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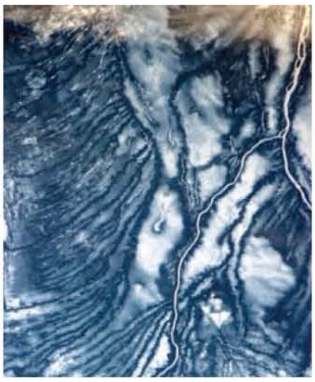

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EARTH OBSERVATION FOR BIODIVERSITY MONITORING:

A review of current approaches and future opportunities for tracking progress towards the Aichi Biodiversity Targets

UNEP WCMC
Convention on Biological Diversity
Biodiversity Indicators Partnership
European Commission
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FOREWORD

The Strategic Plan for Biodiversity 2011-2020 and its Aichi Biodiversity Targets provide a framework for action on biodiversity for this decade and beyond. In order to progress towards the achievement, this Plan needs to be assessed on a continuous basis. Comprehensive and robust monitoring systems, from which indicators of progress can be readily extracted and easily interpreted, would greatly enhance our ability to do this.

Biodiversity datasets are scarce for many parts of the earth's surface. *In situ* data is not always available and often have limitations. Earth observation data from spaceborne, airborne and ground-based sensors have a major role to play in improving monitoring systems by complementing conventional *in situ* data collection or by providing other types of information. Furthermore, the greater availability of earth observation data might encourage increased *in situ* data collection efforts, for instance for ground proofing purposes.

This report shows how earth observation technologies can and should fit into systems for biodiversity monitoring, as well as demonstrates how these approaches could further improve relevant indicators for the Aichi Biodiversity Targets. It illustrates a clear track from observations done by remote sensing platforms through Essential Biodiversity Variables to biodiversity indicators and ultimately to the assessment of progress towards the Aichi Biodiversity Targets and ultimately in support of evidence-based decision making. There is clearly huge potential for involving the wide range of current and emerging Earth Observation products in biodiversity monitoring. However, it is imperative that a balance is achieved between innovation in new products and the continuity of existing earth observations. A consistent, comparable readily available time series of biodiversity-relevant earth observations, such as long-term land cover change, is a pressing need. If this need were filled it would greatly enhance our ability to keep biodiversity and ecosystems under proper review and take well informed policy decisions.

This report is intended as a resource for three communities: Earth Observation specialists, biodiversity scientists and policy makers. It aims to create common ground and initiate further dialogue. We hope that it will encourage an ongoing commitment from all readers to realize the full potential of the invaluable set of tools presented in this report and to take every opportunity and creative steps to enhance monitoring and assessment of biodiversity at the national and international level.

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EXECUTIVE SUMMARY

BACKGROUND

The Strategic Plan for Biodiversity 2011-2020 and the Aichi Biodiversity Targets represent a global call to action to work together in preserving global biodiversity for future generations. Assessing progress towards these targets requires indicators based on reliable observations. Remotely sensed Earth Observation (EO) offers the potential for wide scale, repeatable, cost effective measurement, yet the application of EO methods to global biodiversity monitoring is poorly developed, and building biodiversity indicators from remotely sensed data has proved challenging.

In response to a request from the CBD Secretariat, the United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC), together with a wide range of contributors and interviewees, undertook a review of the use of remotely sensed data for monitoring biodiversity change and tracking progress towards the Aichi Biodiversity Targets.

AIM AND STRUCTURE OF THE REPORT

This report offers an accessible overview of the possibilities that remotely sensed data provide to biodiversity monitoring in the context of the Aichi Targets. Focusing particularly on space-borne (satellite) sensors whilst also considering airborne and ground-based systems, it explores the obstacles and opportunities for greater use of remotely sensed data. Aimed primarily at non-specialist policy users, its intention is to bring some clarity to this complex landscape and to bridge the gap between the EO and biodiversity decision-making communities, enabling productive dialogue through a shared understanding of needs and opportunities.

The report is structured in three main sections. The first section describes operational EO data products as well as those under research and development on a Target by Target basis and discusses some of their current applications and limitations. A traffic light system has been adopted to assess the adequacy of remotely sensed data to monitor progress towards each of the Targets. The second section is a discussion of national-level case studies where EO data have been applied. The value of open access data, application in near real time monitoring of threats and inputs to strategic conservation planning are all illustrated, as are the resource and capacity constraints often faced by governments in attempting to utilize remotely sensed data to develop national data products and indicators. The third section of the report describes the limitations and key challenges that have prevented the uptake of EO data for indicator development more broadly, and ends with some discussion of the way forward.

REPORT FINDINGS

The findings of this report touch on a broad range of technical, societal, political, institutional and financial issues related to biodiversity monitoring and EO-based approaches for reporting on the Aichi Targets. However a fundamental challenge remains in combining the diversity of biodiversity measures in a coherent set of observations, products and services for which a dedicated set of EO-based observation systems can be designed combining satellite, airborne, and *in-situ* data. There are many barriers to developing capacity amongst the biodiversity community in EO-related technologies, especially in developing countries where there are added constraints in education, internet bandwidth and data access. Consensus-building between EO experts, biodiversity scientists and policy users should pave the way for better dialogue and manage the expectations of what EO data can provide. This report will contribute to this process through a clear presentation of the issues involved to all stakeholders.

KEY MESSAGES

1. **The potential for remotely sensed earth observation data to support biodiversity policy is growing, but is yet to be fully realised.** The value of remote sensing depends upon sustained observations over the longer term but many EO products for biodiversity have been developed for research and demonstration purposes at limited spatial and/or temporal scales. Yet there are increasing numbers of robust environmental time series data sets being generated.

2. **There are clear opportunities presented by existing and emerging remote sensing capabilities to support monitoring of the Aichi Biodiversity Targets.** Key areas of development surround spatiotemporal analysis of land cover change including metrics of habitat fragmentation and connectivity and assessing land surface conditions such as vegetation productivity, habitat and water/air quality (Aichi Targets 5 and 8). Innovations in other areas offer additional opportunities including helping to fill some of the key gaps for Targets for which it has proven difficult to develop indicators using only *in-situ* data (such as Aichi Target 9 and 14), and assessing effectiveness of conservation actions (Aichi Target 11). Modelling is emerging as a key area where EO products can contribute to biodiversity monitoring, either as inputs or as a way to constrain the models. Species distribution modelling, for example, uses EO products as environmental determinants.

3. **Remotely sensed data, when processed, packaged and communicated appropriately, can have impacts on policy and practice that yield positive biodiversity outcomes.** Current scientific understanding, computational power and web architecture create the possibility for automated products providing spatially explicit change analyses and alerts in 'near real time', in particular for forest cover. Developments in web architecture, such as cloud computing, can facilitate future large-scale production of highly relevant thematic information based on near real time EO data. This technological development could transform decision making in biodiversity conservation.

4. **However, the use of remotely sensed Earth observation data is often constrained by access to data and processing capacity.** Although a significant amount of data is now available at no cost, very high spatial resolution data remains expensive and in all cases the full value for biodiversity monitoring is not being extracted. A number of factors contribute to this underutilisation but the biggest may be the limited availability on a routine, periodically updated basis of the kinds of derived, analytical products necessary to inform progress towards the Aichi Targets. These products may require considerable human resources and specialised technical expertise to deliver, neither of which may be available or affordable.

5. **Priorities for future development of remote sensing products should be driven by end users needs.** An agreed set of minimum essential requirements, such as the emerging Essential Biodiversity Variables, would provide a focus for the EO community at large to work towards and to concentrate efforts on a small number of essential EO products. A significant, specific requirement remains for a long-term, consistent and regularly updated land cover change product which characterises the whole land system, i.e. land cover, land use and land management. This would help to identify where pressures are occurring and how likely they are to impact current status and future trends in global biodiversity.

6. **Creating a dialogue between data providers and users is critical to realising the potential of remotely sensed data.** To date, this dialogue has been limited. A closer relationship between the EO community and potential users in the biodiversity policy and management communities would help to enhance understanding, align priorities, identify opportunities and overcome challenges, ensuring data products more effectively meet user needs.

执行摘要

背景资料

2011-2020年度生物多样性战略规划(Strategic Plan for Biodiversity)以及爱知生物多样性目标(Aichi Biodiversity Targets)代表了为子孙后代共同保护全球生物多样性的广泛呼吁。然而，基于可靠观察的指标才能对这些目标的进度进行评估。遥感对地观测(EO)为大尺度、可重复的、经济型的测量提供了可能；然而，应用于全球生物多样性监测的EO方法发展尚不成熟。因而根据遥感数据构建生物多样性指标也就颇具挑战性。

为回应CBD秘书处的要求，联合国环境规划署世界环保监测中心(UNEP-WCMC)携手广泛的贡献者和受访者，对用于监测生物多样性变化并跟踪爱知生物多样性目标进程的遥感数据的使用进行了评估。

报告的目标与结构

该报告涵盖了一系列可实现的可能性概述，即在爱知目标背景下，将遥感数据用于生物多样性监测可能产生的情况。报告特别着眼于空载（卫星）传感器，同时也考虑了机载以及陆基系统，并探讨了进一步广泛使用遥感数据的问题与机遇。该报告主要以非专家政策用户为目标群体，拟为此复杂格局带来一定的明确性，并填补EO与生物多样性决策团体之间的鸿沟，从而通过就需求与机遇问题达成共识促成富有成效的对话。

报告共分三大部分。第一部分以目标分类描述了可使用的以及尚处在研发阶段的EO数据产品，并讨论了其中某些产品的当前应用情况以及局限性。我们采用信号灯系统对遥感数据监测各个目标进程的妥善性进行评估。第二部分是讨论内容，我们针对已应用EO数据的国家开展了国家一级的案例研究讨论。我们对开放存取数据的价值、近即时威胁监测的应用，以及对战略性环保规划的投入进行了例证，同时还包括试图利用遥感数据开发国家数据产品及指标的政府所经常面临的资源及产能限制问题。报告的第三部分描述了阻碍进一步应用EO数据开发指标的限制因素和主要挑战，并以对未来前景的讨论收尾。

报告结论

该报告的结论涉及与生物多样性监测相关的一系列技术、社会、政治、制度和财务问题，以及以EO为基础的爱知目标汇报方法。然而，在提供了一系列相关观察、产品和服务的情况下，结合生物多样性测量的多样性过程中仍存在根本性的挑战，因此，可结合卫星、机载以及现场数据专门设计一系列基于EO的观察系统。要提高生物多样性社区的EO相关技术产能还存在许多的障碍，特别是在有着更多教育、互联网带宽和数据存取限制的发展中国家尤为如此。EO专家、生物多样性科研人员以及政策使用者之间共识的达成应该为更加富有成效的对话做好铺垫，并管理对于EO数据功能的期望。本报告将通过明确阐释涉及所有利益相关者的问题来推动这一进程。

重要信息

1. **遥感对地观测数据支持生物多样性政策实施的可能性正在不断提高，但仍尚未完全实现。**遥感技术的价值依赖于长期的持续观测结果，但是很多用作研究和演示的用于提高生物多样性的EO产品都是在有限的空间和/或时间范围内开发而成。当然，还是会有越来越多稳健的环境时间序列数据集产生。

2. **现有及新兴的遥感技术能力显然为支持爱知生物多样性目标监测提供了机会。**不要尝试去做每一件事情。资源应该被用来解决关键要素和信息的差距。可能的地方包括连接的指标涵盖尽可能多的生态系统评估框架（社会生态系统）的很多方面（例如，状态和趋势，驱动力量，政策的有效性）。

3. **如将遥感数据进行恰当地处理、组合以及联系，将能够对可产生积极生物多样性成果的政策和做法产生影响。**当前的科学认识、计算能力以及网络架构为自动化产品创造了可能性，尤其是为森林植被领域提供了明确的“近即时”空间变化分析与预警。诸如云计算等网络架构的发展能够推动未来以近即时EO数据为基础的大规模高度相关专题信息的产生。这一技术发展可能会改变生物多样性保护方面的决策。

4. **然而，遥感对地观测数据的使用往往受限于数据的存取与处理能力。**尽管我们现在已经可以免费使用大量数据，但是高空间分辨率数据仍较为昂贵。而且，无论就何种情况而言，我们均尚未获得这些数据用于生物多样性监测的完整价值。未将其充分利用的因素是多种多样的，但是最重要的一个原因可能是缺乏通知爱知目标进程所需的定期更新的衍生分析产品。我们可能需要相当多的人力资源以及专业化的技术知识来打造这些产品，但是这二者我们均不具备或者无力承担。

5. **终端用户的需求可能推动遥感技术产品未来发展的优先级。**诸如新近产生的《基本生物多样性可变因素》(Essential Biodiversity Variables)等一系列已商定的最低基本要求将为大部分EO社区提供其为之努力的核心，这些社区还将倾力于少量的基础性EO产品开发。长期、一致且定期更新的土地覆盖变化产品仍然是一项重要的具体要求，该产品以整体土地系统为特征，即土地覆盖、土地使用以及土地管理。这可能有助于确定产生压力的地方、它们对当前状态产生影响的可能性有多大，以及全球生物多样性的未来趋势如何。

6. **要实现遥感数据所带来的可能性，就一定要在数据提供者与使用者之间创建对话。**迄今为止，这种对话还很有限。EO社区与生物多样性政策及管理社区潜在使用者之间的密切关系将有助于加深理解、调整优先级、识别机遇并战胜挑战，进而确保数据产品能够更为有效地满足使用者的需求。

SYNTHÈSE

CONTEXTE

Le Plan Stratégique pour la Diversité Biologique 2011-2020 et les Objectifs d'Aichi pour la biodiversité représentent un appel mondial à la collaboration afin de préserver la diversité biologique mondiale pour les générations futures. L'évaluation des progrès réalisés par rapport à ces Objectifs demande des indicateurs fondés sur des observations fiables. Bien que l'observation de la Terre (OT) par télédétection offre la possibilité de mesures répétables et rentables à grande échelle, les méthodes de télédétection ne sont que très peu appliquées au suivi de la biodiversité mondiale et l'établissement d'indicateurs de la biodiversité à partir de données de télédétection s'est avéré difficile.

En réponse à une demande du secrétariat de la CDB, le Centre mondial de surveillance de la conservation de la nature du Programme des Nations Unies pour l'environnement (UNEP-WCMC) a entrepris d'étudier, avec l'aide de nombreux collaborateurs et personnes interviewées variés, l'utilisation des données de télédétection pour le suivi des changements de la diversité biologique et des progrès réalisés par rapport aux Objectifs d'Aichi pour la biodiversité.

OBJECTIF ET STRUCTURE DU RAPPORT

Ce rapport fournit un aperçu accessible des possibilités offertes par les données de télédétection en matière de suivi de la diversité biologique dans le contexte des objectifs d'Aichi. Avec un accent particulier sur les capteurs satellitaires, tout en prenant également en compte les systèmes aéroportés et au sol, il étudie les obstacles et les opportunités d'une utilisation plus répandue des données de télédétection. Visant principalement les utilisateurs et décideurs politiques non spécialistes, ce rapport a pour but de clarifier ce paysage complexe et de combler les écarts entre les communautés de télédétection et les communautés preneuses de décisions relatives à la diversité biologique afin de permettre un dialogue constructif grâce à une compréhension mutuelle des besoins et des opportunités.

Ce rapport est divisé en trois parties principales. La première partie décrit les produits de données opérationnelles de télédétection, ainsi que ceux faisant l'objet de recherches et développement, Objectif par Objectif, et aborde leurs applications et limitations actuelles. Un système de feux de signalisation a été adopté pour évaluer l'adéquation des données de télédétection pour le suivi des progrès réalisés par rapport à chacun des Objectifs. La deuxième partie est une discussion d'études de cas au niveau national dans lesquelles les données de télédétection ont été appliquées. Elle illustre la valeur des données d'accès libre, de l'application quasiment en temps réel du suivi des menaces et des idées en matière de planification stratégique de la conservation, ainsi que les contraintes en termes de ressources et de capacité auxquelles font souvent face les gouvernements lorsqu'ils essaient d'utiliser les données de télédétection pour mettre au point des produits de données et des indicateurs nationaux. La troisième partie de ce rapport décrit les limitations et les défis principaux ayant freiné l'adoption plus étendue des données OT pour l'élaboration d'indicateurs avant de finir sur une discussion sur l'avenir.

CONCLUSIONS DU RAPPORT

Les conclusions de ce rapport abordent diverses questions techniques, sociétales, politiques, institutionnelles et financières relatives au suivi de la diversité biologique et aux approches basées sur l'OT pour évaluer les progrès réalisés par rapport aux Objectifs d'Aichi. La difficulté fondamentale reste cependant de combiner la diversité des mesures de la diversité biologique en un ensemble cohérent d'observations, de produits et de services pour lequel des systèmes d'observation OT spécifiques, regroupant les données satellitaires, aéroportées et *in situ*, peuvent être conçus. Il existe de nombreux obstacles au développement des capacités des technologies associées à l'OT, notamment dans les pays en voie de développement où viennent s'ajouter des contraintes en termes d'éducation, de largeur de bande Internet et d'accès aux données. La recherche d'un consensus entre les spécialistes de télédétection, les scientifiques spécialisés dans la biodiversité et les utilisateurs et décideurs politiques devrait ouvrir la voie à un meilleur dialogue et permettre de gérer les attentes relatives aux données OT. Ce rapport va également y contribuer en présentant clairement les problèmes à toutes les parties prenantes.

MESSAGES CLÉS

1. **Bien qu'en hausse, le potentiel des données d'observation de la Terre par télédétection en termes de soutien de la politique sur la diversité biologique n'est pas encore pleinement réalisé.** La valeur de la télédétection dépend de l'observation continue à plus long terme, mais de nombreux produits OT pour la diversité biologique ont été développés à des fins de recherche et de démonstration à une échelle spatiale et / ou temporelle limitée. De plus en plus d'ensembles de données environnementales de séries chronologiques solides sont cependant générés.

2. **Les capacités de télédétection existantes et émergentes présentent clairement des opportunités de contribuer au suivi des objectifs d'Aichi pour la biodiversité.** Les domaines clés de développement tournent autour de l'analyse spatio-temporelle de l'évolution de l'occupation des sols, y compris la mesure de la fragmentation et de la connectivité de l'habitat, ainsi que l'évaluation des conditions du sol, telles que la productivité de la végétation et la qualité de l'habitat, l'eau et l’air et la (Objectifs d'Aichi 5 et 8). Des innovations dans d'autres domaines offrent des opportunités supplémentaires, notamment pour aider à combler certaines lacunes pour certains Objectifs pour lesquels il s'est avéré difficile de mettre au point des indicateurs à l'aide de données *in situ* uniquement (tels que les Objectifs d'Aichi 9 et 14) et pour déterminer l'efficacité des mesures de conservation (Objectif d'Aichi 11). La modélisation prend de l'importance alors qu'il devient évident que les produits OT peuvent contribuer au suivi de la diversité biologique, soit en tant que données, soit comme un moyen d'appliquer des contraintes aux modèles. La modélisation de la distribution des espèces utilise, par exemple, des produits OT comme déterminants environnementaux. .

