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Le climat change, adaptons-nous avec la nature

OFFICE FRANÇAIS DE LA BIODIVERSITÉ

Action A2 - État des lieux des besoins de connaissance pour la généralisation des SafN

Inventaire des connaissances actuelles et des besoins de recherche

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Préambule

Le projet Life intégré ARTISAN (Accroître la Résilience des Territoires aux changements climatiques par l'Incitation aux Solutions d'Adaptation fondées sur la Nature) est financé par le Programme LIFE de l''Union européenne, le ministère de la Transition écologique (MTE) et le ministère de la Cohésion des territoires et des Relations avec les collectivités territoriales (MCT) et piloté par l'Office français de la biodiversité (OFB).

Ce projet participe à la mise en œuvre du deuxième Plan national d'adaptation au changement climatique (PNACC-2) et du Plan biodiversité de la France. Doté d'un budget total de 16,7 millions d'euros sur une durée de 8 ans (2020-2027), il s'appuie sur 27 bénéficiaires associés[1], dont l'OFB.

L'originalité du projet Life intégré ARTISAN est de placer les Solutions fondées sur la Nature (SfN) au centre de ses actions pour répondre aux enjeux de l'adaptation aux changements climatiques des territoires français. L'ensemble des bénéficiaires associés du projet et partenaires qui nous soutiennent (Commission européenne, MTE, MCT, etc.) sont convaincus de l'intérêt d'utiliser ce concept et ses actions associées qui permettent selon eux :

- de décloisonner les enjeux liés à la biodiversité et aux changements climatiques,
- de mobiliser de nouveaux acteurs traditionnellement pas ou peu présents dans les secteurs d'activités liés au climat et à la biodiversité,
- de mobiliser des financements traditionnellement alloués aux solutions dites « grises »,
- de travailler dans un cadre méthodologique détaillé (cf. Standard mondial de l'UICN sur les SfN).

C'est pourquoi le projet Life intégré ARTISAN a pour objectif de favoriser la mise en œuvre de ces solutions sur l'ensemble du territoire. Pour cela il peut s'appuyer sur plusieurs dispositifs mis en œuvre à travers plus de 100 actions (cf. tableau ci-dessous) aux échelles locale, régionale, nationale et européenne : le Programme Démonstrateur qui regroupe 10 sites pilotes au niveau local, l'animation de 13 réseaux régionaux, l'animation du réseau national ARTISAN, la création et mise à disposition de ressources, l'analyse des freins et la mise en place des leviers pour la démultiplication des Solutions d'adaptation fondées sur la Nature (SafN) sur le territoire français (accompagnement de certaines filières et acteurs économiques dans leur démarche d'adaptation, mobilisation des financements, formations, etc.).

Mais qu'est-ce qu'une Solution d'adaptation fondée sur la Nature (SafN) ?

Les SafN sont des actions qui visent à favoriser la conservation de la biodiversité et la fourniture de services écosystémiques ciblés sur les impacts des changements climatiques permettant à nos sociétés d'être plus résilientes face à ces enjeux.

Plus précisément, les SafN correspondent aux « *actions visant à protéger, gérer de manière durable et restaurer des écosystèmes naturels ou modifiés pour relever directement* [le défi de l'adaptation au changement climatique] *de manière efficace et adaptative, tout en assurant le bien-être humain et en produisant des bénéfices pour la biodiversité*[2] ».

Cette notion de SafN renvoie à la réalisation d'une ou plusieurs actions concrètes de restauration, de gestion ou de protection des milieux dans le cadre d'une approche écosystémique globale. Une telle approche se doit d'englober les enjeux écologiques, sociétaux, politiques, économiques et culturels et ce à toutes les échelles, de l'individu au collectif, du local au national, de la sphère publique ou privée.

A1		Etat des lieux des freins et leviers à la mise en œuvre de SafN	**OFB**, Cerema, ENPC	Freins et Leviers
A2		Etat des lieux des besoins de connaissance pour la généralisation des SafN	**OFB**, ENPC	Freins et Leviers
A3		Etat des lieux de l'intégration croisée des enjeux climat et	**ONERC,** Ademe, OFB, ONERC, Cerema	Freins et Leviers

1 Site du Projet Life ARTISAN : https://ofb.gouv.fr/le-projet-life-integre-artisan

2 Site du Comité français l'UICN : https://uicn.fr/solutions-fondees-sur-la-nature/

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		biodiversité dans la planification territoriale		
A4		Etat des lieux de l'intégration croisée des enjeux climat et biodiversité dans les politiques publiques nationales	**ONERC,** OFB	Freins et Leviers
A5		Conception de la stratégie de communication et de diffusion du projet	**OFB**	Communication
C1		Animation et valorisation du programme démonstrateur	**OFB**, CDC-B, Ademe, Cerema	Programme démonstrateur
C2	Mise en œuvre de 10 sites pilotes de SafN			
	C2.1	Faciliter l'adaptation des forêts au CC pour maintenir leurs multiples rôles	PNR Pyrénées Ariègeoises (PNR PA)	Programme démonstrateur
	C2.2	Eau-Terre-Végétal : rafraîchissement urbain	Ville des Mureaux	Programme démonstrateur
	C2.3	ResSources du Néal	Communauté de Communes Saint-Méen Montauban, Forum des Marais Atlantiques (FMA), Université Rennes 2	Programme démonstrateur
	C2.4	Un maillage bocager résilient et pérenne	Communauté de Communes Cingal Suisse Normande (CCSSN)	Programme démonstrateur
	C2.5	Projet Z'AB	Communauté d'Agglomération du Centre de la Martinique (CACEM)	Programme démonstrateur
	C2.6	Ville Perméable - Acte 2 – Nature et adaptation au changement climatique	Grand Lyon Métropole	Programme démonstrateur
	C2.7	Restauration du marais de l'Estagnol	Syndicat de Gestion de l'Eygoutier (SGE), INRAE	Programme démonstrateur
	C2.8	Ancoeur 2030	AQUI'Brie, Syndicat Mixte des 4 Vallées de la Brie, INRAE	Programme démonstrateur
	C2.9	Végétalisation des cours d'écoles primaires	Ville de Lille	Programme démonstrateur
	C2.10	Promouvoir le génie végétal équatorial pour optimiser les écoulements afin de prévenir les inondations en zone urbaine	Communauté d'Agglomération du Centre Littoral (CACL)	Programme démonstrateur
C2b		Etudes transversales : observation/analyse des freins et leviers rencontrés par les sites pilotes	**OFB,** Ademe, Cerema, ENPC	Programme démonstrateur
C3	Conception et mise à disposition de ressources techniques sur les SafN			
	C3.1	Mise à disposition des ressources via une plateforme numérique - "boîte à outils"	**Cerema**	Réseau et Ressources
	C3.2	Capitalisation, adaptation et production de ressources mis à disposition des porteurs de	**OFB**, ENPC, Cerema, Ademe, CEPRI, UICN-Fr, CDC-B,	Réseau et Ressources

		projets		
C4		Formation initiale et continue	**OFB**, ENPC, Comité 21	Freins et Leviers
C5		Mise en place de 13 plateformes régionales pour appuyer la mise en œuvre de SafN	**OFB,** ARB CVL, ARB IDF, ARB Occitanie	Réseaux régionaux
C6	Accompagnement des acteurs économiques			
	C6.1	Conception d'une stratégie de développement de l'offre privée de SafN	**ADEME**	Freins et Leviers
	C6.2	Accompagnement stratégique à l'adaptation fondée sur la nature de quatre filières économiques	**ADEME**, OFB	Freins et Leviers
	C6.3	Accompagnement à la conception et à la mise en œuvre de plans territorialisés d'adaptation fondée sur la nature pour le secteur de la bioéconomie	**ADEME**, Solagro, CNPF	Freins et Leviers
C7		Appui à l'intégration des SafN dans la stratégie et la planification territoriale	**OFB,** ARB CVL, ARB IDF, ARB Occitanie, CERDD	Réseaux régionaux
C8		Appui à la mobilisation des financements	ONERC, CDC-B	Freins et Leviers
C9		Coordination et animation du dialogue entre la communauté scientifique et les décideurs	**OFB**	Freins et Leviers
C10	Améliorer le cadre règlementaire français et européen			
	C10.1	Amélioration des cadres législatifs et réglementaires nationaux et européens	**OFB**	Freins et Leviers
	C10.2	Intégration des solutions d'adaptation fondée sur la nature dans le référentiel normatif	**ADEME**	Freins et Leviers
	D1	Suivi, capitalisation des données et évaluation du projet life intégré ARTISAN	**OFB**	Gestion de projet
	D2	Suivi des Solutions fondées sur la Nature -(SfN) mobilisées pour la mise en œuvre du PNACC 2	**ONERC,** Ademe, OFB	Freins et Leviers
	D3	Réalisation d'enquêtes nationales multi-cibles pour évaluer l'évolution des besoins, des compétences et des comportements des principales parties prenantes	**OFB**	Freins et Leviers
	D4	Suivi et évaluation du programme démonstrateur du projet life intégré ARTISAN	**Cerema,** CDC-B, ENPC	Programme démonstrateur
E1		Mise en œuvre de la stratégie de communication	**OFB,** UICN-Fr	Communication
E2	Mise en œuvre de la stratégie de dissémination			

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	E2.1	Création et animation du réseau ARTISAN	**OFB, UICN-Fr, Cerema, CDC-B, CEPRI, Ademe**	Réseau et Ressources
	E2.2	Diffusion d'informations sur le projet via des supports numériques	**OFB, UICN-Fr**	Communication
E3		Favoriser l'intégration des SafN dans les politiques d'adaptation au changement climatique à l'échelle européenne	**OFB,** UICN, ENPC	Communication
E4		Faciliter l'accès aux retours d'expériences européens et internationaux	**OFB,** UICN-Fr	Communication
F1		Pilotage du projet	**OFB**	Gestion de projet
F2		Gestion administrative et financière du projet	**OFB**	Gestion de projet
F3		Développer une approche éco-responsable	**OFB**	Gestion de projet
F4		Développer une stratégie post projet ARTISAN	**OFB**	Gestion de projet

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Document disponible en ligne:

Documentation du Projet Life intégré ARTISAN
https://www.ofb.gouv.fr/le-projet-life-integre-artisan/documentation-life-artisan

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Table of content

Executive summary

This deliverable focuses on the creation of a current knowledge and research needs inventory for Nature-Based adaptation Solutions (NbaS). Carried out as part of Action A2 of the ARTISAN project, it aims to: (i) provide a multiscalar (international, regional and national) review of the current NbaS, (ii) identify and list research limitations and gaps, and (iii) propose perspectives for bridging the identified gaps and for developing further knowledge on NbaS. For the international scale, reports issued from the United Nations Framework Convention on Climate Change (UNFCCC), United Nations Environment Programme (UNEP) and the International Union for Conservation of Nature (IUCN) were examinated. The regional scale (Europe) was studied using the works of research projects funded udner the H2020 programme, while the national scale (France) was investigated using scientific literature from the SCOPUS database. The rationale behind the multiscalar approach articulates around two main ideas: (i) understanding and studying the transition from NbS to NbaS and (ii) situate the current state and progress in each scale and compare it with those of the other levels. Consequently, an inventory simultaneously grouping individual and multileveled current knowledge and research needs is provided. The main findings and conclusions of this work are summarized below. For more detailed information per scale, each chapter presents a separate section for analysis.

On the NbaS terminology:

- The concept implicitly appeared since 2009 (with the introduction of the NbS concept), and amply appeared following the 2015-2016 period within the different scales.
- In terms of nomenclatures it is rarely referred to as NbaS, but rather as nature-based solutions for climate change adaptation, or natural adaptation solutions. Ecosystem-based Adaptation (EbA) still occupies a considerable importance and is still being actively used.
- In rare instances such in the regional scale, the term NbS was found to be unsuitable in the first place and was recommended to be replaced by nature plainly.
- The transition from NbS and its associated concepts to NbaS (in all levels of the multiscalar approach) is still ongoing, continuous and progressive.
- Green NbS-NbaS (based on vegetation/green compartments) dominate the current offer and much efforts are needed to tap into other solutions.

Ecosystems and challenges of interest

- Throughout the different scales, the interest in ecosystems was seen to be quite different. While this may be justified by context-specific reasons or priorities, the unequal interest in ecosystems should be rectified for properly unlocking the potential of NbaS.
- The urban realm is the most addressed biome with a very considerable number of devoted reports, projects and studies. Most challenges revolve around urban heat islands, heat stress, storm water management and human well-being.
- The marine and coastal ecosystem is also fairly addressed, at the regional scale it is mostly studied for coastal cities rather than being treated as a distinct ecosystem. Most of the challenges addressed in this realm are related to coastal erosion, flooding and sea level rises.
- A more or less similar pattern can be observed for the freshwater ecosystems however to a relatively lesser extent. A great deal of importance is given to flooding processes and water availability.
- The agricultural realm's absence in the regional and national levels is quite striking as it reveals a reduced interest in climate proofing agriculture. At the international scale the high interest in the agricultural system can be explained by the global concern of food security. Most addressed challenges herein are droughts and reduced yields.
- The mountainous environment is well addressed at the national scale, and in the only project dedicated to mountains under H2020, France is present. Nonetheless, the relative underrepresentation of the mountainous ecosystem in H2020 projects (only PHUSICOS) and in the international scale's Nationally Determined Contributions (NDCs) reveals the need for further related studies. Most addressed challenges in this realm are landslides and erosion.
- In all scales, the forest ecosystem should extend further than a "silver bullet" solution and become addressed as a distinct ecosystem.
- The interest in natural ecosystems and protected areas is far greater at the international level than in the European and French systems. In this regard, the natural environment should be further promoted, and its potential as a NbaS should also be better exploited. The loss of biodiversity and ecosystem services is the

most addressed challenge herein (if applicable).

Identified risks

- Disregarding uncertainties, complexity and the dynamic nature of ecosystems and climate.
- Constraining/mistaking climate change to weather change (short-term planning).
- Overlooking the physical dimensions of climate change, its feedbacks and its numerical integration.
- Isolating adaptation measures from mitigation strategies and missing out on adaptation-mitigation synergies.
- Basing experience and anticipatory responses on past events (hazards/climate change manifestations)
- Oversimplifying NbaS and overselling their potential.
- Planning for NbS-NbaS as isolated interventions without embedding them into a larger strategic matrix.
- Constraining the application/implementation of NbaS into pilot or demonstration sites (punctual/local approaches) rather than upscaling them at the land and seascapes scales.
- Constraining the NbS-NbaS concept into the urban ecosystem hence making the produced knowledge, adopted methods and identified limits inapplicable to other ecosystems.
- Constraining the ecosystem service concept into anthropocentric benefits and points of view rather than extending knowledge and studies to the whole spectrum.
- Insufficient understanding of ecosystem services, functions, and changes induced by the (re)introduction of nature.
- Overlooking the potential of adaptation services within the NbaS framework.
- Treating NbaS like immune solutions and disregarding their inherent sensitivity/vulnerability to climate change.
- Misidentification or wrongful/none accounting for disservices.
- Narrow focuses on geographically limited ecosystems rather than considering ecosystem mosaics and their connectivity.
- Trapping knowledge on NbS-NbaS in disciplinary silos and behind language barriers instead of compiling knowledge from cross and transdisciplinary efforts.

Proposed research perspectives
(refer to each Chapter's perspectives for deeper insights)

<u>Ecosystems and ecosystem services</u>

- Understanding the spatial discrepancy between the location of the sought solution and that of the ecoservices' beneficiaries.
- Expanding the interest in ecosystem services to cover the whole spectrum, particularly regulating ones.
- Producing more conclusive evidence on the role of ecosystem services for the reduction of vulnerability to climate change/variability.
- Developing a deeper understanding of what current ecosystems offer and what services are intended to remain the same or change with climate change.
- Developing further the understanding on ecological responses to climate change, ecosystem thresholds and tipping points.
- Understand how new ecosystem services (generated through the process of an ecosystem's adaptation, i.e. adaptation services) and previous ones interact with and influence each other. In analogy, when a NbaS is introduced into the system, the new services brought about by these solutions will have to interact with previous and transformative services. Nonetheless, exploring this interaction is still an untapped domain and can be considered as a novelty to develop.
- Developing further knowledge on ecosystem services' devaluation and degradation of services.
- Understanding the off-site effects of adaptive land use changes (herein NbaS) since adaptation measures in a specific location might have unintended off-sites effects on other contexts or scales.
- An adaptive change for a context (despite its benefits) might be harmful to another. In this sense, it is useful to study the effects that may result from the introduction of a NbaS into a setting that wasn't planned for in the first place.

<u>In terms of NbaS</u>

- Accounting better for the uncertainties of climate change and NbaS as well as quantifying them better.
- Developing deeper knowledge on nature's and systems' complexity through a better understanding of individual and systematic behaviors by avoiding oversimplifications.

- Enhancing knowledge on the contribution of soils and lands to the NbS-NbaS concept.
- Tapping the potential of protected areas as means to "protect" other neighboring NbaS (e.g. green belt surrounding an urban park).
- Understanding the effects brought about by the connection of solutions is an important line of work to develop. This implies a connection of ecosystems, which in turn creates various ecotones. The ecotone effect allows a maximization of individual efficiencies and multiplies benefits. However, measuring the climatic connectivity effect of NbaS and the ecotone effect are still limited in scope.
- Developing a deeper understanding of the NbaS location's effect in a system.
- Focusing more efforts on solutions to address slow-onset climatic events.
- The role of genetic diversity as a NbaS is still understudied and these solutions are relatively unexplored.
- Studying the "creative" power of NbaS. This point refers to a NbaS that generates another with time [precursor]. Such is the example of permeable dams which throughout their existence have permitted the development of mangroves within, hence another NbaS).
- Developing knowledge on the resource efficiency of sought solutions since these consume natural capital during their existence. For instance, vegetation-based solutions will often require continuous irrigation to remain functional; The consumption of natural resources – here through irrigation – can be a major challenge particularly during periods of law water availability or during the intensification of climate change-induced water shortages.
- Deepening knowledge on trade-offs and synergies between NbaS, socioeconomic conditions, biodiversity and human health. It is equally important to understand the interactions and the relationships between the co-benefits of a solution, as some can reduce the provision of others, hence the solution's overall efficiency.
- Developing an understanding on which NbaS will be more effective on the long run, and which will be more performant immediately after its application (temporal dimension).
- In terms of freshwater (river) ecosystems, a focus on more hydrology/morphology-based NbaS (if possible) might be more advantageous than using vegetation. Nonetheless, careful considerations are needed when modifications to the River's channel, bed and banks are performed as these might have serious hydrosedimentary repercussions. On this basis, knowledge on "other than green" NbS-NbaS should be expanded.

On measuring efficiencies

- Developing clearer targets and metrics for adaptation in an effort to define success thresholds.
- Developing further evidence on the efficiency of NbaS as well as on hybrid solutions (grey-green), as well as deepening knowledge on protected areas (natural areas) as potent NbS-NbaS.
- Developing methods for a more systematic quantification of ecosystem service benefits for climate change NbS [NbaS and NbS for CC mitigation].
- Developing valuation methods that consider seasonal variations of NbaS performance (particularly those based on vegetation). This is particularly relevant as mean values do not represent intra-annual or seasonal variations.
- As NbaS mature with time, the delivery of their co-benefits also happens progressively. Therefore, understanding whether one should account for the final delivered services or also for the intermediate ones also is an open question to answer.
- Developing means for quantifying the "summation" of aggregated NbaS effects.

On the challenge of scales

- While many projects generate(d) substantial amount of knowledge, most of their approaches are still demonstration or pilot-site interventions. Accordingly, these often take the form of awareness-raising elements rather than generators of physical knowledge. The narrow focus on specific scales (pilot sites dozens of km^2) makes the identified limitations, achieved successes and the methods developed not necessarily applicable or replicable at both finer and larger scales. Therefore, efforts for knowledge generation should extend beyond pilot sites and englobe larger levels.
- Accelerating efforts for the assessment of large scale NbS-NbaS (i.e. mountain ranges, basins, cityscapes, etc), watershed scale NbS-NbaS and hybrid structures that contain both small and large NbS.
- Understanding the different scales implicated within a challenge (knowledge through scalar transitions).

Résumé

Ce livrable a pour objectif de créer un inventaire des connaissances et des besoins actuels de recherche sur les Solutions d'adaptation Fondées sur la Nature (SafN). Réalisé dans le cadre de l'Action A2 du projet ARTISAN, il vise à : (i) fournir une étude multi-échelle (internationale, régionale et nationale) sur l'état actuel des connaissances sur les SafN, (ii) identifier et répertorier les limites et les lacunes de recherche, et (iii) proposer des perspectives pour combler les lacunes identifiées et approfondir les connaissances sur ces solutions. L'échelle internationale est abordée à travers les travaux de la Convention-cadre des Nations Unies sur les Changements Climatiques (CCNUCC), du Programme des Nations Unies pour l'Environnement (PNUE) et l'Union Internationale pour la Conservation de la Nature (UICN). L'échelle régionale (Européenne) est abordée à travers les projets de recherche financés dans le cadre du programme H2020. L'échelle nationale (France) est abordée à travers une revue de littérature effectuée via la base de données Scopus pour les articles de journaux à comité de lecture. La logique derrière l'approche multi-échelle s'explique en deux grands axes : (i) comprendre et étudier la transition des SfN aux SafN et (ii) situer le progrès et l'état actuel de chaque niveau par rapport aux autres. Ainsi, un inventaire regroupant à la fois les connaissances actuelles et des besoins de recherches individuels et à différents niveaux est fourni. Les principaux résultats et conclusions de ce travail sont résumés ci-dessous. Pour des informations plus détaillées par échelle, il faut se reporter aux chapitres.

Sur la terminologie NbaS:

► Le terme est implicitement apparu en 2009 (avec l'introduction du concept SfN), et s'est ensuite répandu après la période 2015-2016 au sein des différentes échelles.

► En terme de nomenclature, les SafN sont rarement nommées ainsi, mais plutôt comme solutions basées sur la nature pour l'adaptation au changement climatique, ou des solutions d'adaptation naturelles. Le terme d' « adaptation basée sur les écosystèmes » (EbA) est encore activement et largement utilisé.

► Dans de rares cas détectés à l'échelle régionale, le terme SfN était considéré comme inadéquat, avec la recommandation de le remplacer par le mot nature.

► La transition des SfN et ses concepts associés vers les SafN (à tous les niveaux de l'approche multi échelle) est toujours en cours et demeure progressive.

► Les SfN-SafN vertes (basées sur la végétation/les compartiments verts) dominent l'offre actuelle et de nombreux efforts sont nécessaires pour exploiter d'autres solutions.

Écosystèmes d'intérêt et enjeux

► À travers les différentes échelles, les écosystèmes d'intérêt varient considérablement. Bien que cela puisse être justifié par des raisons ou des priorités spécifiques au contexte, l'intérêt dans les écosystèmes doit être homogénéisé pour comprendre correctement le potentiel des SafN à travers différent milieux.

► L'écosystème urbain est le biome le plus étudié avec un nombre de rapports, projets et études très important. La plupart des enjeux dans ce domaine sont liés aux îlots de chaleur urbains, au stress thermique, à la gestion des eaux pluviales et au bien-être humain.

► L'écosystème marin et côtier est également assez abordé. A l'échelle régionale il est surtout étudié dans le contexte des villes côtières plutôt que comme un écosystème à part. La plupart des défis abordés dans ce domaine sont liés à l'érosion côtière, aux inondations et à l'élévation du niveau de la mer.

► Une tendance plus ou moins similaire peut être observée pour les écosystèmes humides, mais dans une moindre mesure. Une grande importance est accordée aux processus d'inondation et à la disponibilité de l'eau.

► L'absence de l'écosystème agricole aux niveaux régional et national est assez frappante car elle révèle un intérêt réduit pour les enjeux de vulnérabilité climatique de l'agriculture. À l'échelle internationale, le grand intérêt dédié au système agricole s'explique par la préoccupation globale de la sécurité alimentaire. Les défis les plus abordés dans ce domaine sont les sécheresses et la réduction de rendements.

► Le milieu montagnard est bien abordé à l'échelle nationale. Dans le seul projet dédié aux montagnes dans le cadre du programme H2020, la France est présente. Néanmoins, la sous-représentation relative de l'écosystème montagnard dans les projets H2020 (uniquement PHUSICOS) et dans les contributions nationales et internationales révèlent la nécessité d'études complémentaires. Les défis les plus abordés dans ce biome sont les glissements de terrain et l'érosion.

► À toutes les échelles, l'étude de l'écosystème forestier devrait ne devrait pas se réduire à celle d'une solution transversale. Il devrait être abordé comme un écosystème à part.

► L'intérêt pour les écosystèmes naturels et les aires protégées est bien plus important au niveau international qu'aux échelles européenes et françaises. À cet égard, l'environnement naturel devrait être davantage promu et son potentiel en tant que SafN devrait également être mieux exploité. La perte de biodiversité et de services

écosystémiques sont les défis les plus abordés ici.

Risques identifiés

► Intégration limitée des incertitudes, de la complexité et de la nature dynamique des écosystèmes et du climat.
► Confusion entre le changement climatique et le changement météorologique (court terme).
► Intégration limitée des dimensions physiques du changement climatique, ses rétroactions et l'absence de son intégration numérique.
► Séparation entre mesures d'adaptation et stratégies d'atténuation, les synergies adaptation-atténuation étant abordées de manière marginale.
► Mesures d'anticipation reposant trop sur l'expérience des événements passés pour appréhender un futur incertain (risques/manifestations du changement climatique)
► Sur-simplification du fonctionnement des SafN et survente de leur potentiel.
► Planification de SfN-SafN en tant qu'interventions isolées sans intégration dans une stratégie plus large.
► Limitation de la mise en œuvre des SafN aux sites pilotes ou de démonstration (approches ponctuelles/locales) plutôt que de les étendre à des échelles plus larges.
► Réduction du concept de SfN-SafN à l'écosystème urbain rendant ainsi les connaissances produites, les méthodes adoptées et les limites identifiées difficilement applicables à d'autres écosystèmes.
► Limitation du concept de service écosystémiques à des avantages anthropocentriques plutôt que d'étendre les études et connaissances à l'ensemble du spectre de ces services.
► Compréhension insuffisante des fonctions et services écosystémiques, et des changements induits par la (ré)introduction de la nature.
► Sous-estimation du potentiel des services d'adaptation dans le cadre des SafN.
► Perception des SafN comme solutions immunes en ignorant leur sensibilité/vulnérabilité inhérente au changement climatique.
► Identification erronée ou injustifiée des disservices.
► Concentration des travaux sur des écosystèmes géographiquement limités plutôt que sur des mosaïques d'écosystèmes et leur connectivité.
► Restriction des connaissances sur les SfN-SafN à des silos disciplinaires et linguistiques au lieu de compiler des connaissances à partir d'efforts trans- et pluridisciplinaires.

Perspectives de recherche proposées
(Réf. aux perspectives de chaque chapitre pour des informations plus détaillées)

Écosystèmes et services écosystémiques

► Comprendre le décalage spatial entre la localisation de la SafN et celle des bénéficiaires des services écosystémiques dispensés.
► Élargir l'intérêt pour tout le spectre des services écosystémiques, en particulier ceux de régulation.
► Produire des preuves plus concluantes sur le rôle des services écosystémiques pour la réduction de la vulnérabilité au changement et à la variabilité climatique.
► Développer une meilleure compréhension de ce que les écosystèmes actuels offrent et quels services sont destinés à rester les mêmes ou à changer avec le changement climatique.
► Développer davantage la compréhension des réponses écologiques au changement climatique, des seuils écosystémiques et des points d'inflexion.
► Comprendre comment les nouveaux services écosystémiques (générés par le processus d'adaptation d'un écosystème [services d'adaptation]) et les précédents interagissent et s'influencent mutuellement. Par analogie, lorsqu'une SafN est introduite dans un système, les nouveaux services apportés par ces solutions devront interagir avec des services antérieurs et transformateurs. Néanmoins, la compréhension de ces interactions est encore un domaine inexploité et peut être considéré comme une piste à approfondir.
► Développer de nouvelles connaissances sur la dévaluation et la dégradation des services écosystémiques.
► Comprendre les effets « collatéraux » dus à l'introduction des mesures adaptatives d'utilisation des terres (ici SafN) étant donné que les mesures d'adaptation dans un endroit spécifique peuvent avoir des effets négatifs sur d'autres contextes ou échelles (notion de disservice).
► Étudier les effets potentiellement néfaste d'une SafN implantés dans un contexte différent de celui où elle avait initialement pensé. Cet axe de recherche est important à considérer vu les effets potentiels sur le succès des solutions proposées/mises en œuvre (disservices).

En termes de SafN

► Mieux prendre en compte les incertitudes du changement climatique ainsi que ceux des SafN et promouvoir leurs quantification.

► Développer des connaissances plus approfondies sur la complexité de la nature et des systèmes en comprenant mieux les comportements individuels et systématique et en évitant les approches de réductionnisme ou de sur simplification.

► Améliorer les connaissances sur la contribution des sols et des terres au concept de SafN.

► Exploiter le potentiel des aires protégées comme moyen de « protéger » d'autres SafN voisines (par exemple, une ceinture verte entourant un parc urbain).

► Comprendre les effets induits par l'agrégation spatiale des solutions. Cela renvoie à la notion d'écotone qui reste largement non étudiée.

► Développer une compréhension plus approfondie de l'effet de l'emplacement d'une SafN dans un système.

► Concentrer davantage les efforts sur des SafN conçues pour faire face aux événements climatiques à évolution lente.

► Étudier davantage le rôle de la diversité génétique en tant que SafN.

► Étudier l'action créatrice d'une SafN. Ce point se réfère à une SafN qui en génère une autre dans le temps (ex des barrages perméables utilisés comme SafN qui tout au long de leur existence ont permis le développement des mangroves, soit une autre SafN).

► Développer des connaissances sur l'efficacité de ressources des SafN proposées car celles-ci consomment du capital naturel tout au long de leur existence (ex : les solutions vertes souvent nécessitent une irrigation continue pour rester fonctionnelles. Cette consommation de ressource naturelle – ici à travers l'irrigation - peut être un enjeu majeur durant les périodes de faible disponibilité en eau et particulièrement avec la progression du changement climatique).

► Approfondir les connaissances et élaborer des stratégies sur les compromis et les synergies entre les SafN, les conditions socio-économiques, la biodiversité et la santé humaine. Sur le même volet il est également important de comprendre l'interaction et la relation des co-bénéfices d'une SafN, puisqu'un certain co-bénéfice peut diminuer l'apport d'un autre, et par transitivité l'efficacité totale de la solution.

► Identifier quelles SafN seront plus efficace sur le long terme, et lesquelles seront plus performantes immédiatement après leur mise en œuvre (dimension temporelle).

► En termes d'écosystèmes humides, une concentration sur des solutions basées sur l'hydrologie/morphologie des plans d'eaux (si possible) pourra être plus avantageuse qu'un simple recours à des solutions de végétalisation. Néanmoins, des approches prudentes sont nécessaires lorsque des modifications sont apportées aux cours d'eaux, au lit et aux berges des rivières, car elles pourraient avoir de graves répercussions hydrosédimentaires. Sur cette base, les connaissances sur les SafN « autre que vertes » doivent être développées d'avantage.

Sur les mesures d'efficacité

► Élaborer des cibles et des métriques/indicateurs d'adaptation plus clairs pour mieux définir des seuils de réussite des mesures d'adaptation.

► Développer des preuves supplémentaires sur l'efficacité des SafN ainsi que sur les solutions hybrides (gris-vert), et en outre approfondir les connaissances sur les aires protégées (zones naturelles) en tant que SfN-SafN.

► Développer des méthodes pour une quantification plus systématique des avantages des services écosystémiques issus des SfN au changement climatique [SafN et SfN pour l'atténuation].

► Développer des méthodes d'évaluation qui prennent en compte les variations saisonnières des performances des SafN (en particulier celles basées sur la végétation), les valeurs moyennes n'étant pas représentatives.

► S'interroger sur la manière d'appréhender la progressivité des services prodigués au fil du temps, à savoir si l'on doit juste considérer les services finaux ou également les services intermédiaires.

► Développer des moyens pour quantifier l'addition des effets de SafN agrégées.

Sur les défis d'échelle

► Alors que les approches actuelles génèrent une quantité substantielle de connaissances, la plupart sont encore des interventions de démonstration ou sur des sites pilotes. En conséquence, ces approches prennent souvent la forme d'éléments de sensibilisation plutôt que de générateurs de connaissances physiques. La focalisation étroite sur des échelles spécifiques (sites pilotes de dizaines de km^2 au maximum) rend les limites identifiées, les succès et les méthodes développées non nécessairement applicables ou reproductibles à des échelles plus fines et/ou plus grandes. Ainsi, les efforts de production de connaissance doivent s'étendre au-delà des sites pilotes/d’intervention pour englober des échelles plus larges.

► Accélérer les efforts pour l'évaluation des SfN-SafN à grande échelle (ex : l’échelle des chaînes de montagnes, les bassins versants, les paysages urbains, etc.), et les structures hybrides qui contiennent des SfN-SafN de taille différente.

► Comprendre les différentes échelles impliquées dans l’enjeu environnemental ciblé (connaissance à travers divers échelles: transitions scalaires).

General Introduction

This deliverable was produced as part of the LIFE ARTISAN LIFE18 IPC/FR/000007 project (Achieving Resiliency by Triggering Implementation of Nature-based Solutions for Climate Adaptation at a National Scale). ARTISAN aims to contribute to the implementation of the 2nd National Climate Change Adaptation Plan (PNACC-2) in line with the long-term objectives of the Paris Agreement, the European Union's strategy for the adaptation to climate change, the national strategy for biodiversity, and the French Biodiversity Plan. ARTISAN's objective is to facilitate the implementation of the PNACC-2 by raising momentum for the implementation of Nature-Based adaptation Solutions (NbaS) in France.

Action A2 of the ARTISAN project aims to establish a status report on knowledge building needs in order to mainstream NbaS. Coordinated by the OFB and associating the ENPC, action A2 revolves around four main axes:

(i) A state-of-the-art on scientific and technical literature regarding knowledge on the impacts of NbaS.
(ii) An analysis of capacities and a structuring of formalized research via a map of existing research networks around different types of NbaS, and through the identification of key academic stakeholders and organizations working on scientific fronts
(iii) An analysis of priority research needs.
(iv) The development of a roadmap for the science-society interface of ARITSAN's phase 2 (C9), and a basis for the "Research" thematic group described in action E2.

The objectives of A2 are to:

(i) Enable all associated beneficiaries (including non-experts) to hold a solid, rigorous and homogeneous discourse on the expected impacts of NbaS through their communications with different stakeholders.
(ii) Identify priority research needs for subsequent development in order to multiply the number of nature-based solutions.
(iii) Help define the work schedule for the future science-society interface: a. development of priority research projects and research networks and b. identification of strong research outputs for dissemination among managers and project leaders.
(iv) Serve as a reference for jointly defining outputs and indicators for demonstration projects under action D4 (i.e. Evidence-based reporting on the efficiency of sought solutions)

Nature-Based Solutions (NbS): actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits (IUCN, 2018)

Nature-Based adaptation Solutions (NbaS): Nature-based solutions target several societal challenges, NbaS target only one: adaptation to climate change, meaning: (i) Adaptation to sea level rise (flooding and erosion of coastal areas, health risks, economic challenges), (ii) Adaptation to extreme weather conditions and changes in precipitations (floods and challenges related to water quality and availability, health and economic risks), (iii) Adaptation to rise in temperatures (heat waves, forest fires, drought periods, health risks, increase in local pollution, modification of energy consumption and economic challenges, snowmelt), (iv) Adaptation of terrestrial and marine ecosystems, (v) Adaptation of food production, health and economic sectors, etc. (Azzam et al. 2021).

Some examples of NbaS: agroforestry plots for enhancing crop resilience, restoration of slope forests in mountains to mitigate landslides, preservation of mangroves to limit submersion risks, reconnection of watercourses with floodplains for flood risk reduction, creation of urban parks and forests for combatting urban heat islands, etc.

The present deliverable overarches across all four objectives with a particular emphasis on objective (ii). Based on a multiscalar approach, chapter 1 provides a review of the international interest in NbaS and the shift from NbS and other associated concepts to NbaS. It also focuses on the complexity of this progressive shift by underlining several conceptual elements, namely those related to climate change adaptation, while highlighting several lines of research work to develop. For this chapter institutional reports from the United Nations Framework Convention on Climate

Change (UNFCCC), UNEP (UN Environment Programme) and the International Union for Conservation of Nature (IUCN) were used. Chapter 2 provides a detailed review of NbS-NbaS projects under the Horizon 2020 (H2020) program. Accordingly 21 projects were investigated, the shift from NbS to NbaS in Europe was studied, and several research perspectives emerging from the continental scale approach to NbaS were proposed. Finally, chapter 3 reviews national efforts based on French-issued scientific literature, studies the transition from NbS to NbaS, provides insights on academic stakeholders and funding parties, and proposes lines of research work to develop. A synthesis of the multiscalar approach is given at the end of this report.

General objectives

The main objective of this deliverable is to highlight and propose research needs/perspectives for unlocking and tapping the full potential of NbaS. The target audience of this work are numerous: professionals, specialists, scientists, academic personnel, technicians, ARTISAN project beneficiaries and pilot sites' managers.

Based on the presented work and identified needs, a roadmap for both research and practice domains is offered. By providing a review of both current and needed knowledge, general and ecosystem-specific (media defined in action A1) insights are given. That way, a generic and specific panoramas are simultaneously ensured, hence offering readers various options and elements to explore.

As this study adopted a multiscalar approach, three contributions on NbaS have resulted. Through the analysis of different scales, micro to macro insights were obtained (Figure i). The national analysis provided insights on the past, current and future orientations of NbaS in France. The national to regional approach revealed France's position with respect to the European continent, while the national-regional to international approach revealed the position of Europe with respect to global trends. The analysis of each scale drew up independent findings, which at a combined state allowed the establishment of a holistic knowledge inventory.

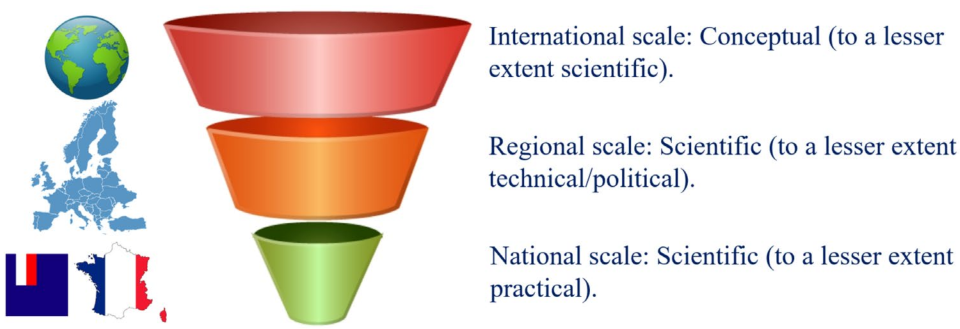

Figure i. A simplified representation of the multiscalar approach

General methodology

Each scale of this approach was based on a three-fold sequential methodology: Search, filter and extract/analyze. A simplified workflow of the adopted methodology is presented in Figure ii. Each chapter then presents in details the utilized materials and methods within under the search, filter and extract/analyze approach. For the international scale, the documents repository of the UNFCCC, UNEP and IUCN were utilized. For the regional scale, the CORDIS webpage of the European Commission was used, while the SCOPUS database was used for the national scale. More details on each can be found in the corresponding chapters.

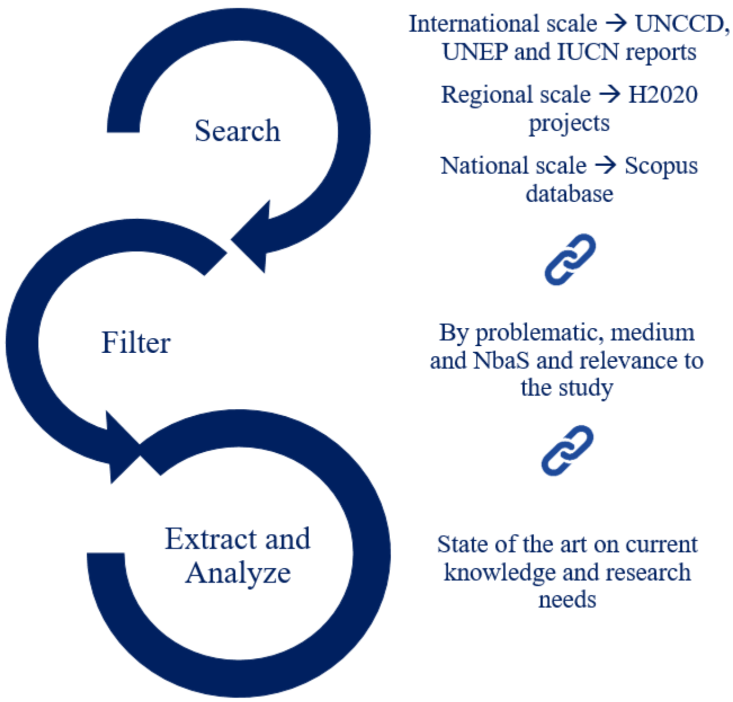

Figure ii. A simplified representation of the general methodology

Chapter 1 - The international scale approach

Summary

This chapter presents findings from the analysis of grey literature issued by international bodies. The international scale is the first level of the multi-scale approach, and was chosen to study global trends. This analysis allowed the establishment of an "*état des lieux*" for NbS-NbaS. It also served to track the transition from NbS and its related concepts to NbaS. The international approach allows to situate France and Europe with respect to global trends and progress. The main advantage of this scale is that the analysis of reports issued by international bodies reveals insights that extend beyond project-based approaches. Accordingly, a wider and more comprehensive examination is made possible. As the NbS concept was introduced and molded by international organizations, and while climate change adaptation is a global challenge, the study of institutional reports is necessary.

To that end, the work of three international bodies was used. These are the International Union for Conservation of Nature (IUCN), the United Nations Framework Convention on Climate Change (UNFCCC) and the United Nations Environment Program (UNEP). One additional report from the United Nations Educational, Scientific and Cultural Organization (UNESCO) was also added to the inventory given its relevance to water solutions. The reasons behind the choice of these organizations is detailed in the course of the chapter. Succinctly, the IUCN has been spearheading the concept of NbS since the late 2000's. The UNFCCC is the most climate change implicated international body with a committee devoted to climate change adaptation, while the UNEP was placed to lead the UN global efforts on NbS. A total of 97 reports were investigated using the study's search, filter, extract and analyze approach. While findings are numerous and very diverse, they converge in several instances and diverge in others. For example, the sectors and media listed as priority for each are sometimes different than the others. Further, different types of NbaS are given different degrees of importance (i.e. a heterogeneous preference), while the Ecosystem-Based Adaptation (EbA) concept is also treated distinctively. Nonetheless, all three institutions agree that NbaS have only started to receive their much deserved attention, that some environments should be better integrated and prioritized, and that some NbS-NbaS deserve further consideration/valorization.

On the NbaS terminology

The concept of NbaS in precise terms appears in recent literature, but shades of its existence are presented in the earliest reports. It encompasses several other concepts, namely NbS, and most commonly ecosystem-based approaches such as EbA, Ecosystem Disaster Risk Reduction (Eco-DRR) and Ecosystem Based Management (EbM). Within these reports, NbaS appear in strict terms both in their French (i.e. Solutions fondées sur la nature pour s'adapter au changement climatique) and English forms (i.e. Nature-Based Solutions for climate change Adaptation), respectively. The adaptation aspect of these solutions is well acknowledged and NbaS are additionally perceived as restoration, management, prevention and preservation tools among other purposes. Even more, NbS and NbaS are seen as the way forward during the post-COVID19 recovery phase under the three organizations. To that end, NbS and NbaS are perceived as fundamental elements for building back better in a greener way. In addition to abundant information on NbS, the **A**daptation dimension is well developed. It is often tackled from conceptual, scientific, and technical points of view with links to several other disciplines, namely DRR. The position of NbS and NbaS with respect to several urgent agendas such as the Sustainable Development Goals (SDGs) is also well aligned. Accordingly, the international interest in NbaS is clear and is even perceived as a priority. This aspect is particularly apparent in the case of the UNFCCC where questions shifted from ***"****do we need to adapt?****"*** to **"***how do we adapt?****"*** and ***"****how do we integrate adaptation into relevant social, economic and environmental policies and actions?****"*** with time.

Types of NbaS

A wide variety of NbaS are discussed throughout the different reports. In a straightforward manner, a greater common interest in green solutions is apparent compared to other NbaS. Some of the most shared examples are afforestation, green roofs, urban green spaces, ecological corridors, agroecology, permeable pavements, blue-green infrastructure and others. The most commonly addressed climatic challenges were found to be coastal hazards, intense precipitation events (along with their cascading effects e.g. floods, erosion, etc…), droughts and temperature rises. A recommendation for prioritizing NbS other than forest-ecosystems' is also transversal. To that end, blue and brown solutions are encouraged. The importance of protected areas as efficient NbaS is heavily underlined in the different reports, and a rapid uptake of these solutions is urged. Within the different sources, grey solutions are not blindly labeled as harmful. Instead, the potential of grey solutions and the basis behind their implementation are well acknowledged, and are perceived as elements that should be complemented by NbS-NbaS. In that sense, hybridizing the grey is strongly encouraged for exploiting the mutual benefits of grey and nature-based solutions (blue or green or both), and to maximize the efficiency of both "colors". Recommendations for tapping underrepresented NbaS are also prevalent. For instance, expanding knowledge on groundwater NbS-NbaS, peatlands, seagrass, cloud forests, and pollination services (among others) was called for. Regardless of their type, NbS intended for climate change adaptation are much less common that those intended for mitigation. NbS that synergize both adaptation and mitigation are as equally rare. Therefore, the NbaS field calls for more research.

Biomes (environments) and priority sectors

While all three organizations stress the importance of healthy and functional ecosystems, key areas and priority sectors differ among them. However, a general consensus on the importance of coastal areas, water resources (waterbodies and freshwater environments), agriculture, terrestrial ecosystems (natural areas, forests and grasslands, etc…) cities, and human health is apparent. Nonetheless, these sectors are ranked differently under each organization, thus reflecting dissimilar interests. Unsurprisingly, water (as both a resource and a medium) is a very central element for all three bodies, and great emphasis on its importance is perceptible. The same is applicable for biodiversity which is also a decisive factor for labelling a solution as NbS-NbaS or not. The urban environment is naturally at the forefront as it is the most human housing biome. Other sectors such as infrastructure, energy, tourism are also highlighted, and the recent inclusion of NbS into these areas (particularly for infrastructure) is well discussed. Soils as a medium are particularly relevant under all three bodies and their importance is highly stressed. While soils are often underrepresented in NbS approaches, an increasing recognition of their potential is herein visible. Conversely, the mountainous environment is seldom discussed despite the acknowledgment of its importance and high sensitivity to climate change. Regardless of the targeted sector, an inclusive overview of the system as a mosaic of environments or ecosystems is well apparent. The argument behind this idea is that ecoservices and ecosystems are not bound by geographical borders. Therefore, there is a need to design inclusive solutions that consider the heterogeneity of current and future landscapes/seascapes.

The complexity of adaptation in NbaS
As all reports converge on the importance and potential of NbaS, the other side of the coin cannot be left out. While the NbS concept is already burdened by several factors such as: the lack of robust evidence on their efficiency, their undefined tolerance limits, the inconsideration of trade-offs, and the relative absence of clear thresholds and tipping points of ecosystems, they are also compounded by other barriers of social, economic and governance nature. The multifaceted challenge of climate change adaptation adds another layer of complexity to consider. Throughout the different reports, and namely those of the UNFCCC's adaptation committee, the demanding and uncertain nature of adaptation is detailed. This uncertainty makes adaptation a complex, iterative and dynamic progress that should be approached with caution. The sources of uncertainties can be attributed to climate change projections, driving forces, and to the absence of adaptation "metrics". Moreover, the heterogeneity of adaptation even within the same context also complicates manners. This is because several factors such as socioeconomic statuses, capacities, vulnerabilities, and intrinsic properties shape the adaptive capacity of systems. Accordingly, there is no "one-size fits all" adaptation tool or NbaS. In response, an explanation of adaptation's complexity and its effects is presented in the chapter. The rationale behind this discussion is to pin-point that the design of NbaS should be based on sound scientific basis to avoid maladaptation and delivering disservices instead of co-benefits.

I. Introduction: Background and objectives

The international interest in both Climate Change Adaptation (CCA) and NbS is relatively recent (IPCC, 2014; Somarakis et al., 2019). The first was formally acknowledged by the UNFCCC as mitigation's equal in 2010 despite its emergence since 1994 (UNFCCC, 2019a, 2006). The second, i.e. NbS, received full attention during the early 2010s despite being introduced in the early 2000's (MacKinnon et al., 2008). Interest in NbS surged after the concept's uptake in the EU's research and innovation policy agenda, and its integration into the IUCN's 2013-2016 program (Cohen-Shacham et al., 2016; European Commission, 2015).

As both CCA and NbS had a more or less parallel evolution (post-2010s), a study of their transitions would logically reveal the shift towards NbaS. The rationale behind this statement is that NbaS can be summarized by the simple equation NbaS = NbS + CCA. Although theoretically simple, both components of the equation should be investigated for a proper understanding of NbaS. Accordingly, two lines of work emerge: the first aims to understand CCA, while the second studies CCA's integration into NbS for yielding NbaS. Understanding CCA is necessary for properly addressing the (A) in NbaS, while studying the transition from NbS and its associated concepts to NbaS reveals trends of international interest and the status of these solutions.
The main objective of this chapter is to establish an inventory on NbaS at the international level based on: the science behind these solutions, their chronological evolution, performance, state of knowledge, potential, and limits. Accordingly, readers will able to situate NbaS with respect to international agendas, study their timeline, and understand their evolution. On this basis, an explanation of the different NbaS types, climatic challenges, media of intervention, priorities, gaps and challenges are given. Ultimately, this chapter will highlight the lessons learnt from the work of several international organizations with time. By capitalizing on these results, clearer insights for designing efficient NbaS can be obtained.

The chapter is structured as follows: Section II presents the research methodology and explains the reasons underlying the choice of the IUCN's, UNFCC's and UNEP's works. Section III presents the timeline for each institution's reports and reveals the studied shifts. Part IV details the (A) in NbaS, while section V showcases results, highlights the lessons learnt and reveals additional findings. Finally, section VI concludes the chapter and proposes recommendations while discussing the way forward.

II. Materials and methods

The chapter was built in analogy to the study's Search, Filter, Extract and Analyze workflow. For the Search phase, the three document repositories of the IUCN (https://portals.iucn.org/library/), UNFCCC (https://unfccc.int/documents) and UNEP (https://www.unep.org/science-data) were used. For the IUCN, nature-based solutions was used as a keyword and the publication box was checked. Additional reports were obtained from the

IUCN's Commission on Ecosystem Management (CEM) database to complement findings (https://www.iucn.org/commissions/commission-ecosystem-management/resources/nature-based-solutions) and the climate change publications portal (https://www.iucn.org/theme/climate-change/events/iucn-unfccc/2019-madrid/climate-change-publications). The CEM was chosen as it is one of the most NbS active parties of the IUCN. For the UNFCCC, a particular focus was given on the adaptation aspect of NbaS. In addition to the documents repository, UNFCCC publications were accessed from the following page: https://unfccc.int/about-us/press-and-media/publications. For the UNEP, nature-based solutions was used as a keyword, the category of browsed documents was set to "reports and publications", while the topic "climate change" box was checked.

The reasons behind the choice of the IUCN's, UNFCCC's and UNEP's works are the following:

- The IUCN has been spearheading the NbS concept since 2009 (IUCN French Committee, 2019). With an active French committee, the analysis of IUCN inputs also provides a double-scale advantage by reflecting French national efforts and international trends simultaneously. It is also during the UNFCCC's Conference Of the Parties (COP) 15 that the IUCN actively promoted the NbS concept.

- In addition for being the most active UN body on climate change, the UNFCCC was chosen for the works of its adaptation committee. As NbS are studied under the UNFCCC, reports of this committee on the conceptual, technical and scientific angles of adaptation were used to tackle the (A) in NbaS.

- The UNEP is trusted by the UN to pave the way for the United Nations Decade on Ecosystem Restoration (2021-2030). Following the UN Climate Action Summit of 2019 held in New York, the UNEP was responsible of coordinating global efforts on NbS and explore the full potential of these solutions. As ecosystem restoration is a major dimension under the NbS and NbaS frameworks, the UNEP gives NbS and NbaS significant importance for the decade to come. Moreover, adaptation has been a central focus of UNEP with regular adaptation gap reports.

The filtering phase consisted of two steps, the first is a general approach where only reports and technical papers as document types were retained (grey literature excluding factsheets, media and press releases), and only material written in French or English was kept. The second filtering step was more specific and consisted of several criteria. First, the retained documents were checked for relevance to the study, and scanned through for the following keywords: *Nature-based solutions, ecosystem-based adaptation, urban green infrastructure, green solutions, ecosystem services, blue green solutions, ecological restoration, urban forests, green spaces, renaturing, ecological engineering, ecosystem-based mitigation, natural infrastructure, natural capital, ecosystem services, climate change and adaptation*. The aim of this step was to ensure that the retained reports surely contained the NbS-NbaS concepts or their associated notions, along with climate change. In the case of the UNFCCC, adaptation was the most stressed word as inputs of the adaptation committee were mostly sought. The second step was more specific and consisted of searching the reports for the occurrence of scientific or knowledge gaps. Accordingly, the documents were checked in detail to see whether they reported on gaps or not. A total of 95 reports were retained for the Extract and Analyze phase. The reports are distributed as follows: 21/24 from the IUCN, 29/38 from the UNFCCC and 45/58 from the UNEP. One additional report of the UNESCO was added given its relevance to water NbS, making the number of reports 96. Additionally, the two latest IPCC reports "Global warming of 1.5 °C – 2018" and "Climate Change and Land – 2019" were investigated to see if NbS-NbaS were mentioned. At no point do the Authors assume that their findings are not debatable. The Authors acknowledge that some sample-related errors may be inherent. However, the best possible measures were taken to avoid any unjustified assumptions and to ensure a minimal error margin.

III. An evolutionary timeline

A chronological analysis of each institution's reports was performed to study shifts and trends. A graphical timeline for the IUCN and UNFCCC highlighting important milestones is presented in Figure 1. For the UNEP, given the large number of reports and for display purposes, the list of reports is presented in Annex A.

Prior to coupling with NbS, reports of all three institutions tackled ecosystems abundantly and discussed Ecosystem-based Adaptation (EbA) to climate change. In certain ways, EbA is still very popular amongst CCA actions even until recent days. However, the years 2010 and 2015 were important milestones for all three institutions. The year 2010 marked the official international recognition of adaptation's importance (UNFCCC, 2019a), while 2015 marked the landmark Paris Agreement and the start of the post-2015 agenda phase. The Paris Agreement dedicated a complete article [Article 7] for adaptation (UN, 2015) and is considered as the most important pillar for CCA (Lesnikowski et al., 2017). The adoption of the Paris agreement reinforced the importance CCA and pumped life in the global interest for adaptation (UNFCCC, 2019a). In turn, the post-2015 agendas consisting of the Paris Agreement, the Sendai Framework on Disaster Risk Reduction (DRR) and the SDGs shaped global policymaking in the years to follow. The role of nature and ecosystems for CCA is amply stressed in the Paris Agreement and the Sendai Framework (OECD, 2020). While for SDGs, the contribution of nature, and particularly NbS were found to be essential for achieving all 17 goals (WWF, 2019). SDG 13 "Action on climate" is of particular relevance as it calls for strengthening the resilience and adaptive capacities of countries to climate-related hazards and natural disasters (UNDP, 2015). While many other agendas also target adaptation, these three not only aim to ensure CCA [Paris], but also to build back better [Sendai] and adapt forward [SDGs] (UNFCCC, 2017). This is mainly due to the interconnectivity between climate change, sustainable development and disaster risk reduction (UNFCCC, 2017).

With this evolution and as can be seen in the figures below, CCA related activities clearly increased after 2010 and 2015 for the IUCN and the UNFCCC. For the IUCN, the post 2015 period (simultaneous to the post-2015 agendas) also showed a pronounced increase of NbS for CCA. For the UNEP the year 2014 marked the start of the transition from emission gap reports to the adaptation gap reports series (UNEP, 2014). This reflects an increasing interest in adaptation now viewed with the same importance as mitigation. Three main gap areas were targeted since 2014: planning, financing and implementation[1]. The latest 2020 adaptation gap report (UNEP, 2021a) particularly stands out for the integration of NbS-NbaS as a main focus topic. The intensification of UNEP contributions in the post-2019 period can be attributed to: i) the 2019 UN Action Climate Summit of New York where the NbS manifesto was signed (UN Climate Action Summit, 2019) and ii) to the start of the UN decade on ecosystem restoration 2021-2030[2] co-led by the UNEP and FAO. As the contribution of nature was underlined throughout these timelines, the relevance of this evolution to the emergence NbaS is explained in the following section.

[1] https://unepdtu.org/project/un-environment-adaptation-gap-reports/
[2] https://wedocs.unep.org/bitstream/handle/20.500.11822/30919/UNDecade.pdf

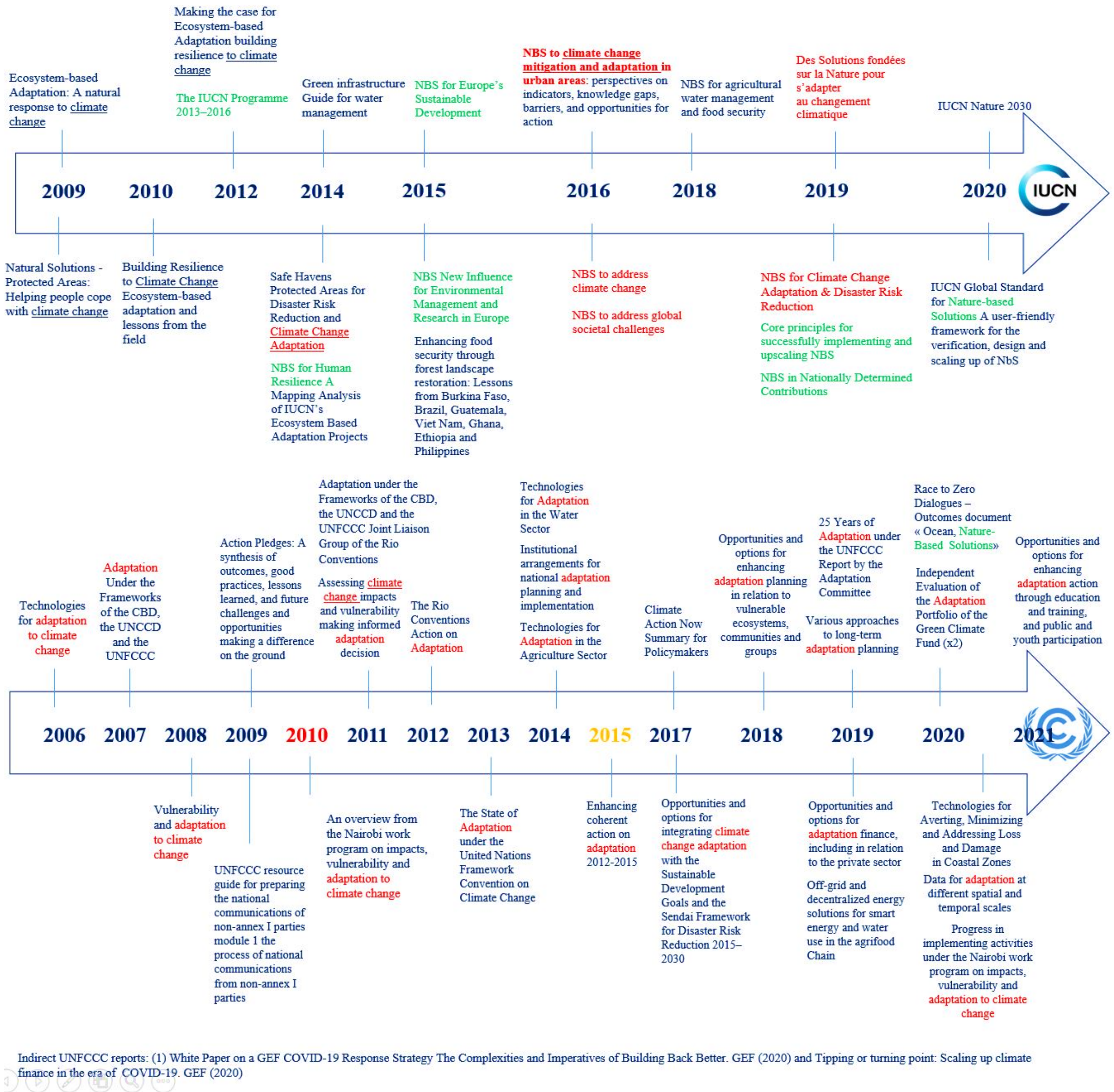

Figure 1: The IUCN and UNFCCC retained reports timeline; the red color refers to the time of appearance of climate change adaptation while the green color refers to the appearance of NbS. In the UNFCCC timeline the 2015 orange color refers to the Paris Agreement

III.1 Emergence of NbaS

Shades of NbS appeared as early as the 1970s under different names, most commonly as ecosystem-based adaptation in relation to ecosystem services (Norgaard, 2010). According to Potschin et al. (2016), the timeline of NbS' appearance as a strict term can be itemized into three major phases: (a) early 2000s as solutions to agricultural challenges, water resource and land management, (b) mid 2000s as industrial design tools and (c) from 2009-onwards as potent tools for building resilience against climate change (among other challenges). Institutionally, IUCN has been spearheading the international recognition and development of the NbS concept since 2009 (IUCN French Committee, 2019). With respect to the IUCN timeline, climate change appeared since 2009 and 2010 associated to EbA. As of 2012, NbS [in strict terms] were integrated as responses to climatic, food and development challenges in the IUCN's 2013-2016 programme (IUCN, 2012). However, EbA and EbM (EbMitigation) were advanced as the NbS to climate change then (IUCN, 2012). As of 2014 and onwards, NbS started to appear in reports' titles under different themes. Concurrently, the French IUCN committee initiated work on the contribution of NbS to climate change adaptation (implicitly NbaS) and mitigation (UICN, 2015). As of 2016, NbS for climate change adaptation started to regularly appear along with several works targeting the development of the NbS framework/concept. During the same year, the French IUCN committee contributed to resolution 22 of the NbS definition, and recommended their integration into climate change planning (Delangue, 2019). Nonetheless, EbA is still a favored approach and frequently appears within the same reports. A comparison between Cohen-Shacham et al. (2016) IUCN and the IUCN French Committee's (2019) reports shows the following difference (Figure 2):

Category of NbS approaches	Examples
Ecosystem restoration approaches	Ecological restoration Ecological engineering Forest landscape restoration
Issue-specific ecosystem-related approaches	Ecosystem-based adaptation Ecosystem-based mitigation Climate adaptation services Ecosystem-based disaster risk reduction
Infrastructure-related approaches	Natural infrastructure Green infrastructure
Ecosystem-based management approaches	Integrated coastal zone management Integrated water resources management
Ecosystem protection approaches	Area-based conservation approaches including protected area management

Nature-based Solution Category	Examples of associated approaches
ECOSYSTEM RESTORATION	Ecological restoration Ecological engineering Forest landscape restoration
ECOSYTEM-BASED MANAGEMENT	Integrated coastal area management Integrated water resource management
ECOSYSTEM PROTECTION	Conservation including protected area management
ISSUE-SPECIFIC	Ecosystem-based adaptation Ecosystem-based mitigation Ecosystem-based risk reduction
INFRASTRUCTURE	Green infrastructure

Figure 2: Difference between Cohen-Shacham et al. (2016) IUCN and the IUCN French Committee, 2019 reports for climate adaptation services

As can be seen, Climate Adaptation Services (CAS) under issue-specific NbS do not appear after the 2016 report. This could be due to the fact that the latter is used as a synonym to EbA despite that it's broader (Lavorel et al., 2015 *in* Cohen-Shacham et al., 2016). It could be also be attributed to the umbrella nature of the NbS concept particularly for climate change applications (Seddon et al., 2019). However CAS appear again in Cohen-Shacham et al., (2019). The fact that NbS is still "*a young concept"* (Cohen-Shacham et al., 2016) may bring some difficulties in its attributions and interpretation, let alone for NbaS. For that reason, the IUCN (2020) set guidelines for clearly separating between what is a NbS and what is not. The same report calls for adaptive governance and flexibility which were found by Cohen-Shacham et al. (2019) - among other factors - as rarely captured or sufficiently detailed in the NbS framework. While the NbS framework is still a matter of studies, from what was presented the emergence of NbaS (in strict terms) under the IUCN can be dated back to 2014. According to Seddon et al. (2019), NbS have a pivotal role for addressing both the reasons and results of climate change. They do so by reducing socioeconomic exposure, decreasing socioeconomic sensitivity and supporting adaptive capacities (Seddon et al., 2020). The stratification of climate change into various challenges necessarily means that addressing CCA will have positive cascading effects. Therefore, for a solution to be considered as an NbS (also NbaS), it should respond to a societal challenge (here climate change) while promoting biodiversity. Regardless of their recent inception, they are trusted as the way forward for the IUCN and significant efforts are being implemented for promoting their uptake.

The emergence of NbaS in the UNFCCC is tightly bound to the evolution of adaptation to climate change. The latter was long described as mitigation's poor cousin and started to receive its well-deserved attention not long ago (Pielke et al., 2007). Under the UNFCCC, this acknowledgment goes back no longer than 2010 after three years of considerable debate (UNFCCC, 2019a). The transition towards adaptation is explained in details in the section **Adaptation under the UNFCCC.** However, in NbS-NbaS terms, COP 15 of the UNFCCC marked the first international station for NbS where the IUCN introduced the concept. As the Paris Agreement falls under the UNFCCC mandate, the call for using NbS for CCA (even indirectly) can be dated back to 2015. Articles 5.2 and 7.1 are the most related, while several references to the role of nature and ecosystems are made throughout the agreement (UN, 2015). The UNFCCC places NbS (implicitly NbaS) under the hardware (physical intervention) component of adaptation technologies (UNFCCC, 2020a, 2014a). Accordingly, NbS correspond to the "tools" needed for achieving CCA. The importance of NbS for addressing many environmental challenges, namely climate change and the water-energy-food nexus, is also rising in prominence and more research on this topic has been recommended by the UNFCCC (2020b). As for the IUCN and UNEP, EbA's importance and potential are also underlined and the concept seems to be widely promoted. In terms of funding, the climate funds of the UNFCCC are considered as some of the most important financial sources for upscaling NbS and NbaS. Many funds were accorded to this type of projects and increased reporting on NbS for CCA is apparent in Nationally Determined Contributions [NDCs] (Seddon et al., 2019). According to the same reference, at least 66% of the Paris Agreement's signatories included NbS for climate change adaptation (implicitly NbaS) or mitigation in their NDCs. To that end, the increasing role of NbaS' importance is underlined.

The intensification of UNEP contributions in the post-2019 period is attributed to the 2019 UN Action Climate Summit of New York, where the NbS manifesto was signed (Nature-based Solutions Coalition, 2019; UN Climate Action Summit, 2019). During the summit, the potential of NbS for climate action (including NbaS) was officially unlocked (UN Climate Action Summit, 2019). The initiation of the UN Decade on Ecosystem Restoration 2021-2030 (UN, 2019) co-led by the UNEP and FAO catalyzed further the UNEP's efforts. As restoration is a fundamental approach of the NbS framework, one of the several aims of rehabilitating ecosystems is to help societies adapt to climate change[3]. At this level, the role of NbS for CCA is particularly relevant, hence their contribution to the upcoming decade. On the other hand, the 2020 Adaptation gap report is the first NbS for climate change adaptation devoted outcome. The report reveals that NbS for CCA (implicitly NbaS) have been steadily growing since the early 2000s. However, there are evidence that this expansion may be slowing (UNEP, 2021a). For the UNEP (2021a), the role of NbS for CCA is pivotal, and its associated multi-benefits are needed for simultaneously responding to several challenges. As for the IUCN, the stratification of climate change into various challenges necessarily means that promoting CCA will have positive cascading effects. For that reason, the UNEP highlighted that these solutions must receive immediately increasing attention. However, EbA is also strongly advocated for and is favoured among the approaches to CCA. Regardless of the solution, the UNEP underlines that research is needed for focusing efforts on the multidimensional, spatial and temporal nature of climate change (UNEP, UNDP and the IUCN 2012). For the UNEP, NbaS have recently occupied an important position under the microscope, and significant efforts are being implemented for tapping their complete potential.

The recent emergence of NbaS (less than 10 years ago), along with the parallel evolution of adaptation, reflect growing notions. To this end, the three institutions converge on the fact that further research is needed for properly

[3] https://wedocs.unep.org/bitstream/handle/20.500.11822/31813/ERDStrat.pdf?sequence=1&isAllowed=y

unlocking these solutions' potential. For articulating this point, a state of the art on NbaS is presented in the following sections.

IV. On the (A) in NbaS

Having explained the timeline of NbS events, concepts, and transitions, a focus on adaptation is presented in what follows. The aim of this section is to highlight the conceptual approach to adaptation and to reveal how the concept is addressed by the three institutions. Generally, all three converge on the fact that adaptation is a dynamic and highly complex process bound by uncertainties. However, the way adaptation is approached may sometimes differ from one institution to the other. Accordingly, an overview of each is presented in what follows.

IV.1 Adaptation under the IUCN

The IUCN acknowledges that climate will continue to change despite ongoing mitigation efforts, hence the need for adaptation (IUCN, 2014). Under the IUCN, adaptation is addressed through the definition of the IPCC (2014) as reported by (Rizvi and Riel, 2014): *"Adjustments in natural or human [social and economic] systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities*". It is also referred to as "*the adjustment of natural or human systems in response to actual or expected stimuli*" (IUCN, 2010) and approached as the ability to live with changes and build resilience (IUCN, 2010). Under the IUCN glossary, adaptation is also defined as: *"Initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects. Various types of adaptation exist, e.g. anticipatory and reactive, private and public, and autonomous and planned."*[4] For supporting adaptation, the IUCN specifically concentrates on the potential of biodiversity (ONERC, 2019), on ecosystems through EbA (Rizv, 2014), and also on NbS (Cohen-Shacham et al., 2016). In France, the national IUCN committee has been focusing on NbS for CCA (NbaS) since 2014 (UICN, 2015). Progressively, efforts have led to the uptake of these solutions into public policies since 2018 (ONERC, 2019). Despite these facts, the IUCN acknowledges that planning for adaptation and designing adaptation responses are not easy. In various sources, the IUCN refers to adaptation as complex, challenging, and uncertain process. The concepts of vulnerability, resilience, recovery, and sensitivity underline adaptation for the IUCN (Rizv, 2014), particularly for biodiversity (IUCN, 2010). In the same manner, climate resilience is tightly bound to that of ecosystems and associated ecoservices (Rizv, 2014).

