activity (Q), number of activities (A), number of participants in activity (P)	Q: 30% A: 3 P: 486	Q: 43% A: NA P: NA
Natural space and biodiversity sources of intrinsic values of existence and heritage	Natural spaces and living organisms with an intrinsic existence value or a legacy value for future generations (e.g. areas and species protected, extraordinary landscapes …).	% quarries organizing the activity (Q), number of activities (A), number of participants in activity (P)	Q: 9% A: 2 P: 6	Q: 100% A: NA P: NA

Table 5. Activities organized in the 23 quarries of the Life in Quarries during 2016 (Phase I sites) and 2018 (Phase II). Greyed cells represent activities organized in the quarries that could not be evaluated.

	Phase I - 2016													Phase II - 2018									
	Quarry 1	Quarry 2	Quarry 3	Quarry 4	Quarry 5	Quarry 6	Quarry 7	Quarry 8	Quarry 9	Quarry 10	Quarry 11	Quarry 12	Quarry 13	Quarry 14	Quarry 15	Quarry 16	Quarry 17	Quarry 18	Quarry 19	Quarry 20	Quarry 21	Quarry 22	Quarry 23
Alpinism / Climbing		x																					x
Slag heaps circuit (open to public)				x																			
Geology club																				x			x
Mineralogy club										x					x		x					x	
CPAS																			x				
Horse riding																					x		
Medieval festival																						x	
Youth Natagora						x																	
Open day							x		x						x								
ADEPS walk					x													x					
Night of batrachians				x																			
Fire brigade															x			x					
Hiking		x							x														
Archery																							x
Trail														x							x		
Trekking												x											
Leisure center visit											x												
School visits		x						x	x				x					x				x	
Secondary education visit	x		x					x		x						x						x	x
Companies visit								x															
Mountain biking				x	x			x	x									x			x	x	

Altogether, about 50 visits were organized at the beginning of the project during 2016 (Phase I) and 2018 (Phase II) and evaluated by a questionnaire with the support of a dedicated team of the project. In total, 5286 people participated in quarry visits. Overall, each quarry provided individually two to seven of the eight cultural services. During the course of the project, quarries staff were left autonomous to register their public activities and to distribute the questionnaires, without dedicated human resources from the project. It appeared that such a task was an additional working charge in an already complex agenda, and was seldom fully met. As a result, only qualitative data could be collected *a-posteriori* through direct contacts with quarry managers, on the presence or absence of each activity category in individual quarries and a valid quantification on the number of activities or participants for the full project period could not be compiled. Hence, the evolution of cultural services was based on the proportion of quarries that delivered each service.

'*Environment for recreation*' includes the most delivered cultural service '*Exclusive natural space for outdoor recreation'* when considering the number of participants (3126) to activities or the percentage of quarries delivering the service (78% - 91%) (Table 4). '*Exclusive natural space for productive leisure activities'* (linked to the provisioning services '*Wild terrestrial animals*' (with hunting) and to '*Fresh water fishes and shellfishes*' (with fishing)) was delivered to a lesser extent with 43% - 59% of quarries involved based on feedback from quarry managers. Data on the number of activities and of participants were lacking as smaller numbers generally concerned those activities.

'*Source of experience and knowledge*', based on activities supporting nature experience, education, and scientific research was also a cultural services category well realized with the highest number of activities (35) at the beginning of the project, a high percentage of quarries involved in the different services (48%-100%, but mostly > 70%), and the second number of participants. '*Natural space and biodiversity supporting the experience of nature*' service involved a high number of participants (1516). In addition to the daily scientific contributions of the Life in Quarries team, the project provided a strong support to education and scientific training ('*Natural space and biodiversity serving as a support for education*' and '*Natural space and biodiversity as a support for scientific research*') with multiple student visits and support to the realization of Master/Bachelor thesis (11) as well as Master/Bachelor stages and projects (9). Student thesis and stages were directed to contribute to the implementation/evaluation of the actions targeting amphibians habitats and translocations (12), actions targeting pioneer and permanent grasslands creation (4) and monitoring (3) (see Annex 9, for details and access to online thesis). '***Source of inspiration and values***' appeared a more specialized service category appealing to a specific public (5 activities, 592 participants) but the percentage of quarries delivering this category increased along the project.

The flow of cultural services was also identified in 2016 and 2021 through question 8 of the action D6 survey – *Socio cultural monitoring of communication actions/consciousness of the sector for biodiversity*[12], assessing the importance given by quarries staff to different ES (see section *Regulating services*, for details on the methodology). Results were very similar through time (Figure 11). Quarryman highlighted the role of quarries as support for education and scientific research, which was consistent with the realized importance of those activities. In contrast, 'outdoor recreation' was less considered, while activities linked to this service welcomed a high number of participants.

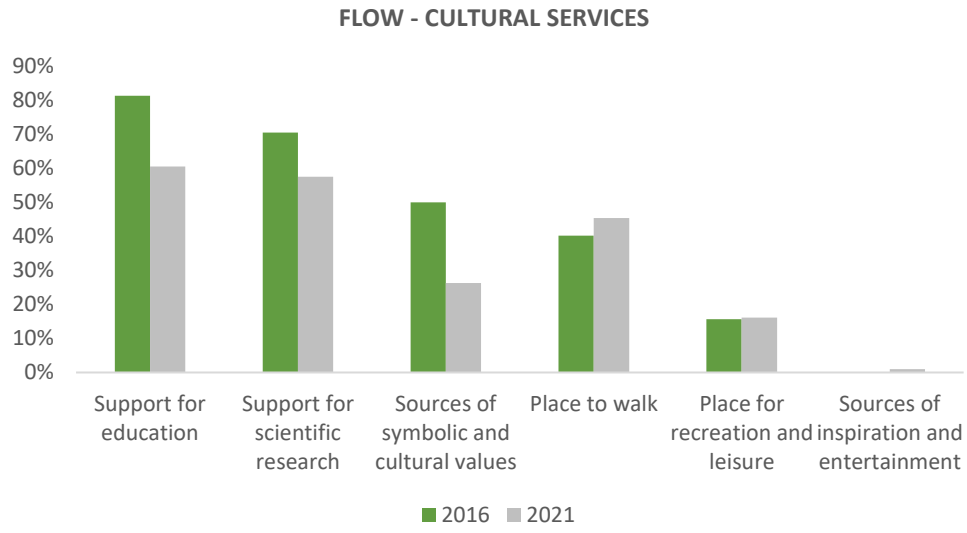


Figure 11. Percentages of operators who considered that the different cultural services are provided by quarries. This value reflects the flow of these services from quarryman perspective.

[12] Mahy G., Maebe L., Dufrêne M., Joassin V., Mercken K., de Wagter A., Druez C. & Séleck M. (2021). Biodiversity perception in the Extractive sector - Lessons from the Life in Quarries project. Gembloux, Belgium: Université de Liège, Gembloux Agro-Bio Tech. http://hdl.handle.net/2268/266146

Demand

More than 60% of visitors in 2016-2018 wanted to come back in quarries, mostly for walking and hiking (Figure 12). It appears from the surveys that the demand for cultural activities in quarries is significant and often underestimated.

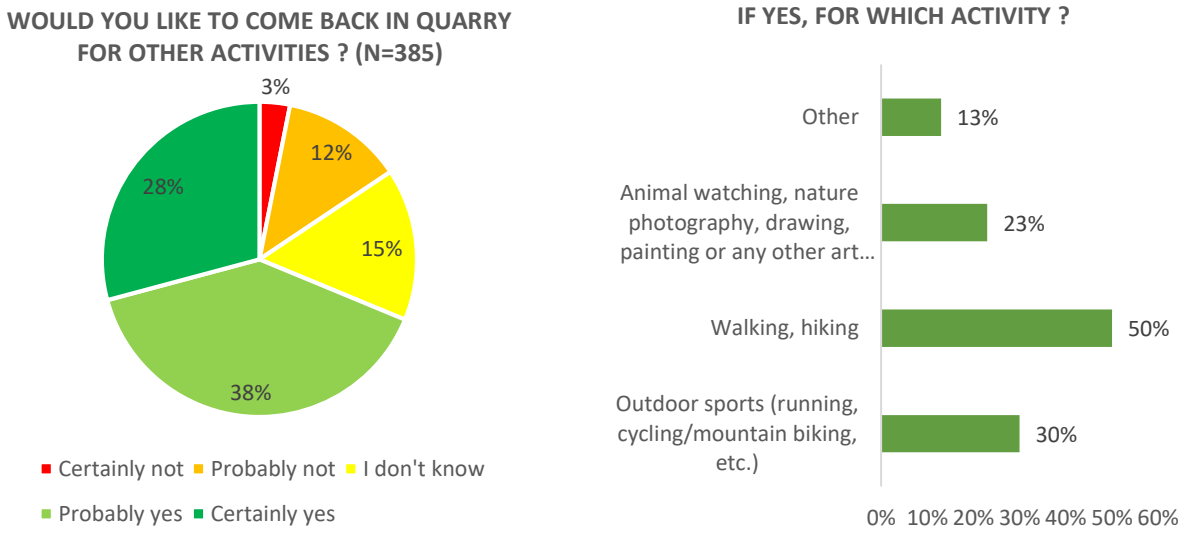


Figure 12. Proportion of people wishing to return in a quarry for new activities (2016) and proportion of people wishing to carry out the following activities in quarries (2016).

Life in Quarries biodiversity actions and Ecosystem Services

By implementing actions for biodiversity, the Life in Quarries modified ecosystems in the quarries and could have modified ES provision. In the same time, ecosystems were also modified by the evolution of the exploitation (progress in exploitation front, change in backfilling areas…) during the project. In order to assess changes in provisioning and regulating services, we distinguished three situations:

i. The **initial** stock and flow of provisioning and regulating services based on habitats areas and derived indicators in 2016 and 2018 (initial assessment, based on the map of habitats in 2016 for phase I quarries and in 2018 for phase II2 quarries);
ii. The **estimated final** stock and flow of provisioning and regulating services based on habitats areas and derived indicators in 2020 including modifications of land use due to Life in Quarries actions and quarry exploitation evolution (based on the map of habitats in 2020) where all habitats modified by the project actions were replaced by projected habitat within a 15 years' timeframe;
iii. The **estimated final** stock and flow of provisioning and regulating services based on habitats areas and derived indicators in 2020 assuming a situation **without implementation of Life in Quarries actions** (based on the map of habitats in 2020) where all habitats modified by the project actions were replaced by projected habitat within a 15 years' timeframe **without** Life in Quarries actions.

This last situation represented change in ES due to the evolution of exploitation without the project's management of habitats for biodiversity. The difference between ii) and iii) is the best estimation of the specific impact of Life in Quarries biodiversity actions on ES.