3. **Lorsqu'elles sont traitées, conditionnées et communiquées de manière adéquate, les données de télédétection peuvent influencer la politique et la pratique pour donner des résultats positifs en matière de diversité biologique.** Grâce aux connaissances scientifiques, aux performances informatiques et à l'architecture web actuelles, il est possible d'avoir des produits automatisés qui fournissent des analyses des changements spatialement explicites et des alertes quasiment en temps réel, notamment pour ce qui est de la couverture forestière. Les avancées de l'architecture web, comme les services du Cloud par exemple, peuvent faciliter la future production à grande échelle d'informations thématiques hautement pertinentes basées sur des données OT quasiment en temps réel. Cette avancée technologique pourrait transformer le processus décisionnel en matière de conservation de la diversité biologique.

4. **L'accès aux données et la capacité de traitement limitent cependant souvent l'utilisation de données d'observation de la Terre par télédétection.** Bien qu'une quantité significative de données soit désormais disponible gratuitement, les données de très haute résolution spatiale restent onéreuses et ne peuvent pas, dans tous les cas, être totalement mises à profit en termes de suivi de la diversité biologique. Plusieurs facteurs contribuent à cette sous-exploitation, mais le plus important est probablement la disponibilité limitée, de manière régulière et fréquemment mise à jour, des types de produits analytiques dérivés nécessaires pour évaluer les progrès par rapport aux Objectifs d'Aichi. Ces produits peuvent nécessiter des ressources humaines importantes et des compétences techniques spécialisées qui ne sont pas toujours disponibles ou abordables.

5. **Les besoins des utilisateurs finaux devraient dicter les priorités pour le développement futur de produits de télédétection.** Un ensemble de critères minimum essentiels défini, tel que les Variables essentielles de la biodiversité (EBV) émergentes, fournirait une direction pour l'ensemble de la communauté de télédétection et lui permettrait de concentrer ses efforts sur un petit nombre de produits de télédétection essentiels. La nécessité de créer un produit pour l'évolution de l'occupation des sols à long terme, cohérent et régulièrement mis à jour caractérisant l'intégralité du système, à savoir l'occupation, l'utilisation et la gestion des sols, est toujours d'actualité. Un tel produit permettrait d'identifier les endroits sous pression et l'impact potentiel de ces pressions sur l'état actuel et les futures tendances en matière de diversité biologique mondiale.

6. **Il est vital de créer un dialogue entre les fournisseurs et les utilisateurs de données pour réaliser le potentiel des données de télédétection.** À ce jour, ce dialogue est limité. Une relation plus étroite entre la communauté de télédétection et les utilisateurs potentiels des communautés de la politique et de gestion de la diversité biologique permettrait d'améliorer la compréhension, d'aligner les priorités, d'identifier des opportunités et de surmonter les obstacles afin de s'assurer que les produits de données répondent plus efficacement aux besoins des utilisateurs.

КРАТКИЙ ОБЗОР

СПРАВОЧНАЯ ИНФОРМАЦИЯ

Стратегический план по биоразнообразию на 2011-2020 годы и Айтинские целевые задачи по биоразнообразию, , представляют собой мировой призыв к совместным действиям, направленным на сохранение мирового биологического разнообразия для будущих поколений. Для оценки достижения этих целей требуются индикаторы, основанные на надежных наблюдениях. Дистанционное зондирование Земли (ДЗЗ) — это метод, заключающий в себе широкомасштабные, регулярные и экономичные измерения. Кроме того, использование методов ДЗЗ для мониторинга биологического разнообразия недостаточно развито, и создание индикаторов биологического разнообразия на основе данных ДЗЗ — действительно трудная и интересная задача. В ответ на запрос от Секретариата Конвенции о биологическом разнообразии Всемирный центр мониторинга природоохраны Программы Организации Объединенных Наций по окружающей среде (UNEP-WCMC) совместно с широким кругом участников и опрашиваемых лиц провел анализ использования данных дистанционного зондирования для мониторинга изменений биологического разнообразия и отслеживания прогресса в достижении Айтинских целевых задач.

ЦЕЛЬ И СТРУКТУРА ОТЧЕТА

В настоящем отчете предлагается доступный обзор возможностей, предоставляемых данными дистанционного зондирования Земли для мониторинга биологического разнообразия в контексте Айтинских целевых задач. Особое внимание в нем уделяется датчикам, устанавливаемым на космических летательных аппаратах (спутники), а также системам воздушных летательных аппаратов и наземным системам, в нем рассматриваются препятствия и возможности для более широкого применения данных дистанционного зондирования. Отчет, главным образом, предназначен для пользователей политики, не являющихся специалистами, его цель состоит в том, чтобы привнести некоторую ясность в сложную картину и устранить пробел между возможностями ДЗЗ и сообществами, принимающими решения, обеспечивая продуктивный диалог благодаря общему пониманию потребностей и возможностей.

Структура настоящего отчета разделена на три основных раздела. В первом разделе приведено описание рабочих продуктов, использующих данные ДЗЗ, а также продуктов, находящихся на этапе исследования и разработки на основе отдельных целевых задач, а также рассматриваются некоторые имеющиеся варианты применения и ограничения. Система «светофор» используется для оценки надежности данных дистанционного зондирования для мониторинга прогресса достижения каждой сформулированной целевой задачи. Во втором разделе рассматривается анализ примеров национального уровня, когда применялись данные ДЗЗ. Также рассматривается ценность открытых данных, применение в мониторинге угроз в режиме почти реального времени, и вклады в стратегическое планирование природоохранной деятельности, поскольку они представляют собой ресурсные и мощностные ограничения, с которымы часто сталкиваются правительства в попытках применения данных дистанционного зондирования для создания средств обработки данных и индикаторов. В третьем разделе отчета содержится описание ограничений и ключевых задач, препятствующих интеграции данных ДЗЗ для разработки индикаторов в более широких масштабах, раздел завершается рассмотрением некоторых вариантов дальнейших действий.

ОТЧЕТ ПО РЕЗУЛЬТАТАМ

Результаты настоящего отчета затрагивают широкий круг технических, общественных, политических, институциональных и финансовых вопросов, относящихся к мониторингу биологического разнообразия и подходам, основывающимся на ДЗЗ, для подготовки отчетности по Айтинским целевым задачам. Однако задача фундаментального характера по-прежнему состоит в объединении различных мер по сохранению биологического разнообразия в последовательный комплекс наблюдений, продуктов и услуг, для которых возможна разработка специальных систем наблюдения, основанных на ДЗЗ и включающих в себя спутники, воздушные летательные аппараты и данные натурных наблюдений на месте. Существует множество препятствий на пути развития потенциала сообществ, направляющих усилия на сохранение биологического разнообразия, в части технологий с использованием данных ДЗЗ, особенно, когда речь идет о развивающихся странах, в которых добавляются ограничения, связанные с образованием, полосой пропускания и доступа к данным. Достижение согласия между экспертами в области зондирования Земли, учеными, занимающимися вопросами биологического разнообразия, и пользователями политики должно проложить путь для более конструктивного диалога и управления ожиданиями от возможностей, предоставляемых использованием данных ДЗЗ. Настоящий отчет внесет свою долю в этот процесс посредством ясного представления вопросов, касающихся всех субъектов деятельности.

КЛЮЧЕВЫЕ СООБЩЕНИЯ

1. **Потенциал использования данных дистанционного зондирования Земли в поддержке политики сохранения и использования биологического разнообразия постоянно растет, но ему только предстоит раскрыться в полной мере.**

   Ценность дистанционного зондирования зависит от устойчивых наблюдений в течение более продолжительного срока, но множество продуктов для зондирования Земли, используемых для мониторинга биологического разнообразия, разработано для исследовательских и демонстрационных целей в ограниченных масштабах или для временного пользования. Кроме того, создается все больше временных экологических данных.

2. **Существуют ясные возможности, представленные действующим и новообразующимся потенциалом дистанционного зондирования, в поддержке мониторинга Айтинским целевых задач.**

   Ключевые области развития включают в себя пространственно-временной анализ изменений почвенно-растительного покрова, включая метрики распада ареала и объединения фрагментов ареала, оценку состояния поверхности, например продуктивность растительного покрова, и качество ареала, воды и воздуха (целевые задачи 5 и 8). Инновации в других областях предлагают дополнительные возможности, включая содействие в заполнении ключевых пробелов целевых задач, для которых сложно разработать надежные индикаторы с использованием данных натурных наблюдений на месте (например, целевые задачи 9 и 14), и оценку эффективности мероприятий по охрано природы (Целевая задача 11). Моделирование становится ключевой областью, в которой продукты по зондированию Земли смогут внести вклад в мониторинг биологического разнообразия, предоставляя входные данные или выступая в качестве средств формирования моделей. Например, в моделировании распределения видов используются результаты зондирования Земли в качестве определяющих факторов окружающей среды.

3. **Данные дистанционного зондирования при надлежащей обработке, пакетировании и передаче могут оказать влияние на политику и практику, которое приведет к положительным результатам в области сохранения и использования биологического разнообразия.**

   Текущее научное понимание, вычислительные мощности и сетевая архитектура создают возможность использования автоматизированных продуктов, которые в пространственном отношении предоставляют развернутый анализ изменений, и предупреждения в режиме почти реального времени, в частности, по лесному покрову. Разработки в области сетевой архитектуры, такие как облачные вычисления, будут полезными в будущем крупномасштабном накоплении тематической информации высокой актуальности на основе данных зондирования Земли в режиме почти реального времени. Такое технологическое развитие может преобразовать принятие решений в области сохранения биологического разнообразия.

4. **4. Однако использование данных дистанционного зондирования Земли зачастую затруднено доступом к данным и мощностями обработки данных.**

   Несмотря на то, что значительный объем данных в настоящее время доступен бесплатно, данные очень высокого пространственного разрешения остаются дорогостоящими, и в любом случае не извлекается полная ценность для мониторинга биологического разнообразия. Ряд факторов способствует такому неполному использованию, но главным из них, возможно, является ограниченная оперативная доступность с регулярным обновлением производных, аналитических продуктов, которые необходимы для информирования о прогрессе решения Айтинских целевых задач. Для создания таких продуктов потребуются значительные человеческие ресурсы и узкоспециальный технический опыт, и то, и другое может оказаться недоступным или слишком дорогостоящим.

5. **Приоритеты будущего развития продуктов дистанционного зондирования должны создаваться в зависимости от нужд конечных пользователей.**

   Согласованные минимальные требования, такие как создаваемые Основные параметры биоразнообразия, смогли бы сосредоточить на себе внимание сообщества зондирования Земли в полном объеме, а также сосредоточили бы усилия на небольшом количестве необходимых продуктов зондирования Земли. Важным и отдельным долгосрочным требованием остается надежный и регулярно обновляемый продукт, предоставляющий информацию об изменениях почвенно-растительного покрова, характеризующий систему землепользования в целом, т. е. растительный покров, землепользование и управление земельными ресурсами. Таким образом, удастся определить зоны повышенной нагрузки и вероятность их воздействия на текущее состояние и будущую динамику мирового биологического разнообразия.

6. **Диалог между поставщиками данных и пользователями — критический фактор в реализации потенциала данных дистанционного зондирования.**

   На сегодняшний день этот диалог скован. Более близкое отношение между сообществом наблюдения за Землей и потенциальными пользователями в рамках политики биологического разнообразия, а также управляющими сообществами поможет в более глубоком понимании, согласовании приоритетов, выявлении возможностей и преодолении трудностей, обеспечивая более эффективное соответствие результатов обработки данных требованиям пользователей.

RESUMEN EJECUTIVO

ANTECEDENTES

El Plan Estratégico para la Diversidad Biológica 2011-2020 y las Metas de Aichi de Diversidad Biológica suponen un llamamiento mundial a la acción para trabajar juntos con el fin de conservar la diversidad biológica mundial para las generaciones venideras. La evaluación del progreso hacia la consecución de estas metas requiere unos indicadores basados en observaciones fiables. La Observación de la Tierra (EO) mediante detección remota ofrece la posibilidad de realizar mediciones a gran escala, repetibles y rentables; sin embargo, la aplicación de los métodos EO para vigilar la diversidad biológica mundial está poco desarrollada y la creación de indicadores de diversidad biológica a partir de datos detectados de forma remota ha resultado todo un desafío.

En respuesta a una solicitud de la Secretaría del CDB, el Centro Mundial de Vigilancia de la Conservación del Programa de las Naciones Unidas para el Medio Ambiente (UNEP-WCMC), junto con un amplio abanico de colaboradores y entrevistados, realizaron un examen sobre el uso de los datos detectados de forma remota para vigilar los cambios en la diversidad biológica y controlar el progreso hacia las Metas de Aichi de Diversidad Biológica.

OBJETIVO Y ESTRUCTURA DEL INFORME

Este informe ofrece una visión general accesible de las posibilidades que proporcionan los datos detectados de forma remota para hacer un seguimiento de la diversidad biológica en el contexto de las Metas de Aichi. Prestando especial atención a los sensores espaciales (satélites), pero considerando también los sistemas terrestres y aéreos, explora los obstáculos y oportunidades para un mayor uso de los datos detectados de forma remota. Destinado principalmente a usuarios no especialistas encargados de políticas, su objetivo es aclarar este complejo panorama y facilitar un acercamiento entre las comunidades responsables de la toma de decisiones en materia de EO y de diversidad biológica.

El informe está estructurado en tres secciones principales. En la primera sección se describen los productos de datos operativos de EO, además de aquellos que se están investigando y desarrollando en base a cada Meta, y se analizan algunas de sus aplicaciones y limitaciones actuales. Se ha adoptado un sistema de semáforos para evaluar la idoneidad de los datos detectados de forma remota con el objeto de controlar el progreso hacia la consecución de cada una de las Metas. En la segunda sección se analizan estudios de caso a nivel nacional en los que se han aplicado datos EO. Se ilustran el valor de los datos de acceso libre, su aplicación en la vigilancia de las amenazas en tiempo casi real y sus aportaciones a los planes estratégicos de conservación, además de la falta de recursos y de capacidad a la que normalmente tienen que enfrentarse los gobiernos a la hora de intentar utilizar datos detectados de forma remota para desarrollar productos de datos e indicadores nacionales. En la tercera sección del informe se describen las limitaciones y las principales dificultades que han impedido una aplicación más general de los datos EO para el desarrollo de indicadores. Se finaliza con un análisis del camino que debe seguirse.

RESULTADOS DEL INFORME

Los resultados de este informe incluyen un amplio abanico de cuestiones técnicas, sociales, políticas, institucionales y financieras relacionadas con el seguimiento de la diversidad biológica, así como estrategias basadas en la EO para presentar informes sobre las Metas de Aichi. No obstante, un desafío fundamental sigue siendo combinar la variedad de medidas sobre diversidad biológica en un conjunto coherente de observaciones, productos y servicios para el que pueda diseñarse un conjunto especializado de sistemas de observación basados en la EO en el que se combinen datos de satélites, aéreos e *in situ*. Existen muchas barreras para desarrollar las capacidades entre la comunidad de la diversidad biológica sobre tecnologías relacionadas con la OE, especialmente en los países en desarrollo en los hay una serie de dificultades añadidas en cuanto al acceso a la educación, a Internet de banda ancha y a los datos. La creación de un consenso entre los expertos en OE, los científicos expertos en diversidad biológica y los usuarios de las políticas debería preparar el camino para un mejor diálogo y gestionar las expectativas de lo que los datos EO pueden proporcionar. Este informe contribuirá a dicho proceso mediante una presentación clara de las cuestiones que afectan a todos los interesados.

MENSAJES CLAVE

1. **Está aumentando el potencial de los datos de observación de la tierra detectados de forma remota para respaldar las políticas sobre biodiversidad, si bien todavía no se ha aprovechado plenamente.** El valor de la detección remota depende de una serie observaciones continuas a más largo plazo, pero ya se han desarrollado muchos productos EO para la diversidad biológica con fines de investigación y de demostración a escalas espaciales y/o temporales limitadas. Aún así, cada vez es mayor el número de datos de series temporales medioambientales fiables que se está generando.

2. **Las capacidades de detección remota existentes y emergentes ya presentan claras oportunidades para ayudar con el seguimiento de las Metas Aichi de Biodiversidad.** Las áreas claves de desarrollo enmarcan el análisis espaciotemporal de los cambios en la cubierta terrestre, incluidas las métricas de fragmentación del hábitat y la conectividad y la evaluación de las condiciones de la superficie terrestre tales como la productividad de la vegetación, el hábitat y la calidad del agua/aire (Metas de Aichi 5 y 8). Las innovaciones en otras áreas ofrecen oportunidades adicionales, tales como ayudar a cubrir algunas de las lagunas clave para las Metas para las que ha resultado difícil desarrollar indicadores utilizando únicamente datos *in situ* (por ejemplo, las Metas de Aichi 9 y 14), y evaluar la efectividad de las acciones de conservación (Meta de Aichi 11). El modelado se está convirtiendo en un área clave donde los productos EO pueden contribuir a realizar un seguimiento de la diversidad biológica, bien como información o como forma de acotar los modelos. En el modelado de la distribución de las especies, por ejemplo, se utilizan productos EO como determinantes medioambientales.

3. **Los datos detectados de forma remota, una vez procesados, empaquetados y transmitidos de manera adecuada, pueden tener un impacto en la política y en la práctica que producen resultados positivos para la diversidad biológica.** Los conocimientos científicos actuales, el poder computacional y la arquitectura de las páginas web ofrecen la posibilidad de contar con productos automatizados que proporcionan análisis y alertas espacialmente explícitos en "tiempo casi real" sobre cambios, en especial en lo relativo a la cubierta forestal. Los avances en la arquitectura de las páginas web, tales como la computación en la nube, pueden facilitar en el futuro la producción a gran escala de información temática muy valiosa basada en datos EO en tiempo casi real. Este avance tecnológico podría transformar la toma de decisiones en cuanto a la conservación de la diversidad biológica.

4. **No obstante, el uso de datos de observación de la tierra detectados de forma remota muchas veces se ve limitado por la capacidad de acceso a los datos y de procesamiento.** Aunque hoy día puede accederse a una cantidad de datos considerable de forma gratuita, los datos con una resolución espacial muy alta siguen siendo caros y en muchos casos no se está aprovechando todo su valor para la vigilancia de la diversidad biológica. Son varios los factores que contribuyen a esta infrautilización, pero quizás el más importante sea la reducida disponibilidad de forma rutinaria y actualizada periódicamente de los tipos de productos analíticos derivados y necesarios para informar sobre el progreso en relación a las Metas de Aichi. Puede que estos productos requieran una cantidad de recursos humanos y de conocimientos técnicos especializados considerables, y puede que ninguno de estos elementos esté disponible o sea asequible.

5. **Las prioridades para el futuro desarrollo de productos de detección remota deberían venir marcadas por las necesidades de los usuarios finales.** Un conjunto de requisitos mínimos esenciales previamente acordado, como las Variables Esenciales de Diversidad Biológica, proporcionaría una guía a la comunidad EO en su conjunto para trabajar y concentrar sus esfuerzos en un pequeño número de productos EO esenciales. Un requisito específico significativo sigue siendo un producto a largo plazo, estable y actualizado con regularidad enfocado a los cambios en la cubierta terrestre que incluya todo el sistema terrestre, a saber, la cobertura terrestre, el uso del suelo y la gestión de suelos. Esto ayudaría a identificar dónde se están experimentando las presiones y qué probabilidades existen de que influyan en el estado actual y en las tendencias futuras de la diversidad biológica mundial.