The most commonly mentioned challenges are:

- The absence of clear guidelines and conceptual frameworks for scoping adaptation (IUCN, 2010).

- The difficulty of understanding how adaptation functions and what its implications for resilience are (IUCN, 2010).

- The absence of clear adaptation thresholds and synergies between adaptation and mitigation actions (Dudley et al., 2010; Rizvi and Riel, 2014; Seddon et al., 2019).

- The need for clearer frameworks and guidelines for the quantification of vulnerabilities (IUCN, 2010; Seddon et al., 2019).

- The need for capacity building on CCA to ensure a homogenous discourse on climate change (IUCN, 2014).

- The uncertainties associated to climate change (emission scenarios), climate variability, tolerance thresholds and the uncertain impacts of a changing climate (Colls et al., 2009; IUCN, 2010; Rizvi and Riel, 2014).

- The uncertainties regarding the response of ecosystems and eco-processes to climate change, and the intangibility of eco-sociological inflection points (IUCN, 2010).

- The absence of metrics and indicators for quantifying adaptation and its outcomes (Rizv, 2014). Thus the need for more evidence on the effectiveness of adaptation measures (Rizvi and Riel, 2014). In addition, most adaptation targets under current form are of qualitative nature (Seddon et al., 2019), hence the need for more quantifiable goals.

While adaptation is a central element for the IUCN, the concept is approached from a more operational/technical point of view for promoting the successful design and implementation of EbA measures and NbS. Adaptation is often highlighted as an important societal-developmental challenge that EbA and NbS can respond to, but it is rarely discussed as a distinct process. It is frequently associated with ecosystems (healthy, managed or restored) to highlight their strategic potential for CCA, or to discuss their vulnerabilities and how they can adapt themselves to changes.

[4] https://www.iucn.org/sites/dev/files/iucn-glossary-of-definitions_en_2021.05.pdf and IUCN (2020): Guidance for using the IUCN Global Standard for Nature-based Solutions.

Adaptation is also considered as a cornerstone for promoting ecosystemic resilience and reducing vulnerabilities, but very few discussions on its limits and effects on risk levels are given. While the IUCN calls for adaptation measures that combine risk prevention, risk mitigation and risk transfer (IUCN, 2014) the uncertainty associated with each step is a considerable challenge. The approach of the IUCN goes in the sense of tangibly building CCA using conceptual knowledge on the importance of biodiversity, ecosystems and nature-based capital (IUCN French Committee, 2019). Accordingly, the IUCN can be considered as the builder of NbS for CCA.

IV.2 Adaptation under the UNFCCC

The history of adaptation under the UNFCCC reflects the global interest in the process. When the UNFCCC came into operation in 1994, its primary focus was on greenhouse gas mitigation while the idea of adapting to human-induced climate change wasn't very popular (UNFCCC, 2013). The underlying logic was that addressing adaptation would undermine the capacity of human and natural systems to adapt, and take away the attention from the urgent need to curb emissions (UNFCCC, 2019a). With advances of climate sciences and following the IPCC's (2007) acknowledgment of adaptation's importance, adaptation finally gained equity with mitigation in 2010 after three years of debate (UNFCCC, 2013). During the same year, the Adaptation Committee was established and adaptation became a central pillar of action on climate (UNFCCC, 2019a). Under the UNFCCC, adaptation is addressed following the IPCC's (2014) principle: "*Adjustments in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts. It refers to changes in processes, practices, and structures to moderate potential damages or to benefit from opportunities associated with climate change*". Through the various national action plans, work programmes, nationally determined contributions and adaptation committee findings, the works of the UNFCCC allow a three-fold approach to adaptation (i.e. conceptually, scientifically and implementation wise). This is particularly made possible through the transition of adaptation thinking in the UNFCCC from "do we need to adapt?" to "how do we adapt?" and to "how do we integrate adaptation into relevant social, economic and environmental policies and actions?" (UNFCCC, 2019a). The Paris agreement in 2015 further added the question "how can we scale up adaptation actions in a holistic and nationally determined yet collectively ambitious manner?" (UNFCCC, 2019a). Accordingly, following this transition different insights can be obtained.

Conceptually, the UNFCCC (2010) describes two types of adaptation: planned and autonomous. The first is put into action before the effects of climate change become tangible. The second is not an intended reaction to a climatic stimulus, but is rather due to changes in the ecology of natural systems or a modification within human systems (UNFCCC, 2010). Adaptation is also characterized by the UNFCCC as: i) actions that climate proof activities through the integration of potential long-term climate risks, ii) actions that promote the adaptive capacity of activities and sectors for dealing with present and future climate risks and iii) actions that clearly target the impacts of climate change in response to the process (UNFCCC, 2008a *in* UNFCCC 2010). The notion of adaptive capacities complements the exposure and the sensitivity of a system in shaping its vulnerability to climate change (UNFCCC, 2008b). Concerning coping capacities, adaptation enhances these properties by modifying tipping points, hence contributing to the reduction of vulnerability to climate change (UNFCCC, 2010). However, insufficient knowledge on current/anticipated impacts and vulnerability is a limiting factor for adaptation planning (UNFCCC, 2009). To that end, the line of separation between risk identification/vulnerability assessments and adaptation planning is not clear as the latter mostly starts with the formers (UNFCCC, 2009). Most vulnerability assessments are constrained within the 2030-2100 period, it is therefore logical to suppose that many socioeconomic and natural conditions will vary at different rates throughout this period (UNFCCC, 2008b). According to the same reference, it is appealing to simplify this complexity by assuming that any adaptation plan will cover current social and natural conditions (i.e. constraining it to the present). Nonetheless, this would not reflect realistic conditions since the vulnerability to climate change and adaptation efficiency may also change with time (UNFCCC, 2008b). As for exposure degrees, these are in harmony with vulnerability and interactions with hazards, and combine to give climate risks a composite nature (UNFCCC, 2020). In response, transformational adaptation has emerged throughout the years (Fedele et al., 2019). As opposed to incremental adaptation, transformational adaptation tends to focus on the long-term changes of climate rather than short-term improvements while accounting for uncertainties (UNFCCC, 2019b). However, there aren't common definitions or comprehensions of what this adaptation is (UNFCCC, 2019b). Regardless of the type of adaptation, the dynamic nature of climate risks and climate change calls for a progressive, dynamic and cyclical adaptation process (UNFCCC, 2018; UNFCCC, 2020). Further, the uncertainties of climate change and its effects, in addition to the complexity of socio-eco-political systems make of adaptation a social learning, knowledge demanding, exhaustive site-specific phenomena (UNFCCC, 2009).

In terms of scientific approaches and implementation, the UNFCCC set a roadmap for an effective adaptation to climate change. Yet, it is important to consider that no one size fits all approach to adaptation is possible (UNFCCC, 2019b). Each action is specific, and depends on the scales, sectors, contexts, and stakeholders considered (UNFCCC, 2010). In addition, the transversal nature of adaptation across different sectors, rather than being constrained into one medium implies a multitude of challenges and stakeholders (UNFCCC, 2006). According to the UNFCCC (2019a) and the UNFCCC (2020), the steps[5] below are required adaptation are required, each one is burdened by several challenges and is listed in what follows:

1- Assessing of the impacts, vulnerabilities, risks and resilience: determine the current and future effects of climate change on human and natural systems, along with an assessment of the latters' capacity for coping with and adapting to these changes. One of the earliest challenges to adaptation at this stage is the gaps in adaptation data (UNFCCC 2020).

2- Planning for adaptation: based on the findings from the first step, the candidate adaptation measures should be assigned and evaluated for efficiency and feasibility. The aim should be to avoid repeating previous measures, to have a sustainable development orientation, and to circumvent undesirable effects. Planning allows to address the effects of both climate change and human activity impacts on the short and long-term (UNFCCC, 2020a), but should be done at various spatial scales (UNFCCC 2020). However, the inconsistencies between projected and observed measures, as well as the nature of climate change enlarge uncertainties as the spatial scales becomes finer [country-region-watershed] (UNFCCC, 2010).

Gaps found in the first two phases have a cascading effect on the following steps, therefore, the planning stage might time consuming in order to ensure a smooth transition to the following phases (UNFCCC, 2021).

3- Implementing the adaptation plan: once the plan is set the implementation phase follows. This step does not only refer to physical applications but also to policies, strategies, projects, programs, budgets, etc. At this stage, the concept of adaptation technology can come into play. The (UNFCCC, 2020a, 2014b) classifies these technologies into three types: hardware (physical implementation-applications), software (the process, know-how and knowledge) and orgware (institutional and governance settings). Despite the importance of all three categories, there are apprehensions regarding the application of hard technologies in isolation to others, as their intended outcomes are prioritized over software and orgware (UNFCCC, 2014c).

4- Monitoring and evaluating adaptation: this is the final step of the roadmap and aims to track progress and outcomes. Despite its importance, this phase hasn't been sufficiently addressed and is mostly challenged by the site-specific nature of adaptation (UNFCCC, 2015). Measuring outcomes and their variables from adaptation projects holds more uncertainties than other types of projects (UNFCCC, 2021).

All four steps require the integration of socioeconomic and climatic data at different timesteps (historical, current and future data). Observational data is particularly needed for properly calibrating the approach and providing a baseline for comparison (UNFCCC, 2011, 2020). However, qualitative and estimated data are also required: qualitative data serve to understand intangible elements such as perceptions, experience, etc. while estimations are needed for predicting future climatic and socioeconomic conditions (UNFCCC, 2020). Nonetheless, the integration of socioeconomic data into adaptation plans is often absent; even when integrated, it isn't always adequately useful for decision making purposes (UNFCCC, 2010). Also, the inconsistencies between projected and observed measures, as well as the nature of climate change enlarge the uncertainties as the spatial scales becomes finer (UNFCCC, 2010). Accordingly assessments may considerably vary depending on the study's subject [e.g. an agricultural system, or infrastructure] and spatio-temporal extent [e.g. harvesting season of a parcel, or the lifetime of a road network] (UNFCCC, 2011). Finally, climate and weather extremes remain significant knowledge gaps that should be addressed (UNFCCC, 2020). In response to these challenges, climate services was created as a concept to bridge between scientifically issued data and the demand of end users for adaptation decision making (UNFCCC, 2020). However, it is still an emerging field and lacks concrete coordination, but appears to be promising once developed (UNFCCC, 2020). For that reason, coping with a certain degree of error is inevitable.

The work of the UNFCCC clearly highlights the complexity of adaptation. It goes to show that designing the (A) in NbaS will require significant efforts. With conceptual challenges and knowledge gaps, research on adaptation is needed for providing informed adaptation decisions (UNFCCC, 2011). While NbS take part of the hardware technologies of adaptation (UNFCCC, 2020a) and correspond to phase 3 of the adaptation roadmap, significant efforts are needed form phases 1 and 2 before arriving to NbS. In the case of NbaS the manner is further complicated by the need to address the software and orgware parts also that are often limiting factors in NbS approaches. The UNFCCC's approach to adaptation can serve as a guideline for designing, conceptualizing and preparing NbaS.

[5] All these elements are reported from the Adaptation Committee's 2020 technical paper on data for adaptation at different spatial and temporal scales, and the committee's report 25 years of adaptation under the UNFCCC.

Interestingly, a high degree of similarity between the roadmap and roadblocks of adaptation and NbS is prevalent. This will be discussed in later sections for highlighting the role of NbaS as a crossroad for various disciplines.

IV.3 Adaptation under the UNEP

The UNEP endorses adaptation in its science-based environmental policy. It is also a component of its climate change efforts (among others), and ranks first in the its six areas of concentration (UN, 2013). With its coordination of several adaptation projects around the world, the works of the UNEP allow a three-fold approach to adaptation from conceptual, scientific and technical/implementation aspects.

Conceptually, adaptation under the UNEP is addressed according to the IPCC's (2014) principle: "The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects". However, the UNEP (2017) highlights that the absence of a global definition for adaptation, and its subjective context-specific interpretations are some of its main drawbacks. Accordingly, adaptation is very site-specific (UNEP, 2021a, 2021b) and is sometimes perceived as an environmental problem rather than a developmental concern (UNDP, UNEP, the World Bank and WRI, 2011). As for the IUCN and the UNFCCC, UNEP believes that adaptation reduces vulnerabilities by increasing coping/adaptive capacities and promoting resilience (Doswald and Estrella, 2015; UNEP, 2021a, 2017). As adaptation consists of or targets several underlying concepts, an investigation of each component was carried out. Accordingly, vulnerability under the UNEP is defined following the IPCC's (2014) terminology as the susceptibility of a system to adverse effects (UNEP, 2014). It is the result of site-specific impacts and underlying sensitivities, in addition to the reigning socio-economic-environmental conditions (UNEP, 2017). The heterogeneous nature of its underlying factors makes vulnerability a dynamic, cross-cutting, and interactive concept (UNEP, 2014), hence its difficulty. Adaptive capacities are addressed as the capacity to learn, cope and ultimately carry on functions while adapting (UNEP and UNEP-WCMC, 2019a). The widely debated resilience concept is traced back by the UNEP to the 1970s under the discipline of ecology[6] (UNEP and UNEP-WCMC, 2019a). Following the IPCC's (2014) definition of resilience, the UNEP refers to adaptation as the management of a system's resilience by sustaining its functions in manners that circumvent losses in the future (Nelson, 2011 in UNEP, 2019b). In some cases resilience is perceived as the opposite of vulnerability, while in others it is considered as an element for reducing vulnerability (Doswald and Estrella, 2015). All three concepts, i.e. vulnerability, adaptive capacities and resilience, as well as climate change, are of inherent nature (UNEP, 2017). Accordingly, the complex nature of each component makes adaptation a conceptually multifaceted challenge (UNEP, 2017).

In terms of scientific approaches: Despite its consideration as a response to a specific type of climate risks in a given setting and time, the magnitude and heterogeneous distribution of adaptation require a global approach (UNEP, 2017). For that purpose, scientific literature on adaptation has been increasing since 2016 with more than 10,000 articles per year (Callaghan et al., 2020 *in* UNEP 2021b) . However, most of these studies are conceptual and do not empirically document concrete applications (UNEP, 2021a). While CCA originates from environmental sciences (Doswald and Estrella, 2015), its transversal nature across various disciplines makes silo approaches insufficient. Similarly to the IUCN and the UNFCCC, the UNEP underlines that the absence of robust adaptation targets, metrics and evidence are a major hurdle to overcome (UNEP, 2021a). To that end, further research on the progression of climate risks and vulnerabilities are needed for more quantitative evidence (UNEP, UNDP and IUCN, 2012). Accordingly, adaptation tracking emerged as a research discipline that aims to: i) complement monitoring and evaluation efforts through the provision of scalable, systematic and replicable methods and ii) simplifying adaptation's complexity (UNEP, 2017). A significant scientific gap is also the need to relate and understand the actual [not only expected] future benefits of adaptation for risk reduction (UNEP, 2021a). However, this line of research is still in its embryonic stage (UNEP, 2021a), despite the significant scientific efforts for developing related quantitative approaches (Challinor et al., 2014 *in* UNEP, 2014).

In terms of implementation, despite the urgency for adaptation and the recent momentum behind it, adaptation projects are still not in place to realize concrete reductions of climate risks (UNEP, 2021a). This could be due to several reasons. First, effective adaptation interventions for promoting long-term resilience fundamentally depend on: i) a transversal understanding of the dependencies and interlinkages within socio-ecological systems, and ii) on the interactions of climatic and non-climatic degradation processes (UNEP and UNEP-WCMC, 2019b). Second, adaptation interventions need to address current negative impacts and help deal with future climatic changes (UNEP and UNEP-WCMC, 2019a), hence a multi-dimensional challenge. Finally, effective adaptation plans often require

[6] Refer to Holling, C.S. (1973) 'Resilience and stability of ecological systems'. Annual Review of Ecology Systematics 4: 1-23

the implementation of several adaptation measures rather than one (UNEP and UNEP-WCMC, 2019c). The underlying nature of climate change itself adds another layer of complexity. According to the UNDP, UNEP, the World Bank and WRI (2011), recent evidence shows that many climatic impacts are not advancing linearly. This means that some incremental changes may become irreversible processes in later stages and provoke greater losses (IPCC, 2014). The high complexity of natural systems adds more difficulties as the overlap between human activities, climatic and non-climatic stressors complicates manners further (UNEP, 2011). The combination of conceptual and scientific challenges exacerbates difficulties for implementing effective and evidence-based adaptation projects. Accordingly, the complexity of adaptation as a concept, a scientific discipline and a physical application is apparent.

An inventory of challenges facing adaptation as extracted from UNEP's work is presented below:

- The burden of uncertainties[7] significantly hampers adaptation efforts. The UNEP (2019a) lists five types of uncertainties that adaptation should deal with. These are scientific, technical, socioeconomic, financial and political. The scientific uncertainties are those associated to climate change projections particularly at fine scales. Technical uncertainties are related to the efficiency of the proposed measures for reducing vulnerabilities at both the short and long-terms. The socioeconomic, political and financial uncertainties relate to the public acceptance, available funds, political framework and social characteristics of the studied contexts.

- Even when set, adaptation goals often lack lucidity in terms of climate risk reduction at both the short and long-terms (UNEP, 2021a).

- The absence of unequivocal and measurable metric(s)-indicator(s) hampers the conversion of adaptation goals into quantifiable targets or baselines (UNEP, 2021a). This challenge is particularly amplified in the case of global adaptation approaches.

- Although two types of metrics (descriptive and evaluative) were described by the UNEP (2017), the same report states that no globally approved adaptation assessment framework exists yet.

- Adaptation values tend to show swiftly decreasing returns (UNEP, 2020a) and evidence on reducing vulnerabilities are very scarce (UNEP 2017).

- Even when outcomes are tracked, evaluating their progress is difficult due to the absence of a scientific understanding on the impacts of adaptation responses on climate risk levels (UNEP, 2021a). The study of climate risk levels is complicated by their challenging assessment under different warming scenarios, thus making the comparison of current adaptation outcomes with future risk reduction results very difficult (UNEP, 2021a). Supposing that an agreement on risk level is possible, the threshold of acceptability will be very different given the intrinsic biophysical and socioeconomic characteristics of each context (UNDP, UNEP, the World Bank and WRI, 2011). Tipping thresholds are also grey zones and significant efforts are needed for identifying them.

- The above-mentioned complexities in addition to the associated uncertainties can be summarized by the Adaptation equation reported in UNEP (2019a) as:

The adaptation challenge = determining risks of climate change at different timescales + accounting for uncertainties + choosing, designing and implementing measures that are in turn resilient to climate change and tailored to local conditions

The UNEP's approach to adaptation offers many insights and flags up several elements. These findings can serve as a roadmap for successfully designing adaptation measures or interventions, and particularly NbaS. The above equation summarizes elements that were also highlighted by the IUCN and the UNFCCC. Its components can be classified into three large groups that are similar to the UNEP's line of work (i.e. conceptual, scientific and executive). The risks of climate change and uncertainties fall under the conceptual and scientific categories. Both are interdependent and the second is often associated to the first. To that end, risk levels and uncertainties require further research efforts. Nonetheless, given the transversal nature of climate change, risks and the multiplicity of factors shaping adaptation, a combination of physical and social sciences is needed. Even when risk levels at different timescales are well established, the uncertainty dimension is a considerably challenging factor to deal with. Ideally, uncertainties can be reduced but never removed. As many factors determine the degrees of uncertainty, confidence levels are hard to determine and at best only estimates can be given. In terms of implementation, the last component of the equation should be based on scientific and conceptual knowledge to derive its executive nature. At this stage, NbS-NbaS as part of the undertaken measures should withstand the full range of temperature increases (UNEP, 2021a) in addition to other climatic manifestations. As local characteristics and site-specific features should be considered,

[7] These uncertainties are adapted from the UNEP (2019) navigating the adaptation challenge report.

no “one-size fits all” approach to adaptation can be expected. Once again, the complexity of adaptation goes to show that the (A) in NbaS will require very significant efforts and can only stem form extensive research answers.

Post scriptum: the relationship with mitigation

While mitigation is not the scope of this chapter, a discussion of adaptation cannot be undertaken without reference to mitigation. All three institutions converge on the fact that adaptation and mitigation are complementary and mandatory. According to the UNFCCC (2006), mitigation is essential while adaptation is inevitable. This is due to the fact that failed mitigation will cause inefficient adaptation, while adaptation will always be needed even if present days emissions are reduced (UNFCCC 2006). Logically, better mitigation means less difficulties for adaptation (UNFCCC, 2021). Most adaptation technologies are more familiar than those of mitigation because adaptation can be considered as a continuity of an ongoing process (UNFCCC 2006). While mitigation is more quantifiable than adaptation (UNEP, 2021a), the inertia of the climate system goes in the sense of continuous changes despite efforts (IUCN, 2014). The multitude of media involved in adaptation, rather its concentration on energy only, also make adaptation much more complex than mitigation (UNFCCC 2006). This relationship under the NbS framework is also translated by different interests and several findings. A corresponding discussion is presented in following sections.

The resilience-adaptation quandary

As can be noticed, the term resilience is present throughout the different sections and under the work of each institution. Different concepts have been explained throughout these paragraphs, namely vulnerability, adaptive capacities, coping capacities, sensitivity, recovery, including resilience (refer to the previous sections). However, resilience and adaptation are quite sensitive issues because the latter is susceptible of promoting and undermining the former at the same time (Nelson, 2011). Under the climate change scope, both concepts show pronounced differences (Leggett, 2021). Generally, climate change response strategies are often considered to require resilience OR adaptation (Wong-Parodi et al., 2015), i.e. a sort of separation-competition between the two concepts. Globally, adaptation is sought for coping with (adapting to) the implications of climate change, while resilience is sought to develop the capacity of withstanding the threat. Accordingly, adaptation is a process, while resilience is a capacity (Leggett, 2021). In the IPCCC’s definition of resilience, a great deal of importance is given to the amount of change that a system can withstand; thus making resilience close to the notion of coping ranges (Levina and Tirpak, 2006). According to the same Authors, other scholars relate the concept of resilience to adaptive capacities since it concerns the ability of a system to withstand changes. To this end, adaptive capacities are referred to by some experts as an umbrella term that is influenced by resilience (Levina and Tirpak, 2006). Arguably, adaptation helps a system absorb shocks while resilience helps the system to do so and to continue despite the changes. In literature, the resilience-adaptation vacuum is very large and polarized. This could be due to the fact that adaptation and resilience have emerged from different research disciplines (Nelson et al., 2007) and under dissimilar problem contexts (Nelson, 2011). However, one might argue that resilience is needed for managing systems in a flexible (i.e. adaptive) way. Yet these flexible (adapted) systems must also find the capacity and to go on with their functioning (Nelson et al., 2007) [i.e. resilience] and even take advantage of the occurring changes. In climatic terms, managing a system requires a certain orientation towards flexibility [adaptation] and towards seeking opportunities from changes [adaptive resilience] (Nelson et al., 2007). Therefore, resilience can be considered as a means to broaden the reach of adaptation, hence the intersection zone between both concepts (Nelson et al., 2007).

In light of what was presented in the previous and current sections, the relevance of resilience to CCA can be summarized (not completely) by the following scheme in Figure 3:

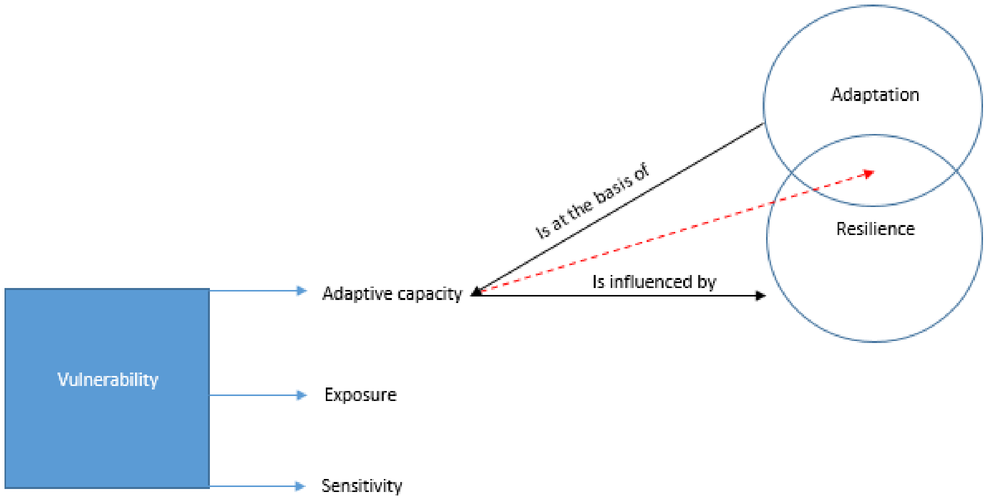

Figure 3: The intersection of resilience and adaptation concepts

Concluding remarks

The UNEP's and UNFCCC's approaches can serve as backgrounds for the (A) in NbaS. While the IUCN spearheads the concept of NbS for adaptation to climate change, inputs and guidelines from the UNEP and the UNFCCC are necessary for successfully integrating the adaptation dimension. The aim of this section was to focus on adaptation in NbaS by studying institutional findings. While there are some differences among the three institutions, a general consensus on the complexity of adaptation is apparent. Its iterative nature makes it a dynamic, uncertain and complex phenomenon. Nevertheless, uncertainties should not be used as excuses for inaction, but instead should be taken into consideration for building successful adaptation measures [herein NbaS] (UNDP, UNEP, the World Bank and WRI 2011). Many of the listed elements can be responded to by practice-oriented research (Swart et al., 2014). However, an approach analogous to the dynamic nature of adaptation should be adopted. Therefore, a certain degree of flexibility for "adapting to adaptation" should always be considered.

Despite the urgent need for NbaS, the integration of adaptation into the NbS framework is a considerable challenge. This stems from the fact that adaptation carries many burdens that will compound those of NbS once integrated within. The latters are explained in the course of the following section to ensure a complete analysis of the NbaS framework.

IV.4 Links between CCA, DRR and NbaS: the post-2015 agendas

The latest IUCN guideline on NbS (IUCN, 2020) indicated that Disaster Risk Reduction (DRR) and CCA are among the seven societal challenges that NbS respond to. DRR and CCA are often associated together since most hazards are climate induced (IUCN, 2014). Around three quarters of disasters are weather and climate-related, and this percentage is expected to grow with the progression of climate change (UNFCCC, 2009). The association of CCA and DRR was clear throughout all the retained reports as NbS were used to address both processes together and/or separately. Yet, EbA seemed to be the most popular approach for the purpose with fairly recent references and projects (Nehren et al., 2014). The prominence of EbA can be attributed to the insufficient research efforts on DRR-NbS (UN World Water Assessment Programme and UN-Water, 2018) and also to:

- The concept of "resilience" and its status as common grounds between CCA [Paris Agreement], sustainable development [SDGs Agenda] and DRR [Sendai Framework] (UNFCCC, 2017). As resilience is known to be a key element addressed by ecosystems and their services, the EbA and ecosystem-based disaster risk reduction (EcoDRR) approaches come into play (Cohen-Shacham et al., 2016).

- The first was developed by the climate change community, while the second was developed by DRR practitioners (Doswald and Estrella, 2015). EbA dates back from the 1970s (Norgaard, 2010), while Eco-DRR first made its appearance in a 2009 IUCN publication (Sudmeier-Rieux et al. 2011 *in* Cohen-Shacham et al. 2016).

- By definition, EbA encompasses the **sustainable management**, preservation and restoration **of ecosystems** for CCA[8], while Eco-DRR functions through one of these approaches: i) **sustainable use and management of natural**

[8] https://www.iucn.org/downloads/iucn_position_paper_eba_september_09.pdf

resources, ii) protection and conservation of healthy ecosystems for risk reduction and iii) restoring degraded ecosystems for reducing risks (Monty et al., 2016). It utilizes EbA and EbMitigation, but also extends beyond climate-induced hazards and can target other events (Cohen-Shacham et al., 2016). From the definition of both, the relevance of ecosystem sustainable management for attending to CCA and DRR can be noticed (IUCN, 2014). Operationally, EcoDRR projects aim to reduce risks and increase resilience against hazards, while EbA projects target the reduction of vulnerability to climate change, adopting adaptive measures and increasing resilience (Doswald and Estrella, 2015). Accordingly, ecosystems and their services can be considered along with "resilience" as connecting dots between CCA, DRR and sustainable development (UNFCCC, 2017).

However, despite the potential of EbA and Eco-DRR, limited knowledge on how ecosystems can be used to address DRR and CCA simultaneously exists (IUCN, 2014). Similarly, in spite of the considerable efforts for enhancing the synergies between DRR and CCA, many challenges remain (UNFCCC, 2009). Nehren et al. (2014) reported that DRR practitioners have only recently began to incorporate future climate variations scenarios into their plans despite the existence of a large fraction of data on climate-related risks in the DRR community (UNFCCC, 2010).

In response to this gap, NbaS might be useful tools for bridging the dividend between DRR and CCA. The logic behind this assumption is that adaptation - along with resilience and ecosystem services - is a central element for all three-post 2015 agendas (UNFCCC, 2017). While NbS can reduce the exposure of humans to natural hazards (IUCN French Committee, 2016), NbaS adds the adaptation layer. By doing so, risk reduction as the bulk of Eco-DRR approaches and as an integral component of CCA (UNFCCC, 2010) is ensured. Ideally, CCA should integrate climatic and non-climatic hazards to account for all scenarios, while DRR should consider climate change scenarios or it will underestimate climate-induced changes of hazard intensities and frequencies (Doswald and Estrella, 2015). When projects do not integrate long term climate change and multiple hazards, chances of maladaptation or pronounced risks become higher (N. Doswald and Estrella, 2015). Therefore, the integration of CCA and DRR to adaptation planning is mandatory (UNFCCC, 2010). Since NbaS are based on ecosystems, their integration will climate-proof Eco-DRR and link both CCA and DRR. That way, a hybrid Eco-DRR/CCA approach to reduce disaster risks through adaptive measures is made possible (Doswald and Estrella, 2015). Moreover, NbaS can link and facilitate the dialogue among the different communities through their transversal nature (Figure 4).

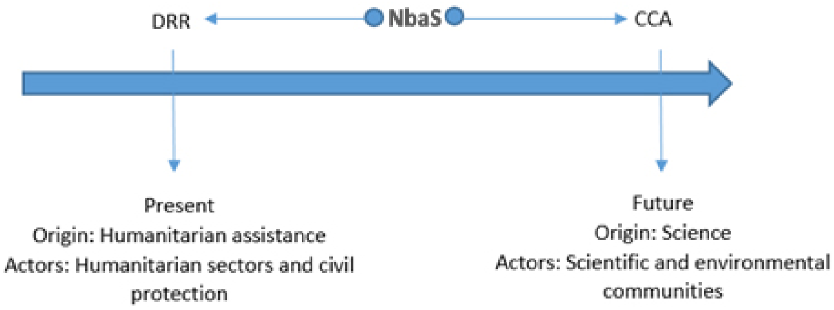

Figure 4: the connecting role of NbaS for DRR and CCA

In simple terms the above-mentioned elements and the CCA-DRR-SDG-NbaS link can be summarized as follows:

a/ According to the UNFCCC (2017), the Paris agreement, the Sendai framework and the SDGs - have a common intersection zone: reducing vulnerability and enhancing resilience. These agendas are represented below (Figure 5) to show their independent yet complementary nature, and their potential link to NbS-NbaS. Since resilience and vulnerability are central elements of these agendas, NbS can respond to both while promoting sustainability (Bayulken et al., 2021), and therefore can be suitable candidates – among others – to occupy the intersection zone. According to the UN World Water Assessment Programme and UN-Water (2018) NbS support many SDGs: 2 zero hunger, 3 good health and well-being, 5 gender equality, 6 clean water and sanitation, 8 decent work and economic growth, 9 sustainable industry, innovation and infrastructure, 11 sustainable cities and communities, 13 action on climate, 14 life below water, and 15 life on land. As NbaS are built on NbS foundations, NbaS can further add the adaptation layer to the previously cited advantages.

b/ Substantial arguments on the direct relationship between SDG progress and climate change resilience exist (UNFCCC 2017). Since NbS cover the three pillars of sustainability (Nesshöver et al., 2017), NbaS may help to adapt forward and sustainably, hence the CCA – NbaS – SDG link.

c/ In terms of the Sendai framework, it is agreed that natural hazards are linked to climate change, and the amplification of the latter will only increase the former (Der Sarkissian et al., 2019). In this field, NbS are also becoming more synonymous with the build back better concept (Der Sarkissian et al., 2021). As resilience is a central element for Disaster Risk Reduction (DRR), and while better adaptation promotes further resilience, the CCA - NbaS – Sendai DRR link can be highlighted.

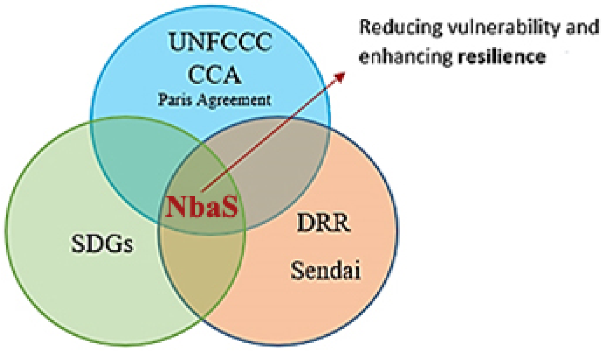

Figure 5: The intersection between the three post-2015 agendas and the position of NbaS.

V. NbaS and adaptation measures

This section details knowledge on NbaS, describes their use, showcases their status in international approaches and discusses their potentials and limits. On this basis, a discussion of ecosystems and their central role in both the NbS and adaptation frameworks will be given.

V.1 Target mediums and sectors

Under the IUCN

The IUCN provided a comprehensive review of Nationally Determined Contributions (NDCs) to the UNFCCC and the role of NbS within (Seddon et al., 2019). Through this study insights on media of intervention and priority sectors are made available. Accordingly, ecosystems rank in the top five more vulnerable sectors to climate change, following food and water security and preceding fisheries, energy and transport (Seddon et al., 2019). Coastal and marine media are also mentioned as vulnerable contexts but are not in the priority list. With a very large focus on biodiversity and ecosystem services, the IUCN's approach is transversal to different mediums. As climate change adaptation and mitigation fall under the societal challenges set by the IUCN, they stratify in all others (ref. Cohen-Shacham et al., 2019, 2016). To that end, the societal challenges of the IUCN reflect its most commonly addressed subject matters: disaster risk reduction, economic and social development, human health, food security, water security, environmental degradation and biodiversity loss (IUCN, 2020).

With respect to the classification of mediums adopted in ARTISAN, the following environments and their associated challenges are targeted by the IUCN:

- Urban medium: urban resilience (IUCN, 2014) which also englobes stormwater and runoff management (UNEP, UNEP-DHI, IUCN, TNC and WRI, 2014) and sustainability (IUCN French Committee, 2019; Kabisch et al., 2016), human health and degradation of natural capital [under the framework of the European Commission], air quality and heat stress (Cohen-Shacham et al., 2016; IUCN French Committee, 2016).

- Agricultural medium: agriculture falls under the food security challenge. Some of the main concerns are ensuring climate-resilient production, higher yields (IUCN, 2020) and food availability (Cohen-Shacham et al., 2016). However, the IUCN's rationale extends beyond the classical production logic and goes in the sense of approaching food security using a multi-faceted scope (Cohen-Shacham et al., 2016). To that end, several manners should be addressed such as genetic resource management and protection, focusing on provision ecosystems, integrating forests (agroforestry) and addressing the food-water nexus in a simultaneous manner (Cohen-Shacham et al., 2016).

- Maritime and coastal media: The main threats reported for coastal areas are flooding sea, level rise, changing sea surface temperatures, storms (Seddon et al. 2019), erosion, saline intrusions (Collins et al., 2009). Nonetheless, the IUCN reports that these environments are poorly presented in NDCs (Seddon et al. 2019). Overall, the IUCN refers to marine ecosystems as complex settings even without the burden of climate change as they are subjected to intensive anthropogenic activity (Dudley et al., 2010).

- Mountainous medium: The IUCN reports that the mountainous environment appear in only 4% of the NDCs on adaptation (Seddon et al. 2019). Mountains are highlighted as vulnerable settings (IUCN, 2010) and are faced by many challenges such as glacier retreats, less snow cover and fauna/flora degradation (Dudley et al., 2010). Nonetheless, they are underrepresented compared to the other media.

- Natural medium: Grassland and rangelands are also marginally addressed. They only appear in 10% of the NDCs (Seddon et al. 2019) and aren't very presented in the queried work.

- Forest medium: In addition to their dominance of the NDCs, forests are approached as an essential pillar under the IUCN. The most mentioned challenges are deforestation, conversion to agricultural parcels, time lags for becoming effective (IUCN French Committee, 2019; UNEP, UNEP-DHI, IUCN, TNC and WRI, 2014). The importance of cloud forests' efficiency is also discussed as atmospheric water harvesting systems (Dudley et al., 2010), while the potential of forest for responding to all the IUCN's societal challenge is stressed.

- Freshwater environments: This medium is related to the water security challenge. Its main challenges are flooding, drought, quality, supply, and storage (Cohen-Shacham et al., 2016; Colls et al., 2009; UNEP, UNEP-DHI, IUCN, TNC and WRI, 2014).

Under the UNFCCC

Signatory parties of the UNFCCC have to report their progress under different forms, mainly as Nationally Determined Contributions (NDCs), National Action Plans (NAPs) and climate fund programs. Throughout these inputs, priority sectors and challenges at the international scale can be extracted. In terms of target sectors for CCA, the UNFCCC underlines the following key areas: agriculture and food security, water resources, coastal and marine zones and human health sectors (UNFCCC, 2019a, 2014c, 2014a, 2010, 2008b). The UNFCCC (2010) further reports terrestrial ecosystems (forests, grasslands, rangelands, etc.), fishery, infrastructure, tourism and energy as additional sectors. However, agriculture and water are listed as top priorities, and regarded as the most vulnerable sectors to climate change (UNFCCC 2008). The most addressed climate change challenges are drought, rainfall variability and flooding and coastal impacts.

With respect to the classification of mediums adopted in ARTISAN, the following environments and their associated challenges are targeted by the UNFCCC:

- Urban medium: urban environments and their associated infrastructure are threatened by sea level rise and by the increased frequency of rapid-onset events such as hurricanes, droughts and floods (Binet et al., 2021). Urban heat island effects are also discussed as their interconnections and complexity are also taken into consideration (UNFCCC, 2006). Urban infrastructures are also targeted from the temperature rise, rainfall variability, flooding and sea level rise dimensions (Binet et al., 2021; UNFCCC, 2011, 2006).

- Agricultural medium: considered as one of the most vulnerable sectors to climate change (UNFCCC, 2014a) as minor variations can have detrimental effects on yields even within a single harvest/growth period (UNFCCC, 2006). Most challenges revolve around the identification and evaluation of practices (farming techniques, irrigation, etc.) and measures (crop choice) that increase productivity (UNFCCC, 2011), promote food security and resilience to climate change (UNFCCC, 2014a).

- Maritime and coastal media: also considered as one of the most vulnerable contexts to climate change and the centre of vulnerability assessments (UNFCCC, 2008b). Hazards and risks in these mediums are in relation with safety, food security and human livelihood/development; in addition to slow onset events such as sea level rise and salinization, as well as hurricanes, storms and floods (UNFCCC, 2020a). Coastal areas also central elements under the Nairobi Work Programme including coral reefs (UNFCCC, 2010). The ocean is also targeted under the UNFCCC and four main topics are addressed for bridging knowledge gaps on the ocean (UNFCCC, 2019c): restoration and protection (including coastal and areas), coral restoration, mudflats, tidal marshes, natural regeneration, and protection of healthy ecosystems.

- Mountainous medium: targeted to a much lesser extent that other media. It was until the COP15 of 2009 (relatively recently) that the advocation of mountains' role in climate change issues was made[9]. Significant efforts for improving observational data of mountains at different scales were recommended particularly for developing

[9] https://unfccc.int/files/adaptation/application/pdf/icimod_further_information_conclusions_october_2010.pdf

countries (UNFCCC, 2007). Nonetheless, mountains are also acknowledged by the UNFCCC as some of the most vulnerable terrestrial ecosystems[10].

- Natural medium: the importance of grasslands is underlined in the Nairobi Work Programme (UNFCCC, 2019c). They are considered as central elements for mitigation and carbon sequestration. The scope of grasslands is gaining increasing interest in the UNFCCC and their role for integration into CCA planning has been recently articulated[11]. However, this interest is relatively recent and grassland action under the Nairobi Work Programme is still an ongoing process (June 2020-November 2021)[12].

- Forest medium: Forests are largely addressed and present in all NDCs as highlighted by Seddon et al., (2019) IUCN review of NDCs. They are given a pivotal role and are the most globally represented environments within (Seddon et al., 2019). The main addressed challenges are forest management, deforestation, reforestation, afforestation, conservation and protection. Forests are also significantly addressed in the Paris Agreement under article 5 (UN, 2015), and are also associated to other media such as agriculture by agroforestry.

- Freshwater environments: Alongside agriculture, water is one the top priority sectors (UNFCCC, 2014c). The main challenges reported for this sector are drought, scarcity, supply, flooding, management, quality degeneration and improving use efficiency (UNFCCC, 2019a, 2014c, 2011, 2008b). The concept of blue and green water is also introduced (UNFCCC, 2006) and the water-energy-food nexus is addressed in the context of NbS (UNFCCC, 2020b). The last element highlights the stratification of water into the different media (namely agriculture) and underlines multidimensional importance.

Under the UNEP

The UNEP adaptation gap report 2020 (UNEP, 2021a) reviewed projects endorsed under the UNFCCC climate funds and NDCs. Results showed that the most commonly addressed sectors as priorities were agriculture, water and health (the latter ranked first for developing countries). Nonetheless, the UNEP (2008) highlighted that silo sectorial approaches, rather than a global strategy viewing sectors as units of a larger interdependent ecosystem, have failed to deliver their purposes. The UNEP (2021b) also found that droughts, rainfall variability and flooding/coastal impacts were the most targeted climate hazards in adaptation projects. Heatwaves, heavy precipitation, droughts and sea level rises were also reported by the UNEP (2020a). According to the UNEP (2021b), most adaptation actions target either water deficiency or excess, extreme events, sea-level rise and subsequent salinization of freshwater and/or soils.

With respect to the classification of mediums adopted in ARTISAN, the following environments and their associated challenges are targeted by the UNEP:

- Urban medium: extreme precipitation and stormwater management, smog formation, urban heat islands, urban and coastal flooding and pollution (UNEP, 2021b, 2021a; UNEP, UNEP-DHI, IUCN, TNC and WRI 2014).

- Agricultural medium: sustainable climate-resilient agriculture, soil salinization, irrigation, water use, water scarcity, fertilizers application, land productivity, increasing yields (UNEP 2021a) and crop selection (UNEP, UNEP-DHI, IUCN, TNC and WRI 2014).

- Maritime and coastal media: sea level rise, coastal erosion, and storm surges (UNEP, 2021a, 2021b). The protection of coastal infrastructure and settlements from flooding is also addressed (UNEP, 2020; UNEP , UNEP-DHI, IUCN, TNC and WRI 2014) and can be considered at the interface or urban and maritime-coastal media. Coastal and marine habitat loss and degradation are also targeted (UNEP-WCMC and IUCN, 2016).

- Mountainous medium: very rarely discussed but they are referred to as some of the most sensitive environments to climate change given their high vulnerability and low adaptive capacities (Immerzeel et al., 2020 *in* UNEP 2021a). Challenges associated to this environment are water provision and the impact of increased rainfall on slope stability, erosion and landslides (UNEP and UNEP-WCMC, 2019d).

- Natural medium: grazing lands are very marginally addressed as potential carbon sinks and have only started to receive consideration (Global alliance for the future of food, 2019).

- Forest medium: Forests are portrayed as the champion solution and are rarely perceived as victims of climate change. This could be due to their autonomous adaptation and high coping capacities. Generally, the choice of species, genetic diversity, land conversion (forests to agriculture), and the need to prevent the proliferation of invasive species

[10] https://unfccc.int/files/press/backgrounders/application/pdf/press_factsh_science.pdf
[11] https://unfccc.int/event/addressing-knowledge-gaps-biodiversity-and-climate-change-adaptation
[12] https://www4.unfccc.int/sites/NWPStaging/Pages/Biodiversity.aspx

are mostly discussed. Nonetheless, forests seem to have a solution for every climatic challenge. They are also referred to for use in combination with different mediums such as agroforestry. Discourse on the importance of afforestation and reforestation is quite common with reference to the time lags needed for forests to become mature (UNEP, UNEP-DHI, IUCN, TNC and WRI, 2014).

- Freshwater environments: freshwater ecosystems are targeted for conservation and restoration efforts, flooding, provisioning, supply use, pollution, flow restoration (UNEP, 2021b, 2021a). River flooding, riparian vegetation and buffer strips conservation, and floodplains management are equally addressed. (UNEP-DHI, UNEP and IUCN 2018; UNEP, 2021b). Regarding wetlands, their conservation, restoration and efficiency, a great deal of interest is given. They are also addressed as sensitive, critical and threatened environments (UNEP, 2021a) and an emphasis is placed on their types (constructed or natural) (UNEP, UNEP-DHI, IUCN, TNC and WRI, 2014). As for forests, they are considered as very potent multi-purpose elements. Coastal wetlands are also addressed and can be considered at the interface of the coastal and freshwater media.

In addition to the above mentioned media, the UNEP (2019e) provided a review of the environments addressed by UNEP-EbA projects. These were listed in descending order as follows: agriculture lands, forests/woodland, coastal area, mountain, grasslands, wetlands, rangelands/savannahs, urban environments, dryland, river watersheds, floodplains and moorlands.

The categorization of each institution's interest per media, sector and challenges reveals a more or less similar distribution (Table 1)

Table 1: Medium of interest according to the medium classification in ARTISAN per institution

Institution/Medium	Urban	Agricultural	Maritime and coastal	Mountainous	Natural	Forest	Freshwater
IUCN	✓	✓	✓	+/-	+/-	✓	✓
UNFCCC	✓	✓	✓	+/-	+/-	✓	✓
UNEP	✓	✓	✓	+/-	+/-	✓	✓

The categorization of each institution's interest per media, sector and challenges reveals a more or less similar distribution. Under all three, recommendations for putting media forward are made (namely the coastal medium). The mountainous environment seems to be underrepresented, while the top ranks fluctuate between the agricultural-forested-urban environments, and to a lesser extent the freshwater media. For the IUCN, UNFCCC and the UNEP, protected areas whether terrestrial or aquatic, are given very significant importance. They are perceived as sensitive media to climate change but also as very potent solutions for CCA. For properly understanding the position of NbaS in the international landscape, the following section will provide information on their current use, potential and limitations.

V.2 NbaS: Status quo, potential and limitations

a. Status quo

To understand how NbaS are being currently used, a *status quo* assessment was carried out. The work of the IUCN and UNEP are most useful in this section as the first reviewed several NDCs and extracted trends, while the Adaptation Gap Report 2020 of the second clearly drew a state of the art on the current use of NbS for adaptation.

* Under the IUCN

Seddon et al. (2019) provided a detailed review of NbS-NbaS in NDCs. A summary of their findings is presented in Figure 3. As can be seen, the underrepestantion of the natural and mountainous environment is quite striking. Similarly, the absence of quantifiable targets and intended outcomes is evident. While 78% of the NDC include NbS and 62% mention NbS for CCA, the low percentage of targets reveals the significant need for research on their efficiency (Kabisch et al., 2016). In addition to Figure 6, the status quo of NbS for CCA (NbaS) is as follows:

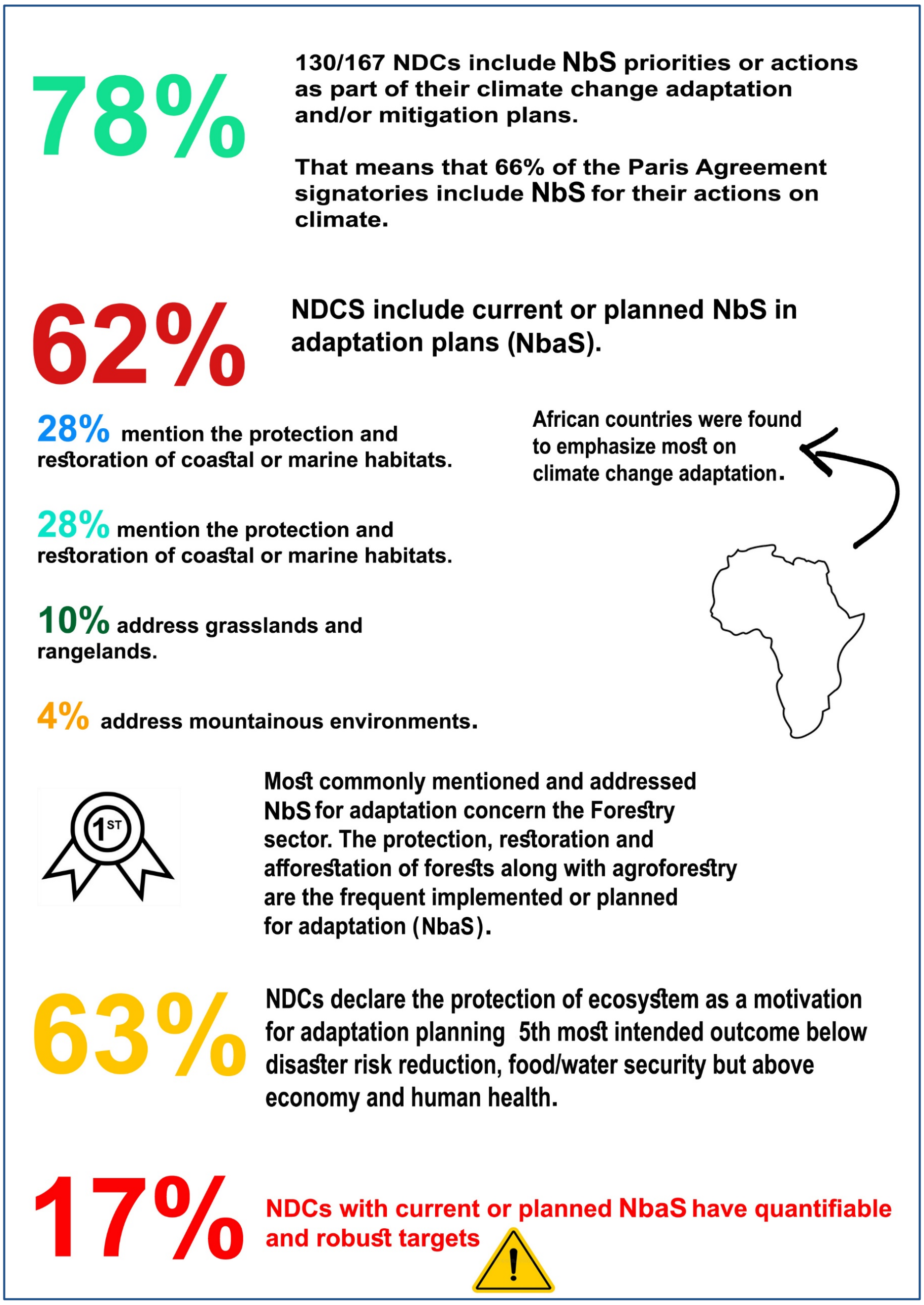

Figure 6: Statistics of NbaS in NDCS, source of information: Seddon et al. (2019); adapted by the Authors.

According to Seddon et al. (2019):

- 70% of the NDCs present elements related to the forestry sector. Yet, only 20% include measurable targets.

- NbS that synergize both adaptation and mitigation are underused. Most emphasize more on the importance of mitigation. Only 17 out of the 167 NDCs tackle adaptation and mitigation together or highlight the mitigative benefits of adaptation measures.

- NbS in other than-forest ecosystems are not sufficiently represented: Forests are by far the most represented NbaS while coastal and marine environments are considerably less addressed.

- In coastal/marine related NbS, the accent on adaptation was more pronounced.

- Concerning targets, even when present, it is unsure if they will be enough for meeting the required adaptation needs. From the 70 countries that include EbA actions, 18 provide time constrained or numerical targets and only 12/18 present measurable ones.

- While the societal challenges that NbS currently respond to are climate change (adaptation and mitigation), DRR, food and water security, human health, socioeconomic development, ecosystem degradation and biodiversity loss, the evolution of the NbS framework might make them encompass other challenges and thus increase the importance of NbS (IUCN, 2020).

- The European Commission primarily focuses of urban environments due to the high number of European citizens that live in cities and the prevalence of challenges such as human health, natural capital and climate change (Cohen-Shacham et al., 2019).

Knowing that other ecosystems may be more efficient than forests for CCA, the relative dominance of forests and green solutions points out that more research efforts should be carried out to understand the importance of other solutions. In simpler terms, thinking beyond trees[13] should become more common and the science behind NbS should be strengthened.

* Under the UNFCCC

The findings presented in the IUCN's section reflect the status quo under the UNFCCC since the main analytical inputs were the NDCs. An additional consideration of the reports cited below allowed also the extraction of the elements below.

- Under the UNFCCC's adaptation technology categorization, NbS correspond to the "hardware" section. Yet for being fully functional, synergies with the software and orgware compartments are needed. While this is one of the most challenging barriers to NbS, significantly relevant efforts should be sought.

In terms of NbS-NbaS the most commonly addressed types were found to be:

- Green solutions e.g. urban parks, greenways, gardens, urban trees, climate smart agriculture, green engineering and agroecology) (UNFCCC, 2020a, 2020b).

- Blue solutions e.g. using coastal ecosystems, mangrove conservation, coral reefs, saltmarshes, wetlands) (UNFCCC, 2020a).

The UNFCCC also encourages the use of hybrid NbS that combine both natural and grey elements for challenging siloed approaches and multiplying benefits (UNFCCC, 2020a). The UNFCCC also underlines that NbS addressing the water-energy-food nexus aren't sufficiently understood (UNFCCC, 2020b) and more efforts in this regard are needed. However, the strategic positioning of NbS into vital sectors such as water, energy and food reveals both their importance and need.

Guidelines for NbS national-scale accounting are awaited from the UNFCCC (Girardin et al., 2021), and the role of NbS for action on climate is expected to be fortified in the upcoming COP26[14]. This can be considered as an effort for shaping adaptation under the UNFCCC beyond the 2020 horizon (UNFCCC, 2013).

* Under the UNEP

The UNEP (2021a) directly reports that NbS for climate change mitigation are much more discussed then NbaS, and the latters need to receive much more attention. A status quo of NbaS under the UNEP is presented in what follows:

- 70 countries endorsed a manifesto on NbS for climate change in the UN Climate Action Summit 2019 (UN Climate Action Summit, 2019). Within this agenda, forests are the most prevalently addressed solutions (Andersen, 2020).

- NbS are acknowledged as an integral factor for the overall effort of achieving the targets set by the Paris Agreement (Nature-based Solutions Coalition, 2019).

- NbS are widely receiving interest for tackling the interlinked climate change and the biodiversity crises simultaneously and for providing additional co-benefits (UNEP, 2021b, 2020a).

[13] Michelle Greve *and others*, 2020. Trees as Nature-Based Solutions: A Global South Perspective. One Earth 3, 140–144. https://doi.org/10.1016/j.oneear.2020.07.008

[14] COP26 in Glasgow UK, 1 – 12 November 2021.

- NbaS are being used to address climate risks by decreasing exposure and vulnerabilities (UNEP, 2021a).

- Nature is one-third of the solution to climate change and for every dollar spent on restoring nature at least nine dollars of returns can be anticipated (Andersen, 2020).

- NbS are already being implemented with reliable outcomes (Nature-based Solutions Coalition, 2019) yet the problem resides in mainstreaming, upscaling and speeding up their implementation (UNEP-DHI, UNEP and IUCN 2018). Moreover, these examples are only project-based (UNEP-DHI, UNEP and IUCN 2018) and do not provide sufficient evidence of efficiency.

- The implementation of NbaS projects has considerably increased throughout the past two decades with a rate of 70 projects per year, but their future progression is not clear as indicators are showing a decelerating rate (UNEP, 2021a).

- A growing acknowledgment of NbS for CCA at the national and international scales is visible but few concrete plans exist (UNEP, 2021a).

- Funding for NbaS is low despite having increased (Nature-based Solutions Coalition, 2019). In an analysis of four climate funds[15], the UNEP (2021a) found that only 12 out of 94 billion US$ intended for climate change adaptation/mitigation plans were accorded to NbS [hence NbaS] (UNEP, 2021a).

- NbS often lack clear objectives (UNEP, 2020a) and the risks of disorientation are high.

- Under the mandate of the UNEP 11 ecoservices are considered as priorities. The most attention demanding ones are climate, water and natural hazard regulation, energy, freshwater and nutrient cycling. The second-most urgent sectors are water purification, waste treatment, disease regulation, fishery, primary production, recreation and ecotourism (UNEP, 2020a).

- NbS are increasingly advancing in the urban realm for enhancing the quality of lives and responding to water-related challenges (UNEP-DHI, UNEP and IUCN 2018). They are on the rise particularly in developed countries, and mostly focus on coastal and freshwater flooding as well as addressing heat-related challenges (UNEP 2021a).

- NbaS are mostly used to target extreme precipitations (floods, erosion and mass movements) [31%], droughts [23%], coastal hazards (sea level rise, erosion, and storms) [16%], increased temperatures (urban heat islands and heat stress) [14%] (UNEP, 2021a).

- An example of the most commonly used NbaS for addressing some climate hazards is provided below (Figure 7)

Coastal flooding and erosion	Urban flooding	River flooding, landslides and erosion	Runoff	Drought-related risks	Heat-related risks
• Restoration or protection of coral reefs, seagrass meadows, coastal wetlands, mangrove forests and dunes and beach vegetation.	• Urban green and blue spaces, as well as upstream NbS.	• Restoring or protecting floodplains and peatlands and by enhancing riparian vegetation.	• Forest and landscape restoration or protection, reforestation, agroforestry and agroecological practices.	• Integrated watershed and landscape management, as well as reforestation and climate-smart agricultural practices such as agroforestry and agroecology.	• Green and blue spaces, as well as green infrastructure.

Figure 7: An example of NbaS in response to climate hazards, source: UNEP (2021a).

As can be seen, the bulk of the adopted approaches lies under the "green solutions" categories. Seemingly, green solutions are the most favored NbS-NbaS for a range of environmental challenges.

The status quo of NbaS under all three institutions reveals that NbaS are being increasingly sought in the international landscape. A general description of their current use showed that efforts are needed for unlocking their full potential. Accordingly, the following two sections will present the potential and limits of NbaS for clearly deriving research needs and showcasing their importance.

[15] The Global Environment Facility, the Green Climate Fund, the Adaptation Fund and the International Climate Initiative)

b. Potential and current knowledge

The nature-based compartment of NbS and NbaS holds a fundamental question: how natural must a solution be to be deemed nature-based? (UNEP, 2020a). Essentially, NbS and NbaS are a multi-benefit ecology-based approach to climate change (UNEP, 2020a). As a starting point, healthy ecosystems are the basis for providing eco-services and natural resources, therefore ensuring their continuity will help people cope better to the effects of climate change (IUCN French Committee, 2019). Terrestrial and marine ecosystems actively participate in the global climatic system by contributing to biosphere-atmosphere interactions (IUCN French Committee, 2019). To this end, NbS aim to protected, conserve or restore ecosystems to ensure their functionality (Cohen-Shacham et al., 2016). According to the ONERC, (2019) these ecosystem management procedures can be considered as NbaS. Regardless of the adopted solution, five approaches can be distinguished (Cohen-Shacham et al. 2019, 2016) :

- Ecosystem restoration approaches (e.g. ecological restoration, ecological engineering, and forest landscape restoration).

- Issue-specific ecosystem-related approaches (e.g. ecosystem-based adaptation, ecosystem-based mitigation, climate adaptation services, and ecosystem-based disaster risk reduction).

- Infrastructure-related approaches (e.g. natural infrastructure and green infrastructure).

- Ecosystem-based management approaches (e.g. integrated coastal zone management and integrated water resources management).

- Ecosystem protection approaches (e.g. Area-based conservation approaches including protected area management).

To determine the potential of each of the above-mentioned solutions Table 2 was built. As can be seen, ecological and forest restoration are quite commonly addressed and frequently used solutions. The same applies for EbA and mitigation while Eco-DRR is still emerging (see section IV.4 for further details). Green infrastructure is fairly common in the urban realm (see section b for further details) while coastal solutions despite their importance are not well represented (Seddon et al., 2019). Concerning protected areas much has to be said. Accordingly, this dimension of NbS seems to be lacking proper attention despite its considerable potential (Dudley et al., 2010). As was highlighted throughout the different reports, the importance of protected areas whether terrestrial, coastal or marine is undermined. To this end, section b.2 provides further details on protected areas while section b.3 is presented as a general fact section on some solutions.

Table 2: An example of NbaS and their potential, source: compilation of different reports.

Type	NbaS	Ecosystem	Environmental challenge	Potential	Comments
Green	Green spaces	Forest/natural	CCA + DRR	Protect people and property from the impacts disaster + provide protection to the livelihood sources such as agricultural fields	The efficiency of green spaces depends on the density of the vegetation, its type, and its state of maturity. It also depends on watering frequency and in some instances grasslands might be more efficient than trees despite their higher evapotranspiration rates
				In urban areas they mitigate heatwaves by cooling the air and improving its quality	
				Promote water infiltration and groundwater recharge + reduce runoff	
				Example rain gardens: store water, manage runoff (reducing its pollutant loads), concentrate nutrients, contribute to bioretention + sequester carbon	
	Forests	Forest	Climate warming + DRR	Increase green biomass and associated ecoservices + carbon storage for climate change mitigation + increase rainfall interception, soil water storage and groundwater recharge.	Choice of species is a very limiting factor: Softwoods store carbon more rapidly during the first years, later the trend is reversed and hardwoods are more efficient in terms of carbon storage on the medium to long term
				Reduce minor to moderate floods in relatively small to medium sized watersheds	Very little effect on major floods at large scales
				Mitigate thermal pollution of neighboring waterbodies by shading them	This effect depends on the type of tree foliage (broadleaved as opposed to narrow leaved)
				Improve water quality by reducing sediment arrival to waterbodies and trapping pollutants	
				Increase pollination services, filtering air, cooling their surroundings by creation of a microclimate, and supporting biodiversity	
				Mountain forests stabilize slopes and reduce the risks of landslides + secure snow covers	This effect will depend on the altitude range. As species are shifting ranges with climate change the efficiency of this solution might be jeopardized.
				Cloud forests are capable of scavenging atmospheric moisture by condensing it on leaves with water gains greater than 100% than ordinary rainfall (example Eucalyptus forests)	
	Agroforestry	Agriculture/Forest	CCA + food security	Cost-effective means for promoting environmental sustainability, food security and CCA/mitigation + managing surface runoff and attending to droughts	The choice of species can be a limiting factor as some tolerant species are not environmentally lucrative as other more climate-sensitive ones. The agricultural runoff is accounted for by the presence of the neighbouring forest or vegetation. Moreover, the canopy creates a more adequate microclimate to crops and creates a more resilient ecosystems for better food production. This system is a win-win solutions that supports food security, increases landscape heterogeneity, mitigates and promote the adaptation to climate change
	Agroecology	Agriculture/Forest	CCA + food security	Adapting agriculture to climate change through the introduction of resilient species + managing surface runoff and attending to droughts	
	Riparian buffers	Natural/Freshwater	CCA + water quality	Mitigate thermal pollution of neighboring waterbodies by shading them and trap eroded soil-sediment particles and associated pollutants + support biodiversity	Riparian vegetation are sensitive ecosystems and can be easily affected by changing conditions namely droughts and disturbances such as grass growth, grazing
B-G	Green infrastructure	Multi	Various	Increase/support water supplies by promoting infiltration, storage capacities and aquifer recharge + mitigate droughts through controlled water releases	See section below
				Stabilize slopes and riverbanks + reduce sedimentation in waterbodies thus preserving their functionality	
				Moderate extreme events namely floods by increasing water storage capacities or floodwater conveying through channels and decelerating flows	

				Urban stormwater runoff moderation by facilitating infiltration, reducing impermeable surfaces and preventing overflow inundations For example: green roofs reduce storm runoff, store water, contribute to climate cooling by evapotranspiration, provide insulation and cooling benefits	
	Blue-green urban areas	Urban	CCA	Decrease the vulnerability and enhance the resilience of cities to climatic change Mitigate climate change-induced impacts and serve as proactive adaptation options for municipalities Provide ecoservices, reintroduce nature into cities, increase aesthetic value and human well-being Respond to flooding and heat stress in urban environments	
	Mangroves	Coastal	Climate warming + DRR + CCA	Among the planet's greatest carbon storehouses, with CO2 burial rates 20 times greater than any other terrestrial ecosystem Coastline protection against storms (reducing wind speed), floods (dissipating wave energy) and erosion Reducing shoreline retreats and marine submersion risks	Mangroves are given considerable importance throughout all the references and are considered as valuable ecosystems with a wide range of implementation around the world
Blue	Coral reefs	Coastal	Climate warming + DRR	Among the planet's greatest carbon storehouses, with CO2 burial rates 20 times greater than any other terrestrial ecosystem + Coastline protection against storms and floods	Without reefs damages from floods and storms would double and triple respectively
	Seagrass meadows	Coastal	Climate warming + DRR	Among the planet's greatest carbon storehouses, with CO2 burial rates 20 times greater than any other terrestrial ecosystem + Coastline protection against storms and floods	Among the most underrepresented solutions that require considerable research efforts and attention.
	Kelp forests	Coastal	Climate warming + DRR	Among the planet's greatest carbon storehouses, with CO2 burial rates 20 times greater than any other terrestrial ecosystem + Coastline protection against storms and floods	
	Sand dune systems	Coastal	Climate warming + DRR	Among the planet's greatest carbon storehouses, with CO2 burial rates 20 times greater than any other terrestrial ecosystem + Coastline protection against storms and floods	
	Salt marshes	Coastal	Climate warming + DRR	Among the planet's greatest carbon storehouses, with CO2 burial rates 20 times greater than any other terrestrial ecosystem + Coastline protection against storms and floods	
	Floodplains	Coastal	Climate warming + DRR	Reduce the impact of floodwaters + physically buffering climate change impacts + promoting groundwater recharge	Among the most fertile ecosystems that have long been at the human/nature interface.
	Barrier islands	Coastal	Climate warming + DRR	Reduce the impact of floodwaters + physically buffering climate change impacts	Very underrepresented solutions that need to be extensively studied
	Wetlands	Coastal/ Freshwater	CCA + DRR + water quality	Regulate floods + protect water resources during drought by controlled releases Intercept and neutralize pollutants + filter effluents and remove sediments; they can act as wastewater treatment "plants" by eco- and phyto- remediation	Knowledge on their assimilative capacities and hydrological behaviour is still needed. Further, if these are not designed efficiently they may cause sediment imbalance downstream their watersheds (M Al Sayah et al., 2019)
Underrepresented solutions	Protected areas	Natural/ Freshwater /Coastal	Multi	Test sites for the monitoring and understanding of climate change impacts on biodiversity, as other anthropogenic stressors are limited Preserve biodiversity and reduces stress on ecosystems and species Can be used as means to protected other NbaS and ensure their optimal efficiency. Example: placing mangroves under protected areas legislations to ensure that they are not disrupted Can be used as an observatory for building knowledge on the role of ecosystems for CCA and DRR Store 15% of terrestrial carbon and supply ecoservices for DRR, water supply, food and public health while maintaining the integrity of existing ecosystems-ecoservices (example: fisheries, agriculture) Buffer local climate and reduce risks of extreme climatic events	See section below

				In terms of DRR examples: they provide space for floodwater dispersion, stabilize slopes and soils, block storm surges, and reduce grazing pressure to reduce desertification. They also break the transmission of zoonic diseases by providing a shield of natural habitats	
	Oceans	Oceanic	Climate warming	The ocean is one of the most major governing factors of climate change and the carbon cycle yet it is rarely represented	Understanding the state of the ocean is crucial for having clear insights on the evolution of climate change and earth system dynamics. The data gap concerning deep oceans are considerable and this lack of knowledge has serious implications on the advance of climate studies and research.
	Soils	Terrestrial	Multi	The time extent of carbon sequestration in the soil is particularly longer than in the aerial parts of ecosystems, ranging from a decade to a millennium	Soil properties, geometry, texture, content and property significantly influence its efficiency
				In forests, soil type is the most significant factor involved in carbon storage among the 3 main storage factors (climate, soil type and tree species)	The degradation of soil is capable of transposing soils from carbon sinks to source and amplify climate change
				Controlling the movement, storage and transformation of water.	Soil properties, geometry, texture, content and property significantly influence its efficiency
				Generate benefits for agriculture and enhances food security along with economic profits	Soil properties, geometry, texture, content and property significantly influence its efficiency
	Peatlands	Terrestrial	CCA+ warming + DRR	Within relatively small surface areas on a global scale (3% of land surface), they comprise twice as much carbon as forests overall	Some of the most underrepresented and underrated solutions that require extensive research work
				Attend to river flooding	
				Support biodiversity, control water quality and quantity, contribute to climate regulation by cooling the atmosphere	
	Ground water-NbS	Freshwater	CCA	Infiltration basins or river water filtering on banks promote the transfer of surface water to the underground layers this contribution to flood reduction, saline intrusion control, ensure water storage, and reduce the price and costs of pumping water as the latter will be closer to the surface	
	Underground taming of floods for irrigation (UTFI)	Freshwater /Urban	CCA	This solution consists of facilitating aquifer recharge to store wet season high flows in catchments, thus mitigating local and downstream flooding. This also allows to cope with droughts by making groundwater more available to human need or to attend to water-use activities such as irrigation	

b.1. Green and grey instead of green versus grey

Generally, the NbS concept discourages the use of structural interventions such as engineering or "concrete-based" approaches (Sahani et al., 2019). These consist of engineered infrastructures and are referred to as grey solutions. By definition, grey infrastructures/solutions are built engineered structures that are often made from concrete or other long-lasting material (Depietri and McPhearson, 2017). The general discourse on NbS and grey solutions is very polarizing. For some, grey solutions are considered unsustainable, polluting, traditional and are often perceived as environmentally harmful. Therefore, they ought to be replaced by greener solutions when possible. For others, the proven track record of efficiency, reduced uncertainties and widespread use of grey solutions (Deely and Hynes, 2020) makes them better than the uncertain NbS. According to the UNEP and UNEP-WCMC (2019c), as these colors are often opposed, a scale of green to grey appears. This scale depends on the degree to which ecosystems are being used for responding to climate change: the foremost grey color corresponds to built solutions (dams, reservoirs, etc.), the grey-green category corresponds to hybrid solutions such as green roofs, while the green color represents purely natural solutions such as forests (UNEP and UNEP-WCMC 2019c). Yet, the blue color should also appear on the scale as Blue-Green infrastructure are also directly related to water management. The opposition of colors and their preferences are underlain by many arguments:

- **NbS-NbaS cost less and function for a longer time:** Grey infrastructures are more rapidly performant than NbS and can deliver outcomes soon after their implementation, however, with time their services will depreciate and will require often costly maintenance (UNEP, 2021a). On the contrary, green infrastructures' value and functions increase with time (UNEP, UNEP-DHI, IUCN, TCN and WRI, 2014) as the solution matures (UNEP, 2020a). However, despite their potential, NbS and NbaS much like grey infrastructure have limits to their capacities and can perform only so much before they become exhausted (UNEP-DHI et UNEP and IUCN, 2018). For instance, a wetland receiving pollutants will not maintain a constant efficiency as the concentration of pollutants increases the capacity of the wetland to neutralize/capture pollutants will decrease (UNEP, 2020a).