For the **provisioning services**, the greatest fluctuations of stock and impact of Life in Quarries actions were observed for '*Fodder*' and '*Commercial and non-commercial breeding'* (Table 6). Without Life in Quarries actions, both services stocks would have decreased (28% for fodder, 11% for breeding) due to the destruction of suitable habitats linked to the evolution of quarries exploitation. However, through Life in Quarries actions, stocks for these services will eventually increase (3% and 31%, respectively) through the creation of permanent grasslands and meadows. For *'Commercial and non-commercial breeding*', eight quarries used the service in 2020 (or 2021, with presence of herds of breeding animals in the quarries) as compared to a single site in 2016. In contrast, Life in Quarries actions had a moderately negative impact on the stock or wood production (slight increase, +2.3%, estimated without Life in Quarries actions, but slight decrease, -2.0%, linked to Life in Quarries actions), due essentially to deforestation for the creation of permanent herbaceous habitats (grasslands and meadows). Creation of permanent ponds slightly raised the stock of the ES '*Fresh water fishes and shellfishes*' (+13%), a slight additional increase as compared to the estimated increase without Life in Quarries actions (+11%). As no Life in Quarries actions directly affected areas suitable for crop production in the quarries, the evolution of the service related to crops production (-5.8% stock) mainly reflects a change in areas due to the evolution of exploitation. The '*Drinking water*' provisioning service remained globally stable during the project, with fluctuations driven by water demand (and thus indirectly climatic conditions). **Changes in provisioning services stocks were mainly linked to actions targeting the creation of permanent habitats (permanent grasslands, meadows, ponds), while actions targeting temporary**

habitat did not influence significantly provisioning services due to their small spatial extension and/or low potential for production.

Table 6. Average change of provisioning services with and without Life in Quarries actions.

Provisioning services		Initial situation	Estimated final situation	
			Without Life in Quarries actions	With Life in Quarries actions
Crops	**Stock**	241.3 ha	Not concerned by Life in Quarries actions	
Fodder	**Stock**	92.8 ha	↘ 28.2%	↗ 2.7%
Commercial and non-commercial breeding	**Stock**	187.4 ha	↘ 11.0%	↗ 30.7%
Wood	**Stock**	629.5 ha	↗ 2.0%	↘ 2.3%
Wild terrestrial animals	**Stock**	1724.7 ha	↘ 4.2%	↘ 3.6%
Fresh water fishes and shellfishes	**Stock**	88.2 ha	↗ 11.8%	↗ 13.0%
Drinking water	**Stock**	Stable with fluctuations according to the demand		
	Flow			

Due to the evolution of the exploitation in quarries, the estimations of **regulating services** stock (without Life in Quarries actions) decreased slightly (-1.8% to -5.0%, depending on services) (Table 7). For fully active quarries of the project, this is in accordance with the finding that quarries capacity to provide regulating services depends on their life-stage with a diminution linked to exploitation progression and an increase resulting from sites' closure (see next section *Evolution of ES Ecosystem Services through the life cycle of* a quarry). For most regulating services, the project's actions resulted in an additional marginal diminution as compared to an estimated situation without actions (difference with – without actions ranging from 0.7 to 3.1%) with most impacted ES related to '***Climate regulation***', '*Mitigation of noise and visual impacts*', and '*Flood protection*'. This situation results from the higher expert scores for these services attributed to woody habitats, negatively impacted through the project by deforestation in favor of permanent grasslands and meadows.

While the service '*Maintenance of habitats for species life-cycle*' ranked as the highest regulating service delivered by quarries (Table 3), the measured impact of actions implemented during the Life in Quarries was low on its stock (+0.7%). This may seem surprising as the project was specifically dedicated to increase quarry capacity to support biodiversity. The main reason of this situation came from the fact that the ES-assessment method used did not reflect the actual impact of Life in Quarries actions on biodiversity as: (i) First, areas with high service's scores for permanent habitats (i.e. *Broadleaved deciduous woodland* – G1, score 5), were replaced by other high scored habitats (*Dry grasslands* – E1, score 4, and, *Mesic grasslands* – E2, score 5), resulting in a similar global score. This scoring does not reflect the gain of biodiversity resulting from the transition from secondary forests with moderate biodiversity potential to highly diversified grasslands. (ii) Second, Life in Quarries actions were in priority dedicated to promote temporary pioneer habitats, typically of small surfaces (hence with low influence the weighted ES scoring) but with high additional value for threatened and protected associated species. This clearly points to the limits of using an anthropogenic global SE approach to evaluate projects focused on increasing species viability on the basis of the recognition of their intrinsic value.

In general, fluctuations in regulating services were low and interpretation of such low variations should be considered with caution as their assessment not only depends on the modification of ecosystems areas, but also greatly on attributed experts scores in the evaluation of the habitats potential to provide each regulating service. In addition, those variations resulted in non-significant changes of global scores

between the beginning and the end of the project, with maximum scoring differences of 0.11 on a scale of 0.00 to 5.00. The method appears thus more relevant in the evaluation of regulating services evolution throughout the quarry life cycle scale.

Table 7. Changes of scoring for regulating services (stocks) with and without Life in Quarries actions. Scoring before the project (initial) and estimated percentage changes in scoring at the end of the project without and with actions.

Regulating services	Initial situation	Estimated final situation		With – without Life in Quarries actions
		Without Life in Quarries actions	With Life in Quarries actions	
Control of erosion	1.65	↘ 2.6%	↘ 3.2%	↘ 0.7%
Attenuation of sediment flows	1.47	↘ 2.0%	↘ 3.3%	↘ 1.2%
Regulation of hydrological cycle	1.72	↘ 3.0%	↘ 4.4%	↘ 1.3%
Flood protection	1.41	↘ 1.8%	↘ 4.9%	↘ 3.1%
Surface water purification and oxygenation	1.54	↘ 3.2%	↘ 4.2%	↘ 1.1%
Groundwater purification and oxygenation	1.61	↘ 2.9%	↘ 4.3%	↘ 1.4%
Capture dust, chemicals and odors	1.38	↘ 2.9%	↘ 4.7%	↘ 1.8%
Mitigation of noise and visual impacts	1.32	↘ 2.8%	↘ 4.8%	↘ 2.1%
Pollination	1.78	↘ 4.3%	↘ 2.8%	↗ 1.5%
Maintenance of habitats for species life cycles	2.56	↘ 5.0%	↘ 4.3%	↗ 0.7%
Biological control	2.43	↘ 5.0%	↘ 4.2%	↗ 0.8%
Regulation of invasive alien species	1.69	↘ 3.2%	↘ 5.6%	↘ 2.4%
Regulation of the global climate by sequestrating greenhouse gases	1.69	↘ 2.9%	↘ 5.0%	↘ 2.1%
Micro-climate regulation	1.61	↘ 2.5%	↘ 5.5%	↘ 3.0%

Through the Life in Quarries, the percentage of quarries contributing to **cultural services** increased, despite the Covid-19 crisis lockdown at the end of the project (2020) (Table 8). Thanks to the project, new public activities, such as research projects or awareness-raising campaigns for employees and nonprofessional on biodiversity in extractive sites, were developed. The largest increase was observed for '*Biodiversity as source of intrinsic values of existence and heritage*' (+91%) in relation to an evolution in the values attributed to biodiversity in quarries and the adoption of ambitious actions plans promoting biodiversity. The second largest increase was observed for cultural services linked to direct experience of biodiversity and nature: '*Natural space and biodiversity supporting the experience of nature* and *natural space*' *and* '*Biodiversity sources of intrinsic values of existence and heritage*'. Cultural services linked to recreation were already provided by a high percentage of quarries at the beginning of the project and slightly increased (Table 8).

Table 8. Evolution of cultural services during the Life in Quarries.

Cultural services	Initial situation	During the Life in Quarries	Evolution
Non-exclusive natural space suitable for daily outdoor activities	70%	70%	→
Exclusive natural space for productive leisure activities	43%	52%	↗ 9%
Exclusive natural space for outdoor recreation	78%	91%	↗ 13%
Natural space and biodiversity supporting the experience of nature	48%	87%	↗ 39%
Natural space and biodiversity serving as a support for education	70%	100%	↗ 30%
Natural space and biodiversity as a support for scientific research	83%	91%	↗ 9%
Natural space and biodiversity sources of inspiration and entertainment	30%	43%	↗ 13%
Natural space and biodiversity sources of intrinsic values of existence and heritage	9%	100%	↗ 91%

Three new viewpoints toward quarries were also developed by the project and will improve the flow of service '*Non-exclusive natural space suitable for daily outdoor activities*' as well as the ***'Everyday environment'*** category of services**.** The viewpoint locations were selected on the basis of a detailed landscape analysis assessing the multi-dimensional valorization of quarries landscape (cultural, patrimonial, scientific, biodiversity …) and their accessibility via existing paths, trails used for leisure walking activities[13]. Explanatory boards are associated to each viewpoints. Biodiversity topics, specifically linked to the Life in Quarries project are presented within a global and integrated presentation of the quarry landscape, allowing a contextualization of biodiversity actions. Those viewpoints provide permanent installations for informing a general public on biodiversity in quarries and increasing cultural services.

[13] Bontemps C. (2020) - Etude sur la valorisation paysagère des carrières actives du projet "Life in Quarries" en région wallonne. http://hdl.handle.net/2268.2/11033

Evolution of Ecosystem Services through the life cycle of a quarry

In order to assess how ecosystem services evolve through a quarry's life cycle, the project's quarries were split into groups characterized by different exploitation stages (Figure 13). To do so, four surfaces estimation were used:

- *Fin*: post-operation areas;
- *Min*: currently exploited area;
- *Per*: areas never exploited;
- *Tot*: total surface area of the quarry.

These different surfaces were used to create two continuous quantitative indicators informing on the exploitation stage of the quarries:

- *Min/Tot*: Describes the proportion of the surface area in activity in relation to the total quarry surface. This value ranges between 0 and 1, with higher values representing sites exploited throughout the whole defined perimeter;
- *Fin/Per*: Describes whether areas that are not currently active have already been impacted by mining operations or not. This value ranges between 0 and an infinite value, with lower values indicating the higher proportions of areas that have never been impacted outside of currently exploited areas.

Based on these two indicators, an unsupervised hierarchical clustering was performed with the reduced and centered data to classify quarries in four groups of exploitation stage. Characteristics of quarries in the four groups are shown in Figure 13:

- Quarries in the first group were the least advanced in their exploitation stage. The exploited area was small, about 35% of the total site area, and the non-active areas, never impacted, were predominant. Their extractive development potential was therefore still significant;
- The second group was composed of quarries with a larger currently exploited area (about 55% of the total site) with a majority of un-impacted areas outside of the exploited zones of the quarry;
- The third group comprised quarries with a currently exploited area representing more than half of the site perimeter (70%), but with post-operation areas twice as large as the never exploited ones;
- Finally, the quarries in the fourth group were the most advanced in their exploitation stage. Their currently exploited area was smaller than for the other groups with an average 50% of the total site surface currently active. The post-operation areas were large and further development potential restricted as the proportion of *Fin/Per* was low.

This classification remains theoretical, as it does not take into account, for example, the depth development of the pits or surfaces included in the perimeter of the quarry but not intended for exploitation.

Only **provisioning** and **regulating services** were studied in this section. Data for **cultural services** were too limited to realize any analysis. Analysis were based on data collected in 2016, in order to avoid any bias due to the implementation of Life in Quarries actions. Only ES stocks were analyzed as flow also depends on habitats management choices and do not strictly reflect the influence of the exploitation stage.