6. **La creación de un diálogo entre los proveedores de datos y los usuarios es fundamental para aprovechar el potencial de los datos detectados de forma remota.** Hasta la fecha, este diálogo ha sido limitado. Una relación más estrecha entre la comunidad EO y los usuarios potenciales de las comunidades políticas y de gestión de la diversidad biológica ayudaría a aumentar el entendimiento, alinear las prioridades, identificar las oportunidades y superar los retos, con lo que se aseguraría que los productos de datos satisficiesen de manera más efectiva las necesidades de los usuarios.

الرسائل الأساسية

1- تتزايد إمكانات استخدام بيانات المراقبة الأرضية التي يتم الحصول عليها بالاستشعار عن بعد في دعم سياسة التنوع البيولوجي ولكن مازال ينبغي تحقيق ذلك بالكامل. تتوقف قيمة الاستشعار عن بعد على الملاحظات المستدامة على مدى أطول ولكن العديد من منتجات المراقبة الأرضية الخاصة بالتنوع البيولوجي تم تطويرها لأغراض البحث والتوضيح بنطاقات مكانية و/أو مؤقتة محدودة. ولكن هناك أعداد متزايدة من مجموعات بيانات السلاسل الزمنية البيئية القوية.

2- هناك فرص واضحة يتم تقديمها بواسطة قدرات الاستشعار عن بعد الحالية والناشئة لدعم رصد أهداف أيتشي للتنوع البيولوجي. تتعلق الجوانب الهامة للتطور بالتحليل الزماني والمكاني للتغير في غطاء الأرض بما في ذلك مقاييس تكسر الموطن وإمكانية الربط وتقييم ظروف سطح الأرض مثل إنتاجية النبات والموطن وجودة الماء/ الهواء (أهداف أيتشي رقم 5 و8). وتقدم الابتكارات في الجوانب الأخرى فرصاً إضافية تشمل المساعدة على ملء بعض الثغرات الهامة للأهداف التي ثبت أنه من الصعب تطوير مؤشرات لها باستخدام بيانات الموقع فقط (مثل الهدف 9 والهدف 14)، وتقييم فعالية أعمال الحفاظ على الطبيعة (هدف أيتشي رقم 11). ويظهر استخدام النماذج كجانب هام حيث يمكن لمنتجات المراقبة الأرضية الإسهام في رصد التنوع البيولوجي، سواءً كمدخلات أو كطريقة لتقييد النماذج. نموذج توزيع الأجناس، على سبيل المثال، يستخدم منتجات المراقبة الأرضية كمحددات بيئية.

3- البيانات التي يتم الحصول عليها بالاستشعار عن بعد من الممكن أن تكون لها تأثيرات على السياسة والممارسة التي يتولد عنها نتائج إيجابية في التنوع البيولوجي وذلك بعد معالجتها ووضعها في حزم وتوصيلها بالطريقة المناسبة. يؤدي الفهم العلمي الحالي والطاقة الحسابية وهندسة الويب إلى إيجاد إمكانية للمنتجات الآلية التي تقدم تحليلات للتغييرات المكانية الواضحة وتنبه في "الوقت شبه الحقيقي" خاصة بالنسبة لغطاء الغابات. التطورات في هندسة الويب مثل الحوسبة السحابية يمكنها تسهيل الإنتاج المستقبلي على نطاق واسع لمعلومات في مواضيع هامة للغاية استنادا إلى بيانات المراقبة الأرضية في الوقت شبه الحقيقي. من الممكن أن يؤدي هذا التطور التكنولوجي إلى تحول في اتخاذ القرار في مجال الحفاظ على التنوع البيولوجي.

4- ومع ذلك فإن استخدام بيانات المراقبة الأرضية التي يتم الحصول عليها بالاستشعار عن بعد يكون في الغالب خاضعاً لقيود إمكانية الوصول إلى البيانات والقدرة على معالجتها. وعلى الرغم من توفر قدر هائل من البيانات في الوقت الحالي بالمجان إلا أن البيانات المكانية عالية الوضوح مازالت مكلفة، وفي جميع الحالات لا يتم استخراج القيمة الكاملة لرصد التنوع البيولوجي. هناك عدد من العوامل يسهم في هذا المستوى المنخفض من الاستخدام لتلك البيانات ولكن العامل الأهم قد يكون هو التوفر المحدود على أساس روتيني دوري تحديثي لأنواع المنتجات التحليلية المشتقة اللازمة للتعريف بالتقدم نحو أهداف أيتشي. وربما تحتاج تلك المنتجات إلى موارد بشرية هائلة وخبرة فنية متخصصة لتقديمها، قد لا يكون أي منها متوفراً أو مناسباً من حيث التكلفة.

5- يجب أن تكون احتياجات المستخدم النهائي هي العامل الذي يقف وراء أولويات التطوير المستقبلي لمنتجات الاستشعار عن بعد. ويمثل الحد الأدنى من الاحتياجات الضرورية المتفق عليها، مثل متغيرات التنوع البيولوجي الأساسية الناشئة، نقطة التلاقي لجهات المراقبة الأرضية بوجه عام للعمل نحو عدد صغير من منتجات المراقبة الأرضية الأساسية والتركيز عليه. ومازال هناك متطلب محدد وهام بشأن منتج تغير غطاء الأرض يكون متناسقا ويتم تحديثه على المدى الطويل، ويمثل نظام الأرض بالكامل، مثل غطاء الأرض واستخدام الأرض وإدارة الأرض. وسوف يساعد ذلك على تحديد مكان حدوث الضغوط واحتمال تأثيرها على الحالة الحالية والاتجاهات المستقبلية في التنوع البيولوجي العالمي.

6- يعتبر إنشاء حوار بين مزودي البيانات والمستخدمين أمراً هاماً لتحقيق الفائدة من البيانات التي يتم الحصول عليها عن طريق الاستشعار عن بعد. حتى الآن مازال هذه الحوار قاصرا. العلاقة الوثيقة بين جهات المراقبة الأرضية والمستخدمين المرتقبين في سياسة التنوع البيولوجي وجهات الإدارة تساعد على تحسين الفهم وترتيب الأولويات والتعرف على الفرص والتخلص من التحديات والتأكد من أن منتجات البيانات تلبي احتياجات المستخدم بشكل أكثر فعالية.

ملخص تنفيذي

فكرة عامة

تمثل الخطة الاستراتيجية للتنوع البيولوجي 2011-2020 وأهداف أيتشي للتنوع البيولوجي دعوة عالمية للعمل معاً للحفاظ على التنوع البيولوجي العالمي للأجيال القادمة. ويتطلب تقييم التقدم نحو هذه الأهداف مؤشرات تستند إلى ملاحظات يُعتمد عليها. المراقبة الأرضية (EO) من خلال الاستشعار عن بعد تقدم إمكانية للقياس المتكرر على نطاق واسع وبتكلفة فعالة، ومع ذلك فإن تطبيق طرق المراقبة الأرضية على المراقبة العالمية للتنوع البيولوجي يتم تطويره بشكل سيء، كما ثبت أن بناء مؤشرات التنوع البيولوجي من بيانات يتم الحصول عليها بالاستشعار عن بعد أمر ينطوي على الكثير من التحديات.

استجابة لطلب من سكرتارية الاتفاقية الدولية للتنوع البيولوجي، قام المركز العالمي لرصد الحفاظ على الطبيعة التابع لبرنامج الأمم المتحدة للبيئة (UNEP-WCMC))، وكذلك مجموعة كبيرة من المساهمين والأفراد الذين تمت مقابلتهم بمراجعة استخدام البيانات التي تم استشعارها عن بعد لرصد التنوع البيولوجي وتتبع التقدم نحو أهداف اتفاقية أيتشي للتنوع البيولوجي.

هدف وأجزاء التقرير

يقدم هذا التقرير موجزاً يمكن الاطلاع عليه عن إمكانية توفير البيانات التي يتم الحصول عليها بالاستشعار عن بعد لرصد التنوع البيولوجي في سياق أهداف أيتشي. هذا التقرير الذي يركز بوجه خاص على أجهزة الاستشعار الفضائية المحمولة جوا ويأخذ في الاعتبار أيضا الأنظمة الأرضية يستكشف المعوقات والفرص المتاحة للاستخدام بشكل أكبر للبيانات التي يتم الحصول عليها بالاستشعار عن بعد. يستهدف هذا التقرير غير المتخصصين من مستخدمي السياسة ويهدف إلى توضيح هذه الصورة المعقدة وتقريب الفجوة بين المراقبة الأرضية ودوائر اتخاذ القرار بشأن التنوع البيولوجي، بما يساعد على تمكين الحوار البناء من خلال فهم مشترك للحاجات والفرص.

يتكون التقرير من ثلاثة أقسام رئيسية. القسم الأول يصف المنتجات التشغيلية لبيانات المراقبة الأرضية والمنتجات التي تخضع للبحث والتطوير على أساس هدف بهدف، ويناقش بعض استخداماتها ونواحي القصور فيها. تم استخدام نظام إشارات مرور ضوئية لتقييم مدى كفاية البيانات التي يتم الحصول عليها بالاستشعار عن بعد لرصد التقدم نحو تحقيق كل هدف من الأهداف. أما القسم الثاني فهو عبارة عن نقاش دراسات حالة على المستوى القومي تم فيها استخدام بيانات المراقبة الأرضية. وقد تم توضيح قيمة الاستخدام المفتوح لبيانات الوصول في الرصد في الوقت شبه الحقيقي للتهديدات والآراء بشأن التخطيط الاستراتيجي للحفاظ على الطبيعة، وتوضيح المعوقات المتعلقة بالموارد والقدرات التي غالبا ما تواجهها الحكومات في محاولتها لاستخدام بيانات الاستشعار عن بعد لتطوير منتجات ومؤشرات البيانات الوطنية. القسم الثالث من التقرير يصف أوجه القصور والتحديات الرئيسية التي حالت دون الاستفادة من بيانات المراقبة الأرضية لتطوير المؤشرات بشكل أوسع، ويختتم ببعض المناقشات المتعلقة بالتطورات المستقبلية.

نتائج التقرير

تتناول نتائج هذا التقرير عدداً كبيراً من الموضوعات الفنية والمجتمعية والسياسية والمؤسسية والمالية المتعلقة برصد التنوع البيولوجي والطرق التي تستند إلى المراقبة الأرضية لإعداد التقارير عن أهداف أيتشي. ولكن لا يزال هناك تحد رئيسي يواجه عملية دمج تنوع مقاييس التنوع البيولوجي في مجموعة متناسقة من الملاحظات والمنتجات والخدمات التي يمكن بشأنها تصميم مجموعة متخصصة من أنظمة الملاحظة المستندة إلى المراقبة الأرضية تجمع بين البيانات الفضائية المحمولة جواً والبيانات التي تُجمع من الموقع. هناك العديد من الحواجز التي تعترض تطوير القدرات بين جهات التنوع البيولوجي في التقنيات المتعلقة بالمراقبة الأرضية، خاصة في الدول النامية حيث توجد عوائق إضافية في التعليم وعرض النطاق الترددي للإنترنت والوصول للبيانات. إن بناء توافق في الآراء بين خبراء المراقبة الأرضية وعلماء التنوع البيولوجي ومستخدمي السياسة يجب أن يمهد الطريق من أجل حوار أفضل والتعامل مع التوقعات التي يمكن لبيانات المراقبة الأرضية تقديمها. وسوف يسهم هذا التقرير في هذه العملية من خلال عرض واضح للموضوعات التي تخص كل أصحاب المصلحة.

1. INTRODUCTION

1.1 BACKGROUND AND PURPOSE

At the 10th meeting of the Conference of the Parties to the Convention on Biological Diversity (CBD COP 10) Parties, through decision X/2, adopted a Strategic Plan for Biodiversity 2011-2020, including twenty Aichi Biodiversity Targets. Parties committed to using these as a framework for setting national targets and to report on progress using indicators. During COP 11 an Indicator Framework for the Strategic Plan for Biodiversity 2011-2020 was adopted (Decision XI/3). It contains an indicative list of 98 indicators providing a flexible basis for Parties to assess progress towards the Aichi Biodiversity Targets.

Biodiversity indicators are a fundamental part of any monitoring system providing the mechanism for determining whether policies and actions are having the desired effect. They are also designed to communicate simple and clear messages to decision makers. Indicators use quantitative data to measure aspects of biodiversity, ecosystem condition, ecosystem services, and drivers of change, and aim to enhance understanding of how biodiversity is changing over time and space.

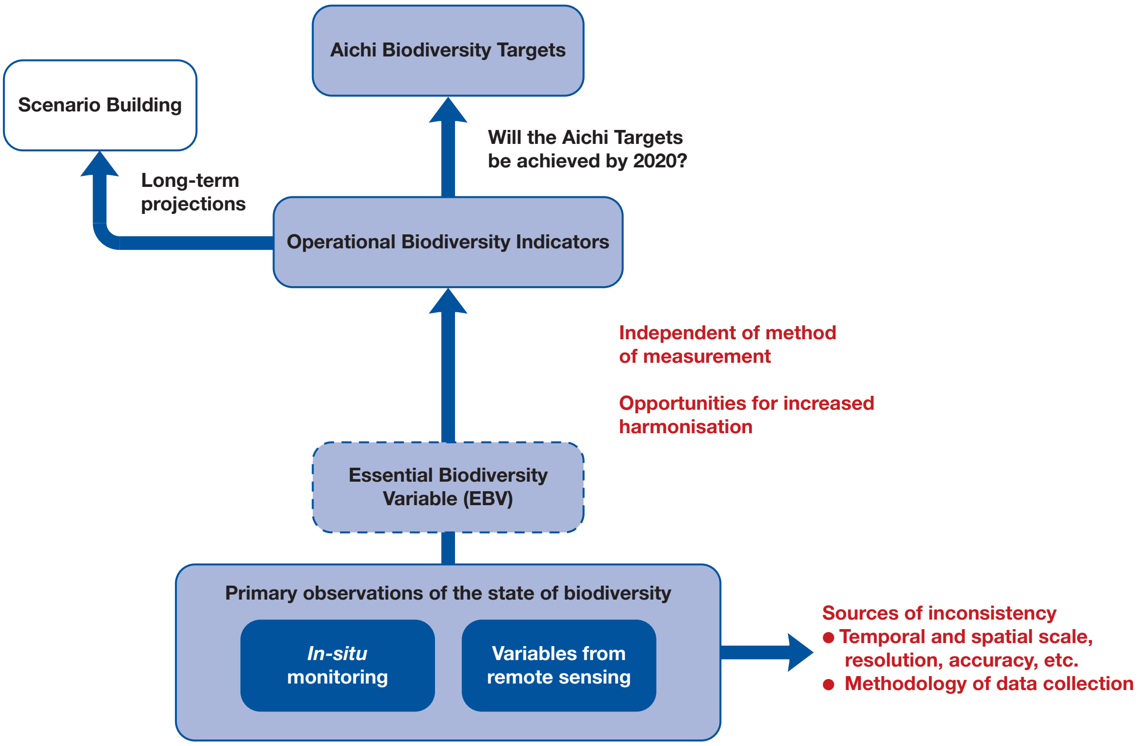
The CBD-mandated Biodiversity Indicators Partnership (BIP) is the global initiative to promote and coordinate development and biodiversity indicators in support of the Convention. The Partnership brings together over forty organizations working internationally on indicator development to provide the most comprehensive information on biodiversity trends. Established in 2007 to support monitoring of the 2010 Biodiversity Target, its mandate was renewed during CBD COP 11 (October 2012), becoming the principle vehicle for coordinating the development of biodiversity indicators at global, regional and national scales, and for delivery of indicator information for monitoring progress towards the Aichi Targets.

To create indicators requires observations, the collection of which may be guided by a set of agreed common variables, such as the proposed Essential Biodiversity Variables (EBVs, Pereira *et al.*, 2013). The EBVs are being developed upon the request of the CBD with the aim to help prioritize by defining a minimum set of essential measurements to capture major dimensions of biodiversity change, and facilitate data integration by providing an intermediate link between primary observations and indicators (Pereira *et al.* 2013). In the context of the Aichi Targets, the EBVs could offer a way to harmonize monitoring efforts carried out by different observation communities, helping the development of a global earth observation system. A number of candidate EBVs have been proposed to guide biodiversity observations. Such observations may be obtained *in situ* by direct, field measurements of individuals, populations, species, habitats, etc., or they may be collected at a distance using specialised instruments for *remote sensing* (Fig. 1).

In situ measurements offer the potential of extracting precise information on the existence and distribution of species. However, since field measurements are particularly time-consuming and expensive they are more practical for small scale, discrete data collection at sample sites rather than extensive, large scale monitoring. In addition, for certain highly variable ecosystems such as wetlands, or those located in remote areas, field-based observation might be difficult.

Remote sensing data, derived from both airborne and satellite sensors, promise a repeatable and cost effective manner to cover spatially extended areas contributing to biodiversity monitoring. However, despite the wealth of remotely sensed data along a spectrum of sensors, wavelengths and resolutions, much of which are available free-of-charge, there is still limited use of remote sensing data for biodiversity monitoring that can detect biodiversity change in time as well as in space. Whilst in part this may be due to data and analytical constraints, it may also in part be due to a lack of adequate connection between user needs (including the specification of standards for each indicator) and opportunities provided by remotely sensed data.

Figure 1. The pathway to biodiversity indicators for the Aichi Biodiversity Targets from remotely sensed data and the role of EBVs.



Biodiversity scientists together with the world's major space agencies are exploring the challenges and opportunities for the use of satellite remote sensing for biodiversity research applications. However, explicit policy needs, such as biodiversity indicators, have to date received little direct attention, partly due to ongoing work on finalising their definitions for the 2020 Aichi Targets.

The present review of the use of remotely sensed data for monitoring biodiversity aims to contribute to fill this gap in the context of the CBD and the Aichi Biodiversity Targets. It has been produced on the request of the CBD Secretariat as a contribution to a developing effort to facilitate and expand the uptake of Earth Observations (EO) in the framework of the Convention. Its objectives are to:

1. Understand the main obstacles to, and identify opportunities for, greater use of remotely sensed data and products in biodiversity monitoring and assessment.
2. Promote and facilitate enhanced, productive dialogue between the remote sensing community and policy end users through a shared understanding of needs and opportunities.

1.2 SCOPE AND DEFINITIONS

This document is not intended to constitute a systematic or exhaustive review of all existing remote sensing technology, neither to be a highly technical discourse on their advantages and disadvantages. It aims to offer an accessible overview of the possibilities remotely sensed data offers to track progress towards the Aichi Biodiversity Targets. Therefore, the content of the core body of the review has been developed with non-specialist policy-users in mind, with additional technical detail contained in the Annexes.