- Grey solutions are more certain: Grey solutions are backed up by proficient engineering research and knowledge as they are underlined by many engineering principles and technical specifications unlike EbA (or NbS and NbaS) whose rarely understood underlying principles are found dispersed in many different disciplines (UNEP and UNEP-WCMC, 2019c). For instance, when a dam is built engineers precisely know its storage capacity, underlying substrate properties, impermeability, stability, geometry, hydrological behavior, losses by leaking or infiltration etc. In the case of NbS-NbaS such precise knowledge is often difficult given the ambiguity of the science(s) behind these solutions. For example, the hydrological behavior/functions of wetland sand floodplains are much more less understood than those of engineered solutions (UN World Water Assessment Programme and UN-Water, 2018). Limited knowledge on the efficiency of NbS also discourages their use as a direct measure of their advantageous nature is often absent.

- **NbS-NbaS provide multi-benefits:** By definition, NbS and NbaS provide multi-benefits by targeting a societal problem (climate change adaptation only in the case of NbaS) and delivering co-benefits to biodiversity. Grey infrastructures on the other hand are not multifunctional and are often designed to respond to a specific challenge. Even more, while solving the intended problem, grey solutions might generate unexpected ones. In that sense, grey solutions can create a false sense of security and when coupled to unsuitable land cover expansion or human management practices they can cause great losses when they fail (UNEP, UNEP-DHI, IUCN, TCN and WRI 2014). In other cases, engineered structures such as dams have been associated with sediment starvation of downstream waterbodies [e.g. Kondolf et al. (2014)], habitat fragmentation, ecological disruption [e.g. da Silva et al. (2020)] and water quality degradation [e.g. Winton et al. (2019)].

- **Grey solutions aren't resilient to climate change:** While the main purpose of NbS-NbaS is to reduce vulnerabilities/risks and promote resilience/adapting capacities to climate change, grey infrastructures are increasingly approaching their failure limit with the progression of climate change (Browder et al., 2019). Their rigid nature, as opposed to the flexible nature of NbS-NbaS makes them statically vulnerable to climate change (Cohen-Shacham et al., 2016). Examples of grey infrastructure failure are common and most have been catastrophic (e.g. the Big Bay Dam failure, the Tiware dam and others). Nonetheless, the critical thresholds of these infrastructures are well known to engineers unlike NbS-NbaS (WRI, UNDP and World Bank, 2011).

- Grey solutions can be easily upscaled: Given the proficient knowledge and experience of engineering disciplines, grey solutions can be easily replicated, upscaled and are already mainstreamed. The same is not applicable for NbS-NbaS that are burdened by the upscaling challenge from pilot/project scales to higher levels (UN World Water Assessment Programme and UN-Water, 2018).

- **NbS-NbaS are more sustainable:** While unsustainability can be largely affiliated to the development of grey cover (Al Sayah et al., 2021; Al Sayah et al., 2019), sustainability can be affiliated to nature-based activities. This element is clearly addressed in NbS-NbaS framework and their role as potent tools for achieving the SDGs has been widely discussed in literature. According to the UN World Water Assessment Programme and UN-Water (2018), NbS share the three basic principles of implementing the SDGs: indivisibility (one goal cannot be achieved without the others), inclusion (no one is left behind) and acceleration (by focusing on actions that have multiple development benefits). In turn, infrastructure also influence both directly and indirectly the achievement of all 17 SDGs, in fact, 92% of the 169 SDGs targets are related to infrastructure (UNEP, 2021c). Accordingly, the concept of sustainable infrastructure is gaining attention globally (UNEP, 2021c) but yet significant efforts need to be done. At this stage, two directly relevant SDGs can be considered: SDG 9 sustainable industry, innovation and infrastructure, and SDG 11 sustainable cities and communities. Both offer platforms for the integration of the sustainability dimension into existing grey infrastructure. Hence, a coupling between grey and green solutions is encouraged.

- Financial, governance, legislative frameworks, public acceptance, availability of space and stakeholder perception are additional elements that increase the dividend between grey and green solutions. For instance, a case study in Nanterre France showed that the annual cost of alternative rainwater network management in the park of Chenvreux ranged between 6.33 and 11.06 euros/m^3 while that of a grey infrastructure in the rue Anatole-France, in Levallois-Perret, was around 37.07 euros/m^3 for the same amount of water (Barra, 2019). However, these parameters are beyond the scope of this report but were mentioned to complete the comparative framework of green and grey solutions

As can be noticed, most of the green-grey debate is focused on water-related challenges (e.g. hydrometeorological hazards, floods, water quality, sea level rise, water supply, runoff, etc.) and solutions. This is due to the fact that water management has strongly relied on engineering approaches for a long time (Fekete and Bogárdi, 2015) and most probably will continue to do so. However, as the potential of NbS-NbaS for water management remains largely under-utilized (UN World Water Assessment Programme and UN-Water, 2018), more research efforts are needed to provide answers concerning their contribution. In any case (green, grey or blue-green), the preference of any solution will depend on the local context (UNEP, 2021a); for what is applicable in a developed megacity is not necessarily transposable to a rural context in a developed country. In real life conditions, grey covers have already expanded and will continue to do so with ever growing populations. Therefore, it is not logical nor realistic to advocate for the replacement of grey by green. Equally, it isn't logical to assume that NbS-NbaS are completely capable of performing the role or functions of grey infrastructures. In the case of megacities such as Paris, waiting for NbS-NbaS to perform their water quality regulation role and provide drinking water to the population is absurd. Even more, the distribution of water from source to destination cannot happen without pipes or engineered delivery systems. Therefore, NbS-NbaS ought to co-exist with the "grey".

To this end, several approaches consider greening or hybridizing the grey. In that sense, hybrid NbS (and NbaS) can be used to challenge siloed approaches and multiply the expected benefits (UNFCCC, 2020) as mutually supportive solutions. However, hybrid adaptation approaches are more than just greening the grey, as they combine both elements to reduce the limitations and maximize the advantages of each simultaneously (UNEP and UNEP-WCMC 2019c). They can be considered as a mix of ecology and engineering and thus a manifestation of ecological engineering (UNEP and UNEP-WCMC 2019c). Hybrid NbS are mostly utilized for flood risk management (Sahani et al., 2019). According to Gammie and De Bievre (2015) in Sonneveld et al., (2018), NbS that couple both existing grey structures and green solutions were capable of decreasing dry-season water deficits by 90% with lower costs than grey solutions alone. As has been mentioned previously, combining both solutions will account for the weaknesses and maximize the potential for each.

That way, returns on investments for both solutions will be secured as green solutions may extend the lifetime of existing grey infrastructures (UNEP-DHI, UNEP and IUCN 2018).

In terms NbaS, effective adaptation will necessitate the implementation of different adaptation measures (UNEP and UNEP-WCMC 2019c). Therefore, a combination of solutions is needed. While EbA occupies the green zone, NbaS can move along the scale and include the hybrid zones with solutions like green facades, green roofs, urban parks and gardens, etc. (UNEP and UNEP-WCMC 2019c). As climate change and its related water challenges (flooding and hydrometeorological hazards) encompass risk, the introduction of ecosystems into green infrastructure is particularly relevant since it can significantly improve risk reduction (UN World Water Assessment Programme and UN-Water, 2018). While 90 trillion US$ will be needed for green infrastructure over the next 15 years, currently only about 3-4 trillion US$ are only spent (Sonneveld et al., 2018). As more research on the interaction between grey and NbS is needed (Kabisch et al., 2016), this certainly can be considered as an incentive for further research on NbaS-grey solutions interactions.

b.2 Protected areas

Going back to Table 2 and in view of the potential of protected areas, the current state of knowledge on these solutions is explained. Presently, only less than 15% of the global terrestrial and inland water, slightly more than 10% of coastal and marine area and nearly 4% of the oceans are covered by protected areas and contribute to CCA and DRR (UNEP-WCMC and IUCN, 2016). By definition, protected areas are defined geographical zones that receive considerable legal or other forms of protection and attention because of their ecological, cultural or natural values[16]. These ecosystems can be terrestrial, marine or coastal and are considered as central elements for DRR and CCA (Dudley et al., 2010). Yet research on the role of protected areas is still not sufficient to fully understand their potential, and significant knowledge/scientific gaps are prevalent (IUCN, 2014). Further, the perception on protected areas as secluded entities has led to their inefficient management, which according to research will reduce their coping responses to climate change (Dudley et al., 2010). Therefore, increasing the size of protected areas, their coverage, connectivity and inclusive management should be envisaged for scaling them up and amplifying their role in action on climate change (Dudley et al., 2010). According to the IUCN (2014) they should be considered as part of a larger conservation strategy that encompasses ecosystem approaches dispersed throughout the landscape. This can be done by increasing their connectivity via ecological corridors or buffer zones thus simultaneously ensuring co-benefits to biodiversity by habitat connectivity and increased fauna/flora migration (Dudley et al., 2010). Consequently, the stronger biodiversity-climate link will promote ecosystemic resilience and the role of these solutions for CCA.

In the case of marine protected areas, the lack of integration of climate change likely exposes highly resilient areas to exhaustive use due to limited attention (IUCN, 2014). While this may be due to the poor understanding of the ocean's feedback into the climatic system and the effects of climate change and variability on marine ecosystems (IUCN, 2010), the marine realm is complex because even without the stress of climate change it already suffers from many burdening factors such as fishery, pollution, eutrophication, tourism and other factors (Dudley et al., 2010).

A very important element that can be extracted from knowledge on protected areas is the importance of connectivity. This concept can be transposed to the case of NbaS which can also benefit from increased connectivity. For example, ecological corridors to connect urban parks, riparian buffers to connect mangroves, grass ways to connect wetlands, etc. However this will depend on the availability of lands, the scale of implementation and type of solution (clearly, it isn't possible to connect green roofs or façades at the scale of buildings). The connectivity of solutions will imply a connectivity of ecosystems which in turn will require a transdisciplinary research and planning approach. While this aspect is important it calls for the development of a relevant line of research.

[16] Adapted from: https://www.iucn.org/theme/protected-areas/about

Post scriptum: General facts on some solutions

- NbS are geographically specific: For instance, Baig et al. (2016) showed that upland and floodplain forest-based NbaS are not frequent throughout the Pacific, instead, coastal and marine ecosystem solutions have a larger spectrum of application.
- Green solutions in urban environments are challenged by the insufficient knowledge on the impacts of climate change on biodiversity and links to ecoservices (Kabisch et al., 2016).
- The implementation of NbS can have effects on atmospheric processes. For instance, a case study in Australia showed that the conversion of forests to agricultural spaces induced modifications to bioclimatic conditions as the formation of clouds above the converted area decreased leading to reduced precipitations (IUCN French Committee, 2019).
- Most urban related NbS are taking place in developed countries and particularly focus on coastal/freshwater flooding and heat stress (UNEP, 2021a).
- Although nature-based, NbaS-NbS are very sensitive to human management. For instance, the carbon footprint and storage capacity of forests not only depends on the soil and trees present but also on the logging procedures (IUCN French Committee, 2019).
- In a mountain EbA or NbS-NbaS, a "whole slope" approach is needed (UNEP and UNEP-WCMC, 2019d). If only a part of a slope is treated in isolation of others, risk transfer along other parts are increased. This means that a combination of solutions along a single slope should be put into place. For example, in response to flooding risks or increased soil erosion, the upper steep slopes should be restored with forests in combination with lower slope agroforestry or wetland restoration, that way, a maximization of adaptation benefits is ensured along the whole gradient (UNEP and UNEP-WCMC, 2019d).
- According to the IUCN (2014), every dollar invested in the Folkestone Marine Park on the west coastal area of Barbados potentially decreases 20 dollars of hurricane-induced losses. Therefore, the potential of NbaS might not be directly tangible but their proactive nature will ensure reduction of environmental and economic losses.

c. Limitations[17]

Despite the potential of NbaS and their importance for strengthening CCA, many limitations exist. These raise the need for further research efforts as their underlying causes can be rooted to several reasons: knowledge, fundamental and implementation gaps. As mentioned previously, NbaS will have to deal with the complexity and difficulties of adaptation (detailed in section IV) in addition to the challenges that NbS usually face. The latters are of different nature (socioeconomic, funding, governance, etc.) and several works explain them abundantly. Given the scope of this report, only the scientific and conceptual challenges will be explained as reported by the institutional frameworks.

In relationship to climate change, any ecosystem-based action is governed by ecological limits: ecosystem resilience is bound by the lower levels of climate change (≤2-3°C), and impacts on ecosystems beyond this threshold will be irreversible (Colls et al., 2009). Accordingly, any targeted NbS-NbaS will only be functional provided that the lower boundaries of climate change have not been breached (UNEP, 2021a). Even if climate change remains in its lower levels, there is a need to clearly separate between anthropogenic effects and climate change impacts in order to tackle them simultaneously (IUCN, 2014). This step is needed to address the positive feedback loops between climate change and human activities. **To this end, several uncertainties regarding the response of ecological processes to human management and climate change may emerge as their tipping-points are not always known** (IUCN, 2010; UNEP and UNEP-WCMC, 2019b). Moreover, the inherent sensitivity, and adaptation capacity vary from an ecosystem to another; hence, some may be more sensitive than others and require more urgent attention (UNEP, 2021a). For that reason, vulnerability assessment is required for highlighting the most vulnerable ecosystems and subsequently designing effective interventions (IUCN, 2010). Without this approach any adaptation intervention will fail to deliver its purpose (IUCN, 2010). However, **evidence on the role of ecosystem services in reducing vulnerability to climate change/variability is still not fully understood** (UNEP, UNDP and IUCN 2012; IUCN 2010). Likewise, **the uncertainties of climate change projections and eco-socio-economic vulnerabilities should be better studied to reduce the scarcity of information on the efficiency of the proposed solutions** (UNEP, UNDP

[17] In this section the UNEP-UNEPWCMC (2019) works on EbA were used to report on limitations. As EbA are endorsed under the NbS umbrella, the mentioned limitations were used as analogous to the limitations of NbaS since: i) they are used to attend to climate change and ii) both concepts (NbaS and EbA) are based on ecosystems and their services.

and IUCN 2012). The uncertainties related to climate change can have cascading effects (WRI, UNDP and World Bank 2011) that compound those of the above-mentioned elements. That is why the relative paucity of information regarding the unceraintties of climate change's/variability's impact on humans and biota singificantly limits any adaptation response (IUCN, 2010). **Unfortunately, at present state, NbS principles do not adequately address uncertainty** (Cohen-Shacham et al. 2019). The latter is exacerbated by the site-specific nature of adaptation which raises **questions on the power of a single NbS-NbaS for addressing multi-hazards and their different levels** (UNEP, 2021a). Accordingly, a NbaS can tend to be very context-tailored, thus compounding uncertainties on their efficiency vis-à-vis ever changing climatic conditions (UNEP, 2021a). **At this stage, it is unsure which will be more effective on the long run and which will be more performant immediately after its application** (Kabisch et al., 2016).

Seddon et al. (2019) also found that there are frequently pronounced mismatches in adaptation planning between climate impacts-vulnerabilities-actions on one hand, and between actions and targets on the other. **The absence of targets is in turn one of NbS' weak spots as robust, measurable and factual goals are often lacking** (Seddon et al., 2019). Even when present, it is uncertain if the targets are sufficient to fulfill the intended adaptation needs (Seddon et al., 2019). For instance, the UNEP (2020) reports that projections of the extent to which a forest can provide protection against erosion are often inaccurate. When the climate change dimension is added (in the case of NbaS), a discontinuity between short-term actions and long-term objectives also appears (Kabisch et al., 2016). To this end, stronger evidence on NbS for CCA are needed (Kabisch et al., 2016; UNEP and UNEP-WCMC, 2019b). This lack of evidence can be due to the confusion that results from the blending NbS with other solutions, or their inconsideration as CCA measures (UNEP, 2021a; Kabisch et al., 2016). This last fact may be contradictory or debatable as the UNEP and UNEP-WCMC (2019b) recommend the implementation of EbA as part of a greater adaptation strategy along other elements. The same was recommended by the IUCN (2014) when evoking the connectivity of protected areas to wider ecosystems. **In any case, the fundamentals and applications of CCA are relatively recent (IUCN, 2010), and evidence of in relation to trade-offs and synergies between NbaS, socioeconomic conditions, biodiversity and human health are still partial** (Kabisch et al., 2016).

Under climate change also, slow-onset events such as salinization, sea level rise, drought, desertification and land degradation, etc. should be taken into consideration (UNFCCC, 2020a, 2012). **To that end, solutions to address slow-onset events are often neglected, with little to no research on specifically related NbS-NbaS** (UNEP, 2021a). It is also useful to distinguish between extreme climatic and extreme weather (meteorological) events that often do not follow the same temporal frequency (Duvernoy, 2019). Accordingly, the lack of adequate knowledge on climate change can expose resilient zones to extreme pressures due to limited attention (IUCN, 2014). On this basis, it is useful to ask if NbaS should be designed to withstand climate or weather change and how would the interaction between the first and the latter influence their efficiency, upscaling and lifetimes.

In terms of ecosystems, there is no direct separation between NbS and other human-driven ecosystem management measures (Sonneveld et al., 2018). Furthermore, the wide coverage of multiple ecosystem concepts by NbS can overestimate their potential, whereas they can only fulfill few goals simultaneously (Sonneveld et al., 2018). While NbS and NbaS are based on ecosystems and their functions, the latters are:

i. Complex and require significant ecological-technical knowledge that is still lacking (Kervinio and Vergez, 2019).

ii. Vulnerable to climate change in their own rights (Kervinio and Vergez, 2019). At this stage, the question of ecological thresholds defined by Groffman et al. (2006) as: *"The point at which there is an abrupt change in an ecosystem quality, property or phenomenon, or where small changes in an environmental driver produce large responses in the ecosystem"* should be considered during the design of NbaS. This consideration is necessary to account for the limits of adaptation and to properly understand the system's behavior (UNEP, 2021a). Accordingly, an approach encompassing natural sciences, ecology, geosciences, and social parameters is needed for obtaining accurate insights on the concerned system's boundaries, functions, interdependencies, and future evolution (Rey, 2019; UNEP, 2011). To this end, ecosystem risk assessments are being used for this purpose (UNFCCC, 2020a). However, significant efforts are still needed for accurately determining thresholds and addressing their uncertainties (IUCN, 2010).

iii. Transdisciplinary and too complex to be dealt with using a single discipline; therefore, a broad range of academic fields are needed to approach them beyond the boundaries of the scientific community by integrating scientific and context-specific knowledge (Sonneveld et al., 2018).

iv. Interdependent with various degrees, hence an ecosystem service is not provided in isolation than others (UNEP, 2008). This interdependence also means that damage to one service may also influence the others making them more or less a bundle (UNEP, 2008). Accordingly, siloed and sectoral responses targeting a single ecosystem rather than focusing on the bundle notion have generally failed (UNEP, 2008). Sonneveld et al. (2018) reported similar findings as **failed NbS interventions were attributed to an insufficient understanding of ecosystem-ecosystem services functions.**

v. Bound by thresholds that aren't evident until breached (WRI, UNDP and the World Bank, 2011). **The notion of thresholds is a significant knowledge gap that needs to be addressed to understand and determine tipping-points beyond which systems fail** (UNEP-DHI, UNEP and IUCN, 2018). In relation to point ii, these factors are needed for understanding and respecting the carrying/assimilation ability or tolerance boundaries of the concerned systems (UNEP, UNEP-DHI, IUCN, TCN and WRI 2014). Such knowledge is essential for avoiding inaccurate design and subsequent implementation that may lead to maladaptation (UNEP, 2021b).

Maladaptation and disservices are two significant limitations to consider. The first is due to the unexpected, unaccounted or unplanned disturbances of a system's ecological attributes that may harm its components [particularly biodiversity] (IUCN, 2010). On the other hand, disservices can be considered as a backfire in the plan that lead to negative outcomes. Increased proliferation of mosquitoes, allergens and land/property price as a result of green solutions or asthmatic incidences/waterborne diseases due to blue solutions are an example (e.g. Lõhmus and Balbus, 2015). However, **disservices have only recently started to appear in eco-services research** (Von Döhren and Haase, 2015 *in* Kabisch et al., 2016). Equally, for both CCA and ecosystem services, the concept of diminishing returns should be taken into consideration. This goes in the sense that adaptation measures and ecoservices tend to show rapidly diminishing returns, in which the value of these services decreases rapidly at the scale of their providing ecosystems (UNEP, 2020a). To this end, **ecosystem services and their valuation/devaluation is an element for integration into NbaS research, design and implementation**. Therefore, the assessment of risks associated with NbS should be mandatory to ensure that they will deliver solutions instead of becoming a NBProblem.

c.1. An example of reporting on evidence and NbaS limitations

de Munck et al. (2019) provided a scenario case study on the efficiency and limits of green roofs and urban parks as NbaS. The Authors reported the following results:

- Extensive greening of individual and collective buildings' roofs and of the area's reduced air conditioning demands by nearly 4% especially in the case of poorly insulated buildings.
- Energy saving becomes more pronounced (around 12%) when green roofs are watered during summer.
- The urban park significantly cooled temperatures between -2.5 and -4° C on average, with a potentially amplified effect when combined with a stream (between -3 and -6 ° C). The cooling effect is more marked at night than during the day (with a maximum between 1 a.m. and 5 a.m.).

On the other side of the coin, green roofs, even when watered have a very limited cooling potential of no more than 0.5 °C of air temperature at the street level. In the case of the urban park, the cooling effect is very localized and does not extend beyond a diameter of a few hundred meters (de Munck et al. 2019).

The irrigation of urban vegetation is primordial for taping their refreshing or buffering capacities (de Munck et al. 2019). Nonetheless, this issue raises two main problems: i) increased water resource consumption and stress especially during summer or drought periods and ii) increasing costs at the expense of benefits (Paço et al., 2019). Even if a range of suitable species (e.g. drought tolerant species) are introduced based on biogeography and functional capacities (Lundholm et al., 2015), the synergistic and antagonistic effects of several forms of vegetation are not yet well known (de Munck et al. 2019). While this discussion only targeted the cooling effects of green roofs (single objective), much more complications are added when other objectives are also included (e.g. stormwater management). Accordingly, the multifunctionality of NbS-NbaS may be a double-edged sword that influence their perfectionist nature. For that reason, extensive planning, research and scientific investigations should be carried out prior to the design of a NbaS. The integration of "harder" science behind NbS is needed to ensure a maximal distance from "greenwashing" while accounting for the complexities of adaptation.

VI. Conclusion and recommendations

VI.1 NbaS in the international landscape

Despite a relative recent emergence the term NbaS has been evolving with time and its applications are widespread. In terms of etymology, the concept appears under its NbaS name and as "NbS for adaptation" or as "NbS for climate change adaptation". In terms of implementation, the review of NDCs showed that NbS for climate change adaptation are being increasingly sought and that the role of NbS is gaining more recent momentum in the international landscape. As the UNEP (2021a) highlighted, NbaS are being used to address coastal hazards, extreme precipitations, droughts, and temperature rises in a multitude of environments. While their use depends on the reigning priorities, NbaS are responding to a set of challenges that mostly revolve around food and water security, climate change adaptation and/or mitigation, and disaster risk reduction. Human health, the economy and natural capital preservation (by adaptation) are also addressed. With reference to definition of NbaS adopted in the ARTISAN project, the occurrence in NbaS in the retained reports answers all the listed elements:

« Les solutions fondées sur la nature visent plusieurs défis sociétaux, les SafN n'en visent qu'un seul : l'adaptation au changement climatique :

- Adaptation à l'élévation du niveau de la mer (inondations et érosion des zones côtières, risques sanitaires, enjeux économiques) ✓
- Adaptation aux conditions météorologiques extrêmes et aux modifications des précipitations ✓ (inondations et enjeux liés à la qualité de l'eau et de sa disponibilité, risques sanitaires et économiques)
- Adaptation à la hausse de la température (vague de chaleurs, incendies de forêts, épisodes de sécheresse, risque sanitaire, augmentation de la pollution locale, modification de la consommation d'énergie et enjeux économiques, fonte des neiges) ✓
- Adaptation des écosystèmes terrestres et marins ✓
- Adaptation de la production alimentaire, santé, économie…✓ »

The beginnings of NbaS can be affiliated to the work of the IUCN and particularly its French Committee. Onwards, the UN Climate Action Summit and its NbS manifesto gave proof of NbS' increasing recognition. Equally, the UN Decade on Ecosystem Restoration 2021-2030 paved the way forward for the upcoming years and placed NbS as central strategies for CCA [hence NbaS] (UNFCCC, 2020a). For NbaS the increasing push behind CCA and adaptation as a process are of particular relevance. As the importance of adaptation is rising in prominence, means for achieving its goals are needed. Seemingly, NbaS are trusted to be reliable tools for the purpose. Yet, despite these ambitions, it is necessary to keep in mind that an adaptive system is a learning system (UNFCCC, 2021). Therefore, significant efforts are needed to aliment NbaS and attend to their challenges. This demanding nature comes from the integration of adaptation into the NbS framework as the former requires continuous calibration given its cyclical and iterative nature (UNFCCC, 2018).

VI.2 Environments and solutions to put forward

Current trends revealed that some environments are relatively underrepresented. This is particularly the case of the mountainous and natural media that are rarely targeted as complete systems. The same is applicable for the oceanic medium that is even less addressed along with relevant NbaS. The high interest in food (agriculture) and water security (freshwater and coastal media) is justified by the concerns of meeting the growing global population's needs. This same motive also explains the interest in the urban realm. The most adopted NbaS were found to be green solutions of different types (e.g. green corridors, green roofs, permeable pavements, etc.) with a clear dominance of forestry related activities (agroforestry, afforestation and reforestation). Coastal solutions come in second place and are mainly presented by mangrove forests and dunes.

Nonetheless there is a need to think beyond green. Other equally potent solutions were found to be underrepresented, peatlands (UNEP, 2019) and blue carbon ecosystems (UNEP, 2020b) are relevant examples. Despite the important attention given to soils and lands, both aren't sufficiently treated as distinct sensitive ecosystems nor as solutions. While both are indispensable substrates for supporting human activities, expansion and food production, they aren't sufficiently addressed. This may be due to two main reasons: i) the misconception of the urban society's disconnection to soils in contrast to the rural society's dependence on soils that led to decreasing interests and reduced contact with soils (FAO and ITPS, 2015) and ii) the false conception of the global abundance of soils (Dooley et al., 2015). The only contribution devoted to land was the UNEP IRP (2019) report that highlighted the role of lands and soils for responding to different challenges. According to the IRP (2019) improving land and soil quality will strengthen adaptation capacities to climate change, extreme weather, droughts and other disasters. It will also provide co-benefits other than CCA (similar to other NbaS) by promoting biodiversity and enhancing the functional diversities of ecosystems (IRP, 2019).

The rationale for considering lands and soils as efficient NbaS is as follows:

Condition: An NbS solution encompasses the restoration, conservation or protection of ecosystems (IUCN, 2020) while NbaS adds the CCA layer.

Answer: Land restoration and sustainable management (conservation/protection) are directly relevant activities to the NbS framework. The FAO reports that soils and lands are the largest sinks of terrestrial carbon. Their organic Carbon content is considered as one of the most cost-effective measures for both CCA and mitigation in addition to combatting desertification, land degradation and food insecurity (FAO, 2019). In simple terms, healthy soils will store carbon that will increase their organic Carbon content and hence their fertility and functions (Dlamini et al., 2014). This in turn will make soils and their related activities more resilient to climate change and increase their adaptive capacities (IRP, 2019) [NbaS function]. Conversely, degraded soils will release carbon and amplify greenhouse gas emissions (Cossio et al., 2012). Given the climate-land feedback loops (Ioras et al., 2014), soils and lands can either complicate climate change or contribute in the fight against it.

Condition: An NbS should contribute to a societal challenge (in addition to conserving biodiversity) by relying on ecosystems and delivering co-benefits to biodiversity (IUCN French Committee, 2019).

The status of soil and lands as ecosystems is no longer debatable, it is more than a substrate to support other activities as it is characterized by a wealth of organisms, microbiota and essential components (Ponge, 2015). With respect to the IUCN's (2020) societal challenges, soils can directly respond to CCA and mitigation (explained above), food security, and socio-economic development. The ecological attributes of a healthy soil then deliver co-benefits to biodiversity by sustaining soil organisms that can control phyto-diseases, establish symbiotic relationships with plant roots, ensure nutrient cycling/recycling and support a wide range of fauna and flora (FAO, 2009).

Therefore, the integration of soils and lands as a target media and as NbaS is a recommended. Recent scientific evidence have confirmed that land-based solutions are needed for effective action on climate. Similarly, other untapped solutions should be further studied to reveal their potential and increase their use.

VI.3 Enhancing the science behind NbS and NbaS

While many eco-services provided by NbS and NbaS are related to "hard science" disciplines (e.g. physical, biological and chemical processes), the NbS framework seems to overlook this dimension. This simplification might be intentional for ensuring a widespread diffusion of the concept among different target audiences. Yet, one of the most prevalent challenges highlighted was the lack of evidence reporting, metrics and efficiency assessments. This problem is particularly pronounced in the case of NbS for CCA and mitigation (van Ham and Klimmek, 2017). To bridge this gap, the integration of hard sciences is needed as they are the main providers of quantifiable outcomes and results. In the case of NbaS, several functions and processes can be related to different disciplines, for example: hydrological parameters such as cooling by evapotranspiration and energy balance, and reduction of runoff through infiltration and regulation of discharges[18]. Also, the efficiency of NbaS is governed by reigning properties that are in turn rooted to scientific disciplines, for example: substrate behavior in green solutions directly relates to the pedology of the concerned settings, while

[18] Refer to Versini et al. (2020, 2018, 2015) for research evidence on the performance and efficiency of green roofs.

the choice of species for vegetation lies in the domain of ecology. Currently, these elements are rarely discussed even if they are taken into consideration, and NbS-NbaS are often perceived and represented from a practitioner's point of view. Clearly, the NbS-NbaS framework is in need of a transversal approach that cuts-across "harder" disciplines and takes into consideration the spatio-temporal variation of processes.

In the case of NbaS, the temporal dimension is particularly relevant since climate change is also a time-bound and time-variable process. Therefore, prior to the implementation of any NbaS three temporal scales should be targeted: the pre-NbaS, peri-NbaS and post-NbaS conditions. The first encompasses the use of current and historical climate data, the second utilizes current data while the third has to integrate future projections and compare changes with respect to baseline conditions. Given the large uncertainties regarding the evolution of future climate, the third phase can be very challenging and will require significant efforts for reducing uncertainties. Per example, Japan's National Action Plan revealed many challenges when dealing with the uncertainties of IPCC scenarios and mitigation pathways (UNFCCC, 2021).

Several research needs were raised in the section of adaptation and the section on the limitations of NbS-NbaS. These findings stress the need to extend beyond research on environmental impacts and englobe a study of the synergies, antagonism, expected targets and delivered outcomes. Some NbS-NbaS limitations are presented in the box below to summarize some of the most relevant elements. Keeping in mind that climate change is transversal to all media, and that ecosystems do not exist in isolation from others but rather as a mosaic of environments, a multidisciplinary approach is needed to account for the interconnectivity of media and their interactions. The difficulty of NbaS is that they require further research in both their climatic (CCA) and NbS compartments. Accordingly, the integration of hard sciences is needed for responding to the stated research needs.

Summary box for NbS-NbaS fundamental challenges:

- Several uncertainties regarding the response of ecological processes to human management and climate change may emerge as their tipping-points are not always known.
- Evidence on the role of ecosystem services in reducing vulnerability to climate change/variability is still not fully understood.
- The uncertainties of climate change projections and eco-socio-economic vulnerabilities should be better studied to reduce the scarcity of information on the efficiency of the proposed solutions.
- At present state, NbS principles do not adequately address uncertainty.
- Skepticism on the power of a single NbS-NbaS for addressing multi-hazards and their different levels.
- It is unsure which NbaS will be more effective on the long run and which will be more performant immediately after its application.
- The absence of targets is one of NbS' weak spots as robust, measurable and factual goals are often lacking.
- In any case, the fundamentals and applications of CCA are relatively recent and evidence of in relation to trade-offs and synergies between NbaS, socioeconomic conditions, biodiversity and human health are still partial.
- Solutions to address slow-onset events are often neglected, with little to no research on specifically related NbS-NbaS. NbS are in turn sensitive systems to climate change and should not be treated as immune solutions.
- Failed NbS interventions were attributed to an insufficient understanding of ecosystem-ecosystem services functions.
- The notion of thresholds is a significant knowledge gap that needs to be addressed to understand and determine tipping-points beyond which systems fail.
- Disservices have only recently started to appear in eco-services research.
- Ecosystem services and their valuation/devaluation is an element for integration into NbaS research, design and implementation.

While these challenges are common to NbS and NbaS, the adaptation challenges detailed in the corresponding section compound the complexity of NbaS. Research in these domains cannot be monodisciplinary as it will oversimplify the reality of the NbS-environment-climate link (Sonneveld et al., 2018).

VI.4 Designing NbaS based on knowledge: A roadmap

The IUCN (2020) set eight criteria and several indicators to ensure the clarity of NbS as a concept as the success of its implementation. In analogy to their work, an adaptation of the UNFCCC's roadmap (UNFCCC 2020b) was made for proposing a NbaS design plan while taking into consideration the several listed research challenges.

1- Assessing climate risks

- Determine what the reigning climatic challenge is (e.g. drought, flood, intense precipitation, etc.) while taking into consideration the different climatic regimes even within the same context. For instance, in the case of France the southern Mediterranean climate will require a different approach than the temperate oceanic climate of the central region. This is due to the fact that the evolution of both climate types is not the same, making climatic risks in turn different and heterogeneous.

- Conduct a vulnerability assessment to determine which ecosystems are in need for immediate attention and to categorize others into different levels (highly vulnerable, moderately vulnerable, and low to not vulnerable). Naturally, these assessment will differ according to the targeted sector, geographic extent and timeframe (UNFCCCC, 2011). In case of a coastal environment, both land-based and sea-based risks should be considered for ensuring an accurate representation (UNFCCC, 2020a).

- Consider the mosaic of media instead of treating environments as isolated entities to account for the interconnectivity and interdependence of media. This comes from the fact that ecological services and thresholds are not bound by geographical boundaries and cascading effects can be expected.

- Measure pre-NbaS conditions to establish a baseline that will be used to track outcomes and determine efficiency. Ideally, if weather station data is available its integration is better than the use of global datasets since the uncertainties are less.

- The future evolution of climate change and its impacts on the concerned setting should also be incorporated to provide the expected effects.

- Set priority goals and targets. While this step is a significant roadblock, a set of targets should be present for accurately navigating the adaptation challenge and set a goal for the proposed solutions. Targets can be quantitative and qualitative. In the case of a NbaS for reducing the urban heat island effect quantitative targets can be changes in day/night time temperatures, while qualitative targets can be positive changes in the well-being of the city's inhabitants or reduced uses of air conditioning systems. Naturally, this task isn't completely straightforward but synergizing both adaptation and mitigation can be considered as a compromise. The logic behind this statement is that mitigation targets are more quantifiable and hence can be used to complement the descriptive or evaluative metrics of adaptation (UNEP, 2017).

2- Planning for adaptation

- Assess a wide variety of NbaS for choosing the best possible candidate based on its expected impacts, feasibility, cost, and ease of monitoring. The scale of implementation should be also taken into consideration while adopting a "thinking beyond green" mentality.

- Consider the interaction among the different NbaS for avoiding antagonistic effects. For example, a wetland installed next to an agroforestry parcel can receive inputs of agricultural pollutants from the neighboring parcel. Accordingly, the assimilative capacity of the wetlands and its useful lifetime will be considerably affected. Therefore, the co-existence of several solutions should be closely studied to avoid maladaptation, disservices or relapses

- Assess disservices, times of relapse and potential failure scenarios and impacts.

- Consider the inherent sensitivity of the chosen NbaS with respect to climate change since these are not completely immune systems to climate change and might be affected by the process.

- Conserve a degree of flexibility to adapt the chosen solution in function of the changing conditions (particularly climatic ones).

3- Implementing the chosen solution and monitoring its efficiency

- Once the proper NbaS is chosen and implemented, its efficiency should be monitored. Despite the fact that NbS may take a long time to become fully mature - particularly in the case of vegetation-based solutions - monitoring should be carried out during the earliest stages to ensure that the solution is functioning as planned. The aim of the peri-NbaS monitoring is to provide feedbacks or insights whether the planning phase should be modified or not.

- When negative findings (metrics) revealing that the proposed solution is losing efficiency the whole design cycle should restart again. This goes in the sense that the proposed NbaS doesn't have a permanent efficiency (in the case of hybrid solutions) and that it has a certain lifetime (trees or wetland services). Further, given the dynamics of climate change the adopted NbaS should not be considered as a rigid solution but should rather evolve with time as climate.

Concluding remarks

The aim of this chapter was to study the evolution of NbaS with time in the international landscape. Many findings resulted and several research needs were highlighted. While certainly important, the NbaS concept is still in early emergence and much still needs to be done. The work of the studied institutions highlighted NbaS as the way forward, yet it seems it hasn't reached a full sphere of acknowledgment as the IPCC still favors EbA. As has been shown through the chapter NbaS – while very important - are not as simple as they seem. The science behind them is still untapped and the complexity of adaptation only compounds the difficulties that the NbS framework faces. Although coming back to nature is a sensible and reasonable solution, proof of this approach's superiority is still not completely decisive in all sectors. For instance, the cooling capacity of vegetation is well acknowledged and proved, however their role in water management and hydrology is not as clear. Further, the complex problems that humanity face cannot wait for a NbaS to come fully mature and deliver it benefits. Accordingly, NbaS should not be viewed as "the" answer but instead should be part of a broader matrix of solutions. As mentioned previously, the findings of this chapter are not undebatable as the sample choice and size may induce a certain degree of error. However, the error margin was reduced as much as possible by filtering the documents thoroughly and by avoiding assumptions. To that end, all the chapter's findings are referenced to their corresponding works to ensure the least possible errors. It should also be mentioned that the chosen organizations are not pure research institutions. However, since the concept was born in the works of international organizations, related knowledge and progress were studied to understand its history, evolution and progression.

In an effort to draw scientific answers on NbS-NbaS, the European Union has placed significant monetary resources on related research through the H2020 program. Accordingly, an investigation of several related projects and their findings will be presented in the following chapter.

Annex A: Retained UNEP reports (oldest-newest)

1- UNEP ecosystem management programme: An ecosystem approach – *2008*

2- CCCC kick the habit – a UN guide to climate neutrality – *2008*.

3- Decision making in a changing climate – Adaptation challenges and choices – *2011*.

4- Taking steps toward marine and coastal ecosystem-based management an introductory guide *2011*.

5- Making the Case for Ecosystem-based Adaptation Building Resilience to Climate Change – *2012*.

6- The Ecosystem-based Disaster Risk Reduction Case Study and Exercise Source Book – *2014*.

7- Green infrastructure guide for water management – EbM approaches for water-related infrastructure projects – *2014*.

8- Promoting ecosystems for disaster risk reduction and climate change adaptation: Opportunities for integration – *2015*.

9- UNEP Medium Term Strategy 2018-2021 - *2016*.

10- Protected Planet Report 2016: How protected areas contribute to achieving global targets for biodiversity – *2016*.

11- The Adaptation Gap Report. Towards Global Assessment – *2017*.

12- Our Planet: The First United Nations Environment Assembly –*2017*.

13- Nature-Based Solutions for Water Management: A Primer – *2018*.

14- Emissions Gap Report 2019 – *2019*.

15- The Nature-Based Solutions for Climate Manifesto Developed for the UN Climate Action Summit 2019 - *2019*.

16- Climate Change and the Ocean - adaptation strategies for fisheries and aquaculture – *2019*

17- FAO contribution to the Nature Based Solutions work stream for the Climate Action Summit – Recarbonization of global soils: a facility for implementing the Koronivia joint work on agriculture (KJWA) with focus on agricultural and degraded soils – *2019*.

18- Making EbA an effective part of balanced adaptation strategies: Introducing the UNEP EbA briefing notes Briefing note 1 – *2019*.

19- Navigating the adaptation challenge Briefing note 2– *2019*.

20- EbA in different ecosystems: placing measures in context – Briefing note 3- *2019*.

21- Selecting complementary adaptation measures Briefing note 4 – *2019*.

22- Developing the economic case for EbA – Briefing note 5 – *2019*.

23- UNEP and EbA Briefing note 7 – *2019*.

24- Engaging with the Nature-Based Solutions coalition for the Climate Action Summit- *2019*.

25- Bamboo for Climate Change – *2019*.

26- Contribution to Track #6 Nature-Based Solutions by the EU/European Commission drawing on existing policies and strategies – *2019*.

27- Land Restoration for Achieving the Sustainable Development Goals an international resource panel think piece – *2019*.

28- Peatlands rewetting, restoration and conservation offers a low-cost, low-tech, high impact Nature-Based Solution for Climate Action – *2019*.

29- Nature-Based Solutions Workstream Contribution on Soil Carbon – *2019*.

30- Letter from the Executive Director UNEP in 2020 – *2020*.

31- Economics of Nature-based Solutions: Current Status and Future Priorities – *2020*.

32- Global status report for buildings and construction: Towards a zero-emissions, efficient and resilient buildings and construction sector– *2020.*

33- Human rights, the environment and COVID-19 – *2020.*

34- Multi-partner trust fund for the UN Decade on Ecosystem Restoration 2021-2030 – *2020.*

35- Enhancing Nationally Determined Contributions through Nature-Based Solutions and Resource Efficiency – *2020*.

36- Opportunities and Challenges for Community-Based Seagrass Conservation – *2020*.

37- Global Risks Report 2020 Insight report 15th Edition – *2020*.

38- Making Peace with Nature a scientific blueprint to tackle the climate, biodiversity and pollution emergencies – *2021.*

39- Nature for Climate Action – *2021*.

40- Step up climate change adaptation or face serious human and economic damage - Aligned to the Adaptation Gap Report – UN report – *2021*.

41- For people and planet: the United Nations Environment Programme strategy for 2022–2025 to tackle climate change, loss of nature and pollution – *2021*.

42- Adaptation gap report 2020 key messages – Adaptation Gap Report 2020 - *2021*

43- Adaptation Gap Report 2020 –- *2021*.

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Chapter 2 – The regional scale approach

"Rapidly growing cities in low and middle income countries need to learn from – and avoid – the mistakes of European and North American cities." – Anne Hidalgo, Mayor of Paris (Our Planet UNEP, 2017)

Summary

This chapter presents findings from the analysis of deliverables from Horizon 2020 (H2020) projects. The regional scale is the second level of the multi-scale approach and was chosen to study European trends. This analysis allowed the establishment of a European "*état des lieux*" for NbS-NbaS. It also served to study the transition to NbaS as Europe aims to position itself as the world's leader in NbS. In relation to the previous scale, the regional approach allowed to situate Europe with respect to global trends and progress. The main advantage of this level is that the analysis of reports issued by H2020 projects revealed findings from pilot sites that have already implemented NbS-NbaS or are expected to do so. Accordingly, the results obtained reflect actual outcomes from field applications, while projects that did not implement their solutions provided a substantial amount of relevant knowledge. With increasing trends of urbanization and city development, climate change adaptation is a pressing challenge in Europe, and urgent actions are needed. Accordingly, adaptation strategies are needed to cope with the current climatic effects and to anticipate future ones. To this end, NbS and climate change adaptation are high on European priority agendas and are trusted to be the way forward.

The H2020 programme was chosen since it corresponds to and reflects the role of the European Commission in research and innovation on NbS, in allocating funds for NbS, and in the production of tools, databases and scientific contributions. As aligned with European priorities, the urban realm presents a clear dominance as the medium of interest. While H2020 is one of the world's biggest efforts for NbS, the programme is relatively recent and dates back no longer than 2014. The integration of NbS into the programme happened in 2015. Accordingly, NbaS are still relatively recent and are continuously evolving with the advance of the projects, science and policies. However, it is important to mention that climate change adaptation is not a recent interest in Europe. In fact, the EU has continuously adopted strategies for climate change adaptation under which the most recent one (24/02/2021) positions NbS for climate change adaptation (hence NbaS) as one of its three cross-cutting priorities. Accordingly, the NbaS-CCA nexus in Europe is under continuous evolution and efforts for unlocking all its aspects are still undergoing. To this end, this review compiles these efforts from different backgrounds into a state-of-the-art on knowledge, highlights extracted knowledge needs and proposes relevant perspectives for research.

On the NbaS terminology

Under the H2020 programme the NbaS terminology appears as Nature-based Solutions for climate change adaptation. They are also often stressed as a potential tool to achieve both adaptation and mitigation angles of climate resilience. A very pronounced interest in NbS-NbaS for DRR is apparent with a strong focus on hydrometeorological hazard and risk reduction. In this context, floods are the most targeted challenges within the different ecosystems. Much as mentioned throughout the different references, NbS-NbaS are coined at the European level. In this level, significant theoretical, fundamental, technical, technological, and socio/political/economic knowledge is produced and or reviewed in the different projects.

The coupling European settings to other contexts (namely Asian and Latin American cities) shows that Europe aims to extend its experience throughout the world, thus solidifying its position as the leader and pioneers of NbS-NbaS. The surge of NbaS presented through the H2020 programme offers a platform for studying these solutions from both R&D and operational perspectives. The heavy action of the EU aims to ensure the uptake and mainstreaming of NbS-NbaS in development planning and policies as part of the continent's resilience future. Accordingly, the EU's momentum is considered as the fuel for the paradigm shift using NbS and NbaS.

Types of NbaS

A plethora of NbaS is presented and discussed throughout the different projects. A compiled classification and detailed explanations of each are presented in the Annex section of this report (Tables in Annex A). Yet, similar to the international scale approach, the dominant interest in green solutions (particularly urban ones) is very apparent. Some of the most common examples are green roofs, urban parks, urban forests, ecological

corridors, agroecology, afforestation, reforestation, permeable pavements, etc. This distribution is due to the dominance of the urban realm in most of the projects, urban related NbaS are the most common. Solutions related to water encompass several types of approaches, namely river surfacing, giving room to the river, aquifer storage, disconnection of draining canals, river bed vegetation, etc. Interestingly, some H2020 projects deal with unclassical NbS-NbaS that are usually underrepresented or overlooked. For instance, live cribwalls, palisades, pole drains, ground anchors, microbe assisted seed mixtures, coal remediation, wood allotments, aquaponics, fruit walls, as well as natural sealing of leaky streams (among others) are presented. Pollination is also an element of focus in several projects with considerable importance given to the role of pollinators in maintaining healthy and functional ecosystems. Protected areas are also acknowledged as important solutions yet are underrepresented, and hybridizing the "grey" is amply called for. Regardless of the environments, an interesting aspect in some projects is the call for connecting NbS-NbaS by means of other ones. Per example, urban parks are planned to be connected by ecological corridors or greenways (NbS-NbaS in their own right). That way, the NbS connection maximizes the efficiency of both solutions and taps the potential of their "ecotones".

The most commonly addressed climatic challenges were found to be urban heat islands, coastal hazards, flash floods, sea level rise, heavy rainfall, temperature rises, heat stress, erosion, landslides, and storm surges. Another tier of challenges is focused on socioeconomic disadvantages, social inequities, vulnerable populations' status, human health, environmental and resource degradation, overpopulation, air quality, reduction of green cover, agricultural decline, social cohesion and the insurance value of ecosystems.

Biomes (environments) and priority sectors

While ecosystems are at the heart of all projects, a clear dominance of the urban medium is observed. Accordingly the distribution of media by projects is as follows: 61% urban, 15% freshwater environments, 9% maritime and coastal environments, 9% natural (including forested) settings, 3% mountainous contexts and 3% all media (e.g. the ThinkNature platform). The dominance of the urban realm is attributed to the priorities of the EU where the level of urbanization is expected to increase to 83.7% in 2050, and built-up areas are foreseen to expand to 7% of the EU's surface by 2030[19]. To this end, most pilot sites are in European cities and neighborhoods. The watershed scale is regarded as a functional unit in different projects. Several sectors such as human health (particularly for vulnerable groups), sustainable consumption and use of resources, food networks and security, environmental protection, and socioeconomic well-being are studied. In all projects, the urban environment is considered as a complex system that needs to overcome shocks and develop resilience. Accordingly, the urban environment is approached from different angles and diverse thematics. Unsurprisingly, water is a directly and indirectly central element in all projects and so are hydrometeorological hazards. A great part of the projects considerably focuses on the occurrence of natural hazards with heavy rainfall and floods as some of the most prevalent. Water as a medium is also fairly targeted through several related projects focusing on riverine, estuary, freshwater environments and maritime-coastal settings. Similar to the international scale, the mountainous environment is rarely targeted (only one project PHUSICOS), despite the acknowledgment of its importance. While the media of intervention are project-based, the importance of connectivity is recognized throughout the course of most projects. To that end, the concept of connectivity between people and the environment on one hand, and between ecosystems in the studied settings on the other is clearly underlined.

Gaps and limits of NbaS

Several gaps and limits were found throughout this report. Below is a non-exhaustive list that summarizes some of the most recurring ones (for example and not limited to). However, each section of this chapter contains further gaps and limits that cover a wide range of topics. To this end, a separation between current knowledge and limits is presented in the course of this chapter.

- In terms of study media: the agricultural ecosystem is only targeted through minor interventions in specific study areas with no projects dedicated to this medium. Only one project EdiCitNet, deals with urban agriculture through edible solutions. However, for its most part, the above-mentioned project focuses on the urban realm more than the agricultural counterpart.

[19] https://knowledge4policy.ec.europa.eu/foresight/topic/continuing-urbanisation/developments-and-forecasts-on-continuing-urbanisation_en

- **In terms of solutions typology:** most presented solutions correspond to Type 3 NbS (management of ecosystems in extensive ways – new ecosystems) that target the management or creation of new ecosystems. Consequently, a lesser focus on Type 2 NbS (some interventions in managed ecosystems and landscapes) is given, while Type 1 (minimal interventions – protected ecosystems) are relatively rarely to never targeted. Accordingly, the contribution and role of protected areas is relatively underrepresented.

- In terms of ecosystems and ecosystem services: the concept is presented in a very anthropocentric way, often overlooking the value of nature within and constraining it to a monetary instrument instead.

- Understanding ecosystem tipping points and ecological thresholds is a must. Currently, very few to no efforts focus on these central elements.

- An understanding of the supply and demand of ecosystems and their services in complex multidimensional contexts is still limited.

- The lack of systematic quantification of ecosystem service benefits for NbS for climate change [NbaS and NbS for CCM] is prevalent.

- Often, ecoservices provision is measured using annual mean values despite the existence of considerable intra-annual or seasonal variations. Overlooking the latter can significantly influence the accuracy of ecoservices provision calculation.

- The existence of a spatial discrepancy between the location of the sought solution and the location of the ecoservices' beneficiaries.

In terms of NbS-NbaS:

- Most NbS-NbaS knowledge gaps come from the lack of integration across disciplines and from not knowing/adopting knowledge from other fields of study.

- A leap beyond conservationism is needed for fully leveraging the use of NbS-NbaS.

- A solid understanding of nature's and systems' complexity is needed to unlock the full potential of these solutions and for upscaling them.

- The labelling of the NbS challenges as societal makes the concept tip towards more practice-centered orientations rather than knowledge generation or science-focused priorities. Moreover, under any context, the definition of the societal/environmental challenge to be targeted by NbS-NbaS should be an ongoing process.

- While many projects generate(d) substantial amount of knowledge, most of their approaches are still demonstration or pilot-site interventions. Accordingly, these often take the form of awareness-raising elements rather than generators of physical knowledge.

- Regardless of the type of knowledge generated, the narrow focus on specific scales (pilot sites dozens of km^2) makes the identified limitations, achieved successes and the methods developed not necessarily applicable or replicable at both finer and larger scales.

- There is a need to consider the trade-offs between co-benefits of the sought solutions. This is due to the fact that a certain co-benefit can decrease the delivery of another, meaning that the overall effectiveness of NbS-NbaS will also be influenced.

- A call for the connection between solutions is common in some projects. The latter implies a connection of ecosystems, which in turn creates various ecotones. This ecotone effect allows a maximization of individual efficiencies and multiplies benefits. However, measuring the climatic connectivity effect of NbaS and the ecotone effect are still limited in scope.

- The absence of acceptable thresholds to consider the solution as a success. This point stems from the fact that adaptation is often challenged by the absence of decisive metrics. In its own respects, measuring adaptation is another uncertainty barrier to overcome.

- In the same vein, the behavior of NbS-NbaS in highly complex systems such as urban areas, in addition to the unpredictable behavior of climate change are significant gaps to bridge.

- Accordingly, there is a need to develop a solid database on the climatic benefits of different solutions for properly mainstreaming NbaS and NbaS for DRR.

- A systematic approach to understand how the different systems, i.e. ecosystem-NbS-NbaS, interact with and influence each other is still limited. Hence the need to provide a more inclusive and holistic evaluation framework for properly understanding combined benefits, co-benefits and disservices

- As NbaS mature with time, the delivery of their co-benefits happens progressively. It is unclear if one should account for the final delivered services or also for the intermediate ones delivered from throughout the existence of the solution.

- Significant efforts are needed for the assessment of large scale NbS-NbaS (i.e. mountain ranges, basins, cityscapes, etc), watershed scale NbS-NbaS and hybrid structures that contain both small and large NbS.

- The development of research on the assessment of gaps and barriers related to NbS for hydrometeorological risk reduction is needed.

- Often, the challenges involved call for different scales, and that itself is a considerable barrier (scalability). For instance, pluvial flooding requires an urban zone scale, while river flooding requires a whole watershed scale approach.

Nonetheless, as mentioned previously this list of gaps summarizes some of the most major ones. For a more detailed analyses and deeper insights, the different sections of the chapter should be referred to.

France in the studied projects

As this chapter is the second level of the multi-scale approach, an analysis of France's position with respect to European efforts was made. Accordingly, 14 French pilot sites appeared in 14 projects, these are: The city of Brest in "GrowGreen", the Albarine river in "DRYvER", the Var river basin and Les Boucholeurs district in "RECONECT" , the city of Cannes in "UNaLab", the French part of the Pyrenees mountains in "PHUSICOS", the city of Paris in "REGREEN", the city of Montpellier in "NATURVATION", the Brague and Lez basins in "NAIAD", the city of Nantes in "URBiNAT" and three case studies under the "ThinkNature" platform: BIOVEINS for Paris' connectivity of green and blue infrastructures, agroforestry for Montpellier, and Bragu DEMO for flash floods and wildfire hazards in Mediterranean settings.

In terms of project coordination and participation, French institutions are lead coordinators in two projects (DRYvER and Nature4Cities) and participants in 16 others. The contributions of France in terms of pilot sites, coordination and participation reveal the country's strong position and implication in European agendas. With the highest post-COVID19 global expenditure on R&D for green measures of 14.3 billion US$ (UNEP, 2021), France is clearly investing in economics and research on NbS. Accordingly, the findings of this section will introduce Chapter 3 of this study: The National approach, NbaS in France.

I. Introduction: Background and objectives

The apex position of Climate Change Adaptation (CCA) and NbS-NbaS in European priority agendas clearly reveals the importance of these concepts for Europe. Since 2013, CCA has been a central interest for the EU and was given a proper strategy called the EU Adaptation Strategy (European Commission, 2013a). In terms of NbS, the European Commission has its own definition of the concept as: *"Solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally* ***adapted****, resource-efficient and systemic interventions*" (European Commission, 2015a). From this definition, the belief of Europe that long-term economic competiveness and security depend on the sustainable use of natural resources is apparent, hence its interest in NbS for achieving the above-mentioned targets (Maes and Jacobs, 2017). Given the importance of NbS for the European Union, these were made part of Europe's H2020 programme. This inclusion made the study of NbS-NbaS under research, innovation and evidence-based lenses possible, while strengthening their position in legislative and political settings. In addition to its conceptual, financial and theoretical contributions, Europe - along North America – is physically implementing NbS (Seddon et al., 2019), thus ensuring a transition from concept to application. More recently, NbaS were set as one of the three cross-cutting priorities of the most recent EU strategy on adaptation to climate change (European Commission, 2021a). Accordingly, the strong CCA-NbaS background of Europe is a pivotal platform to explore under any NbS-NbaS related studies.

In light of what was presented, the main objective of this chapter is to establish a knowledge inventory of NbaS at the regional level based on: the lessons learned from the completed projects, the chronological evolution of concepts, ongoing efforts, target areas, potential, and limits. Accordingly, readers will able to situate NbaS with respect to European agendas and link them with those presented in Chapter 1. On this basis, an explanation of the different NbaS types, climatic challenges, media of intervention, priorities, gaps and challenges are given. Ultimately, this chapter will highlight the lessons learnt and expected outcomes from the work of several H2020 projects. By capitalizing on these results, clearer insights behind the science of NbS-NbaS and for designing efficient NbaS can be obtained.

To this end, the chapter is structured as follows: the second section details the methodological approach of this study and explains the basis for the retention of the studied projects and deliverables. The third section presents a general overview of NbS-NbaS in Europe at the political and publication level. The fourth section presents the bulk of this review and presents a state-of-the-art on current knowledge and gaps. Section four is divided into different sub-sections based on an exhaustive compilation of the elements retained from section three. The fifth and last section concludes the presented work and paves the way for the French National approach.

II. Materials and methods

Search: The chapter was built in analogy to the study's Search, Filter, Extract and Analyze workflow. For the Search phase, the European Commission's Community Research and Development Information Service (CORDIS) website [https://cordis.europa.eu/] was used to identify the relevant projects. The search query consisted of "nature-based solutions" as a keyword, and the "programme" and "collections" filters were used to refine the search. The chosen date range started from the year 2014 onwards, as the latter marks the start of the H2020 program. Within this interval, the year 2015 is one of the most important NbS landmarks in Europe, with the official integration of NbS into the EU's agenda (European Commission, 2015a). Under the "programme" filter, the H2020 box was selected, while the project box was selected under "collection". Accordingly, the first search *(search 1)* yielded nature-based solutions H2020 projects. The selected projects were then validated against the Oppla database, Wild (2020) and Dumitru and Wendling (2021). As a first result, 41 projects were found. These were listed according to their acronyms, CORDIS web-reference, project's website, full name, start-end dates, and status (ongoing or ended). Given the scope of the study (i.e. NbS for climate change adaptation, therein NbaS), a second refinement step was performed *(search 2)*. The aim of search 2 was to zero in on strictly NbaS related projects. For that purpose, each CORDIS webpage was revisited to determine under which topic and programme is the project listed. To this end, projects with the following topics were selected:

SC5-10-2016 - Multi-stakeholder dialogue platform to promote innovation with nature to address societal challenges.

SCC-02-2016-2017 - Demonstrating innovative nature-based solutions in cities.

SC5-09-2016 - Operationalizing insurance value of ecosystems.

SCC-03-2016 - New governance, business, financing models and economic impact assessment tools for sustainable cities with nature-based solutions (urban re-naturing).

SC5-08-2017 - Large-scale demonstrators on nature-based solutions for hydro-meteorological risk reduction.

SC5-13-2018-2019 - Strengthening international cooperation on sustainable urbanization: nature-based solutions for restoration and rehabilitation of urban ecosystems.

LC-CLA-06-2019 - Inter-relations between climate change, biodiversity and ecosystem services.

SC5-14-2019 - Visionary and integrated solutions to improve well-being and health in cities.

For further validation, the programme heading in each project's CORDIS webpage was also examined for inclusion. Accordingly, the following programmes were of interest:

H2020-EU.3.5.1. - Fighting and adapting to climate change.

H2020-EU.3.5.1.2 - Assess impacts, vulnerabilities and develop innovative cost-effective adaptation and risk prevention and management measures.

H2020-EU.3.5.2.1. - Further our understanding of biodiversity and the functioning of ecosystems, their interactions with social systems and their role in sustaining the economy and human well-being.

To make sure that no project was left out, each project's website was revisited. Accordingly, any elements related to the scope of the study (NbaS or climate change adaptation) in the project's impacts, description or objectives were considered as additional inclusion factors. Following Search 2, a total of 27 projects sourced from CORDIS and from their related websites were conserved. Accordingly, these can be considered as NbaS related H2020 projects. Two tables summarizing the findings of the Search phase can be found in Annex B.

Each project's deliverables were then investigated using the project's CORDIS results tab as well as the project's webpage. This step was performed since some deliverables are not yet listed on CORDIS despite their existence on the project's webpage. Accordingly, a double check for each project was performed.

Filter: The filtering phase consisted of two steps. The first was a general approach where deliverables were retained based on their titles, general content and relevant sections. The aim of this step was to ensure that the retained reports surely contained the NbS-NbaS concepts or their associated notions, along with climate change. At this stage it is important to mention several elements: (1) textual material was compiled and collected during the January-July 2021 period. Therefore, any outcome following this period is not included. (2) At the time of this study[20] several projects were still ongoing while others have only begun in 2020. Some were affected by the COVID-19 pandemic while others were still in their pre-results phases. Consequently, some projects had no deliverables during the study period. (3) Some projects had no/restricted access to deliverables and hence were unavailable. In order to account for these shortcomings, the results packages on the related CORDIS webpage and scientific publications issued from these projects were included where applicable. Accordingly, 21/27 projects with 138 deliverables were passed to the second filtering phase. Three external sources were added given their relevance to the study, these are: the IPCC's most recent report, one report of Dumitru and Wendling (2021) and one scientific article (Davies et al., 2021). A list of these projects along with the number of deliverables can be found in Annex C equally.

The second step was more specific and consisted of examining the reports individually for elements related to the study. A total of 137 out of the 173 deliverables were retained for the Extract and Analyze phase. The list of retained reports can be found in Annex C. At no point do the Authors assume that their findings are not debatable. The Authors acknowledge that some sample-related or selection errors may be inherent. However, the best possible measures were taken to avoid any unjustified assumptions and to ensure a minimal error margin.

Extract and Analyze: This step forms the "tip of the funnel" where the 137 retained reports (or articles where applicable) were analyzed for extracting the study's findings. Accordingly, all findings reported in this study are strictly from H2020 contributions unless otherwise indicated.

III. A general overview of NbS-NbaS in Europe

This section showcases the evolutionary timeline of the NbS and NbaS concepts in EU issued reports and policies. The aim of this section is to build an inventory of European efforts and reveal how NbS-NbaS are approached in the EU.

At the political level: the European Commission (2019) lists the following as EU strategies and policies in direct favor of NbS. Others policies may also be relevant, however the strategies below were chosen given their direct link with NbS:

- 2011: The EU set the 2020 Biodiversity Strategy in which member states are called to map and assess ecosystems, their status and services, as well as their potential for Climate Change Adaptation (CCA) and mitigation (European Commission, 2011).

[20] The year 2021 with respect to the milestones set for action A2 of the ARTISAN project.

- 2012: The EU "Blueprint to Safeguard Europe's Water Resources acknowledges the role of Natural Water Retention Measures for attending to flood risks while providing co-benefits (European Commission, 2012).

- 2013: The EU strategy on adaptation to climate change and the EU Green infrastructure strategy. The first aims stresses on the importance of ecosystem-based adaptation (EbA), while the second strengthens actions on green infrastructures and equally recommends the use of EbA for CCA (European Commission, 2013a, 2013b).

- 2016: The EU policy on international ocean governance calls on the use of NbS approaches for valorizing the role of the oceans for action on climate (European Commission, 2016a), while the EU's Action Plan on the Sendai Framework for Disaster Risk Reduction calls for eco-DRR approaches (European Commission, 2016b).

- 2021: In its new strategy on CCA, adopted on the 24th of February 2021, the EU placed NbaS as one of its three top priorities (European Commission, 2021a). With this increased momentum, the position of NbaS in Europe is very clear: the EU believes that these solutions are the way forward. Further, the Union believes that these solutions should be actively pursued - even regardless of climatic trajectories - given the several co-benefits they deliver (European Commission, 2021a).

It is also worth mentioning that many references attribute the EU Water Framework Directive an important role in supporting NbS (e.g. Wild, 2020).

The interest of the EU in ecosystems, their services and health increased even more after the COVID-19 pandemic. Accordingly, the EU is one of several parties developing programs that integrate natural solutions (thereby NbS) into post-COVID plans as nature-positive stimulus packages (Armstrong, 2021; GEF Secretariat, 2020). On a global scale the EU's post-COVID19 recovery package is the most eco-friendly, with 37 per cent of the planned 750 billion euros directed towards green initiatives (Bayat-Renoux et al., 2020). To this end, the EU is planning for an ambitious 2030 biodiversity strategy that aims to transform minimum 30 percent of Europe's lands and sea into protected areas (even partially) to ensure healthy societies via healthy ecosystems (GEF Secretariat, 2020).

At the EU publication level, and in addition to the H2020 programme, the interest of the EU in NbS can be traced back (indirectly) to the year 2012 according to Davies et al. (2021). The same Authors compiled a collection of EU issued publications that incorporated the NbS concept to track its evolution in the Union's context. The following reports[21] (excluding conference proceedings) were found:

2012: EU Research-Natural Hazards and Disasters and Soil and Sustainable Land Use Management (European Union, 2012a, 2012b)

2014: Biodiversity and In-depth Report: e-consultation on Nature-Based Solutions (European Commission, 2014; European Union, 2014).

2015: Towards an EU Research and Innovation Policy Agenda for NatureBased Solutions & ReNaturing Cities (European Commission, 2015b)

2017: EKLIPSE Expert Working Group on Nature-Based Solutions (Raymond et al., 2017).

2021: Evaluating the impact of Nature-based Solutions: a handbook for practitioners (European Commission, 2021b).

In addition to the several public policies and research efforts, public awareness in Europe is another positive factor. According to Maes and Jacobs (2017), citizens of the EU expect and demand a sustainable economic development model that does not cause irreversible or unexpected changes to ecosystems. However, in strict NbS terms, citizen awareness seems to be low expect in Nordic countries (Van der Jagt et al., 2020). To this end, several H2020 projects are directly related to the NbS-citizen nexus (e.g. proGIreg), and citizen science seems to be a growing discipline within different projects (e.g. EdiCitNet).

[21] The Authors do not acknowledge this list as not an exhaustive inventory of EU NbS publications. This list was added from Davies et al. (2021) to introduce the efforts of the EU in a general way.

IV. Detailed analysis of the H2020 projects

In this section, findings of the retained database are listed. First, a description of the retained projects' objectives, targets and scales is presented. Second, the geographical distribution of projects and pilot sites is displayed and explained with relation to NbS-NbaS. Third, the target ecosystems (media) per project are detailed and are followed by an exhaustive inventory on current knowledge and knowledge needs per medium. Section IV.4 reveals research needs and gaps extracted from the various elements of the retained corpus while highlighting potential lines of future research.

IV.1 A description of the H2020 NbaS projects

The retained projects are of different types and encompass several objectives for the use of NbS-NbaS within. Only those with deliverables, i.e. 21 NbaS H2020 projects, will be detailed from this point onwards. The list of retained projects is as follows: CLEARING HOUSE, CLEVER Cities, Connecting Nature, DRYvER, EdiCitNet, EuPOLIS, FutureMARES, GrowGreen, NAIAD, Nature4Cities, NATRUVATION, OPERANDUM, PHUSICOS, proGIreg, RECONECT, REGREEN, RENATURE, ThinkNature, UNaLab, Urban GreenUP and URBiNAT.

Connecting Nature, GrowGreen, UNaLab and Urban GreenUP utilize NbS for climate and water resilience in cities. Nature4Cities and NATURVATION investigate governance, business, finance and economic models and assessment for NbS. The NAIAD project complements the actions mentioned-above by providing an assessment of the insurance value of ecosystem services. OPERANDUM develops NbS to mitigate hydro-meteorological phenomena, URBiNAT focuses on regenerating and integrating deprived urban contexts through NbS, proGIreg harnesses the power of nature for urban regeneration, while RECONECT aims to reconcile Europe with its citizens through democracy and the rule of law. PHUSICOS will demonstrate how NbS can reduce risks in mountain landscapes in one the very few H2020 mountain related projects. ThinkNature aims to develop a communication platform to connect various stakeholders and to support the understanding and promotion of NbS at different geographical levels. RENATURE builds a strategy and research cluster targeting NbS for sustainable development through scientific excellence and innovation. EdiCitNet aims to explore the potential of Edible City Solutions in cities to increase social cohesion, equality, food security and adapt these solutions to the urban realm. CLEVER Cities targets urban regeneration (social, environmental and economic improvements) through NbS. CLEARING HOUSE aims to mobilize urban forest-based solutions for rehabilitating, restoring and reconnecting urban settings. REGREEN aims to generate evidence on the integration of ecosystem services and biodiversity into NbS and to advocate the latter for urban planning. FutureMARES aims to provide NbS for CCA in CCM in marine environments around Europe. EuPOLIS aims to utilize natural systems (NbS) to enhance public health and well-being and create resilient urban ecosystems. DRYvER aims to established strategies for the mitigation and adaptation to climate change effects in dry river networks through the integration of hydrological and ecological (NbS) perspectives among other factors.