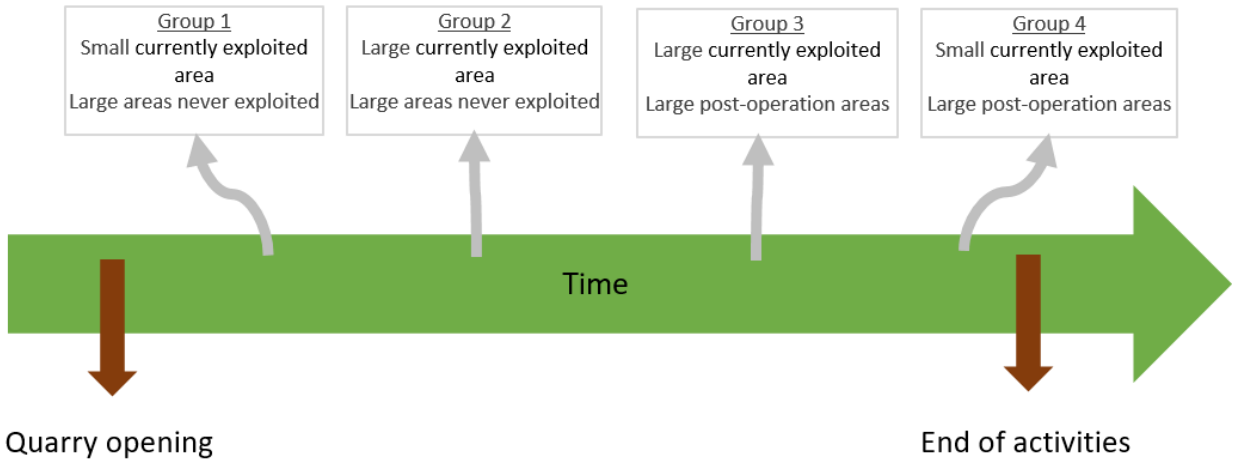


Figure 13. Schematic representation of the different groups of quarries representing different exploitation stages of an extractive site.

The trends in **provisioning services** along the life cycle of the quarries are summarized in Table 9:

- '*Commercial cultivated crops*' and '*Fodder*' stocks decrease with increasing exploitation stage, with a spectacular decrease for crops. Farmland activities areas, sometimes important at the beginning of the operation, are indeed gradually encompassed in the activity while – in unconstrained exploitations - the post-exploitation areas are often not conducted towards the rehabilitation of cultivated areas.
- The stock of ES related to '*Wood*' production and '*Wild terrestrial animals*' (hunting) first decrease with exploitation stages, due to the growth of active areas in the sites. However, they tend to increase at final stages of exploitation as disused areas will typically evolve towards woody or favorable to wild game habitats. The stock of these two services is higher in exploitation stages 1 and 4 where non-active zones covered larger areas without specific speculations for commercial use.
- The stock of the service '*Fresh water fishes and shellfishes*' is highly dependent on the freshwater surfaces of quarries. These water surfaces appear stable over time and usually increase in the final exploitation stage when water is progressively left to submerge pits situated under the water table (group 4).
- The '*Commercial and non-commercial breeding*' service stock increases with the age of the quarry along with an increase in habitats suitable for its provision. This service can be linked to the post-exploitation surfaces which, in active restoration schemes such as the ones of the Life in Quarries, are often rehabilitated into grasslands or meadows suitable for grazing and presenting added value in the conservation of semi-natural grasslands. These areas could also evolve, in constrained rehabilitation plans involving a return to agriculture, towards intensive grazing.
- No visible trend was observed for the '*Drinking water*' service as it seems rather linked to the location and opportunity to valorize water than to the age of the quarry.

Figure 14 illustrates the distribution of scores for the **regulating services** of the different exploitation stages in 2016. Each vertex of the polygon corresponds to a regulating service with a weighted score between 0 and 5. The larger the area delineated on the graph for an exploitation stage of quarries, the larger the stock of regulating services for that group. Exploitation stages 1 and 4 present higher global stocks of regulating services, than exploitation stage 2 and 3. The minimum stock of regulating services was present at stage 3, which correspond to the maximum development of the mineral active zone of

the quarries. The stock of regulating services therefore decreased with the age of the quarry and then increased for quarries at the end of their operation plan.

Table 9. Trends in provisioning services in function of exploitation stages of quarries. Numbers represent the percentages of surface the service compared to the whole perimeter of the quarries pertaining to the groups. Arrows indicated the trend from the previous stage.

Provisioning services		Evolution of ES			
		Exploitation stage 1	Exploitation stage 2	Exploitation stage 3	Exploitation stage 4
Commercial cultivated crops	**Stock**	14.3%	1.4% ↘	1.3% →	0.6% ↘
Commercial and non-commercial breeding	**Stock**	2.6%	0.7% ↘	0.8% →	1.2% ↗
Wild terrestrial animals (hunting)	**Stock**	48.6%	3.5% ↘	8.8% ↗	13.0% ↗
Fresh water fishes and shellfishes	**Stock**	0.5%	0.2% →	0.3% →	1.1% ↗
Wood	**Stock**	22.1%	0.9% ↘	1.5% →	5.5% ↗
Fodder	**Stock**	3.8%	0.6% ↘	0.8% →	0.6% →
Drinking water	**Stock**	→			

While the influence of the exploitation stage of the quarry on **cultural services** could not be studied, numerous and diverse cultural services are to be found in all the quarries of the project, suggesting that cultural services are provided regardless of the age of the quarry. We could however assume that while services linked to '***Environment for recreation***' and '***Sources of inspiration and values***' categories are limited during the first stages as a consequence of security concerns, they would tend to evolve favorably towards stage 4 of the quarries' life.

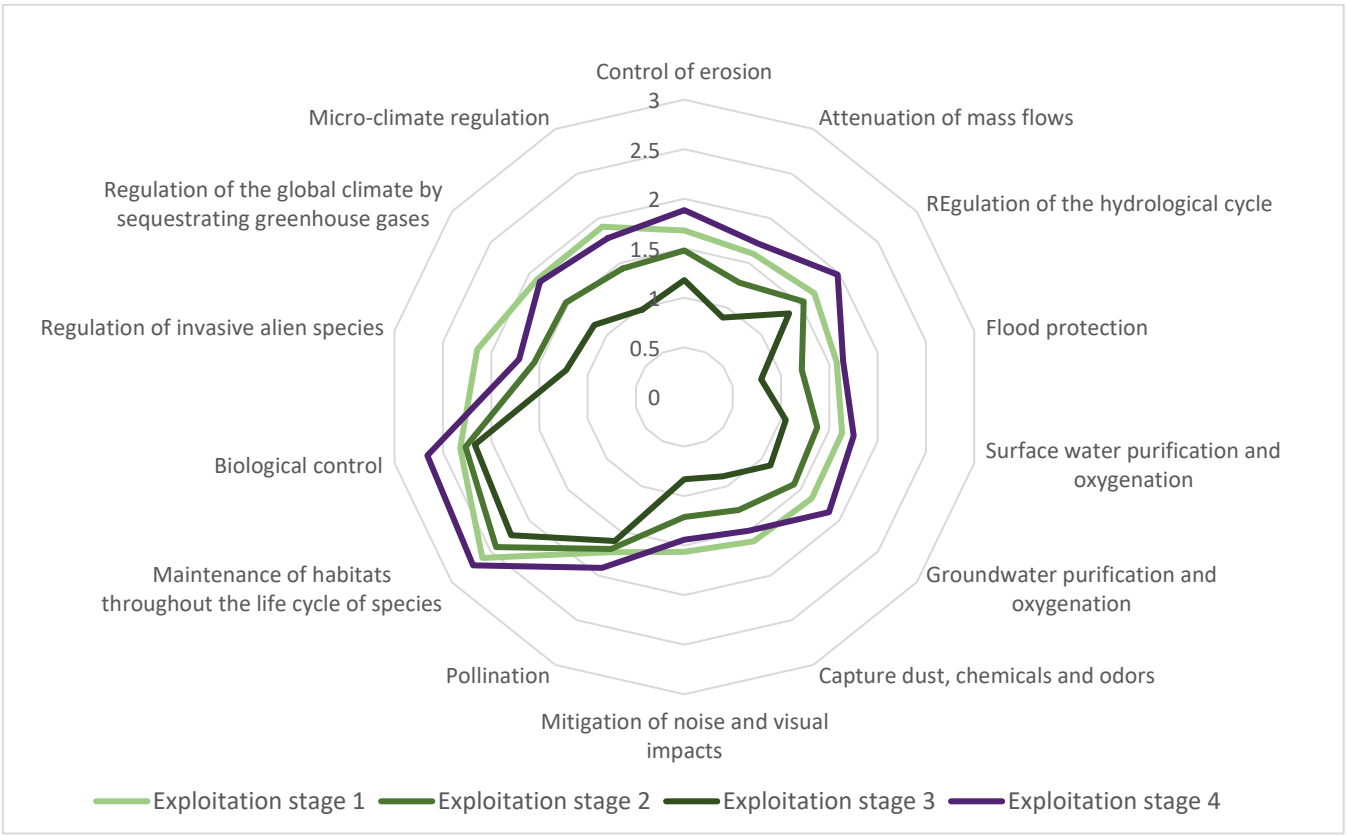


Figure 14. Distribution of regulating services scores for the four quarry groups in 2016.

Synthesis and perspectives

The assessment of ecosystem services in quarries, realized during the Life in Quarries project, demonstrates that **active quarries can support a diversity of provisioning, regulating and cultural services stocks**. This potential for multiple services is linked to the diversity of ecosystems in active extraction sites, including important ecosystems for provisioning and regulating services (pre-existing and recolonization forests, managed and spontaneous grasslands-meadows, bodies of water) and heterogeneous, original landscapes supporting numerous cultural services.

Through the diversity of ecosystem services stocks they generate, quarries can contribute to the development of Green/Blue Infrastructure especially in highly anthropogenic, homogenized landscapes. As demonstrated by the ES assessment and biological monitoring of the project's biodiversity actions[14], quarries can act as important places for the regulating service '*Maintenance of habitats for species life cycles*', acting as stepping stones for species with high dispersal capacity (dragonflies, pollinators, bats, birds) or even core habitats for populations of less mobile species (e.g. amphibians). These quarries thus can bring an interesting contribution **to the connectivity of Natura 2000 Network outside N2000 sites.** The importance of cultural services highlighted in this assessment supports the fact that **quarries are also opportunities to connect people to nature** in quarries embedded into biologically impoverished landscapes by increasing ES related to '***Sources of experience and knowledge***' and '*Natural space and biodiversity sources of intrinsic values of existence and heritage*'. Besides, quarries provide opportunities for various forms of recreation activities. Through their ecosystemic diversity, **quarries can diversify the offer of provisioning services in homogeneous landscapes**: '*Commercial crops*' and '*breeding*' production in non-exploited and restored areas, '*Drinking water*', '*Wild terrestrial animals* and '*Fresh water fishes*' products. Most ecosystems in quarries are linked to regulation services and this potential can be used to mitigate environmental impact of extraction activities on environmental quality.

However, mobilizing the full potential of ES-quarries to contribute to Green/Blue infrastructure still needs to meet challenges.