In the context of this review we have adopted the definition of *remote sensing* proposed by the United Nations in 1986 which defines the term Remote Sensing as "the sensing of the Earth's surface […] by making use of the properties of electromagnetic wave emitted, reflected or diffracted by the sensed objects, for the purpose of improving natural resource management, land use and the protection of the environment" (UNGA A/RES/41/65). The review focuses on space-borne (satellite) sensors as they offer the greatest current potential for accessible global data coverage and for operationally viable EO products which can be used for national or regional reporting on the Aichi targets. However, the potential of air-borne and ground-based sensors is also considered, as some ongoing developments could offer novel applications for future biodiversity monitoring although these are still in 'research and development' stages. It is important to emphasize that much of the information derived from remote sensing systems and methodologies result in surrogate, rather than direct measures of biodiversity. This makes it challenging to achieve the quantitative data measures that are needed for conservation targets, nevertheless there are considerable opportunities for progress. A brief description of the different remote sensing technologies and how they can be used to monitor biodiversity can be found in Annex 1.

Spatial resolution is an important attribute of any digital image, describing the level of spatial detail which can be seen in the image. However, a balance must be struck between spatial detail in a satellite image and the field of view of the sensor recording the information conveyed in the image. Generally higher spatial detail requires a sensor with a narrower field of view hence less spatial coverage per image scene. Satellite sensors with a smaller field of view are generally constrained by low revisit times. Coarser spatial resolution sensors tend to image larger areas in one overpass of the satellite sensor with more regular repeat cycles. There are also a number of important biodiversity tradeoffs when considering the spatial resolution of a satellite sensor. For example, low resolution data are perfectly adequate for monitoring current status and recent trends of highly mobile, wide ranging species. In addition, low resolution data are often sufficient for more regional to national level monitoring, while higher resolution data are often desirable for monitoring of individual protected areas. For the purposes of this report four categories of spatial resolution (in metres) have been defined:

- Very high resolution (≤5m)
- High resolution (10- 30m)
- Medium resolution (100-300m)
- Low resolution (>300m)

1.3 APPROACH

The review was based on a desk study of available literature on remote sensing alongside an expert consultative process. An initial list of relevant literature was compiled by consultation with a small group of four specialists in the application of remotely sensed data; which was expanded afterwards following a thematic approach based in the literature referenced in the initial list of publications and by consultation with a larger group of 15 experts.

The expert consultation was conducted through a series of qualitative semi-structured surveys to compile expert knowledge. A group of around 30 specialists consisting of appropriate representatives from the major space agencies and remote sensing scientists/analysts and indicator specialists from the international biodiversity policy community were selected to take part in the process. A questionnaire was specifically developed, structured in three sections: (1) technical and analytical section which focused on collecting information on ecological parameters and EO products currently used, how remotely sensed data is produced, processed and consumed, and existing obstacles in each step; (2) indicators section, in which challenges in the use remotely sensed data to develop indicators were discussed, and existing indicators derived from remote sensing recorded; and (3) future development section, in which interviewees had the opportunity to indicate up to three remote sensing priorities that could realistically be developed or improved within a 5-years framework that would significantly enhance the potential use of remote sensing for monitoring biodiversity. The survey was conducted in person or by telephone when possible, and through completion of the questionnaire in other cases.

1.4 STRUCTURE OF THE REVIEW

The review is organized into an accessible main report of five sections supported by technical annexes.

Section 2 maps remote sensing products against each of the Aichi Biodiversity Targets. Opportunities, as well as gaps and limitations for the use of remote sensing to develop indicators for each target are highlighted.

Section 3 contains a number of case studies illustrating different approaches, methods and products used at national level to monitor diverse aspects of biodiversity, and their impact in decision-making and policy implementation.

Section 4 outlines the key limitations that have hindered the use of remotely sensed data in indicator development to date, and the main challenges encountered. For most of them improvements and possible solutions are suggested using practical examples.

Section 5 summarises the key conclusions of the review and offers final thoughts and recommendations.

Annex 1 gives the reader a brief introduction to remote sensing methods and terminology, and compares these against traditional *in situ* measurements as a tool to monitor biodiversity. It answers common questions about what remote sensing is and how it is used.

Annex 2 analyses existing operational EO products according to their applications in biodiversity monitoring, and specifically in the framework of the CBD. Their potential for supporting the Strategic Plan for Biodiversity 2011-2020 and tracking progress towards the Aichi Biodiversity Targets is discussed.

Annex 3 introduces emerging applications of remote sensing for both marine and terrestrial environments relevant for biodiversity monitoring and outlines new areas of work and potential for future directions in the use of remote sensing in the context of the CBD.

Annex 4 contains a series of detailed tables mapping the various remote sensing products against the Aichi Targets and the EBVs in support of Section 2. Information on spatial and temporal resolution suitable for global, regional and national levels, type of data and appropriate sensors required to develop each of the indicators contained in the indicative list of indicators (Decision XI/3) is described. Potentially appropriate sensors for each Aichi Biodiversity Target and details of their characteristics are also provided (e.g. host organization, repeat viewing frequency, availability, data products).

Annex 5 provides a view on some of the costs involved in using remotely sensed data that policy-end-users should take into account when planning to incorporate remote sensing in their monitoring systems.

2. REMOTE SENSING OPPORTUNITIES FOR MONITORING THE AICHI TARGETS

2.1 OVERVIEW

The field of remote sensing is a discipline in fast and constant evolution, with an increasing number of operational EO products that could be used for biodiversity monitoring. The choice of product can be daunting, as it is difficult to keep up-to-date with the latest developments and improvements in different areas. Nonetheless, the choice of product is in first instance determined by what is to be monitored. A detailed summary of currently available EO products according to their applications in biodiversity monitoring and their potential to support the Convention can be found in Annex 2.

Most of the work done to date to use remotely sensed data for biodiversity monitoring has been focused on the status and trends of selected habitats and species, and on ecosystem integrity, through the use of land cover and land use information. However, research on EO products is continuously evolving and opening new possibilities, as are the satellite sensors themselves. For example, variables which describe the condition of the land surface such as the Normalized Difference Vegetation Index (NDVI), fraction of absorbed Photosynthetically Active Radiation (FAPAR), Leaf Area Index (LAI) and other biophysical indices are continually improving in terms of accuracy, spatial resolution and temporal coverage due to developments in sensor technology. A summary of emerging applications of remote sensing for both marine and terrestrial environments relevant for tracking progress towards the Aichi Biodiversity Targets can be found in Annex 3. Note that these emerging applications are not yet producing operational EO products but hold bright promise for future product development.

In order to support Parties to monitor the Aichi Biodiversity Targets this review analyses the potential use of remote sensing per Target. In general, each Aichi Target has a physical component, e.g. land management, and a societal component based on human practices or understanding, e.g. awareness of biodiversity values. While the former component lends itself to direct observation from space, the latter component does not. As a result, several of the targets may always experience limitations towards developing “adequacy” for EO and remote sensing tools. Nevertheless, in this report a series of factsheets are presented, in which operational EO products have been mapped against each target and its operational indicators.[1] These are suggested products only and end users are encouraged to explore the strengths and weakness of the operational EO products and select those which might be best suited to develop a particular indicator in their own context. The fact sheets do not present an exhaustive list of EO products but only provide a sample of relevant EO products. Furthermore, only operational indicators that can be supported by an EO-based approach are listed e.g. indicators pertaining to Targets 1, 2 and 3, based on non-physical, community awareness values have been omitted, hence Target 4 operational indicators start at operational indicator 11. For most of the operational indicators, EO products are often not direct measures of the indicators but are rather used with biodiversity models in order to derive indicator measurements. For some targets, upcoming EO applications that could be used by Parties in the near future are discussed. A traffic light system has been adopted to assess the adequacy of remotely sensed data to monitor progress towards each of the Aichi Biodiversity Targets. As table 2.1 shows, this varies greatly. Potential applications for Strategic Goal A and E are limited, opportunities to contribute to Strategic Goal B and C have already proven to be extensive, whilst recent developments hold promising options for Strategic Goal D.

Footnote

[1] The Ad Hoc Technical Expert Group on Indicators for the Strategic Plan for Biodiversity 2011-2020 identified three categories of operational indicators. Indicators which are ready for use at the global level are denoted by the letter (A). Indicators which could be used at the global level but which require further development to be ready for use are denoted by the letter (B). Additional indicators for consideration for use at the national or other sub-global level are denoted by the letter (C) and given in italics. The set of (A) and (B) indicators are those which should be used to assess progress at the global level, while the (C) indicators are illustrative of some of the additional indicators available to Parties to use at the national level, according to their national priorities and circumstances.

Table 2.1 Mapping of the current adequacy of remote sensing to support tracking progress towards the Aichi Biodiversity Targets.

🔴 Currently not observable by EO-based approach but some of the targets under this category maybe technically feasible in the future;

🟡 Could be partially derived from EO-based information or EO-based approaches currently in development;

🟢 Can be totally or partially derived from existing EO-based information.

While these categories rate each Target based on adequacy of current and future EO products, only some of the corresponding operational indicators fit the category. The categories are subjective estimates of adequacy based on the most recent information available to authors.

Strategic Goal	Aichi Biodiversity Target	Current remote sensing adequacy		
A	1. Awareness of biodiversity values	🔴		
	2. Integration of biodiversity values	🔴		
	3. Incentives	🔴		
	4. Sustainable production and consumption		🟡	
B	5. Habitat loss, fragmentation and degradation			🟢
	6. Sustainable exploitation of marine resources		🟡	
	7.Biodiversity-friendly agriculture, forestry and aquaculture		🟡	
	8. Pollution reduction			🟢
	9. Control of invasive alien species		🟡	
	10. Coral reefs and other vulnerable ecosystems		🟡	
C	11. Protected areas			🟢
	12. Prevented extinction of threatened species		🟡	
	13. Genetic diversity of socio-economically and culturally valuable species	🔴		
D	14. Ecosystem services			🟢
	15. Ecosystem resilience		🟡	
	16. Access and benefit sharing	🔴		
E	17. NBSAPs	🔴		
	18. Traditional Knowledge and customary use	🔴		
	19. Biodiversity knowledge improvement and transfer	🔴		
	20. Resource mobilisation	🔴		

In addition to the summary factsheets a range of more detailed information can be found in Annex 4. A more detailed mapping of Aichi Biodiversity Targets to operational EO products, with a summary of key features and various available datasets, can be found in Annex 4, Table 4.3. In addition, an in-depth mapping of each of the 98 indicators included in the indicative list of indicators, providing information on spatial and temporal resolution suitable for global, regional and national levels, type of data and appropriate sensors required to develop the indicator, can be found through tables 4.4A to 4.4E, also in Annex 4. It should be noted this mapping does not mean to be absolute. It should be regarded as a guideline, and is subject to review and refinement. To complement these, a description of existing remote sensing sensor characteristics and their potential use for each Aichi Biodiversity Target can be found in Table 4.5.

2.2 TARGET BY TARGET ASSESSMENT

Target 1. Awareness of biodiversity values
By 2020, at the latest, people are aware of the values of biodiversity and the steps they can take to conserve and use it sustainably.

●	Currently not measurable by an EO-based approach
Operational Indicators that can be (partly) derived from remotely-sensed data	None
Limitations	While it is expected that awareness leads to positive gains for biodiversity including measurable environmental factors such as reforestation, sustainable agriculture, increased fish stocks, restored habitats and the preservation of species diversity, there is no way to directly correlate human awareness with a change in environmental conditions using remote sensing. However, the potential of comprehensive maps of biodiversity change, showing deforestation over time, for example, is yet to be fully realised in influencing human awareness of ecosystem changes. Their broader integration into educational curricula at school level would be one way forward in creating awareness amongst the youth.

	Target 2. Integration of biodiversity values By 2020, at the latest, biodiversity values have been integrated into national and local development and poverty reduction strategies and planning processes and are being incorporated into national accounting, as appropriate, and reporting systems.
●	Currently not measurable by an EO-based approach
Operational Indicators that can be (partly) derived from remotely-sensed data	None
Limitations	Green infrastructure such as ecological networks, forest corridors, viaducts, natural water flows and other realisations of the integration and implementation of biodiversity values into spatial planning are potentially possible to measure with remote sensing, if they are represented by visible features on the surface of the Earth. Whilst monitoring these might inform national accounting, it says little about actual integration into accounting, planning and development strategies.

<table>
<tr><td colspan="2">Target 3. Incentives
By 2020, at the latest, incentives, including subsidies, harmful to biodiversity are eliminated, phased out or reformed in order to minimize or avoid negative impacts, and positive incentives for the conservation and sustainable use of biodiversity are developed and applied, consistent and in harmony with the Convention and other relevant international obligations, taking into account national socio economic conditions.</td></tr>
<tr><td>●</td><td>Currently not measurable by an EO-based approach</td></tr>
<tr><td>Operational Indicators that can be (partly) derived from remotely-sensed data</td><td>None</td></tr>
<tr><td>Limitations</td><td>Although the impacts of subsidy reform (for example on land cover and ecological condition) may be partly assessed via remote sensing, subsidy reform cannot be directly measured with remotely sensed data.</td></tr>
</table>

	Target 4. Sustainable consumption and production By 2020, at the latest, Governments, business and stakeholders at all levels have taken steps to achieve or have implemented plans for sustainable production and consumption and have kept the impacts of use of natural resources well within safe ecological limits.
●	EO-based products can contribute to this Target but must be combined with other sources of data for a more comprehensive overview
Operational Indicators that can be (partly) derived from remotely-sensed data	11. Trends in population and extinction risk of utilized species, including species in trade (A) 12. Trends in ecological footprint and/or related concepts (C) 13. Ecological limits assessed in terms of sustainable production and consumption (C) 14. Trends in biodiversity of cities (C)
Relevant Operational EO products	Landcover, EO-based measures of productivity (NDVI, FAPAR), carbon content and emissions, greenhouse gas emissions, fire occurrence, Fire Radiative Power and burned areas.
Current EO-based approaches	Carbon parameters are one of the newest remote sensing metrics for monitoring sustainable production and assessing ecological footprint. Historical levels of carbon dioxide and other greenhouse gases (GHGs) provide a baseline to which present day levels, largely available via satellites, can be compared. Carbon dioxide available for plants is measured at ground level either using *in-situ* measurements of gas exchange or using models of light interaction and light use efficiency. These measurements are easier for elevated canopies (forests) than for grasslands. Information on fire occurrence needs to be integrated in the carbon estimates to take into account the carbon loss through biomass burning (as direct emission or as a consequence of forest loss or degradation). Carbon and GHG emissions can also be combined with other remotely sensed data products, such as landcover, vegetation indices, burned area maps, crop yield estimation and habitat degradation in order to measure sustainability in production (agriculture and forestry) (**indicators 12** and **13**). **Indicator 11** has a very broad focus and the adequacy of remote sensing technologies for this task must be evaluated on a species basis. Typically, EO technologies for counting populations of species are not adequate for any but the most dominant species. Agricultural monitoring has long been conducted with EO-based terrestrial vegetation products combined with traditional agro-meteorological forecasts which estimate crop yields (**indicator 13**). However, linking such agro-meteorological information and other resource production information with ecological limits for sustainable production presents a new twist on this application.
Limitations	**Indicators 11** and **14** are currently limited by the temporal, spatial and spectral resolution of current operational EO-based products, as well as *in situ* data (used, for example, to calibrate and validate the models). With the exception of MODIS many EO sensors measure atmospheric carbon content and not CO^2 available to plants. Canopy-level approaches to carbon estimation do not currently converge and vary between models and direct observations using *in-situ* sensors.
Upcoming EO-based approaches	Such a product could provide the means to quantify global production on a regular basis and for forecasting future production with respect to defined ecological limits. Hyperspectral data greatly improves species discrimination of vegetation and therefore habitat, among other high precision surface condition measurements, e.g. pigment concentration and chlorophyll fluorescence. However, while airborne hyperspectral data are available now, and new satellite-based sensors are being developed, existing operational hyperspectral sensors have not yet achieved seamless global coverage and may not do so within their lifetime.

Target 5. Habitat loss fragmentation and degradation
By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced.

●	EO-based information can make a significant contribution to monitoring this Target and is already widely in use in assessing changes in forest cover
Operational Indicators that can be (partly) derived from remotely-sensed data	17. Trends in extent of selected biomes, ecosystems and habitats (A) 18. Trends in proportion of degraded/threatened habitats (B) 19. Trends in fragmentation of natural habitats (B) 20. Trends in condition and vulnerability of ecosystems (C) 21. Trends in the proportion of natural habitats converted (C) 22. Trends in primary productivity (C) 23. Trends in proportion of land affected by desertification (C) 24. Population trends of habitat dependent species in each major habitat type (A) 25. Trends in fire regimes and fire frequency (B)
Relevant Operational EO products	Land cover, NVDI, LAI, FAPAR, and marine EO-products (ocean chlorophyll-a concentration, ocean primary productivity, suspended sediment, sea surface wind speed, sea surface temperature, sea surface salinity, and sea surface state).
Current EO-based approaches	Landcover mapping is routinely performed in terrestrial environments by remote sensing based methodologies using land cover as a surrogate for habitat type. Habitat distribution represents one of the most common pieces of information reported by Parties to the CBD. Optical sensors are the primary choices for this task because the optical sensor products are most widely available and easy to use. Radar and thermal imagery are technically more advanced requiring specialist knowledge. For example, Global Forest Watch (GFW) 2.0 of the World Resources Institute is a near-real time deforestation monitoring tool based on a time series of Landsat satellite imagery from 2000 to 2012. A global forest cover change product at 30m is now available for the analysis of forest fragmentation, deforestation and proportions of forest converted to other land use (**indicators 19** and **21**). High resolution imagery such as Landsat, SPOT, ASTER and IRS are often sufficient for the purpose of habitat mapping over large areas, even in complex fine-scale habitat mosaics. Land cover is useful for terrestrial habitat loss and fragmentation (**indicators 18** and **19**) while NDVI, LAI and FAPAR are used to assess vegetation condition, status and health and hence trends in primary productivity (**indicator 22**). Fire represents a major habitat disturbance so monitoring fire occurrence (hot spots) and the burned areas extent is also very important to understand and quantify habitat loss and land cover change. Long term monitoring of these data in areas of high aridity and prone to drought can provide data for **indicator 23** and **indicator 25**. Marine products such as ocean chlorophyll-a concentration, ocean primary productivity, suspended sediment, sea surface wind speed, sea surface temperature, sea surface salinity and sea surface state define the physical and biological state of the marine environment. Synthesising these products offers the potential to assess the overall condition of marine habitats and identify where degradation is occurring, e.g. in the detection of coral reef bleaching events (**indicator 18** and **20**). The NOAA Coral Reef Watch monitoring programme operationally monitors coral bleaching in this way. EO-based assessments of marine and coastal habitat extent are common in mangrove, saltmarsh, seagrass and coral reef mapping. Although submerged aquatic habitats, e.g. seagrasses, are more challenging for EO-based techniques than exposed mangroves, for example.