As can be noticed, the projects cover a range of different backgrounds, and possess objectives that do not cover the same scopes. Generally, a two-fold line of work classification is observed: the first is generic and consists of socioeconomic and/or environmental (encompassing urban, water, climate, and marine resilience as well as urban regeneration and resilience as well as natural hazards) themed approaches. The second line of work classification is more detailed and encompasses the topics mentioned in section II. In this vein, the different projects are attributed to the following topics:

- Strengthening international cooperation on sustainable urbanization: NbS for restoration and rehabilitation of urban ecosystems: REGREEN and CLEARING HOUSE.

- Multi-stakeholder dialogue platform to promote NbS to societal challenges: ThinkNature.

- New governance, business, financing, models and economic assessment tools: Nature4Cities and NATURVATION.

- Insurance values of ecosystems: NAIAD.

- Inter-relations between climate change, biodiversity and ecosystem services: DRYvER and FutureMARES.

- Demonstrating innovative NbS in cities: Connecting Nature, GrowGREEN, Urban GreenUP, UNaLab, URBiNAT, CLEVER Cities, proGIreg and EdiCitNet.

- Large-scale demonstrators on NbS for hydrometeorological risk reduction: RECONECT, OPERANDUM and PHUSICOS.

- Visionary and integrated solutions to improve well-being and health in cities: EuPOLIS.

RENATURE is not attributed to the same topics, but generally it can be listed under several ones.

The different nature, scales, data, objectives and methods of the projects makes drawing parallel between them difficult. Hence, the outcomes of different projects cannot be directly compared; the same applies to outcomes from the same project. However, it is possible to draw on similar lines or orientations of research needs from several elements that are detailed in the sections to follow.

IV.2 The geographical distribution of the retained projects

The geographical distribution of the retained projects was studied and mapped (Figure 1). The corresponding cartography can be found on the following link: https://www.google.com/maps/d/u/1/edit?mid=1OScN37smu3dWN9w1_W2gHDDP3HwNySP4&usp=sharing . Several large scale projects such as full mountain ranges, the EU scale or the whole EU's coastal environments are not represented in the map for display purposes. These projects are PONDERFUL, FutureMARES, MaCoBioS, Green CURIOCITY, OPERANDUM, RECONECT, PHUSICOS and NAIAD. As can be seen from Figure 1, several sites are scatted across the European continent particularly in its Western and Southern parts. Accordingly, the most targeted climatic regions are the temperate continental climate, followed by the oceanic and northern temperate regimes, and the Mediterranean climate (Nikolaidis et al., 2019). A dense concentration can be seen in Southern Europe due to the following facts: 1) The reigning Mediterranean climatic regime is foreseen to be the most impacted by climate change and its manifestations (Finér et al., 2019; Grace et al., 2021); and 2) there is a need for more evidence on the efficiency and co-benefits of NbS-NbaS in Mediterranean contexts (IUCN 2019 *in* Grace et al. 2021), as well as on the ecological responses of Mediterranean ecosystems under changing environmental conditions (Balzan et al., 2020). Northern and Eastern Europe display scattered concentrations with much less sites in the Eastern part. This could be a cause/consequence from the facts that: to: 1) since 2005 the number of NbS in Europe has been sharply increasing except in Eastern Europe (Cooper et al., 2018) and 2) scientific publications on NbS-NbaS in Eastern Europe are significantly less than those of the Western counterpart (Hanson et al., 2017). Accordingly, the NbaS distribution shows a dense South-West geographic gradient reveals in contrast to a less developed North-East axis. This spatial pattern underlines the need for increased attention in order to homogenize continental NbaS efforts.

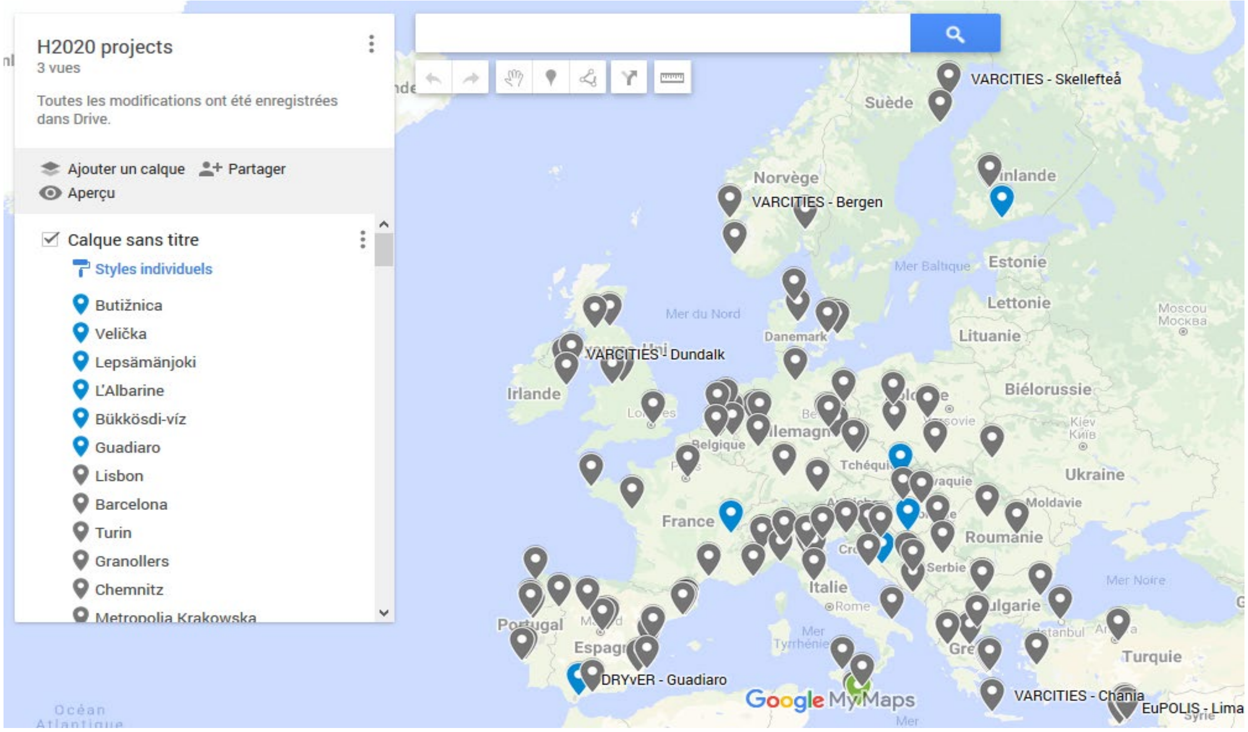

Figure 1: The geographical distribution of the retained projects' intervention sites.

The different geographic and climatic distributions of the intervention sites complicates further the comparison between outcomes since the performance of a NbS-NbaS is greatly dependent on the geographic, climatic and geomorphological conditions (UNaLab, 2019). In terms of national representation, the following distribution was found (Figure 2):

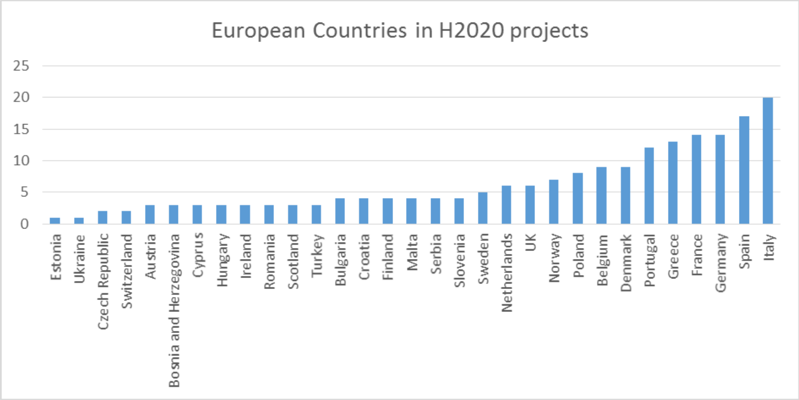

Figure 2: Location of the pilot sites of European countries in H2020 projects

As can be seen from Figure 2, the top two countries correspond to Southern Europe (Mediterranean climatic regime) followed by two countries of Western Europe. France ranks fourth among the pilot countries thus revealing its synchronization with European efforts. Regardless of the geographic distribution, Collier (2021) reports that NbS in Europe are predominantly oriented towards CCA and CCM agendas. This solidifies that the concept of NbaS, much like NbS (Somarakis et al., 2019), is coined in Europe. Despite this fact, uneven degrees of importance are accorded to different European ecosystems with some much more studied than others under the NbaS scope. Findings of the following section support this statement.

IV.3 Target ecosystems

The targeted media in each project is presented in Figure 3. As can be seen, the urban environment predominates the ecosystem panorama. This distribution is in line with European strategies that are mostly focused on cities and urban contexts under climate change and demographic development. Most recently, since 2020, NbS have been promoted as key tools for cities housing more than 20 000 inhabitant as of 2021 in the EC's Urban Greening plan: *"the promotion of healthy ecosystems, green infrastructure and NbS should be systematically integrated into urban planning, including in public spaces, infrastructures and the design of buildings and their surroundings within the cities of the EU member states"* (European Commission 2020 *in* Mitić-Radulović and Lalović, 2021).

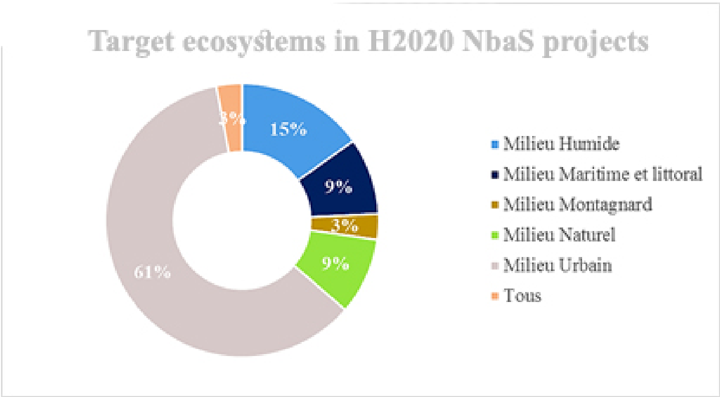

Figure 3: Target ecosystems of H2020 NbaS projects

However, this interest comes at the expense of other media that are significantly underrepresented and understudied. Accordingly, the coastal and mountainous environment are remarkably overlooked with coastal resilience and marine protection being one of the least targeted goals (Hanson et al., 2017; Nikolaidis et al., 2019; Ruangpan et al., 2020; Veerkamp et al., 2018) while mountainous environment are only targeted by a single project (PHUSICOS). This dominant focus on urban ecosystems makes urban green and blue-green solutions the most studied type of NbaS, thus missing out on a variety of other solutions that target other than urban media. Moreover, targeting the urban realm which ranges from the building to the city level at best, only covers relatively small scales. This "narrow scale" approach leads to missing out on macroscale interventions, and subsequent large scale NbS-NbaS. In the same vein, most presented solutions correspond to Type 3 NbS (management of ecosystems in extensive ways – new ecosystems) that target the management or creation of new ecosystems. Consequently, a lesser focus on Type 2 NbS (some interventions in managed ecosystems and landscapes) is given, while Type 1 (minimal interventions – protected ecosystems) are relatively rarely to never targeted. Further explanations that reveal relevant research gaps are detailed in the following sections.

In terms of climatic challenges, urban heat islands, coastal hazards, floods, sea level rise, heavy rainfall, temperature rises, heat stress, erosion, landslides, and storm surges are the most addressed. From these challenges, flooding occupies the top position and is almost present in all intervention sites (Debele et al., 2019). Urban Heat Islands (UHI) are the second topmost addressed challenge. While UHI mostly concern the urban environment, other challenges are cross-sectorial, yet the focus on urban ecosystems reduces the efforts needed to address these challenges in other media. To this end, several research orientations are detailed in later sections.

Another tier of challenges is focused on socioeconomic disadvantages, social inequities, vulnerable populations' status, human health, environmental and resource degradation, overpopulation, air quality, reduction of green cover, agricultural decline, etc. Within different ecosystems, socioecological conditions determine the efficiency of the sought solutions. However, these are beyond the scope of this study as the latter focuses more on the biophysical angles of NbS-NbaS.

IV.4 A state-of-the-art on current knowledge and research needs

In this section, current knowledge and research needs are presented under different titles that are also interlinked with one another.

IV.4.1 Overview of the current state of NbS-NbaS

A detailed classification of each project's intervention zones and solutions is presented in Annex A. In these tables, the different solutions for different media and challenges were extracted and detailed for each project and its corresponding intervention sites. As can be seen, a plethora of NbS-NbaS is presented in throughout the H2020 projects. Some solutions are quite unclassical and not very common in classical literature on NbS-NbaS [e.g. live cribwalls, palisades, pole drains, ground anchors, microbe assisted seed mixtures, coal remediation, wood allotments, fruit walls, as well as natural sealing of leaky streams (among others) are presented]. Given the dominance of the urban medium, most solutions correspond to the urban NbS-NbaS family, i.e. green or blue-green infrastructures. Some of the most common solutions are green roofs, urban parks, urban forests, rain gardens and green corridors among others. Regardless of their types, most solutions correspond to the type 3 NbS, to lesser extent type 2 NbS and much less to the type 1. These observations converge with those of Wendling et al. (2019) who reported that most European NbS are of type 3 nature.

IV.4.2 The approach to climate change and the transition from NbS to NbaS

As the major challenge addressed by the retained projects is climate change, an investigation of their climatic approach along with their introduction of NbaS was performed.

i. On the approach to climate change and CCA

A wide range of discussion on the underlying concepts and basics of climate change is available throughout the different references. The current red line threshold is the 2 ˚C increase, beyond which climate change is assumed to become dangerous and its effects on ecosystems irreversible (Garcia Blanco et al., 2021). Therefore, adaptation to climate change stands first among the priority areas mentioned in international, European, national, local and regional policies reviewed by Knobaulch et al. (2019). It is followed by the protection of existing networks of green and blue spaces, ecosystems and their functions, place quality, social cohesion, environmental justice, mental and physical health, air pollution, mobility and noise and light pollution (Knobaulch et al., 2019). All projects agree that in the face of a changing climate, adaptive policymaking is needed to account for uncertainties, while a certain degree of flexibility is inevitable to avoid robust decision making (Zorita et al., 2021). The importance of research at this level lies not only in the generation of a successful solution, but also in refining interventions once implemented (Naylor et al. 2012 *in* Kiss et al. 2019). A general agreement on the importance of environmental risk evaluation for ensuring the success of NbaS and NbS for CCM (Garcia Blanco et al., 2021) is also common between the projects. Most projects approach CCA from the IPCC's (2014) perspective, where risk is expressed as a function of hazard, exposure and vulnerability. To this end, an analysis of all three risk components is often seen throughout the projects. Accordingly, this can be considered as a lever to overcome the classical confusion between risk and hazard in climate-related risk assessments (Kumar et al., 2019). Nonetheless, several challenges are apparent due to the difficulty of calculating/quantifying the occurrence probabilities for climatic hazards (Kumar et al., 2019), and the short-term variability of exposures and vulnerabilities due to intra annual variations (Fletcher et al., 2020).

In numerical terms, current and future climate change are approached using a multitude of methods that can be categorized under: the use of historical and present weather station data, the use of global/regional datasets and downscaling, climate change predictions/projections (IPCC scenarios or European databases), climate modeling, and to lesser extents remote sensing techniques. The socioeconomic dimension of climate change and its evolution are also considered, hence complete climate change profiles are present throughout the projects.

However, some comments on the use of the different methods mentioned above can be made.

The use of historical and present weather station data (current climate analysis): This method is considered as the most suitable as it is based on field observations that often span across a large time period, and allows the depiction of complete climatic cycles. It forms one of the several strong points of the European approach, as often fine-scale and accurate data is available. Through this method, the analysis of local microclimates and environmental conditions - particularly at fine scales such as those of the pilot sites addressed in the projects – is made possible. This not only helps the survival of the chosen solutions, but also allows a maximization of their potential and multi-benefits (Boskovic et al., 2021).

The use of global datasets and climatic projections: Many projects use the IPCC's scenarios[22] to project future changes, i.e. the Representative Concentration Pathways (RCPs) and Shared Socioeconomic Pathways (SSPs). The EEA Copernicus program also works on these scenarios but mainly focuses on RCPs 4.5 and 8.5 (most optimistic and most pessimistic) while disregarding the other two (Garcia Blanco et al., 2021). The use of scenarios such as the RCPs or the SSPs can help center adaptation efforts by providing insights on climatic evolution and characterizing the responses of stakeholders (FutureMARES, 2021). Generally, the RCPs and SSPs should be used together (FutureMARES, 2021), yet they are seldom combined in literature. However, in data rich settings as the EU, such approaches should not be prioritized if possible. This is due to the fact that the generalization of IPCC emission scenarios and global or regional downscaling are based on the assumptions of large scale atmospheric processes (Trzaska and Schnarr, 2014)[23]. For proper downscaling to the local scale, several assumptions are made with each downscaling process. In turn, these approximations are coupled at each step to several uncertainties that sequentially affect the accuracy of outputs through increased biases and errors (Trzaska and Schnarr, 2014). In most of the studies utilizing global datasets or their downscaling, there is a tendency to overlook or not discuss uncertainties, often leading users to rely on the more or less questionable numerical values (Trzaska and Schnarr, 2014). Further, when comparing the downscaled climatic dataset to actual observed data, considerable biases and deviations are often observed; therefore, the coarse resolution of current and projected data must be considered (Trzaska and Schnarr, 2014) particularly for fine scale applications. In addition, the IPCC scenarios do not easily represent extreme weather events. Therefore, given the need for accurate climatic data, the use of global or generalized models - despite their importance - is not always reliable, since it is beyond their capacity to represent detailed processes that are required for designing NbS-NbaS in scales as fine as cities, districts or pilot sites. To this end, adequate spatial resolution (often at the scale of pilot sites, i.e. dozens of km^2), with a sufficient time coverage (more than the 30 years threshold, i.e. a complete climatic cycle), is a major concern since accurate representation is crucial for the identification of impacts, weakness and designs of subsequent adaptation interventions (Garcia Blanco et al., 2021).

Climate modeling: This approach is done by using regional/local models that are fed by data other than the IPCC scenarios. This method can be challenging as it is bound by four types of errors: model physical errors, model input errors, observational errors and different variability sequences (Connop et al., 2020).

Remote sensing: While it is a very valuable tool for mapping and monitoring the evolution of NbS, it does not allow a prediction of their effects or an accurate quantification of their (co)benefits (Connop et al., 2020). Nonetheless, these techniques are ideal in zones where climatic data availability is a limiting factor [e.g. Al Sayah et al., (2021)].

ii. On the shift from NbS to NbaS and their relationship with climate change

Nota Bene: The nomenclature Nature Based Adaptation Solutions does not appear in strict terms within any reference. Instead, these are referred to as Nature-Based Solutions for climate change adaptation.

The entry of NbS into the academic, planning, governance and policy discourse, fueled a polarizing debate on the efficiency of nature as a solution to anthropogenic driven environmental changes (Collier, 2021). While the concept of NbaS may be recently coined and gaining interest in climate regulation policies (Kalas et al., 2019; Mitić-Radulović and Lalović, 2021), NbS have been associated to climate change, climate resilience, and mitigation since 2009 (Potschin et al., 2016 *in* Da Rocha et al., 2017). Usually, responses to environmental problems happen in analogy to Newton's third law: action-reaction; only when a problem emerges a solution is proposed (Zorita et al., 2021). However, Newton's third law is not sufficient to tackle climate change given the latter's properties and inherent nature. Accordingly, increasing resilience to climate change through NbS is considered as a suitable proactive response that extends beyond reactive measures.

Climate resilience englobes two interacting concepts: adaptation and mitigation (GMV et al., 2019 and Raymond et al. 2017 *in* GMV et al. 2018). In the case of NbS (including NbaS), mitigation and adaptation are closely entwined as any adaptation activity will promote mitigation potential, and subsequently promote climate resilience (GMV et al., 2019). To this end, both NbaS and NbS for CCM commonly aim to enhance ecosystemic resilience and stabilize ecoservices (Morello et al., 2018). For NbaS specifically, the aim is to:

[22] Refer to the IPCC (2014) report for further information
[23] Reference not included in the H2020 database

1) preserve the services needed by humans to make the impacts of climate change less adverse (Bailly et al., 2019b); and 2) to decrease the impact of the expected climatic effects (Morello et al., 2018). However, it is possible for a NbaS to target CCM (Morello et al., 2018), hence the advantage of these solutions. For example, a green park established from reducing the Urban Heat Island (UHI) effect [CCA] can simultaneously store carbon in its above and below ground components [CCM]. Another strong point of NbaS is that they cover the cross-cutting elements of climate action, i.e. environmental, social, cultural, and economic factors (Tozer and Xie, 2020) through the provision of multi-benefits.

The most commonly addressed climatic challenges were found to be urban heat islands, coastal hazards, flash floods, sea level rise, heavy rainfall, temperature rises, heat stress, erosion, landslides, and storm surges. Another tier of challenges is focused on socioeconomic disadvantages, social inequities, vulnerable populations' status, human health, environmental and resource degradation, overpopulation, air quality, reduction of green cover, agricultural decline, social cohesion and the insurance value of ecosystems.

In a review performed by Xie and Bulkeley (2020), both NbaS and NbS for CCM were found to operate on five levels: 1) flood prevention and regulation, 2) UHI mitigation, 3) carbon sequestration-reduction of emissions, 4) microclimate enhancement and 5) drought and desertification prevention or reduction. In the case of NbaS, current research efforts are mostly focused on green infrastructures, ecological connective functions and ecoservices provision for climate change resilience (Collier, 2021). However, a significant knowledge gap for assessing the impact of NbaS across a range of climate resilience challenges, and through different geographic levels exists (Somarakis et al., 2019). Another gap concerning the assessment of their long-term effectiveness under climate change scenarios is also prevalent (Bowyer et al., 2020; Gómez Martín et al., 2021). This last point should be particularly focused on as it can help understand the conditions these solutions will face and will have to perform under (Bowyer et al., 2020).

From the five levels listed by Xie and Bulkeley (2020), flood (Debele et al., 2019) and drought-related NbS-NbaS still require significant efforts (Xie and Bulkeley, 2020). According to Douglas et al. (2019), literature on flood NbS-NbaS mostly focuses on the type of the implemented solutions and their benefits, while only very few studies assess their actual effect on flood reduction. Nonetheless, flooding is the most addressed hazard/rapid onset climatic event in Europe, and is being mostly targeted through an array of nature-based and hybrid solutions (Debele et al., 2019). To this end, nearly all the retained H2020 NbaS projects target floods and their related solutions.

Limits and research needs

In the case of droughts, research needs are more pronounced, as studies on NbS-NbaS for slow onset events and their post-occurrence effects are still limited (Tuomenvirta et al., 2019). Within some of H2020 projects that include droughts, the latter are mainly addressed as a lack of precipitation (e.g. Mayor et al., 2018). This may be due to their confusion with water scarcity which is also often wrongly used as a synonym (GMV et al., 2018). **However, this representation constricts the process to precipitation availability, and does not consider the four natures of droughts, i.e. meteorological, hydrological, agricultural and socioeconomic** [these four types are identified byWilhite and Michael, 1985] . Accordingly, this depiction might lead to an underestimation of drought risks (Vogt et al., 2018 *in* Tuomenvirta et al. 2019), which in reality are the most complex weather-related disasters due to their widespread cross-sectoral impacts (Tuomenvirta et al., 2019). The underestimation of risk will subsequently affect the accuracy of the related solutions [knowledge limit]. This can be considered as the starting gap for drought NbS-NbaS research [research need].

Whether designed for slow or rapid onset climatic events, climate change, the climatic characteristic of the concerned setting, and the frequency and intensity of extreme weather events are very susceptible of reducing the efficiency of NbS-NbaS (Gomez Martin et al., 2019). Climate change also influences the benefits and trade-offs provided by these solutions (Gomez Martin et al., 2019). To consolidate this fact, the following examples are given:

- Climate characteristics: Small natural water retention features showed considerable potential in the UK, but had very reduced efficiency in Mediterranean contexts (Douglas et al., 2019). This is due to the differences of rainfall intensities that require a greater number of retention measures in the Mediterranean climatic regime (Douglas et al., 2019). In cold climates, the efficiency of edible solutions is questionable since they won't be able to deliver their service around the year (Wubben et al., 2020) due to plant growth factors.

- Seasonal variations: A spatial-temporal variation in the capacity of NbS-NbaS to provide ecoservices can be observed in several cases (Fletcher et al., 2020). Per example, solutions based on broad leaved trees can become relatively inefficient during autumn and winter as they shed their leaves (seasonal variation of ecoservices provision). In climates where evapotranspiration fluctuates throughout the seasons, the flood volume reduction capacity of green solutions will equally vary (Fletcher et al., 2020). Other NbS-NbaS used to reduce incoming solar radiation on buildings will fulfill their functions in summer, but might cause increases in heating loads during winter (Canton et al. 2001 *in* Bailly et al., 2019a).

- Extreme weather events: In summer, an unexpected succession of rapid storms may saturate water storage capacity much faster than the solutions' evapotranspiration rates, hence overpowering the NbS-NbaS (Fletcher et al., 2020). Similarly, increasing rainfall return periods can reduce the effectiveness of green roofs, pervious pavements, bio-retention elements and rain gardens (Majidi et al., 2019).

Research need: This last point raises two fundamental research questions: are NbS-NbaS being currently designed to withstand weather change and/or climate change? And will these solutions be capable of overpassing weather change to then withstand climate change?

In light of what was presented, the transition from NbS to NbaS can be considered as progressively ongoing. Accordingly, efforts are still proceeding and research gaps and needs are well outlined. Nonetheless, it is safe to assume that this transition is a subject of study in Europe (since 2014 at least), and several projects tend to extend their knowledge to extra-European contexts (namely in Asia and Latin South America), as can be seen in Annex A. This observation converges with the findings of Davies et al. (2021) who highlighted the role of the EU in the expansion of NbS-NbaS best practices to cross-continental knowledge generation and sharing.

IV.4.3 Risks of oversimplification: "Everything should be made as simple as possible, but not simpler" (A. Einstein)

Post scriptum: Remarks

1- Douglas et al. (2019) reported that flood and drought NbS-NbaS are designed to protect from events that are seldom observed. However, one might disagree with this point of view, particularly in Europe, where floods and droughts have been regularly increasing (UNEP, 2021b). To this end, floods are the most costly hazards in Europe, while heatwaves and extreme temperatures are the deadliest (Debele et al., 2019). With the progression of climate change, these events will only intensify and become more frequent (Dudley et al., 2010; World Economic Forum, 2020). Accordingly, the "rarity" of these events cannot be considered as a decisive argument.

2- It is short-sighted to think that NbaS alone can abate climate change, the latter needs to be drastically reduced by stabilizing or reducing GHGs (Somarakis et al., 2019).

3- It is also very important not to oversell NbS and NbaS as the only viable solutions. In several instances, these might not be the adequate answer to all climate change related aspects, and in some cases they may also be less performant than traditional or hybrid solutions (Solheim et al., 2021).

One of the strongest points of the NbS-NbaS concept is its relative simplicity that makes it widespread and more or less grasped by a large audience. However, a significant conceptual debate on the definition and components of NbS was found in the various retained references. Some projects utilize the EC's definition, others compare between the EC's and IUCN's definitions, while many reformulate their own definition of the concept. This discrepancy throughout the different projects shows that the scientific progress behind the concept has not been fully transposed into the policy and management angles (Grace et al., 2021). Two remarkable and important insights from H2020 projects stand out: 1) some Authors believe that NbS are sometimes oversold, and 2) other Authors do not favor the term NbS in the first place.

In this context, Bailly et al. (2019a) state the following: "*NbS is a recent European expression that is <u>inappropriate</u>. Experts and researcher prefer the term Nature. NbS can be interesting to refer to the ecosystem services of nature, but tends to reduce nature to its utility without considering the others dimensions that surround it.*" In this vein, O'Sullivan et al. (2020) report that in current NbS literature, a discussion of what forms the N of NbS-NbaS is still missing. According to the same Authors, it is unclear if nature only refers to biotic components, or also includes the abiotic factors and their effect on biotic ones. This may be due to the fact that "nature" in NbS-NbaS is defined and interpreted according to the viewer's background or discipline (CER et al., 2018). Most commonly, it seems that actual nature (ecological resources, processes, and feedback loops) is undervalued, with most of the discourse focusing on nature's positive socioeconomic outcomes (O'Sullivan et al., 2020). This narrow focus on benefits makes NbS and NbaS utilitarian anthropocentric concepts (CER et al., 2018). While in reality, these concepts encompass complex processes that include different components of the geosphere, hydrosphere, atmosphere and a range of ecosystems (Kumar et al., 2019). Many scholars have expressed their concern regarding this representation that leads to an oversimplification of nature (O'Sullivan et al., 2020). In terms of NbaS, not only is nature undervalued, but their potential for reducing climate vulnerability and promoting sustainability is also oversold (O'Sullivan et al., 2020). According to Sekulova and Anguelovski (2017) *in* O'Sullivan et al. (2020), nature is romanticized and overestimated to the point where the concepts of NbS-NbaS risk becoming unscientific (O'Sullivan et al., 2020).

The same Authors provide a "dose of reality" through a literature discussion of the current perspectives on nature using five references; the most important elements to retain are:

- In terms of NbaS: Nature is being represented as an injection primarily into cities (Kaika, 2017 *in* O'Sullivan et al. 2020) to help governments make citizens immune to climate change (Esposito, 2013 *in* O'Sullivan et al., 2020).

- In terms of NbS and NbaS: The drive for green and blue spaces is not environmental nor scientific, but is rather economic, i.e. growth obsession (Kabisch et al., 2016 *in* O'Sullivan et al. 2020). According to Sekulova and Anguelovski (2017) *in* O'Sullivan et al. (2020), the environmental angle will almost always lose at the expense of the socioeconomic goals. This might be due to three facts:

i. Emerging literature on urban NbS-NbaS deals mostly with the ecological, socio-cultural and economic dimensions (Veerkamp et al., 2018). The integration of "harder science" insights is still lacking and can be considered as an important line of research to develop. Hence, one might consider that there is a lack of ready-to-apply scientific knowledge (Egusquiza et al., 2017).

ii. The IUCN labels challenges that NbS-NbaS respond to as societal challenges. This nomenclature can be assumed to be logical as these arise from a combination of natural and anthropogenic causes (Balzan et al., 2020). However, this indirectly undermines the scientific background of these challenges and gives NbS-NbaS a more "practical" nature. This simplification may be beneficial for spreading the concepts across different target groups, but risks oversimplifying the underlying science behind the challenges, the solutions and the intended outcomes.

iii. Environmental challenges are marked by complexity, uncertainty, large spatio-temporal variability and often irreversibility (van den Hove, 2000 *in* Fohlmesiter et al., 2019). These elements are particularly amplified in the case of climate change, hence the increased difficulty of NbaS compared to NbS. The latter rely largely on the ecosystem service concept in which also insufficient scientific basis coupled to the inconsideration of nature's intrinsic value are major weak points (Bull et al., 2016). For NbaS, the same principles apply in addition to the layers of complexity brought about by the introduction of the already uncertain and complex climate change (ref. Chapter 1).

Limits and research needs:

If the environmental dimension and science(s) behind NbS-NbaS remain underdeveloped as the concept favors its practical and economic sides, NbS-NbaS risk being lost as buzzwords. To overcome these barriers, the introduction of hard sciences is needed to reduce the current oversimplification of the concept. For this purpose, significant research efforts are required along with long term visions of resilience (particularly for climate change), instead of short-term research on quality (Bailly et al., 2019a). At this stage, the cross-sectoral nature of NbS-NbaS might be a helpful factor, yet current efforts are compartmentalized (silo approaches), and the concerned disciplines have very limited interactions with each other (Maksimovic et al., 2021). Even when solid knowledge exists, it is often scattered across different disciplines (Bulkeley and Raven, 2018). This current state opposes the inter and transdisciplinary nature of NbS-NbaS that often require inputs from various disciplines (Egusquiza et al., 2017; Holscher et al., 2019). In this regard, within many transdisciplinary NbS-NbaS projects, scientific language is very discipline-specific, and the need to overcome "language" and conflicting priority barriers is pronounced (Banzhaf et al., 2020). Consequently, most NbS-NbaS knowledge gaps come from the lack of integration across disciplines and from not knowing/adopting knowledge from other fields of study (Van der Jagt et al., 2020).

Joint research efforts were also called for in the studied works of the international organizations (ref. Chapter 1). However, oversimplification and the disconnection between research fields, can be considered as an addition from H2020 projects to the conceptual debate on the NbS-NbaS concept. While oversimplification might be attended to by increasing the integration of "hard" sciences, the above-mentioned open-ended research questions underline major lines of work and collaboration. Undoubtedly, the success of a NbS-NbaS strongly depends on sufficient scientific knowledge of their functions, behaviors, efficiency, performance and benefits. This includes a solid understanding of the complexity of natural systems and their processes, as well as rich knowledge on NbS-NbaS design to ensure their resilience and adaptability to local and changing conditions (Schmalzbauer, 2018; Somarakis et al., 2019). However, a careful balance between simplification and complication should always be kept to avoid "losing" the concept. In this vein, oversimplifying the concept can make it a simple buzzword, while overcomplicating it can make it lose its acceptance/popularity among the different groups that are needed to leverage these solutions.

IV.4.4 On the notions of complexity and uncertainty

Following the discussion on oversimplification, a discussion on complexity and uncertainty under the retained H2020 projects is presented. The basis for this discussion is that addressing NbS, and to a certain extent NbaS, from the EC's perspective requires a complex interplay between definitions, challenges and sought solutions (Morello et al., 2018). Moreover, addressing multi-faceted solutions such as NbS-NbaS requires the consideration of complexity, redundancy and associated uncertainty particularly through different scales (Egusquiza et al., 2017). Both complexity and uncertainty are well accounted for in the retained projects, and several relevant research needs were highlighted. In a general way, both complexity and uncertainty are grouped into two clusters: 1) the targeted environmental challenges and 2) within the different phases concerned in NbS-NbaS solutions (design, implementation and monitoring). In this section, both clusters will be generally described as each is developed in a corresponding section throughout the course of this report.

i. Complexity

A solid understanding of nature's and systems' complexity is needed for successfully designing NbS-NbaS (Schmalzbauer, 2018). This element is currently one of the major gaps for upscaling NbS-NbaS (Ruangpan et al., 2020). Whether of small or large scale, the introduction of NbS-NbaS into an already existing (eco)system implies the introduction of new nature processes that are often complex and interdependent (Debele et al., 2019).. Nearly all the retained projects acknowledge this state and call for adopting complex thinking. The latter is necessary for dealing with the associated uncertainties and risks (Morin 2014 *in* Bailly et al. 2019b), as it also allows to draw attention to the undesirable effects (disservices) that may be brought about (Bailly et al., 2019b). Within the retained projects complexity is addressed in both theoretical and technical angles.

The most pronounced aspect of theoretical complexity stems from the targeted environmental challenges, namely climate change and hydrometeorological risk reduction. In terms of CCA, as mentioned in chapter 1, both climate change and adaptation are complex entwined elements (refer to chapter 1 for further details). In terms of hydrometeorological risks, the combined meteorological and hydrological processes that give rise to a certain event (hazard) create a layer of considerable complexity to consider (Debele et al., 2019). Moreover, hydrometeorological hazards are also capable of occurring simultaneously, in a cascading manner or even additively (Aguzzi et al., 2019). This means that a multitude of factors can interfere hence compounding complexities.

In terms of technical and fundamental knowledge on NbaS, the different projects acknowledge that some solutions are more complex than others, and thus require different approaches. For example, reconnecting floodplains (along with the involved hydrological, geomorphological and pedological processes and knowledge) is much more complex than designing allotment gardens (Somarakis et al., 2019). Similarly, some solutions are less complex to grasp given their relative simplicity and their direct tangible effects. For instance, urban farming delivers edible products in a relatively fair amount of time, making it simpler and more lucrative than green roofs that provide less tangible effects, and require extensive expert [scientific and technical knowledge] (Wilk et al., 2020). On the implementation side, Saraco et al. (2020b) revealed that during their project, the implementation phase was longer and more complex than originally planned. This operational complexity is often a significant hurdle that complicates the dialogue between the different concerned actors and can even be a backdrop for a given plan.

While most of the theoretical and technical difficulties can be resolved through the introduction of more knowledge, several limits and gaps should be addressed:

- The complexity of the environmental challenges and the solutions themselves calls for significant efforts that are still somewhat underdeveloped, **particularly in the domain of assessing the changes brought about by the (re)introduction of "nature" and its processes into a specific ecosystem.** Accordingly, there is a need to develop tools that take into consideration the interconnectivity of the natural and newly inserted system (Altamirano et al., 2020). This aspect calls for better understanding of ecological dynamics, in which often a particular's system equilibrium comes from the dynamic interactions of factors that result in zero net entropy. While understanding this equilibrium and its components might be a difficult task, it certainly forms and important line of research to develop.

- Solutions that target the links between stressors, driving forces and causal factors, while addressing adaptation at different spatial and temporal scales are particularly required for addressing multi-hazard approaches (i.e. multipurpose NbaS and/or NbaS for DRR).

ii. Uncertainty

A chain of uncertainties associated with NbS-NbaS can be observed throughout the different projects:

- The starting point of uncertainties in NbS-NbaS are the dynamic and complex nature of the challenges these respond to (Somarakis et al., 2019), namely climate change. The uncertainty of NbS for reducing hazards can be explained by the uncertainty regarding the origins and factors linked to these hazards (Debele et al., 2019).

- The second point comes from the unpredictability and uncertainty of the nature (NbaS) basis itself (Somarakis et al., 2019). Linked to that point are two facts: i) under the natural hazard scope, nature is perceived by people as an unstable element that might generate catastrophic events, accordingly, the use of nature under the form of NbS-NbaS to reduce risks raises some skepticism (Chou, 2016 *in* Han and Kuhlicke, 2019). ii) NbS-NbaS build on ecosystem functions and services, which in turn are dynamic, uncertain and evolve over time often in non-linear manners (Somarakis et al., 2019).

- The use of NbS as tools for CCA is still relatively recent and not very widespread due to underlying conservationism (Kuban et al., 2019). The latter might be due to lack of knowledge that creates a fear of the unknown (Solheim et al., 2021) that subsequently propagates across the various elements of the NbS-NbaS chain (design, implementation, operationalization, etc.). As NbS-NbaS are still perceived as innovations, their conception as uncertain elements is a source of risk (Altamirano et al., 2020; Stahlbrost et al., 2018). In this vein, upscaling and mainstreaming NbS-NbaS become challenged by: i) the difficulty of capturing the value of NbS-NbaS, ii) the lack of understanding of long-term benefits and iii) the uncertainties due to the disconnection between short-term actions and long-term goals (Perrin, 2018).

- Adaptation is often challenged by the absence of decisive metrics. Therefore, measuring adaptation is an uncertainty barrier to overcome for NbaS. To this end, when adaptation is questionably calculated, NbaS are inaccurately designed, and uncertainties for quantifying climate resilience increase since the latter is the sum of CCA and CCM actions.

The role of uncertainties in NbS and NbaS should be better accommodated and explored through further research (Bailly et al., 2019b; Han and Kuhlicke, 2019; Van der Jagt et al., 2020). The same can be said for uncertainties and trade-offs (Kumar et al., 2019). While these are developing lines of work, their current acknowledgment under all projects reflects the attainment of an ample awareness level (van der Jagt et al., 2017). Further medium specific information on uncertainties and complexities are provided in the section *"Knowledge and research needs per ecosystem"*

IV.4.5 The scale quandary of NbS-NbaS

Most H2020 NbaS projects are demonstration projects that often target small or specific pilot scales (except for OPERANDUM, PHUSICOS, RECONECT, FutureMARES and PONDERFUL). With the global spread of NbS around the world, European pilot-sites and cluster projects intervention are making Europe stand out as the world NbS leader (CLEVER Cities, 2021). Per example, living labs are much addressed throughout different projects, namely those that concern the urban medium (Wilk et al., 2020). In these units, economic/technological methods and concepts are developed and put to the test in a small real-life context (Wilk et al., 2020). It is believed that the diversity of size and scales of the pilot sites facilitates the extrapolation of findings to bigger scales having similar climatic properties (Boskovic et al., 2021). However, despite their importance, demonstration projects only generate applied and site-specific knowledge (Xie et al., 2020) and are often practical variations of earlier research (Strout et al., 2021). This recurrently makes of them NbS-NbaS awareness raising projects (Altamirano et al., 2020), rather than physical-based knowledge generating elements. This might be due to the site-specific nature of NbS-NbaS that complicates the generation or communication of "harder" aspects of knowledge (Xie et al., 2020), or to the oversimplification of the concept as discussed in the previous section (ref. O'Sullivan et al. 2020).

Regardless of the type of knowledge generated, the narrow focus on specific scales (mostly pilot site interventions that do not extend beyond a plot, district or neighborhood scale or plot, tributary, sub-basin) makes the identified limitations, achieved successes and the methods developed not necessarily applicable or replicable at both finer or larger scales (Somarakis et al., 2019). This observation clearly opposes the one made by Boskovic et al. (2021) and shows that scalability is a matter of debate in the NbS-NbaS framework (Bailly et al., 2019b). In this vein, upscaling to larger scales (i.e. greater than pilot sites) is a significant challenge for scientists and researchers, as the knowledge and methods utilized in pilot sites may not be applicable at larger scales (von Wirth et al., 2019 *in* Schmalzbauer, 2018). Moreover, the scales used by the research community do not always match those of planners (Knaus and Haase, 2020). This scale mismatch poses direct barriers to knowledge transfer and researcher-practitioner contact (Knaus and Haase, 2020). While the pilot scale approach is very important, NbS should be considered beyond their local effects, must be connected and should have a multi-scalar nature (Bailly et al., 2019a), i.e. they should be studied across and through different scales. To that end, there is a pronounced gap in the amount of research on small scale (e.g. urban) and large scale (e.g. catchment or regional) NbS (Ruangpan et al., 2020). Currently, the implementation of NbS-NbaS at large scales is limited, and is rather restricted to pilot site interventions of limited sizes (Altamirano et al., 2020). The complexity of larger systems might be a valid underlying reason, however this disconnection between scales is a significant hurdle for upscaling (Ruangpan et al., 2020). The lack of experience in large scale ecosystem restoration practices (Banwart et al., 2019, 2018) may also be a contributing factor. However, many researchers argue that small-scale (punctual/local) or single NbS are not sufficient to face events of large amplitude or extent (Ruangpan et al., 2020). This means that despite current efforts, not much is to be expected from current solutions. Under this context, NbS for DRR (hydrometeorological hazards) and NbaS are particularly relevant.

In the case of NbS-NbaS for DRR, particularly hydrometeorological hazard reduction, implementation is often at small-scale, and hence with a negligible effect on large hazards (Kumar et al., 2019). Expecting from a single NbaS to reduce risks and damage costs, as well as provide a quantum leap in resilience might be too ambitious. Per example, punctual/local stormwater management solutions aren't as effective as watershed scale NbS-NbaS that buffer peak runoff and flooding risks in the whole spatial unit including the target area (Somarakis et al., 2019). However, relevant evidence and knowledge are still somewhat limited when NbS-NbaS are part of a larger hydrological system (Ruangpan et al., 2020 *in* Solheim et al., 2021; Turconi et al., 2020; van Soesbergen and Mulligan, 2018). The same applies for watershed scale hybrid solutions that contain both small size or large sized NbS-NbaS (Watkin et al., 2019). As a result of these factors, most risk assessments target small scales (local to regional approaches) often leaving out the larger matrix (Renaud et al., 2019). Consequently, large scale NbS for hydrometeorological risk reduction are left out of the picture as the spatial unit of assessment disregards them. Therefore, these solutions are still in serious need for further studies particularly in European reference frameworks (Vojinovic et al., 2019). This knowledge gap can be considered as a major bottleneck for holistic risk management and resilience plans where large scale NbS-NbaS interventions are often needed (Somarakis et al., 2019).

In the case of NbS for climate resilience (i.e. NbaS and NbS for CCM), the difference of scales is also a complex factor. Generally, these type of solutions call for two scales: for mitigation, solutions are sought at macro scales while adaptation solutions target the meso and micro scales (CAR et al., 2017; GMV et al., 2018). However, other Authors believe the opposite and stress that adaptation plans and actions should target the landscape or wider scales to account for all the interactions of the concerned ecosystems (Kapos et al. (2019) *in* Altamirano et al. 2020). Yet different climatic challenges also require different scales and that itself is an additional barrier. For instance, NbaS for UHI reduction require a city scale approach, pluvial flooding requires an urban zone scale intervention, while river flooding requires a watershed scale approach (Somarakis et al., 2019). Arguably, evidence of small scale interventions is more or less established, however similarly to NbS for DRR, evidence of efficiency is particularly lacking at large scales (landscape or watershed). As the concerned challenges are often multi-scalar, the difficulty of measuring the solutions' multi-benefits and efficiency increases (Davis et al., 2018). To this end, sufficient best practices in different settings are still lacking (Knobaulch et al., 2019) and significant research efforts are still needed.

Limits and research needs

For bridging the above-mentioned gaps, several perspectives are proposed. First and foremost, for the implementation of system scale NbS-NbaS, a leap beyond conservationism is needed (Altamirano et al., 2020). Studying a mosaic of existing projects as a large scale NbS-NbaS approach through scale transitions may be a good start (Altamirano et al., 2020). To this end, large scale NbS-NbaS (when existent) should be treated as aggregated multi-scale small NbS-NbaS interventions to attend to their implementation, monitoring and benefit quantification angles (Banwart et al., 2018; Ruangpan et al., 2020). In the same vein, combining NbS at small and large scales and studying their interactions, effects, benefits and services (Ruangpan et al., 2020) may serve the same purpose. The H2020 programme might bring solutions to these problem, yet despite its efforts and interventions, the overall scale of NbS-NbaS interventions is still relatively low (Knobaulch et al., 2019).

To complement these referenced lines of work, several additions can also be made. First, it is important to consider that large scales (e.g. watersheds) cover a mosaic of ecosystems. That means that different responses to various stimuli (in this study's case climate change) are to be expected. For this purpose, understanding tipping points and thresholds is a must. However, this task is quite complicated and is still a major gap in research (as mentioned in Chapter 1). Even when defined, these often consist of assumptions and do not necessarily reflect real conditions. Second, even when aggregated small-scale solutions are considered as a large system NbS-NbaS intervention, there are no direct way for quantifying the "summation" of their aggregated effect. Often, indicators cannot be simply added up or extrapolated. Third, the optimal location to provide a certain kind of ecosystem service benefit or to attenuate a particular pressure may not be the same for different NbS-NbaS (Fletcher et al., 2020). For that purpose, connecting the different solutions scattered throughout a large area might be a better idea than aggregating small disconnected solutions. The connection between solutions implies a connection of ecosystems, which in turn creates various ecotones. This ecotone effect allows a maximization of individual efficiencies and multiplies benefits (UNaLab, 2019). To the knowledge of the Authors, tapping the potential of NbS-NbaS ecotones hasn't been dealt with yet in literature, neither have their transitions through different scales. **Accordingly, this recommendation can be considered as a novelty and as an important line of work that should be developed.**

IV.4.6 Knowledge and research needs per ecosystem

In this section, a state-of-the-art on current knowledge and needs for each ecosystem targeted in the H2020 projects is presented. The aim of this section is to synthesize knowledge, and highlight specific sets of research gaps and needs per medium. Figures 4, 5 and 6 provide a summarized example of NbaS and ecosystem services by medium. More detailed insights can be found in Annex A.

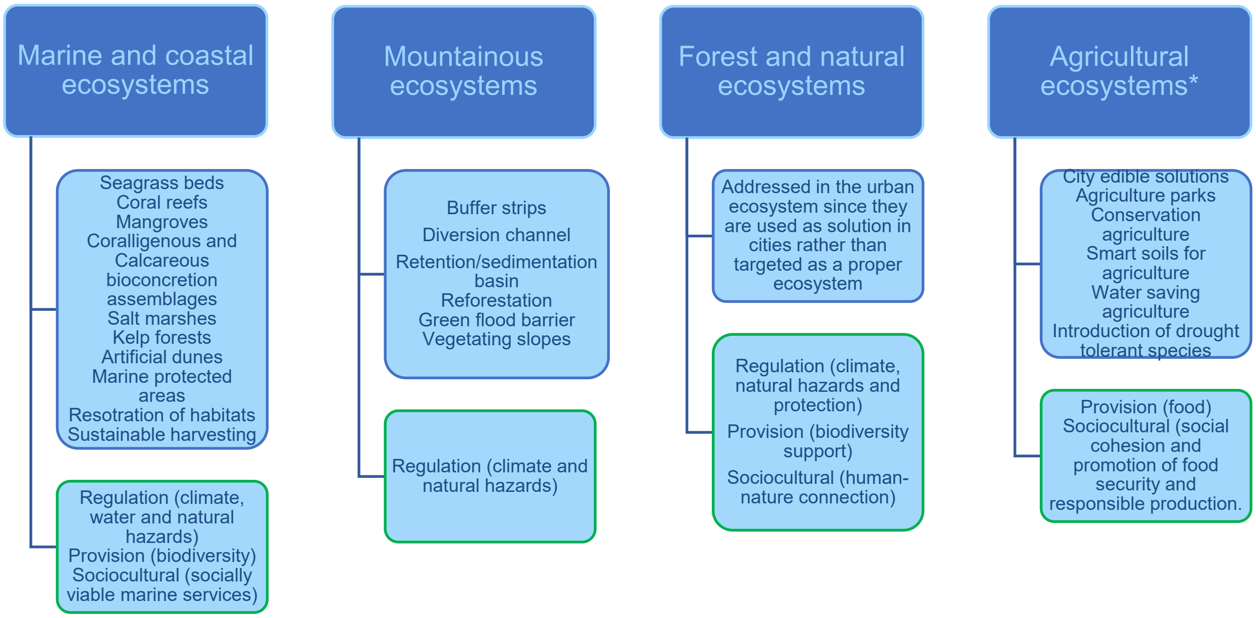

Figure 4: NbaS and ecosystem services per marine and coastal, mountainous, forest, natural and agricultural ecosystems

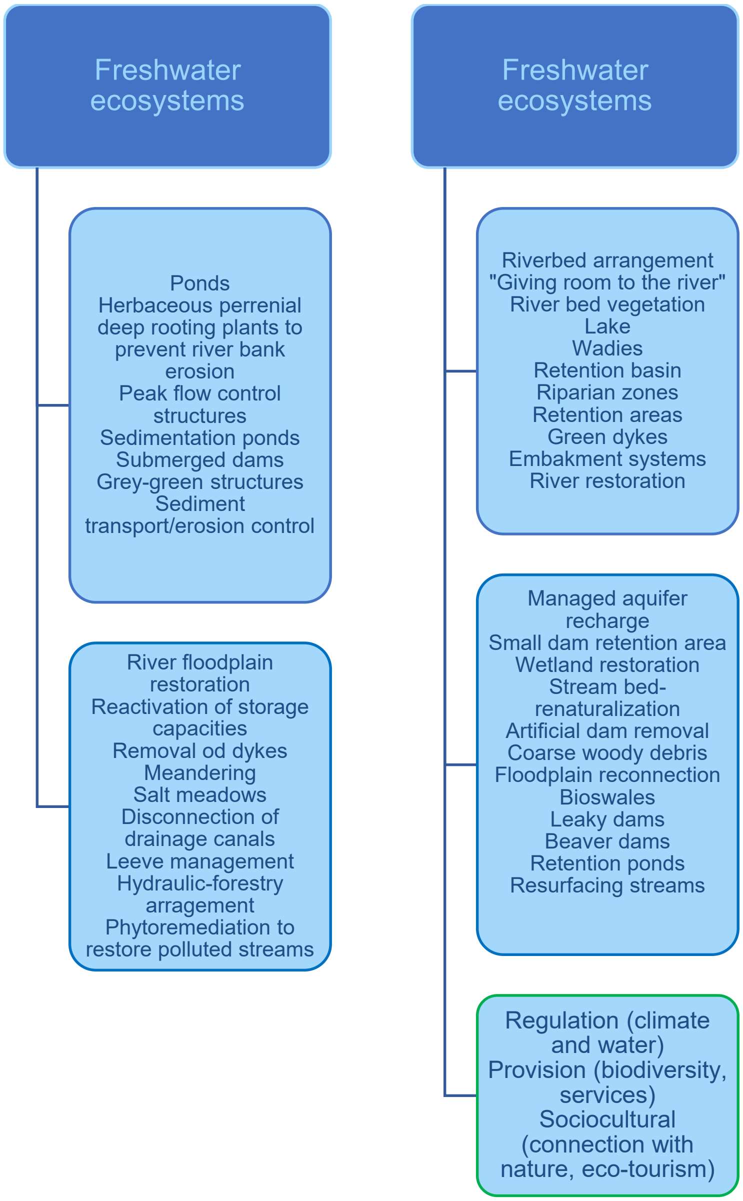

Figure 5: NbaS and ecosystem services in the freshwater ecosystem

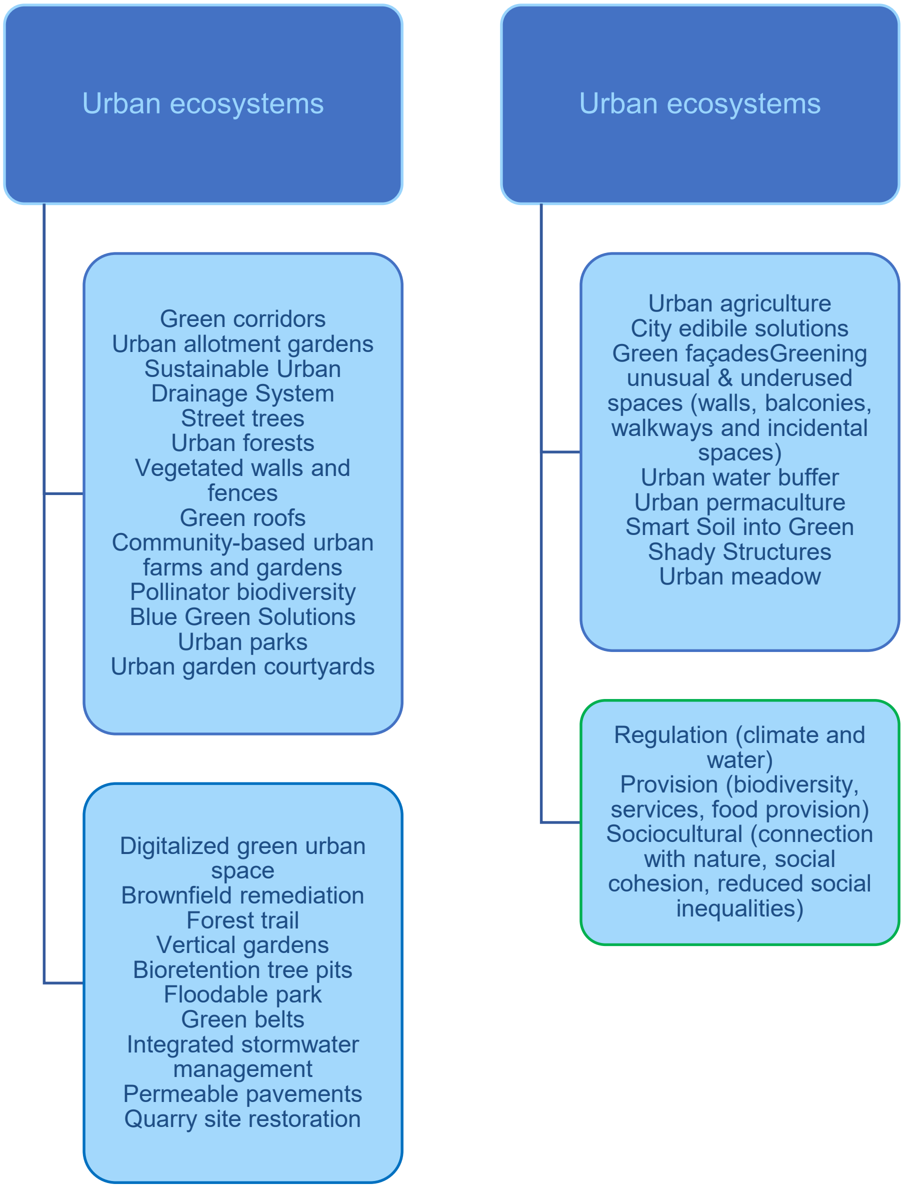

Figure 6: Urban NbaS and ecosystem services

i. The urban ecosystem

The European Commission focuses mostly on the urban medium due to two main reasons: i) the increasing number of European populations living in cities, and ii) the urge to address numerous challenges, namely climate change, impacts on human health, and the degradation of natural capital (Cohen-Shacham et al., 2019). Despite being major contributors to climate change, and one of the most affected contexts, cities can also be part of the solution (Arlati et al., 2021; Gerstetter et al., 2020; Knobaulch et al., 2019; Tozer and Xie, 2020). This is mainly due to the long term accumulation of emitted carbon dioxide in urban vegetation and underlying soils, that also makes the latter sources of important ecosystem services for cities (Richter et al. 2020).

In this regard, the concept of NbS is the most recent entry in the debate on nature's role for increasing the climatic resilience of urban settings (Bailly et al., 2019b; O'Sullivan et al., 2020). In the latter, NbS are being developed as part of urban climate infrastructure strategies for which cities use resilience principles as a guiding framework (Oke et al., 2021). The logic behind this approach is that NbS allow progress towards flexible and equitable urban resilience while promoting CCA (Mahmoud and Morello, 2018). NbS are also considered as key factors for retrofitting and rehabilitating existing urban areas (Maksimovic et al., 2021) and also contribute to urban biodiversity (Xie and Bulkeley, 2020). At this level, the role of biodiversity is multi-leveled: a) it can be part of the NbS-NbaS, b) it can serve as an important attribute to help the sought solutions withstand pressures such as climate change, or c) it can be obtained as an end product from the implemented solution (Fletcher et al., 2020). Nonetheless, the approach to urban NbS-NbaS biodiversity is not very centric, but rather focuses on ecosystem-based approaches for protecting and restoring functionalities, or ensuring the connectivity of habitats (Xie and Bulkeley, 2020).

In terms of NbS for climate change, the academic domain is racing to keep up with the advances of the concept, and particularly to make use of its umbrella nature for addressing sustainability challenges such as CCA and CCM (Cohen-Shacham et al., 2019 *in* Mahmoud and Morello, 2021). Most research on NbS in the urban environment is biased towards disciplinary perspectives (Haase et al., 2014 *in* Veerkamp et al. 2018). In this regard, there is a new role of science with cities instead of science for cities (Holscher et al., 2019). However, as most city science is generated by consultants, scientific researchers are needed to generate new knowledge and to avoid synthesizing already existing information (Holscher et al., 2019). To this end, a scientist's critical logic can be beneficial for providing perspectives and recommendations that take into consideration the complexity of cities and the urban climate (Steiner, 2014 *in* Holscher et al. 2019). Therefore, among the different stakeholders involved in the urban settings, actors of the knowledge domain are expected to take leadership for promoting the uptake of urban NbS-NbaS (Van der Jagt et al., 2020).

However, many elements related to the urban realm still pose significant challenges for this task, these can be considered as current knowledge limits that should evolve intro research lines of work:

- Limit: First, the relationship between nature and cities is inversely proportional for its most part (Bailly et al., 2019a). Research need: In this regard, there is a need to clearly define all aspects of the city-nature relationship and determine how the trade-offs between these two different ecosystems can be balanced in terms of service provision and delivery, as well as to understand the negative feedback loops and counteract them.

- The urban context is highly non-uniform and is not a single space, it is rather formed from a mosaic of different systems, landscapes and media (Bulkeley and Raven, 2018). Similarly, urban nature extends beyond the misconception of scarce vegetation and artificial nature, and englobes water, lands, soils, air, and energy (Bailly et al., 2019b). The often oversimplified representation of the urban realm undermines the contribution of different land cover elements to the modification or creation of services or processes (Babí Almenar et al., 2018) [knowledge limit]. Therefore, any approach should consider this heterogeneity to adequately define the challenge in hand and the subsequent solutions. Research need: Nonetheless, complex approaches to mosaics of ecosystems are still rare. This is due to the fact that ecosystems, much like their services, are not bound by geographical boundaries, which means that these engage in loops that aren't still well understood. To this end, a mosaic of ecosystems means different tipping points, different ecological thresholds and different responses. Therefore, no solution can be accurately designed without a sufficient understanding of the stated elements. While this aspect is certainly difficult and bound by many challenges, it remains a necessary line of work to develop.

- Evolving urbanization constrains planners and scientists to design solutions in continuously limited spaces (Knaus and Haase, 2020). This is also compounded by the fact that turning impervious areas to green or blue spaces often conflicts with the need of building more housing structures. Therefore, space-sensitive solutions are needed (Knaus and Haase, 2020). Research need and limits: Nonetheless, space-sensitive solutions often imply small-scale interventions. The efficiency of the latter, particularly on large scale challenges such as climate change is yet to be decisive. To this end, NbaS for microclimate adaptation (i.e. a proportional scale to the proposed solutions) rather than climate change adaptation might be a more logical approach to develop.

- The effect of urban morphology (degree of compaction, extension and sprawling) significantly influences both the targeted environmental challenge and its solution (Van der Jagt et al., 2020) and makes any approach very context specific. Hence the absence of "read to apply" science and methods in cities. Research need: It is crucial to acknowledge that the city will continue to develop throughout the existence of the solutions. Therefore, the parallel evolution of both ecosystems should be further studied in order to determine how both influence each other and to orient proper decision making. Tracking the parallel evolution (current and future) of both ecosystems and solutions is still a relatively untapped domain that deserves further attention.

- The urban setting is a multi-scalar context. It encompass different scales: building, urban zone and cityscape level (Somarakis et al., 2019). Limit: The multiplicity of scales complicates the choice of a scale-efficient solution. For instance, a green roof at the building scale will have a negligible effect at the cityscape level. Likewise, an urban park at street level while have negligible effects at the building scale. Research need: The behavior and efficiency of solutions through different scales (scalar transition) is an important to platform to develop, as to the knowledge of the Authors, this aspect of NbS scalability remains relatively unexplored.

- In urban sustainability strategies more weight is still given to CCM than CCA (Hawxwell et al., 2018). This may be due to the fact that NbS for CCM are relatively easier than NbaS, as the latter call for completely reshaping existing urban models (Bailly et al., 2019b).

- Isolated NbS-NbaS (small interventions) can collapse under the “harshness” of the urban realm where entwined pressures may significantly surpass the solutions’ capacity, and cause an inflexion of their functions (Bailly et al. 2019a). Research need: In this vein, understanding the interactions between the solution and the medium it has been introduced in is an important platform to consider. Often, NbaS are wrongfully introduced as immune systems without considering how the components of the ecosystems they were introduced into influence their survival/efficiency.

- The behavior of NbS-NbaS in highly complex systems such as urban areas, in addition to the unpredictable behavior of climate change are significant gaps to bridge (Somarakis et al., 2019). This factor is both a knowledge limit and a research need that needs considerable efforts for being properly accounted for.

- In hydrological terms, the urban water cycle differs significantly from the natural water cycle (UNaLab, 2019). This difference is pronounced in studies, namely in hydrological modeling related ones, where in dense urban settings, calibrating flood or hydrological models can be a challenging tasks since the closely packed covers (urban, green cover and other elements) create obstacles that divert and guide flows thus creating a micro-hydrological system (Douglas et al., 2019) [knowledge limit].When these models are to integrate NbS-NbaS for scenario analysis or simulations, the above-mentioned complexities become more pronounced and can lead to reduced output accuracy. Consequently, insights on NbS efficiency become questionable. Research need: In this vein, developing urban hydrology models to accommodate for these factors is needed. For this purpose, expanding the use of fractal and multi-fractal analysis of NbaS in urban cities is of particular importance.

- The most studied domains in urban NbS studies are urban parks and forests, followed by urban green spaces, blue areas, and community gardens (Cooper et al., 2018). Accordingly, there is a need for mapping and deriving more evidence from a wide range of NbS other than Blue Green Infrastructure (BGI) (Hanson et al., 2017) [knowledge limit]. However, measuring the effects of NbS-NbaS in this ecosystem is a complex task (CER et al., 2019), despite its necessity for establishing resilient cities based on concrete evidence (EKO et al., 2019). The approach to blue-green infrastructures might be challenged by the complexity of the processes involved in these solutions. However, expanding current knowledge on urban solutions beyond the already existing inventory should be envisaged for properly out-scaling these NbaS in urban ecosystems.

Another set of challenges comes from the approach to the concept of ecosystem services. In the urban realm, ecosystem services are amply represented as an anthropocentric concept, i.e. they only exist when they are demanded for in a specific location (Fletcher et al., 2020). A support to this statement is Cortinovis and Geneletti's (2020) recommendation who stress the fact that urban transformation must aim to minimize adverse effects on current supplies of ecosystem services, while maximizing positive impacts especially in areas of high demand. While efforts and scientific literature on ecosystem service valuation have been growing, applications in urban settings are still limited (Bulkeley and Raven, 2018; Croci et al., 2021). The most relevant approaches target the local climate regulation, freshwater supply and recreation (Banzhaf et al., 2020). Despite the increasing research interest significant research gaps for understanding the supply and demand of ecosystems in complex multidimensional contexts such are still prevalent (Alberti 2005 *in* Banzhaf et al., 2020) [knowledge limit]. Research needs: **Under this context, the acknowledgment of ecosystems as critical infrastructures (Altamirano et al., 2020) is an important platform to consider, as it can lead to further studies, particularly in the urban realm.**

a. The urban climate and related solutions

What differentiates the urban medium from others is its particular climatic behavior. This is mainly due to the multitude of land covers that form the urban settings and the morphology of cities (degree of compaction, building heights, extension and sprawling). Urban Heat Islands (UHIs) are the most studied and documented urban climate phenomena[24] (Bailly et al., 2019a). They have become central elements of planning particularly under an ever changing climate (Gutierrez et al., 2020). Water management comes second after UHI and is particularly addressed for stormwater management and urban flooding reduction. In response to both challenges, green cover expansion and green roof installation are the most frequent solutions throughout the retained projects. In what follows, an explanation of each one's effects along with knowledge needs are presented

Trees

Street trees, along with other types of plantation, are considered as key elements for stormwater management in urban settings through precipitation interception, runoff reduction, increased evapotranspiration and infiltration (Baker et al., 2021). However, the extent of their efficiency has yet to be defined, and related literature hasn't been objectively reviewed (Baker et al., 2021). They are also efficient measures for reducing temperatures through evaporative fluxes and shading. Under this aspect, if these are imperfectly designed, they can disrupt air flow, hence causing localized increases in air temperatures (Connop et al., 2020). While the general consensus is that temperature increases in urban environments will only worsen UHIs, these may also induce longer vegetation growing season, increased photosynthesis rates, and hence more carbon storage (Vasenev and Kuzyakov, 2018 *in* Richter et al., 2020). This could also possibly mean promoted cooling as a result of biomass growth or development. Nonetheless, these feedbacks should be better understood when an NbS-NbaS is designed. At this level, the definition of buffer zones for the analysis of NbS-NbaS impacts could be helpful as their effect may not extend beyond a certain zone (Leopa and Elisei, 2020) particularly for cooling.

The arrangement of trees in urban cities dictates the nature of the solution, however evidence on the effect of tree arrangement for maximizing performances and benefits is inconclusive (Baker et al., 2021). Considering this aspect is important as tree arrangement is often dictated by space availability in cities. In this regard, individually spaced stand trees arranged in a linear manner are considered street trees, while closely arranged or grouped trees mean that these elements are part of a larger urban park or forest system (Baker et al., 2021). Regardless of their sizes and arrangements, trees and green covers address CCA and CCM simultaneously as they can sequester carbon while reducing temperatures (Tozer and Xie 2020). However, prior to the design and implementation of any green solution, several factors should be accounted for. For instance, some green solutions are irrigation dependent. This raises concerns in terms of resource efficiency, particularly in the context of climate change where water scarcity is expected to increase and droughts to extend further. In this context, the resource efficiency of any planned solution should be better investigated as throughout their existence, NbaS consume natural capital in their own rights. Understanding how NbS-NbaS utilize natural resource and nature is relatively understudied, and to the knowledge of the Authors, is an explored line of work.

Even if green spaces are perceived as performant NbS-NbaS, heatwaves and extended drought periods can severely degrade them (Morakinyo et al., 2017). Additionally, tree (or juvenile species) survival rate is very low during the first year as these are prone to be affected by climate change and particularly heat stress (Richter et al., 2020). Accordingly, what seems to be a solution to an intended problem can also be susceptible to the challenge it was intended to address.

[24] Refer to Gutierrez et al. (2020) and Oke et al. (2017) for further details on UHIs

Post scriptum: trees, grass, lawns and scrublands

1- In various cities street trees are installed in pits surrounded by asphalt or even planted in asphalt like material. While often under considered, the size of the pit is a determinant factor for their runoff reduction potential (Rahman et al., 2019 *in* Baker et al., 2021). According to Armson et al. (2013) *in* Baker et al. (2021), street trees in pits remove almost 62% of generated runoff at plot scale (3x3 m plot) through a study period of around 140 days with amounts between 0 to more than 10 mm of daily rainfalla percentage much less efficient than that of grass lawns that are able to abate runoff almost entirely. However, there is a significant paucity of research on possible NbS to lawns and urban plant communities (Morakinyo et al., 2017). To this end, much more solid evidence through higher intervention to catchment area ratio is needed (Baker et al., 2021).

2- Like any other green solutions, trees, lawns, grass and scrublands require significant irrigation for delivering their ecosystem services (carbon storage, heat mitigation, biodiversity support, water infiltration, evapotranspiration) and for survival (Morakinyo et al., 2017). However, in many countries such as Germany, Sweden and England, public area irrigation is not allowed during hot summers, thus green spaces become significantly water stressed and at the limits of degradation (Morakinyo et al., 2017).

3- Carbon storage in trees is well-discussed in literature, however, not much literature on carbon storage in grass or shrublands is available (Aevermann and Schmude, 2015 in Hérivaux et al. 2019). Therefore, this aspect in grass and scrub containing NbS and NbaS should be better studied.