Because quarries are isolated spots, their contribution to Green Infrastructure as '*a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services*'[15], needs ES management in quarries to be aligned with ES priorities in surrounding landscapes. In the Life in Quarries project, quarries were not selected from a strategic point of view to ensure maximum connectivity or a coherent network as such, but rather for a pilot project to engage quarries in biodiversity conservation, with the aim of expanding this for the full

[14]Hauteclair, P., Séleck, M., Taymans, J., Gauquie, B., Mathelart, C., & Mahy, G. (2021). Rapport synthétique de suivi de la biodiversité du projet Life in Quarries. Gembloux, Belgique: Université de Liège, Gembloux Agro-Bio Tech. http://hdl.handle.net/2268/266063

[15] Source: EU - COM(2013) 249 final https://ec.europa.eu/environment/nature/ecosystems/index_en.htm

Walloon region and abroad in the long term. In addition, as the main aim of the project was to explore to what extent quarries can contribute to biodiversity conservation during exploitation, a global management of ES in line with landscape connection was not the primary focus, as biodiversity targeted actions were expected to generate additional benefits in the form of ES at the local - quarry scale.

Nevertheless, the development of biodiversity actions during the project provided the opportunity for the federation (FEDIEX) to support a parallel program aiming at exploring opportunities for connecting quarries to surrounding agricultural areas to reinforce ecological networks[16]. One dimension lacking in the current assessment allowing understanding the potential of quarries for Green/Blue infrastructure, is the evaluation of loss-gain in ES as compared to the pre-exploitation status. Gains and losses in ES resulting from opening quarries will strongly depend on pre-existing ecosystems, their biological value and their existing ES.

Developing the full potential of ES in quarries appears a complex task for quarry managers.

This assessment demonstrated that ES stocks change over a quarry life cycle in relation to land use and ecosystems modifications. This was particularly true for regulating services with a global decrease for quarries progressing in their exploitation stages, as compared to quarries in their initial or more advanced exploitation stages. Provisioning services also evolves along with the evolution of available areas for agriculture and other production activities in the perimeter of the quarries. This means that **evaluations of ES management in quarries need to be framed in adequate and evolving repositories that consider the local environment and the exploitation stages**.

While stocks of ES may be important in quarries, potentialities for ES are not always seized. For example, flows of services '*Wild terrestrial animals*'/'*Fresh water fishes*' were low despite existing stocks. The ecosystem services concept is complex, rather recent and is far from being fully understood by stakeholders. In addition, most valued regulating services identified as important by quarryman for their direct link with the management of environmental extractive activity impacts ('*Mitigation of noise and visual impacts*', '*Capture dust, chemicals and odors'* …), eventually presented the lowest stocks. The valuation of ES is not only a question of the type of ecosystems present in quarries, but is also dependent on human actions/management for increasing the delivery of ES. **Future directions for the valuation of ES in quarries should explore the conditions to promote Nature Based Solution increasing the capacity of quarries ecosystems to contribute to environmental quality**.

Because ES are interrelated, any management decision to promote a specific ES will affect (negatively or positively) the delivery of others ES. This is illustrated by the creation of permanent grasslands and meadows supporting biodiversity; their restoration increased the provisioning service '*Commercial and non-commercial breeding*' and the regulating services '*Pollination'/* **'***Maintenance of habitats for species life cycles'*, but in the same time, was probably responsible for the decrease in provisioning '*Wood*'/'*Wild terrestrial animals*' and regulating services '*Regulation of the global climate by sequestrating greenhouse gases*' linked to associated deforestation. In addition, managing and valuing ES all along the quarry life cycle will include a huge diversity of stakeholders within and in the surroundings of quarries:

[16] https://www.fediex.be/upload/carrieres-et-zones-agricoles-fediex-wgbj6k.pdf

quarries employees at all positions, subcontractors, farmers, hunters, water production companies, environmental regulatory agencies, various publics for cultural services. **The multi-value dimension of ES in quarries, their interrelationships and the diversity of stakeholders implies that solutions to manage ES are multiple and should be contextual and allowed for evolutions. There is no such thing as a unique ES mix maximizing all outcomes and ES assessment in quarries cannot be based only on a single set of simple indicators**. Experts support is needed but to increase stakeholders ES awareness and independency in managing them, it is essential to develop training programs of the extractive sectors, as well as intuitive management supports and tools to be integrated in existing environmental management systems.

The main target of the Life in Quarries project was to explore to what extent quarries can contribute to biodiversity conservation during exploration. While this is expected to generate some additional benefits in the form of ES, this was not the primary focus. However, during the planning phase of biodiversity actions, care was taken to identify the best locations and management modalities. Obviously, the main impacts of a project such as Life in Quarries, dedicated to promote biodiversity during the activity of quarries, on ES lies in the increase of quarry ecosystem capacity to support biodiversity. This includes not only direct improvement of conservation status for target species, but also on regulating services such as '*Pollination*' and '*Maintenance of habitats for species life cycles*' due to direct implementation of actions on the field, and increase in cultural services '*Natural space and biodiversity sources of intrinsic values of existence and heritage*' which increased the values attributed to biodiversity in quarries and facilitated the adoption of ambitious programs promoting biodiversity. However, despite the demonstrated success of the Life in Quarries actions for targeted species, low variation observed in the related ES reveals the limits of using a global anthropogenic ES approach evaluating the recognition of their intrinsic value to monitor projects focused on increasing species viability. **Classic indicators of populations/species status and habitat conservation states should be at the heart of the assessment of Biodiversity projects**. An increase in **provisioning** and **regulating services** stock, linked to the Life in Quarries actions, were mainly linked to the creation of **permanent habitats** (permanent grasslands, meadows, ponds) in the restoration phase, as has been done in a diversity of quarries restoration projects. Actions targeting **temporary habitat** - at the heart of the project - do not influence significantly provisioning and regulating services as they were of smaller spatial extension and/or low potential for production but are rather favorable to the development of **cultural services**.

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Annexes

Annex 1. List of all Life in Quarries actions

LIFE14 NAT/BE/000364 - C0

LIST OF ALL PROPOSED ACTIONS

A. Preparatory actions, elaboration of management plans and/or of action plans

- A1 Assesment of the state of the art on temporary nature management
- A2 Setting up of a set of indicators
- A3 Inventory and mapping of the main stakes
- A4 Analysis of the legal framework: suppression of the possible legal obstacle and support to the participating quarries
- A5 Construction of a quarry network
- A6 Evaluation of the ES significance of quarries in the landscape

B. Purchase/lease of land and/or compensation payments for use rights

C. Concrete conservation actions

- C1 Tests on the creation and maintenance of temporary habitats
- C2 Implementation of the temporary nature management plan
- C3 Implementation of the permanent nature management plan
- C4 Generalisation at Regional and International level

D. Monitoring of the impact of the project actions (obligatory)

- D1 Monitoring of tests and adaptation of techniques
- D2 Monitoring of biodiversity and ecosystem functions restoration
- D3 Monitoring of Ecosystem Services
- D4 Basic monitoring
- D5 Management plan update
- D6 Socio cultural monitoring of communication actions / consciousness of the sector for biodiversity

E. Public awareness and dissemination of results (obligatory)

- E1 Notice boards
- E2 Website creation
- E3 Networking with other projects
- E4 Redaction of the Layman's report
- E5 Good practices dissemination
- E6 Increased public awareness
- E7 Dissemination at the European Level
- E8 International workshop

F. Project management and monitoring of project progress (obligatory)

- F1 Overall project management
- F2 Financial audit
- F3 After-LIFE Plan
- F4 Indicators

Annex 2. List of WalEunis habitats in Life in Quarries

The entire WalEunis typology is available on the Walloon biodiversity portal (http://biodiversite.wallonie.be/fr/biotopes.html?IDC=858)

C1 – Surface standing waters
C2 – Surface running waters
C3 – Littoral zone of inland surface waterbodies
D5 – Sedge and reedbeds, normally without free-standing water
E1 – Dry grasslands
E2 – Mesic grasslands
E3 – Seasonally wet and wet grasslands
E5 – Woodland fringes and clearings and tall forb habitats
E5.2 – Thermophile woodland fringes
E5.4 – Moist or wet tall-herb and fern fringes and meadows
E5.6 – Weed communities of recently abandoned urban and suburban constructions, weed communities of recently abandoned rural constructions, weed communities of recently abandoned extractive industrial sites.
F3 – Temperate and mediterraneo-montane scrub habitats
F4 – Temperate shrub heathland
FA – Hedgerows
FB – Shrub plantations
G1 – Broadleaved deciduous woodland
G3 – Coniferous woodland
G4 – Mixed deciduous and coniferous woodland
G5 – Lines of trees, small anthropogenic woodlands, recently felled woodland, early-stage woodland and coppice
H1 – Terrestrial underground caves, cave systems, passages and waterbodies
H2 – Screes
H3 – Inland cliffs, rock pavements and outcrops
I1 – Arable land and market gardens
I2 – Cultivated areas of gardens and parks
Ia – Agriculturally-improved, re-seeded and heavily fertilized grassland, including sports fields and grass lawns
J1 – Buildings of cities, towns and villages
J2 – Low density buildings
J3 – Extractive industrial sites
J4 – Transport networks and other constructed hard-surfaced areas
J5 – Highly artificial man-made waters and associated structures