Limitations	Although a global forest cover change dataset has very recently been made available, and planned to be periodically updated, no such dataset exists for non-forest habitats. The global forest data are limited, however, in that the classification of forests only considers trees > 5m tall. In addition, land use type is not considered in the classification, making the separation of primary, secondary and plantation forest challenging without additional contextual information. Although EO-based landcover data do exist for the development of **indicator 17**, there are limitations due to the lack of consistent time series of landcover to conduct a robust change analysis to assess trends in habitat extent over time VHR satellite, airborne or unmanned aerial vehicle (UAV)-based imagery can provide fine scale mapping of habitats with high spatial heterogeneity but are generally expensive and perhaps time consuming to procure and process. Although hyperspectral data can greatly improve mapping and understanding of the situation on the ground, it is mostly limited to airborne sensors and so is limited in geographic scope. This is also true of LiDAR, which is excellent for describing the vegetation architecture of a habitat, especially forests. The different intra- and international definitions of various types of habitats make it difficult to develop global or often regional views, even when the EO observations exist, hindering the ability to track progress toward achieving Target 5. Key gaps in data on habitat extent, fragmentation and degradation include: the condition of temperate coastal marine habitats, offshore marine breeding and spawning grounds, kelp forests, intertidal and sub-tidal ecosystems, vulnerable shelf habitats, seamounts, hot-and cold seeps, ocean surface, benthic and deep sea habitats; inland wetland, non-forested terrestrial habitats and polar habitats. Better information is also needed on small-scale habitat degradation in all habitats.
Upcoming EO-based products	Recent very high resolution (VHR) satellites such as WorldView-2 are beginning to open up the possibility of combining high spatial and spectral resolution in the same platform. This holds promise for applications in the intertidal zone which has traditionally been difficult to monitor due to wave action, tides, and other challenges to interpretation. Active remote sensing using Radar and LiDAR also holds great potential for the mapping and identification of structurally complex habitats, especially in tropical areas where there is high and/or frequent cloud cover. Satellite-based hyperspectral sensors are being developed and these can greatly improve species discrimination of vegetation.

References: Lengyel *et al.*, 2008; Lucas *et al.*, 2011; Nagendra and Rocchini, 2008; Szantoi *et al.*, 2013.

	Target 6. Sustainable consumption and production By 2020 all fish and invertebrate stocks and aquatic plants are managed and harvested sustainably, legally and applying ecosystem based approaches, so that overfishing is avoided, recovery plans and measures are in place for all depleted species, fisheries have no significant adverse impacts on threatened species and vulnerable ecosystems and the impacts of fisheries on stocks, species and ecosystems are within safe ecological limits.
●	EO-based products can contribute to this Target but must be combined with other sources of data for a more comprehensive overview. Economic information on fisheries would be particularly beneficial in this regard.
Operational Indicators that can be (partly) derived from remotely-sensed data	26. Trends in population of target and bycatch aquatic species (A) 29. Trends in fishing effort capacity (C)
Relevant Operational EO products	Ocean chlorophyll-a concentration, ocean primary productivity, suspended sediment, sea surface wind speed, sea surface temperature, sea surface salinity and sea surface state.
Current EO-based approaches	As with terrestrial species, direct observation of aquatic species with satellite remote sensing is not usually possible. In order to estimate populations of aquatic species, EO-based oceanographic products (mainly but not exclusively ocean colour products) are usually used together with species modeling to assess habitat condition. In the marine environment, primary productivity has been linked to phytoplankton abundance and diversity which in turn is estimated through measures of ocean colour (chlorophyll concentration). Much progress has also been made in monitoring these constituents in inland waters. Other EO-based oceanographic products e.g. sea surface temperature can help in understanding the condition of marine habitats. However, **indicators 26** and **29** do not lend themselves to such EO-based measures and are best monitored using national-level statistics on fisheries which can be aggregated to the global level where needed.
Limitations	Most remote sensing methods can only derive information from the upper layer of the ocean hence the EO technique mostly used in the marine environment is measurement of Ocean Colour. Space-borne optical sensors are naturally limited at shallow ocean depths (20-30 meters) due to the light absorption properties of sea water. The best available sensors at airborne ranges (i.e.LiDAR) can potentially only reach up to depths of 70 meters, but more commonly penetrate in a range from 35-50m. This focus on shallow water monitoring impedes the monitoring of many marine species, with the exception of some marine mammals and phytoplankton. Although optical and radar sensors have the potential to monitor over-exploitation of fisheries by detecting marine vessels and monitor vessel movements **(indicator 29**), this is very expensive and the real time requirement is challenging, particularly for satellite-based systems.

References: Corbane *et al.*, 2010 ; Guildfor and Palmer 2008; Kachelreiss *et al.*, 2014; McNair 2010; Rohmann and Monaco 2005.

Target 7. Biodiversity-friendly agriculture, forestry and aquaculture By 2020 areas under agriculture, aquaculture and forestry are managed sustainably, ensuring conservation of biodiversity	
●	EO-based products can contribute to this Target but must be combined with other sources of data for a comprehensive overview of status of the Target. Land use information would be particularly beneficial in this regard as would socio-economic data on sustainability values in order to complement EO.
Operational Indicators that can be (partly) derived from remotely-sensed data	32. Trends in population of forest and agriculture dependent species in production systems (B) 33. Trends in production per input (B) 34. Trends in proportion of products derived from sustainable sources (C) 35. Trends in area of forest, agricultural and aquaculture ecosystems under sustainable management (B)
Relevant Operational EO products	Land cover, agricultural and forestry production estimates (where available), fire occurrence and burned area maps.
Current EO-based approaches	A land cover dataset with regular and repeated updates is essential base information for measuring and monitoring agricultural and forestry production (**indicators 32** to **35**). Crop production datasets, often regional, are produced by models that use a variety of EO and other inputs. Understanding disturbances and land cover change drivers is essential to address the causes of biodiversity loss. Monitoring fire occurrence can help understand some of the drivers in land use change since fire is often used for land conversion (for example to establish new agriculture areas).
Limitations	A strict definition of "biodiversity-friendly" land use needs to be provided in order to fully evaluate the application of EO technologies to monitoring 'biodiversity-friendly' agriculture, aquaculture and forestry. However, using existing land cover mapping methods, it is feasible to combine a land cover map with non-EO spatial data layers on land use, e.g. on the type of agriculture, forestry and aquaculture being practiced, and land management to create a 'biodiversity-friendly' land use layer. Such hybrid approaches, combining EO-based landcover with non-EO information on land use and land management could be useful for this Target. More work is needed to identify and define sustainable practices that enable biodiversity conservation. Indicators of 'biodiversity friendly' practices will need to be identified and the feasibility to measure those indicators by remote sensing either directly or indirectly, will need to be ascertained. For example, it would be useful to determine how various mixtures of agriculture and forest plots, and their species content, affect biodiversity. Monocultures, for example, can feasibly be mapped by EO since they are homogenous in composition and should have a consistent spectral signature but are unlikely to be biodiversity friendly. Aquaculture may be more challenging, however, since the spectral information alone may not be sufficient to characterise aquaculture from spaceborne sensors.

Target 8. Pollution Reduction By 2020, pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity	
●	EO-based products can contribute to this Target but must be combined with other sources of data for a comprehensive overview of status of the Target. Information on sources and sinks of pollutants would be particularly beneficial in this regard.
Operational Indicators that can be (partly) derived from remotely-sensed data	36. Trends in incidence of hypoxic zones and algal blooms (A) 37. Trends in water quality in aquatic ecosystems (A) 39. Trends in pollution deposition rate (B) 41. Trend in emission to the environment of pollutants relevant for biodiversity (C) 44. Trends in ozone levels in natural ecosystems (C) 46. Trends in UV-radiation levels (C)
Relevant Operational EO products	Ocean chlorophyll-a concentration, suspended sediments and dissolved organic matter, tropospheric ozone.
Current EO-based approaches	Algal blooms can be monitored globally by measuring Chl-a levels, using a variety of EO sensors designed for sensitivity to the abosorption spectra of chlorophyll. Trends in chlorophyll levels can indicate water quality issues such as excessive nutrients, which results in algal blooms and cause hypoxic zones (**indicators 36** and **37**). Land use in the form of agriculture and development can have negative effects on marine biodiversity due to run-offs. Tropospheric ozone measurements are used to estimate UV radiation levels; UV radiation can damage plants and cause problems for exposed animals. The NASA Total Ozone Mapping Spectrometer (TOMS) measures monthly ultraviolet radiation potentially usable in **indicator 46**. However, the data were only gathered from 1996 to 2004, and are at a coarse resolution (~110km) limiting national level use of these data. Atmospheric monitoring of haze, smoke and smog occupy a large proportion of remote sensing studies on pollution monitoring. All of these pollutants are caused by harmful particles emitted to the environment by burning fossil fuels. Although, there are examples of EO-based approaches to measuring these emissions, as discussed in 2.1.3 in annex 1, EO-based trends in these emissions are difficult to produce systematically due to the lack of routine monitoring at the national level as needed for **indicator 41**. The main parameters for monitoring pollution in coastal and inland waters include Suspended Particulate Matter (SPM) and Coloured Dissolved Organic Matter (CDOM), while chlorophyll is also important as changes in phytoplankton diversity and abundance could be triggered by pollution events. SPM, like many biophysical parameters available from remote sensing serves only as an indicator for land-based pollutants that cannot be detected by remote sensing. SPM and CDOM can also be inferred from ocean colour data but only when ground calibration data is available. Remote sensing can be critical in tracking oil spills through the use of synthetic aperture radar (SAR) or infrared sensors, which can 'see' through clouds, and hyperspectral data, which are very good at discriminating hydrocarbons and minerals. Radar-based oil-spill detection is now operationally used by many agencies such as the European Maritime Safety Agency (EMSA) in Europe.
Limitations	EO-based sensors are limited in their measurement of ozone to the upper atmosphere. Ground-level ozone, which is most harmful to plant life, is not currently measurable with EO data (**indicator 44**). Hyperspectral imagery, e.g. from EO-1, Hyperion or the Advanced Land Imager (ALI), require complex processing and computing capacity and may not provide coverage where it's needed most, e.g. in the event of a major pollution event. Satellite-based oil spill detection potentially has a role to play in the development of **indicators 37** and **39**, however, the significance of oil spill pollution as a biodiversity indicator requires further understanding.

References: Kachelreiss *et al.*, 2014; Oney *et al.*, 2011.

Target 9. Control of invasive alien species
By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment.

●	Direct detection of invasive alien species such as plants and algae with remote sensing is limited to organisms which cover wide areas, provided that they are the dominant fraction in an image pixel. Monitoring the movement of smaller organisms, including those that are invasive, can be achieved directly with animal-based tags or indirectly using environmental niche modelling, incorporating remotely sensed environmental variables on habitat condition.
Operational Indicators that can be (partly) derived from remotely-sensed data	47. Trends in the impact of invasive alien species on extinction risk trends (A) 48. Trends in the economic impacts of selected invasive alien species (B) 49. Trends in number of invasive alien species (B) 52. Trends in invasive alien species pathways management (C)
Relevant Operational EO products	Land Cover/Land Cover Change and Land Cover disturbance such as deforestation, fires and burnt areas and anomalies in measures of vegetation condition which highlight disturbance.
Current EO-based approaches	EO is used to directly monitor the spatial distribution of certain plant species either by thematically classified images of plant species or communities or as an input to models that predict their distribution. In addition, EO-based products are used to map physical pathways for invasive plant species which frequently occur along disturbance routes, e.g. roads and other infrastructure in forests or drainage channels in wetlands. Both fire and land cover change products can be used to map pathways for invasive plant species to enter previously intact habitats. Animal-based tags proved the means to answer questions about species' distributions or their pathways, and therefore are of high importance for the control of invasive animal species. Airborne hyperspectral imagery is especially useful when timing the acquisition of data with critical phenological stages of flowering or leaf senescence of the invasive plant species provided it differs from that of surrounding native vegetation. Given free access to imagery from AVIRIS or from the Airborne Prism Experiment (APEX), this is entirely feasible for selected sites. Employing measures of image texture with NDVI, derived from sub-metre resolution imagery, can greatly improve classification accuracy and overall ability to track invasive species. EO-based data for **indicator 47** are not routinely generated but can be produced using specialist knowledge. This would then need to be combined with information on extinction risk. Once a satisfactory layer of invasive species distribution has been derived, **indicators 48** to **52** are feasible given access to comparable economic and management information
Limitations	Intra-species variation, mixed pixels due to high levels of heterogeneity and shadowing in the image can decrease success when using multispectral and hyperspectral imagery. Accurate discrimination of all top-canopy species is therefore unlikely, particularly in high density forests where there is a substantial amount of overlap between leaves and branches of different species. This problem is unlikely to disappear even if image resolution and noise to signal ratios improve significantly in the future. Very High Resolution imagery (e.g. Quickbird, IKONOS, GeoEye) has been found to be unsuitable for invasive species identification and monitoring because of the very small pixel sizes and lack of a short-wave infrared band, increasing the variability between different tree canopies in the scene. Invasive animals are difficult to detect directly, but indirect methods based on measures of disturbance, such as observing the consequences of a pathogen, may be useful.

References: Fuller 2005; Nagendra 2013.

Target 10. Coral reefs and other vulnerable ecosystems

By 2015, the multiple anthropogenic pressures on coral reefs, and other vulnerable ecosystems impacted by climate change or ocean acidification are minimized, so as to maintain their integrity and functioning.

●	EO-based products can contribute to this Target but are mostly limited to shallow-water environments and site-specific studies.
Operational Indicators that can be (partly) derived from remotely-sensed data	53. Extinction risk trends of coral and reefs fish (A) 54. Trends in climate change impacts on extinction risk (B) 55. Trends in coral reef condition (B) 56. Trends in extent, and rate of shifts of boundaries, of vulnerable ecosystems (B)
Relevant Operational EO products	NOAA Coral Reef Watch products (bleaching alert area, degree heating weeks, bleaching hotspots, Sea Surface Temperature (SST), SST anomalies).
Current EO-based approaches	Coral bleaching can be directly detected using a variety of sensors, including commercial VHR sensors, Landsat, and MERIS, however, detection and mapping precision depends on the extent of the bleaching event and sensor resolution. NOAA Coral Reef Watch (CRW) uses a variety of EO products based on the retrieval of surface water parameters that are related to (or can condition) the presence of bleaching events, such as SST. Consequently, bleaching alerts and disease risks are issued based on models which are built on EO parameters such as SST. Therefore, CRW data can be used for **indicator 53**, especially for over 200 virtual stations which have time series data since 2000 to present. Information on extinction risk is best derived from existing biodiversity datasets. **Indicator 55** is difficult to monitor globally since global datasets on coral reef condition are not available. The same limitation holds for **indicator 54** on other vulnerable ecosystems such as wetlands. Regional datasets do exist related to climate change impacts on vulnerable ecosystems and shifts in their boundaries (e.g. Reefs at risk), however, a lack of time series data and operational monitoring poses a challenge to further indicator development (**indicator 55** and **56**).
Limitations	The Coral Reef Watch 50km resolution products makes them useful for identifying potential problem areas, but they do not pinpoint the location of problem areas. The limitations of monitoring marine habitats and species due to shallow depth penetration of spaceborne and airborne sensors was discussed in Target 6 but is also relevant for Target 10 as it affects the ability to directly monitor coral reefs and other potentially vulnerable marine ecosystems in deeper waters. However, monitoring coral reefs is generally limited by the lack of EO sensors with combined spectral content and high to very high spatial resolution. Mapping coral reef species is feasible with the rich spectral content offered by hyperspectral sensors but this is largely research-based work. The best solution for bathymetric mapping and under-water habitat classification are proving to be those provided by LiDAR with its pin-point precision and high resolution; however, even LiDAR falls short of capturing the complexity of coral reefs and other complex habitats. This means that for the foreseeable future, mapping individual colonies or reefs will remain unfeasible with airborne or satellite remote sensing. Airborne and spaceborne sensors are more appropriate for marine habitat mapping in pelagic ecosystems which are influenced by broader oceanographic patterns and can therefore be monitored synoptically.
Upcoming EO-based products	Linked airborne LiDAR and underwater-towed side-scan sonar, datasets are currently being developed. High-accuracy depth measurements, good geolocation, and side scan sonar are combining to provide more accurate benthic habitat maps.

References: Kachelriess *et al.*, 2014; Purkis and Klemas 2011.

Target 11. Protected areas
By 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes.

●	EO-based information can make a significant contribution to monitoring this Target, when combined with non-EO data, on protected area distribution and can be complemented by field-based information to assess protected area effectiveness.
Operational Indicators that can be (partly) derived from remotely-sensed data	59. Trends in coverage of protected areas (A) 60. Trends in extent of marine protected areas, coverage of key biodiversity areas and management effectiveness (A) 61. Trends in protected area condition and/or management effectiveness including more equitable management (A) 62. Trends in representative coverage of protected areas and other area based approaches, including sites of particular importance for biodiversity, and of terrestrial, marine and inland water systems (A) 63. Trends in the connectivity of protected areas and other area based approaches integrated into landscapes and seascapes (B)
Relevant Operational EO products	Land cover and land cover change, NDVI, NDVI-derived anomalies such as the Vegetation Condition Index or the Vegetation Productivity Index, LAI, FAPAR, fire extent, Global Forest Watch 2.0
Current EO-based approaches	Although global land cover and land cover change datasets are not routinely available (except, recently, for forests), many EO sensors are available, at various scales, that provide information on condition, representative coverage, habitat fragmentation and connectivity, though combination with other sources of data are generally needed for routine monitoring of **indicators 59** to **63,** e.g. in assessing management effectiveness (though, this information by itself is not sufficient). Hyperspectral, hyperspatial, optical, radar and LiDAR remote sensing can all be beneficial to monitoring biodiversity within and around protected areas. Informatics tools such as the JRC Digital Observatory for Protected Areas (DOPA) deliver up to date EO-based information on protected areas via web-based technologies. In addition, a new JRC Fire Tool based on EO data uses the World Database of Protected Areas to monitor global fire activity in protected areas. This has particular relevance to **indicator 61**, related to condition, as the DOPA combines time series of EO parameters on vegetation condition and water bodies with meteorological information on rainfall, air temperature. However, this indicator requires other social data in order to evaluate "more equitable management."
Limitations	Protected area condition cannot always be assessed using remote sensing, for example, selective logging, invasive species, and agricultural encroachment can be missed, and hunting is not detectable.

	Target 12. Prevent extinction of threatened species By 2020 the extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained.
●	EO-based information can make a significant contribution to monitoring this Target but only for certain species and in specific habitats. Ground observations of species could be particularly beneficial when combined with EO-based information on habitat status.
Operational Indicators that can be (partly) derived from remotely-sensed data	65. Trends in abundance of selected species (A) 66. Trends in extinction risk of species (A) 67. Trends in distribution of selected species (B)
Relevant Operational EO products	NDVI, FAPAR, LAI, and Land cover
Current EO-based approaches	Habitat monitoring and predictive modeling, provides information on whether a species' habitat is disappearing or threatened, thus helping to assess extinction risk. However, good habitat condition doesn't always imply a healthy population. Nevertheless, operational parameters such as NDVI, FAPAR, and LAI can be used to characterise the vegetation state and hence habitat condition for areas of threatened terrestrial species of animals and plants. Species distribution modelling helps determine the dependency that a species has on certain environmental conditions. The trends of those conditions thus can indicate distribution trends (**indicator 67**) as well as extinction risk **(indicator 66** - if those conditions are disappearing) and, potentially, if enough additional data are available, abundance (**indicator 65**). A suite of many environmental variables are available as input to species distribution models, landcover being one of the most commonly used input into models that predict habitat change. Animal telemetry is an invaluable technology for monitoring the distribution trends of selected species at risk of extinction (**indicator 67**) as discussed in section 3.5 of Annex 3. In relation to monitoring species, the direct observation of individual species is usually not possible using remotely sensed information, with exceptions only among mega-fauna where the animals or their habitats can be easily detected. Examples where this kind of monitoring has been successful include blue shark, bluefin tuna, whale sharks, seabirds, elephants, wildebeest and zebra, marmots, and penguins. Nonetheless, biophysical parameters that are reported to structure biodiversity patterns can be derived from remotely sensed data.
Limitations	Abundance can be challenging as direct measurements for both plants and animals is difficult or impossible. Hyperspectral data and LiDAR can enhance the ability to model (or measure) species distributions but these are expensive and of limited availability.
Upcoming EO-approaches	Hyperspectral observations combined with LiDAR can discriminate individual species in a tree canopy; however, this is an emerging technology and has been done only at selected sites. For the foreseeable future, this approach will require airborne measurements, and so be limited in scope, expensive, and require specialized expertise.