O*n urban soils*

Any land-based green NbS-NbaS will forcefully be installed on underlying soils. Therefore, soil remains “a” if not “the” decisive factor for the efficiency of a land-based solution. This is due to the fact that green biomass along with its functions and root growth strongly depend on soil properties, composition and health. The soil-vegetation interface is also the decisive factor for the fate of precipitation infiltration, runoff generation, groundwater recharge and the hydrologic behavior of soil (Hérivaux et al., 2019). Hence, the effect of soil on the efficiency of green solutions for water management.

To this end, urban soils have an important role to be considered. Richter et al. (2020) provide detailed findings on their contribution to CCA and CCM (all findings listed below are from the above-mentioned reference, unless cited otherwise):

- More than two-thirds of accumulated carbon in cities are found in soils (particularly in subsoil compartments), followed by urban forests and park trees. Usually, carbon accounting in cities is only viewed from one dimension, where above-ground land use/cover are only taken into consideration within calculations. In the same logic, some broad-scale methods also fail to account for the variation of carbon storage in the mosaic land cover pattern (1D approach) (Davies et al., 2013 *in* Cannop et al. 2020) and its underlying compartments. In this vein, the most commonly used method for this purpose is measuring above ground vegetation storage, however, these methods do not accurately reflect carbon dynamics in settings where vegetation cover is often rare (Velasco et al., 2016 *in* Cannop et al. 2020).

- Subsoils usually store more carbon as a result of less disruption/disturbance and because some former topsoil layers could have been buried underneath by land cover changes. Deep excavation or any subsoil related activity can significantly release large amounts of carbon from the soil. This should be taken into consideration during the design phase of solutions to limit as much as possible changes to the topsoil horizons.

- By combinedly estimating carbon stocks in soils and vegetation, a robust and more accurate method for accounting for urban carbon storage is provided. However, the interactions between above-ground and below-ground compartments makes mapping carbon storage difficult, and the dynamic nature of storage (rapid evolution) also adds a layer of uncertainty.

Research need: The urban environment is often considered as a built medium in which soils are covered by impermeable material. However, existing soils are often regarded as impotent and their efficiency is seldom studied. In this vein, an inventory of urban soils (despite their scarce existence), along with information on their attributes should be built whether NbaS are planned or not. This inventory can then be considered as reference conditions that can be compared with changes brought about by the introduction of a NbaS.

As shown by the above-mentioned references, urban soils, despite their reduced spatial extent have the potential to mitigate carbon. However, the role of soils for CCA is still understudied. In NbaS terms, in any soil-based urban NbaS, the soil dimension should be better investigated and integrated to ensure a holistic efficiency profile of the sought solutions.

Green roofs: A solution for limited spaces

As can be noticed, green roofs are very widely targeted under various H2020 urban projects. In cities, infrastructural and space availability challenges can limit the expansion of NbS-NbaS (Kuban et al., 2019). That is why cities often cannot support large NbS projects (Bailly et al., 2019b). For this purpose, green roofs are considered as some of the most effective multi-purpose "ground-free" solutions that are ideal for cities and their continuous densification (Knaus and Haase, 2020). According to Zölch et al. (2017) *in* Baker et al. (2021), green roofs even outperform trees in terms of runoff reduction due to their larger permeable surfaces when aggregated, as opposed to the limited surface of trees planted in urban settings. In Europe, green roof shifts started in Germany at the end of the 19th century by replacing flammable tar with sand and gravel for fire protection (Getter and Rowe, 2006 *in* Knaus and Haase, 2020). Seeds naturally grew on these substrates and subsequently vegetation covered the roofs (Getter and Rowe, 2006 *in* Knaus and Haase, 2020).

The most decisive factor for a green roof is its substrate as it also defines its type, i.e. extensive or intensive (Knaus and Haase, 2020). Most green roof studies focus on extensive roofs rather than intensive ones (Knaus and Haase, 2020), despite the fact that the latter outperform the former on an environmental scale (Morakinyo et al., 2017 *in* Knaus and Haase, 2020) [knowledge limit]. Regardless of their types, these roofs are mainly used for climate resilience and long-term urban water management (Snep et al., 2020). They are important surfaces for ecological compensation in cities, and have a large potential for renaturing urban contexts (Santos et al., 2016). They effectively retain incoming water, help in CCA/CCM, modify surface energy balances, reduce runoff/peak flows, and promote urban biodiversity (Pardela et al., 2020). Whether intensive or extensive, the performance of green roofs is highly related to rainfall events and the initial saturation of their substrate. Roofs without local species and with shallow substrates such as the case of most Parisian green roofs tend to poorly deliver biodiversity support or cooling and water retention services (Bailly et al., 2019b).

Many studies report several insights on the behavior of green roofs on peak reduction and water retention [e.g. (Fassman-Beck et al., 2013; Getter et al., 2007; Hakimdavar et al., 2014; Stovin et al., 2012; Wong and Jim, 2014; Zhang et al., 2021)][25]. Values range from 15% to 100% according to substrate depth. However, lesser studies focus on assessing their impact on temperature reduction (Jamei et al., 2021). In a review of the effect of green roofs in Germany (in relation to the CLEARING HOUSE and CONNECTING Nature projects), Knaus and Haase (2020) found the following:

- At a street level, the cooling effect of green roofs is very minor with values as low as 0.04˚C, on a pedestrian level, the maximal reduction effect is of 0.3 ˚C, also negligible.

- The most pronounced effects on temperature are observed at the roof's level with a decrease of surface temperature by as much as 26 ˚C, Physiological Equivalent Temperature (PET) by 4 ˚C compared to street-level, and by 9 ˚C when compared with a non-green roof.

- At a street level, the effect of green roofs is negligible as air temperature and PET only show very minor variations

- In areas of mid to high buildings, the down spill of cool air generated by green roofs hardly reaches the street. According to Müller et al., (2014) *in* Knaus and Haase (2020), the downward effect of green roofs is negligible for buildings higher than 10 meters.

However, these findings are case-specific and are applicable to the specific conditions they were found in (Davis et al., 2018). In a different climatic setting, different behavior could be expected. Regardless of their exact number, in general terms, these findings indicate that the effect of green roofs is only pronounced at the level of the building they are located on, and hence do not replace ground greening (in terms of cooling), but can be only considered as a complementary effort (Knaus and Haase 2020). However, when considering the surface of green roofs when spread over the city, a considerable increase of green cover can be noted (Knaus

[25] These references are not from the H2020 database

and Haase 2020). For instance if green cover in a city was of X green ground cover units, the addition of green roofs would cause this distribution to shift towards higher values, i.e. total green cover = X green ground cover + Y green roof cover. Another advantage of green roofs is that these can be coupled to other solutions. For instance, urban farming on a green roof (Somarakis et al., 2019), or a constructed wet roof that combines an extensive green roof and a constructed wetland for water treatment (UNaLab, 2019). However, further investigations on the combined effects of ground and roof solutions are still a line of work to develop.

b. An increasing interest in edible solutions (urban farming)

EdiCitNet is a project that targets edible solutions in cities through different examples, from which fruit walls are most common. This type of solutions is much more unconventional than the above-mentioned NbS-NbaS or other BGS. In fact, edible solutions are significantly underrepresented and understudied solutions (Saumel et al., 2019). They also suffer from the absence of a uniform definition, and are a widely debated topic that is often openly defined (Schmutz et al., 2020). Much like other interventions, edible solutions are local approaches to global challenges, consequently, their efficiency is hard to assess and the threshold for considering an intervention as sufficient or successful is undefined (Wubben et al., 2020). They also require extensive technical efforts and continuous maintenance to remain functional (Schmutz et al., 2020). While they can help strengthen food security under a changing climate, their main environmental goals are not directly related to climate resilience. However, these are valuable solutions for achieving responsible and sustainable resource consumption, promoting food security and ensuring resilient cities (as revealed by Schmutz et al., 2020). **In this regard, studying their effect and relationship with climate change could be an interesting platform to consider, in order to maximize their benefits, or to design them in ways that make them promote climate resilience.** Under any circumstance, edible or agricultural NbS shouldn't be implemented without an investigation of soil properties, since undetected soil contamination can lead to increased costs for cleaning the soil, and threatens the efficiency of the sought solution (Jafari et al., 2020). However, soil contamination does not condemn the solution, as the edible NbS can be replaced by a non-edible solution such as grasslands or soilless solutions such as aquaponics (Jafari et al., 2020).

c. Concluding remarks (research perspectives)

Regardless of the type, it is vital to consider that while NbS-NbaS are implemented, urban development still occurs rapidly (Holscher et al., 2019), along with climate change. Therefore, it is logical to question if NbS-NbaS can deliver enough regulation in terms of temperature, air, and water management if cities continue to progress the way they are (Kiss et al., 2019). At a city scale, one must also measure the aggregated effect of several NbS-NbaS to have a clearer picture of their effects (Somarakis et al., 2019). However, this aspect is still one of the most challenging domains for NbS-NbaS research.

With the progression of climate change, fortifying existing or new solutions should be a priority. An adequate contribution to this target could be the promotion of connectivity between green and blue areas, as well as between different NbS-NbaS. This is due to the fact that connected ecological features can enhance the provision of ecoservices, hence maximizing benefits (Thomas et al. 2020 *in* Fletcher et al. 2020). This objective is particularly pronounced under the CLEVER Corridor project that aims to spatially connect several existing/expected NbS across the areas of intervention to tap their bridging functions (Arlati et al., 2021). When connecting solutions, a special attention should be given to the durability, sustainability and the multifunctionality of the proposed solutions (Maksimovic et al., 2021). Per example, in a blue-green solution, the blue compartment can serve as a source of watering for the green counterpart (Maksimovic et al., 2021). According to the same project, barriers facing the exploitation of urban NbS-NbaS lie in the socioeconomic and political domains rather than in the biophysical sphere (Perrin, 2018). This may be due to the fact that the current urban institutional context is not susceptible of simultaneously accounting for the cross-sectorial nature of sustainability, NbS, urban development, CCA and CCM (Hawxwell et al., 2018). Nonetheless, both the aggregate and connective effects are still underdeveloped and significant efforts are needed as part of research efforts.

ii. Marine and coastal ecosystems

The EC's seven NbS actions for R&I are according to Morello et al. (2018): Urban regeneration through NbS, NbS for well-being in urban areas, NbS for coastal resilience, multi-functional nature-based watershed management and ecosystem restoration, NbS for sustainability of the use of matter and energy, NbS for enhancing the insurance value of ecosystems, and NbS for carbon sequestration. Despite the high rank of coastal resilience on this list, coastal areas are very rarely addressed within the NbS-NbaS framework (Ruangpan et al., 2020). In terms of Nationally Determined Contributions, the European Union is one of the several parties that do not have references to their marine and coastal ecosystems (Seddon et al., 2019). In a review performed by Hanson et al. (2017), climate action for adaptation, resilience and mitigation were found to be NbS priority number one, while coastal resilience was quasi-absent. Another review by Nikolaidis et al. (2019) for case studies in the ThinkNature database revealed that coastal resilience is also one of the least targeted goals. The same was also found in a review conducted by Veerkamp et al. (2018), where climate adaptation, resilience and mitigation were found to be the most targeted aspects within ecosystem service assessment, in contrast to coastal resilience and marine protection. Several of the retained projects target coastal areas as part of their pilot zones (ref. Annex A, OPERANDUM). However, only two H2020 NbaS project are dedicated for coastal and marine areas (FutureMARES and MaCoBioS). Both are still undergoing (2020-2024) and consequently not many related references have been produced during the time of this study[26]. Therefore, not much research gaps were extracted from these projects.

However, a general picture of current knowledge shows that the underrepresentation of marine and coastal ecosystems is surprising, since these are some of the most influenced contexts by hydrometeorological hazards and climate change (Debele et al., 2019). The complexity of these settings might be a reason (Dudley et al., 2010), as challenges in these systems may be closely overlapping [e.g. coastal resilience and climate change] (Bulkeley and Raven, 2018). Some hazards may be also interlinked, for instance storm surges and coastal erosion have a cause-consequence relationship (Debele et al., 2019). Under the current reviewed offer (excluding FutureMARES and MaCoBios), coastal erosion is an addressed hazard in coastal urban contexts (coastal cities). The main objective behind this approach is to protect or adapt the concerned cities to coastal hazards.

Limits and research needs

As such, coastal resilience and the coastal ecosystem are not targeted for land loss, sediment balance, foreshore stability or seafloor configuration (i.e. the ecosystem's intrinsic value), but for the sake of the urban system. **This indicates that the importance of an ecosystem increases only when an urban context is in vicinity. Subsequently, the proposed NbS-NbaS will be indirectly implemented as utilitarian anthropocentric interventions**.

Moreover, the solutions offered by marine and coastal ecosystems are also somewhat underutilized despite their potential. For instance, marine habitats such as seagrass, salt marshes, mangroves, coastal wetlands and kelp forests, coral and shellfish reefs are efficient coastal protection elements that help adapt to increased storms, sea level rise and climate change induced floods (FutureMARES, 2021). For example, salt marshes and coral reefs are capable of decreasing flood waves by 70% and 72% on average (Debele et al., 2019). However, these are still underused and are not studied as much as green or blue-green solutions. Much of these solutions are expected to be implemented and studied in the FutureMARES and MaCoBioS project, and hence considerable knowledge is expected to be generated. However, during the time of this study[4], no data was yet available. Dunes and dune rehabilitation are addressed in the Italian Bellocchio beach (UNESCO World Heritage site) in the OPERANDUM project as means for abating coastal erosion.

In terms of research needs, these solutions as well as the marine realm require more studies. In contrast to land-based habitats, the focus on marine habitats and their restoration is still juvenile and long-term success stories are still limited (Stewart-Sinclair et al., 2020). The distribution of ecosystems in the NbaS H2020 projects supports this point of view. For marine NbS-NbaS, considerable knowledge is lacking particularly for the subtidal zone (O'Shaughnessy et al., 2021), hence the need for more research efforts in this realm.

iii. Mountainous ecosystems

Similar to the international scale, the mountainous medium is also the least targeted ecosystem in H2020 projects. The only dedicated NbS-NbaS project is PHUSICOS that aims to demonstrate how NbS can reduce risks in mountainous landscapes. Currently, none of the present platforms on NbS are specifically focused on natural risks in hilly and mountainous regions (Baills et al., 2021), nor on climate change adaptation.

[26] January-July 2021

Moreover, despite the role of mountains in amplifying hydrometeorological risks, particularly under a changing climate, not much attention is given to these environments especially in European DRR plans (Autuori et al., 2019). Accordingly, very little research on NbS for DRR in mountainous environment has been conducted so far (Accastello et al., 2019 *in* Martin et al., 2019). In the very few studies of DRR in mountainous areas, most address floods while fewer target landslide and rockfall hazards (Baills et al., 2021). To this end, success stories of NbS-NbaS for landslide and flood mitigation in rural and mountainous areas are still meagre (Solheim et al., 2021). When considered, most solutions in this consist of forests (afforestation/reforestation) for stabilizing slopes, reducing rockfall, landslides and avalanches, as well as for buffering flood risks.

Limits and research needs

The inconsideration of mountainous environments is surprising since:

- They are some of the most sensitive settings to climate change, and are hence considered as priority regions for adaptation measures and planning (Palomo et al., 2021).

- Stabilizing them will subsequently lead to less risks downstream their path, and will also prevent the accumulation of small events into large-scale disasters (Solheim et al., 2021).

As a result of the minor attention to mountainous environments NbS for hydrometeorological risk reduction in rural and mountainous media still suffer from the absence of adequate proof for replicability and upscaling (Fohlmeister et al., 2018). As large scale settings, mountain may require proportional NbS-NbaS. However, as mentioned previously, such large scale approaches are still limited by many factors. With reference to Chapter 1, any mountain NbS-NbaS intervention should not be local or punctual, but rather several solutions should extend in a whole slope approach. **To this end, including mountains in NbS-NbaS watershed planning schemes, in analogy to hydrological studies, might be a good starting point for increasing NbS-NbaS research in mountainous ecosystems**. The rationale behind this recommendation is that mountains form the upper parts of watersheds and extend with their slopes to the watershed's lower regions. In this sense, NbS appraisal of headwater sections might allow a better achievement of downstream adaptation benefits. Accordingly, as part of a watershed scale approach, the whole slope plan would be covered provided that NbS-NbaS are implemented or planned. The underlying logic is that watershed scale approaches are important to reveal the efficiency of aggregated NbS-NbaS that are spread across the studied basin (Burke et al., 2018).

iv. Forest and natural (protected areas) ecosystems

Within the retained projects, forests are some of the most common solutions, but are rarely addressed as target ecosystems. The range of environmental challenges that forests are used as solutions to is wide, and spans across climate change adaptation/mitigation, disaster risk reduction, biodiversity support, climatic regulation, stormwater management, air regulation, erosion counteraction, water quality support, floodplain restoration, and others. Seemingly, trees and forests are "the" solution for almost all environmental challenges in different ecosystems. They are also used as means to address socioeconomic challenges in various settings (ref. Annex A), especially in cities. Under the retained projects, most of their use was concentrated in the urban ecosystem. To this end, several relevant knowledge levers and gaps were stated in the above corresponding section (urban ecosystem). In other than urban systems (namely the mountainous environment and watersheds), forests were mostly used for risk reduction (landslide and flood risk reduction, respectively).

Limits and research needs

Despite the state of forests as the "silver bullet", numerous facts should be taken into consideration:

- Regardless of the ecosystems they are inserted in, the total range of benefits from these solutions is expected/reached only when forests become mature, especially when newly installed or designed. This means that a certain time lag for the maturation of the solutions' ecological component should be expected (Rahman Shah et al., 2019), while the challenge they were introduced to solve continues to evolve.

- While forests (afforestation/reforestation/plantation) are perceived as a powerful solution, they are rarely considered as subjects to the challenges they were designed to face. In simple terms, very few projects consider that weather and climate change (especially in urban contexts) might overpower these solutions.

- The potential of forests is always presented more than the potential of their underlying soils, that are often the main determinant for the above-ground compartment's efficiency (further details on the role of soils are presented in later sections).

- Under the air quality scope, it is often more logical to suppress or attend to the source of pollution rather than overestimating the potential of trees to drastically clean the air (Bailly et al., 2019b).

As reported in the section urban ecosystem, the efficiency of forests as potent NbS-NbaS is well established. However, deeper insights to their vulnerabilities when used as solutions could be an interesting platform to consider.

Protected areas (limits and needs)

In their own right, protected areas are relatively untapped despite their spread across the European continent (Natura 2000, regional parks, and others). This is a major research gap to address, as the potential of these solutions is relatively underutilized in NbaS projects. The same was found in the international approach (Chapter 1). However, the attention these solutions/ecosystems received under the regional approach is much less. This could be due to the fact that the urban medium is the most favored ecosystem, and that protected areas do not correspond much to urban priorities. However, when implemented at the outskirt of cities or urban contexts, protected areas can increase the connectivity between urban, peri-urban and rural contexts, thus promoting the resilience of urban ecosystems (Naumann and Davis, 2020). This concept of connectivity is well developed in the H2020 projects as a large number targets this aspect through green/ecological corridors. However, these cannot be considered as protected areas since the management of these zones differs significantly. In this vein, most project implemented green spaces aim to increase the recreational access of people to nature, and to strengthen the human-nature bond (among other goals). The same isn't always applicable in the case of protected areas, where access to some zones might be restricted (i.e. different degrees of anthropogenic pressure). As a result of less anthropogenic disturbance, connective protected areas will have a richer ecological composition/structure, and subsequently more ecosystem services delivered. Accordingly, the benefits brought by connective protected areas might surpass those delivered by traditional connective solutions. Moreover, the use of protected areas as means to protect other NbaS is not very developed. While some projects propose the use of buffer strips to protect downstream waterbodies from agricultural runoff, none make use of protected areas for the same purpose (protection of other NbaS). **This could be an interesting line of work to develop for maximizing the use of protected areas as part of NbaS or for their protection.**

In terms of marine protected areas, the narrow focus on marine environments can also be a reason for the relative absence of protected areas. On these bases, significant efforts are needed to leverage the use of protected areas (both terrestrial and aquatic) as NbS-NbaS, and to define relevant knowledge and research needs. The latter might be addressed throughout the EU's far-reaching 2030 biodiversity strategy that will transform at least 30 percent of Europe's lands and seas into effectively managed protected areas (GEF, 2020).

v. Freshwater ecosystems

The freshwater medium is the second most targeted ecosystem under the H2020 projects. In each project, different freshwater realms of various scales are present (ref. Annex A). These range from lakes, to rivers, to river networks and watersheds. The focus on freshwater bodies, while less than that on urban environments also reflects European priority strategies. Most of the prevalent measures are of structural or functional measures. Examples are river restoration, floodplain enlarging, river meandering, daylighting, installation of levees, wetland restoration, modification of the hydrologic network (connection/disconnection), retention basins and others.

At this level, nature contributes to CCA through flood management and the provision of better water quality (Bailly et al., 2019b). Water quality is mainly addressed through phytoremediation, the use of wetlands or other small water retention features for sediment or soil bound pollutant retention. Another measure is the installation of grass or vegetation belts and canals around waterbodies to protect the latter from pollutant bound runoff from neighboring systems (urban or agricultural).

In river management and flooding, several projects highlighted many factors that are responsible for the complexity and difficulty of NbS-NbaS:

- The multitude of factors that interfere [i.e. socioeconomic, climatic, geological, and geomorphological, etc] (Banwart et al., 2018) make the design and conceptualization of these solutions complicated.

- The role of ecosystems (underlying basis of NbS and NbaS) on water supplies is still an open empirical research topic (Hérivaux et al., 2019).

- The challenges involved call for different scales, and that itself is a considerable barrier; for instance, pluvial flooding requires an urban zone scale, while river flooding requires a whole watershed scale approach (Somarakis et al., 2019).

- The size and location of NbS-NbaS is also an important factor to consider. According to Burke et al. (2018), small (many) interventions should be concentrated in upper watershed sections where flows are less than the downstream parts where large interventions should take place (Burke et al., 2018).

- The same hazard, e.g. flooding, can be initiated by different triggering factors. For instance, river floods can be initiated by precipitation in a particular context (e.g. Western Europe), while in other regions (e.g. Northern Europe), snow melt can be the main reason (Aguzzi et al., 2019). An example would be the case of Finland (Finér et al., 2019), where significant efforts are needed to take into consideration the effect of melting, its timing (changes) and the effects on the sought solutions. Accordingly, sought solutions in these contexts should take account for these manifestations along with other ones. Therefore the same NbS-NbaS for the same freshwater hazard cannot be applicable in different locations.

In addition to the above-mentioned elements, literature (as current knowledge and limits) on freshwater ecosystems is H2020 projects is rather abundant. It is particularly pronounced in the case of flooding where the following information were extracted from the concerned projects:

In a detailed approach to flooding, NbS-NbaS aim to increase the floodwater storage capacity upstream of urban or other settings (Muligan et al., 2017). Storage capacities usually concern four compartments: water bodies, canopy, floodplains and soil (Muligan et al., 2017). Increasing the storage capacity of any compartment impacts flood hydrographs by reducing the velocity of floodwaters, influencing peak flows and buffering risks in both the river and downstream sections (Muligan et al., 2017). Van Soesbergen and Mulligan (2018) found through storage capacity analyses that targeting soil and canopy storages was needed to reduce flood risk. While several NbS-NbaS target the floodplain (e.g. floodplain enlarging), water body (e.g. river restoration and daylighting) and canopy compartments (e.g. increase of green cover), rare are those who target soils despite the fact that increased soil infiltration can significantly reduce flood risks (Muligan et al., 2017). The latter fact is a H2020 identified limits that can be considered as a research need, i.e. developing the contribution of the soil compartment in flood reduction. Infiltration solutions are also potent drought NbS-NbaS as these can increase groundwater storage (Muligan et al., 2017). However, groundwater systems are not routinely monitored (Douglas et al., 2019). Moreover, increased infiltration is not always an advantage, in contexts where groundwater supply is high as increasing infiltration will only compound groundwater flooding risks due to water table rise (Hérivaux et al., 2019). A relevant example is karst saturation as the latter can lead to amplified risks particularly when soil saturation is also high (Graveline et al., 2018). It is also important to understand how NbS-NbaS can influence groundwater levels after extreme events (Pérez-Lapena et al., 2018) [knowledge limit]. In this vein, the groundwater-aquifer-NbS nexus has been highlighted in several sources as a significant gap to address [research need] particularly given their importance for attending to droughts and floods simultaneously (Tuomenvirta et al., 2019).

Post scriptum

1- Karst hydrological and hydrogeological modeling can be a complex task since these systems are highly heterogeneous (Douglas et al., 2019). This makes their hydrological behavior very hard to depict due to the difference of time dynamics between surface and groundwater flows (Abdallah and Bou Kheir, 2009; Bou Kheir et al., 2008). Therefore, karst water modeling often calls for a coupling several models, which in turn may increase uncertainties as a result of associated modeling errors.

2- In the case of the Lez River, early pumping of water in the summer from the Karst is considered as a NbS (Douglas et al., 2019). Yet this is questionable, as changes in management regime are not necessarily NbS-NbaS.

Currently, flooding under most contexts is mainly addressed using hybrid solutions (Debele et al., 2019). In the green versus grey debate, NbS-NbaS often lose the argument of collected experience and evidence compared to grey infrastructures (Knobaulch et al., 2019) [knowledge limits]. Therefore, it is important to develop tools and indicators to assess mixed solutions (Nikolaidis et al., 2019) [research need]. The environmental impact of hybrid solutions also requires further investigations (Kiss et al., 2019) [knowledge limit[. It is therefore logical to question if NbS-NbaS are fully capable of masking the disruptive effect of their grey counterparts [research need] . The latter's performance under an uncertain evolution of climate is also still relatively unknown, and can be considered as an important line of work to explore (Watkin et al., 2019) [limit + research need]. Under this context, significant efforts are needed for the assessment of large scale NbS-NbaS, watershed scale NbS-NbaS and hybrid structures that contain both small and large NbS (Watkin et al., 2019).

One of the main disadvantages of NbS-NbaS over grey solutions is that the formers usually require considerable time to reach their functionality or full potential (Altamirano et al., 2020). However, NbS-NbaS provide primary benefits along with secondary ones often termed as co-benefits (Hérivaux et al., 2019). These co-benefits make NbS-NbaS superior to grey infrastructure who would have gained an upper hand on NbS-NbaS if only primary benefits were compared (Hérivaux et al., 2019). It is also believed that since NbS-NbaS are based on nature, they will tend to appreciate with time rather than depreciate like conventional grey infrastructure (Collier, 2021). However, considerable efforts are still required to draw a decisive line in this regard particularly with the possible impact of climate on the efficiency of sought solutions [research need].

It is worthwhile mentioning that a considerable advance in freshwater systems is presented through the DRYvER project. The latter is the only H2020 project that considers intermittency of water bodies. Although the project is still undergoing, the work done by Messager et al. (2021) provides solid arguments on the gaps this project is filling. According to the same Authors, unlike rivers and permanent streams, the value and future of intermittent water bodies are often undermined, understudied and overlooked (Messager et al., 2021). Until recently, freshwater sciences were particularly concentrated on perennial water bodies, and it isn't until lately that scientists acknowledged the seriousness of intermittent water bodies' degradation (Messager et al., 2021). As a result, the related scientific methods and management tools are either limited or absent (Messager et al., 2021). In a map presented by the same Authors, stream intermittency was shown to be particularly pronounced in Southern Europe (i.e. the region under Mediterranean climate) where droughts are causing significant stress on water resources. However, as mentioned-above, this discipline is still nascent and more significant efforts are needed. → **In this vein, NbS-NbaS that take into consideration intermittency are also an interesting line of research to develop.**

Post scriptum: Hydrological modeling, a lever in freshwater systems NbS-NbaS applications

1- In the case of freshwater ecosystems, an important element that assist in these applications: the use of hydrological models. According to Mayor et al. (2018), modelling any basin or a study area is a powerful decision-support tool for a prioritized approach. This can help determine whether a sub-basin NbS-NbaS approach would suffice, or a whole watershed approach would be better suitable. Accordingly, more oriented and focused decisions can be made. This can help resolve the challenge of NbS-NbaS scale and location. It can also provide information on the effect of these solutions on the different hydrological processes through pre and post-NbS/NbaS scenario simulations. Nonetheless, modeling challenges such as calibration, the availability of observational data and other factors may be limiting factors.

2- Wetland modeling is a very complicated task as very detailed models are needed to account for the behavior of these small water bodies particularly when they become connected to the main streams during periods of high flow or flooding (Burke et al., 2018).

Post scriptum: An important case of lessons learned

The Ningbo China case of the proGIreg project offers an important insight on the failure of a water-based NbaS. Lake sediment was expected to be transformed into soil fertilizer as one of the solution's co-benefits. However, the high content of heavy metals in the sediments blocked this goal and led to the abandonment of the solution (Saraco et al., 2020b). Despite this loss, proGIreg's decision of dropping the solution was much better than having it implemented and then suffering from its inevitable subsequent effects.

vi. Agricultural medium

As can be noticed in the topics and scopes of projects, the agricultural medium as an ecosystem of interest is absent. Many projects target agriculture in some related pilot sites (Annex A), however not as a primary focus. The absence of the agricultural sector as a biome of interest is a significant element to consider given the importance of the latter for food security and the sustainability of humans and ecosystems.

While edible solutions have been proposed as part of urban agriculture in the EdiCitNet project, very few other solutions are proposed. The reduced interest in the agricultural sector causes a subsequent underrepresentation of agricultural NbS-NbaS, and hence underlines a major gap to address.

IV.4.7 Cross-ecosystem current knowledge and gaps

While the section above presented ecosystem-specific knowledge, this section presents knowledge and gaps that span across the different media. The first and foremost challenge is that NbS-NbaS should move post pilot site and experimentation phases (Hawxwell et al., 2018). Second, in any media, when adaptation is targeted, risk should be acknowledged, accepted and dealt with (Bailly et al., 2019a). While the NbS concept can be considered as an EU invention, and despite the political momentum behind the concept, the actual mainstreaming of NbS, let along NbaS, is far from reaching its potential (Knobaulch et al., 2019). Despite the high level of awareness on NbS, the initiative to take action is still often low (Lupp et al., 2021).

Under any context, the definition of the societal/environmental challenge to be targeted by NbS-NbaS should be an ongoing process (Garcia Perez et al., 2018). Currently NbS-NbaS are still of limited use, and are often focused on specific interventions for particular challenge, instead of harnessing their potential to address multiple problems (Bulkeley and Raven, 2018). To this end, a significant dividend between the potential of these solutions and their utilization for multi-benefit provision exists (Perrin, 2018). At this stage, it is important to consider that the implemented NbS-NbaS will bring benefits that are not directly linked to the challenge they were introduced to respond to (Somarakis et al., 2019). To exploit this potential, it is important to recognize the trade-off and synergies of these co-benefits (Gomez Martin et al., 2019). However, this cannot be properly addressed until an understanding of the interrelations and interdependencies between the (eco)system, its components (Freyer et al., 2019) and the introduced solution is established.

i. On ecosystems, restoration and ecoservices

Regardless of the target ecosystem, the relationship between NbS and ecosystem restoration is bidirectional: NbS can restore ecosystems, while ecosystem[27] restoration can be considered as a NbS-NbaS (Banwart et al., 2019). In this vein, the ecosystem service concept is growing to become a major element of current sustainability debate (Bull et al., 2016), and forms a fundamental aspect of the NbS-NbaS concepts. However, this concept is challenged by many factors that be considered as knowledge gaps (as highlighted by the different projects):

- Its anthropocentric nature is a question of debate even if it positions humanity in harmony with nature (Bull et al., 2016).

- The perception of nature as an instrument instead of being valued for its intrinsic value (Veerkamp et al., 2018).

- Limited knowledge on the connection between sustainability and human well-being (Chan et al., 2012 *in* Bull et al. 2016).

- The lack of systematic quantification of ecosystem service benefits for NbS for climate change [NbaS and NbS for CCM] (Bockarjova and Wouter Botzen, 2017).

- Often, ecoservices provision is measured using annual mean values despite the existence of considerable intra-annual or seasonal variations (Fletcher et al., 2020). Overlooking the latter can significantly influence the accuracy of ecoservices provision calculation and therefore can be considered as a gap to bridge. Moreover, ecosystem services are mostly assessed from a monetary/economic perspective; this overemphasis on

[27] An ecosystem feature can only be considered as an NbS-NbaS when its potential for addressing a challenge is recognized through research, among other factors (Bulkeley et al., 2017).

financial aspects (Bull et al., 2016) weakens the potential of scientific analysis, conceptualization and development.

- In addition to the nature of delivered ecosystem services, there is need to understand how these provide solutions to the targeted challenges (Bulkeley and Raven, 2018).

- The spatial discrepancy between the location of the sought solution and the location of the ecoservices' beneficiaries (Fletcher et al., 2020).

- The absence of a systematic approach to understand how the different systems, i.e. ecosystem-NbS-NbaS, interact with and influence each other (Freyer et al., 2019).

- The mismatches between the demand and supply of ecoservices that need to be addressed for maximizing the efficiency of NbS-NbaS, accurately representing their behavior, and for choosing their design/location (Fletcher et al., 2020).

ii. Soils: an undervalued medium and solution in land-based ecosystems

Soil is a land-habitat transversal NbS-NbaS that should be better studied (Tuomenvirta et al., 2019). In NbS literature, only a minor fraction of studies investigate soil as resource, while much less studies include any related response indicators (Andrés et al., 2021). This could be due to the fact that soil indicators could take a long time to unravel (Insam and Domsch, 1988 *in* Andrés et al., 2021).

Nonetheless, several H2020 projects incorporate the soil dimension. Some utilize it as an NbaS (e.g. new/regenerated soil production in proGIreg, soil as a water retention measure in VARCITIES, and smart soils in Urban GreenUP), others as an indicator. However, this line of work remains underdeveloped in literature on NbS-NbaS and significant efforts are needed. In the case of NbaS the need is more pronounced as the solution to climate change is beneath our feet (Velibeyoglu and Gokcen Akkurt, 2019).

The importance of soils comes from various factors (in addition to those listed in section *the urban ecosystem*): First, soils affect natural water cycles, hydrological regimes/responses, and the energy balance of the concerned area (Connop et al., 2020), and hence its implemented NbS-NbaS. Their interaction with the atmosphere also is a reigning factor for many solutions. Second, the states of soils can be considered as important indicators. For instance, soil sealing is an important indicator of anthropogenic pressure on the natural environment (Weng et al., 2011 *in* Cannop et al. 2020). Third, in any plant based NbS-NbaS, green compartments are not only influenced by atmospheric or above-ground processes (Tuomenvirta et al., 2019). They are also controlled by the properties of their substrates. Therefore, the inconsideration of soils and their properties could be a significant barrier for the success of a planned solution (Saraco et al., 2020a). For example, many references stress the importance of the substrate's effect on the efficiency of green roofs. The same is applicable for blue solutions whose underlying pedology should be considered. For instance, sandy soils are not suitable for building artificial wetlands. Regardless of the type of solution, soil hydrology needs to be better investigated for designing adequate solutions (Debele et al., 2019).

It is worthwhile mentioning that the implementation of new NbS-NbaS in sites may lead to soil disturbance (Connop et al., 2020). The latter can have a considerable impact on soil respiration and hence release carbon (Velasco et al., 2016 *in* Cannop et al. 2020). **This seldom considered fraction should be accounted for during planning, carbon calculations for accurate estimations of carbon release and storage and efficiency monitoring (Andrés et al., 2021).**

iii. On the other side of the coin: disservices and unwanted impacts

One of the most perceivable risks of NbaS is climate gentrification (Kiss et al., 2019).

One of the main advantages of the NbS framework is that it acknowledges the existence of disservices (Schaubroeck, 2017). However, it isn't until recently that disservices became well discussed in NbS literature. Almost all of the retained projects acknowledge their existence and incorporate some related types of analysis during their design or planning phases. However, only accounting for disservices is not enough. There is an equal need to account for trade-offs particularly when one ecosystem service decreases due to an increase of another (Bailly et al., 2019a). In that sense, NbS-NbaS may lead to negative consequences on ecosystemic balance (Banwart et al., 2019). It is therefore important to acknowledge that any NbS-NbaS can get out of hand, **for despite their importance, NbS and NbaS consume natural resources while they exist (Somarakis et al., 2019)**. Therefore, one should not assume that the NbS-NbaS intervention will surely work (Burke et al., 2018). That is why the risk of failure should always be accounted for. Therefore three scenarios are recommended to be expected. The first is a case where everything occurs as planned, the second is a best scenario where all expected elements are achieved to the maximum, and the third is a critical scenario where failure is expected.

However, disservices and risks are often outweighed by the long-term benefits of NbS-NbaS (Hawxwell et al., 2018). Nonetheless, this does not mean that disservices are to be treated lightly as in some cases these can have serious consequences. For instance, with a changing climate, increasing the extent of water bodies might be a serious proliferation factor for water-borne diseases (particularly in tropical or equatorial settings). Such considerations need to be made according to the reigning climatic regimes. To this end, disregarding disservices during early analysis is a significant threat that can amplify risks and lead to efforts in vain (Bailly et al., 2019a).

Post scriptum: Island ecosystems

The ARTISAN project encompasses several intervention sites in the French overseas territories. As most of these are islands, a specific approach to these settings in required given their particular settings. While NbS-NbaS differ from one context to another, large differences should be expected in the case of islands as these are often isolated entities with distinct geoclimatic properties and biodiversity characteristics. **Therefore, the line of research on NbS-NbaS transposability and applicability in islands is an interesting line of research to develop.**

ReNATURE is the only project that deals with an island setting (Malta). Accordingly, several findings were extracted to present a state-of-the-art on NbaS in island settings.

Grace et al. (2021) found several NbS-NbaS priority knowledge and research needs in Mediterranean islands, with respect to the scope of this chapter, the most relevant are:

- A more exact definition of the NbS concept.
- The need to know which NbaS are best adapted to the dry Mediterranean conditions.
- How can NbS-NbaS be integrated in current infrastructures.
- What NbS-NbaS make the best use of lands when these are scarce (particularly in islands)?

Balzan et al., (2020) equally reported the following:

- Studies on the contribution of Mediterranean agricultural systems to ecosystemic regulation services, as well as on biodiversity-ecosystem functionality are still relatively scarce
- Studies concerning the impacts of climate change on biodiversity and biodiversity-ecosystem links in Mediterranean contexts are still limited.

Another gap is the absence of studies that relate ecological responses of Mediterranean agroecosystems to

iv. NbaS and DRR

Most engineering responses to DRR are of reactive nature, while NbS-NbaS for DRR can be considered as proactive responses[28] that simultaneously develop co-benefits next to their primary purpose (Fohlmeister et al., 2018; Rutzinger et al., 2019). While nature is perceived as a triggering factor for hydrometeorological hazards, the NbS-NbaS concepts aims to harness the power of nature to reduce these events (Han and Kuhlicke, 2019). However, regardless of the target ecosystems, when NbS-NbaS are used for DRR there are several elements to consider. These mostly stem for knowledge and research gaps to be addressed:

- There is need to develop more studies for understanding the interactions between hazards and how these mold vulnerabilities and risks (Majidi et al., 2019).

- In the NbS-NbaS for DRR realm, there is a gap in knowledge about the potential of NbS-NbaS to deliver co-benefits in addition to their risk reduction effects (Solheim et al., 2021). As can be noticed, this statement opposes the observations of Fohlmeister et al. (2018) and Rutzinger et al. (2019), thus showing that this matter is a polarized research question.

[28] Nature has been sought as a measure to mitigate risks since the late 1980s (Zingraff-Hamed et al., 2020).

- Throughout different contexts, the assets at risk are quite different, therefore no NbS-NbaS approach can be considered as universal. For example, within Western Europe, the most exposed assets are high populated areas, agricultural and infrastructure-dense areas, while infrastructure are mostly at risk in Southern Mediterranean contexts (Burke et al., 2017).

- While the potential of NbS for DRR is well-known, there is still a need for quantifying their positive effects (Moos et al. 2018 *in* Baills et al. 2021).

- There is a need to develop a solid database on the climatic benefits of different solutions for properly mainstreaming NbaS and NbaS for DRR (Tozer and Xie, 2020).

- To have a significant performance in terms of temperature reduction and flood mitigation, different measures (NbS-NbaS) are needed in different locations (Majidi et al., 2019). However, there are no studies on the combined assessment of NbS-NbaS' efficiency for flooding and heat stress mitigation simultaneously, among other hazard/risk couples. (Majidi et al., 2019).

- NbS-NbaS for DRR not only assist in attenuation of risks, but can also serve as important factors in post-disaster recovery phases (Tuomenvirta et al., 2019) by promoting the resilience of the concerned context.

- In hydrometeorological DRR terms: i) Han and Kuhlicke (2019) found that many papers describe hydrometeorological risk reduction from a generic point of view without sufficient methodological robustness to determine perceptions on NbS-NbaS for DRR. ii) Both surface and subsurface water conditions should be evaluation in the case of NbS for hydrometeorological hazards (Rutzinger et al., 2019).

v. On the connectivity of solutions

The connectivity of solutions was introduced in the urban ecosystem section. However, in any ecosystem, NbS-NbaS can help reduce habitat fragmentation and restore ecological connectivity (Babí Almenar et al., 2019). However, assessing the connectivity of solutions (as evoked in many different H2020 projects) is challenging since the related methods and perspectives are still somewhat limited (Bailly et al., 2019b). However, the connectivity of solutions can be evaluated using two approaches: structural and functional connectivity. The first relates to the spatial configuration to patches, while the second integrates further the ability of organisms to move among the connected spaces (Iojă et al., 2014 and Tischendorf and Fahrig, 2000 *in* Cannop et al., 2020). As one NbaS is not sufficient to attend to CCA and CCM, the multiplicity of solutions will deliver more pronounced effects since these power the necessary interconnections (Bailly et al., 2019b). **However, to the knowledge of the Authors, measuring the climatic connectivity effect of NbaS is still an untapped domain.** To this end, the combined effect of different NbS-NbaS in a specific location is also rarely studied (Ruangpan et al., 2020).

IV.4.8 Monitoring, evaluation and measuring efficiencies

The efficiency and the success of a solution are generally measured after its implementation by determining the changes between its pre and post existence phases. However, a solid base on NbS evidence is still lacking in scientific literature (Douglas et al., 2019). NbaS also still lack well-established proof of their effectiveness for CCA/CCM, especially in relation to the achievement of their set targets (CAR et al., 2019). Accordingly, NbaS are still in a state of unknown performance (CAR et al., 2019). In this vein, research efforts yielded many evidence of climate change, yet no conclusive evidence of NbS-NbaS benefits, performance and functionalities is established (Bailly et al., 2019a). The same also applies in the domain of NbS-NbaS for hydrometeorological hazards (Debele et al., 2019).

In response to this state, current research on NbS is focusing on finding/building indicators for providing conclusive evidence on the efficiency of these solutions (Collier, 2021). However, this line of research is still somewhat embryonic, and further efforts are needed (Somarakis et al., 2019). Under the H2020 projects, a multitude of monitoring and assessment frameworks, and a plethora of indicators are used and presented (namely MAES, UNaLab, NATURVATION, EKLIPSE and others). Most projects use the EKLIPSE framework (Raymond et al., 2017), while others develop their own assessment frameworks such as the projects listed in Table 1 (for example, not limited to)

Table 1: An example of monitoring and impact assessments, adapted by the Authors from Dumitru and Wendling (2021), European Commission.

Project	Challenges addressed	Monitoring and assessment means	Lessons learnt
EdiCitNet	- Green space management - Biodiversity - Place regeneration - Knowledge and social capacity building - Participatory planning and governance - Social justice and social cohesion - New economic opportunities and green jobs	An extensive literature review was performed to derive a plethora of indicators for measuring social, environmental and economic performances of edible solutions. Accordingly, a project toolbox was developed Indicators are chosen on the basis of expressed goals and anticipated side-effects (disservices)	Impact assessment can be very time-consuming. Project managers (local actors) do not always tolerate time delays and thus tend not to consider this step as a priority during early phases of design. Scientists are needed to match the outcomes of the intended solutions with indicators
proGIreg	- Climate resilience - Green space management - Biodiversity - Air quality - Place regeneration - Knowledge and social capacity building - Participatory planning and governance	Assessment and monitoring of social aspects. Health, environment and economy. District level benefits were derived from existing administrative and GIS-databases. Pre and post-NbS population survey (social, health and economic indicators) and comparison with	The involvement of researchers is key among local administration. The scientific robustness of the gathered evidence is of considerable importance. In case the NbS is too small to be

	- Social justice and social cohesion - Health and wellbeing - New economic opportunities and green jobs	a control setting with similar characteristics but without NbS. A set of tools to monitor NbS impact	detected by the indicators a case-specific approach is required. However, this can limit comparison with other solutions that are monitored differently.
CLEVER Cities	- Climate resilience - Green space management - Biodiversity - Air quality - Place regeneration - Knowledge and social capacity building - Participatory planning and governance - Social justice and social cohesion - Health and wellbeing - New economic opportunities and green jobs	1. Theory of change model 2. Cross-comparison of the theory of change model against baseline data of each city 3. SMART model analysis for priority-based impact monitoring 4. Development of monitoring plans based on 4 group of indicators: i) Environmental, ii) human-health and well-being, iii) safety and security and iv) economic prosperity	Considerable technical support is required for applying the theory of change model. Social outcomes such as health and well-being indicators were hard to define. Highlighted the need for robust scientific evidence for building indicators

However, there still isn't a commonly accepted or uniform monitoring and evaluation framework (Schmalzbauer, 2018). Even when monitoring occurs, the length of monitoring period is often short or is characterized by a low frequency. This may be due to the fact that an unknown amount of time is needed for a NbS-NbaS to become fully effective (Somarakis et al., 2019). According to Kuban et al. (2019), the difference of time scales between the short to medium NbS-NbaS interventions, and the long time needed to unravel their effects makes this type of analysis difficult. In this sense, Garcia Perez et al. (2018) recommend that monitoring and evaluation should go along with the maturity of the solution, i.e. at least five years post-implementation. Conversely, Holscher et al. (2019) recommend the integration of monitoring and evaluation as early as the design phase, since the whole NbS-NbaS chain is loaded with underlying assumptions and uncertainties. Accordingly, the NbS-NbaS monitoring and evaluation framework should be progressive and continuous, to the point where outcome data following implementation can become baseline data for the future implementation of other solutions. Following this logic, NbS-NbaS should be gradually introduced to have a sufficient time period for a detailed and careful assessment of their efficiency (Albert et al., 2017). This gives a certain degree of flexibility for refinement throughout the process (Albert et al., 2017) and ensures the gradual success of the solution. Then again, the question of measuring success is raised: what are the acceptable thresholds to consider the solution as a success and at what scale (Wendling et al., 2019)? This last point is particularly important since the most significant difficulty for designing a monitoring scheme is to determine the scale of impact (Wendling et al., 2019). Accordingly, the following questions are also raised: will the implemented NbS-NbaS have benefits beyond its location? Is it part of a bigger NbS-NbaS network? If so, how can it be individually assessed within the larger matrix?

All of the retained projects contained different sets of Key Performance Indicators (KPIs) for monitoring and evaluating their implemented solutions. Some projects also address monitoring and evaluation through a modeling and/or impact assessment approaches. The former surpasses the latter with it predictive capacities (Bulkeley and Raven, 2018) that can provide better insights, namely by comparing pre, peri and post NbaS phases. They can also serve to project future changes in scenarios (NbaS expansion, climate change, etc.). However, it is crucial to acknowledge data and model limitations as even the best available data can hold large uncertainties at different scales (Burke et al., 2018). For instance, engineering models are not very suitable for tackling NbS-NbaS interventions as the latter are of highly distributed nature (Burke et al., 2018). Stochastic models are also unsuitable for modeling physical processes; this makes them incapable of understanding changes of exposures that result from the introduction of adaptation measures (Muligan et al., 2017). Modelling can also be a source of skepticism since it is based on assumptions that are not necessarily justifiable in real-life cases (Olsson and Andersson, 2006 *in* Kumar et al. 2019). In addition, over ambition in modeling must be avoided as in some cases, simulations are run on the basis of scenarios that may never occur (e.g. 100% case of green roofs in an urban setting).

In terms of indicators, a plethora is presented in each project. Most biophysical NbaS related indicators (for example and not limited to) revolved around changes of temperatures (air, surface, mean, peak daytime, etc.) in the site of the solution, its vicinity and the surrounding environment. Estimates of carbon storage were also provided. In terms of stormwater management (for example and not limited to), estimations/calculation of runoff abatement and peak flow decreases, as well as infiltration rates, evapotranspiration rates, peak heights and times were provided. The very ample focus and development of monitoring and evaluation schemes underlines that this domain is well accounted for under the H2020 NbaS projects. It is worthwhile mentioning that a very wide array of socioeconomic KPIs are equally presented. Biophysical measurements, and despite being direct means of valuations for NbS-NbaS, do not capture all uses and can only be considered as lower bound estimates (Hérivaux et al., 2019). Nonetheless, some projects focus more on the socioeconomic angles compared to the more environmental/ecological/biophysical indicators, and thus target less quantitative data. Therefore, a careful balance between the two types of indicators is needed. An example of indicators used in SCC-02-2016-2017 (Demonstrating innovative nature-based solutions in cities) is presented below (Table 2). The above-mentioned projects can be referred to for exhaustive lists of their utilized indicators.

Table 2: Example of indicators common to the SCC-02-2016-2017 [Demonstrating innovative nature-based solutions in cities] category of H2020 projects (source: UNaLab, 2019)

Indicator	Metric	Method
Carbon emissions	Total amount of carbon stored in vegetation	Modeling (ex: i-Tree tools)
	Carbon removed or stored per unit area per unit time	Total carbon removed or stored (tonnes/ha/y or similar units) Forest C sequestration (FCS) is usually estimated as a function of forest area, forest type, and forest age: $FCS = (FIA_{rate}/FOREST_{mean\text{-}pct}) \times NONF_{mean\text{-}pcti} \times NON_{Fareai}$ where FIA_{rate} is net forest growth rate for the most common type group in county i, $FOREST_{mean\text{-}pct}$ is mean canopy cover percentage for all forested pixels in the county i, $NONF_{mean\text{-}pct}$ is mean canopy cover percentage for all non-forest pixels in county i, and $NONF_{area}$ is area sum of all non-forest pixels in county i. The sum of FCS in both forested and non-forest pixels is the total net FCS by urban and community trees in county i
Temperature	Mean or peak daytime local temperatures	Direct measurement, PET calculation or modelling (°C), or by PMV-PPD (Predicted Mean Vote-Predicted Percentage Dissatisfied) calculation (unitless value)
	Heatwave risk	Number of combined tropical nights (>20°C) and hot days (>35°C)
Vulnerability to floods	Flood peak height	In situ measurements or hydrologic/flood models
	Time to flood peak	In situ measurements or hydrologic/flood models
	Runoff in relation to precipitation quantity	Runoff in relation to precipitation quantity (mm/%), runoff coefficient direct measurement, curve number method, rational method, Intensity-Duration-Frequency curves, etc.
Water quality	Nitrogen and phosphorus in surface water and/or groundwater	Nitrogen and phosphorus in surface water and/or groundwater

		(%, expressed as total annual. N or P load and/or reduction of maximum annual concentration) along with their speciations. Methods are direct measurements, laboratory analysis or modeling approaches
	Metal pollutants in surface water and/or groundwater	Metal pollutants in surface water and/or groundwater (%), expressed as total annual metal pollutant load and/or reduction of maximum annual concentration. Identical to above, lab analysis can also be of relevance.
Green space management	Distribution of public green space	Distribution of public green space expressed as a proportion of total urban surface area or per capita
	Accessibility of urban green spaces	Accessibility (measured as distance or time) of urban green spaces
Biodiversity	Structural and functional connectivity	Degree of connectivity between natural environments within a defined urban area $Meshindicator = (A1^2 + A2^2 + \cdots + An^2 \; A1 + A2 + \cdots An \; / A1+A1+ \ldots An)$ With A as the area of different patches. This index (in hectares) is a metric - mesh indicator - used in the indicator value
Air quality	Concentration of PM10, PM2.5, NO2, and O3 in ambient air	Direct measurements: Concentration of PM2.5 and PM10 (µg/m3) in ambient air – Direct measurement Concentration of NO2 (µg/m3) in ambient air Concentration of ground-level O3 (µg/m3) in ambient air
	Annual O3, SO2, NO2, CO, and PM2.5 capture/removal by vegetation	Annual capture of O3, SO2, NO2, CO and PM2.5 by trees and shrubs and grass (all expressed in units of mass) – Quantified through modeling
	Estimated years of life lost due to poor air quality	Reduction in years of life (y) due to premature mortality in comparison with standard life expectancy $\Delta R = IR \times CRF \times \Delta C \times Pop$

		Where, - ΔR is the response as a result of the number of the unfavourable implications (cases, days or episodes) over all health indicators; - IR is the baseline morbidity/mortality annual rate (%); this information is available in the national statistical institute of each country; - CRF is the correlation coefficient between the pollutant concentration variation and the probability of experiencing a specific health indicator (%; i.e. Relative Risk (RR) associated with a concentration change of 1 μg·m−3); - ΔC indicates the change in the pollutant concentration (μg·m−3) after adoption of the adaptation/mitigation measure; - Pop is the population units per age group exposed to pollution
	Estimated morbidity and total mortality associated with air pollution	Morbidity: Long-term (annual) incidence of chronic bronchitis due to poor air quality calculated using atmospheric NO2 and PM10 data Mortality: Long-term (annual) incidence of mortality due to poor air quality calculated using atmospheric PM2.5, PM10, O3 and NO2 data
Economic activity & green jobs	Establishment of new businesses in the area surrounding NbS	Number of new businesses established in the area surrounding implemented NbS
	Value of rates paid by all businesses in the area surrounding NbS	Trends and business activities before and after NbS implementation
	Land and property value	Mean or median value of land and property within a specified distance from NbS
As can be noticed, "adaptation metrics" are not common throughout this table, hence indicating that these are also not common in SCC-02-2016-2017 projects		

Regardless of its nature, any indicator is highly contextual and cannot be considered applicable under all conditions. The abundance of indicators presented, while very advantageous, can make the choice of indicators daunting. A rich review of indicators is presented in the different projects and a justification for each one's use is equally given. Presenting an exhaustive list of these indicators is difficult, but is certainly an important platform to consider[29].

NbaS aim to address climatic challenges through specific actions. In turn, each action has an associated set of awaited impacts that also requires specific array of quantitative indicators related to climate resilience (Bailly et al., 2019b). To that end, there are still questions concerning: i) the efficiency of NbS-NbaS under different climatic situations, and ii) how NbS-NbaS accelerate the adaptability of a context (Debele et al., 2019). Therefore, indicators on ecosystem complexity, resilience and stability are strongly required (Andrés et al., 2021). Additionally, there are still no global methods to assess NbS-NbaS impacts from an ecological perspective (Veerkamp et al., 2018). Evidence on the capacity of biodiversity and NbS in supporting successful CCA and CCM (Bailly et al., 2019b) are also limited. As NbS-NbaS require time to mature and become fully effective, the delivery of their co-benefits can be gradually produced at different time steps (Giordano et al., 2020 *in* Gomez Martin et al. 2019). **A certain co-benefit can decrease the delivery of another, meaning that the overall effectiveness of NbS-NbaS will also be influenced (Gomez Martin et al., 2019). This issue should also be monitored** as the success of a NbS-NbaS not only depends on the delivery of co-benefits, but also on producing a balance between them (Gomez Martin et al., 2019).

The debate on qualitative versus quantitative assessment is also polarized. While quantitative indicators are needed to provide solid numerical insights, qualitative indicators are equally needed to provide context-specific information that often characterize NbS-NbaS (Da Silva et al., 2020). Even if several indicators of quantitative nature have been built, there's still a call in literature for more robust numerical frameworks to assess the performance and benefits of existing or newly installed NbS (Watkin et al., 2019). In their own right, defining qualitative indicators - e.g. measuring well-being - is a challenge, since these can be subjectively interpreted and lack a straightforward/consistent methodology (Da Silva et al., 2020). This limitation poses subsequent difficulties for the evaluation of these solutions' efficiency, values and benefits (Ruangpan et al., 2020). Despite the various efforts of some projects for developing a common indicator framework (e.g. ThinkNature), measuring intangible values is still a considerable hurdle to overcome (Schmalzbauer, 2018). For this purpose, significant multi and transdisciplinary approaches are needed (European Commission, 2021b). However, according to Basta (2021), none of their examined H2020 projects up until 2019 implemented frameworks for evaluating the credibility, relevance and effectiveness of the knowledge generated or reported during their research phases. This means that there weren't any uses of systematic monitoring and evaluation for documenting transdisciplinary research or methods (Basta, 2021). The importance of this fact was stressed by many projects, however it is still part of ongoing efforts. Under this context, clustering of H2020 project is interesting since these are of various backgrounds. This can address innovation gaps namely in research and education (Protopapadakis et al., 2021).

If NbS-NbaS are expected to be mainstreamed, their upscaling and outscaling should be unlocked (Connop et al., 2020). (Connop et al., 2020). Therefore, identifying barriers and gaps along with their interconnected factors is necessary for gathering evidence and knowledge, as well as for understanding the opportunities to bridge them (Kuban et al., 2019).

A focus on NbaS and NbS for DRR from a hazard and risk perspective

Whether intended for a climatic or a hydrometeorological risk, for properly understanding the impact of NbS-NbaS their effects on the hazard, vulnerability and exposure should be well characterized (Graveline et al., 2018; Tuomenvirta et al., 2019). Most vulnerability/risk assessment frameworks and indicators for NB(a)S-DRR are of socioecological, socioeconomic and sociopolitical nature (Renaud et al., 2019). More efforts are particularly needed to characterize ecological subsystems (Renaud et al., 2019). In a review performed by the same Authors, most of the inventoried studies for risk/vulnerability assessment reported the dominance of social indicators over ecological ones (Renaud et al., 2019). To this end, **the integration of biophysical angles is still somewhat limited and needs further development**. This gap is crucial since inadequate adaptation efforts will only trigger increases of hydrometeorological risks (Debele et al., 2019).

Garcia Blanco et al. (2021) stress the importance of considering impact chains that link hazard with elements at risk, these chains are defined as: "*a cause-effect relationship among elements that contribute to the consequences of a given combination of hazard and exposed object of a system"*. According to the same

[29] Refer to the European Commission's (2021) report: Evaluating the impact of Nature-Based Solutions: A handbook for practitioners.

Authors, studying these chains are of particular importance for successfully designing NbaS and NbS for DRR. However, to the knowledge of the Authors, this approach is not frequently studied in literature and only a few works go the length. An impact chain first starts with a driver that causes intermediate and main impacts. For each element of the chain, indicators are needed to clearly draw a picture (Garcia Blanco et al., 2021). During these phases, the temporal dimension should never be overlooked, that is why pre- and post-NbS implementation data should be available for obtaining accurate insights on efficiency (Davis et al., 2018).

In the case of a NbaS, climatic drivers are most relevant (without excluding contributions of non-climatic drivers as well). The challenge at this stage is that climatic drivers are not controllable, hence their indicators are quite dynamic and should be regularly updated. For instance, in the case of erratic precipitations (driver), pluvial and river floods are expected to increase (intermediate impact). In turn these floods will cause a flooding of an urban setting (main impact). While addressing the driver in this case is hard, addressing the intermediate impact might reduce the subsequent main impact. In simple terms, the introduction of a NbaS should target the intermediate impact chain to prevent the main impact from becoming bigger. Despite the theoretical simplicity of the idea, its implementation is often hard particularly in the face of slow onset events such as droughts, in relation to which very few NbS-NbaS have been studied or designed**. Moreover, this raises a question if one should account for the final delivered ecosystem services or also for the intermediate services delivered from throughout the existence of the solution (de Groot et al., 2010 *in* Babí Almenar et al., 2018).**

It is crucial to bear in mind that NbS-NbaS are not systematic, meaning that the implementation of a NbS-NbaS is not forcefully followed by positive impacts (Bailly et al., 2019a). Therefore, during the assessment of both intermediate or end services, disservices should equally be considered (Babí Almenar et al., 2018)

V. Conclusion

The conceptual approach to NbaS was covered in Chapter 1 of this report. In this chapter, deeper insights on the fundamentals behind NbS-NbaS were targeted. For that purpose, a thorough analysis of the H2020 programme was performed. 41 NbS projects were found in the CORDIS database under the H2020 programme. A careful analysis of this first database led to the reduction of the initial number to 27 projects. 21 out of the retained 27 had deliverables at the time of this study and thus formed its basis. From a total number of 173 deliverables, 137 were retained and analyzed with respect to the scope of this chapter. In this regards, only environmental and biophysical elements were included, while technical, political and socioeconomic aspects were disregarded. Nonetheless, this does not take away any element of their importance and their necessity for designing, planning and mainstreaming NbS-NbaS.

The purpose of this review chapter was to build a scientific state-of-the-art on current knowledge and research needs from the analysis of European contributions. In this vein, one of the main challenges for this study was to synthesize and compile knowledge from very different sources as a result of the projects' diverse background (different nature and disciplines). This last element prevents drawing clear parallels between projects and directly comparing their outcomes even within the same study areas. The different targeted contexts, climatic settings, and socioecological characteristics also added another layer of complexity for direct comparisons. To account for this factor, an extensive review and in-depth analysis were performed to connect the different dots and draw a clear line of work.

While many projects generate(d) substantial amount of knowledge (as revealed throughout the chapter), most of their approaches are still demonstration or pilot-site interventions. Accordingly, these often take the form of awareness-raising elements rather than generators of physical knowledge. However, many knowledge elements and several research gaps were extracted after careful investigation. **These can be found in their corresponding sections along with recommendations for research lines of work that could be potent elements to develop**. As mentioned previously, the findings of this chapter are not undebatable as the sample choice and size may induce a certain degree of error. However, the error margin was reduced as much as possible by filtering the documents thoroughly and by avoiding assumptions. To that end, all the chapter's findings are referenced to their corresponding works.

V.1 NbaS in the European landscape

As demonstrated throughout this chapter, the concept of NbaS, much like NbS, is coined at the European level. It is being mainly used to address the challenges of the urban environment over a wide range of domains (climatic, social, economic, etc.). The geographic coverage of these solutions revealed a strong South-West gradient as opposed to a less developed North-East axis.

A plethora of NbaS was included in the different projects. A compiled classification can be found in Annex A. Similar to the international scale approach, the dominance of green solutions can be noticed. Nonetheless, some H2020 projects presented "unclassical" NbS-NbaS that rarely studied. Per example, live cribwalls, palisades, pole drains, ground anchors, microbe assisted seed mixtures, coal remediation, wood allotments, aquaponics, fruit walls, as well as natural sealing of leaky streams (among others).

An interesting aspect under the H2020 programme is the call of some projects for connecting NbS-NbaS by means of other ones. This aspect might be the key for addressing the scale-effect discrepancy of NbS-NbaS and for facilitating their uptake and upscaling. However, the need for further evidence on efficiency, as stressed by all the projects remain a significant hurdle to overcome. It is believed that the progression of the H2020 programme will significantly bridge this gap. However, a sufficient period of time is needed since NbS-NbaS require considerable time to become fully functional.

V.2 Environments to put forward

The interest of the EC's H2020 programme in the urban realm is justifiable. Yet, a deeper approach to other ecosystems is much needed. This is particularly the case of mountainous, forested and marine and coastal environments. While forests are very appreciated as NbS-NbaS, they are rarely targeted a sensitive media to climate change. In its own right, the mountainous environment is significantly underrepresented despite its importance and relative widespread coverage in Europe. The marine and coastal realms are also underrepresented as both a medium and a source of solutions.

The relative dominance of the urban medium makes most of the knowledge generated from the H2020 projects urban derived. Accordingly, this makes a large proportion of utilized/created methods and knowledge inapplicable to other settings. That itself is a significant gap to overcome for providing more scientific and research evidence on NbS-NbaS.

V.3 On the N in NbS-NbaS

In chapter 1, a particular focus for the A (adaptation) in NbaS was apparent. When the multi-scale approach passed to the second level, European findings underlined the need to focus more science on the N (nature) behind NbS and NbaS. For this purpose, scientific and physical methods are needed to better understand the interaction of nature both with and within the implemented or planned NbS-NbaS. This is due to the fact that the introduction of these solutions into ecosystems causes the entry of new systems along with their processes. Yet the investigation of these interactions and their cascading effects is still somewhat limited. This gap could be on the most pronounced challenges for upscaling and outscaling NbS-NbaS as well as for unlocking their full potential.

Concluding remarks

NbaS, much like NbS, are being coined at the European level and significant efforts in terms of research and economic investment are being dedicated. However, a leap beyond conservationism is needed to fully tap the potential of NbS-NbaS and outscale them from pilot and demonstration scales to elements of the land or seascape. While all of the findings of this study mostly derive from the regional scale, chapter 3 will aim to see if the same applies for France as part of Europe. Hence Chapter 3: The National approach.

Annex A and B

https://cloud.enpc.fr/s/Paq8YNcsBfKtWjF

Annex C

Project name	CORDIS page	Website	Topic	Retained deliverables
CLEARING HOUSE	https://cordis.europa.eu/project/id/821242	http://clearinghouseproject.eu/	SC5-13-2018-2019	2
CLEVER Cities	https://cordis.europa.eu/project/id/776604	https://clevercities.eu/	SCC-02-2016-2017	9
Connecting Nature	https://cordis.europa.eu/project/id/730222	https://connectingnature.eu/	SCC-02-2016-2017	3
DRYvER	https://cordis.europa.eu/project/id/869226	https://www.dryver.eu/results	LC-CLA-06-2019	1
EdiCitNet	https://cordis.europa.eu/project/id/776665	https://www.edicitnet.com/medialibrary/deliverables/	SCC-02-2016-2017	11
EuPOLIS	https://cordis.europa.eu/project/id/869448	http://eupolis-project.eu/	SC5-14-2019	3
FutureMARES	https://cordis.europa.eu/project/id/869300	https://www.futuremares.eu/	LC-CLA-06-2019	2
GrowGreen	https://cordis.europa.eu/project/id/730283	http://growgreenproject.eu/	SCC-02-2016-2017	4
NAIAD	https://cordis.europa.eu/project/id/730497	http://naiad2020.eu/	SC5-09-2016	7
Nature4Cities	https://cordis.europa.eu/project/id/730468	https://www.nature4cities.eu/	SCC-03-2016	10
NATURVATION	https://cordis.europa.eu/project/id/730243	https://www.naturvation.eu/	SCC-03-2016	14
OPERANDUM	https://cordis.europa.eu/project/id/776848	https://www.operandum-project.eu/	SC5-08-2017	10
PHUSICOS	https://cordis.europa.eu/project/id/776681	https://phusicos.eu/	SC5-08-2017	12
proGIreg	https://cordis.europa.eu/project/id/776528	https://progireg.eu/	SCC-02-2016-2017	5
RECONECT	https://cordis.europa.eu/project/id/776866	http://www.reconect.eu/	SC5-08-2017	9
REGREEN	https://cordis.europa.eu/project/id/821016	https://www.regreen-project.eu/	SC5-13-2018-2019	4
RENATURE	https://cordis.europa.eu/project/id/809988	http://renature-project.eu/	*	7
ThinkNature	https://cordis.europa.eu/project/id/730338	https://www.think-nature.eu/	SC5-10-2016	8
UNaLab	https://cordis.europa.eu/project/id/730052	https://unalab.eu/en	SCC-02-2016-2017	6
Urban GreenUP	https://cordis.europa.eu/project/id/730426	https://www.urbangreenup.eu/	SCC-02-2016-2017	9
URBiNAT	https://cordis.europa.eu/project/id/776783	https://urbinat.eu/	SCC-02-2016-201	1

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Chapter 3 – The national scale approach

«Rien n'est dans la nature à l'abri des orages» ~ Le dictionnaire des proverbes français (1749)

Summary

This chapter presents findings from the analysis of French-issued scientific literature. The regional scale is the third and last level of the multiscale approach and was chosen to study National trends. This analysis allowed the establishment of a French "*état des lieux*" for NbS-NbaS. It also served to study the transition to NbaS as France is in the midst of its second national climate change adaptation plan. In relation to the previous scale, the national approach allowed to situate France with respect to global and European trends and progress. The main advantage of this level is that the analysis of publications issued by French institutions (not only limited to French study areas) revealed findings from various studies that have already implemented NbS-NbaS or are expected to do so. Accordingly, the results obtained reflect either actual outcomes from field applications, or from the analysis of conceptual and theoretical advances. One of the main challenges for France is the multiplicity of climate types that characterize both its metropolitan and overseas components. As such, a wide range of challenges exist (namely climatic) and much is expected from NbS-NbaS in this regard.

Scientific literature was reviewed as it reflects the contribution of French institutions in research on NbS and NbaS. It also allowed the establishment of academic actors maps and to identify NbaS research funding parties. Accordingly, financial and research stakeholders inventories were built. Using three queries from the SCOPUS database, first the transition from NbS and its associated concepts to NbaS was determined. Then, NbS general research trends were underlined and the distribution of related labs and financial bodies was compared with those of NbaS. However, for NbaS, research trends were investigated in further depth given the scope of the study. Query 1 consisted of NbS and its associated concepts, query 2 consisted of NbS in strict terms, while query consisted of NbaS publications. Further details on the queries, their use and content are given in the course of the chapter. As mentioned in Chapter 1, the French committee of the IUCN can be considered as the main introducer of NbaS in the international landscape (2015-2016). With respect to European trends, and as revealed by Chapter 2, France actively takes part of several projects, leads others and participates with various pilot sites. On the national scale, scientific literature showed that NbaS contributions have started since 2017. Therefore, one can consider that both NbaS and the transition towards them are relatively recent. However, it is important to mention that climate change adaptation is not a recent interest in France. In fact, the country has aligned adaptation priorities and strategies since 1999 with the acknowledgment of climate impacts and the GICC (Gestion et les Impacts du Changement Climatique) and the subsequent national adaptation strategy of 2006 that paved the way over to the current adaptation plan PNACC-2 (Plan National d'Adaptation au Changement Climatique).

<u>On the NbaS terminology</u>

In French scientific literature, NbaS appear as « solutions d'adaptation fondées sur la nature » or as « solutions d'adaptation au changement climatique ». A very pronounced interest in NbS-NbaS for DRR is apparent with a strong focus on hydrometeorological hazard and risk reduction. In this context, floods are the most targeted challenges within the different ecosystems. Much as mentioned throughout the different references, NbS-NbaS are coined at the European level. In this level, significant theoretical, fundamental, technical, technological, and socio/political/economic knowledge is produced and or reviewed in the different projects.