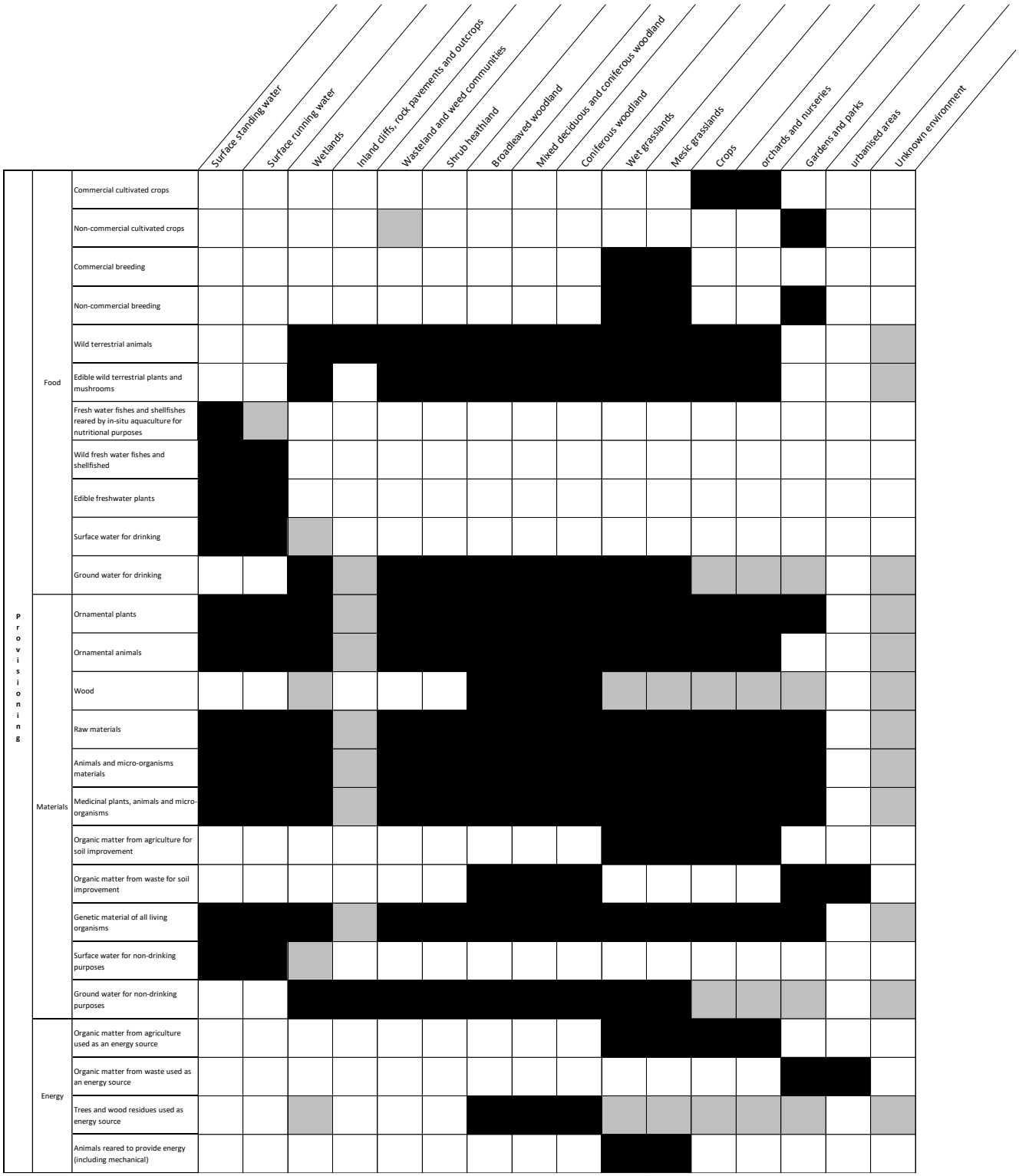
Annex 3. Wal-ES typology of ecosystem services

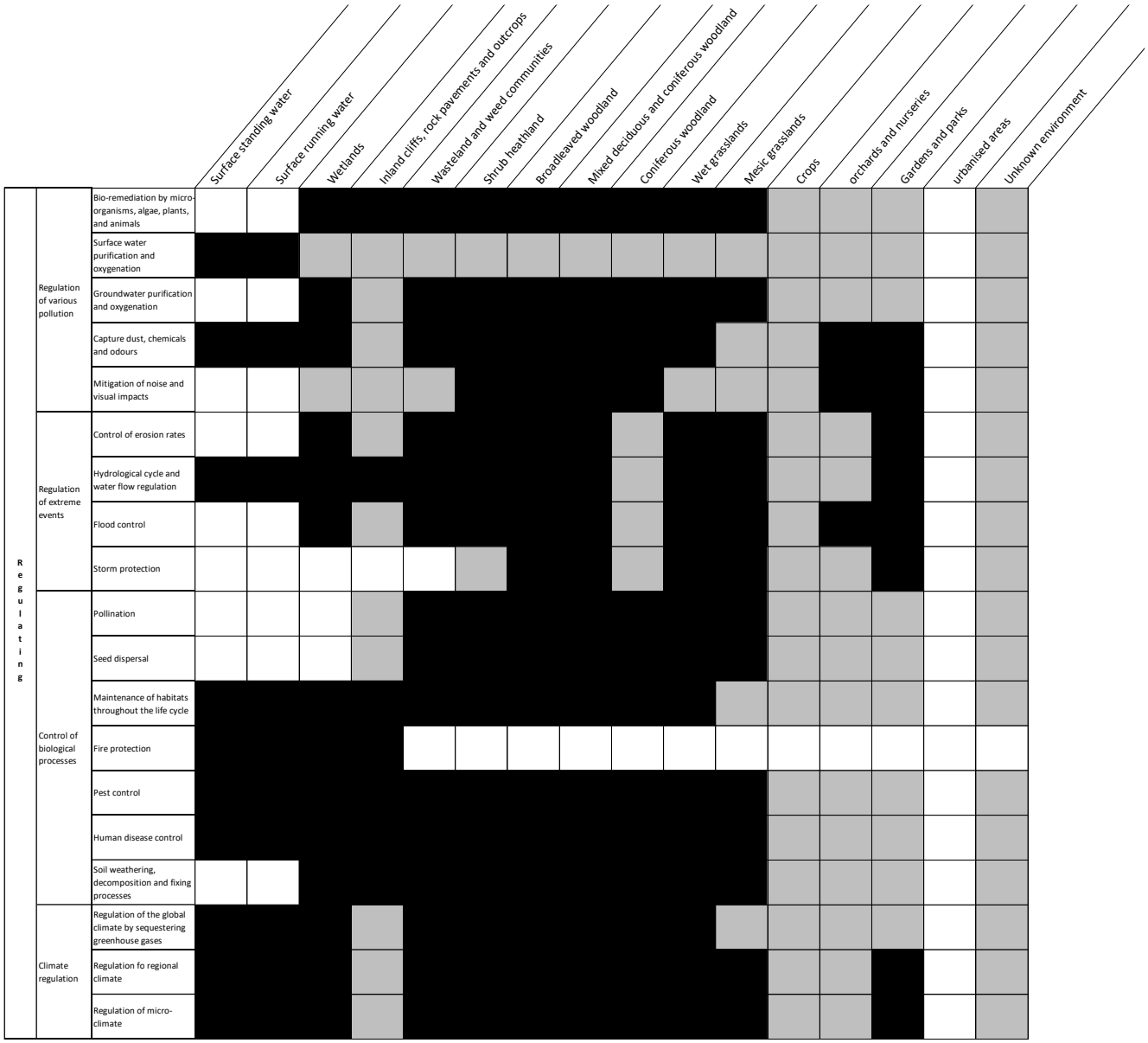
Provisioning	Food	Commercial cultivated crops
		Non-commercial cultivated crops
		Commercial breeding
		Non-commercial breeding
		Wild terrestrial animals
		Edible wild terrestrial plants and mushrooms
		Fresh water fishes and shellfishes reared by in-situ aquaculture for nutritional purposes
		Wild fresh water fishes and shellfished
		Edible freshwater plants
	Raw materials	Ornamental plants
		Ornamental animals
		Wood
		Other plant materials
		Medicinal plants, animals and micro-organisms
		Organic matter from agriculture for soil improvement
		Organic matter from waste for soil improvement
		Fodder
		Genetic material of all living organisms
	Fresh water	Surface water for drinking
		Ground water for drinking
		Surface water for non-drinking purposes
		Ground water for non-drinking purposes
	Energy	Organic matter from agriculture used as an energy source
		Organic matter from waste used as an energy source
		Trees and wood residues used as energy source
		Animals reared to provide energy (including mechanical)
Regulating	Regulation of various pollution	Bio-remediation by micro-organisms, algae, plants, and animals
		Surface water purification and oxygenation
		Groundwater purification and oxygenation
		Capture dust, chemicals and odours
		Mitigation of noise and visual impacts
	Regulation of extreme events	Control of erosion rates
		Hydrological cycle and water flow regulation
		Flood control
		Storm protection
		Fire protection
	Control of biological processes	Pollination
		Seed dispersal
		Maintenance of habitats throughout the life cycle
		Pest control
		Human disease control
		Soil weathering, decomposition and fixing processes
	Climate regulation	Regulation of the global climate by sequestering greenhouse gases
		Regulation for regional climate
		Regulation of micro-climate

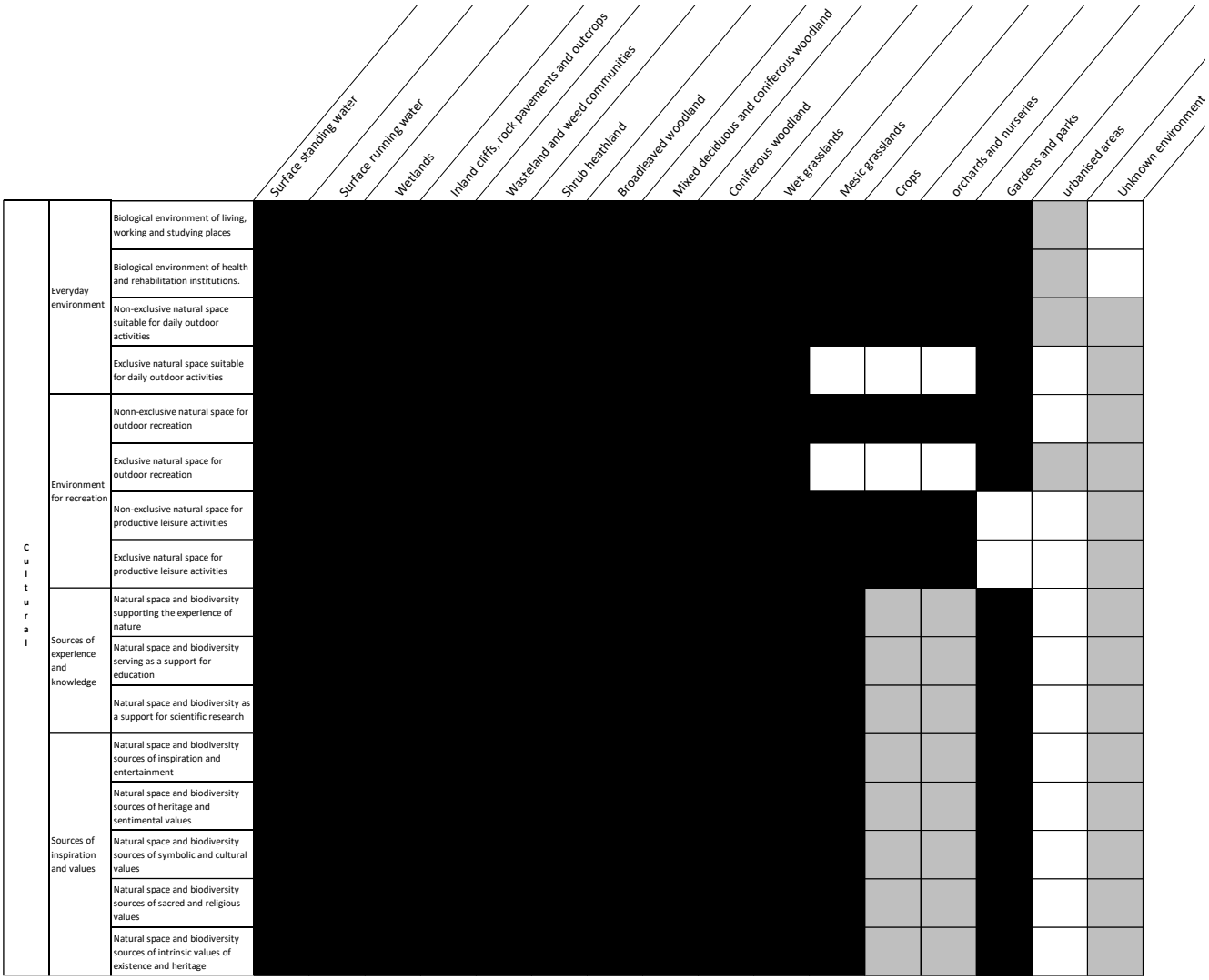
Cultural	Everyday environment	Biological environment of living, working and studying places
		Biological environment of health and rehabilitation institutions.
		Non-exclusive natural space suitable for daily outdoor activities
		Exclusive natural space suitable for daily outdoor activities
	Environment for recreation	Non-exclusive natural space for outdoor recreation
		Exclusive natural space for outdoor recreation
		Non-exclusive natural space for productive leisure activities
		Exclusive natural space for productive leisure activities
	Sources of experience and knowledge	Natural space and biodiversity supporting the experience of nature
		Natural space and biodiversity serving as a support for education
		Natural space and biodiversity as a support for scientific research
	Sources of inspiration and values	Natural space and biodiversity sources of inspiration and entertainment
		Natural space and biodiversity sources of heritage and sentimental values
		Natural space and biodiversity sources of symbolic and cultural values
		Natural space and biodiversity sources of sacred and religious values
		Natural space and biodiversity sources of intrinsic values of existence and heritage

Annex 4. Ecosystems X ecosystem services matrix

In the three tables below, a white square means that the ecosystem under consideration is not provider of the corresponding ecosystem service. If it is black, the ecosystem is a major provider of this service, and if it is grey, the ecosystem provides this service to a lesser extent and/or magnitude of its provision varies greatly with the management practices applied to the ecosystem.