References: Druon, 2010; Fretwell *et al.*, 2012; Petersen *et al*, 2008; Queiroz *et al.*, 2012; Sequeira *et al.*, 2012; Velasco, 2009; Yang, 2012.

Target 13. Genetic diversity of socio-economic and culturally valuable species

By 2020, the genetic diversity of cultivated plants and farmed and domesticated animals and of wild relatives, including other socio-economically as well as culturally valuable species, is maintained, and strategies have been developed and implemented for minimizing genetic erosion and safeguarding their genetic diversity.

●	Currently not measurable by an EO-based approach
Operational Indicators that can be (partly) derived from remotely-sensed data	None
Limitations	In order to understand the exchange of genetic material between isolated populations, long time series are needed spanning several decades, ideally while remotely sensed imagery has only been available for the last few decades at most,
Upcoming EO-approaches	Genetic material contained in an individual animal or plant cannot be measured directly by remote sensing, based methods or current operational EO products. However, EO-based methods of monitoring populations of species directly, e.g. by counting individuals or estimating their coverage, could potentially contribute to this Target. Monitoring isolated populations of the same species over time could be used to assess the level of exchange of genetic material and whether genetic diversity is being safeguarded. The benefit of an EO-based approach is the ability to measure the spatial distribution of different populations over large areas using image interpretation techniques. The extent to which these populations mix could be reasonably estimated in this way. Studies have incorporated EO-based information on contemporary species ranges with their modelled distributions in the past to assess how genetic changes have occurred over time among isolated populations of species. This is largely an experimental but a highly promising application of EO data to map spatial variation in genetic diversity. Other approaches in development include linking of genetic microsatellite markers assessing genetic diversity to pigment diversity at forest canopy scale and, at a broader scale, linking genetic diversity to remotely-sensed land surface phenology.

14	**Target 14. Ecosystems and essential services safeguarded** By 2020, ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded, taking into account the needs of women, indigenous and local communities, and the poor and vulnerable.
●	EO-based information can make a significant contribution to monitoring this Target by providing inputs to ecosystem service models.
Operational Indicators that can be (partly) derived from remotely-sensed data	73. Trends in benefits that humans derive from selected ecosystem services (A) 75. Trends in delivery of multiple ecosystem services (B) 76. Trends in economic and non-economic values of selected ecosystem services (B) 78. Trends in human and economic losses due to water or natural resource related disasters (B) 79. Trends in nutritional contribution of biodiversity: Food composition (B) 80. Trends in incidence of emerging zoonotic diseases (C) 81. Trends in inclusive wealth (C) 82. Trends in nutritional contribution of biodiversity: Food consumption (C) 84. Trends in natural resource conflicts (C) 85. Trends in the condition of selected ecosystem services (C) 87. Trends in area of degraded ecosystems restored or being restored (B)
Relevant Operational EO products	Precipitation, water body distribution, carbon/biomass, landcover fragmentation and fire.
Current EO-based approaches	Habitat extent and condition affects the amount and quality of a variety of ecosystem services, so these are an important input to ecosystem services models. Carbon and water-based ecosystem services are the most readily observable by EO-based technologies, provided that the appropriate base layers can be readily derived at the national or global scale, depending on the needs of the indicator. Therefore, **indicators 73** to **87** are potentially measurable for selected ecosystem services. These include: • Carbon storage using above-ground woody carbon terrestrial biomass measurements derived from a combination of field measurements, LiDAR and MODIS imagery. • Water provision using models of water-based ecosystem services — precipitation inputs can be derived from the NASA/JAXA Tropical Rainfall Measuring Mission (TRMM); — land surface temperature data derived from satellite sensors such as Landsat, AVHRR, MODIS and ASTER; — groundwater provision can be measured indirectly from temporal variation in Earth's gravity field as measured by the Gravity Recovery and Climate Experiment (GRACE) mission; — landcover and/or vegetation cover, e.g. MODIS/VCF, is central to ecosystem models.
Limitations	For terrestrial ecosystems, Ecosystem Service (ESS) mapping relies heavily on land cover as an input to ecosystem models, in order to estimate the value of ecosystem services. Therefore, the result will only be as good as the model and the land cover inputs used. Global mapping of carbon, stored in terrestrial vegetation, is not straightforward. As a result, published datasets have major differences, not only in terms of the estimates for quantity of biomass (carbon), but also in terms of the distribution pattern of carbon they provide. It is worth noting that without appropriate statistics on socio-economics, health and other humanitarian themes, an EO-based approach alone is unlikely to contribute directly to the operational indicators listed in this Target.
Upcoming EO-approaches	ESS mapping using remote sensing is an area undergoing huge development and expansion. For instance, models capable of assigning dynamic vegetation change to climatic drivers or human and other drivers are being developed. This demonstrates that it is possible to attribute drivers to different cause-effect relationships. The EBV concept will also play a key role in guiding how ESS mapping from EO data will develop and mature.

	Target 15. Ecosystem resilience By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced, through conservation and restoration, including restoration of at least 15 per cent of degraded ecosystems, thereby contributing to climate change mitigation and adaptation and to combating desertification.
●	EO-based products can contribute to this Target but must be combined with other sources of data for a more comprehensive overview of progress towards achieving this Target.
Operational Indicators that can be (partly) derived from remotely-sensed data	88. Status and trends in extent and condition of habitats that provide carbon storage (A) 89. Population trends of forest-dependent species in forests under restoration (C)
Relevant Operational EO products	NDVI, FAPAR, fire, land cover and land cover change.
Current EO-based approaches	Time series of NDVI and FAPAR can be used to derive measures of primary productivity and vegetation phenology, which in turn can be related to the rate and timing of carbon sequestration in terrestrial vegetation. NDVI and FAPAR/LAI can also be used to identify and monitor degraded lands. Land cover and land cover change can be used to assess conservation and restoration of habitats. An increasing trend indicates recovery and (presumably) increasing biodiversity and carbon stock. Remotely sensed information on the parameters required for measuring progress toward Target 15, such as NDVI and FAPAR, are globally available but would be more appropriately mapped for specific habitats, e.g. coastal habitats such as saltmarshes or mangroves or terrestrial habitats such as tropical forests or peatlands, as these are essential ecosystems for climate change mitigation as well as harbouring important biodiversity. The high carbon storage capacity of salt marshes, mangroves and sea grasses has already been recognised by the blue carbon scientific working group for example. **Indicator 88** has been designed to measure the extent and condition of these habitats. However, although time series of satellite imagery and derived products can be used for measuring trends in spatial extent, condition is a more challenging variable to measure using an EO-based approach and usually requires ground-based observations to accurately assess their state in terms of degradation and overall health. Initiatives such as the ESA GlobWetland II and the WRI GFW 2.0 have recognised the importance of these ecosystems and promoted EO-based approaches to their conservation and management. GFW data can support efforts to monitor **indicator 89**, however, further research is needed to assess how forests under restoration could be accurately characterised. The timing of EO-based information is also important as utilising seasonal data timed with peak phenological and physiological changes can be useful for early identification of climate change impacts.
Limitations	EO-based carbon estimates are essential for monitoring carbon stocks but are not operationally produced or globally available. Monitoring ecosystem resilience necessities multi-decadal time series of EO data which rules out many sensors except for Landsat and NOAA-AVHRR. Mission continuity must be assured by space agencies if consistent time series of EO data are to be maintained and usable for tracking progress towards this target. Current operational EO products which are typically ≥1km in spatial resolution are not appropriate for the ecosystem-level information that is required to monitor this target comprehensively.

	Target 16. Access and benefit sharing (ABS) By 2015, the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization is in force and operational, consistent with national legislation.
●	Currently not measurable by an EO-based approach
Operational Indicators that can be (partly) derived from remotely-sensed data	None

Target 17. National Biodiversity Strategies and Action Plans (NBSAPs)
By 2015 each Party has developed, adopted as a policy instrument, and has commenced implementing an effective, participatory and updated national biodiversity strategy and action plan.

●	Currently not directly measurable by an EO-based approach but EO data can be utilised in NBSAP planning, e.g. for identifying priority habitats from land cover data or pressures from land cover change or pollution measures
Operational Indicators that can be (partly) derived from remotely-sensed data	None
Current EO-approach	Indirectly, the achievable monitoring of other Aichi Targets over time and within national contexts could potentially indicate whether a country is succeeding at implementing its NBSAPs.

	Target 18. Traditional knowledge and customary use By 2020, the traditional knowledge, innovations and practices of indigenous and local communities relevant for the conservation and sustainable use of biodiversity, and their customary use of biological resources, are respected, subject to national legislation and relevant international obligations, and fully integrated and reflected in the implementation of the Convention with the full and effective participation of indigenous and local communities, at all relevant levels.
●	Currently not directly measurable by an EO-based approach. However, EO-based products could contribute to this Target if combined with other sources of data. Existing EO-based landcover information could enhance existing socio-economic information on land tenure and landuse for a more comprehensive overview of status of the Target.
Operational Indicators that can be (partly) derived from remotely-sensed data	None

<table>
<tr><td colspan="2">Target 19. Biodiversity knowledge improvement and transfer
By 2020, knowledge, the science base and technologies relating to biodiversity, its values, functioning, status and trends, and the consequences of its loss, are improved, widely shared and transferred, and applied.</td></tr>
<tr><td>●</td><td>Currently not directly measurable by an EO-based approach. However, if knowledge and technology in the use of remote sensing to monitor other measurable Aichi Targets is improved as suggested herein, it would contribute toward meeting this target.</td></tr>
<tr><td>Operational Indicators that can be (partly) derived from remotely-sensed data</td><td>None</td></tr>
</table>

	Target 20. Resource mobilisation By 2020, at the latest, the mobilisation of financial resources for effectively implementing the Strategic Plan for Biodiversity 2011-2020 from all sources, and in accordance with the consolidated and agreed process in the Strategy for Resource Mobilisation, should increase substantially from the current levels. This target will be subject to changes contingent to resource needs assessments to be developed and reported by Parties.
●	Currently not directly measurable by an EO-based approach
Operational Indicators that can be (partly) derived from remotely-sensed data	None

3. LESSONS LEARNT FROM NATIONAL EXPERIENCES

Over the last years, countries have adopted different approaches to the use of remote sensing to monitor biodiversity at a national level, according to their particular needs, capacities and circumstances. The following case studies provide an insight into the application of different methods and products at national and subnational level, and their impact on decision-making and policy implementation. They also offer examples of how particular limitations and challenges have been overcome. The value of open access data, national-scale EO data products and indicators, near real time monitoring of threats and inputs to strategic conservation planning are all illustrated, as are the benefits of integrated monitoring networks with observations at multiple spatial scales.

3.1 REMOTE SENSING AS A SURVEILLANCE TOOL: FIRE MONITORING IN AUSTRALIA

Due to the low population base and large size of Australia's land-mass (7.5 million km^2), remote sensing technologies have been used for wildfire ("bushfire") monitoring, fire-scar mapping and general environmental monitoring ever since the first earth observation satellites were launched in the 1970's. For Australia, satellite technologies have proven to be one of the most appropriate technologies for use in wide-area fire detection and tracking, as well as general environmental monitoring, fuel-load mapping and fuel dryness monitoring.

In 2003, the CSIRO (Commonwealth Scientific and Industrial Research Organisation), together with the department of Defense and Geoscience Australia, developed the "Sentinel Hotspots" bushfire tracking system and associated webGIS portal, which used the Moderate Resolution Imaging Spectrometer Sensor (MODIS) onboard NASA's Aqua and Terra satellites. Through the use of these two satellites, a full continental coverage is achieved up to four times every 24 hours, at a spatial resolution of about 1 km, and a time-latency from satellite overpass to visualization of the hotspot location on the webGIS system of approximately 45 minutes, making this a suitable synoptic near real-time fire monitoring system. Today, the Sentinel system is housed at Geoscience Australia (http://sentinel.ga.gov.au/), and continues to be used on a 24/7 basis by federal and state fire management agencies, natural resource managers, ecologists and the general public as fire conditions develop across the country. The Infrared Program from the United Stated Department of Agriculture (USDA)/Department of the Interior (DOI) have also contributed to assisting Australian efforts. Other state-based or regional systems such as "FireWatch" in Western Australia and the NAFI (Northern Australia Fire Information) system in the Northern Territory, use similar approaches.

This operational concept was also adopted in 2006 by the Asia Pacific Regional Space Agencies Forum (APRSAF), as it established the "Sentinel Asia" disaster monitoring system, which now has over 15 regional member governments and relevant agencies supplying and using the information, to help countries in the Asia Pacific monitor the progression of impending disasters, and assess the impacts of floods, rainfall, landslides, earthquakes and other natural disasters.

In parallel, these remote sensing technologies have also been used in Australia to map the burnt area and burn-scars, grass-curing and other fire-related variables associated to bushfires around Australia. The "AusCover" remote sensing data facility (www.auscover.org.au) of the Terrestrial Ecosystem Research Network (TERN – www.tern.org.au) of Australia, has since 2009 been providing free and open satellite-derived information, at regional and continental scales, for use in fire ecology studies, assessment of fire impacts on protected areas and for estimation of greenhouse gas emissions, to name a few uses. A key satellite-derived product called the "fire-severity index", developed and produced for AusCover by Dr. Stefan Maier at the Charles Darwin University in Darwin, allows local land managers and ecologists to monitor the effect of often unplanned fires and strategically implement controlled burns during less damaging times of year. Similarly the "grass curing index" produced by another partner, the Bureau of Meteorology, provides a way to evaluate the dynamics of grass drying and fire-risk, as dry seasons and summers progress across the continent. Such derived datasets provide ecosystem researchers and conservation managers with greater information about the effects of fires on ecological communities, and improve estimates of carbon emissions resulting from fires in different types of ecosystems.

3.2 THE EFFECTIVENESS OF FREE AND OPEN ACCESS DATA: THE BRAZILIAN EXAMPLE

As Brazil is large geographically—more than 8.5 million km^2—and has high biodiverse, special ecosystems such as the Amazonian and Pantanal regions, an ever-growing agriculture, a fast-changing land use and land cover, and a long coastline, it is especially suited for space-based remote sensing technologies. Therefore, Brazil has been at the forefront of remote sensing research and application since 1973 when it was among the first countries to build and operate its own ground station to receive Landsat-1 data.

At the end of the 1980's, Brazil began the development of a civilian remote sensing satellite program with China called China-Brazil Earth Resources Satellite (CBERS), becoming part of one of the first programs in the world involving two developing countries collaborating to develop and launch remote sensing satellites. To date, a constellation of three satellites has been launched (CBERS-1 in 1999, CBERS-2 in 2003 and CBERS-2B in 2007), and one more satellite is on the way (CBERS-4 planned for 2104).

One of the main aspects of the CBERS Program is the data policy adopted after the CBERS-2 launch. Brazil adopted the free-of-charge CBERS data distribution policy when data are requested in electronic format, opening the field of remote sensing to new users, applications and business. Initially adopted for Brazilian users, it was extended for neighboring countries, and then to the world. Currently, all CBERS data gathered at Cuiaba, the Brazilian ground station, is distributed free of charge to everyone www.dgi.inpe.br/CDSR).

Since the adoption of this open-access data policy, more than 100,000 scenes have been distributed each year inside Brazil to thousands of users and institutions. The processing system is very fast and it takes only a few minutes for the user to have his request for a full-resolution scene fulfilled. This kind of data policy and easy distribution system promoted a strong increase in the number of users and applications. As a result, there is no organization related to agriculture, environment, geology, or hydrology in the country that is not a CBERS user. Hundreds of businesses in remote sensing were opened after the adoption of the current data policy. Significantly, environmental control by society has also increased.

Brazilian legislation requires that each farmer identify and notify the environmental agency about areas to be protected on each farm. This procedure is called environmental licensing and has been adopted in many states around the country. Currently, most of this procedure is done based on CBERS images and has opened hundreds of small businesses specializing in this kind of service. An interesting application of CBERS images is in tax enforcement. Some states use CBERS to help them to monitor farms to assure that all declarations made by farmers are in accordance with the tax law.

Another important environmental application of the fast and free access to CBERS data is to map and measure deforested areas. It is often the case that governmental institutions have difficulty in acquiring up-to-date remote sensing data, especially in developing countries. In Brazil the deforestation in the Amazon region is a major environmental problem. Actions from the governmental environmental protection agency depend on monitoring. Monitoring in the Amazon region on an annual basis used to be based on NASA owned Landsat data, but with the launch of CBERS, the Brazilian capacity to monitor the Amazonia experienced a major increase. In addition, CBERS data is also used, together with MODIS data, in a permanent monitoring system for the Amazonia under a project called Detection of Deforestation in Near Real Time (DETER). It allows detecting early signs of deforestation, and alerting the environmental agency in time to take action.

3.3 USING REMOTE SENSING FOR PROTECTED AREA PLANNING IN CANADA

Canada is the second largest country in the world by land area, at nearly 10 million km^2 in size. Monitoring biodiversity and associated ecosystems for a nation the size of Canada requires approaches that enable broad scale national assessments. Over the past five years the Universities of British Columbia (UBC) and Victoria (UVic) with the Canadian Forest Service (CFS) of Natural Resources Canada (NRCan), have investigated the role remote sensing can play in the assessment of biodiversity across Canada.

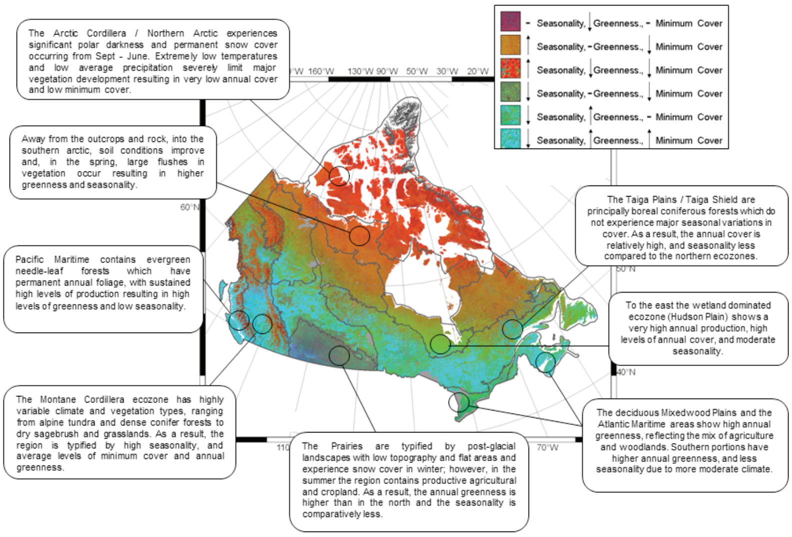
This research includes the national level application of indices which capture different aspects of species habitats, and the production of regionalizations or environmental domains which allows for the assessment of, for example, the representation of park networks which can be used to inform national biodiversity planning.