The coupling French interest into other contexts (as revealed by studies conducted by French labs for non-French study areas) shows that France aims to extend its experience throughout the world, thus promoting the mainstreaming and uptake of the concept. The relatively recent interest shows growing trends with an increasing number of publications. However, contributions are still limited and significant efforts are needed for unlocking the full potential of the concept. In this vein, ARTISAN has a significant role of play by extending both theoretical and practical knowledge on NbaS throughout the French territory.

<u>Types of NbaS</u>

The pattern of French ecosystems of interest is translated in the studied NbaS. In this vein, urban solutions that mostly revolve around Type 2 and 3 interventions (solutions in managed ecosystems and creation of new

ecosystems) dominate the current offer. The same is applicable for the marine and coastal environments with interventions ranging from dunes and vegetation cover increase to hybrid structures. Blue solutions are equally present however in one case only (genetic diversity). Protected areas are relatively absent thus underlining the need for more research on Type 1 (protected ecosystems) NbS-NbaS.

For forests, afforestation or reforestation measures are most adopted, while for the mountainous realm grasslands and re-vegetation are most relevant. In the freshwater ecosystem, vegetation, wetlands and hybrid structures are mostly used. One may notice that EbA is quite common in various ecosystems and is still somewhat present despite the progressive shift towards NbS-NbaS.

Interestingly, the soil compartment is particularly addressed in the urban realm. This interest shows that soil is recognized as a solution of interest and is being targeted as such. While this aspect is lacking in classical literature, French research seems to be conscious about it and is acting accordingly.

In terms of climatic challenges, the most addressed challenges were found to be: urban heat islands, surface warming, thermal comfort of people, surface overheating, sea level rise and storm water management. Coastal flooding, rock falls, landslides, avalanches, pluvial flooding, drought, erosion, storms and flash floods are equally targeted.

Biomes (environments) and priority sectors

The urban environment is the most addressed ecosystem followed by the marine and coastal, humid, forest, mountainous, natural and agricultural settings in descending order. Recalling the distribution of French ecosystems in H2020 projects, a more or less similar pattern is observed (i.e. the dominance of the urban environment and the low presence of the agricultural and natural realms). In the case of agriculture, the interest in NbS terms is much higher than that of NbaS. This also raises the need for further agriculture-based NbaS for climate proofing agriculture. The only difference between the French H2020's and scientific literature's ecosystems of interest is that in the latter the marine and coastal environment is more or less well addressed. Surprisingly, in the case of NbaS, overseas France and island ecosystems are very rarely addressed in contrast to NbS studies. While being the world's second most overseas territories housing country, significant efforts are needed to increase the climatic resilience and adaptive capacities of these contexts given the latter's higher degree of vulnerabilities and sensitivities than metropolitan France.

In all contributions, the urban environment is considered as a complex system that needs to overcome shocks and develop resilience. Accordingly, the urban environment is approached from different angles and diverse thematics. Water is a directly and indirectly central element throughout the different studies.

While the media of intervention are study area-based, a very important insight that wasn't addressed in the previous scales is offered. This aspect mainly revolves around the use of a NbaS not only for its direct/indirect benefits but also as a precursor to another NbaS. Per example, permeable dams are used for regulating water flows and sediment trapping which later forms the substrate for mangrove plantation. To the knowledge of the Authors, this aspect very rarely to not addressed and deserves to be considered as a line of work to develop.

Gaps and limits of NbaS

Several gaps and limits were found throughout this Chapter. Below is a non-exhaustive list that summarizes some of the most recurring ones (for example and not limited to). However, the NbaS section of this chapter contains further gaps and limits that cover a wide range of topics.

- In terms of study media: the agricultural and island (overseas) ecosystems should be better addressed.
- In terms of solutions typology: most presented solutions correspond to Type 3 NbS (management of ecosystems in extensive ways – new ecosystems) that target the management or creation of new ecosystems. Consequently, a minimal focus on Type 1 (minimal interventions – protected ecosystems) solutions is noted. To this end, the contribution and role of protected areas in the French land/sea scapes is relatively underrepresented.
- In terms of ecosystems and ecosystem services: the concept is presented in a very anthropocentric way, and is accounted for in terms of provision services with a reduced interest in regulation related ones.

- There is a need to understand better of what current ecosystems offer and what services will transform with the adaptation of an ecosystem to climate change.

- The lack of systematic quantification of ecosystem services should be better addressed.

- While adaption services have been amply presented, there is still a need to understand how the latter evolve with the ecosystem's adaptation process, and how will the introduction of a NbaS into the system influence these interactions and trade-offs.

- Understanding how newly introduced/derived ecosystem services and previous ones interact with, and influence each other.

- In terms of NbS-NbaS:

- Understanding the off-site effects of adaptive land use changes (herein NbaS) as an important aspect to develop as adaptation measures in a specific location might have unintended off-sites effects on other contexts or scales

- There is a need for developing a deeper understanding of the effect of NbaS locations (emplacement) in a system. Per example, regardless of its intended purpose, the position of the sought NbaS in a watershed might have an effect on the basin's hydrologic behavior. For instance, if a UHI reduction NbaS is placed in a hydrologically-false position it might compound hazards, thus creating a new problem while resolving another.

- Insights on the resource-efficiency of NbaS should be obtained as throughout their existence, these solutions often consume natural capital.

- The role of genetic diversity (as an NbaS) should be better exploited at it might help catalyze transitions into NbaS faster.

- Within the freshwater realm, there is a need to focus more on hydrology/morphology based NbaS rather than contouring challenges with green (vegetation-based) solutions.

Nonetheless, as mentioned previously this list of gaps summarizes some of the most major ones. For a more detailed analyses and deeper insights, the different sections of the chapter should be referred to.

I. Introduction: Background and objectives

The apex position of Climate Change Adaptation (CCA) in France clearly reveals the importance of this challenge for the country. The first French efforts for CCA go back to 2006 with the national strategy on adaptation. As adaptation and its importance were internationally acknowledged in 2010 (ref. Chapter 1), one may note that France had a four years head start. Since then, France has been forcefully pushing actions on climate leading to the first national plan on adaptation to climate change 2011-2015 (PNACC-1), followed by the landmark 2015 Paris Agreement. While the French committee of the IUCN introduced the concept of NbaS, the Paris Agreement gave the latter a strong momentum for international recognition and adoption. Nonetheless, efforts for harnessing the power of nature have been recorded since the start of the 19th century in France. During that period, engineers of the École Nationale des Ponts et Chaussées (ENPC), then those of the "Eaux et Forêts" office were implementing NbS to protect the newly sown maritime pines in the Aquitaine region (Gouguet, 2019). ENPC engineers raised coastal dunes by using wooden palisades to accumulate the sand as close as possible to the sea, then planted *Ammophila arenaria* for fixing the accumulated sands. With the second PNACC underway (2018-2022), the ARTISAN project comes as a lever for promoting the implementation of NbaS throughout the French territory.

In this vein, this chapter forms the last level of the multi-scale approach following the investigation of the international and regional NbaS efforts. With respect to international efforts, as mentioned previously, France started its interest in CCA since 2006 (pre-2010), while its IUCN committee spearheaded the introduction of NbaS in 2015. With respect to regional efforts (H2020 projects, ref. Chapter 2), France can be seen to occupy the fourth most top position in H2020 intervention sites with 14 sites in 14 projects. The distribution of the sites is as follows: 8 cities, 1 river, 4 basins and 1 mountain range. In further details, the French sites are: the city of Brest in "GrowGreen", the Albarine river in "DRYvER", the Var river basin and Les Boucholeurs district in "RECONECT" , the city of Cannes in "UNaLab", the French part of the Pyrénees mountains in "PHUSICOS", the city of Paris in "REGREEN", the city of

Montpellier in "NATURVATION", the Brague and Lez basins in "NAIAD", the city of Nantes in "URBiNAT" and three relevant case studies under the "ThinkNature" platform: BIOVEINS for Paris' connectivity of green and blue infrastructures, Agroforestry for Montpellier, and Brague DEMO for flash floods and wildfire hazards in Mediterranean settings. In terms of project coordination and participation, French institutions are lead coordinators in two projects (DRYvER and Nature4Cities) and participants in 16 others. With an active participation in the H2020 programme, and with a French IUCN Committee that catalyzed the transition to NbaS, the well-established regional and international position of France in the NbaS landscape is quite clear. Nonetheless, early on, from the distribution of media under H2020 projects, one can notice that French natural, forest, agricultural, marine and coastal ecosystems are not sufficiently covered in H2020 NbaS projects. **Hence, a first gap to potentially investigate at the national scale.**

In light of what was presented, the main objective of this chapter is to establish a knowledge inventory of NbaS at the national level based on: the transition from NbS and its sister concepts to NbaS, findings from scientific literature issued by French institutions, ongoing efforts, target areas, potential, and limits. Accordingly, readers will able to situate NbaS with respect to French agendas and link them with those presented in Chapters 1 and 2. On this basis, an explanation of the different NbaS types, climatic challenges, media of intervention, priorities, gaps and challenges are given. Ultimately, this chapter will highlight the experience and expected outcomes from research work on national NbaS efforts. By capitalizing on these results, a state-of-the-art on current knowledge, limits and research gaps in France are obtained.

To this end, the chapter is structured as follows: the second section details the methodological approach of this study and explains the basis for the retention of the peer-reviewed journal articles. The third section presents general research trends, while the fourth section details findings on NbS and sister concepts literature. Section five details published literature on NbS, while section six synthesizes the major individual findings from NbS and NbS-associated concepts individual document analysis. Section seven forms the bulk of this review and presents a state-of-the-art on current knowledge and gaps of NbaS along with proposed research perspectives. Sections eight and nine conclude the presented work and pave the way for the synthesis of the multi-scalar approach.

Post scriptum: The French capital in H2020 projects

Within the retained projects, the city of Paris is commonly addressed, and several insights on the French capital were found:

a) From 2000 to 2020 and as a result of urban expansion, 646.1 km^2 of cropland, 50.5 km^2 of deciduous forests and 10.9 km^2 of grasslands have been lost in the Paris region, i.e. a loss of 707.5 km^2 (Banzhaf et al., 2021).

b) In the REGREEN project, air pollution is one of the most problematic challenges in the Paris Region with values of particulate matter, NOx and O_3 well beyond the World Health Organization's recommendations. This escalating threat reached the point of becoming a public health emergency (Fletcher et al., 2020).

c) Heat waves, air pollution, UHI, flooding, lack of green spaces, loss of biodiversity and climate change are the main challenges facing the Paris region (Fletcher et al., 2020).

d) Flooding is also an integral concern in the Parisian region and is mainly due to extreme weather conditions and soil waterproofing as a result of a 840 hectare/year urbanization rate (Fletcher et al., 2020).

e) Wetland loss is a significant challenge in the Parisian region along with continuous pressures on the remaining wetlands of all types and sizes (Fletcher et al., 2020).

f) Despite having ceased the use of pesticides in 2017 in the whole Île-de-France department, all rivers were found to be contaminated with pesticides in 2020 (Fletcher et al., 2020).

g) Most of the Parisian region's green roofs are without local species and have shallow substrates (Bailly et al., 2019).

Based on the above-mentioned elements, significant challenges that call for quantum leaps are needed in the French capital. With a multitude of solutions being planned, and France's "France Relance" plan significant momentum behind NbS-NbaS is building up.

II. Materials and methods

Search: The chapter was built in analogy to the study's Search, Filter, Extract and Analyze workflow. For the Search phase, the SCOPUS database was used to find peer-reviewed articles in indexed journals. The search phase ended in October 2021 and covered the 2004-2021 period. Three different queries were used in the SCOPUS' advanced search tab:

1- "nature-based solution" OR "ecosystem based adaptation" OR "green solutions" OR "ecosystem services" OR "green blue solutions" OR "ecological restoration" OR "renaturing" OR "ecological engineering" OR "natural capital" OR "ecosystem based mitigation" OR "natural infrastructure" OR "green infrastructure" OR "biophilic infrastructure" OR "urban green space" OR "biophilic design" OR "urban forest" OR "urban biodiversity" AND "stakeholder" OR "public" OR "citizen" OR "resident" OR "community" OR "expert" OR "actors" AND "climate change" AND "adaptation" AND "France" AND (LIMIT-TO (PUBSTAGE, "final")) AND (LIMIT-TO (DOCTYPE,"ar")) AND (LIMIT-TO (AFFILCOUNTRY , "France"))

2- "nature-based solution" AND "France" AND (LIMIT-TO (PUBSTAGE, "final")) AND (LIMIT-TO (AFFILCOUNTRY,"France")) AND (LIMIT-TO (DOCTYPE,"ar"))

3- "nature-based solution" AND "climate change" AND "adaptation" AND "France" AND (LIMIT-TO (PUBSTAGE, "final")) AND (LIMIT-TO (AFFILCOUNTRY , "France")) AND (LIMIT-TO (DOCTYPE, "ar"))

The first query was used to study how the transition from NbS and its sister concepts to NbaS has progressed. The second query was studied to determine when French efforts started to concentrate on NbS in strict terms, and how was this approach done. The third query served to study French NbaS efforts.

Filter: The filtering phase consisted of two steps. The first was a general approach where articles were retained based on their titles and abstracts. The aim of this step was to ensure that the retained articles surely contained the NbS-NbaS concepts or their associated notions, along with climate change. At this stage it is important to mention that textual material was compiled and collected during the January-October 2021. For query 1 the search phase was paused in 2020 as this query was used only to reveal shifts and transitions without focusing on research perspectives since it does not focus on NbaS. Therefore, any outcome following this October 2021 is not included in any query. Accordingly, each query resulted in the following: query 1 - 1338 articles, query 2 - 169 articles and query 3 - 62 articles.

The second filtering step was more specific and consisted of examining the articles one by one and individually for elements related to the study. A total of 500 articles were retained for the Extract and Analyze phase. However, at no point do the Authors assume that their findings are not debatable. The Authors acknowledge that some sample-related or selection errors may be inherent. However, the best possible measures were taken to avoid any unjustified assumptions and to ensure a minimal error margin.

Extract and Analyze: This step forms the "tip of the funnel" where the 500 retained articles were analyzed for extracting the study's findings. Accordingly, all findings reported in this study are strictly from French issued scientific literature in peer-reviewed journals from the SCOPUS database. As the scope of this study focuses on NbaS and the development of their research perspectives, the first two queries were investigated using a text-mining approach. The aim of this step was to reveal general trends and current interests without going into much details in terms of research questions or line of works. This was done to study the progressive shift from earlier concepts to NbaS later. For that purpose, the Orange software was used. Further details are given in the corresponding sections.

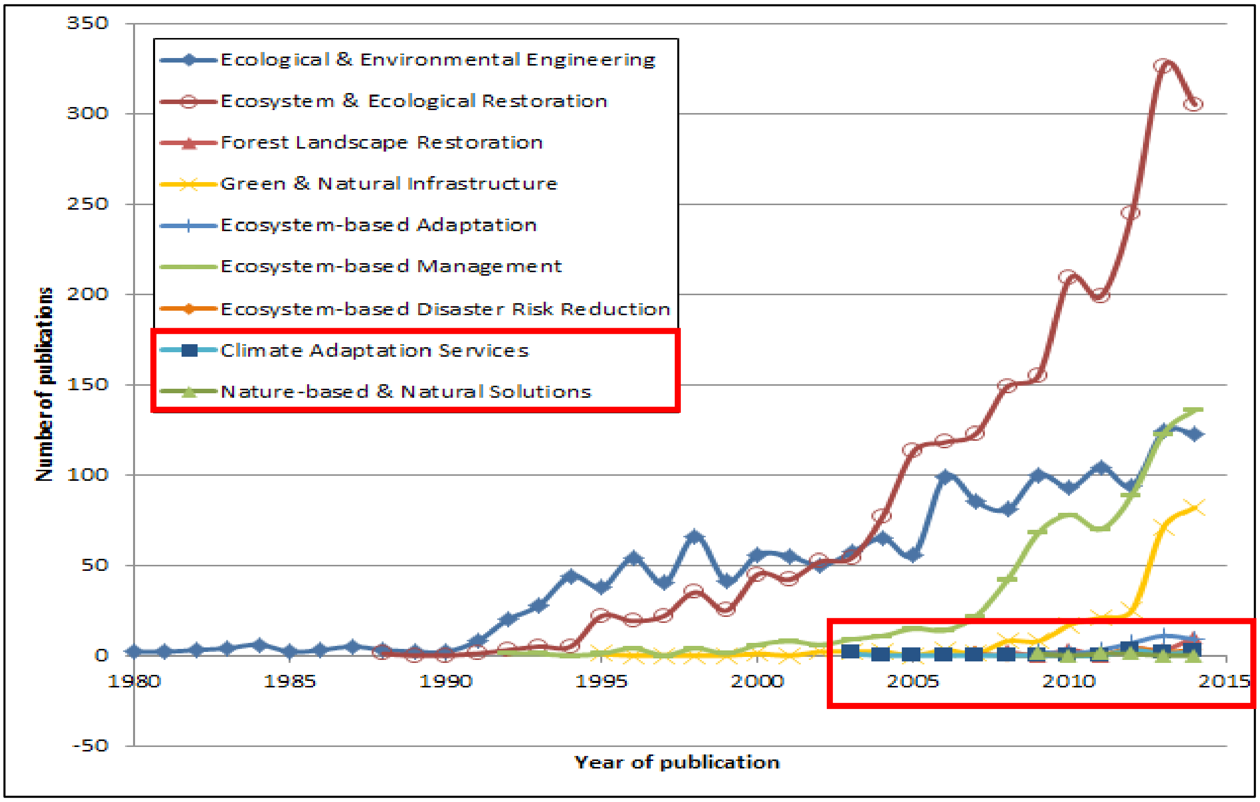
III. Research trends

The retained articles from the three queries were plotted and compared against the international publication trends identified by the IUCN (2016). The aim of this step was to situate French efforts with respect to international trends. Since at the time of this study the year 2021 was still ongoing the query graph was limited to the year 2020 (Figure 1). Many conclusions can be drawn from the graphs:

i. Trends of scientific literature on NbS and associated concepts (query 1) in France are somewhat similar to the international trends determined by the IUCN.

ii. At the international scale, climate adaptation services and NbS publications were still relatively absent. The same can be said for French scientific literature. Publications on NbS (in strict terms – query 2) started appearing in 2016 in France, while those on NbaS (query 3) started to appear in 2017. This might be due to the fact that the French IUCN Committee introduced the NbaS concept in 2015.

iii. Both French NbS and NbaS curves indicate an increasing trend. However, publications on NbaS are still relatively scare, hence the need for further efforts.



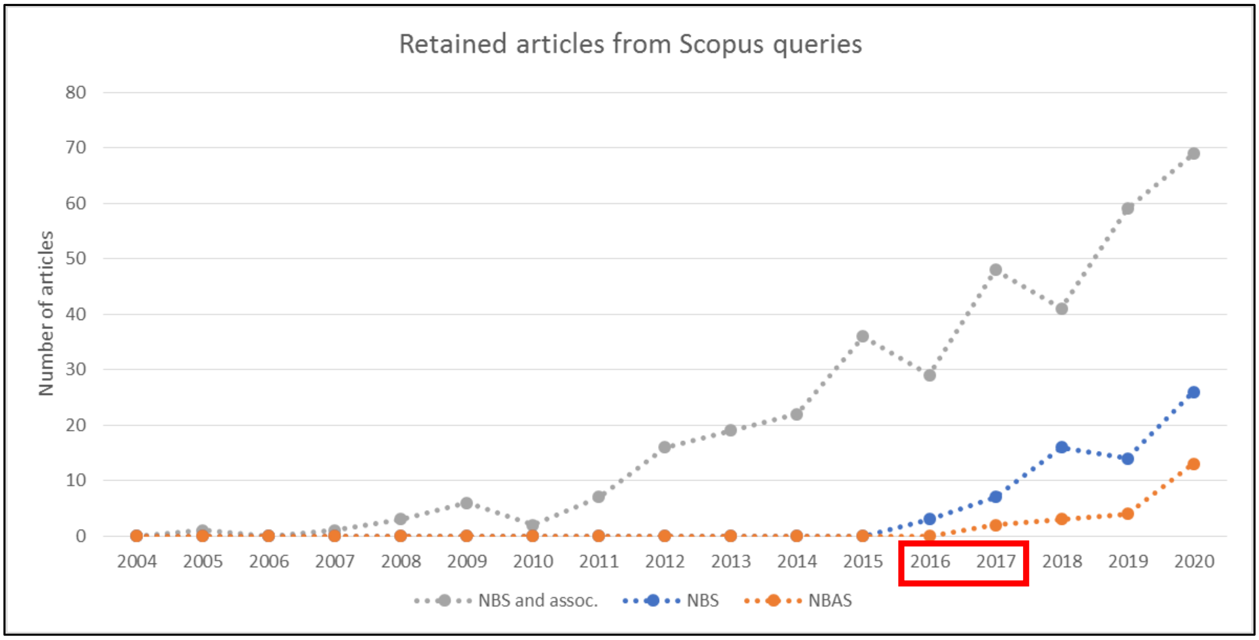


Figure 1: Trends of international and French published scientific literature

IV. Published literature on NbS and sister concepts: A text mining approach

After the establishment of research trends in section III and the identification of the shift towards NbaS, text mining was performed on findings from queries 1 and 2 to reveal general patterns. The aim of this approach is to briefly present a panorama of the current offer for paving the way towards the detailed individual document analysis of query 3's findings.

The Orange software developed by the University of Ljubljana was used in its 3.27.1 version for this purpose. Orange is an open source machine learning, data visualization and data analysis/mining toolkit written in Python, Cython, C++ and C languages. It is mainly characterized by a high and interactive user friendliness through its canvas graphical front-end. Another important aspect of Orange is its ability to read pdf files without the need to restructure or transpose documents and their content to other forms. More information on its basis, components and workflows can be found on https://orangedatamining.com/

For this study, the text mining add-on was used and the following workflow was built for both queries (Figure 2). The retained articles that formed the corpora of queries 1 and 2 can be found in Annexes A and B, respectively.

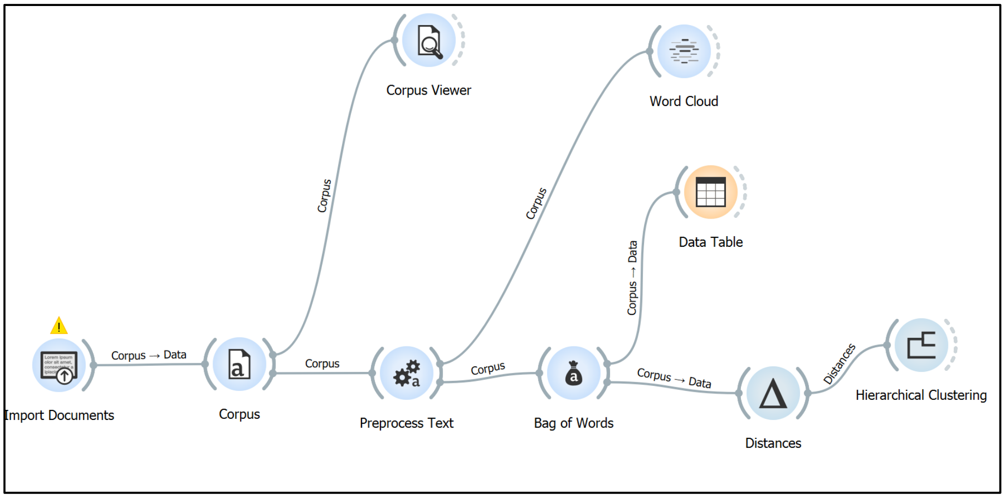


Figure 2: The text-mining workflow using Orange

The import documents function served to integrate the retained articles which were ten transformed into the corpus in the corpus widget. The corpus viewer was then used to display the retained texts and check for any anomalies. Text preprocessing was then performed to remove punctuation and uninformative words. In this step, accents htmls and URLS were first removed. Using the regular expression split function of the tokenization window, texts were transformed into regular expressions keeping individual words (tokens). Stopwords were filtered out using the filtering window, regular expressions such as commas, semi-columns, points, parenthesis, brackets, special characters, etc were also fileted out. A list of lexicons (words of interest) was added to refine the search phase. The lexicon list contained meaningful words that were of interest to the study, e.g. climate change, adaption, nature-based solutions, ecosystems, etc. The bag of words widget was then used to determine word counts in data table format. This step helps obtaining a data matrix for subsequent machine learning analysis. For this purpose, the bag of words was the connected to the distance widget to determine distances, similarities and relationships. To visualize findings and finalize the text analysis process, the distance widget is connected to hierarchical clustering. At this point, Orange's user friendly nature allows to perform several "trial and error" steps for helping users to determine the best distance metric for their data through visualization in the hierarchical clustering dendrograms. For distances, there are five distance metric type: Euclidean, Cosine, Manhattan, Jaccard and Bhattacharya. Through trial and error the Euclidean distance was found to correspond best to the retained corpora, hence its use. The greater the distance between clusters/components the lower their similarities and connections. Hierarchical clustering was used due to:

i) Its ability of revealing all possible linkages between clusters, hence allowing an inclusive understanding of data.
ii) Its limitations on subjective calls that do not allow a predefinition of cluster numbers (unlike unsupervised methods as k-means), hence significantly reducing subjective biases.
iii) Its options for linkage types (single, average, weighted, complete, ward), and the possibility of testing their effect graphically on outputs. For this study, the Ward linkage was determined to be best suited.

The only contras of using hierarchical clustering are its scalability limitations where it can become considerably complicated to analyze the dendrograms when the number of observations is high and its computationally demanding nature. However, in our case the number of observations-computational demands balance was not problematic.

IV.1 Findings of the text-mining approach

Reminder of the SCOPUS query: "nature-based solution" OR "ecosystem based adaptation" OR "green solutions" OR "ecosystem services" OR "green blue solutions" OR "ecological restoration" OR "renaturing" OR "ecological engineering" OR "natural capital" OR "ecosystem based mitigation" OR "natural infrastructure" OR "green infrastructure" OR "biophilic infrastructure" OR "urban green space" OR "biophilic design" OR "urban forest" OR "urban biodiversity" AND "stakeholder" OR "public" OR "citizen" OR "resident" OR "community" OR "expert" OR *"actors" AND "climate change" AND "adaptation" AND "France" AND (LIMIT-TO (PUBSTAGE, "final")) AND (LIMIT-TO (DOCTYPE,"ar")) AND (LIMIT-TO (AFFILCOUNTRY , "France"))*

Number of retained articles: 364

As can be seen from Figure 3, the first publication on NbS and related concepts dates back to 2005. It mainly dealt with the effects of biodiversity on ecosystem functioning, hence implicitly on the two bases of NbS, i.e. biodiversity and ecosystems. Publications then progressively increased until 2016 where thereafter NbS publications (in strict terms) started to appear, followed by those of NbaS in 2017 (ref. Figure 1).

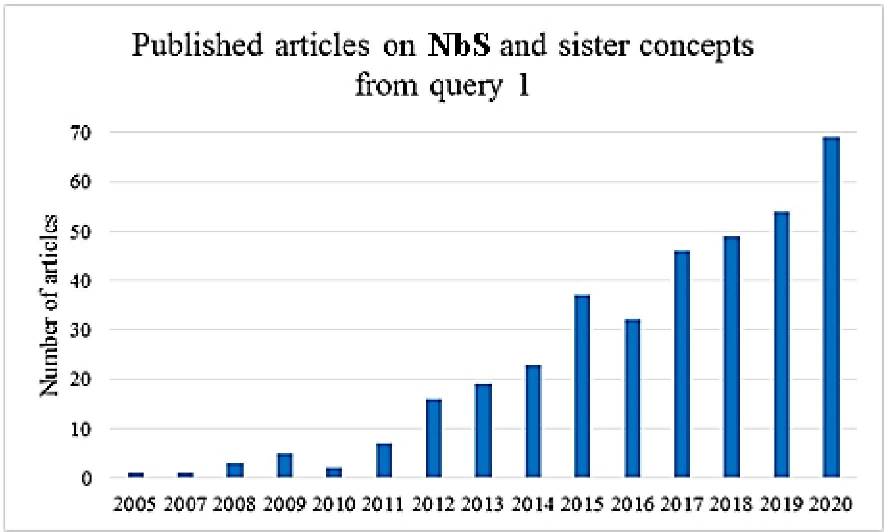


Figure 3: Temporal distribution of French peer-reviewed publications on NbS and sister concepts

Findings from query 1 were investigated using the above-described workflow. A simplified representation of the most recurrent terms is presented in Figure 4.

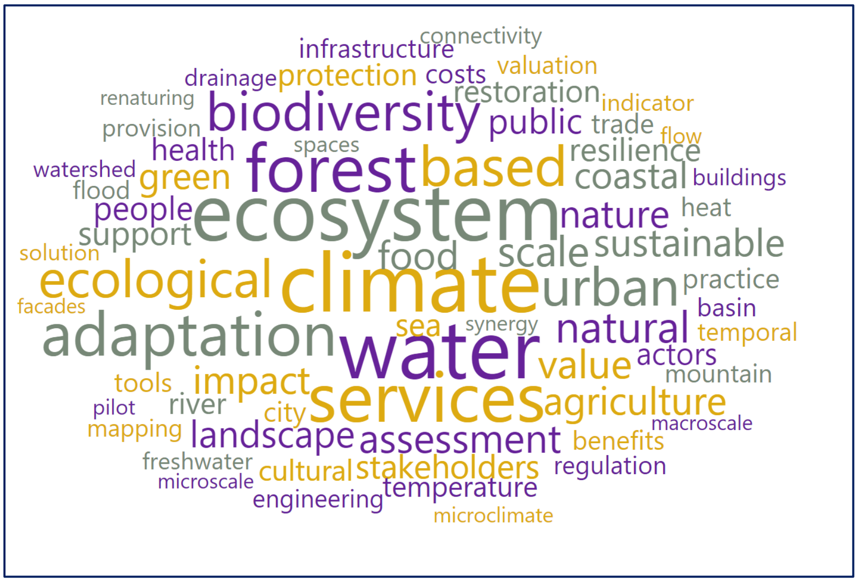


Figure 4: Word cloud from query 1

Several observations can be drawn from Figure 4:

1. Unlike other scales and queries, in query 1 aquatic and forested ecosystems are most addressed. This rather unclassical distribution underlines the fact that as much as the scope of the papers gets closer to NbS and NbaS in strict terms the more urban they become (as revealed in later sections). This could be due to the fact that the urban medium is the most nature-missing biome. In this general query, the scope of focus revolved more around water as a primary resource and climate change implications on diverse ecosystems.

2. Different scales appear in this query (unlike the word cloud of query 2 presented in the following section). Accordingly, one notices the presence of different spatial units, e.g. buildings, microscale, macroscale, landscape, city, watershed, basin, pilot. As scalability is a main barrier for NbS-NbaS, in other associated concepts scale seems to be a lesser concern. Moreover, as indicated in chapter 2, most NbS-NbaS implementations/studies do not extend beyond demonstration or pilot-sites. Other approaches such as ecological engineering, EbA (among others included in query 1) seem to extend beyond experimental plots to englobe wider scales.

3. Unsurprisingly, ecosystems occupy a central position in as revealed by significant occurrence records of the term. Concerning ecosystem services, support services rank first and are followed by cultural, regulative and provision services, respectively. This distribution was identically found for query 2 (detailed in the following section) and hence reveals that the use of NbS and their associated concepts focuses more or less on a restricted range of the ecosystem services spectrum with the regulative functions ranking second to last.

4. Mapping benefits, assessment, impacts and indicators amply appear throughout the word count hence underling the high level of awareness on efficiency reporting and measuring success. Although this matter remains a polarized topic in NbS-NbaS literature, calls for developing tools and methods are abundantly present in the different contributions.

5. Synergies and tradeoffs are well-underlined even more than in query 2 (as revealed in the following section).

6. In terms of climate change, the occurrence of the terms climate, microclimate, microscales, heat and temperature reveal that climate change is addressed throughout different scales with a considerable attention to adaptation. Accordingly, throughout different literature topics climate change seems to occupy the status of a major environmental challenge.

For more detailed insights, clusters and their links were examined using the hierarchical clustering dendrograms (Figure 5). The vertical separation line was set at a distance of 350 as cluster distribution above and below was unsuitable. Accordingly, 8 different clusters were identified.

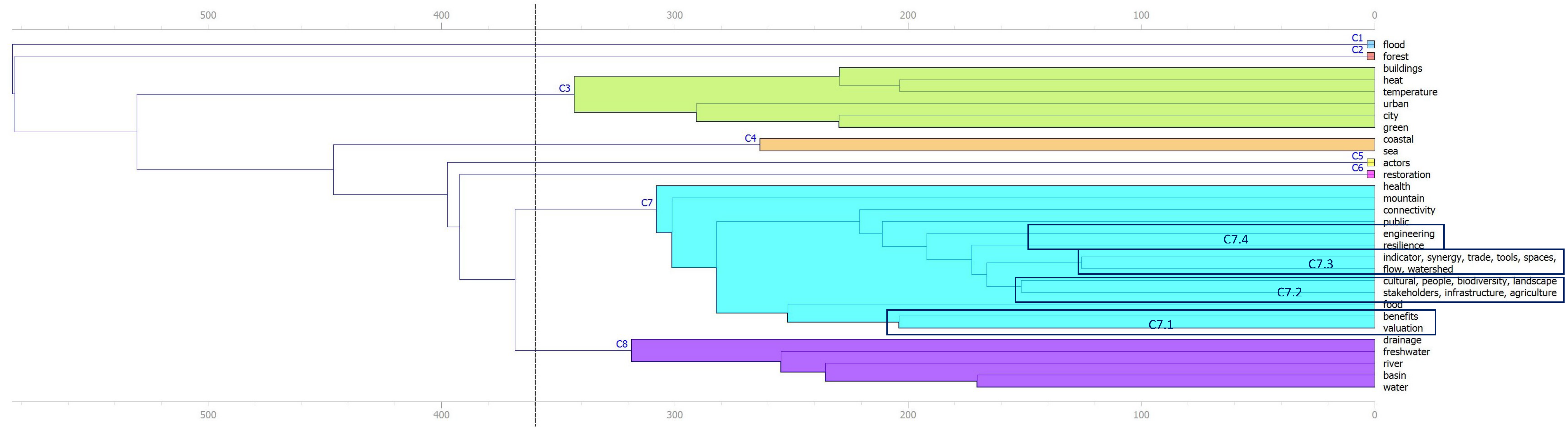


Figure 5: Hierarchical clustering of articles from query 2

The first cluster consists of floods and is apparently isolated from all the others with no major connections with any apart from forests at relatively large distances. The same can be said more or less for cluster 2 forests that eventually connects with a very weak link to the urban cluster as part of the adopted solutions therein. The third cluster concerns the urban ecosystem and highlights the interest in heat stress and temperature increases particularly at the scale of buildings and cities. Accordingly, one can notice that thermal stress as a manifestation of climate change is addressed mainly at two different levels. For this purpose, green solutions seem to be the most adopted response particularly at the city scale. Cluster 4 relates to the marine and coastal environment and is found to be largely disconnected from other ones except restoration. Cluster 5 seems an outlier with a few connections to the clusters. This could be due to the transversal use of the term without a clear relationship to the studied challenges. The restoration cluster also falls away from other ones however with a weak connection to both clusters 7 and 8, hence its existence as a measure (NbS or associated concepts) in both. Within cluster 7, several sub-clusters can be found. These were defined based on the short distance between branches (hence stronger bonds and connections). Accordingly, C7.1. highlights the valuation of benefits line of work that remains one of the most significant challenges facing the NbS-NbaS concepts. While at this stage the analysis is still limited to NbS and associated concepts (not necessarily NbS), the valuation of benefits can be considered as a long sought objective that aims to "monetarize" or give a concrete description of benefits and efficiencies. C7.2. connects people and stakeholders to cultural services, agricultural production, biodiversity and costs across the landscape scale. C7.3. connects indicators, synergies, trade-offs, tools, sustainability, spaces, adaptation, assessment and microclimates to the watershed scale. While certainly dense, C7.3. reveals several important elements: i) the importance of indicators and tools to study synergies, account for trade-offs and assess adaptation efforts, ii) the consideration of microclimatic effects and hence adaptation to both short and long-terms changes and iii) the extension beyond pilot scale or demonstration sites to englobe larger functional units such as watersheds. C7.4. indicates the orientation of engineering practices towards more resilient forms, hence resilient engineering. While this sub-cluster should logically relate more to the urban cluster, the use of the term engineering in this context comes as an associated concept to NbS as set in the query. Accordingly, a strong transition and interest in the concept of resilience is observed. The 8th and final cluster represents the aquatic environment and is mostly concerned with water drainage challenges at the scale of rivers, freshwater bodies and basins. While the watershed scale should have been logically associated here, the interchangeable use of the term watershed (US vocabulary) and basin (European vocabulary) might be an underlying reason. In an effort to provide results further linked with the scope of the study, section VI summarizes findings from the individual analysis of articles from queries 1 and 2.

V. Published literature on NbS

Reminder of the SCOPUS query: "nature-based solution" AND "France" AND (LIMIT-TO (PUBSTAGE, "final")) AND (LIMIT-TO (AFFILCOUNTRY, "France")) AND (LIMIT-TO (DOCTYPE,"ar"))

Number of retained articles: 96

V.1 Research trends, academic actors and funding parties

Recalling Figure 1, the emergence of NbS (in strict terms) in French peer-reviewed literature goes back to 2016. Since then, considerable increases have been observed (Figure 6). Despite their increasing numbers, NbS contributions are more or less still limited. This may be due to the fact that other concepts such as EbA are still being favored over or labeled as NbS.

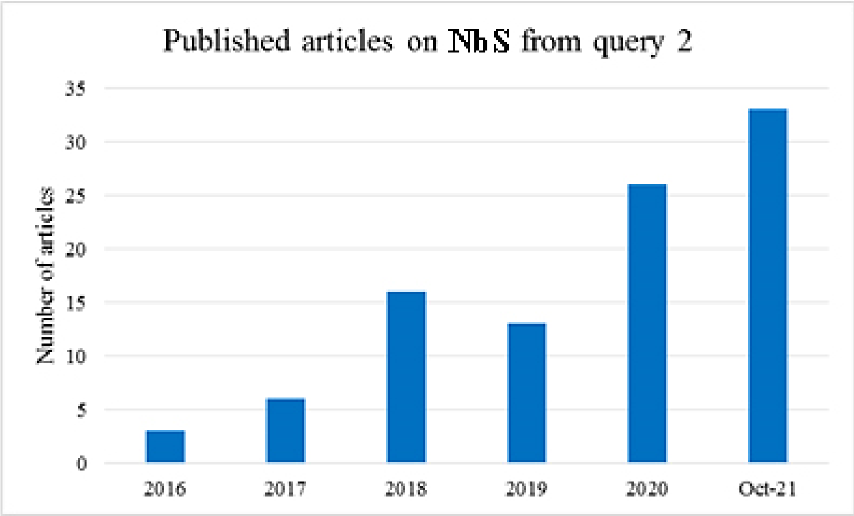


Figure 6: Temporal distribution of French peer-reviewed publications on NbS

In terms of academic actors, French labs were extracted from the retained articles and mapped to study the geographical gradient of interest in NbS (Figure 7). The presented map can be accessed using the following link: https://www.google.com/maps/d/u/1/edit?mid=1B43M66m6pBtJYl5Cv-izzpXSK_Eqc8NG&usp=sharing. As can be noticed, the number of labs targeting NbS is fairly common in the country and extends further to the overseas territories. Spatially, the distribution of labs shows a very dense aggregation in the Parisian region (Ile-de-France), and a dense aggregation in the South and South-Eastern sections of the country. The presence of labs along the Western coastal area is also quite apparent.

Concerning the media of interest, the geographical location of labs influences more or less their studied ecosystems (Figure 8). For instance, Moorea's (French Polynesia) and Mayotte's labs target the marine and coastal ecosystems, while Guiana's and Guadeloupe's labs target freshwater environments. The mountainous ecosystem is mostly targeted in the Grenoble-Alpine region, the marine and coastal ecosystem is mostly addressed in Western and Southern France, while the urban environment is studied in or around the largest French cities (Paris, Nantes, and Montpellier) as well as throughout the whole territory. Freshwater ecosystem labs are mostly concentrated in the South with a very scarce distribution elsewhere. The same applies for the forest ecosystems. The abundance of labs focusing on the agricultural medium across the country reflects a particular interest in food security. Almost all ecosystems are targeted by the labs of the Parisian region despite the urban nature of this setting.

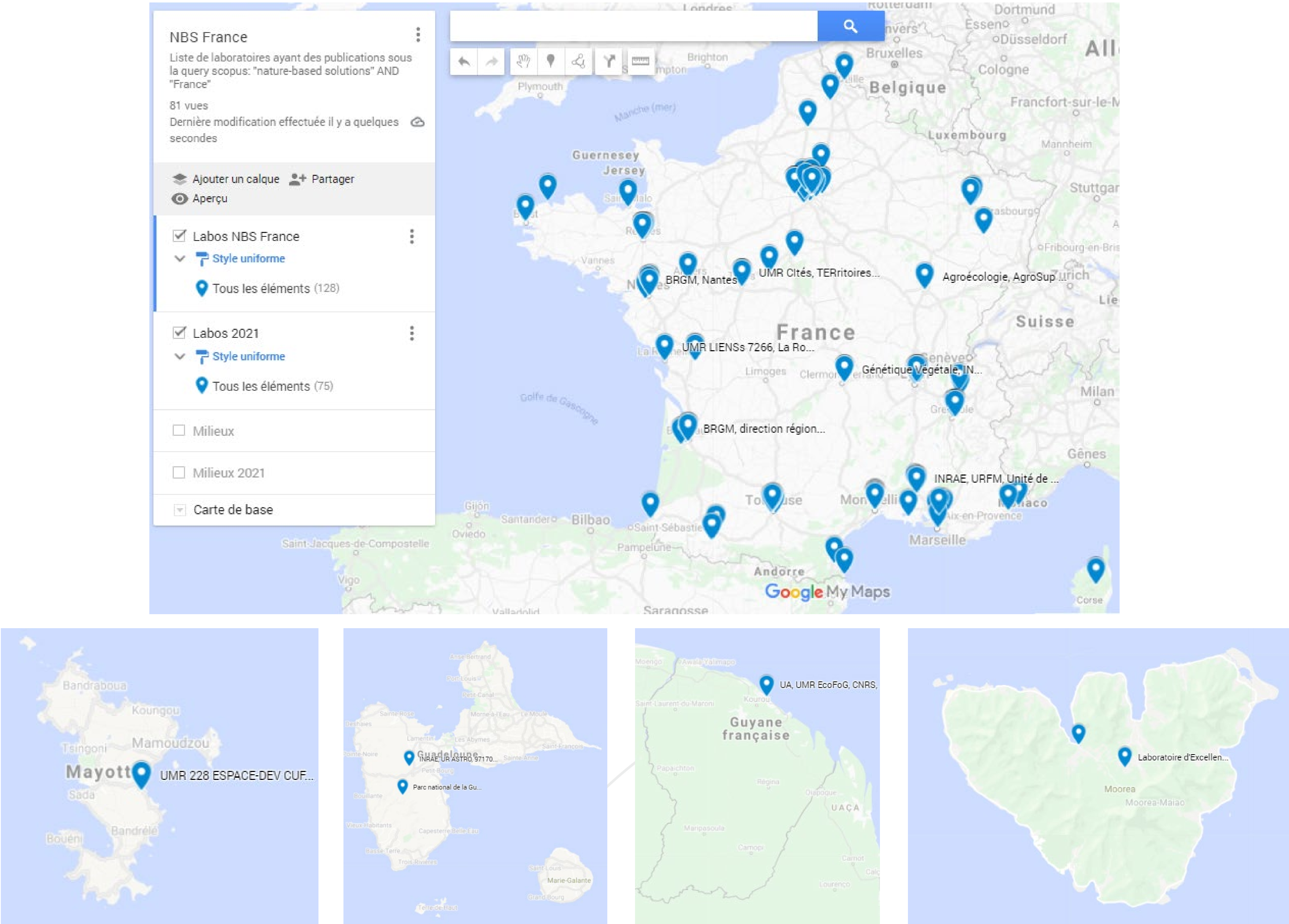


Figure 7: Geographical distribution of NbS labs in France

Generally, the distribution of French NbS labs per ecosystem is as follows: Urban (77), marine and coastal (29), agricultural (28), freshwater (23), other (20), forest (13), all (12), and mountainous (6). Three labs focus on soils as distinct systems as well. Strikingly, the natural medium is completely absent, thus highlighting a considerable gap in French NbS research: tapping the potential of natural/protected areas.

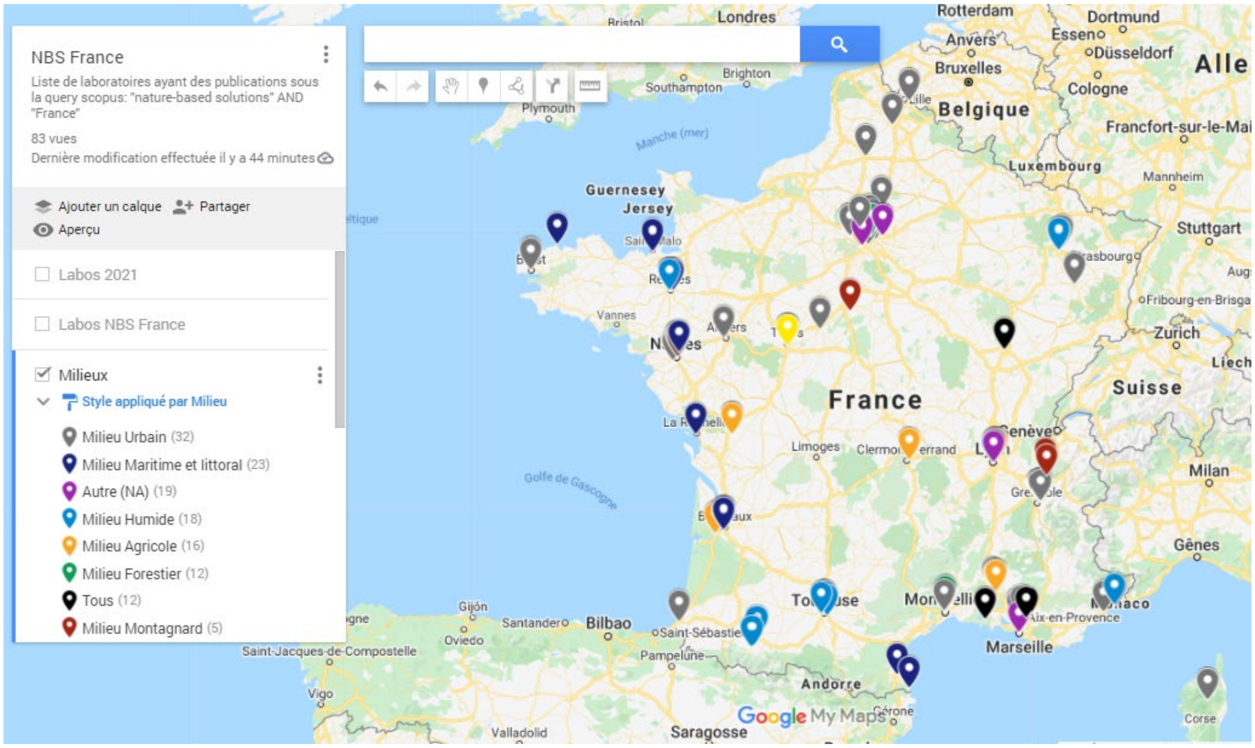


Figure 8: NbS labs distribution per ecosystem

In terms of funding parties (Figure 9), the French National Research Agency (ANR) was found to be the most implicated funding party followed by the European Commission’s programmes (H2020, FP7, etc.). Ministries and public agencies, as well as national/regional offices are also well implicated in funding research on NbS. This pattern reveals a high level of awareness on these solutions and the interest in developing them further for maximizing the derived benefits.

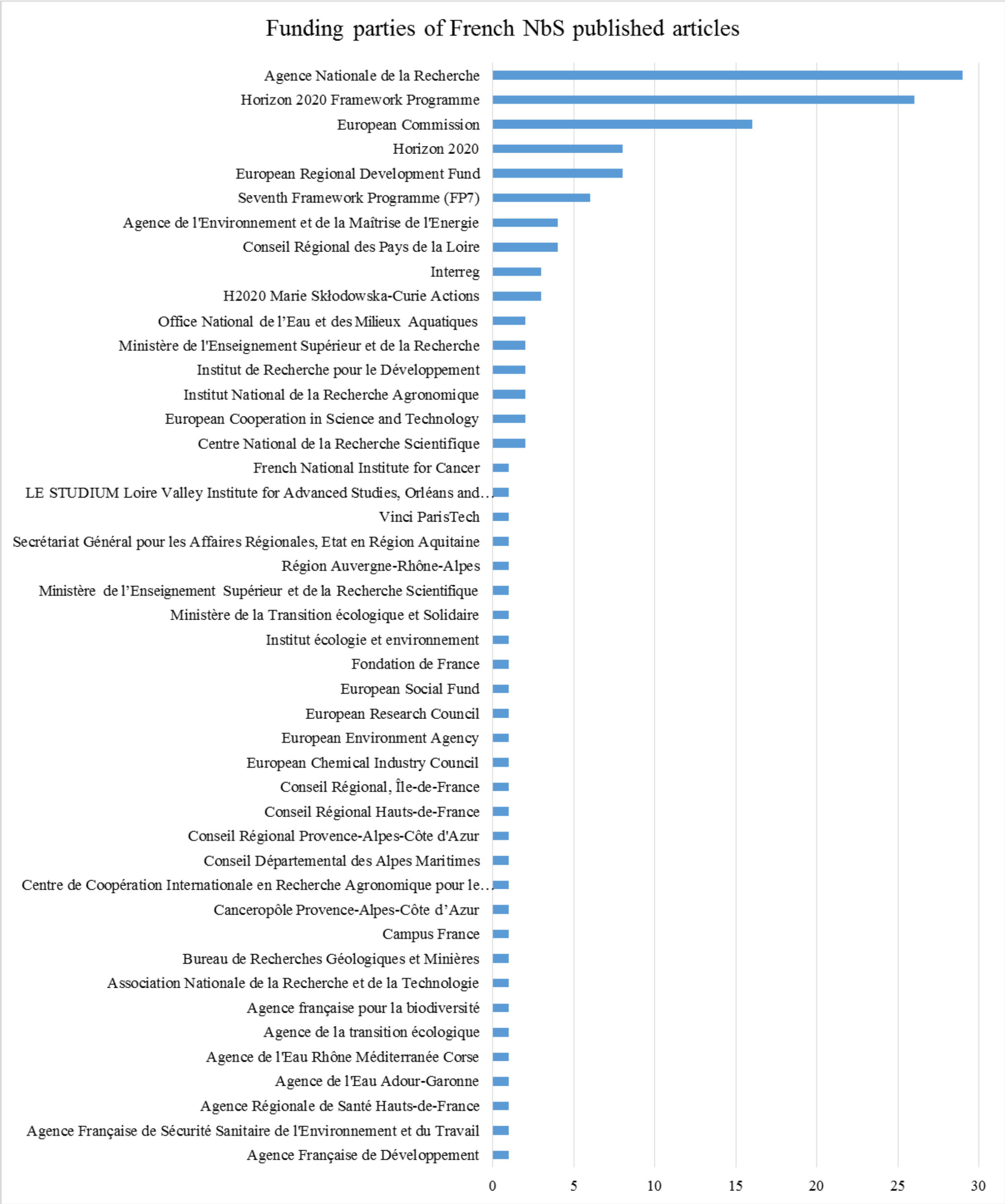


Figure 9: Funding parties of French NbS scientific literature.

V.2 Findings from the text mining approach

Findings from query 2 were investigated using the same methodology described in the text-mining section of the first query. A simplified representation is first presented in Figure 10. From a simple word count the word cloud reveals several elements:

1. The urban environment is the most addressed ecosystem followed by water (freshwater), coastal, forest, agricultural and mountainous realms in decreasing order. This somewhat classical distribution highlights the constant need to widen further the horizons of the concept and to extend knowledge and interest into other ecosystems.

2. A great deal of importance is given to green solutions and infrastructures. Accordingly, one can deduce a dissymmetrical interest in NbS types (i.e. other than green solutions).

3. Unsurprisingly, ecosystems occupy a central position in NbS literature as revealed by significant occurrence records of the term. Concerning ecosystem services, support services rank first and are followed by cultural, regulative and provision services, respectively. This distribution reveals that the use of NbS focuses more on the biodiversity (as revealed by the high occurrence of the term), and social angles of the concept in contrast to its regulative capacities.

4. The occurrence of the words temperature and heat reveal that thermal variations as climate change manifestations are a major concern.

5. The occurrence of the term connectivity underlines a high level of awareness on the connectivity of ecosystems, NbS and habitats. The appearance of the word scale equally underlines an important line of work in NbS literature that herein appears within French contributions. In this regard, NbS scalability remains one of the most significant hurdles that require considerable efforts.

6. The recurrent use of the word drainage highlights another climate change-related challenge, that of stormwater management.

7. The high occurrence of the word climate underlines a strong interest in the process. However, that does not mean that the process is accurately accounted for or quantitatively analyzed. The occurrence of the term adaptation equally reveals a certain level of awareness on the potential of NbS for CCA. Nonetheless, its occurrence does not necessarily mean that the concept of NbaS is well addressed. Further elaborations on this topic are given in what follows.

To understand further the relationship between the different elements of the 97 documents corpus, hierarchical clustering was performed using the same method and principles described in the text mining section of NbS and sister concepts. Figure 11 represents the obtained dendrogram.

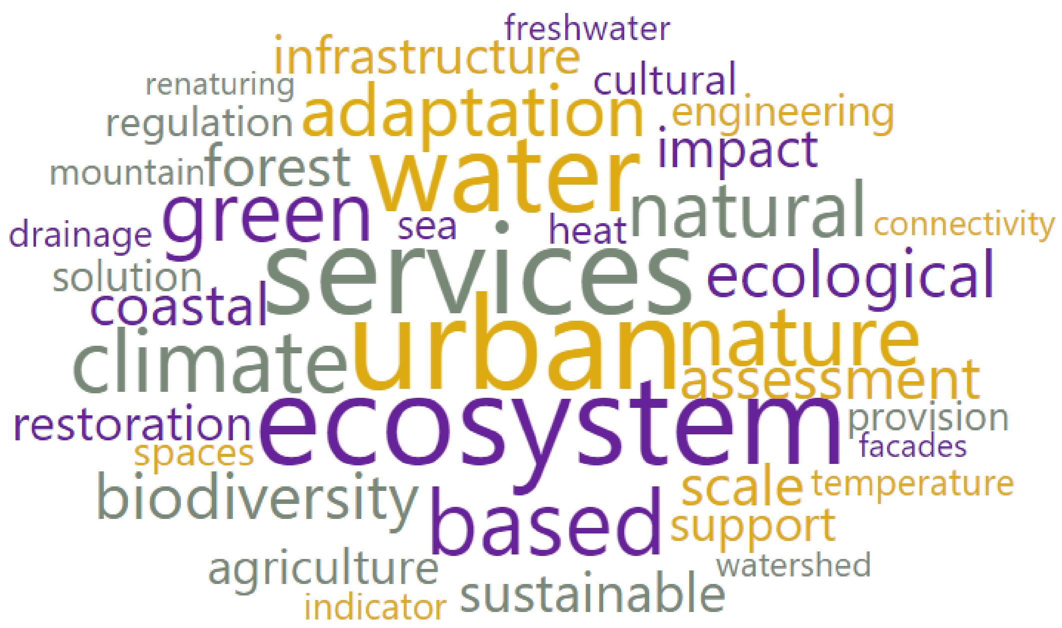


Figure 10: Word cloud from query 2

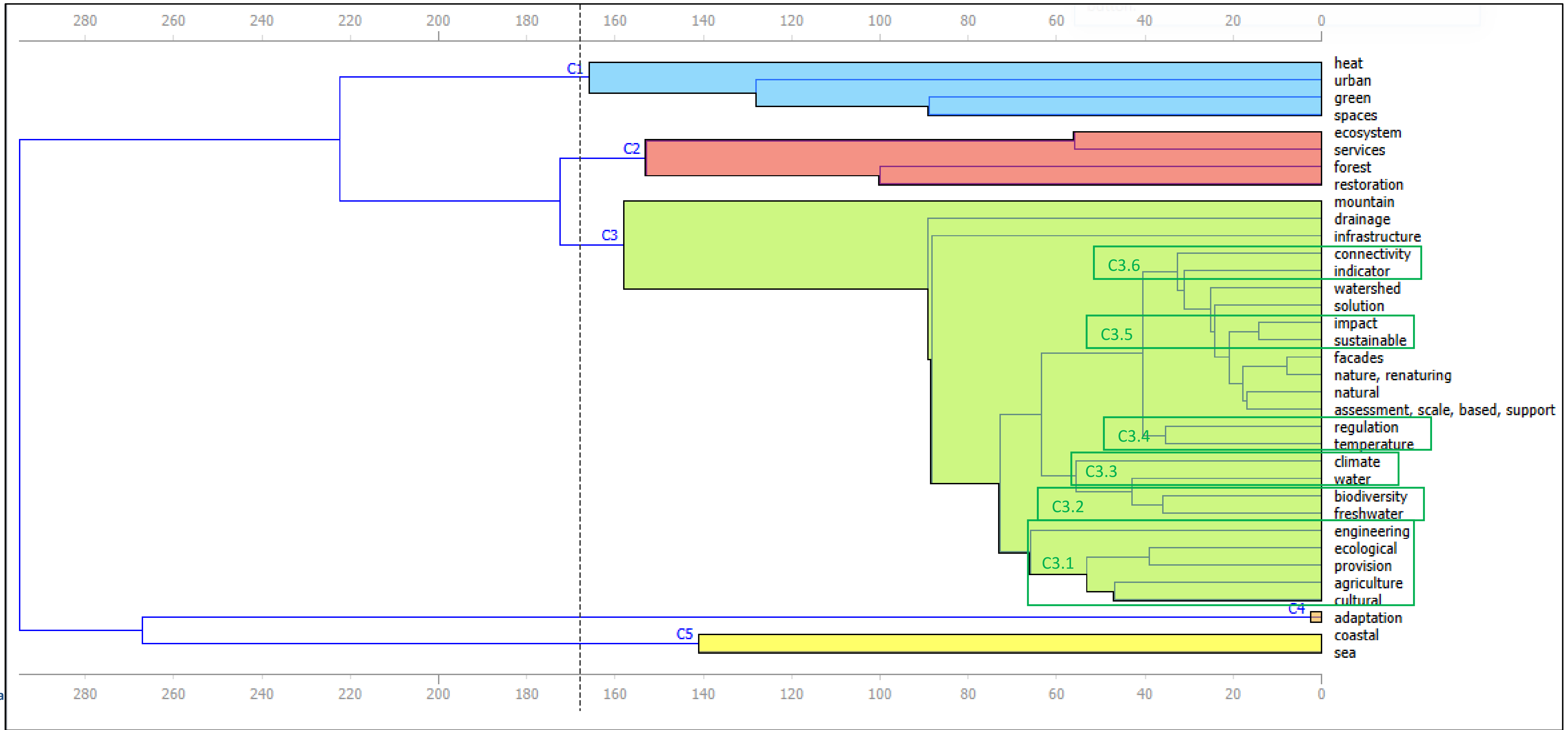


Figure 11: Hierarchical clustering of articles from query 2

As can be noticed, 5 clusters were found. The vertical separation line was set at a distance of 170 as cluster distribution above and below was unsuitable. Cluster 1 corresponds to the urban environment/challenges, cluster 2 corresponds to forests, cluster 3 (NbS cluster) groups the largest number of observations with significant connected sub-clusters, and cluster 4 represents the adaptation cluster, while cluster 5 corresponds to the coastal and maritime environment.

Cluster 1 reveals that the most addressed climatic challenge in the urban realm was heat stress, while green spaces were used as the target NbS. Cluster 2 highlights the link between forest restoration (as part of ecosystem restoration) and ecosystem services. As can be noticed, clusters 2 and 3 are also linked through the ecosystem services compartment. Keeping in mind that the short distance between components indicates a higher level of similarity and hence a stronger bond/grouping, one can notice several tight groupings in cluster 3:

C3.1. where ecological engineering is utilized for agriculture and for the delivery of provision and cultural services. C3.2. where the major interest for freshwater environments was found to be biodiversity. C3.3. reveals that the interest in climate is more or less focused on aquatic environments, hence underlining both the importance and the concerns on the availability of this resource. C3.4. where temperature regulation forms a central element of concern that later connects with the sub-cluster C3.6. which in turn highlights the need for indicators on connectivity. Finally, C3.5. underlines the awaited sustainable impacts and the sustainable dimension of NbS. C3.6 reveals a high level of research awareness as the connectivity of habitats, ecosystems and NbS was found from the previous scales to be a significant line of work to develop.

Concerning adaptation, and despite the high occurrence of the term, the adaptation cluster remained relatively disconnected (distant) from all other clusters until significant heights (high Y axis values). This indicates that the linkages between adaptation and other components/clusters were relatively weak. At a distance of around Y=270, a connection between adaptation and the maritime/coastal environment was found, while the adaptation-urban connection was established at a height greater than 300. In addition to the weak connection, this distribution highlights the fact that adaptation efforts were only concentrated into two media, leaving others unaccounted for. In this sense, this pattern might be indicative of NbaS-ecosystem orientations as it implies more or less the use of NbaS.

VI. Insights from the individual analysis of findings from queries 1 and 2

It is worthwhile noting that the concept of NbaS might have been addressed, however without any direct links or any strict labelling of solutions as NbaS.

- The earliest study on the role of biodiversity in ecosystem functioning dates back to 2005. In 2006 and 2007, studies on the effect of climate change on biodiversity followed.

- In 2008, an implicit appearance of the NbS-NbaS framework emerges, as the term stakeholders, climate change adaptation and mitigation were used.

- In 2010, an early form of awareness on the choice of species for planning solutions is apparent with recommendations for studying the effect of climate change on the proposed vegetation. In the same vein, the importance of considering the adaptive capacity of introduced species is underlined.

- In 2011 and 2012, the term EbA and its studies amply gained prominence and related literature started to increase since then. In 2012, climate change was considered to occur so rapidly that adaptation couldn't have still taken place. Another important perspective was also given in 2012 with the call to study the eco-evolutionary responses of biodiversity to climate change. The importance of understanding the impact of any solution on the biotic and abiotic components of ecosystems was equally underlined. In the same year, the interest in conservation agriculture as an ecological means for abating climate change and the need to consider feedback loops when planning solutions were also highlighted.

Side note: The exponential increase in ecology/ecosystem studies could be attributed to the development of the national ecological transition program.

- In 2013, the first studies on the potential of green roofs in the urban realm appeared. The importance of studying ecosystemic responses and understanding ecological resilience was equally highlighted. The potential of blue solutions for climate change adaptation and mitigation was underlined, but they were also labelled as climate-sensitive solutions. Accordingly, the awareness on avoiding the misconception of NbS-NbaS immunity can be noted. Regardless of their potential, according to 2013 literature, an NbS-NbaS can only be efficient as much as it is efficiently managed. Hence the importance of adequate NbS-NbaS management.

- In 2015 and onwards, a certain deepening of knowledge can be noticed. In this regards, many different solutions started to appear (e.g. Sustainable Urban Drainage Systems [SUDS], Low Impact Development solutions [LID], Best Management Practices [BMPs] and Water Sensitive Urban Design [WSUD], etc.). The need for developing indicators for measuring efficiencies and performances is highlighted, and the importance of vulnerability assessments for proposed solutions is stressed. Another important insight from this year is that while some ecosystem services can work in synergy, others are hardly compatible. Therefore, there is a need to carefully account for ecosystem services trade-offs, interactions and relationships. This can be considered as an important research question that underlines a high level of awareness in French NbS literature.

- In 2016, the limited knowledge on marine protected areas (and overall NbS type 1) was underlined. The need to consider the microclimatic setting of the context where a NbS is planned was also highlighted. This reveals once again that there is an ample awareness on the misconception of NbS as climate-proof solutions and that the NbS-local climate interaction should be directionally accounted for. An important insight from 2016 literature relates to the fact that adapting to climate change will not necessarily lead to success, as the root causes should be addressed through mitigation. For this purpose, the synergy between adaptation and mitigation actions should be ensured both in research and implementation terms. Therefore, it might be beneficial to address several climatic challenges simultaneously, to ensure as much as possible an overall inclusive response.

- In 2017, an important insight for forest-based solutions (in any realm) was given where the introduction of uneven aged species was recommended for ensuring a wide-range of ecosystem service provision and for promoting resistance in the face of climate change. For the coastal realm, recommendations for targeting both sea and landscapes simultaneously were given since the coastal environment lies at the interface between both. In terms of climate change and despite the potential of mutli-faceted research for reducing the complexity of problem, much remains to be done for understanding the physical, social, cultural, economic and political forces that foster adaptation. That is why, among different factors, there is a need to improve the predictive capacity of models for depicting future climate changes in the physical environment at different scales.

Regarding ecosystems, the management of the latter is still a difficult task as it must encompass knowledge from the ecological, economic and social domains of socioecological systems. Such complex knowledge is necessary as action in any component can have an effect on others, and subsequently on the organization of the entire system.

Lastly, any climate/ecosystem related plan must consider the effects of extreme events as these are capable of causing abrupt shifts to the system's to the solutions' behavior/performance.

- In 2018, the term nature-centered solutions appeared. The use of multiple NbS synonyms shows that the concept is still not grasped/accepted by everyone and that it is a subject of subjective interpretation, understanding and analysis.

The need to focus on coastal/ocean-based actions rather than just solely land-based actions for CCA/CCM is stressed and understanding uncertainties better is amply recommended.

- In 2019, two new nomenclatures appear: nature-based defense and social-based solutions. This underlines once again above-mentioned factors.

- In 2020, a three-fold classification of adaptation measures was listed: i. measures that reduce the current vulnerability of a system, ii. measures that improve the efficiency of the system and iii. measures that require changes in the fundamental attributes of a system. Yet, despite the enthusiasm behind these approaches, evidence in scientific literature remains limited. For this purpose, research has to address further the physical dimensions of hazards, vulnerabilities and risks. However, despite the increase of knowledge on these notions and on climate change impacts, there is still a lack of comprehensive overviews of impacts throughout and across scales.

VII. Published literature on NbaS

Reminder of the SCOPUS query: *"nature-based solution" AND "climate change" AND "adaptation" AND "France" AND (LIMIT-TO (PUBSTAGE, "final")) AND (LIMIT-TO (AFFILCOUNTRY, "France")) AND (LIMIT-TO (DOCTYPE, "ar"))*

Number of retained articles: 40

VII.1 Research trends, academic actors and funding parties

Recalling Figure 1, the emergence of NbaS in French peer-reviewed literature happened in 2017. Since then steady increases have been observed until present (Figure 12). Despite their increasing numbers, NbaS contributions can still be considered shy with more or less a limited number of publications per. These findings reveal that the scientific interest in NbaS is still relatively recent (less than five years) and is progressing very slowly and clearly with less interest than NbS.

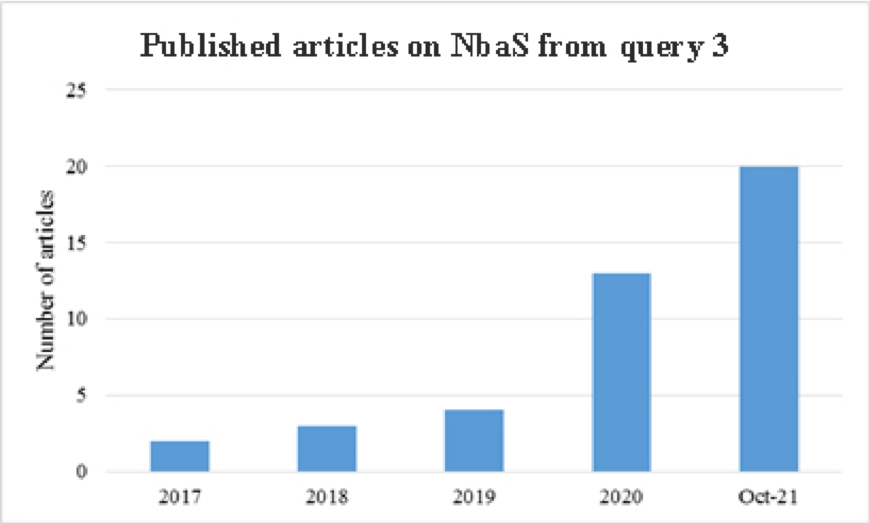


Figure 12: Temporal distribution of French peer-reviewed publications on NbaS

In terms of academic actors, French labs were extracted from the retained articles and mapped to study the geographical gradient of interest in NbaS (Figure 13). The presented map can be accessed using the following link: https://www.google.com/maps/d/u/0/edit?mid=1O2un6-5uOGnUEjQKPja1P7GhSSDiVlmw&ll=46.83397192401185%2C1.1073212868562585&z=6

As can be noticed, the number of labs targeting NbaS is much less than those of the NbS map. Spatially, the distribution of NbaS labs shows two aggregations: the first is in the Parisian region (Ile-de-France), while the second lies in the South-Eastern section of the country, namely in the Grenoble-Alpine region. Southern France also shows a growing cluster of labs in contrast to Northern, Central and Western France where few labs are active on the topic. The relative absence of labs in the North is quite apparent, as is the absence of labs in French overseas territories (in contrast to the NbS map). Knowing that overseas France is much more sensitive to climate change than Metropolitan France, significant NbaS efforts are needed on these islands.

Concerning the media of interest, one can notice that the geographical location of labs influences more or less their studied ecosystems. For instance, the mountainous ecosystem is mostly targeted in the Grenoble-Alpine region, the marine and coastal ecosystem is mostly addressed in Western and Southern France, while the urban environment is studied in or around the largest French cities (Paris, Nantes, and Montpellier). The absence of studies related to the agricultural medium especially in areas where the country's UAA (Useful Agricultural Area) is the highest, such as in the Lille-Marseille axis and the Central Region is striking and reveals an important gap to bridge. While French food security isn't currently threatened by climate change, proactively immunizing the agricultural sector with relevant NbaS should be foreseen to avoid catastrophic losses. Almost all ecosystems are targeted by the labs of the Parisian region despite the urban nature of this setting. The capital's growing attention on NbaS may be a lever for spreading interest on the topic to other regions.