Surface standing water
Surface running water
Wetlands
Inland cliffs, rock pavements and outcrops
Wasteland and weed communities
Shrub heathland
Broadleaved woodland
Mixed deciduous and coniferous woodland
Coniferous woodland
Wet grasslands
Mesic grasslands
Crops
orchards and nurseries
Gardens and parks
urbanised areas
Unknown environment
Regulating
Regulation of various pollution
Bio-remediation by micro-organisms, algae, plants, and animals
Surface water purification and oxygenation
Groundwater purification and oxygenation
Capture dust, chemicals and odours
Mitigation of noise and visual impacts
Regulation of extreme events
Control of erosion rates
Hydrological cycle and water flow regulation
Flood control
Storm protection
Control of biological processes
Pollination
Seed dispersal
Maintenance of habitats throughout the life cycle
Fire protection
Pest control
Human disease control
Soil weathering, decomposition and fixing processes
Climate regulation
Regulation of the global climate by sequestering greenhouse gases
Regulation fo regional climate
Regulation of micro-climate


Surface standing water
Surface running water
Wetlands
Inland cliffs, rock pavements and outcrops
Wasteland and weed communities
Shrub heathland
Broadleaved woodland
Mixed deciduous and coniferous woodland
Coniferous woodland
Wet grasslands
Mesic grasslands
Crops
orchards and nurseries
Gardens and parks
urbanised areas
Unknown environment
Cultural
Everyday environment
Biological environment of living, working and studying places
Biological environment of health and rehabilitation institutions.
Non-exclusive natural space suitable for daily outdoor activities
Exclusive natural space suitable for daily outdoor activities
Environment for recreation
Nonn-exclusive natural space for outdoor recreation
Exclusive natural space for outdoor recreation
Non-exclusive natural space for productive leisure activities
Exclusive natural space for productive leisure activities
Sources of experience and knowledge
Natural space and biodiversity supporting the experience of nature
Natural space and biodiversity serving as a support for education
Natural space and biodiversity as a support for scientific research
Sources of inspiration and values
Natural space and biodiversity sources of inspiration and entertainment
Natural space and biodiversity sources of heritage and sentimental values
Natural space and biodiversity sources of symbolic and cultural values
Natural space and biodiversity sources of sacred and religious values
Natural space and biodiversity sources of intrinsic values of existence and heritage

Annex 5. List of ecosystem services from Wal-ES typology not studied

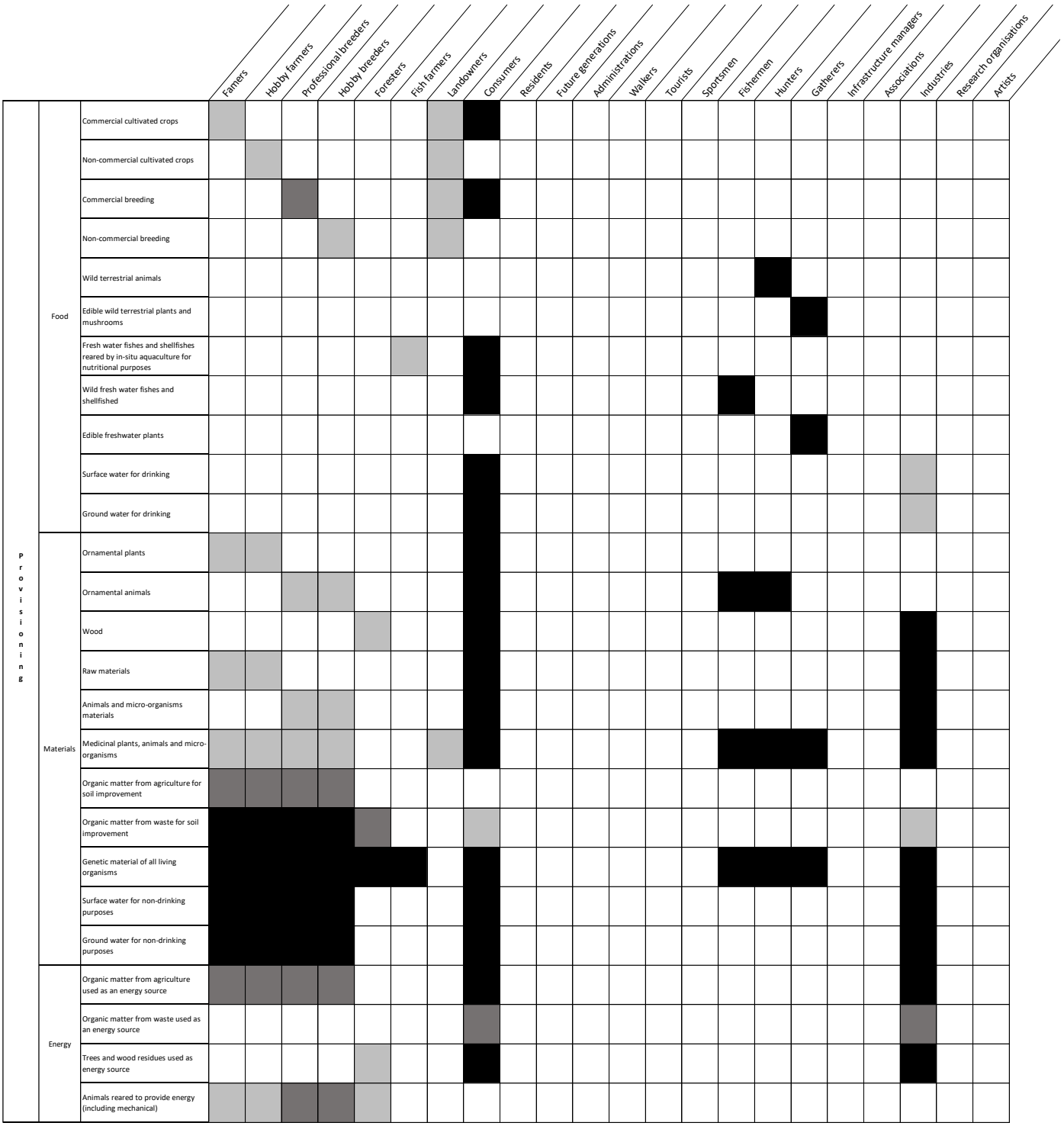
Provising	Food	Non-commercial cultivated crops	Non-commercial cultivated crops include vegetable gardens and orchards established by individuals or communities as a supplementary food source.
		Edible wild terrestrial plants and mushrooms	This service includes wild plants and mushrooms that can be collected by humans for their own consumption.
		Fresh water fishes and shellfishes reared by in-situ aquaculture for nutritional purposes	This service includes fish, shellfishes raised for human consumption.
		Edible freshwater plants	This service includes freshwater plants that can be consumed, the best-known example being duckweeds.
	Materials	Ornamental plants	This service include plants, both wild and cultivated, that can be used to embellish homes and gardens.
		Ornamental animals	This service includes interior and exterior decorations that may have their origin in wild or domestic animals (e.g. hunting trophies, stuffed animals, decorative objects made from feathers).
		Medicinal plants, animals and micro-organisms	This service includes plants, animals and micro-organisms that can be used for the prevention, diagnosis or treatment of physical and psychological diseases.
		Organic matter from agriculture for soil improvement	This service includes agricultural by-products (livestock manure and crop slash) that can be applied for soil improvement.
		Organic matter from waste for soil improvement	This service includes industrial, household and forestry organic waste that can be spread on the soil to improve its quality.
		Genetic material of all living organisms	This service includes the genetic material of living beings, which has two types of application: its diversity allows the improvement of certain traits of domesticated species, while its variability ensures the discovery of new compounds used in industry or medicine. Due to the lack of information on this subject, this service was not evaluated.
	Energy	Organic matter from agriculture used as an energy source	This service includes agricultural products (energy crops, livestock manure, etc.) that are burned for energy.
		Organic matter from waste used as an energy source	This service includes organic waste, both household and industrial, which is burned for energy.
		Animals reared to provide energy (including mechanical)	This service includes animal traction, which is a source of mechanical energy in agriculture or forestry.
		Ground water for drinking	This service includes fresh groundwater, which is a source of drinking water. This service was not assessed due to lack of data availability.
		Surface water for non-drinking purposes	This service includes freshwater from water bodies and wetlands, which can be used for a variety of applications: crop irrigation, sanitation, industrial processes and truck and road washing.
		Ground water for non-drinking purposes	This service includes fresh groundwater, which can habe various applications: dust control (in quarries), crop irrigation, hygiene or industrial processes.