Application of a Dynamic Habitat Index (DHI) across Canada

Vegetation productivity is the most widely supported predictor of broad scale biodiversity patterns. In general, regions with higher productivity support higher levels of species richness. Productivity is easily amenable to rapid, repeatable monitoring with remote sensing data. A dynamic habitat index (DHI) has been applied across Canada, a tripartite measure of vegetative productivity, to monitor habitat condition repeatedly and over large extents. The DHI is computed from satellite estimates of the fraction of Photosynthetically Active Radiation (fPAR), an index which provides an indicator of vegetation growth capacity. The three components are:

1. Annual average landscape greenness which integrates the productive capacity of a landscape across a year and has long been recognized as a strong predictor of species richness.
2. Annual minimum greenness which relates the potential of a given landscape to support permanent resident species throughout the year. Locations without significant snow cover at the end of the summer will often maintain greenness into winter, and vegetation fPAR remaining above 0. In areas where snow covers the vegetation, fPAR approaches 0.
3. Seasonal variation in greenness is an integrated measure of climate, topography, and land use. For example, forests and grasslands in the mountainous and interior regions of continents display a much shorter growing season than those in the more maritime ecoregions. High seasonality values signify seasonal extremes in climatic conditions or limited periods with agricultural production. Sites with low values typically represent irrigated pasture, barren land, or evergreen forests.

These three components of the DHI make it a prime candidate to test hypotheses related to diversity-productivity relationships. Its dynamic nature, which is tailored to ecological theory, makes it more informative than single remote-sensing metrics (Figure 3.1).



The Arctic Cordillera / Northern Arctic experiences significant polar darkness and permanent snow cover occurring from Sept - June. Extremely low temperatures and low average precipitation severely limit major vegetation development resulting in very low annual cover and low minimum cover.

Away from the outcrops and rock, into the southern arctic, soil conditions improve and, in the spring, large flushes in vegetation occur resulting in higher greenness and seasonality.

Pacific Maritime contains evergreen needle-leaf forests which have permanent annual foliage, with sustained high levels of production resulting in high levels of greenness and low seasonality.

The Montane Cordillera ecozone has highly variable climate and vegetation types, ranging from alpine tundra and dense conifer forests to dry sagebrush and grasslands. As a result, the region is typified by high seasonality, and average levels of minimum cover and annual greenness.

The Prairies are typified by post-glacial landscapes with low topography and flat areas and experience snow cover in winter; however, in the summer the region contains productive agricultural and cropland. As a result, the annual greenness is higher than in the north and the seasonality is comparatively less.

The Taiga Plains / Taiga Shield are principally boreal coniferous forests which do not experience major seasonal variations in cover. As a result, the annual cover is relatively high, and seasonality less compared to the northern ecozones.

To the east the wetland dominated ecozone (Hudson Plain) shows a very high annual production, high levels of annual cover, and moderate seasonality.

The deciduous Mixedwood Plains and the Atlantic Maritime areas show high annual greenness, reflecting the mix of agriculture and woodlands. Southern portions have higher annual greenness, and less seasonality due to more moderate climate.

Figure 3.1. The Dynamic Habitat Index of Canada. Different ecological zones throughout the country exhibit different DHI components of productivity, seasonality and minimum cover. As a result spatial differences across the country are apparent as changes in color

The DHI has been derived from MODIS (NASA 2000 onwards) or AVHRR (Advanced Very High Resolution Radiometer (1986 onwards) and is freely available to researchers. The use of these low resolution sensors in mapping the DHI across Canada is a good example of the utility of low resolution, broad-coverage sensors for ecological monitoring over inaccessible and remote areas. The DHI has also been applied across North America and a global DHI product is underway. In addition, the United States has the National Land Cover Data (NLCD), LandFire and the National Gap Analysis Program (GAP) which are ongoing programs that successfully monitor land cover change at various levels of detail.

Environmental Domains and Conservation Representativeness

Another approach for the use of remotely sensed derived indicators of biodiversity is to provide information for the characterization of the landbase. The DHI has been used together with other remotely sensed datasets, such as information on land cover, fragmentation, disturbance, snow cover to develop clusters (pixels) into environmental domains, or areas sharing common environmental conditions. Such domains are analogous to traditional ecoregions, however unlike ecoregions, which are forced to include atypical areas by the requirement of spatial contiguity; environmental domains are not spatially discrete and, therefore, allow a more consistent classification of homogenous units. These environmental domains can then be used to assess, for example, representativeness in Canada's network of parks and protected areas and systematic conservation planning of future reserves.

Work in Canada has focused on its Boreal forest where currently, ~8.1 % (448 178 km^2) is under some form of protection, with many of these areas in low productivity environments located in the far north or at higher elevations. However, because of its remoteness and inaccessibility, ~80% of the boreal already functions as though protected; thus, there exists a vast potential for conservation investment in the region. Methods which utilized 15 remotely sensed clusters and species at risk data to assess a variety of hypothetical reserve network scenarios were applied, with (i) varied levels of conservation targets and reserve compactness and (ii) the preferential prioritization of remote or intact wilderness areas (Figure 3.2).

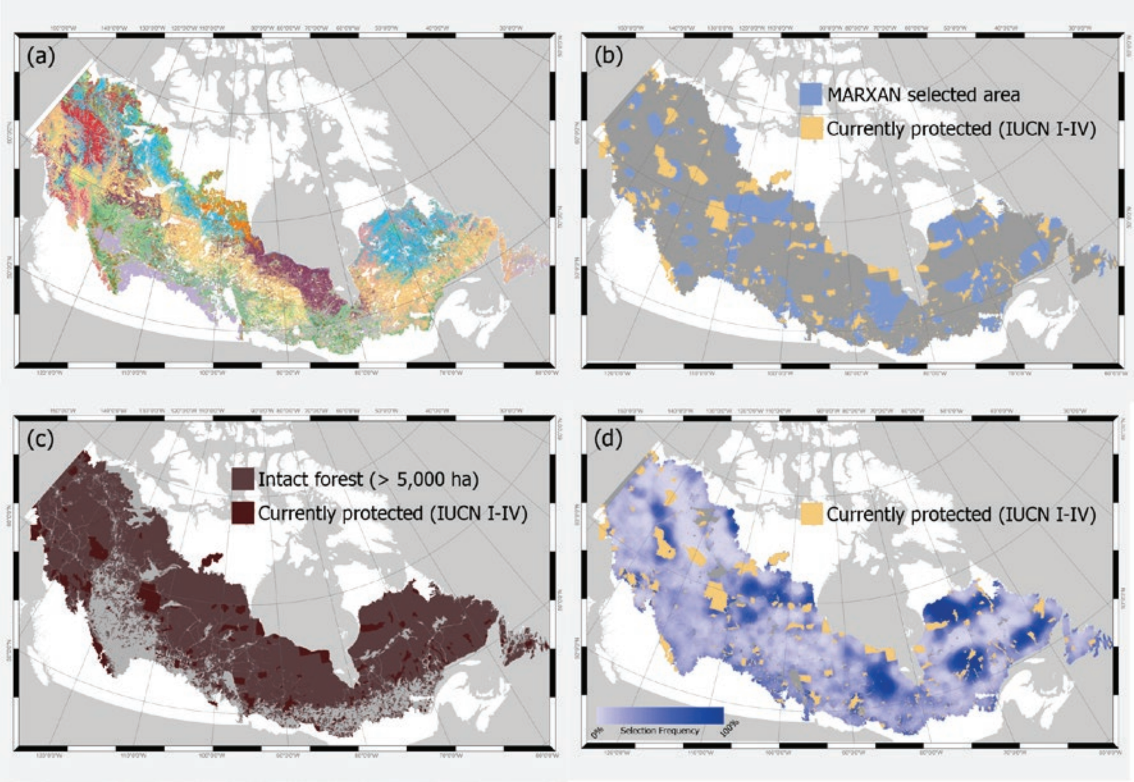


Figure 3.2. (a) Spatial distribution of 15 environmental domains (Powers *et al*., 2013). (b) A best or near optimal MARXAN reserve design solution for a scenario that preferentially prioritizes remote areas away from human presence using an accessibility cost layer. (c) Global Forest Watch Canada (GFWC) intact forest landscape and current protected areas (IUCN I-IV). (d) The sum of all MARXAN solutions for 500 runs (iterations) of the same scenario. It is used to determine the selection frequency of each planning unit (0-100%), and provides an indication of how important the planning unit is for an efficient reserve design.

Results suggest that reserve compactness greatly influences the reserve area and cost and that restricting conservation to only intact wilderness areas also reduces flexibility and reserve cost efficiency. However, preferentially prioritizing remote portions of the boreal or areas with low human accessibility was able to provide the reserve design flexibility needed to meet all scenario targets and demonstrates that this approach is useful for aiding in biodiversity conservation efforts. Results show that the indirect indicators of biodiversity, which are available from remote sensing, are effective tools for modeling and monitoring biodiversity at national and continental scales and provide valuable insights into basic and applied ecological research.

In order to ensure the preservation of species and habitat diversity and current and anticipated future conditions, all environmental domains should be adequately represented in a comprehensive conservation network. The clustering analysis used to identify domains has also identified environmental conditions that are unique, and thus may be the most deserving of conservation attention. Spatial conservation planning tools such as MARXAN can be used to help determine where (spatially) conservation investment should be prioritized. This method works by finding cost-effective solutions to conservation problems by achieving conservation targets for the least cost, which can include a variety of factors such as area or economic costs associated with land acquisition, management, human accessibility and forgone activity.

3.4 USE OF REMOTE SENSING IN DATA CREATION FOR USE IN BIODIVERSITY INDICATORS IN SOUTH AFRICA

Remotely sensed data has formed the basis of many indicators used by the South African National Biodiversity Institute (SANBI) in both the National Spatial Biodiversity Assessment (NSBA), 2004 and the National Biodiversity Assessment (NBA), 2011. A total of 16 indicators have been derived (totally or partially) from remotely sensed data.

Although the remotely sensed data is widely used in indicators, there are only two core data layers that have been created from a direct analysis of remotely sensed data, the National land cover datasets dated 1994 and 2000. The next national land cover dataset is expected to be finalized in 2017. In the interim SANBI (South African National Biodiversity Institute) has updated the National land cover 2000 dataset with updated provincial land cover data and various other vector data sources. This has provided the base data for the NBA 2011 indicators. The following biodiversity indicators have made use of the land cover as a base data set: Terrestrial ecosystem threat status; Climate change stability in Biomes; and, Biodiversity priority areas.

The following indicators in the NBA 2011 were created using either satellite or aerial photography: River ecosystem threat status; River ecosystem protection levels; Freshwater ecosystem protection areas; Flagship free flowing rivers; Wetland ecosystem threat status; Wetland ecosystem protection levels; Estuarine ecosystem threat status; Estuarine ecosystem protection levels; Priority estuaries; Marine and coastal ecosystem threat status; Marine and coastal ecosystem protection levels; Species of special concern (specifically medicinal plants and threatened freshwater fish); Invasive alien species (specifically woody invasives).

3.4.1 Limitations

The following limitations have been experienced in using remotely sensed data. In most cases these limitations have resulted in the decision not to use remotely sensed data for indicator generation.

Raw data cost vs. spatial resolution

The South African National Space Agency (SANSA) provides Level 3A and 3B SPOT 5 imagery (with a spatial resolution of 2.5m and 10m) to the provinces, the Presidency, government departments and government agencies such as SANBI. The first Spot 5 mosaic of the country was compiled in 2006. Cape Nature used SPOT 2005 imagery in the CAPE Fine scale analysis (SANBI, 2007); SANBI does not currently pay to access this imagery. Landsat imagery has been obtained via download from United States Geological Survey (USGS) and Landsat 5 imagery was used in the SANBI vegetation (Mucina & Rutherford, 2006, p. 19).

However, certain biodiversity features, such as wetlands, bush encroachment, streams, etc. cannot be identified on Landsat or SPOT. Unfortunately imagery generated by GeoEye and QuickBird are not available to SANBI free of charge and the cost of purchasing all the tiles for South Africa are excessive. This limits the use of remotely sensed data to areas where there are biodiversity features that cover areas in excess of 2.5 m^2.

Analysis of various vegetation types

The differing biomes in South Africa require different remote sensing approaches to identify the vegetation types within them. In the Fynbos biome it is problematic to identify vegetation using remote sensing, because veld age seems to be an overriding signature in the vegetation and skews the interpretation (Mucina & Rutherford, 2006, p. 22). This limitation has been mitigated by making use of vector vegetation distribution data. Certain invasive species such as Acacia are also misidentified as Fynbos. This limitation cannot be mitigated due to a lack of invasive distribution data.

In the Grassland biome remote sensing faces other challenges. Fallow agricultural fields are identified as natural grassland, whereas in reality they contain only a small number of the grass species that pristine Grasslands should contain. This limitation is mitigated through the introduction of a vector layer of cultivated fields (SANBI, 2009).

Differing mandates and the cost of going commercial

In South Africa there are very limited numbers of remote sensing experts. National Geo- spatial Information, a component of the national Department of Rural Development and Land Reform, is responsible for creating and maintaining the National land cover and land use datasets. Unfortunately the process has not yielded a complete dataset since 2000 (released in 2005) and plans to complete the classification and change detection for the entire country only in 2017 (images captured in 2012 – 2014), with a pixel size of 10 m and a minimum mapping unit of 1 hectare. To mitigate this limitation the provinces have turned to commercial experts to provide land cover data at a high cost. Three provinces out of a total of nine have developed their own provincial land covers (SANBI, 2008), while a further three provinces have partial land covers. SANBI has mitigated this issue by generating an updated land cover of sorts through the intersection of provincial land covers and various other updated vector layers. This updated national land cover has been generated for 2009 (SANBI, 2009) and will now be updated again for 2013, this layer is primarily used for the generation of other data layers and biodiversity indicators (Driver, *et al.*, 2011).

Ground truthing

The ground truthing of land cover data is a limitation for remote sensing in South Africa, since the country is vast and diverse in its land cover; commercial entities have mitigated this by making use of aerial or high resolution satellite imagery to undertake random ground truthing (SANBI, 2008). The fine scale planning project made use of expert workshops (SANBI, 2007) to review the newly generated land cover and determine if it was accurate.

Lack of experience

SANBI has as yet not been able to create a full national land cover due to all the limitations mentioned above along with an additional limitation of a lack of skilled staff, software and hardware. Recently SANBI has had one staff member trained in the use of ENVI and has acquired licenses for both ENVI and ERDAS, however the staff required to advise on the science underlying this work are still lacking.

3.4.2. Spatial and temporal resolution

National monitoring requires the highest spatial and radiometric resolution possible, so that mapping and analysis can occur at regional as well as national scale. The ideal model of data capture and analysis for monitoring in South Africa is that much of the work happens at the regional (municipal and provincial) scale; this data is merged and gaps are filled to produce the national scale data. However, in undertaking this approach it is imperative that the results reflected in the national and regional analyses do not differ, it is thus impossible to make use of SPOT imagery regionally and then Landsat imagery nationally.

The requirements for temporal resolution vary between one and five years. Although five years is an acceptable time lapse between land cover data sets, it is also desirable to be able to monitor large land cover changes that happen in much shorter time spans. Considering that it takes approximately one year to collect, classify, check and create a land cover change map, it would be prudent to suggest that the temporal resolution be a minimum of two years and a maximum of four years. In addition when mapping biodiversity features it is imperative to obtain imagery for the wet and dry seasons, in South Africa this would mean a minimum of a December and a June image.

3.4.3 Complementary information to develop an indicator

Two key data types are used to complement remote sensing data.

- Existing non-remotely sensed vector and raster data: This data informs the data creation by revealing what is known to be in that location already, for example, a portion of land cannot revert back to a natural classification if it has been cultivated, it is most likely fallow instead.
- Expert opinion: Expert opinion in vegetation mapping is crucial. The group of experts, constituting the South African Vegetation Map committee, still meets on a regular basis to discuss changes to the National vegetation map (Mucina & Rutherford, 2006). These changes may be as a result of new species classifications or new field work.

3.4.4 Priorities for the future

South Africa is urgently in need of a series of regularly updated land cover datasets that allow for the assessment of the condition of terrestrial ecosystems, rivers, wetlands and estuaries (Driver, *et al.*, 2011). This task would benefit from well- defined leadership and international exposure to best practices in land cover creation, specifically in a biodiversity context.

3.5 THE JAPANESE BIODIVERSITY OBSERVATION NETWORK (J-BON) WORKING GROUP ON THE INTEGRATION OF REMOTELY SENSED AND *IN-SITU* OBSERVATIONS

In order to fully integrate the monitoring and detection of the spatio-temporal distribution of biodiversity and its links to ecosystem services under climate and land-use changes, J-BON and the Asia Pacific Biodiversity Observation Network (AP-BON) established an "*In- Situ* / Remote sensing integration" Working Group (WG) in 2009. The WG activities involve efforts to link remote sensing data and *in-situ* ecological data in both terrestrial and aquatic ecosystems with two main objectives:

i) Support intensive collaborative research and knowledge sharing, especially in super-sites of ecosystem function study and ecological studies such as those contributing to Japan-Flux (under AsiaFlux/FLUXNET) and JaLTER (under ILTER-EAP/ILTER) in Japan. At these sites, the link between ecological variables within plots is examined and from this the distribution of biodiversity outside the plot is estimated by inter/extrapolating the relationships.

ii) Support extensive collaborative research with field scientists/groups expertise in biodiversity at the species level in order to provide finer scale and species-specific information on vegetation distribution. This compliments direct satellite observations and also assists in habitat estimation for the non-observable species component.