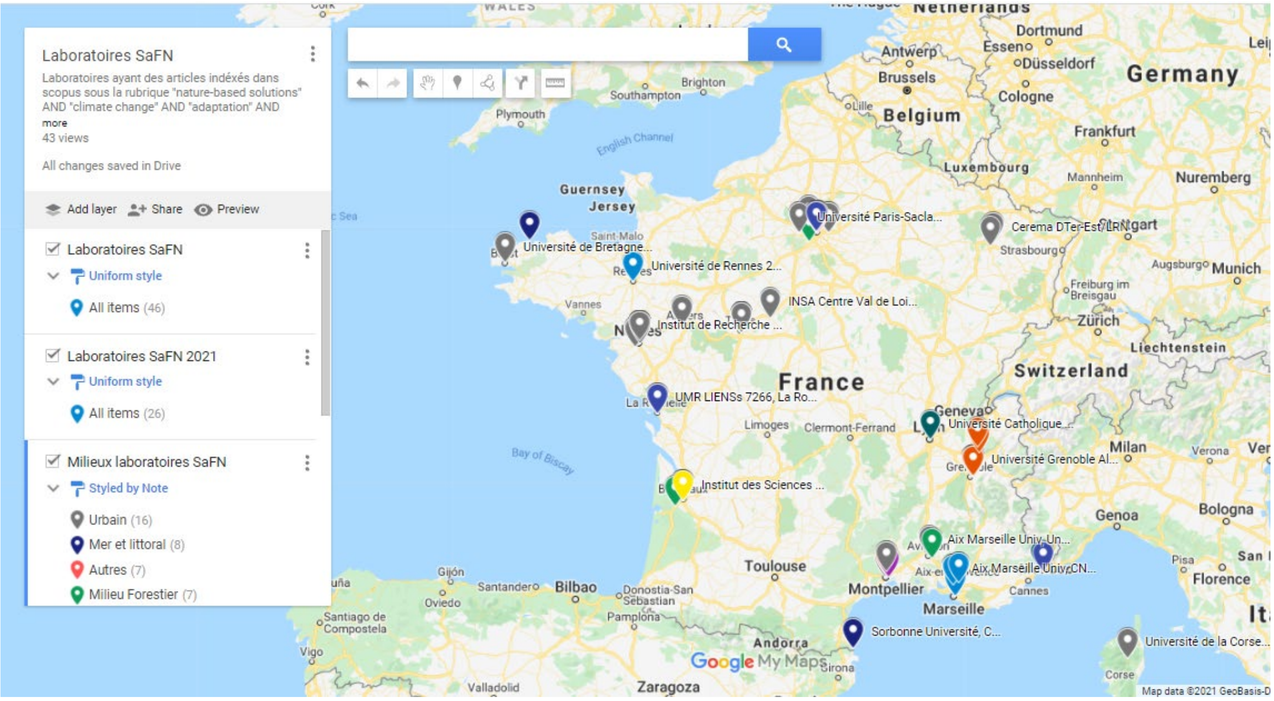


Figure 13: Geographical distribution of NbaS labs in France

In terms of funding parties (Figure 14), the H2020 program was found to be the most implicated funding party followed by the French National Research Agency (ANR). Ministries and public agencies are also well implicated. Funding bodies in the Alpine region are also apparent and highlight the academic/economic investment of the region in NbaS. While much less than NbS funding parties, scientific investment in NbaS is still somewhat limited and should be further developed.

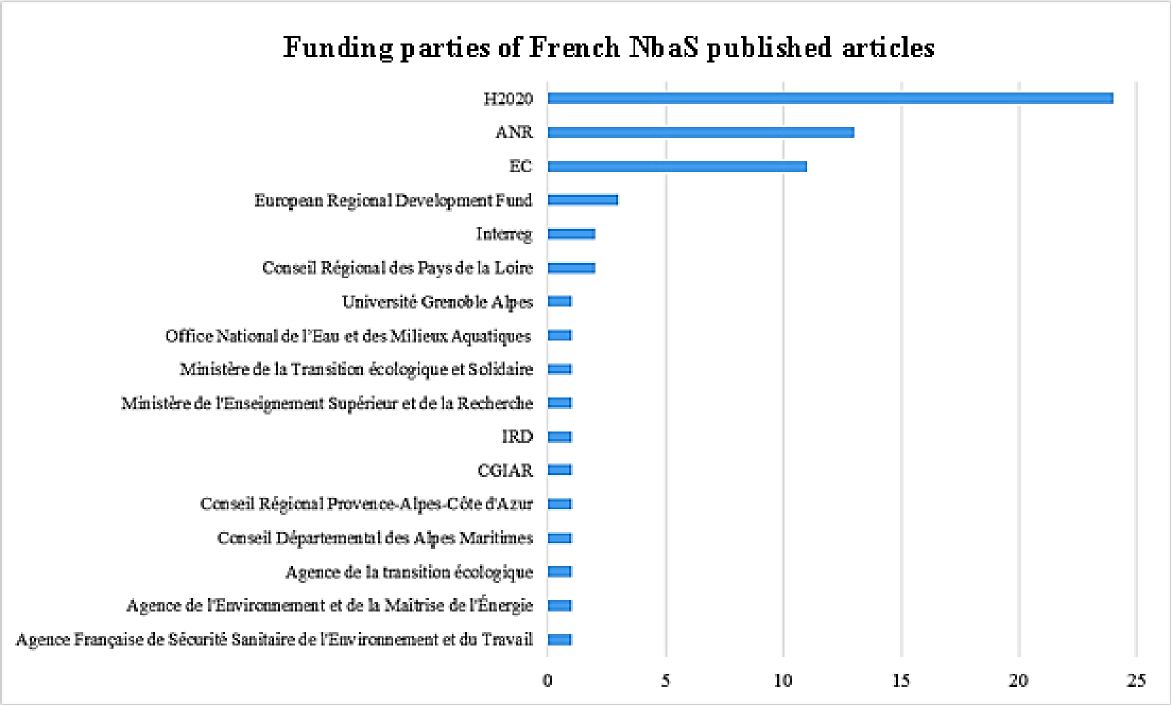


Figure 14: Funding parties of French NbaS scientific literature.

VII.2 Target ecosystems, solutions and environmental challenges

Table 1 presents the inventory of retained NbaS articles, along with their ecosystems, solutions and environmental challenges. As can be noticed, the urban environment is the most addressed (18) followed by the marine and coastal (7), humid (6), forest (4), all (3) mountainous (3), various, not applicable, natural and agricultural settings (1 each). Recalling the distribution of French ecosystems in H2020 projects, a more or less similar pattern is observed (i.e. the dominance of the urban environment and the low presence of the agricultural and natural realms). The only difference between the French H2020's and scientific literature's ecosystems is that in the latter the marine and coastal environment is more or less well addressed.

The pattern of French ecosystems is consequently translated in the studied/chosen NbaS. In this vein, one may notice the clear dominance of urban solutions that mostly revolve around Type 2 and 3 interventions (solutions in managed ecosystems and creation of new ecosystems). The same is applicable for the marine and coastal environments with interventions ranging from dunes and vegetation cover increase, to hybrid structures. Blue solutions are equally present however in one case only. Protected areas are relatively absent thus underlining the need for more research on Type 1 (protected ecosystems) NbS-NbaS.

Table 1: Retained articles, ecosystems, NbaS of interest and environmental challenges

Title	Year	Ecosystem	NbaS	Environmental challenge
Morphological and ecological responses of a managed coastal sand dune to experimental notches	2021	Marine and coastal	Managed coastal sand dune	Investigate the morphological and ecological responses to notches
Human–River Encounter Sites: Looking for Harmony between Humans and Nature in Cities	2021	Urban	Various	Human-nature relationship in cities
Simplified performance assessment methodology for addressing soil quality of nature-based solutions	2021	Urban	Gardening areas, green roofs, urban allotment garden	Assessment methodology for addressing soil quality of NbS
Assessing nature-based solutions for transformative change	2021	Mountainous	93 NbS case	The potential of NbS to deliver transformative change
How to evaluate nature-based solutions performance for microclimate, water and soil management issues – Available tools and methods from Nature4Cities European project results	2021	Urban	Swales, green roofs and SUDS	Climate change (urban heat islands, surface warming, increasing the thermal comfort of people, limiting the overheating surfaces due to impervious areas) and urban hydrology
Land- based measures to mitigate climate change: Potential and feasibility by country	2021	Various	NA	Climate change mitigation
Review and Comparative Study of Decision Support Tools for the Mitigation of Urban Heat Stress	2021	Urban	NA	Evaluation of decision support tools for the mitigation of urban heat stress
State of the Art and Latest Advances in Exploring Business Models for Nature-Based Solutions	2021	All	NA	Business Models for Nature-Based Solutions
Experimental Comparative Study between Conventional and Green Parking Lots: Analysis of Subsurface Thermal Behavior under Warm and Dry Summer Conditions	2021	Urban	Vegetated urban soil	Experimental comparison of the thermal behavior of different parking lot types (PLTs) with vegetated urban soil
Coupling detailed urban energy and water budgets with TEB-Hydro model: Towards an assessment tool for nature based solution performances	2021	Urban	Urban vegetation	Assessment tool for NbS assessment performance (hydro-microclimate)
Reflecting on twenty years of forest landscape restoration	2021	Forest	Forest landscape restoration	Review of advances in forest landscape restoration
Actions and leverage points for ecosystem-based adaptation pathways in the Alps	2021	Mountainous	EbA	Actions and leverages for the implementation of EbA
Seawalls as maladaptations along island coasts	2021	Marine and coastal	Prospects mangrove replanting, revegetation, dune, restoration of near shore ecosystems	Shoreline changes
Forecasting agroforestry ecosystem services provision in urban regeneration projects: Experiences and perspectives from Milan	2021	Urban	Agroforestry	Urban regeneration
Natural assurance schemes canvas: A framework to develop business models for nature-based solutions aimed at disaster risk reduction	2021	All	NA	Natural Assurance Scheme for disaster risk reduction and climate change adaptation
Applying the food-energy-water nexus approach to urban agriculture: From FEW to FEWP (Food-Energy-Water-People)	2021	Urban	Urban agriculture	Food-Energy-Water-People nexus, development of the Food-Energy-Water nexus
Investing in Blue Natural Capital to Secure a Future for the Red Sea Ecosystems	2021	Marine and coastal	Blue solutions (MPA, MSP, coral reefs, seagrass, etc.)	Preserving the Red Sea and creating a sustainable blue economy
Nexus between nature-based solutions, ecosystem services and urban challenges	2021	Urban	Various	Various
Barrier identification framework for the implementation of blue and green infrastructures	2020	Urban	BGI	Determining barriers facing BGI for climate change and climate change-related events
Assessment of coastal risk reduction and adaptation-labelled responses in Mauritius Island (Indian Ocean)	2020	Marine and coastal	EbA (beach restoration, artificial reefs, sand bags, dunes, seagrass restoration and vegetation planting), hybrid and engineering solutions	Assessment of changes in coastal risk reduction and adaptation-labelled responses in Mauritius Island (Coastal erosion and flooding)
Towards adaptation pathways for atoll islands. Insights from the Maldives	2020	Marine and coastal	Ecosystem resilience strengthening, and minimization of the risk of maladaptation but mostly is dominated by hard engineering approach	Sea level rise
Managing erosion of mangrove-mud coasts with permeable dams – lessons learned	2020	Marine and coastal	Permeable dams for mangrove protection	Rehabilitation of mangrove habitat
Genetics to the rescue: managing forests sustainably in a changing world	2020	Forest	Genetic diversity	Forest adaptation to climate change
Parameters influencing run-off on vegetated urban soils: A case study in Marseilles, France	2020	Urban	Vegetated soils	Runoff floods mitigation
Stakeholder mapping to co-create nature-based solutions: Who is on board?	2020	All	Various	Coastal flooding, rock falls, landslides, avalanches, pluvial flooding, drought, erosion, storms, flash floods,
A text-mining approach to compare impacts and benefits of nature-based solutions in Europe	2020	Urban	Various	Urbanization and climate change
Reviewing the role of ecosystems services in the sustainability of the urban environment: A multi-country analysis	2020	Urban	BGI	Assessing urban ecosystem services as a tool for sustainability
Global overview of ecosystem services provided by riparian vegetation	2020	Humid areas	Riparian vegetation	Overview of ecosystem services provided by riparian vegetation (namely carbon sequestration)

Co-producing ecosystem services for adapting to climate change	2020	Mountain, natural, agriculture and humid	Various	Adapting ecosystems to climate change
The calm before the storm: How climate change drives forestry evolutions	2020	Forest	Forests	Forest adaptation to climate change
Supporting NbS restoration measures: A test of VBN theory in the Brague catchment	2020	Humid areas (Watershed)	Various	Analysis of the influence of socio-psychological factors in building public support for flood risk mitigation NbS
The (re) insurance industry's roles in the integration of nature-based solutions for prevention in disaster risk reduction-insights from a European Survey	2019	Urban	NA	NbS for disaster risk reduction
Communicating (nature-based) flood-mitigation schemes using flood-excess volume	2019	Humid areas (Watershed)	Trees, reservoirs, leaky dams, retention, flood walls, Giving Room to the River	Nature-based flood-mitigation schemes
Climate resilience in Paris: A network representation of online strategic documents released by public authorities	2019	Urban	Green solutions (green areas, trees)	Investigating climate resilience in Paris
Mustering the power of ecosystems for adaptation to climate change	2019	Mountainous	Grasslands	Climate change adaptation in mountain socio-ecosystems
Management initiatives in support of the soil quality of urban allotment gardens: Examples from Nantes (France)	2018	Urban	Urban allotment gardens	Supporting urban soils for sustaining their ecoservices (protecting soils from pollution for the provision of food, ensuring social cohesion, residents' well-being, and prevention of UHI)
Harnessing positive species interactions as a tool against climate-driven loss of coastal biodiversity	2018	Marine and coastal	Biodiversity interaction (species)	Fighting against climate-driven loss of coastal biodiversity
Reducing risks by transforming landscapes: Cross-scale effects of land-use changes on ecosystem services	2018	Forest	Reforestation, agroforestry (management changes to forest protection and conversion)	Understanding the effect of land-use changes on ecosystem services
An integrative research framework for enabling transformative adaptation	2017	NA	NA	Transformative adaptation
Natural Assurance Scheme: A level playing field framework for Green-Grey infrastructure development	2017	Humid areas (Watershed) and Urban	Green-Grey infrastructure	Shift from Disaster Risk Reduction to Disaster Resilience Enhancement via natural assurance schemes

For forests, afforestation or reforestation measures are most adopted, while for the mountainous realm grasslands and re-vegetation are most relevant. In the freshwater ecosystem, vegetation, wetlands and hybrid structures are mostly used. One may notice that EbA is quite common in various ecosystems and is still somewhat present despite the progressive shift towards NbS-NbaS.

Interestingly, the soil compartment is particularly addressed in the urban realm. This interest shows that soil is recognized as a solution of interest and is being targeted as such. While this aspect is lacking in classical literature, French research seems to be conscious about it and is acting accordingly.

In terms of climatic challenges, the most addressed challenges were found to be: urban heat islands, surface warming, thermal comfort of people, surface overheating, sea level rise and storm water management. Coastal flooding, rock falls, landslides, avalanches, pluvial flooding, drought, erosion, storms and flash floods are equally targeted.

VII.3 Findings from the retained articles

In this section, the publications of each year are analyzed separately for accurately revealing progress on a yearly timesteps. Accordingly, current knowledge is first presented, followed by highlighted limits and research perspectives/gaps. The observations (comments and perspectives) made by the Authors of this chapter are highlighted in blue. At the end of this section, a conclusion linking the findings from the different years is presented.

VII.3.1 2017

The term transformative adaptation appears in the title of a manuscript in 2017. As mentioned previously, this year can be considered the starting point for NbaS in French scientific literature. In this regard, the adopted approach in both papers is rather conceptual and revolves around the integration of adaptation.

Findings from Colloff et al. (2017):

- There is an ample call for adaptively managing the trade-offs between socioecological systems and biophysical changes for properly addressing climate change.

- Adaptation is labelled as a short and long term challenge that requires addressing continuous threats and a cross-sectorial/trans-scalar uncertainty.

- Adaptation is considered as a continuum of resilience (Pelling, 2011 *in* Collof et al. 2017).

- Reactive adaptation is referred to as short sighted and punctual. It is also pointed out as a possible maladaptation compounding factor since it does not consider the long term effects of environmental changes, their interactions, and uncertainties.

- The above-mentioned fact comes from the principle that reactive adaptation does not consider the dynamism of ecosystems but is rather *ad hoc*.

- Dynamic ecosystems consequently implicate dynamic services that can be threatened by the evolution of climate change.

- The concept of adaptation services is introduced. The latter comes from the properties of ecosystems to buffer and adapt to changes. For instance, during their adaptation (transformation), ecosystems can provide new services, unravel existing but underutilized services, maintain existing ones, and manage the provision of services to support others.

- The concept of adaptation services was highlighted to be superior to ecosystem services, as the latter is bound with limits and tends to be valued for its provisioning parts (bankable services) mostly.

- Under the adaptation services scope, trying to economically estimate adaptation services is risky as it eliminates the delayed and uncertain effect of climate changes on these services. Therefore, while adaptation services often extend to the future they need to be managed presently to ensure an optimal future outcome.

- In this regard, there is a call for coupling adaptation services with ecosystem restoration (implicitly NbaS as the sum of adaptation and ecosystem restoration [NbS] → NbaS).

- In this context, adaptation should particularly be of transformative nature to ensure adaptive transitions in ecosystems, decision making and capacity development. This aspect is particularly important to consider for matching both the transformation of ecosystems and the dynamic nature of climate change.

Findings from Denjean et al. (2017):

- The complexity of ecosystems challenges the political transposition of natural resilience and its uptake in DRR plans. Accordingly, losses of natural capital are not accounted for properly, nor is the contribution of NbS.

- NbS are referred to as potentially powerful solutions for enhancing disaster resilience through the exploitation of multi-functional and resilient natural processes.

- The concept of ecosystem thresholds is addressed and the difficulty of their definition is underlined. In the same manner, the challenges for defining the limits for adaptation strategies are stressed. According to the Authors, the above-mentioned challenges are complex even without the consideration of climate change, let alone its introduction.

- The green versus grey debate is addressed and the popular preference of grey infrastructures' safety is highlighted. The difficulty of engineering NbS is also underlined. In this regard, the cyclical nature of NbS is pointed out and the subsequent difficulty of measuring their performance with respect to grey infrastructure is highlighted.

- The difference of language between the parties behind the green and grey counterparts is highlighted, and the challenge of defining metrics (namely KPI) is stressed.

- The scalability of NbS namely across different scales is mentioned. According to the Authors and per example, at the watershed scale it is recommended to follow a source-to-sea approach (whole scale) to **connect resilience at various spatial scales.**

Concluding remarks: As one may notice, both retained articles approach the concept of NbaS in a more or less implicit way. Nonetheless, both contain very important conceptual elements that are needed to form the basis of any NbaS approach. In Denjean et al. (2017) particularly, the observation on scalar transition is particularly relevant as it underlines a very important line of work that was also underlined in Chapter 2. The awareness on connectivity through scales can be considered as a strong point for French scientific literature as it highlights the acknowledgment of major research gaps. On the bases of the 2017 literature, one may observe that the conceptual basis for NbaS are well presented.

VII.3.2 2018

The first NbaS paper for French study area appears in 2018: Le Guern et al. (2018). The study area is the French city of Nantes, the target NbaS are urban allotment gardens and the aim of the approach is to study management initiatives for supporting/sustaining the soil quality of these gardens.

Findings from Le Guern et al. (2018):

- Despite the various advantages of urban allotment gardens (social, climatic and environmental), the soil of these green spaces may be adversely affected by pollution due to their proximity to road networks or to other anthropogenic activities. Accordingly, NbaS are not perceived as immune systems, but instead are considered as vulnerable elements in their own right. The state of soils is studied to ensure that the gardens stay viable, performant and do not generate disservices. This approach indicates a high level of awareness as NbaS disservices are accounted for. Moreover, as soil is a scope of focus, the acknowledgment of its importance/sensitivity reveals a holistic approach to the system (substrate properties + disservices + a look beyond the green), instead of the classical interest in above-ground components.

- Three solutions for polluted soils are presented ranging from excavation and removal, to excavation and on site-management and lastly phytoremediation. The limits of the latter are well listed, namely its incapacity to perform as fast as urban development progresses. The consideration of NbaS shortcomings equally reflects a high level of awareness that is particularly relevant for planning interventions.

- The status of soils was also related to effects on humans through soil ingestion, dust inhalation and vegetation consumption. While certainly necessary since urban gardens are in direct contact with humans, the anthropocentric nature of the concept appears at this level. This is translated by the interest in the soils' provision ecoservices at the expense of cultural, supportive and regulative services. In this regard, there is a need to expand the interest in ecoservices to cover the whole spectrum.

- The status of soils can be easily quantified and compared against baseline or threshold levels (in this study French and EC norms). In this study, several elements were studied (Pb, As, Cu and Zn). This step echoes to the quantification paradigm in NbS-NbaS where numerical insights and evidence are much needed. Accordingly, the introduction of soil as an ecosystem can solidify arguments on the efficiency/performance of a solution given its easily quantifiable parameters. Yet, most of the utilized indicators are of chemical nature. While certainly indicative, other physical properties such as the degree of compaction, susceptibility to soil erosion, exposure, organic matter content and bulk density are equally important to consider. However, soil indicators might take some time to unravel and some can be easily skewed by a number of external pressuring factors. For this purpose, developing soil KPIs for NbS-NbaS interventions is an important line of work to consider.

- The study's proposed solutions (labelled as NbS), i.e. soil change, raised bed, non-accumulative cropping, phytoextraction, orchard, open space, shipyard do not fully fall under the NbS scope as some relate more to change of management approaches. In this regard, the adopted approach does not count as NbS-NbaS. For this purpose, the definition of NbaS-NbS should be better promoted to ensure its adequate use.

- Soil NbS were recommended for low to moderate contamination levels, meaning that high levels cannot be treated by NbS. Setting the limits of NbS also reveals solid knowledge as often the level of success/failure of NbS is not defined. However, even if soils are being treated, the driving forces of their pollution are constantly evolving. Therefore, there is a need to make soils more resilient and better adapted to their external stressors.

Findings from Bulleri et al. (2018):

- The climatic angle of NbaS is very pronounced in this study that aims to harness the potential of habitat-forming populations for reducing climate-induced losses of biodiversity. This aspect was integrated as the study highlights the underrepresentation of these solutions (are part of blue solutions) under future climate change scenarios.

- The study highlights an important research gap: While climate change is known to influence the distribution of species, species interaction are rarely integrated into models that aim to study climate change influenced distributions.

- Another important gap is pointed out: The role of habitat-former species for influencing (buffering) climate change induced distributions, and despite its importance for conservation and restoration efforts, is undermined in both terrestrial and marine realms.

- The role of habitat-forming species as climate rescuers is underlined not only for their resilience/resistance properties, but also for their potential of providing adequate environmental conditions for species that wouldn't be able to withstand changing conditions (namely climatic or climate-induced). In this regard, the role of biodiversity is highlighted as an integral element in NbaS, as well as an end product of this solution (biodiversity preservation). Accordingly, biodiversity is portrayed as a benefactor and a beneficiary at the same time.

- The observations within this article put a great deal of importance on the role of biodiversity as a central part of NbaS. In this regard, the two disciplines of ecology and biology cross paths to harness the potential of specific species to protect others (e.g. sea cucumbers and brown macroalgae). The study derives this principle from coastal ecosystems and shows its analogy to other ecosystems (namely terrestrial). For this purpose, several examples are given. For instance, in high-alpine systems, cushion plants can reduce the effects of warming on native grasses, while canopy-forming mosses ensure the survival of smaller mosses in their understory during droughts.

Findings from Fedele et al. (2018):

- An important limitation for NbaS is identified in the beginning of the article: the limited understanding of how land use change influence trade-offs between ecoservices and their benefits **through scales.** Accordingly, two large research questions are well acknowledged: i) trade-offs between ecoservices and changes brought about by the introduction of land use change (herein NbaS) and ii) transition through scales.

- The effect of land use changes propagates throughout the landscape scale (studied ecosystem) by feedback loops. When these changes become sufficiently ample, they can affect ecoservices with repercussions beyond the local scale. If one is to consider the introduction of NbaS as a land use/cover change, then the previously mentioned elements should also be taken into consideration. However, this line of work is relatively nascent and corresponding efforts are still needed.

- Again on the notion of scale, local-scale adaptation interventions are considered as not necessarily sufficient to address larger scales' developmental and adaptation challenges (regional or national). According to the Authors, deeper knowledge on the impacts of local-EbA actions is necessary for scaling up adaptation measures.

- The notions of complexity, uncertainty and interconnectedness of environmental challenges (namely climate change) are addressed. While these aspects are not new particularly under climate change, their acknowledgment highlights the need for equally considerate solutions.

- The important contribution of ecosystems (provision, regulation and cultural services) strongly depends on the management of lands and more specifically of the sought solutions. Accordingly, even if a NbaS is implemented, its benefits cannot be adequately derived without suitable management. This indicates that even when "nature" is introduced, it needs to be sustainably managed by humans. While this fact underlines the importance of the NbS-NbaS concept for connecting humans and nature and harnessing the power of the latter, it also highlights the anthropocentric and practical natures of the concept.

- Changes of land use may unequally influence ecosystem services while potentially boosting some at the expense of others. Per example, as food production increases the provision services, the latter undermine the regulative services. For this reason, there is a need to extensively understand what the current ecosystem offers and what services are intended to remain the same or change. This is particularly important to avoid unwanted effects or the loss of key ecosystem services.

- In this regard, the paper underlines an important aspect to consider: adaptive land use changes in a specific location might have unintended off-sites effects on other contexts or scales. While certainly important, this element is seldom studied and accounted for in NbS-NbaS literature. Its acknowledgment indicates a high level of awareness that is particularly relevant for the conception and design phases of land use or NbaS plans. Based on this observation, on and off-site effects of NbaS should be well understood prior to the implementation of these solutions.

Concluding remarks: Findings from the retained articles underlined many important findings. Accordingly, the importance of soil as an ecosystem and as a substrate for NbaS was highlighted, the importance of biodiversity interactions for climate change resilience was stressed, and the need to understand changes induced by the introduction of nature or land use/cover change with respect to ecosystem services was underlined. The notions of scale and spatial transitions were also addressed thus underscoring an important line of work.

On the basis of the various findings, the following additional perspectives (in addition to those mentioned next to their correspond bullet points) are proposed

- While some solutions have been proposed, these do not fully fall under the scope of NbaS (by definition). In this regard, more research efforts on soil solutions are needed. The quantifiable nature of soil properties might facilitate this task as relevant Key Performance Indicators can be readily defined and monitored against baseline or set thresholds. Accordingly, while soil replacement was mentioned, the use of biochar may be an interesting platform to consider as the latter has shown a powerful performance for carbon sequestration, soil fertility enhancement and soil cover protection. In analogy to what was presented in the second article, tapping the potential of soil biodiversity as a NbaS is also an important platform to consider as it has been shown to sustain and support soil functions making the soils and the overlying components better adapted to changes. That way, when a soil-based NbaS supports another

NbaS at its surface (e.g. parks or green cover), benefits are combined and performances are synergistically enhanced. While trade-offs might occur, a complete analysis of pros and cons along with plausible negative or positive interactions should be carried out.

- In terms of habitat-forming species, an important line of work would be the development of metrics or indicators to track their individual success, as well as their effect at scale of the ecosystems they take part of. For instance, the number of species protected due to their existence, the maintained/created ecosystem services due to their presence, and the possibility of reintroducing them into ecosystems they had perished from without causing imbalances in ecosystem dynamics. In the same vein, a thorough identification of habitat-forming climate-rescuer species in different ecosystems is needed. This is particularly relevant for the urban environment where nature is often limited and the remaining species are under major stressing factors (climatic and others). The same goes for the agricultural medium where the decline of species not only implies a loss of biodiversity but also potentially threatens food security.

- As mentioned in Chapter 2 and article number three in this chapter, there is need to understand what changes are caused by the (re)introduction of nature into a system and the rippling effects through scales. Often the introduction of a solution implies changes in land use/cover. What was newly introduced in this chapter was the fact that an adaptive change for a context (despite its benefits) might be harmful to another. In this sense, what seems to be a NbaS for a setting might be a NBaproblem to another. This line of work is important to consider as it can significantly influence the success of proposed/implemented solutions. Accordingly, studying the combined effects of land use and climate change on the targeted context and its vicinity prior to the implementation of a solution should be envisaged. Since most NbaS are still local/punctual interventions a multitude of methods can be tested, as the study scale is still somewhat limited. In this logic, a careful profile for each solution can help prevent the accumulation of negative outcomes as a result of their aggregated effect in the larger landscape. While this recommendation still lacks relevant methodologies or frameworks, its development can minimize risks of failure.

VII.3.3 2019

Two of the four retained articles year deal with the NbS-NbaS-DRR nexus. One deals with NbS for flood mitigation, while the second tackles the NbS-DRR-insurance relationship. The remainder two articles are more climate centric, where one focuses on the strategic investigation of documents issued by public authorities to determine the climatic resilience of Paris; and the second aims to harness the power of ecosystems for CCA in mountainous environments.

Findings from Bokhove et al. (2019):

- With the increasing interest in NbaS to complement hard infrastructure for reducing floods, flood protection strategies have become more complicated and harder to assess. The call for greening the grey is quite ample, and hybrid infrastructure are some of the most utilized solutions for flood management. However, as indicated in chapters 1 and 2, there is still a need for more conclusive evidence on the efficiency/performance of these solutions.

- This study proposed the use of the flood-excess volume (FEV) as a means to measure the effectiveness of several NbaS. Accordingly, through the implementation of these solutions, fractions of FEV are expected to be reduced (FEV refers to the volume that exceeds a certain level and causes flood damage). Yet, the paper reports that findings on the effectiveness of these solutions are case-specific given the multitude of contributing factors. The site-specific nature of NbS-NbaS, while a core principle of the concept, is one of the main reasons for the absence of a uniform/universal basis for assessment. This adds a layer of complexity for drawing clear parallels and comparing solutions intended for the same challenge. In this vein, the Authors also underline the fact that the effectiveness of these solutions is often qualitatively reported, while quantitative aspects are particularly missing at the catchment scale.

The Authors also point out that large floods can overpower individual solutions, and that the aggregation of small-scale solutions might imply greater installation and maintenance cost, hence a questionable cost/benefit ratio.

- In the course of this paper NbS-NbaS are referred to as Natural Flood Management (NFM) tools. The use of this nomenclature highlights the discipline specific nature of the concept that is often perceived, defined and approached from the viewer's/user's background. While this might be considered as an advantage, it also indicates the basis and fundamentals of NbS, let alone NbaS, are not universally uniform.

- Regardless of their nomenclature, the main intended outcome of their implementation is to slow down flows by increasing flood depths in certain locations, hence reducing flood peaks downstream. However, reducing flood peaks in tributaries does not directly translate to reduced flood peaks in the main stem. Accordingly, the location of the planned solution is key to ensure it delivers its expected benefits in the desired and adequate emplacement. In this regard, assessing the solution's location should be a pre-requisite prior to its implementation. Regardless of its intended purpose, the position of the sought NbaS in a watershed might have an effect on the basin's hydrologic behavior. For instance, if a UHI reduction NbaS is placed in a hydrologically-false position it might compound hazards, thus creating a new problem while resolving another. This insight can be considered as an interesting line of work to develop as it can help avoid unwanted effects while multiplying benefits.

- In the case of the River Calder, the Authors highlighted that the planted trees contributed to less than 1% in the reduction of the required FEV for mitigating an extreme flood with a 1:100-year return period. While in contrast, river-bed widening in the River Brague led to major reductions of the FEV. Keeping in mind the site-specific limitations for implementing solutions, in terms of freshwater (river) ecosystems, a focus on more hydrology/morphology-based NbaS (if possible) might be more advantageous than using vegetation. Nonetheless, careful considerations are needed when modifications to the River's channel, bed and banks are performed as these might have serious hydrosedimentary repercussions. For this purpose, detailed information on the river's morphology, bathymetry, flow, sediment transport and ecology are needed. Certainly, the use of models can provide important insights, nonetheless, repercussions on the watershed's hydrological response should also be considered.

<u>Findings from Vicari et al. (2019):</u>

The presented study reviewed French political strategies for extracting the status of climate risk management issues with a particular focus on resilience solutions in Paris.

- Recalling the following finding from H2020 projects: "Flooding is also an integral concern in the Parisian region and is mainly due to extreme weather conditions and soil waterproofing as a result of a 840 hectare/year urbanization rate (Fletcher et al., 2020)", Vicari et al. (2019), found that the Seine floods of 2016 (June) and 2018 (January) have underlined the region's technical and organizational vulnerability. Vicari et al. (2019) further reported that this state was due to the massive urbanization of the Seine's riverbed. As the findings of Vicari et al. (2019) and Fletcher et al. (2020) converge, there is a considerable need for developing flood related NbaS in the Parisian region. While urbanization has already settled and is progressively increasing, a thorough study of the Seine's watershed should be envisaged with plans to develop specific NbaS in key locations (around the main steam or tributaries, e.g. the Marne River or others), or to adopt a basin-scale approach. Nonetheless, the latter is a challenging task that is hampered by several limits as discussed in Chapter 2. Another solution would be to target the Seine immediately with river-based NbaS (river-bed widening, giving room to the river, flood plain restoration, artificial meandering, day lighting some its contributing streams, etc.). However, significant research efforts are needed to assess its current situation and to target adequate measures. Nonetheless, looking beyond Paris for tracking the origins/solutions to floods is an important insight to consider.

- The Authors also found that the Climate and Energy plan outlines the need to have long-term resilience solutions instead of emergency management. The same can be said for the Paris Resilience Strategy. This finding reveals that proactive reactions are being favored at the expense of reactive responses. Both the long-term target, the notion of resilience and the proactive response directly point towards NbaS.

- Through a text-mining approach of political documents 2015-2017, the terms adaptation, resilient, climate change, adaptation strategy (among others) appeared in a specific cluster. The temporal occurrence of the above-mentioned elements indicates that NbaS have been actively advocated for since. This trend shows a degree of agreement with literature on NbaS as the latter started to appear since 2017. According to Vicari et al. (2019), despite this occurrence, hard defense structures were still favored. Therefore, one can conclude that NbS-NbaS in the Parisian region are still relatively recent and more efforts are needed for mainstreaming their use.

<u>Findings from Marchal et al. (2019):</u>

- The role of NbS is particularly becoming relevant under the context of changing climate and increase extreme weather events. In this regard, the concept of Ecosystem-based Disaster Risk Reduction (Eco-DRR) is particularly relevant. From this statement, it is clear the concept of EbA is still popular and is still widely used. Several studies have separated between EbA and NbS. However, this debate is still very polarized and clear lines of separation are not widely accepted. Accordingly, there is still a need to promote the concept of NbS and NbaS by providing more evidence on their efficiencies.

- Climate change is believed to be one of the main catalysts for the increasing interest in NbS and more generally towards proactive management.

- In France, the Caisse Centrale de Réassurance (CCR) estimates that property damage from natural disasters will rise by half if no prevention measures are implemented (CCR, 2018 *in* Marchal et al. 2019).

- The Authors highlight than since 2016 research aimed to link CCA, DRR and NbS (therefore NbaS) through different sectors of the insurance domain. While this interest is not purely scientific, it highlights a high level of awareness. The direct association of CCA and DRR underlines the general consideration of all risks as climate related. While most of them are, a significant fraction of hazards/risks are not climate-induced. In this vein, there is a research need to devise solutions to non-climate-induced hazard.

- The Authors also found that respondents to their survey reported that the vulnerability of NbS to climate change might be a reasons that restricts their successful integration. It is essential to consider NbS-NbaS as non-immune solutions. The previous statement highlights a high level of awareness that extends beyond the use of NbS-NbaS as invincible silver bullets. While certainly beneficial, NbaS cannot be expected to be “the” solutions to all challenges. Coupling NbaS to hard infrastructure might be a solution for climate proofing and extending the benefits of grey solutions. Nonetheless, more studies on this manner are needed for obtaining conclusive findings.

Findings from Lavorel et al. (2019):

- The importance of the mountainous realm is that it provides ecosystem services that extend beyond its limits. Nonetheless, these contexts are sensitive to climate change and its manifestations.

- Mountains are characterized by an innate adaptive capacity. However, it needs to be supplemented by climate adaptation measures to become efficient. From a resilience-vulnerability point of view, there are two trade-offs to consider: 1) adaptation to short term threats might result in actions that increase long-term vulnerabilities, and 2) long-term adaptation measures might disregard short-term needs (Maru et al., 2014 *in* Lavorel et al. 2019). For this purpose, the research question highlighted in Chapter 2 is re-stated here should NbaS be designed to withstand climate or weather change, and will they be sufficiently resistant to weather change to then face climate change?

- NbaS are highlighted potent solutions that link societal dependence on ecosystem with biodiversity. Yet they are underlined as nascent solutions that still require practice-issued findings and a stronger framework (Nesshöver et al., 2017 *in* Lavorel et al. 2019).

- The adaptation pathway (as a mode of NbS governance) is highlighted as an important element for informing NbS-NbaS approaches as it allows learn by doing.

- Adaptation services are also highlighted as complements to NbS that may be of particularly importance to manage as much as possible the climate-change induced transformation of ecosystems (anticipatory approach). Refer to the findings from Filho et al. (2020) for a discussion on the role of adaptation services in NbS-NbaS.

- According to Abson and Termansen (2011) *in* Lavorel et al. (2019), the value of regulating Ecosystem Services (ES) is underappreciated but will increase with the exacerbation of climate change. Nonetheless, this highlights once again the reactive nature of responses and their utilitarian use. In this regard, research should focus more on the valuation of other than provision services and extend knowledge on the whole spectrum of ES. Without regulative services, provision services can be seriously threatened by climate change. Therefore, there is a need to understand the interaction between different services, and to promote equity of research/interest among them to ensure that all types are functional.

Concluding remarks: The year 2019 was particularly relevant for highlighting several NbaS shortcomings. For instance, they were referred to as potent yet climate-sensitive solutions. They were also shown to be underappreciated with respect to provision services, and time sensitive as the disconnection between short and long terms potentially leads to their failure in one or either timesteps. In terms of types, the need to look beyond green solutions as silver bullets was highlighted, while the complexity and specificity of water-related NbS-NbaS was underlined. Accordingly, several research limits were extracted/identified and corresponding perspectives were proposed.

VII.3.4 2020

As can be noticed from Figure XX, a surge of publications started to appear since 2020. Findings are various and extend over a wide range of media and solutions. To this end, the following observations are listed.

Findings from Filho et al. (2020):

- Despite the ongoing pressures faced by urban ecosystems, a variety of existing ecoservices within can be harnessed to address the reigning challenges. Accordingly, the urban realms shouldn't be perceived as nature's enemy by definition, but instead should be considered for their ecoservices as means to balance between the need for housing population and environmental sustainability.

- The combination of NbaS is an important aspect to consider, as for instance combining urban green spaces and urban agriculture areas can multiply co-benefits while promoting the sustainability of the studied context. Yet, there are no direct ways for quantifying the "summation" of aggregated NbaS effects. Often, indicators cannot be simply added up or extrapolated. An interesting line of work to develop would be a study on combined indicators in order to account for the aggregated effects of coupled NbaS.

- The concept of Ecosystem Services (ES) is mostly criticized for its anthropocentric nature and relative vagueness. It is mainly challenged by subjective interpretations and the uncertainty of ecosystems and their functions. When considering climate change adaptation, uncertainties increase and a proper valuation of ecosystem adaptation services becomes harder. In this vein, it is necessary to develop clearer frameworks and extend the use of the ES concept to CCA actions. The absence of adaptation metrics might complicate the task, yet it is necessary to have more accurate adaptation capacity/services measures to ensure a stronger resilience.

- As highlighted by the paper, the valuation of indirect driving forces of ES is a substantial methodological gap. Under this context, accounting for the intangible services provided by NbaS is equally difficult. Accordingly, the exclusion of these benefits during NbaS efficiency assessment can result in biased or false accounting. This in turn threatens the monitoring/evaluation phases of the NbaS life cycle. For this reason, more research efforts for quantifying the intangible ecoservices, drivers and benefits are needed.

- Three recommendations (among others) are given by the Authors of this paper: i) the need to report and document success stories on ES and their benefits particularly in the urban realm, ii) develop more qualitative assessments of ES, and iii) perform comprehensive ES valuations in cities to highlight areas where interventions are needed. In terms of recommendation ii, the qualitative assessment framework should also be complemented by deeper quantitative insights in order to avoid biased or subjective interpretations. In terms of recommendation iii, the use of ES valuation to highlight priority areas is an important platform to explore. However, this approach should be cautiously adopted as the provision (increase) of a certain ES might reduce another. For this purpose recommendation iii should be complemented by a careful analysis of ES trade-off analysis which is still a line of work that should be further developed.

Findings from Riis et al. (2020):

- Riparian vegetation is considered as a hybrid ecotone that forms a transition between land and riverine systems. The ecotone impact (discussed in chapter 2) is well addressed in French issued scientific literature. This can be considered as a strong point that reveals an ample and progressive awareness on research needs for NbaS. Accordingly, one might conclude that the transition from NbS to NbaS in French peer-reviewed publications is ongoing, progressive and evolving.

- In the same manner, the distinction between end and intermediate ES (also discussed in chapter 2), and the question of which ones should be accounted for are addressed. This also reveals a high level of research awareness.

- Riparian vegetation deliver disproportionately a high amount of ES with respect to their extent in the landscape due to their ecotone functions. In this vein, studies on other ecotone NbaS (such as green corridors connecting urban parks for example) is an interesting line of work to develop. Yet, it is questionable if the full range of ES these provide can be covered, particularly given the fact that their *intra* and *extra* trade-offs are not well documented.

- In terms of CCA, the ES provided by riparian vegetation are carbon sequestration, erosion control, flow regulation, evaporative cooling, and the reduction of the frequency, spread and magnitude of fire through reduction of fire damage. Supporting biodiversity is an equally relevant ES. Shading waterbodies is also an important ES as it helps avoiding thermal pollution, reduces instream primary production and ultimately preserves dissolved oxygen rates. As can be noticed, the ecotone nature of riparian vegetation makes them provide benefits for both the freshwater and land compartments. Nonetheless, investigating disservices is also a must to ensure an accurately representative profile of these solutions. The same analogy can be applied to other ecotone NbaS.

- Similar to Filho et al (2020), the Authors of this article stress the importance of an ES-driven decision making approach to highlight intervention areas and to avoid missing out on important ES once solutions are implemented. Yet, as the ES concept is anthropocentric, important ES will be ranked based on subjective interpretations that aren't necessarily uniform/applicable in other than the studied context. Decoupling subjectivity from NbaS decision making is therefore a highly important manner.

- The Authors also highlight several understudied ES such as seed dispersal, genetic resources and fire protection. They also underline the scale quandary and stress the fact that it is a cross-ecosystemic challenge. Cultural benefits are also indicated as quantitatively difficult to assess and hence are potentially capable of skewing management plans and decisions.

Findings from Fouqueray et al. (2020):

- The amplitude of current climate change calls for a shift in forestry principles (i.e. to adapt forests). Accordingly, the forestry paradigm has to be updated to match the progression of climate change. In this statement, one can notice the necessity of ensuring a parallel dynamism between climate change and ecosystems. In this regard, the latter have to dynamically adapt to the former to ensure its continuity. Nonetheless, dynamics systems imply uncertain behaviors which in turn mask and challenge the understanding of adaptation developments. Addressing uncertainties is a very animated research topic, yet ecosystem and ecological uncertainties are still in need of further studies.

- The Authors state that a knowledge gap of adaptation implementation in French forests is persistent. This observation converges with the distribution of French ecosystems in H2020 projects where forests were seen as the some of the least addressed. In this regard, research on forest NbaS should be further promoted.

- Six important observations were made by the Authors:

i. Adaptation in the French forestry sector currently focuses on productive ecoservices at the expense of other essential ones such as water supply or habitat for biodiversity

ii. Adaptation is mainly translated by technical changes in management and does not account for climate change impacts through organization or economic measures

iii. The use of ecological processes for adaptation is limited both spatially and temporally.

iv. Climate change is not the major driving force of the French forestry sector's adaptation.

v. Extreme events can be considered as opportunities for driving adaptive changes.

vi. Proactive adaptation to unexperienced hazards is very weak.

The above-mentioned elements can be considered as adaptation gaps within the French forestry sector. Each of them can be considered as a line of work to develop particularly point vi. As NbaS are considered proactive measures, this gap (vi) underlines the fact that NbS-NbaS are still limited within this ecosystem and that further efforts are still needed.

- Current knowledge indicates that the diversification of silvicultural practices and objectives is being used as a climate proof measure for forest adaptation. However, very few efforts investigate how foresters are currently dealing with the impacts and uncertainties of climate change.

- Adaptation is deemed successful based on personal and subjective interpretation. The question of success thresholds was also raised in Chapter 2. The acknowledgment of this matter in French scientific literature also highlights a high level of research questions awareness. While no clear lines of work can be proposed given the context-specific nature of adaptation, an objective guideline would certainly help in addressing this issue.

- According to the Authors, the most pressing climatic challenges for French forests are severe droughts and windstorms. From this typology, one can notice that slow onset events such droughts (and their post-occurrence manifestations) are serious threats for all ecosystems. Yet NbaS for slow onset events are still relatively understudied and significant efforts are needed to develop them.

- By only focusing on the occurrence of past hazards without integrating plausible future ones, the risks of maladaptation multiply. Accordingly, reactive adaptation overcomes proactive adaptation thus threatening the efficiency of the sought measures.

- The consideration of productive ecosystems only, while disregarding non-productive ones, can have dramatic effects on CCA efforts. For this purpose, perceiving ecosystems as inherently important entities rather than service providers is a must. In addition, integrating non-productive ecosystems into NbaS planning phases is needed to avoid the failure of the sought solutions.

- Ecological processes are only viewed as utilitarian concepts and ecological conservation is not high on foresters' agendas.

- The absence of a shared understanding on how to efficiently counteract the impacts of climate change among foresters was reported. This concern might be due to the relatively long period of time that is often required for forests (vegetation) to become mature/deliver counteraction services. Similarly, questions on medium and long term efficiency were raised with fears from promoting the standardization of forest ecosystems through the neglection of mixtures. In this regard, CCA should be better integrated into the forestry sector whilst adaptation visions should be set (for example 5, 10 and 15 years) in order to track changes and to keep up with the dynamic nature of climate change.

- Most attention is given to above-ground compartments with almost no interest in soil ecology. While adaptation practices are performed on trees, the effects of these measures on soils are rarely taken into consideration. This can lead to serious repercussions as the basis for a successful forest is its substrate. Similar to the international and regional scales' findings, the full consideration of soil as an ecosystem of interest and the design of soil NbS-NbaS are major gaps to bridge. For this purpose, significant research efforts are needed for properly integrating this dimension into the NbaS framework.

- The scale quandary also appears within the forestry sector as approaches are mainly focused on the tree or stand level with a reduced attention to landscape scales. As also highlighted throughout the course of chapters 1 and 2, transitions through scales and upscaling are common knowledge gaps for different ecosystems. Accordingly, considerable research efforts are needed to overcome the vibrant challenge of scalability. As little is known on the mechanisms and conditions for upscaling, a multitude of factors intervene. Within the research domain, efforts for understanding how environmental/physical interactions change with scale are particularly needed. When these bases become established, the changes brought about by introduction of adaptation measures at different scales should also be subsequently addressed.

- In the end of the article, EbA and NbS are labeled as potential solutions for overcoming the limitations of adaptation. However, introducing NbS is not a silver bullet for facilitating adaptation. **Actually, the (re)introduction of nature into a system might interfere with the system's autonomous adaptation capacity (particularly in forests).** For this reason, careful considerations such as ES-derived decisions, vulnerability analysis and suitability assessments are needed prior to the introduction of NbS-NbaS as their success is not guaranteed.

Findings from Castellanos et al. (2020):

- The Authors of this manuscript have performed a thorough review of three EC projects: EKLIPSE, MAES and NATURVATION using text-mining techniques. Through their approach, the Authors reviewed a literature database of nearly 1960 sources that comprise the three reports they utilized. In a way, outcomes of this article also fit chapter 2 of this report as it provided insights on regional European trends. Therefore, any findings listed in chapter 2 are not repeated here for the sake of the report's clarity and coherence.

- In terms of ecosystem services the Authors found that these were often assessed based on different frameworks with different degrees of interest particularly for supporting ES. While most target the urban ecosystem, the concept of ES and their assessment should extend further than the urban realm and englobe other ecosystems to reduce its anthropocentric orientation.

- The Authors of the manuscript highlight two important lines of work to develop further the NbS-NbaS framework

i. The need to define newer and more holistic tools to assess the efficiency of NbS-NbaS through scalar transitions.

ii. The important role of fractal and multi-fractal analysis for targeting multi-scale approaches quantitatively while accounting for the spatial and temporal factors that govern the performance of NbS-NbaS.

Findings from Deely et al. (2020):

- When studying Blue-Green Infrastructure (BGI), considering the presence or absence of barriers is not enough. Instead, a threat level should be assigned to each barrier to determine the probability of facing it. While certainly important, the Authors highlighted that these levels of probability (low, medium and high) should be defined based on expert opinion. At this level, the notion of thresholds comes into play again along with potentially subjective insights that may not reflect actual conditions. Certainly, barriers and levels are context-specific, however the absence of concrete bases or guidelines for defining what is a low, a medium or a high probability of occurrence imposes considerable uncertainties. The consequences of misclassifications should also be considered, as wrongly classifying a barrier as high and advancing accordingly may induce significant drawbacks. While NbaS are learn by doing solutions, increased reporting on misclassifications could be beneficial.

- The Authors of this paper list several barriers encountered by BGI. With respect to the scope of this chapter, only the knowledge and technical/biophysical barriers are addressed:

Knowledge barriers are defined as issues related to the misunderstanding of BGI, their function and how the alternative grey infrastructures may impact biodiversity or multiple ES. Some of the most relevant ones are:

i. Lack of awareness and lack of knowledge on co-benefits. The lack of knowledge on co-benefits can be complicated by the dual nature of BGI (blue and green). The interactions between both counterparts and the benefits they can provide for each other are rarely studied. In this vein, studying the intra-NbaS behavior, interdependence and interactions between solutions made up from different compartments (such as BGI), could be an interesting line of work to develop. Subsequently, the understanding of the multiple benefits both components can provide to their ecosystem can be facilitated.

ii. Inconsideration/uninformation on the non-bankable benefits of BGI. As mentioned in previous sections, the integration of intangible benefits and their valuation is a methodological constraint to overcome. In addition, the behavior of these benefits under changing climatic conditions should also be investigated as they are often perceived from a qualitative point of view on the basis of human derived benefits.

iii. The absence of standards, frameworks and catalogues for BGI increases the favoring of more conventional well-documented solutions. At this stage, the green versus grey debate emerges. While the general consensus is that both colors should be merged, the discussion is still vibrant due to the absence of metrics to evaluate hybrid structures. In turn, BGI success stories are also not well-documented. Therefore, significant efforts are needed to develop broader and more representative indicators.

Technical/biophysical barriers

i. The interactions of BGI with the current ecosystems they are implemented in is unknown. This gap has been addressed in previous sections and in chapter 2. The effects on the (re)introduction of nature (as represented by NbaS) should be further developed as an open-ended research question to reduce the uncertainties of these solutions.

ii. The maintenance of BGI is problematic and imposes considerable uncertainties. Arguably, the blue and green compartments of BGI should be a lever for the maintenance of these solutions. For instance, the blue component can serve as a source of water for the green counterpart during dry periods, while the green components protects the blue counterpart through shading. Nonetheless, through their existence BGI as part of NbaS also consume natural resources. Therefore, in addition to the need of understanding how these solutions ought to be maintained, their environmental footprint should also be determined. Very few studies have performed such an approach as it remains an important perspective to consider.

Findings from Zingraff-Hamed et al. (2020) and Arfaoui and Gnonlonfin (2020):

The Authors of the first article provide a detailed stakeholder mapping method based on the review of 16 NbS projects involving 359 stakeholders. The second article investigates how the Values, Beliefs and Norms (VBN) link to the preference of NbS in order to mitigate flood risks in the Brague catchment area of France. However, since the scope of this chapter focuses more on environmental/biophysical research needs, the findings of both articles were not included.

Findings from Fady et al. (2020):

- With the lag of mitigation targets, genetic diversity will have an important role for the adaptation of forests to climate change through natural selection and artificial breeding.

- Genetic diversity is labelled one of the few NbaS that can keep up with the fast pace of climate change. However, the role of genes with considerable effect on adaptive traits is still not well-explored. This is due to the limited understanding of the complex genotype-phenotype nexus across different ecosystems.

- Evidence on rapid adaptation for most forest species is still limited while the fast pace of climate change raises serious questions on the potential of forest to locally adapt.

The role of genetic diversity as a NbaS is still understudied and these solutions are relatively unexplored. This could be due to the multitude of disciplines involved (genetics, botany, plant physiology/histology, etc.). However, trans-disciplinary efforts on this topic might generate a substantial amount of knowledge for tapping the potential of genetics and revolutionize their use as NbaS.

Findings from Lavorel et al. (2020):

- In this article the concept of Adaptation Services (AS) is addressed. The importance of understanding the trade-offs and co-benefits of adaptation services is highlighted as an important objective. As can be noticed from above, AS were also addressed in the 2017 literature. In this regard, one can notice that both AS and ES are accounted for. The inclusion of AS indicates that French literature aims to expand the NbS-NbaS framework beyond the ES to unlock its CCA potential. Accordingly, this can be considered as another strong point of French NbaS publications.

- The existence of trade-offs and co-benefits in the core of adaptation is acknowledged. The difficulty of achieving multiple goals simultaneously (taping all co-benefits) is also highlighted. In this regard, it is important to keep in mind that despite their multi-beneficial nature, not all their services can be obtained. Accordingly, an interesting line of work would be to assess during the design phase which services can be attained and check if those were attained post-implementation. That way, a more realistic/accurate representation of NbaS would be obtained.

- The Authors state the need to resolve current trade-offs, consider new ones under adaptation actions and ensure the synergies between co-benefits. These elements can be considered as very important lines of work to develop and as insightful research perspectives.

- As ecosystems transform in response to climate change, they might produce new ES (AS). Classically, climate change is often approached as a threat, pressuring factor and as a negative cause/consequence. Yet, few research efforts concentrate on how one might extract opportunities from climate change or take advantage of it. Certainly, this perspective does not take away any element from the seriousness of the problem nor does it undermine it. Nonetheless, it may allow a more unconventional approach to climate change by exploring the other side of the double edged sword.

- Different AS are delivered progressively or additively. For instance, ecological resilience, latent and sustained ES appear at the first stages of adaptation, while transformative and new services appear as the environmental challenges (here climate change) intensify. This also means that AS, much like ES, have intermediate and/or end products. In this sense, the same research question arises: when AS (ES) are delivered progressively, should end products be accounted for only? or is there a need to integrate the intermediate services for obtaining a complete NbaS service profile. Moreover, the means for quantifying additive (summated) benefits are still not developed, hence an important line of work to develop.

- An important insight is mentioned by the Authors: climate change alters the relationship between ecosystem drivers and services. In this regard, understanding how climate change influence ecosystem drivers is an important line of work to develop. It can serve as a first step to understand pre-NbaS conditions and compare outcomes once these solutions have been implemented. It is equally important to consider that the driver of ecosystem change is dynamic and can potentially continue to influence the system while the solutions exist. Therefore, deeper research on ecological mechanisms and their interactions is needed.

- As mentioned previously, during their transformation phase, ecosystems can produce novel or transformative ES. These in turn will interact with previous one. However, there are still no direct methods to understand how the new and previous ES interact with and influence each other. In analogy, when a NbaS is introduced into the system, the new services brought about by these solutions will have to interact with previous and transformative ES. Nonetheless, exploring this interaction is still an untapped domain and can be considered as a novelty to develop.

- Synergies of services are not only influenced by climate change. In this regard, the management of services also determines the type of interaction between services. According to the Authors, the most optimal way to ensure synergies is through management for resilience as the mechanisms underlying resilience (here ecological), ensure the delivery of multi-benefits.

- The concept of connectivity is also addressed and is highlighted as crucial for fostering the transformation of ecosystems. However, the question of transformation in the case of connectivity is not very clear as the latter creates "ecotones" that can be considered as novel ecosystems. The Authors then highlight that the current evidence on the management for transformation is limited. Accordingly, this can be considered as an important line of work to develop.

- The creation of novel ES, while certainly attractive may also be harmful. In this sense, there are no guarantees that new ES are strictly beneficial as their generation might reduce the provision of other key services or even generate side effects (disservices). In the case of NbaS (even if co-produced and co-managed), careful planning should be carried out to avoid maladaptation or disservices as a result of negative feedback loops between generated and existing ES. Accordingly, more research efforts for understanding NbaS-ecosystem feedback loops should be undertaken. While transformative ES can be considered as a reactive response and NbaS as a proactive one, the reactive-proactive nexus could be an interesting platform to study for deriving knowledge on combined adaptation reactions.

Findings from Magnan and Duvat (2020):

In this article the island ecosystem was studied. The introduction of this ecosystem is particularly relevant for France as it englobes thirteen overseas territories of which most are islands. However, the study focused on the Maldives given the diverse profiles (natural to intensively managed/exploited) this atoll represents. The Authors found that different profiles require different adaptation pathways and approaches, while in human dominated contexts the window of adaptation is closing fast. While this study is certainly insightful, more efforts on French overseas territories should be carried out.

- In islands, future risk levels will depend on the extent and effectiveness of societal and ecosystemic responses to extreme events and slow-onset changes. This fact calls for solutions that can address both temporal scales (fast and slow-onset events). However, NbaS for slow onset events such as drought and ocean changes are still very limited, as is their current knowledge. In this vein, there is a need for more research efforts on these solutions for both terrestrial and water ecosystems.

- Coastal adaptation measures are mainly focused on coastal erosion and flooding and correspond to four major categories:

i. Protection through shoreline stabilization by built infrastructure or soft engineering.

ii. Ground elevation through the creation of new lands.

iii. Accommodation: doing with nature and maintaining natural functions via technical interventions to livelihood means diversification

iv. Retreat through the relocation of assets, individuals, activities and infrastructure at risk further into lands

However, literature indicates that trade-offs between the different measures exist and that they should be combined for effective reduction of climate change impacts. In terms of NbaS, these can only fit within measures i (soft engineering) and iii (accommodation). Nonetheless, the combined effect of NbaS with the remaining measures is not well explored and remains an open research question.

- In response to the existence of trade-offs, the adaptation pathway approach as a decision cycle based strategy that explores a set if possible actions based on alternative external and uncertain developments is relevant. The logic behind it is that the study of various paths and cycles provides a means to reduce uncertainties by allowing the shift from one path to another when threshold or tipping points are breached. The adaptation pathway echoes to adaptive governance highlighted through different H2020 projects for obtaining a successful NbaS. The Authors of this article relate to this fact by highlighting the importance of restoring/maintaining coastal ecosystems such as mangroves, seagrass beds and coral reefs (blue NbaS). This in turn provides means for strengthening the resilience of ecosystems and enhances their adaptation pathways. Nonetheless, these solutions (namely coral reefs and seagrass beds) are sensitive to climate change induced modifications to water and might collapse under the weight of ongoing changes. Therefore, there is a need to determine the tolerance thresholds of these solutions for integrating them into the adaptive pathway.

- Minimizing maladaptation in the coastal realm according to the Authors is done by limiting the main causes of exposures of future human assets to ocean changes. This implies the need to limit the anthropogenic drivers of vulnerability regardless of the end-century warming scenario. In this regard, maladaptation appears to be a product of anthropogenic factors rather than a climate-related risk. However, it is well known that beyond the forecasted 2˚C increase, the damage done to ecosystems will be irreversible. Therefore, when ecosystems in NbaS are harnessed for adaptation, increased attention of the way these are managed is essential to avoid maladaptation yet keeping in mind that warming scenarios have the potential to multiply maladaptation risks even if NbaS are efficiently managed.

Findings from Duvat et al. (2020):

Similar to the article above, this paper also addresses the island ecosystem. In this case the Mauritius Island is the study area while the environmental challenge is coastal risk reduction.

- The failure of hard protection measures shifted the attention towards more ecosystem-based actions while favoring retreat actions. The shift to NbaS or ecosystem-based actions should happen progressively and convincingly instead of happening as a response to the failure of other solutions. Despite the positive outcome (shift to natural solutions), it is rather questionable if place-specific or site restricted NbaS are capable of having an effect on large events. In this vein, NbaS (and their associated concepts) should be carefully publicized without overselling their potential as evidence on their efficiency is still inconclusive.

- According to the Authors, knowledge on the physical implementation of ecosystem-based measures is still limited particularly in island contexts as most is generated from pilot-scale approaches or technical reports but rarely from systematic analysis. In this regard, there is an ample need to develop further adaptation studies in island contexts, particularly with regards to NbaS (ref. Chapter 2).

- The Authors stress the importance of assessing the potential effectiveness of current responses to future risks. While certainly important, the multitude of factors capable of influencing the response of NbaS might be a challenging factor. However, most analysis refer to risks that have already occurred without taking into consideration new ones. This can constrain the range of analysis to past events which are feared to happen again without integrating potential new ones. In turn, this limits the analysis of NbaS efficiency and constrains it to the "near-future" without further insights.

Findings from Díaz-Sanz et al. (2020):

- The article starts by listing a very important research gap: urban soils are rarely considered in spatial planning documents. The aim of this paper is to determine the soil parameters that influence infiltration for harnessing the power of soils for runoff mitigation (under Marseille's Mediterranean climate extreme precipitations).

- According to Prévost and Robert (2016) in this article, local urban planning practice is very uneven in Southern France. Díaz-Sanz et al. (2020) further add that urban soils within French spatial planning documents (PLU, SCOT, SLGRI and PPRI) are not considered as a means for minimizing runoff. The exclusion of urban soils (hydrology) from urban planning schemes can be considered as a significant issue to address. This might be due to the fact that most urban soils are covered by impermeable layers, or to the misconception that all urban soils have the same properties (Díaz-Sanz et al. 2020). However, disregarding soils can significantly influence the outcomes of any spatial planning effort since all land-based activities and processes necessarily involve them.

- Urban soils are characterized by the removal of topsoil layers, backfilling with fine and coarse material, earthworks and ploughing, thus leading to the obtention of Anthrosols and Technosols. The latter contains coarse material produced by humans while the former comes for intensive agricultural land-use and filling with fine material. Compaction and the reduction of infiltration areas in both soils limit their infiltration capacities. However, this does not necessarily mean that these soils cannot reduce runoff.

- The Authors found that vegetated Anthrosols and Technosols can infiltrate enough stormwater to limit runoff based measures of their field-saturated hydraulic conductivity (K_{fs}). Moreover, the history of the soil's land use was found to be a determinant factor for K_{fs} as soils lying on former clay quarries or tile factories and those with land-use younger than 13 years had lower K_{fs} than other soils. Combined to soil depth, K_{fs} measures indicated that despite their urban nature, a significant fraction of urban soils had low levels of runoff protection.

- However K_{fs} was found to be influenced by seasonality as it changed when soils were humid, and by the composition of the material that made up Technosols. In this regard, further analysis on the infiltration capacity of urban soils using other parameters (e.g. infiltration rate mm/hour) could be beneficial to obtain deeper insights.

- Three main lessons can be extracted from this study:

i. Urban soils should be acknowledged and studied with respect to their unique physical-physiochemical characteristics.

ii. The history of the soils' land use should be incorporated into soil performance analysis

iii. Not only should soils be better integrated into spatial planning, but their use as potent NbaS should also be investigated.

Findings from Winterwerp et al. (2020):

- While the general orientation for coastal protection is shifting towards increased used of NbS-NbaS such as mangroves, bamboo fences and brushwood, most of these measures are based on best-engineering practice without a robust scientific background/knowledge.

- The construction of permeable dams for mangrove restoration focuses on the re-establishment of fine sediment dynamics for providing a substrate for mangrove growth. Despite the relative theoretical simplicity the Authors of this article underline several important factors to consider:

i. A successful functioning of permeable dams requires a complete understanding of the implicated physical-biological processes involved, namely the physics of hydro-sedimentological processes, the geology, morphology, ecology and hydrodynamics of the studied system.

ii. Mangrove restoration within takes considerable time to occur and regular maintenance is required

iii. A very high degree of stakeholder implication is required.

In the context of this article, permeable dams are being used as a NbaS which throughout their existence allow the development of another NbaS (mangrove). Very few approaches have studied such relationships and relevant examples of one NbaS becoming the precursor of another are very scarce in literature. In this vein, this line of research might be an interesting platform to develop as other "NbaS couples" might be identified and subsequently exploited.

- The Authors underline a very important research gap in the coastal and marine solutions domain that often underlies the failure of sought solutions: the inconsideration of sediment balance disruption. This is a very important line of work to investigate as sediment balance is known to influence the continental shelf, landforms, landscape, and the coastline's dynamics. Often even the smallest intervention disrupts considerably sediment balance thus tipping the scale towards erosion or accretion. Therefore, any planned NbaS should take into consideration these facts and adapt accordingly.

- Permeable dams reduce wave activity ad erosion while promoting the sedimentation of particles. They are relatively simple and low-tech solutions and are labelled within the article as nature-based adaptive approaches.

- The dams can be placed offshore thus assisting in land reclamation where lands have been lost through sedimentation. Once water levels exceed the level where tidal inundation becomes lower than the threshold of mangrove tolerance, the latter can grow. After their maturation there will be no further need for maintenance of the permeable dams, and other can be built for expanding the mangroves.

- While their implementation might be easy, their design/monitoring phases may be challenged by the availability of data on wave height, direction, coastal geometry, bathymetry, sources and properties of sediments. According to the Authors of the article, sediment related characteristics are scarce for mangrove –mud coasts systems as these are relatively understudied realms.

- It is necessary to keep in mind that rehabilitation obeys the rule of nature and is not a fast process. Considerable time lags should be expected. That is why a long-term vision considering risks of failure should be considered.

Concluding remarks: As can be noticed, the increase of publications on NbaS is translated by the relatively high number of extracted research insights. A wide range of ecosystems were covered in this period notably with the introduction of island ecosystems. In terms of solutions, the importance of urban soils was highlighted while the relationship between NbaS couples (precursor-successor) can be considered as the innovation/novelty research perspective. In conceptual terms, AS and ES and their *intra/extra* interaction remains a vibrant research question. Several research perspectives have been proposed next to each relevant point with some offering new insights that weren't revealed during the international and regional approaches. This goes to show that "downscaling" in the case of NbaS offers more detailed insights and underlines several strong points in French scientific literature.

VII.3.5 2021

As 2021 contains the highest number of records from query 3, findings from this year are numerous and extend over a range of ecosystems. What characterizes this year is the clear development of the concept and its extension beyond conventional limits. In this regard, various novel insights were obtained:

Findings from Bouzouidja et al. (2021):

- Often as NbaS consist of different components, a range of reported metrics come into play for assessing their performances, and a relationship between various indices is needed. However, this task is not simple as various elements prevent a direct evaluation. For instance, in a typical urban NbaS such as allotment gardens, the soil, climate and water compartments are implicated with considerable interactions and several feedback loops. Nonetheless, tools or indicators for measuring the cascading interactions and loops between different compartments are still limited. Equally, the simultaneous influence of NbaS on the various implicated compartments are seldom accounted for. In this regard, there is a need to develop metrics that can cover simultaneously the implicated components and/or account for the interactions between them.

- According to the Authors, the conceptual basis of the NbS concept is still a matter of debate. While the concept was introduced in 2009, almost 12 years after it still very open. As the concept of NbaS is much more recent (2015 at the international scale, 2017 at the French), very significant efforts are needed to promote both the term and the concept of NbaS.

- The scale quandary is also addressed, and the neighborhood scale is referred to as the smallest unit that integrates the complexity of the urban setting while allowing the observation of the interactions within. Nonetheless, the Authors point out again that most NbS are studied (particularly hydrologically) at smaller scales. The scale mismatch between an intervention and its expected outcomes should be better addressed and accounted for. In this vein, studying scale mismatches would be an important line of work to develop.

- According to the Authors, NbS improve soils by improving their functions or by altering flow of material (water, sediment, nutrient, etc.) based on connectivity (Parsons et al., 2015 *in* Bouzouidja et al. (2021). However, soil connectivity is rarely accounted for in NbS-NbaS studies and can be considered as an important line of work to develop.

- As NbS-NbaS deliver multiple co-benefits and can simultaneously respond to several challenges, the assessment of their multiplicity is itself a challenging task. While this gap has been addressed earlier by stating that indicators can be simply added, the call for combined indicators is again stressed as a research perspective.

- Another challenge to take into consideration is how to account for the dynamism of indicators, particularly those related to soil and climate. This can also be considered as an important line of work to develop.

- Assessing the performance of NbS for CCA (herein NbaS) is challenging as their benefits are connected to several processes. For instance, if one is to consider their cooling effects, the latter happens through shading and/or evapotranspiration. Accordingly, both are difficulty accounted for in the same modelling framework. While this fact calls for significant advances in modeling, the underlying basis behind the modus operandi of NbS-NbaS for CCA should be better understood.

Findings from Cziesielski et al. (2021):

- Within the marine/coastal realm, the term blue natural capital refers to three types of NbaS: mangroves, seagrass and coral reefs. These solutions are capable of providing CCA services while promoting the resilience of marine ecosystems. Yet, in terms of efficiency for carbon sequestration, much like the case of green solutions, their substrates (i.e. underlying sediments and soils) are mostly implicated. In analogy to the recommendation for further research on soil NbaS, the role of sediments as solutions in the marine realm should be equally exploited. This recommendation comes from the fact that sediments are known as the building blocks of aquatic habitats. Moreover, their dynamics are often implicated in flooding processes and erosion/deposition regimes. Therefore, further research on the potential use of sediments as NbS-NbaS could be beneficial for various objectives in addition to CCA/CCM.

- The Authors propose an important line of work that consists of understanding the contribution of genetics in coral environments (coral genetics) among other marine ecosystems. While this line of work has been proposed for terrestrial ecosystems (namely forests), transposing its application into the marine realm is an important line of work to develop.

- Coral reef restoration (under the title of ecosystem restoration NbS) is also addressed. Nonetheless, the restoration of these ecosystems might be harder than terrestrial realms since coral reefs are sensitive to changes in the water's quality and temperature. Therefore, serious considerations should be made prior to restoration measures if no controls on the water's quality/properties are ensured. Moreover, there is a need to assess the effect of coral reef reinstallation to ensure that the surrounding ecosystems will not be affected by their new presence. The underlying logic behind this statement is that the autonomous adaptation capacity of the surrounding system to the absence of coral reefs might be disrupted by the reintroduction of the latter. Therefore, a careful assessment should be performed prior to coral reef (or any other marine ecosystem) restoration process.