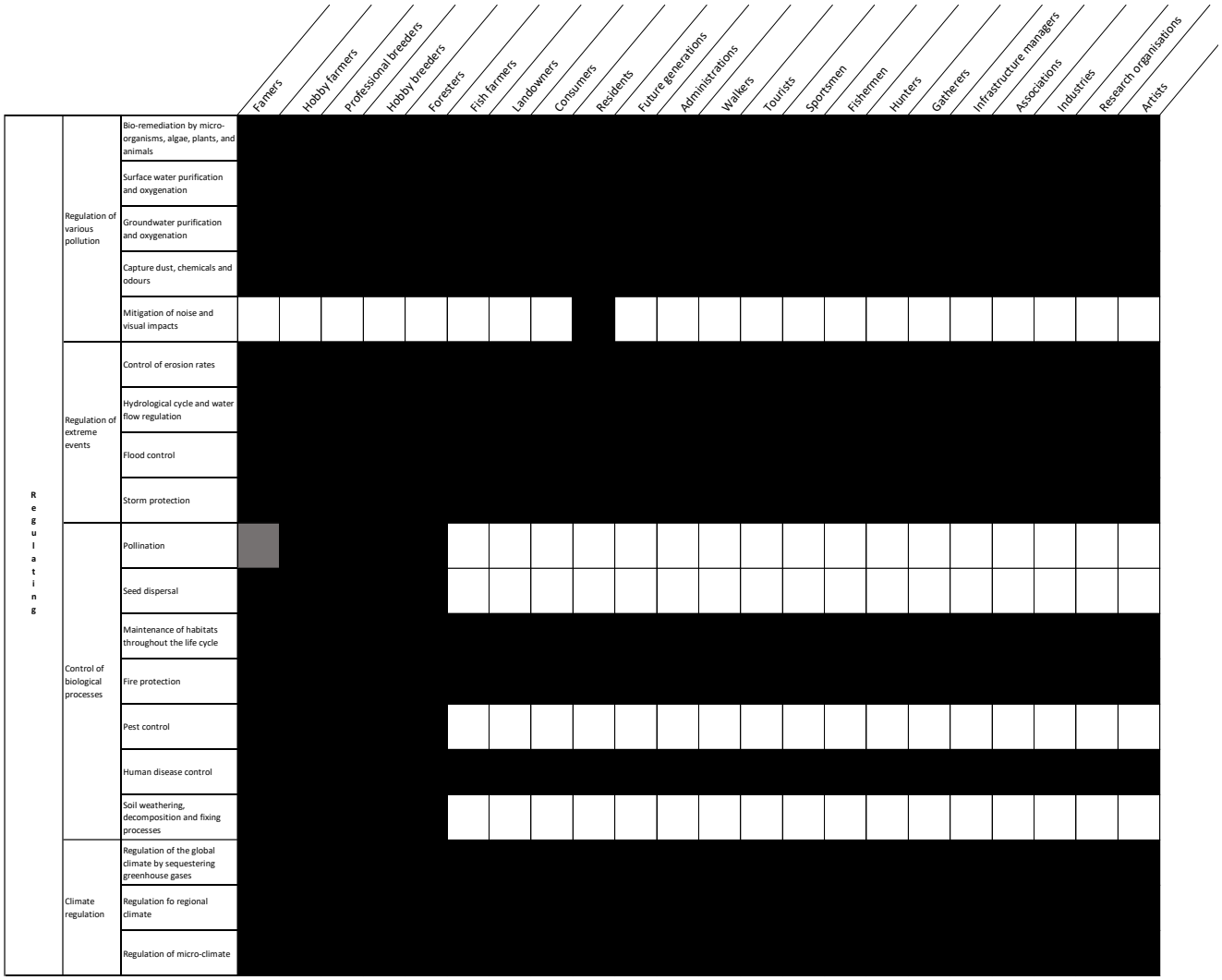
Regulating	Regulation of extreme events	Storm protection	This service recognize that ecosystems reduce the risk and intensity of storms by reducing wind speed through their vegetation.
		Fire protection	Ecosystems regulate the intensity and frequency of fires according to several of their intrinsic properties (amount of vegetation that is the main source of fuel, micro—climate created by the ecosystem, type of vegetation determining its level of flammability, soil water retention capacity, etc.).
	Regulation of various pollution	Bio-remediation by micro-organisms, algae, plants, and animals	Ecosystems (including soil) play a role in soil remediation by capturing, diluting, filtering and storing certain pollutants. Edaphic microorganisms participate in the degradation of these pollutants through their biological activity.
		Groundwater purification and oxygenation	Edaphic ecosystems and their living beings are responsible for oxygenation, filtration, sequestration and degradation of pollutants, thus contributing to the purification of groundwater.
	Control of biological processes	Seed dispersal	Plant species use different ways of dispersing their seeds. This spatial dispersal can be favored in certain habitats
		Human disease control	Changes in ecosystems can directly alter the abundance of human pathogens, such as cholera, and can alter the abundance of disease vectors, such as mosquitoes.
		Soil weathering, decomposition and fixing processes	This service includes the formation and fixation of soils by plants, macro- and micro-organisms.
	Climate regulation	Regulation for regional climate	Ecosystems help regulate the regional climate by influencing climatic variables such as temperature, air humidity, wind speed through evapotranspiration from plants and soil, changes in albedo (proportion of reflected solar radiation), aerosol production, etc.
Cultural	Everyday environment	Biological environment of living, working and studying places	This service takes into account the proximity of natural spaces or elements to the built environment, allowing a perspective on them, a visual or sound experience, without direct use or occupation of the natural space in question.
		Biological environment of health and rehabilitation institutions.	This service includes specific facilities such as therapeutic gardens and vegetable gardens in health and rehabilitation institutions to facilitate and accelerate recovery.
		Exclusive natural space suitable for daily outdoor activities	This service covers natural areas whose use is reserved for certain users or their owners, such as private gardens, private company parks, etc.
	Environment for recreation	Non-exclusive natural space for outdoor recreation	This service concerns natural or semi-natural areas with shared use and which provide a setting with conditions and characteristics that allow for human leisure activities and outdoor tourism such as hiking, cycling, kayaking, etc.
		Non-exclusive natural space for productive leisure activities	Concerns natural or semi-natural areas whose use is shared and which allow activities to be carried out that allow the area to be enjoyed while at the same time ensuring the harvesting of productive goods. This is the case, for example, of fishing in rivers, harvesting mushrooms, wild fruit, etc. in publicly accessible areas.

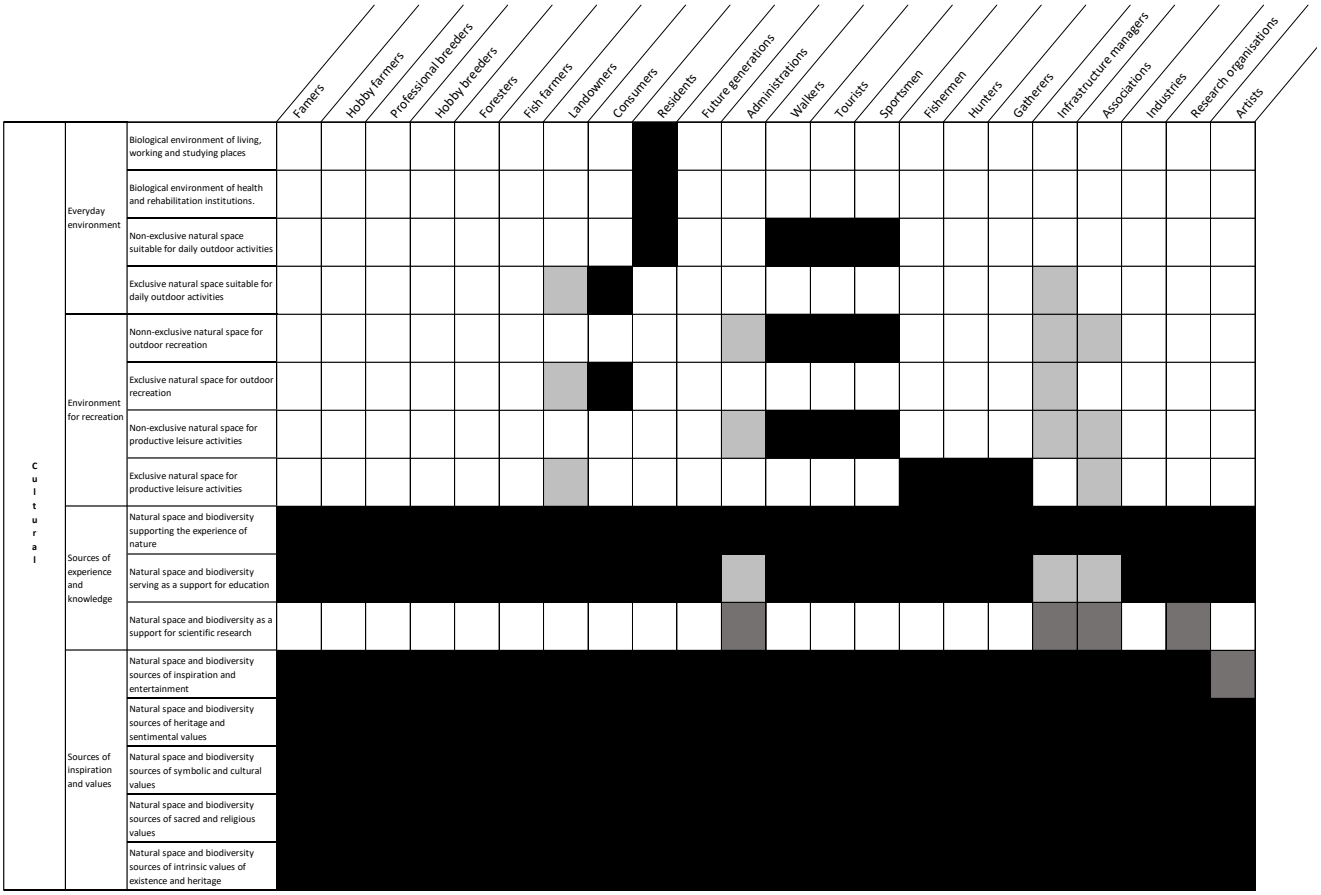
	Sources of inspiration and values	Natural space and biodiversity sources of heritage and sentimental values	This service concerns natural or semi-natural spaces, elements of biodiversity that are symbols of a collective, family or individual heritage with sentimental and affective value.
		Natural space and biodiversity sources of symbolic and cultural values	This service includes typical landscapes of bogs, moors, limestone grasslands, cathedral forests, hedgerows ... or emblematic species with symbolic and cultural values.
		Natural space and biodiversity sources of sacred and religious values	This service takes into account places or species of sacred or religious value.

Annex 6. Ecosystem services X stakeholders matrix

In the following three tables, a light grey square represents a co-producer of the ecosystem service; a dark grey square corresponds to an actor who is both a co-producer and a beneficiary of this service; and a black square identifies a beneficiary of this service.




Famers
Hobby farmers
Professional breeders
Hobby breeders
Foresters
Fish farmers
Landowners
Consumers
Residents
Future generations
Administrations
Walkers
Tourists
Sportsmen
Fishermen
Hunters
Gatherers
Infrastructure managers
Associations
Industries
Research organisations
Artists
Regulating
Regulation of various pollution
Bio-remediation by micro-organisms, algae, plants, and animals
Surface water purification and oxygenation
Groundwater purification and oxygenation
Capture dust, chemicals and odours
Mitigation of noise and visual impacts
Regulation of extreme events
Control of erosion rates
Hydrological cycle and water flow regulation
Flood control
Storm protection
Control of biological processes
Pollination
Seed dispersal
Maintenance of habitats throughout the life cycle
Fire protection
Pest control
Human disease control
Soil weathering, decomposition and fixing processes
Climate regulation
Regulation of the global climate by sequestering greenhouse gases
Regulation fo regional climate
Regulation of micro-climate


Farmers
Hobby farmers
Professional breeders
Hobby breeders
Foresters
Fish farmers
Landowners
Consumers
Residents
Future generations
Administrations
Walkers
Tourists
Sportsmen
Fishermen
Hunters
Gatherers
Infrastructure managers
Associations
Industries
Research organisations
Artists
Cultural
Everyday environment
Biological environment of living, working and studying places
Biological environment of health and rehabilitation institutions.
Non-exclusive natural space suitable for daily outdoor activities
Exclusive natural space suitable for daily outdoor activities
Environment for recreation
Nonn-exclusive natural space for outdoor recreation
Exclusive natural space for outdoor recreation
Non-exclusive natural space for productive leisure activities
Exclusive natural space for productive leisure activities
Sources of experience and knowledge
Natural space and biodiversity supporting the experience of nature
Natural space and biodiversity serving as a support for education
Natural space and biodiversity as a support for scientific research
Sources of inspiration and values
Natural space and biodiversity sources of inspiration and entertainment
Natural space and biodiversity sources of heritage and sentimental values
Natural space and biodiversity sources of symbolic and cultural values
Natural space and biodiversity sources of sacred and religious values
Natural space and biodiversity sources of intrinsic values of existence and heritage

Annex 7. Description of methods for calculating the indicators of provisioning services

FOOD

	Description
Commercial cultivated crops	The **stock** indicator is the area (ha) of the quarry used for feed crop production. To determine the area of crops present in the quarry perimeter, the SIGeC data were used between 2013 and 2015 for the initial assessment (A6 report) and between 2016 and 2018 for the final assessment. A table with the name of the different crops, the number of plots and the sum of the crop areas was created for each of the 3 years, for each assessment. An average of the areas from 2013 to 2015 and from 2016 to 2018 was made to represent the stock of this service, running through a typical crop rotation. The **flow** indicator is the production of the quarry's agricultural areas, in tons and tons/ha. The production of the different crops depends on the agricultural region in which the quarry is located. This production was researched in the literature (UFS, 2016; Portail de l'Agriculture wallonne, Couvreur et al., 2004; Bouquiaux et al., 2009; Pameseb ASBL, 2013; Belgapom, 2016). The average production of the crop by region was used. An average of the productions from 2013 to 2015 and from 2016 and 2018 was made to represent the flow.
Commercial and non-commercial breeding	The indicator of the **stock** of this service is the area suitable for grazing. The area of these environments was measured on the basis of the habitat map. The **flow** indicator is the presence or not of grazing in the quarry. This information was obtained from the operators.
Wild terrestrial animals	The surface area of the quarry habitats suitable for hunted terrestrial wildlife (ha) was chosen as the **stock** indicator for this service. In order to find out which habitats are favourable for game, the DEMNA[17] was contacted. The quarry habitats favourable to game are woodland (WalEunis code G), scrub (WalEunis code F), grassland (WalEunis code E), crops (WalEunis code I) and surface water (WalEunis code C). The area of these environments was measured on the basis of the habitat map. The **flow** indicator is the presence or not of hunting in the quarry. This information was obtained from the operators.
Fresh water fishes and shellfishes	The surface area of the quarry habitats suitable for fish, crustaceans and molluscs (ha) represents the stock indicator for this service. This area was calculated from the habitat mapping, selecting standing and flowing water environments (WalEunis code C1 and C2). The **flow** indicator is the presence or not of fishing in the quarry. This information was obtained from the operators.

[17] Département de l'Etude du Milieu Naturel et Agricole /Department of Natural and Agricultural Environment Studies

RAW MATERIALS & ENERGY

	Description
Wood	The **stock** indicator for this service is represented by the total wooded area (ha) on the quarry territory. This information was obtained from the habitat map (Code WalEunis G). The **flow** indicator is the presence of wood exploitation in the quarry. This information was obtained from the operators.
Fodder	In this report we are only interested in plant materials used as fodder for animal feed. In order to know the **stock** of this service, the areas of grassland and crops used for fodder production were measured. The production of grassland depends on the region in which the quarry is located. The production of permanent grasslands and fodder crops (maize, beet, …) according to the agricultural region of Wallonia was researched in the literature (Luxen, 2014; Décelait, 2010, Knoden, 2009, ASBL Fourrages Mieux, 2015). The average forage production of the years 2013 to 2015 and 2016 to 2018 are the indicator of the **flow** of this service for the initial and final assessment respectively.

FRESH WATER

	Description
Drinking water	The operators were asked whether the water was potable or not. The area of potable water (ha) represents the **stock** indicator and is calculated from the habitat mapping, based on information from the quarryman. The volume of potable water in 2016 and 2020 (**flow** indicator) was also requested from the operators.

Annex 8. Type questionnaire filled in by participants of activities organized by quarries

In the framework of the Life in Quarries, co-financed by the European Commission and Wallonia, which aims to develop and preserve nature in quarries on various active extraction sites in Wallonia, the Gembloux Agro-Bio Tech faculty (University of Liège) is studying the various activities offered in quarries.
We would like to consult you to find out more about your interests, your expectations and your impressions of the ADEPS walk you have just participated in at the Clypot quarry.
You will only need a few minutes to complete this questionnaire, which contains about ten questions.
We thank you in advance for you participation.

1 Since when have you been participating in ADEPS walks?
Less than one year 1-3 years 3-5 years 5-10 years More than 10 years

2 How often do you participate in these ADEPS walks?
1 time per week 1 time per month 1 time a year
2 times a month 4 times a year Less than once a year

3 Do you know the Clypot quarry before participating in today's ADEPS walk?
Yes No

4 Why did you participate in this ADEPS walk?
Nature experience Physical activity, staying fit
For the eyesight Discovering new places
For the landscape, the scenery Entertainment
Spending time with family and friends Other:……..
Relaxation
Which of the following reasons for participating in this ADEPS walk did you experience in the Clypot quarry?
Nature experience Physiccal activity, staing fit
For the eyesight Discovering new places
For the landscape, the scenery Entertainment
Spending time with family and friends Other:……..
Relaxation

5 Did you enjoy the ADEPS walk in the Clypot quarry?
Not at all A little Quite A lot

6 What did you enjoy in the Clypot quarry?
The diversity of animals Viewpoints
The diversity of plants Stony paths
Natural, wild landscapes Hilly paths
Rocks and cliffs Quarry facilities
Water bodies (ponds, lakes, etc.) Nothing
The beauty of the landscape Other:……

7 Would you like to return to the Clypot quarry for another ADEPS walk?
Certainly not Probably yes I don't know
Probably not Certainly yes

8 Would you like to come back to the Clypot quarry for another activities than an ADEPS walk (walks, dog walking, mountain biking, etc.)?
Certainly not Probably yes I don't know
Probably not Certainly yes
If yes, for which activity(ies)?
Walking, hiking Animal watching, nature photography, drawing, painting or any other art form
Outdoor sports (running, cycling/mountain biking, etc.) Other:……

9 Do you know the Life in Quarries project?
Yes No
If so, through which means of communication did you find out about this project?
Notice board Social networks
Website Poster
Brochure or leaflet Newsletter
Media (radio or TV) I don't know
Other:……..
If yes, what did you learn from the project?

	…… If yes, do you consider that the project provides good quality information? Yes No I don't know			
10	Age group: Under 12 years 12-17 years old	18-29 years old 30-39 years old	40-49 years old 50-59 years old	60-69 years old Over 70 years old
11	Gender: Male Female			
12	Postcode of the place you live in ……			
13	Composition of the group …… adults and …… kids			
14	Which distance did you cover? 5 km 10 km 15 km 20 km			

Annex 9. List of Master and Bachelor training activities realized in support to the Life in Quarries

Master thesis:

Aurélie Tock (2021) – Utilisation d'abris temporaires par le Crapaud calamite (*Epidalea calamita*), l'Alyte accoucheur (*Alytes obstetricans*) et d'autres amphibiens ciblés par le Life in Quarries. To be available on https://matheo.uliege.be

Aurore Deflandre (2021) - Industrial sites as opportunities for the conservation of endangered amphibians: translocation of natterjack toads (*Epidalea calamita*) in active quarries. https://matheo.uliege.be/handle/2268.2/13237

Johan Jacob (2021) - Habitats temporaires en carrières actives wallonnes: Opportunité pour la conservation d'espèces végétales pionnières et menacées? https://matheo.uliege.be/handle/2268.2/11125

Camille Bontemps (2020) - Etude sur la valorisation paysagère des carrières actives du projet "Life in Quarries" en région wallonne. http://hdl.handle.net/2268.2/11033

Vladimir Joassin (2020) - Les successions spontanées sur les remblais de terres de découvertures limoneuses des carrières calcaires: Implication pour la restauration de la diversité des pelouses. http://hdl.handle.net/2268.2/8672

Lison Cowez (2020) - Translocation du Bufo calamita dans le cadre du projet LIFE in Quarries.

Anne Laure Desmet (2020) - Contribution à l'amélioration de l'état de conservation du Triton crêté (*Triturus cristatus*) en Wallonie par la constitution de nouveaux noyaux de populations par le biais de la translocation d'oeufs au sein de mares aménagées dans différentes carrières wallonnes dans le cadre du projet LIFE in Quarries.

Emilie Guilmin (2019) - Etude des stades initiaux des trajectoires écologiques de création de prairies de fauche de l'*Arrhenatherion elatioris* dans le cadre du projet Life in Quarries. http://hdl.handle.net/2268.2/7607

Luca Fagnan (2019) - Monitoring de mares en Wallonie pour la détermination de l'abondance du Triton Crêté (*Triturus cristatus*) et de la qualité de son habitat de reproduction dans le cadre du projet LIFE IN QUARRIES avec NATAGORA.

Elise Glaude (2018) - Evaluation du succès de la mise en œuvre des mares pionnières et des méthodes de quantification de l'effectif du crapaud calamite dans trois sites carriers participant au projet "LIFE in Quarries". http://hdl.handle.net/2268.2/5143

Eva Cagnati (2017) - Evaluation de la qualité de différents substrats pour la création de pelouses pionnières fleuries analogues en carrières. http://hdl.handle.net/2268.2/3680

Master and Bachelor Stages:

Ana de Wagter (2021) – Conscience du secteur carrier post projet Life

Hugo Fonteneau (2019) - Participation aux campagnes de translocations de Calamite (sites source set récepteurs)

Philippe Morgan (2019) - Participation aux campagnes de translocations de Calamite (sites source set récepteurs)

Elise Zimny (2018) – Suivis Life in Quarries - Translocations calamites

Delphine Grison (2018) – Évaluation des populations de Bufo calamita dans des sites situés autour de carrières du projet "LIFE in Quarries" en vue de futures translocations

Clément fauconnier (2018) - Évaluation des populations de Bufo calamita dans des sites situés autour de carrières du projet "LIFE in Quarries" en vue de futures translocations

Laurent Larsy (2017) - Immersion dans le domaine professionnel de la recherche scientifique ou celui de l'étude et de la gestion des écosystèmes naturels et anthropisés: inventaires floristiques et faunistiques, cartographie des micros-habitats en carrière en cours d'exploitation mais également l'accompagnement de l'équipe « Patrimoine naturel et biodiversité » sur d'autres projets.

Luca Covone (2017) - LIFE in Quarries Rapport de Stage: Translocation d'Amphibiens en milieu carrier

Master Project:

Dubourg Caroline, Labonté Audrey, Julien Paquet (2018) – Construction d'un cadre d'indicateurs de suivi de la biodiversité en carrière pour le projet 'Life in Quarries'