- The Authors propose an interesting idea that consists of using blue solutions in coastal cities for CCA in urban settings. This recommendation is particularly important as it underlines the awareness on looking beyond green solutions. In this vein, investigating further the benefits of blue solutions for coastal cities is an important line of work to develop.

- The concept of ecosystem connectivity is underlined by the Authors. According to them, marine ecosystems are both interconnected and transboundary. In analogy to the recommendation of assessing the importance/performance of connected terrestrial NbaS and tapping their ecotone effect, a similar proposal for increasing research efforts on the connectivity of blue solutions is given.

Findings from Roe et al. (2021):

While the main scope of this study is climate change mitigation rather than adaptation, an important insight underlined by the Authors cannot be overlooked.

It is particularly relevant since it cuts-across all the retained articles from the NbaS query (hence French scientific literature on NbaS):

a. **Climate change mitigation and adaptation are studied/targeted as distinct processes following a more or less silo approach. In contrast to the regional scale (ref. Chapter 2) where both climate actions are amply targeted simultaneously, French NbaS research efforts seem to be missing out on this opportunity. In this vein, there is a need for research from two perspectives (i.e. looking with both eyes) for properly achieving climate resilience. Accordingly, the synergies between mitigation and adaptation should be better explored (despite its difficulties and namely scale challenges).**

b. **As mentioned in Chapter 2, for mitigation, solutions are sought at macro scales while adaptation solutions target the meso and micro levels (CAR et al., 2017; GMV et al., 2018). Simultaneously addressing both might be helpful for covering the whole scale spectrum. Nonetheless, this statement should be backed up by more studies and can be considered as an incentive for further research.**

Findings from Bruley et al. (2021):

- Up until 2021, the concept of EbA is still relatively present and in active use. However, the Authors of this article highlight that its implementation remains a challenge as it requires the integration and the understanding of nature's contribution to adaptation. In this vein, the Authors highlight that EbA is being currently harnessed for its CCM power rather than CCA as evidence on its integration into adaptation strategies is still lacking (Reid et al., 2019 *in* Bruley et al. 2021). While certainly odd as the concept integrates adaptation into its name, this gap underlines not only a research need but also a governance/management barrier that should be addressed. Several examples of successful EbA actions in literature exist, yet the non-quantifiable nature of adaptation might be a reason for the lack of evidence. As highlighted many times before, research on adaptation metrics should be further promoted.

- While adaptation strategies might be implemented at large scales, adaptation measures are implemented at the local. As mentioned previously, scale mismatches not only complicate research efforts, but also widen the dividend between the research and practice communities. In this regard, addressing the transition of adaptation under its various forms (strategies and measures) through different scales is an important line of work to develop.

- As landscape multifunctionality is a critical aspect for ensuring efficient adaptation, the protection of natural areas and the adequate use of agricultural land is crucial (Huber et al., 2020 *in* Bruley et al. 2021). This statement amply calls for the use of natural and agricultural NbaS and underlines the fact that these solutions are still underappreciated. In the same vein, actions for producing water and energy are also a window of opportunity. Accordingly, positioning NbS and NbaS within the Water-Energy-Food nexus can be considered as a very important line of research that can also help tapping the NbaS-Energy link.

Findings from Palomo et al. (2021):

- Despite the widespread success of NbS in science and policy, their potential to ensure transformative change is relatively untapped. According to Palomo et al. (2021), NbS area as much people based as nature based. In analogy to this statement, NbS-NbaS should further be science-based for properly assessing their potential for providing transformational shifts.

- In a review of 93 NbS cases from 54 countries, most reported NbS came from the Andes and Himalayas. This could be due to the fact that a large number of population depends on mountains in these contexts as a result of their rural settings. When transposing the situation to France and its mountain ranges, the dependency of populations on mountainous socioecological systems is not as major. Accordingly, the importance of an ecosystem is often centered on its relationship with humans, hence the dominant focus on urban settings in France. Nonetheless, insufficient attention to the mountainous environment might cause downstream impacts for lower lying regions. Accordingly, this aspect should be further addressed in French scientific literature.

- According to the Authors: *"Evaluating transformative change becomes increasingly complex when we move from approaches that assess single variables, such as greenhouse gas emissions to inter- and transdisciplinary approaches that assess several dimensions"*. While the Authors here refer to NbS, challenges become further compounded when NbaS are addressed as the latter incorporate the adaptation dimension and its complexities (ref. chapter 1). Therefore, there is a need for frameworks that assess both the processes and outcomes of NbaS.

Findings from Bouzouidja et al. (2021b):

In this study, a comparison between conventional and green parking lots from a thermal behavior point of view during dry and warm periods was performed. Several findings are of important relevance:

- From an UHI perspective, the hygrothermal properties of the utilized material should be taken into consideration even in hybrid NbS-NbaS as their evaporative cooling properties depend on them.

- In pervious pavements, water availability may dramatically change during warm and dry periods as evaporation is significantly reduced, hence minimizing their cooling benefits. In the same vein, without precipitations previous pavements become sources of heat rather than sinks through overheating. In this regard, there is a need to assess the seasonal variation (temporal variation) of NbaS and their services. Failing to account for these variations can significantly bias accurate representation of performances/efficiencies and lead to inaccurate solutions' profiles. Moreover, the future evolution of climate should be taken into consideration during the design of the solutions to assess whether the latter will be viable or not. For instance, in regions with forecasted reduction in precipitations, water-dependent solutions should be avoided.

- According to the Authors, the urban climate of Lille hasn't been sufficiently investigate, hence the paucity of data on UHI there. While this limitation is France-specific (other than knowledge from literature), efforts for bridging this gap are needed.

- The novelty of this study was the investigation of both surface and sub-surface heat transfer in permeable pavements. Using 4 types of pavements made up of different material [asphalt (P1), concrete paving stone (P3), grass-covered slab filled with a mix of soil and sand (P4), slab filled with wood chips (P5)], and compared with a silt profile covered with grass, the Authors reported the following.

* The addition of wood chips could be a valuable solution in urban settings as they also contribute to soil loss mitigation (Buchanan et al., 2002 *in* Bouzouidja et al. 2021b).

i. Comparing P4 and P5, both pavements had a similar pattern in the first day of observation. Then, with time P5 became cooler at noon due to the retention of morning dew by the wood chips making its behavior somewhat similar to the control soil profile. This fact underlines the potential of wood chips for evaporative cooling and highlights their importance as potent components of NbS-NbaS in cities. The use of wood chips might be more beneficial than vegetation cover as the latter require considerable watering during dry days. In this sense, it is crucial to consider the resource efficiency of the sought solutions and find alternatives (here wood chips). This aspect is particularly important with increasing climate change and reduction of water availability. The underlying logic is that solutions should be designed to be resource efficient while minimizing their consumption of natural resources. For this reason, research on more water (or natural resource) independent solutions should be a priority.

ii. Pavements made up of concrete and asphalt not only warmed at the boundary layers (3 cm) but also transmitted heat downwards to soil layers at 55 cm of depth. While heat decreased with increasing temperature, sub-surface heating was certainly observed. According to the Authors, this thermal performance can affect both atmospheric and underground UHI. At this level, the importance of this study is its extension beyond the consideration of atmospheric UHI only. According to Oke et al. (2017), UHI are divided into 4 types: surface, sub-surface, canopy and boundary layer. Often, surface UHIs are most accounted for leaving behind the remaining three. In this vein, it could be useful to determine the efficiency of NbaS across the different UHIs since atmospheric ones do not provide sufficient inputs for climate change research (Gutierrez et al., 2020), hence an incentive for further research.

iii. Subsurface heat transfer of solutions must be better understood and modelled. This recommendation can be considered as an important line of work to develop for accurately establishing the thermal profiles of NbS-NbaS (particularly urban ones).

Findings from Qureshi and Rachid (2021):

- According to Amorim et al., (2009) *in* Qureshi and Rachid (2021), most studies focus on UHI in densely populated mega cities or capitals more or less disregarding smaller ones. This statement is confirmed by the article above (i.e. Bouzouidja et al. (2021b), where Lille was stated to be lacking UHI records. In this sense, there is a further need of research on UHIs in cities of different sizes.

- In this article, several models were reviewed for testing their efficiency as UHI decision support tools/systems, these are: Analytical Hierarchy Process (SWOT); Multi-criteria outranking approach (MCDA and IBVA); Enhanced Fuzzy Delphi Method (EFDM); Fuzzy decision-making trial and evaluation laboratory (FDEMATEL); Multi-criteria method by linear regression; The technique for order of preference by similarity to ideal solution (TOPSIS); Spatial Multi-Criteria Evaluation (SMCE); Fuzzy Analytic Hierarchy Process; Fuzzy TOPSIS. Although the Authors provide the necessary arguments as well as the pros and cons for the use of each, the site-specific nature of NbS-NbaS and of the studied contexts dictate the tool of choice. Most importantly, input data as the starting point governs the accuracy of the model's outcomes. Therefore, prior to any application or following implementation (monitoring), sufficient information should be made available for integration into decision support systems/tools.

Findings from Stavropulos-Laffaille et al. (2021):

- While NbS are designed for UHI mitigation, the release of subsequent latent heath requires the presence of water in urban soils to dissipate it. That is why there is a need for models capable of representing both budgets for accurately assessing NbS-NbaS.

- Even if several NbS and NbaS are being efficiently used for cooling, the principals of their cooling potential are still misunderstood (Hesslerová et al., 2021 *in* Stavropulos-Laffaille et al. 2021) , hence the need for establishing a better understanding of NbS' (NbaS) effects on both hydrologic and energetic cycle (Mitchell et al., 2008 *in* Stavropulos-

Laffaille et al. 2021). Both aspects cited by Stavropulos-Laffaille et al. (2021) can be considered as important lines of research to develop.

- While the cooling effect derived from NbS-NbaS comes from their evapotranspiration capacities, urban hydrological models and urban climate models do not quantify the process in the same way. This discrepancy potentially skews findings and subsequent decisions, thus forming a scientific problem to overcome (several references *in* Stavropulos-Laffaille et al. 2021). In this sense, accounting for models' discrepancies, differences and biases is a must.

- Similarly, disregarding the availability soil water increases the risks of overestimating the cooling effects of green solutions during dry periods. As Bouzouidja et al. (2021b) also highlighted, considering urban soils hydrology is key for better understanding the cooling/regulation effects of urban NbS-NbaS, hence an important line of research work to develop.

- The Authors highlight the importance of models that couple both water and energy budgets are needed for better understanding the behavior of NbS-NbaS in urban settings. In this regards, models such as the Multi-Hydro model developed by the HM&Co laboratory (https://hmco.enpc.fr/portfolio-archive/multi-hydro/) might be a potent solution. As multi-hydro covers the different parts of the hydrological behaviors, its NbS-NbaS input interface can be used to study the benefits of these infrastructures.

- Classically, latent and sensible heat fluxes are not commonly integrated into the evaluation of hydrological models. In this sense, there is a need for constraining and accounting better for all heat related aspects in order to prevent inadequate thermal profiles of sought solutions.

Findings from Caputo et al. (2021):

- For promoting the resource efficiency of urban agriculture, the use of urban wastes as rainwater (and its runoff), grey water and food waste is one of the best means (Weidner and Yang 2020 *in* Caputo et al. 2021). Without it, urban agriculture would be as environmentally impactful as conventional agriculture (Goldstein et al., 2016 *in* Caputo et al. 2021). This type of "urban recycling" promotes the resource efficiency of NbS-NbaS and should extend to other solutions in other ecosystems as well. This line of work helps understand how NbS-NbaS can derive means for their continuity from their surrounding ecosystem without consuming natural resources, while simultaneously providing it with benefits. For instance, the Authors estimated that per kg of harvested products, 3 kWh of electricity and 122 L of water were used. Hadn't been water utilized from the neighboring urban context, such high consumption rates can seriously make the resource efficiency of urban agriculture questionable.

- The Authors of this article tapped one of the most important lines of research for NbS-NbaS: their position within the water-food-energy nexus with three large research and pertinent questions:

i. Is the concept of the nexus, initially developed for **large scale food systems**, appropriate for urban agricultural practices that significantly differ from industrial food production in scale, quantities produced and purpose?

ii. What can be learned from existing nexus concepts and how can this be **tailored** effectively to urban agricultural practices?

iii. How can **existing and novel indicators and methods capture associations** between resource use, production and social benefits?

From these three questions, the notions of scale, specificity, and the need for indicators whether new, existing or combined are particularly relevant. Each as mentioned in previous sections of this chapter is a line of research to develop.

- In the same logic of scale, within nexus approaches multi-scalar interactions are operationalized in a rather limited manner despite the acknowledgment of scalar connectivity.

- Urban agriculture are not only potent solutions for CCA but also can satisfy cities' vegetable demands by up to 100% depending on the cities' climate, morphology and adopted practices. Yet from a climate change perspective, agricultural activities are well-known sources of GHGs. In this vein, it could be useful to assess their emissions as these may compound urban heating potentially aggravating the UHI effect. In this regard, the Authors of the article highlight the importance of developing urban agriculture indicators and using them as pathways for research efforts.

- The Authors state that while urban agriculture is an important NbS-NbaS, there is a need to evaluate the ecosystem services they provide. This can be considered as research perspective to develop.

Findings from Nunn et al. (2021):

- Seawalls as (grey infrastructure) are considered as maladaptive solutions that are embraced by islanders who judge them efficient based on their use in richer continental or urban contexts. At this stage, the ample effect of public perception on the adoption of solutions appears. While this aspect does not relate to research gaps, it highlights the important need to establish sufficient science-based evidence on island solutions (of all types) to avoid false analogies with other contexts (particularly continental ones).

- Solutions for DRR are often built in the hopes of having rapid effects, the long time-lag required by NbaS to become “DRR functional” might be one of the main reasons for the slow momentum behind them. Whether in islands or other contexts, NbS-NbaS cannot be considered as sufficient to withstand disasters but should be incorporated into a larger matrix of adaptation measures and strategies.

Findings from Bouzouidja et al., (2021a):

- In NbS-NbaS terms, the properties of urban soils are considered as a solution to climate regulation and storm water management in cities. Nonetheless, they are rarely accounted for in the ecosystem services framework. For this reason, the Authors highlight that there is a need to develop soil related indicators that are as generic as possible.

- In terms of urban sols indicators, Anne et al. (2018) *in* Bouzouidja et al. (2021a) proposed the following:

i. Using a limited number of indicators derived from measurements or computations.

ii. Using descriptive and integrative indicators that express the functions of soils.

iii. Taking into consideration the vertical and horizontal heterogeneities of urban soils.

iv. Ranking indicators

While such indicators can apply to the physical and chemical characteristics of soils, in the case of biological properties indicators are harder to reveal and obtain as these depend on the interactions between soil microorganisms, soil-vegetation interface and the soil-atmosphere boundary. In this domain, there is a need to understand better these processes for obtaining more representative indicators. Concerning the ranking of indicators, this approach should be cautiously adopted as biases due subjectivity and judgment calls might affect rankings. For this purpose, clear guidelines for ranking indicators while taking into consideration the specificity of each context are needed.

- While the Authors of the article utilized soil fertility and contamination as a means to study urban soils under different NbS-NbaS, it is not quite clear whether these parameters are sufficient to determine the performance of these solutions (here green roofs, gardening areas and urban allotment gardens). In this vein, soil quality can be combined with other parameters such as soil hydrology for obtaining more comprehensive insights. As these solutions combine green components that utilize soils as their substrates, soil-vegetation interactions could be beneficial to study. The variability of soil responses to climate change could also be an interesting platform to consider.

- When integrated, urban soils are just studied within the topsoil horizon ranges without any additional attention given to deeper layers. It is therefore important to consider soil as a full functional unit by incorporating all of its profiles. This knowledge limitation highlighted by the Authors can be considered as a research perspective to develop.

Findings from Laporte-Fauret et al. (2021) :

- Coastal dune remobilization is considered as an optimal mean to maintain coastal dunes in sectors characterized by erosion through landward mitigation and dune ecology restoration. Yet, the efficiency of this measure has been tested in the wet Nordic conditions but never transposed to the drier Southern Europe.

- A 4-km stretch of coastal dune in southwest France was tested where Experimental Notches (EN) were excavated in the incipient foredune - the West Experimental Notch (WEN), and in the established foredune, - the East Experimental Notch (EEN). The WEN aims to simulate erosion of the inception dune during storms, while the EEN aims to mimic blowout conditions under wind erosion.

- While dunes are built to protect the environments located to their back, most stabilized dunes and as a result of a uniform morphology suffer from the exposure to swash, wind, sediment transport and salt spray thus affecting their diversity of habitats and ecology. This in turn can lead to a reduction in vegetation dynamics and hence a reduction of the dunes' ecosystem services.

- Ecological competition is necessary for shielding the diversity of habitats. In the absence of competition disturbance decreases species diversity. That is why the aim of notches is to increase back-dune diversity through increased disturbance. Accordingly, they allow both a morphological and ecological assessment of dunes. Then again, more information on ecological competition is necessary to determine at what thresholds it is considered as acceptable, since beyond a certain level the competition can lead to dominance, extinction or altered dynamics.

- According to the Authors, the notches affected sediment transport through either vertical accretion or landward sand deposition. The latter caused an increase of species through the development of ruderal species. Accordingly, notches as promoters of disturbance increased the ecological diversity of dunes making them more resistant. While vegetation promotes the stability of dunes and increases their ecosystem services, dunes can be considered as the growing substrate for this vegetation. In the same logic, studying the symbiotic relationship between various solutions as well as the mechanisms to promote them could be an interesting platform to consider.

Findings from Babí Almenar et al. (2021):

- In urban settings, urban challenges for sustainability and urban challenges for resilience overlap and share several limitations. The complexity of NbaS is that they are expected to target both aspects. Yet, it might be too ambitious to consider the capability of NbaS as standalone features to address the whole range of challenges due to the multiplicity of implicated factors. This statement is support by Albertí et al. (2017) *in* Babí Almenar et al. (2021) which report that in urban settings, natural, built, social and ecological components are densely connected in a blurred manner. Accordingly, there is a need to understand how and if NbaS are capable of covering the whole spectrum along with their interconnections.

- In this regard, the Authors of the article highlight two needs that can be considered as line of work to develop:

i. Understanding the causal relationship between different NbS, ecosystem services and urban challenges.

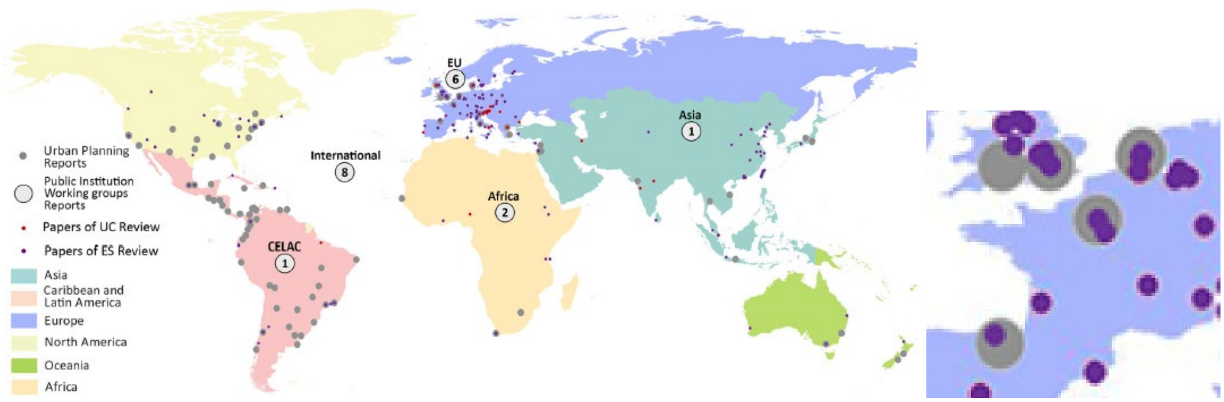
ii. Understanding how and which attributes of NbS affect the supply of specific ecosystem services.

- According to the Authors, challenges that are rooted in biophysical limits can be solved by natural capital (herein NbS-NbaS). However, as mentioned previously the interactions that are brought about by the (re)introduction of nature into a system should be better understood to derive conclusive evidence.

- According to the Authors, in the case of NbS-NbaS that are biophysical structures (i.e. created ecosystems – here referring to Type 3 NbS), their contribution occurs if their abiotic and biotic attributes are involved in the socio-ecological processes. In the case of NbS as actions applied on ecosystems (e.g. management –and restoration actions here referring to Type 2 NbS), the contribution occurs if they positively actions influence the attributes of the ecosystems involved in the socio-ecological processes. From these facts, one first concludes that the role of Type 1 NbS in urban settings is completely overlooked. Second, the value of NbS-NbaS is not judged based on its contribution to biophysical/natural processes, but through what are their socioecological benefits. Even for Type 2, they are judged based on how the components they modify benefit the social-ecological system. This fact underlines again the anthropocentric nature of the NbS-NbaS making them a practical concept that still lacks a holistic understanding of the science behind it.

- The Authors highlight an important knowledge limitation that can be considered as a research perspective to develop: Urban challenges still lack an exhaustive classification, hence the need to develop this aspect.

- In the figure below [extracted from Babí Almenar et al. (2021)] that represents the geographical distribution of their analyzed case studies, one notices that French publications focus more on ecosystem service reviews rather than on reviews for urban challenges (as for most of the EU). This might be due to the fact that urban challenges are well-documented. Nonetheless, with the progression of climate change, urban challenges will also acquire a dynamic nature (namely resilience challenges), hence the need for progressive and continuous studies on this topic.



- The main cause for the prevalence of Type 3 NbS in cities is that nature should be brought back again to be then managed (type 2) or preserved (type 1). While NbS-NbaS call for changing current urban models, it is not clear whether these solutions are capable of responding to all types of urban challenges. For instance, they are not enough to respond to all societal challenges. That is why the Authors consider that biophysical challenges are more easily resolvable using NbS-NbaS since the integration of natural capital is relevant. Nonetheless, as mentioned previously the biophysical processes involved/derived by NbS-NbaS should be better studied, quantified and listed in order to achieve accurate responses.

- The Authors report that studies on green roofs and their ecosystem services have considerably increased. They also found that green roofs, woodland-like, urban grasslands and meadows, horticultural gardens, natural(ised) wetlands and natural(ised) ponds have links to a higher number of ecoservices classes than other urban NbS-NbaS. All of the above-mentioned solutions have strong links with regulation services, namely for climate and water management. Within these services, evapotranspiration is one of the most relevant processes. Yet, significant efforts are needed to better understand evapotranspiration particularly at fine scales and with changing climatic conditions. This aspect is currently a scope of focus under various studies, namely Castellanos et al. (2020) and (forthcoming) and Qiu et al. (2021) where the use of multifractal analysis coupled to on-site measurements seems to be a very promising platform.

- As also mentioned in Chapter 2, the Authors of this article highlight that the provision of a certain ecoservices might influence the supply of others, hence the need to study NbS-NbaS services in bundles. This might also help in understanding trade-offs better. **Nevertheless, ecosystem services interactions and feedback loops are still an open research question that was not observed in none of the retained NbaS articles, hence the need for developing further this line of work.**

Findings from Zanzi et al. (2021):

- Urban agriculture projects particularly in peri-urban areas can be considered as an important means for urban land restoration through the creation of new niches and ecosystems. This in turn aids in the regeneration of urban settings and promotes their sustainability.

- While the implemented agroforestry scenario was assessed for air quality changes, carbon sequestration, oxygen production, and avoided runoff, the Authors state that they had the possibility to include extreme simulation events yet they did not. **This aspect is also missing in all of the retained articles as the behavior of NbS-NbaS, along with their ecosystem services provision under climate change is very rarely addressed. In that sense, integrating climate change in numerical terms, rather than simply referring to it as a "qualitative problem" is a considerable research gap to bridge.**

- While most of the studied services were derived from the trees, shrubs and vegetation present, the role of soil in agroecology, agroforestry was not accounted for. As soils form the major substrate in such solutions, assessing soil ecosystem services is of particular relevance.

Findings from Zingraff-Hamed et al. (2021):

- This article deals with an important aspect: the river/urban interface (urban riverscape). The latter's design still lacks clear and explicit recommendations, hence the importance of this study particularly in French contexts where several rivers cross various cities.

- In addition to compounding floods and modifying river hydrographs, urban settings close to rivers have considerably influenced the rivers' ecological status. The major focus on attenuating floods more or less shifted the attention from other river challenges, and namely river-human interactions.

- The ecology of rivers is rather complex as it encompasses a wide range of organisms, their interactions, abiotic components, water and sediments. In this vein, even if physical modifications to the river occur (such as flow or morphology restoration) these do not necessarily have positive effects on the river's ecology/chemistry. One of the best means to ensure a healthy physical, chemical and biological status of rivers is through natural flooding. Nonetheless for urban rivers, flooding often has deleterious effects on the urban realm and even if flooding is to be accommodated for, the challenges reside in addressing the balance between ecological dynamics, urban hydrology and waterscape scenery (Nillesen and Kok, 2015 *in* Zingraff-Hamed et al. 2021). For that purpose, the inclusion of hydrology, hydrodynamics and climate change to understand the hydrological stochasticity of rivers has been growing. In that sense, flood measures have shifted from vertical to horizontal solutions (submersible neighborhoods, wetlands, flood retention/detention measures, etc.). Yet, large scale approaches are still limited.

- For ensuring a high level of ecosystem functionality capable of providing ecosystem services to humans and processes to support biota, the river and its floodplain must be: i) managed to provide natural water/sediment dynamics, ii) have a sufficient spatial extent and iii) an enhanced connectivity between the main stem and the floodplain. The first and third points are particularly challenging in urban settings as they are characterized by a water cycle that considerably differs from the natural one, and by considerable disconnections due to the development of infrastructures and buildings. For that purpose, the connectivity/water-sediment regimes of urban riverscapes should be better understood and managed to understand what the current pattern are and what changes will result from the implementation of NbS-NbaS. As highlighted in Chapter 2, in urban settings calibrating flood or hydrological models can be difficult as the closely packed covers (urban, green cover and others) create obstacles that divert and guide flows thus creating a micro-hydrological system (Douglas et al., 2019). Therefore, considerable efforts are needed in this domain particularly in cities where the river and urban covers intersect.

Findings from Mayor et al. (2021) and Mayor et al. (2021b):

- While the scope of these articles are business models for NbS-NbaS, several non-scientific/biophysical research gap were highlighted. Nonetheless, the causal factors of these gaps are rooted in biophysical/ fundamental knowledge domains, hence their extraction. The listed knowledge gaps are listed as the followings needs:

i. Advancing knowledge of business models for NbS-NbaS since the concept is still an innovation namely on the long-term (impacts and efficiencies).

ii. Making the value of NbS-NbaS explicit and measurable (in monetary and non-monetary terms) as the full value of these solutions is still underappreciated.

iii. Developing and ensuring the uptake of tools that are able to account for the plurality of NbS-NbaS performances.

iv. Understanding how the value of NbS-NbaS can be transposed into a model that provides DRR and CCA services.

v. Most of current NbS-NbaS business models were designed for urban settings. Thus, the lessons learnt, methods used and limits identified are not necessarily applicable to other ecosystems, hence the need to extend business models beyond the urban realm, particularly those of large scales (watersheds, aquifers, etc).

vi. As NbaS primarily target DRR and CCA, their effect on the reduction of hazards, vulnerabilities, risks, and damages needs to be better defined and assessed.

Findings from Mansourian et al. (2021):

- This article is a contribution for the upcoming UN Decade on Ecosystem Restoration, it targets forest restoration and explains its advances. Yet, as ecosystem restoration is a type of NbS-NbaS, several findings are relatable.

- The term landscape entered into forest restoration (hence Forest Landscape Restoration - FLR) to shift the scale from local (forest) to larger extents (landscape) as the latter accounts better for reconciling the human-ecological interactions.

- Nonetheless, the multidimensionality of FLR (as for other NbS-NbaS) complicates their implementation due to the multitude of involved disciplines. The difference of disciplines creates language barriers that often cause knowledge on NbS-NbaS to be trapped in disciplinary silos. That is why, considerable transdisciplinary efforts are needed to tap the full range of knowledge on this concept. This aspect was seldom observed in French scientific literature where publications were often monodisciplinary, often lacking the combination of different fields.

- The Authors raise a point of vigilance concerning the need to avoid random afforestation under the guise of FLR particularly in fragile ecosystems. This statement amply underlines the need to look beyond green solutions in certain cases and widen the scope of application for other solutions.

Concluding remarks: In the same manner as 2020, the increase of publications on NbaS is translated by the relatively high number of extracted research insights. Likewise, a wide range of ecosystems were covered in this period notably with a focus on urban soils. In terms of solutions, the importance of urban soils was again highlighted and the importance of understanding better soil hydrology was stressed. Several research perspectives have been proposed next to each relevant point with some offering new insights that weren't revealed during the international and regional approaches. In an effort to synthesize all the presented elements, the following section groups the different proposed perspectives.

VIII. Grouped research needs per ecosystem

In terms of knowledge per ecosystem, the following distribution was found: Urban (17), marine/coastal (7), all/various (4), humid environments (4), forests (4) and mountains (3). The agricultural and natural ecosystems are relatively absent. Recalling the distribution of French ecosystems under H2020 projects, the natural, forested, agricultural, marine and coastal ecosystems were found to be insufficiently covered in H2020 NbaS projects. Excluding the marine/coastal realm, the same distribution was found at the national scale. The relative absence of the agricultural and natural media amply calls for more research in these realms. Although addressed, the mountainous and forested ecosystems fall short behind the urban environment that dominates French NbaS literature. In this regard, there is a need to develop more knowledge on NbaS from non-urban media. For a concentrated presentation of knowledge per ecosystem, Figures 15 and 16 compile non-exhaustively the major research needs highlighted in the section above.

In terms of research perspectives that are generic and applicable in all ecosystems, the following lines of work are proposed:

- Reporting further on uncertainties, whether those related to the solutions or to climate change, and quantifying them.

- Covering the whole spectrum of climatic regimes in France to understand the behavior of the different NbaS under various climatic settings.

- Integrating climate/weather extremes as well as future climate change scenarios for accurately designing the proposed NbaS and, for anticipating the effects of climatic evolutions. In the same vein, it could be beneficial to investigate the seasonal effect (variation) of the NbaS' efficiency (particularly green solutions).

- Investigating better the tipping points of the concerned ecosystems as well as setting the thresholds for failure/success of the sought solutions.

- Extending the use of the Ecosystem Services (ES) framework further than the provision domains and increase studies on regulating ones. Likewise, the ES concept should extend beyond the urban environment as most of the generated knowledge is urban related and cannot be considered as applicable in other ecosystems.

- Increasing investigations and reporting on disservices as very few studies have targeted this aspect.

- More biophysical assessments of NbaS efficiency should be envisaged as the presented evidences as scarce. In the same vein, the development of indicators capable of accounting for the interconnectivity and interactions between the different components of the ecosystem (including the NbaS) is needed.

- While floods are the most preoccupying hazard in France, other natural hazards should also be investigated with the same momentum as the progression of climate change might significantly exacerbate them (e.g. drought). Therefore, designing NbaS only on the basis of past or present hazards might be a missed opportunity for efficiently planning these solutions.

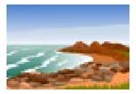
- The synergy between NbaS and mitigation actions should also be tapped

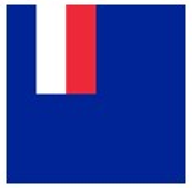
- The resource efficiency (namely in terms of water consumption) of the designed NbaS should be studied further particularly with the intensification of climate change and its effects.

- Perhaps one of the most important perspectives/strong points highlighted in French literature is the use of one solution as a precursor to another (permeable dams-mangroves). Very few approaches have studied such relationships and relevant examples of one NbaS becoming the precursor of another are relatively inexistent. This line of research is a very advanced platform to develop as other "NbaS couples" might be identified and subsequently exploited.

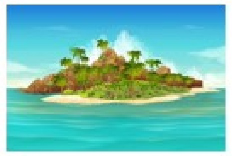
- As the concept of adaptation services encompasses the creation of novel services, the apparition of latent ones, and/or the modification of existing services, investigating the relationships between the AS and NbaS concepts is an interesting platform to consider.

Research perspectives per ecosystem





While the island ecosystem has been addressed by French studies, significant efforts are still needed to study NbaS in French overseas territories. This comes from the fact that these islands/departments/collectivities are more sensitive/vulnerable to climate change (and hence in equal or greater need for adaptation) than Metropolitan France.



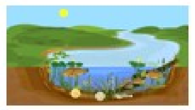
Islanders who judge grey infrastructure as efficient based on their use in richer continental or urban contexts. To avoid this misconception, there is a need to establish sufficient science-based evidence on island solutions (of all types) to avoid false analogies with other contexts (particularly continental ones).

Media/NbaS to put forward

- Promote the study/use of blue solutions in coastal cities for CCA in urban settings.
- Information on ecological competition for dune restoration is necessary to determine at what thresholds it is considered as acceptable. This is because beyond a certain level, competition can lead to dominance, extinction or altered dynamics.
- While vegetation promotes the stability of dunes and increases their ecosystem services, dunes can be considered as the growing substrate for this vegetation. In the same logic, studying the symbiotic relationship between various solutions as well as the mechanisms to promote them could be an interesting platform to consider.
- As marine ecosystems are both interconnected and transboundary, and in analogy to the recommendation of assessing the importance/performance of connected terrestrial NbaS and tapping their ecotone effect, a similar proposal for increasing research efforts on the connectivity of blue solutions is given.
- Understanding the contribution of genetics in coral environments (coral genetics) as well other marine ecosystems to harness the use of genetics for adaptation.
- The role of sediments as solutions in the marine realm should be exploited since these are the building blocks of aquatic habitats. Moreover, their dynamics govern flooding processes and erosion/deposition regimes. Therefore, further research on the potential use of sediments as NbS-NbaS could be beneficial for various objectives in addition to CCA/CCM
- Blue solutions (namely coral reefs and seagrass beds) are sensitive to climate change induced modifications to water and might collapse under the weight of ongoing changes. Therefore, there is a need to determine the tolerance thresholds of these solutions for integrating them into the adaptive pathway.

- Insufficient attention to the mountainous environment might cause downstream impacts for lower lying regions. Accordingly, this aspect should be further addressed mainly through the understanding of how adaptation under its various forms (strategies and measures) transitions through different scales.

- The (re)introduction of nature into a system might interfere with the system's autonomous adaptation capacity (particularly in forests). For this reason, careful considerations such as ecoservices-derived decisions, vulnerability analysis and suitability assessments are needed prior to the introduction of NbS-NbaS as their success is not guaranteed.
- NbaS for slow onset events (such as droughts that threaten forests) are still relatively understudied and significant efforts are needed to develop them.
- The role of genetic diversity as a NbaS is still understudied and these solutions are relatively unexplored. This could be due to the multitude of disciplines involved (genetics, botany, plant physiology/histology, etc.). However, trans-disciplinary efforts on this topic might generate a substantial amount of knowledge for tapping the potential of genetics and revolutionize their use as NbaS.



- A need for more conclusive evidence on the efficiency/performance of hybrid solutions (that are mostly used in this ecosystem).
- Assessing the NbaS' location should be a pre-requisite prior to its implementation. Regardless of its intended purpose, the position of the sought solution in a watershed might have an effect on the basin's hydrologic behavior. For instance, if a UHI reduction NbaS is placed in a hydrologically-false position it might compound hazards, thus creating a new problem while resolving another.
- A focus on more hydrology/morphology-based NbaS (if possible) might be more advantageous than using vegetation. Nonetheless, careful considerations are needed when modifications to the river's channel, bed and banks are performed as these might have serious hydrosedimentary repercussions. For this purpose, detailed information on the river's morphology, bathymetry, flow, sediment transport and ecology are needed.

- The effect of NbaS introduction on the autonomous adaptation capacity of ecosystems (particularly in forests) should be investigated. If an ecosystem is capable of autonomously adapting to changes, then risking with the (re)introduction of nature and bearing uncertainties

Figure 15: Research perspectives per ecosystems (a)

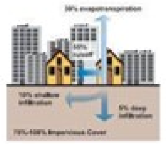
Research perspectives per ecosystem

General research perspectives

- Understanding better how NbS-NbaS can derive means for their continuity from their surrounding ecosystem without consuming natural resources, while simultaneously providing it with benefits.
- Studying intra-NbaS behavior, interdependences and interactions between solutions made up from different compartments (such as BGI).
- Coupling NbaS to hard infrastructure might be a solution for climate proofing and extending the benefits of grey solutions. Nonetheless, more studies on this manner are needed for obtaining conclusive findings.
- Promote the use of Type 1 NbS in urban settings after the reintroduction of nature
- Research on scale mismatches between an intervention and its expected outcomes.
- Development of tools or indicators for measuring the cascading interactions and loops between different compartments of an urban NbaS (climate, water, soil, vegetation, etc.)

NbaS research perspectives

- Promoting the use of urban soils as potent NbS-NbaS.
- Understanding better the interactions between soil microorganisms, soil-vegetation interface and the soil-atmosphere boundary.
- Considering the hydrology of urban soils is key for better understanding the cooling/regulation effects of urban NbS-NbaS
- The variability of soil responses to climate change could also be an interesting platform to consider.



Urban hydrology research perspectives

- Increasing research on urban hydrology (urban water cycle) for understanding better the hydrological behavior of cities (due to their micro-hydrological properties), and the changes induced by the introduction of NbS-NbaS.
- While urban flooding is a major challenge, cities often take part of larger watersheds. There is a need to accurately determine the hydrologic position of a sought solution with respect to the hydrologic behavior of the watershed in order to avoid multiplying risks rather than decreasing them.
- Another solution for floods would be to target urban rivers immediately with river-based NbaS (river-bed widening, giving room to the river, flood plain restoration, artificial meandering, day lighting some its contributing streams, etc.). However, significant research efforts are needed to understand and account for the various implicated factors (morphology, runoff and sediment connectivity with the neighboring cities, etc.)

- Determining the efficiency of NbaS across the different UHIs types since atmospheric ones do not provide sufficient inputs for climate change research.
- Understanding better urban evapotranspiration regimes particularly at fine scales and with changing climatic conditions. In this sense, utilizing multi-fractal studies under this domain is an important platform to exploit.
- Constraining and accounting better for all heat related aspects (latent + sensible) of a sought solution in order to prevent inadequate thermal profiles.

Figure 16: Research perspectives per ecosystems (b)

IX. Conclusion

IX.1 NbaS in the national landscape

As mentioned in the previous chapters, the works of the French Committee of the IUCN can be considered as the first national/international effort behind the NbaS concept. In terms of implementation, the review of the H2020 projects as well as French scientific literature showed that NbaS are being increasingly sought. In France, these solutions are being used to address a wide range of challenges namely those related to the urban realm. While their use depends on the governing environmental challenges, they are mostly responding to challenges revolving around disaster risk reduction (namely flooding), urban climate and maintenance/preservation of ecosystem services. Nonetheless, this narrow focus, while a sign of multiplying efforts is also a limiting factor. Many other natural hazards are prone to increase with changing climates, while several ecosystems (other than urban areas) are becoming increasingly fragile. In this sense, there is a need to extend the use of NbaS beyond the current scope of foci. In terms of geographic distribution, there is a need to promote efforts in the Northern, Central and Central-Eastern parts of the country. Most strikingly, NbaS studies are mostly focused in Metropolitan France, leaving the more vulnerable overseas territories in significant need. With the advances of the ARTISAN project, the situation might change, yet significant theoretical/implementation efforts are needed in overseas France. The particularity of these settings is that they encompass more or less the same ecosystems as the hexagon but with significantly higher vulnerabilities, exposure and sensitivities. They also house more endemic, more "natural" media and higher biodiversity rates that require urgent attention. Given the difference between the context of the hexagon and the overseas territories, the knowledge generated in the former cannot be applied to the latter. Therefore, a stronger focus is needed to ensure that the whole French territory benefits from these solutions.

IX.2 Environments and solutions to put forward

Current trends revealed that some environments are relatively underrepresented. This is particularly the case of the agricultural and natural media that are rarely targeted as complete systems. The same is more or less applicable for the oceanic medium that is even less addressed along with relevant NbaS. While few studies target islands as ecosystems, as mentioned previously this attention remains limited and should be further developed. The relatively limited interest in food production systems and water security (even if addressed through the Water-Energy-Food nexus) in terms of NbaS is also a factor to consider. The most adopted NbaS were found to extend beyond green solutions (unlike the previous scales) yet also with a clear dominance of urban related solutions. Nonetheless, French scientific literature stands out with various solutions that were not found in the regional and international scale approaches. For instance, genetic diversity is promoted as a potent tool in both terrestrial (forests) and marine (coral) ecosystems. Using a NbaS as a precursor for another (permeable dams to mangroves) is also a very important aspect that stands out in French literature. The interest in soils (particularly urban ones) is more developed than the other scales, and reflects a high level of awareness translated by the extension beyond the use of green solutions as silver bullets. Investigating the hydrological position of sought solutions is also an important factor even if it is not intended to solve a hydrology-related problem. In this regard, widening the scope of NbaS designs and site assessments is particularly relevant. Contrarily to the international scale, the use of protected areas (Type 1 NbS) is relatively absent. While this current state can be considered as a missed opportunity, the use of these solutions should be promoted where possible.

In terms of indicators and means of quantification, reporting on efficiencies is more or less limited. There is also an ample call to develop indicators capable of accounting for the "aggregated effect" of different solutions. While this calls for significant research efforts, current reporting on efficiencies and NbaS performance should be further developed.

It is important to mention that while several studies do not have French study areas, the presence of French Authors/labs in these papers highlights the level of national awareness and participation.

IX.3 Enhancing the science behind NbS and NbaS

To start with, the ecosystem services concept should be extended beyond the provision angles (i.e. beyond socioeconomic benefits). This extension is particularly relevant for NbaS that are more pertinent to regulation services. In the same vein, studying better the adaptation services-NbaS nexus is a must to understand better the array of services these solutions can offer (ES+AS).

The scale quandary is well-acknowledged and addressed throughout the retained articles. A particular focus is also given to cross-scalar (through different scales) transitions. Nonetheless, to unlock this challenge, understanding better the biophysical processes and their changes/propagation behind each scale is required. A good starting point would be to study differences in hydrological processes at different scales (neighborhood, district, city, sub-basin and watershed) to determine similarities, differences, interactions, and interdependencies. Once the scalar transition of the environmental challenge becomes understood, the investigation of NbaS effects on each can be better studied, hence unlocking the multi-scalar potential of the concept (if it exists).

In terms of temporal dimensions, only a few studies integrate the climate change aspect in quantitative terms and as both a function of time and an environmental challenge. Often, climate change is addressed as a problem but without clearly targeting its “numerical behavior”. The way things are currently presented relates more to weather change or climate variability rather than actual climate change. In the same vein, addressing uncertainties and quantifying them is also a missing element. A large fraction of the retained studies relates more to the economic and socio-ecological dimensions of NbS-NbaS with a reduced attention to the science behind them. While this gap is highlighted in many references, the general orientation of the NbaS concept still lacks hard science insights.

Several research needs were raised in section VII. Most of them relate to the need of extending beyond the current offer to encompass a study of synergies, antagonism, expected targets and delivered outcomes. Keeping in mind that climate change is transversal to all media, and that ecosystems do not exist in isolation from others studying the connectivity/mosaic of ecosystems is a major elements to consider.

Annex A and B

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General synthesis of the multi-scalar approach

In this deliverable, a throughout state-of-the-art of the current status of NbaS and research needs was presented. For the purpose of this study, a three leveled multi-scalar approach was adopted. First, the international trends were studied using institutional reports issued from several UN bodies, namely the UNFCCC, UNEP and the IUCN. Second, regional advances were studied from the works (reports and peer reviewed literature) of 21 H2020 projects. Finally, the national scale was investigated using three different queries with one particularly focused on NbaS. The rationale behind the multi-scalar approach was that through the analysis of different scales, micro to macro insights are obtained. The national analysis provides insights on the past, current and future orientations of NbaS in France. The national to regional approach reveals France's position with respect to European efforts, while the regional to international approach reveals the position of Europe with respect to the global trends. The analysis of each scale drew up independent findings that were presented in each corresponding chapter. In this synthesis, a combined analysis is presented for concluding the multi-scalar approach.

I. On the approach to climate change and CCA

International scale: The official interest in adaptation goes back to 2010 and can be considered as relatively recent (11 years). The approach to climate change and CCA is rather conceptual/theoretical and revolves around the definition of risks, vulnerabilities, sensitivities, exposures and the link to resilience. The IUCN, UNEP and UNFCCC agree on the difficulty of scoping adaptation, setting relevant targets, measuring it and accounting for its uncertainties. They also stress the need for site or context-specific adaptation actions and recommend a tailored approach. Globally the works of these three institutions highlighted the progressive, dynamic, iterative and complex nature of CCA and stressed the need to define relevant indicators. In this sense, the international scale allowed to properly understand the "A" behind NbaS, and early on revealed the complexity of NbaS as a summation of NbS and adaptation challenges.

Regional scale: In this scale, climate change is addressed numerically using several means: the use of historical and present weather station data, the use of global/regional datasets and downscaling, climate change predictions/projections (IPCC scenarios or European databases), climate modeling, and to lesser extents remote sensing techniques. A discussion on the use of each was given in the corresponding section, and was namely focused on the limitations of using IPCCC scenarios for regional or small-scale interventions. Climate analysis under the different projects involved the understanding of past, current and future climate change scenarios/predictions. The latter were also incorporated to the planning and design phases of NbaS to account for their effects. In terms of the approach to climate change, the regional scale was better than the preceding and following levels. Concerning adaptation metrics, several references also highlighted the difficulty of measuring adaptation and highlighted that each action on climate has to be associated to asset of awaited impacts and a specific array of indicators related to climate resilience.

National scale: Climate change is addressed in a rather diffuse way and is often referred to as a challenge without numerically revealing its amplitude. In this sense, only very few studies incorporate climate change scenarios, projections or climatic data. This disintegration forms a significant line of work to develop for accurately understanding how ecosystems and the planned NbS-NbaS will respond to climate change. In terms of adaptation metrics and indicator tracking, very limited reporting was noticed.

On the basis of what was presented, developing and defining better adaptation indicators/metrics across the three scales is a significant line of research work to develop.

II. On the shift from NbS to NbaS

While the analysis of all three-scales revealed a steady transition towards NbaS, it is early to determine whether this shift will become a trend. In current form, the transition is still progressive, dynamic and ongoing. It is not clear whether NbaS will become a separate concept from NbS and its associated notions (namely EbA), or if the latter will always be used as an umbrella that covers several challenges including climate change.

At the international scale, the beginnings of NbaS can be affiliated to the work of the IUCN (2015-2016) and particularly its French Committee. Onwards, the Paris Agreement, the UN Climate Action Summit 2019 and its NbS manifesto gave proof of NbS' increasing recognition. Equally, the UN Decade on Ecosystem Restoration 2021-2030 paved the way forward for the upcoming years and placed NbS as central strategies for CCA, hence NbaS.

At the regional scale, the H2020 program's interest in NbaS dates back to 2015. Despite ongoing efforts, some projects are still reluctant while others consider that the concept still lacks operational and scientific clarity. The same can be said more or less for NbS. Within Europe, the transition from NbS to NbaS is still not fully achieved despite the apex position of CCA on European priority agendas. In geographic terms, both NbS and NbaS are still limited in the Eastern part of the continent, hence the need for homogenizing efforts before mainstreaming the concept.

At the national scale, and in addition to the contribution of the IUCN's French committee, scientific interest in NbaS appeared in 2017. However, NbS and its associated concepts are still better favored as was revealed from the comparison between query 2 and 3, namely in the case of academic and funding actors. In this sense, there is still a need to drive more momentum behind the scientific development of the NbaS concept. At this stage, ARTISAN comes as both an important lever and a platform for promoting the mainstreaming of NbaS across the French territory. One of ARTISAN's strong points is that it will extend the implementation of NbaS into French overseas territories. This aspect is particularly important, as the cartography of the NbaS offer showed a severe lack in these regions.

A more or less similar starting date of interest in NbaS appears for all three scales. At best, this interest in strict terms dates back no longer than 6-7 years. Accordingly, it's still relatively natural to have several gaps to bridge as the concept is still nascent. Moreover, as NbaS have to deal with climate science, their advances will also be limited by the progress of the latter. In this sense, a complete shift to NbaS will require considerable time and efforts

III. Risks of oversimplification

The relative absence of hard science behind the concept is a significant matter to overcome. Often both NbS-NbaS are being utilized as anthropocentric and utilitarian tools in the quest for rapid and potentially sustainable socioeconomic benefits. However, this rush leaves behind the scientific dimension of the concept as often nature and its processes are oversimplified or simply disregarded. Despite their potential, NbS-NbaS cannot be considered as a silver bullet but should be coupled to larger strategies and measures. Overselling the idea that NbS-NbaS are the panacea for current and future environmental challenges is absurd. The simplification of the NbS-NbaS concept might be a beneficial factor for ensuring its widespread diffusion amongst different target audiences. However, oversimplifying the concept makes it tip towards its practical nature and misses out on chances for its development through scientific knowledge. Under current form, NbS-NbaS are presented as green (or blue) injections into existing ecosystems without sufficient consideration of natural dynamics, processes and the complexity of interconnected/interdependent nature-based feedbacks. For this purpose, the NbS-NbaS framework is in need of a transversal approach that cuts-across "harder" disciplines. While all three scales identify knowledge limits, highlight needs and propose perspectives, a high level of awareness on the dangers of oversimplifying the concept was noted. For the international scale oversimplification lies in the domain of adaptation (A), while for the regional scale oversimplification lies in nature (N) and what is based on nature (BS)

Keeping in mind that the NbS concept, let alone NbaS (2015) are recent, and given that nature has always been a matter of scientific/research debate, the relatively small share of hard scientific disciplines can be understood. Yet, to fully unlock the potential of NbS-NbaS a greater biophysical understanding is needed.

At the international scale: Oversimplification is mainly addressed for adaptation plans. According to the UNFCCC, one should not simplify the complexity of adaptation plans/measures (herein NbaS) by assuming that any adaptation plan will cover current social and natural conditions (i.e. constraining it to the present). This is mainly due to the fact that the vulnerability to climate change and the efficiency of adaptation measures may change with time. To this end, wrongly planning for adaptation condemns the efficiency of any NbaS early from the beginning. As adaption is an iterative process, continuous modifications are needed. While NbS-NbaS are more flexible than conventional solutions it is still unclear if these should be designed to withstand weather or climate change.

At the regional scale: In this approach, the oversimplification and overselling of NbS-NbaS are addressed particularly in O'Sullivan et al. (2020). For the authors, it seems that actual nature (ecological resources, processes, and feedback loops) is undervalued, with most of the discourse focusing on nature's positive socioeconomic outcomes and what benefits it brings to humans. In terms of NbaS, not only is nature undervalued, but the potential of these solutions for reducing climate vulnerability and promoting sustainability is also oversold (O'Sullivan et al., 2020). According to Sekulova and Anguelovski (2017) *in* O'Sullivan et al. (2020), nature is romanticized and overestimated to the point where the concepts of NbS-NbaS risk becoming unscientific (O'Sullivan et al., 2020). The same could be said for the use of NbaS for DRR as little is understood on their effect on risk levels and hazard mitigation.

At the national scale: French literature does not directly address this aspect, but places more or less a certain emphasis on the potential of these solutions and rarely reports on disservices and limits of failures, hence a certain form of masking.

Oversimplification was addressed best by the regional scale. The corresponding detailed discussion can be found in Chapter 2.

IV. Ecosystems of interest

Throughout the different scales, the interest in ecosystems was seen to be quite different (Table 1). While this may be justified by context-specific reasons or priorities, the unequal interest in ecosystems should be rectified for properly unlocking the potential of NbaS.

Table 1: Interest in ecosystems per levels in the multi-scalar approach

Level/Medium	Urban	Agricultural	Marine and coastal	Mountainous	Natural	Forest	Fresh water
International	✓+	✓	✓	+/-	+/-	✓	✓
Regional	✓+	-	✓	+/--	-	+/-	✓
National	✓+	-	✓	+	-	✓	✓

As can be noticed, several similarities and differences between the three levels are apparent. Clearly, the urban realm is the most addressed biome with a very considerable number of devoted reports, projects and studies. A more or less similar pattern can be observed for the freshwater ecosystems however to a lesser extent. While the marine and coastal ecosystem is also fairly addressed, at the regional scale it is mostly studied for coastal cities rather than being treated as a distinct ecosystem. The agricultural realm's absence in the regional and national levels is quite striking as it reveals a much reduced interest in climate proofing agriculture. While this reason could be attributed to the high level of food security in Europe and France, agricultural NbaS should be incorporated and studied further to avoid future risks. At the international scale the high interest in the agricultural system can be explained by the global concern of food security. At the same level, the interest in natural ecosystems and protected areas is far greater than in the European and French systems. In this regard, the natural environment should be further promoted, and its potential as a NbaS should also be better exploited as Type 1 NbS are only approached in the international scale. The mountainous environment is well addressed at the national scale, and in the only project dedicated to mountains under H2020, France is present. Nonetheless, the relative underrepresentation of the mountainous ecosystem in H2020 projects (only PHUSICOS) reveals the need for further related studies. The same applies for the international scale (as determined by a review of NDCs). In the same vein, the forested ecosystem should extend further than a "silver bullet" solution and become addressed as a distinct ecosystem.

Soils have been gaining prominence in the three levels as their use as NbaS is growing. In this regard, they are being increasingly studied and their potential to influence planned and existing NbS-NbaS is being better explored. However, they are rarely addressed as ecosystems of interest and limited attention is given to their hydrology, climate change behavior and biological processes (pedosphere-atmosphere-biosphere interactions). For the regional and national scale, the island ecosystem is of particular relevance as several European countries (including France) are/have overseas territories. Yet this ecosystem is very rarely addressed despite its high vulnerability, exposure, sensitivity and low adaptive capacity.

The relative dominance of the urban ecosystem makes the current knowledge on ecoservices, NbS-NbaS, limitations, potential and perspectives inapplicable in other biomes. To this end, constraining and confining the NbS-NbaS concept is a significant red flag to raise. Then again, the urban ecosystem is the most in need for nature realm, hence its fertility for NbS-NbaS. However, this shouldn't be taken as an excuse to justify the current narrow focus that should be extended in all of the studied levels.

V. Geographical gradients

Throughout the different scales, an analysis of the geographical distribution of studies, pilot sites, NbaS planning/implementation and actors was performed. In this section, a review of the different distributions and their significance is presented.

At the international scale: In a review of NDCs, Seddon et al. (2019) found that African countries were the most to emphasize on CCA, and that 62% of NDCs include current or planned NbS-NbaS with around 66% of the Paris Agreement signatories including NbS for actions on climate. This global panorama reveals a growing interest in NbaS spanning across different geographical contexts.

At the regional scale: The most targeted climatic regions were found to be the temperate continental climate, followed by the oceanic and northern temperate regimes and the Mediterranean climate (Nikolaidis et al., 2019). When the intervention sites of several H2020 projects (except large scale-demonstrators were plotted), a dense concentration was observed in Southern Europe mainly due to the occurrence of the Mediterranean climate. This interest could be explained by the facts that the latter is expected to be the most affected by climate change, by the need for more evidence on the efficiency NbS-NbaS in Mediterranean contexts, and by the urgency to understand the ecological responses of Mediterranean ecosystems better. Northern and Eastern Europe were seen to have less concentrations than Western Europe with significantly much less sites in the Eastern part. Generally, the H2020 NbaS distribution revealed a dense South-West geographic gradient in contrast to a less developed North-East axis. This current spatial pattern underlines the need for balancing the geographical interest in NbaS in order to homogenize continental efforts.

At the national scale: The number of laboratories targeting NbaS was seen to be less than those addressing NbS. Spatially, the distribution of NbaS labs revealed two aggregations: the Parisian region (Ile-de-France), and the South-Eastern section of the country (namely the Grenoble-Alpine region). Southern France also revealed a growing cluster of labs in contrast to Northern, Central and Western France where few labs are active on the topic. The relative absence of labs in the North is quite apparent, as is the striking absence of labs in French overseas territories (in contrast to the NbS map). Knowing that overseas France is much more sensitive to climate change than Metropolitan France, significant NbaS efforts are needed on these islands.

VI. The scale quandary

The scale quandary is well-addressed throughout the different levels. Considerable insights were obtained as each part of the multi-scale approach deals with the concept of scalability from a different perspective. Most similarities were found between the European and French levels as these address NbS-NbaS in a more straightforward manner than the international reports. In what follows a synthesis of scale-related findings is presented.

At the international level: Scalability is mostly addressed from an adaptation perspective and forms one of the UNFCCC's (Paris Agreement) central questions: *"how can we scale up adaptation actions in a holistic and nationally determined yet collectively ambitious manner?"* This question comes after the acknowledgment of adaptation's importance in earlier years and forms a recent interest under the UNFCCC for upscaling adaptation measures. Within this domain, the UNFCCC highlights that scale is one of the determinant factors for adaptation planning - and that the latter although scale and context specific - should extend through different spatial and temporal scales. In this regard, NbS-NbaS are still locked in the pilot/project scale without sufficient efforts to unlock their up and outscaling. For grey solutions, upscaling is easier and that is probably one of the several strength points grey solutions have over NbS-NbaS.

The matter of scale is also implicated in the use of climatic data. It namely appears in the differences between observed, projected, simulated and forecasted data and in the downscaling processes of global climatic models. In this regard, the use of regional/global models, their downscaling and adaptation to finer scales is burdened by uncertainties and assumptions that pose limitations to consider.

At the regional level: With the exception of OPERANDUM, PHUSICOS, RECONECT, FutureMARES and PONDERFUL, all H2020 projects target small or very specific pilot sites. It is believed that the diversity of pilot scales' size and scales facilitates the extrapolation of findings to bigger scales with similar climatic properties (Boskovic et al., 2021). However, more evidence is needed to determine whether a similar climate is enough to ensure an accurate upscaling. Despite the importance of the projects and their pilot sites, they only generate applied and site-specific knowledge and are often practical variations of earlier research. Even if knowledge is generated from these narrow focus approaches, it is rather questionable whether it will be applicable to either/both larger and smaller scales. Nonetheless, the increase of large-scale demonstrator projects under the H2020 programme might be a promising platform for bridging scale-related gaps within the NbS-NbaS framework.

At the national level: Scalability is well-addressed throughout the different references. In addition to the common elements between the three scales, French scientific literature places an importance on the connectivity of resilience through various spatial scales, the transition of NbS-NbaS through upscaling, and the effects that might ripple across different levels once NbS-NbaS have been introduced. Scale mismatch between the research and practice communities is also highlighted. However, similar to the regional scale, most interventions do not extend beyond restricted study areas with an absence of large-scale implementations. To this end, significant efforts are needed to extend national knowledge beyond local scale approaches.

For all three scales, there is a clear and pronounced difference in numbers between research on small scale and large scale (e.g. catchment, mountain range or larger scale) NbS-NbaS. The complexity of larger systems might be a reason for this limited momentum. However, the current mismatch is a significant hurdle to overcome. In implementation terms, it is highly questionable whether local-scale interventions will have any or some sort of pronounced effects on large hazards. In this regard, it is believed that NbaS will only become sufficiently effective when they target the landscape or wider scales through the inclusion of the different concerned interactions.

The NbaS-scale relationship, as well as the NbS-NbaS transition through scales should be further studied by understanding how environmental/physical interactions and processes change with scale. Only then will the upscaling of NbS-NbaS be properly understood as its underlying basis will have become well established. Nonetheless, this knowledge exhaustive perspective might take a long time to unravel given the multitude and the complexity of its implicated factors. The progression of climate change adds yet another layer of difficulty to overcome. In this sense, a shift towards harder scientific disciplines within the NbS-NbaS framework is needed.

VII. On the notions of complexity and uncertainties

At the international scale: The matter of adaptation's complexity was addressed as a product of climatic, socioeconomic and context-specific characteristics. For attending to the complexity of adaptation, adaptation tracking (as a research discipline) aims to provide reliable, robust and replicable methods. However, this line of work is still emerging and is mainly challenged by the need to assess actual future effects, not only expected ones. The non-linear advancement of climatic impacts adds additional layers of complexity and uncertainty that make projections falls in the range of estimations rather than accurate predictions. According to Cohen-Shacham et al. (2019), NbS (let alone NbaS) principles do not adequately address uncertainty so far. Accordingly, significant efforts are needed to develop this line of work.

At the regional scale: Insights on complexity and uncertainty are more comprehensive than those offered by the two other levels. The different projects account for complexity from various points of view and stress the need to build an inventory of its driving forces/factors. According to the H2020 projects, addressing multi-faceted solutions such as NbS-NbaS requires the consideration of complexity, redundancy and associated uncertainty particularly throughout different scales. Understanding nature's and ecosystems' complexity is currently one of the major gaps for upscaling NbS-NbaS. Nearly all the retained projects call for adopting complex thinking to deal with uncertainties and risks, as it also allows to draw attention to the undesirable effects of NbS-NbaS (disservices).

The most pronounced aspects of complexity come from the nature of the targeted environmental challenges, particularly climate change and hydrometeorological risk reduction. In terms of CCA, both climate change and adaptation are complex and entwined elements. In terms of hydrometeorological risks, the combined meteorological and hydrological phenomena that give rise to a certain hazard create a high degree of inherent complexity. The latter requires both a climatic and hydrological approach. The multitude of involved factors in both CCA and DRR can also aggravate complexities. In terms of NbaS complexity, some solutions are more complex than others, and thus require different approaches. For example, reconnecting floodplains is much more knowledge exhaustive than designing allotment gardens. Operational complexity during the implementation of planned solutions is also a significant hurdle that can delay the delivery of ecoservices, hence reducing the efficiency of the NbaS.

In their own right, uncertainties are mostly attributed to the complex nature of climate change, the unpredictability and uncertainty of nature itself, and to the disconnection between short term actions and long-term goals. Nonetheless, these are rarely quantified or numerically justified.

At the national level: Both uncertainty and complexity are addressed however in a diffuse way. The first is attributed to climate change, while the second stems from the nature of ecosystems. No particular efforts are concentrated on their quantification or on their integration into the NbS-NbaS cycle. Their effect on the design and the efficiency of the planned solutions is also not accounted for.

Compared to the international and national levels, the regional scale dealt more in-depth with uncertainties and complexity. However, under all three levels a quantification of uncertainties is still missing. For this purpose, the role of uncertainties in NbS and NbaS should be better accommodated for and explored through further research. In terms of complexity, there is a need to understand better ecological dynamics and their equilibrium to resolve current challenges. While this task is certainly daunting, it remains a necessary platform to develop for properly investigating the science behind NbS-NbaS.

VIII. Ecosystem services and adaptation services

Central to all scales and to the concept of NbS-NbaS, the concept of ecosystem services is of particular importance.

At the international scale: The three institutions support the idea that ecoservices and ecosystems are not bound by geographical borders. Therefore, there is a need to design inclusive solutions that consider this heterogeneity and account for a mosaic of ecosystems. According to the UNFCCC, ecosystems and eco-services along with resilience are linkers between CCA, DRR and sustainable development. Nonetheless, according to the three institutions, the role and efficiency of ecosystem services for reducing vulnerability to climate change/variability are still not fully understood. It is worth mentioning that at the international scale, regulative ecoservices are of greater interest than the other types.

Concerning disservices, these have only recently started gain sufficient prominence in ecoservices research. In this regard, the concept of diminishing returns should also be taken into consideration. This goes in the sense that both adaptation measures and ecoservices tend to show rapidly diminishing returns, as the value of these services decreases rapidly at the scale of their providing ecosystems. To this end, ecosystem services and their valuation/devaluation is an element for integration into NbaS research, design and implementation

Often, failed NbS-NbaS interventions are attributed to the insufficient understanding of ecosystem-ecoservices functions. While many ecoservices provided by NbS and NbaS are related to "hard science" disciplines (e.g. physical, biological and chemical processes), the NbS-NbaS framework seems to overlook this dimension, hence an important gap to bridge.

On the other hand, Climate Adaptation Services (CAS) appear under the title of issue-specific NbS in the works of the IUCN, but does not appear after the IUCN's 2016 report. This could be due to the fact that the latter is used as a synonym to EbA despite its broader extent or to the umbrella nature of the NbS concept. CAS appears again in Cohen-Shacham et al. (2019), but without much attention or emphasis.

At the regional scale: The interest of the EU in ecosystems, their services and health considerably increased after the COVID-19 pandemic. In the case of NbaS, current research efforts are mostly focused on ecological connective functions and ecoservices provision for climate change resilience. Nonetheless, these ecosystem functions and services are dynamic, uncertain and evolve over time often in non-linear manners. The spatial-temporal variation in the delivery of ecoservices from NbaS (seasonal variation of ecoservices provision) is also a matter of debate. According to Fletcher et al. (2020), overlooking these variations can significantly influence the accuracy of ecoservices provision calculation and therefore can be considered as a gap to bridge. Most often, ecosystem services are assessed from a monetary/economic perspective. This overemphasis on financial aspect is weakens the scientific background of the concept and enhances its anthropocentric/utilitarian nature. In this regard, a careful balance between disciplines of interest should be maintained.

The H2020 projects also highlight that in addition to the nature of delivered ecosystem services, there is need to understand the spatial discrepancy between the location of the sought solution and the location of the ecoservices' beneficiaries. In a parallel manner, as solutions mature, they progressively deliver ecoservices at different time intervals. Yet, it is still not clear whether the end ecoservices should be accounted for only, or if there's a need to integrate the intermediate ones also.

Regardless of the approach, it is crucial to bear in mind that NbS-NbaS are not systematic, meaning that the implementation of a NbS-NbaS is not forcefully followed by positive impacts. Therefore, during the assessment of both intermediate or end services, disservices should equally be considered. At the scale of European projects, disservices are well accounted for despite their recent inclusion into the NbS framework. However, this line of work should be further developed for properly establishing the profile of the sought NbS-NbaS.

At the national scale: Similar to the regional scale, the dynamism of ecosystem services and the additional complications from climate change are acknowledged. The need to extend the interest in ecosystem services beyond provision services is also highlighted. It is believed that the value of regulating ecoservices will increase with the progression of climate change. However, this reactive response might be a challenge as the nature of climate change calls for proactive measures. In this sense, regulation services can be used to protect provision services provided the relationship between different ecoservices is understood. Despite the fact that NbS-NbaS provide multi-benefits, not all their services can be actually delivered. Therefore, there is need to understand which services will be delivered and which will not. That way, a more accurate representation of NbaS-related ecoservices can be obtained. In terms of disservices, these are rarely addressed and significant efforts are needed within this field.

More importantly than ecosystem services, the French scale study revealed an increasing interest in the adaptation services concept. As a reminder, the latter comes from the properties of ecosystems to buffer and adapt to changes. During their adaptation process, ecosystems can provide new services, unravel existing but underutilized services, maintain existing ones, and manage the provision of services to support others. The concept of adaptation services is believed to be superior to that of ecosystem services given the latter's limitations and its constriction to monetary/socioeconomic benefits. This constriction is not applicable within the adaptation services domain as it dismisses the delayed/uncertain effect of climate change. Under this context, it is particularly relevant to study the adaptation services-NbaS link as they are closely entwined.

Most of ecosystem services research gaps stem from the regional scale analysis. Some of the most relevant are the need to account for intermediate services as well as end products, to understand how a service influences others (i.e. ecoservices feedback loops), and how to determine thresholds and tipping points. The national scale highlighted the need to extend the study of ecosystem services beyond those related to provision ones, and most importantly to tap the NbaS-adaptation services relationship. Contrary to both scales, the international institutions place a greater emphasis on regulative services, an approach to develop at the regional and national levels.

IX. Indicators and measuring performances

To study the efficiency of the sought/implemented solutions, monitoring and evaluation are a must. However, finding suitable and widely-accepted indicator remains on the most significant research gaps to bridge. This aspect was particularly articulated in all three scales as a more or less general consensus was apparent.

At the international scale: The absence of metrics and indicators for quantifying adaptation and its outcomes was amply highlighted by the three institutions. Although two types of metrics (descriptive and evaluative) were described by the UNEP (2017), the same report states that no globally approved adaptation assessment framework exists yet. In addition to the indicators challenge, the need for quantifiable and robust adaptation targets as a starting point was equally stressed. This aspect is particularly apparent in the NDCs with only 17% out of the 167 NDCs having quantifiable and robust targets. In this sense, there is a need to develop further a global adaptation framework.

At the regional scale: Under the H2020 projects, a multitude of monitoring and assessment frameworks, and a plethora of indicators are used and presented (namely MAES, UNaLab, NATURVATION, EKLIPSE and others). Most projects use the EKLIPSE framework, while others develop their own (such as EdiCitNet, proGIreg and CLEVER Cities). However, there still isn't a commonly accepted or uniform approach.

In terms of indicators most of the biophysical ones revolved around changes of temperatures. In terms of stormwater management (for example and not limited to), estimations/calculation of runoff abatement and peak flow decreases, as well as infiltration rates, evapotranspiration rates, peak heights and times were provided. The very ample focus and development of monitoring and evaluation schemes underlines that this domain is well accounted for under the H2020 NbaS projects. It is worthwhile mentioning that a very wide array of socioeconomic KPIs are equally presented. Nonetheless, some projects focus more on the socioeconomic angles compared to the more environmental/ecological/biophysical indicators, and thus target less quantitative outcomes. In this regard, a careful balance between the two types of indicators is needed.

Indicators on ecosystem complexity, resilience and stability are also required. The same applies for ecological indicators. Measuring intangible benefits is also a challenge in its own right as it is subjected to considerable subjective biases and a lack of straightforward methodology.

At the national scale: A more or less limited reporting on efficiency, discussion of indicators and use of metrics were observed. Yet, there are ample calls for developing indicators capable of accounting for the aggregated/combined effect of different solutions, and for measuring the cascading interactions between different compartments of a NbS-NbaS. The difference between the national and regional scale might be due to the fact that projects should give more proof of efficiency to guarantee or advocate for their effects. Nonetheless, developing further the indicators aspect in French research domains is highly recommended.

The context-specific nature of indicators makes the proposition of unified perspectives rather challenging. As such, it remains one of the most open-ended research questions under the NbS-NbaS framework that cannot be solved with a cross-disciplinary collaboration.

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