For the terrestrial ecosystems and biodiversity observations, three case studies were developed to support the multidisciplinary observation networks (see Muraoka et al. 2012):

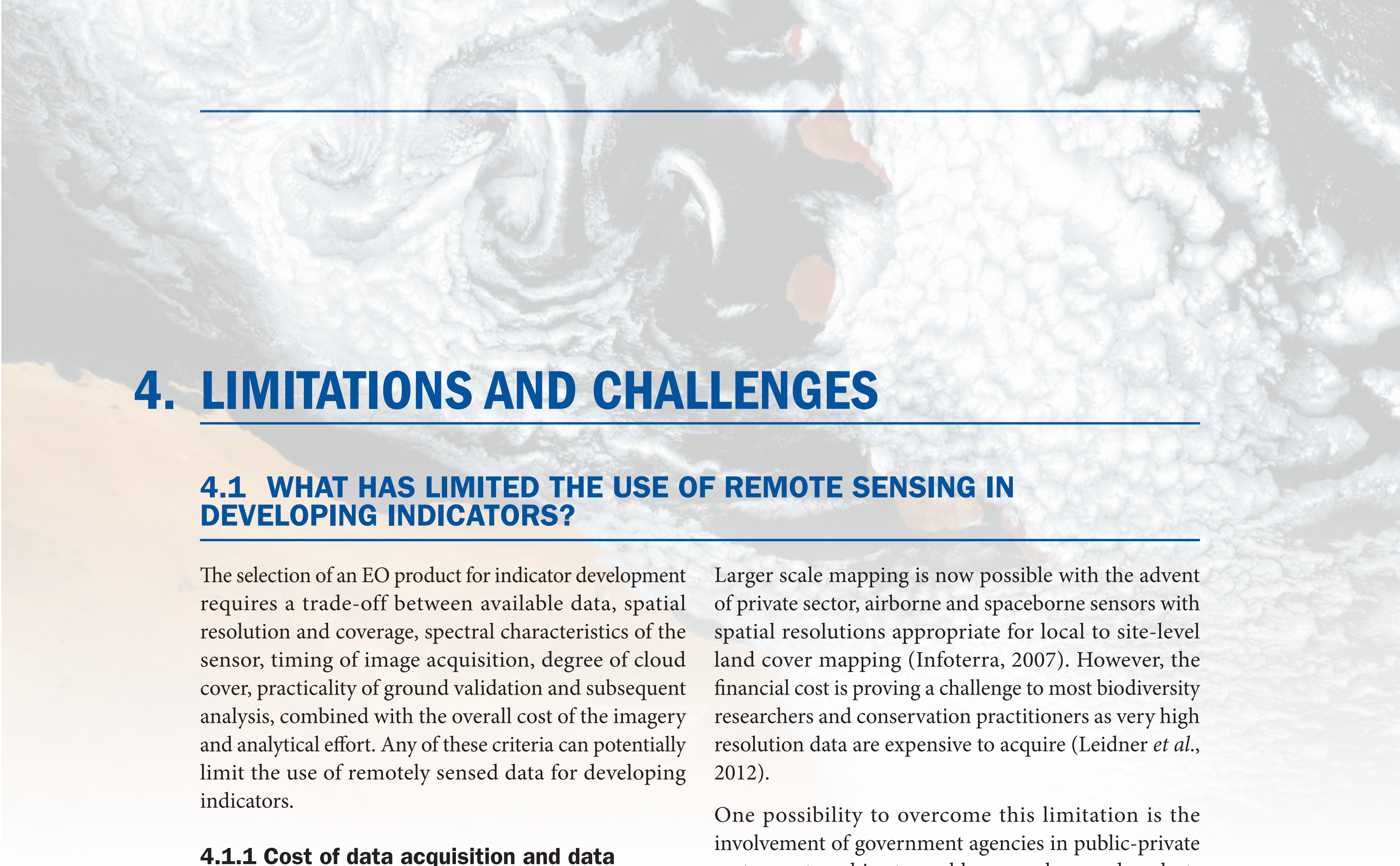
1. "Vertically deep – laterally sparse network" to find links between ecosystem composition, structure and functions for various ecosystems along environmental gradients, by networking 'super-sites' of existing research networks. Multiple and long-term *in situ* observations of the ecosystem properties or their spectral properties is critical to link with satellite remote sensing.
2. "Vertically shallow – laterally dense network" to characterise general relationships between the ecological aspects of plants, animals, birds and microorganisms (i.e., assessment of habitat quality and preferences, distribution patterns, etc.). High spatial resolution map of land use and ecosystem types are linked with various plot-scale observations.
3. "Integration of biological, ecological and physical data by GIS" to achieve a comprehensive understanding on the ecosystem composition – structure – functions, and then to predict these changes under climate and human impacts. Empirical statistical models and/or process-based ecological models, which incorporate the dynamics of ecosystems, biodiversity and their drivers, would be the optimal approach to navigating the links between natural ecosystem scientists, social systems, and decision makers.

J-BON as a whole has been organising expanded cooperation with existing ecosystem observation networks, earth-science institutions and government ministries for the implementation of its aims. The In-situ/Remote sensing integration WG aims to deliver the following outputs:

- Land use/vegetation maps of current status by classification of satellite imagery (starting from Japan and expanding to East Asia) which will serve as critical base information for ecosystem function analysis, potential habitat estimation of wildlife and threatened plants, and ecological footprints of ecosystem services.
- A map of biophysical vegetation parameters that can be used as indicators of biodiversity and potential habitat, such as leaf area index (photosynthetic potential), tree height, and above-ground biomass.
- Models (theoretical with some practical implementation) to connect global climate change, regional/local climate change, its impacts on or responses of ecosystem structure and function, and biodiversity (and their possible feedback to ecosystem function, e.g., carbon and nutrient cycling).
- Validation of the above observatory and modeling analyses at 'super-sites' for Long-Term Ecological and biogeochemical Research (LTERs) and CO_2/water fluxes. The former could be provided by JaLTER (under ILTER-EAP) and the latter by JapanFlux (under AsiaFlux). As part of this initiative, the "Phenological Eyes Network (PEN)" was established in 2003 to validate satellite remote sensing data by optical measurements of ecosystem structure and functions, including phenology (Nishida 2007).
- Linking the various databases, of existing observation networks, such as JaLTER and JapanFlux, is necessary to share knowledge for integrated understanding on ecosystems, and their possible changes due to climate change. By organizing the "JaLTER-JapanFlux-JAXA-JAMSTEC-J-BON" collaborative community (network of networks), J-BON would lead this task, and attempt to emphasize its necessity for the Asia-Pacific region via ILTER-EAP and AsiaFlux networks.

In order to achieve these aims and deliver the outputs, J-BON is increasing its level of collaborative between the ecosystem science community and the Japanese space agency, JAXA. This collaboration involves J-BON, not only as users of the JAXA satellite data (ALOS, Terra/ASTER, GOSAT, TRMM) or as providers of the ground-based observation data, but also to network with ecosystem scientists in designing future satellite observation by providing their ecological interests, needs and knowledge, which are crucially important for effective and sound development of sensors and satellites (e.g., ALOS-2, GCOM, GOSAT-2, GPM). J-BON envisions benefits from this collaboration for all stakeholders involved. However, to make this collaboration sustainable and beneficial for both sides, JAXA have been requested to make their satellite data open to the science community.

Using remotely-sensed spatial data and field observatory systems on ecosystem structure and functions, the J-BON members have been mapping the biodiversity and ecosystem functions/services in Japan and East-Asia in a five-year project (2011-2015) under support of Asia Pacific Biodiversity Observation Network (AP-BON) and the Ministry of the Environment of Japan (Project S-9). Some of the results for each dataset based on the publication year, spatial resolution, data format, geodetic system, and land-use/cover categories required are summarized in Akasaka *et al.* (2012).



4. LIMITATIONS AND CHALLENGES

4.1 WHAT HAS LIMITED THE USE OF REMOTE SENSING IN DEVELOPING INDICATORS?

The selection of an EO product for indicator development requires a trade-off between available data, spatial resolution and coverage, spectral characteristics of the sensor, timing of image acquisition, degree of cloud cover, practicality of ground validation and subsequent analysis, combined with the overall cost of the imagery and analytical effort. Any of these criteria can potentially limit the use of remotely sensed data for developing indicators.

4.1.1 Cost of data acquisition and data access policy

Access to EO data is frequently highlighted as a key limitation by many biodiversity stakeholders. Many space agencies and some countries are now offering free and open data access to their satellite data, so, a tremendous amount of Earth Observation data products are now freely available to the community. However, high and very high spatial resolution imagery, which are generally available only from commercial sources, remain expensive (Leidner *et al*., 2012). To date, this has limited the development of EO-based products in the biodiversity community to Landsat and MODIS which are typically free and suited for regional scale applications. The launch of NASA Landsat 8 in February 2013 and the upcoming ESA/EC Copernicus Sentinels will further increase the amount of freely available data available. For more detailed information on data production and acquisition, please refer to Annex 5.

However, open access to remote sensing data is sometimes conditional on the type of user, whether it is a research organization, private sector or academic department. More barrier-free approaches with no organizational or user access limitation, such as NASA's access policy to its USGS archive and Landsat data would be extremely useful. However, a full and open access data policy does not necessarily mean easy and fast data access. For example, ESA/EC Copernicus Sentinels data policy will allow a free and open data access but it is not yet clear how easy the data will be accessible especially outside ESA Member States.

Larger scale mapping is now possible with the advent of private sector, airborne and spaceborne sensors with spatial resolutions appropriate for local to site-level land cover mapping (Infoterra, 2007). However, the financial cost is proving a challenge to most biodiversity researchers and conservation practitioners as very high resolution data are expensive to acquire (Leidner *et al*., 2012).

One possibility to overcome this limitation is the involvement of government agencies in public-private sector partnerships to enable researchers and analysts to access high resolution data at low cost. For example, several federal agencies of the U.S. government have established data purchase programs with commercial image providers in order to access new commercial remote sensing products which meet research and operational requirements (Birk *et al*., 2003). This requires initiative on the part of government bodies to recognise the duty that central Government plays in providing mapping and monitoring information to meet the needs of its citizens. An agreement between NASA Earth Science Enterprise (ESE) and the Space Imaging IKONOS system has been a good example of cooperation between industry, government and end users (Goward *et al*., 2003). However, the organisational and legal aspect of the partnership is more of an important determinant of success than any technical factors (Goward *et al*., 2003).

4.1.2 Data access: Internet and search systems

Linked to the above limitations is the issue of Internet access in certain regions. For example, access to the USGS Landsat archive is considerably constrained by a limited bandwidth in many African countries (Roy *et al*., 2010). However, while the situation is improving, with new fibre-optic cables opening up access to broadband connectivity, there are still problems of establishing networks within countries. Government regulation may also continue to restrict Internet access across the continent (Roy *et al*., 2010).

In addition, traditionally, most space agencies have oriented their data products and search and order systems towards users with considerable technical expertise and training. While this is changing, it is still true that many search and order systems that provide access to remote sensing data are suitable only for experts, and many data products are in formats that require knowledge or tools that many biodiversity users will be unfamiliar with. These two barriers—difficulty in finding suitable datasets, and then in using them—limit the degree to which remotely sensed data have been used in conservation applications.

4.1.3 The need for processing

Assuming the right dataset has been found it will often require pre-processing such as georeferencing, topographic correction, orthorectification and atmospheric correction, before it is suitable for use. This may best be done centrally and systematically, so as to produce a consistent set of EO products which are ready to use. More standardisation of approaches can be achieved under initiatives such as the Global Monitoring for Environment and Security (GMES) fast-track service, making EO-based analysis more cost effective and efficient to the end-user community (Infoterra, 2007). The Joint Research Centre (JRC) Digital Observatory for Protected Areas (DOPA) web service has automated the collection and pre-processing of remotely sensed imagery in order to provide protected-area level biodiversity information (Dubois *et al*., 2011). The GFW 2.0 monitoring system also incorporates a consistent set of pre-processing steps to generate consistent deforestation information from Landsat imagery although this is also in development and has not been officially launched at the time of writing. Therefore initiatives are under way to address the need for a centralised system of digital image collection and processing.

4.1.4 Level of product development: The need for more "derived" products

The level of product development from unprocessed satellite imagery is also an important concern. Frequently, derived geophysical fields, such as vegetation indices, are more useful than raw remote sensing data to non-specialists (Leidner *et al*., 2012), but many systems only provide minimally processed datasets such as reflectance or radiance products. The Copernicus Global Land service and similar systems in use by NASA, e.g. the Distributed Active Archive Centers (DAACs), enhance end-user capabilities by providing ready to use and free geophysical and biophysical products from satellite imagery. However, limitations on bandwidth and internet access speed in developing countries can be a constraint on data access and limit the use of EO data (Roy *et al*., 2010).

4.1.5 Capacity to use EO-based data in indicator development

A lack of capacity among biodiversity experts is frequently cited as a limitation in using remote sensing for monitoring biodiversity and developing indicators (Leidner *et al*., 2012). A greater understanding of how to use remotely sensed information is often sought in preference over more computing power or more advanced EO products but remotely sensed datasets are often in specialized formats — creating an immediate access hurdle - and analysis can require the use of specialized tools that require technical training (sometimes very sophisticated training, e.g. for LiDAR or hyperspectral data). These tools can also be expensive and so there have been calls for more access to open-source software (Leidner *et al*., 2012).

Generally, indicator development from raw remote sensing data requires capacity and expertise in working with remotely sensed data, as well as numerical data processing and statistical analysis. This is a common limitation to both developed and developing nations. More information on data analysis and process costs can be found in Annex 5. Centres of expertise for remote sensing to address user needs at a regional or national level may be beneficial, as has been done with the Canada Centre for Remote Sensing (CCRS) for example.

It should be pointed out that not all remote sensing data are difficult to find and use, and there has been a trend towards increasing user-friendliness. One example is TerraLook[2] which makes georeferenced jpeg images available at no cost, and provides a simple and intuitive toolset to do various types of processing. TerraLookimages, as well as the related LandsatLook products that USGS offers, are easy to find and suitable for many applications, if not for sophisticated numerical processing. Another example is the Rapid Land Cover Mapper[3] which is a tool that provides a very easy way to map and quantify land cover and land use.

Footnote

[2] *http://terralook.cr.usgs.gov/*

[3] *http://edcintl.cr.usgs.gov/ip/rlcm/index.php*

4.1.6 Effective data validation strategy

The lack of sufficient validation has limited the use of remote sensing data by biodiversity practitioners. More *in-situ* measurements are required for the calibration and validation of terrestrial EO products if they are to be used with confidence by biodiversity practitioners (Infoterra, 2007). Space agencies should also be concerned with *in situ* data for validating EO products, without which EO-based products are less likely to be used with confidence (Green *et al*., 2011). However, there are efforts to address this issue. For example, the Committee on Earth Observation Satellites (CEOS) Land Product Validation (LPV) subgroup has eight thematic areas where it is actively pushing efforts to globally validate EO-based products using *in-situ* measures. The themes are diverse and vary from validation of phenology products to snow cover, fire/burn area and land cover products (CEOS LPV, 2013). The U.K. Department of Environment, Food and Rural Affairs (Defra) Science Directorate has already addressed some of the limitations in the use of EO data for biodiversity monitoring in the UK. In China, significant investment in land cover classification and validation is likely to yield global land cover change products in the near future.

Land cover is a thematic area that needs advanced ground validation strategies especially if land cover change is to be monitored with reliability (Green *et al*., 2011; Hansen and Loveland, 2012). The most frequent reason for the absence of accuracy assessment is the lack of contemporary ground data with sufficient spatial coverage (Infoterra, 2007). Field campaigns are generally costly, labour intensive and sometimes difficult to synchronise with satellite image acquisition. However, an effective validation strategy is critical if the EO-based approach to landcover and habitat mapping is to be proposed as a cost-effective alternative to field-based methods (Vanden Borre *et al*., 2011). Online tools such as DOPA will provide capacity for the validation of uploaded products by end users using Google Earth.

4.1.7 Insufficient spatial resolution and spatial scale

The issue of spatial scale is often cited as a limitation to indicator development as operational remote sensing products are provided at spatial resolutions which are often coarser than needed for operational monitoring. For example, tackling conservation issues, such as loss of habitat, at the level of protected area, requires an indicator which is sensitive to that scale of change. Land cover, for example, is a particularly scale-sensitive parameter. A global or continental scale landcover product such as GLC 2000 or Globcover might meet national level needs but not be appropriate to address change at the protected area level. However, a product developed to meet the needs of protected area level monitoring is unlikely to be generated globally, on a routine basis, due to sensor limitations.

There is a demand among the biodiversity community for land cover products at the Landsat spatial scale (≤30m) and MODIS/AVHRR scales (250-1000m) (Leidner *et al*., 2012). However, very high resolution land cover (≤5m) information can also be very beneficial for monitoring site-specific variation at the plant community level or to map surface objects such as tree crowns and hedgerows. Two European GMES projects, Biodiversity Multi-Source Monitoring System: From Space to Species (BIOSOS) and MS MONINA, are researching EO-based tools and models for monitoring NATURA 2000 sites and their surroundings incorporating high or very high resolution satellite imagery. Indicator development at the local level, using airborne or higher resolution satellite sensors, can be a potential solution to address site-specific conservation needs but is not yet operational.

4.1.8 Long temporal repeat cycle and short time series for trend analysis

The temporal rate of change in surface processes is inconsistent with the repeat cycle of some EO satellites and therefore may limit the sensitivity of the product to detect certain surface changes. For example, the 16-day repeat cycle of Landsat is further limited by seasonality and cloud cover, especially in tropical areas; reducing the effectiveness of annual land cover updates (Hansen and Loveland, 2012). However, the National Institute for Space Research (INPE) in Brazil has developed the Detection of deforestation in near real time (DETER) product (see section 3.2 for further details), which uses daily MODIS data to provide a near-real time alert system to relevant authorities to monitor Amazon deforestation (Hansen and Loveland, 2012).

The low revisit time can limit the applicability of Landsat to indicator development, especially where surface change is on a daily to weekly time scale. Furthermore, time composited satellite products, e.g. 8-day MODIS, are insensitive to some natural phenomena, e.g. phenological changes in terrestrial vegetation, which occur on finer time scales (Cleland *et al*., 2007). A high revisit time is required for optimal change monitoring, as provided by for example Sentinel 2 satellites, with a revisit time of 4-5 days. However, there is always a careful balance between the spatial resolution, spatial coverage and repeat visit time of the satellite sensors.

The duration of remote sensing time series can be limiting on efforts to monitor long-term change in ecosystems. As some EO products are relatively new, they do not have sufficient time series data yet. This is a particular challenge in developing indicators which rely on land cover and land use change information at the global scale where there is a need for a decadal-scale land cover change classification with ecosystem level thematic classes (Leidner *et al*., 2012). Such multi-decadal time series are only available for certain sensors, e.g. Landsat and AVHRR, while others, e.g. MODIS and MERIS time series are limited to a decade approximately. An example of a periodically updated landcover classification which has potential for use in a trend analysis is the pan-European CORINE Land Cover (CLC) classification from 1990, 2000 and 2006 with a further update due in 2014.

4.1.9 Harmonisation of methodologies and data collection at national and international level

Greater coordination of methods in data collection and processing is required for harmonised EO products. This is one of the aims of the GMES initiative (Infoterra, 2007). For example, there are calls for a consistent pan-European habitat typology to reduce the uncertainty surrounding the inter comparison of national-level habitat classification systems (Vanden Borre *et al*., 2011). However, the kind of habitat parameters which can be retrieved is highly dependent on pixel size and sensitive to scale (Nagendra, 2001). Therefore, any harmonisation of efforts across national systems must take into account the availability of appropriate imagery. The Group on Earth Observations Biodiversity Observation Network (GEO BON) has been set up to focus efforts among different agencies in linking observing system for an integrated biodiversity monitoring system (Scholes *et al*., 2012).

4.1.10 Cloud clover

Cloud cover is a significant limitation to optical remote sensing. There are some very productive and diverse habitats that are regularly cloud covered (e.g. montane forest) and will never be adequately imaged by traditional optical satellite systems. This has forced end users to accept a 'use what you can get' approach that has made it difficult to streamline EO-based working procedures (Infoterra, 2007). However, there has been progress in automating the process of cloud removal and atmospheric correction through a harmonised approach to pre-processing methodologies. For example, the Landsat Ecosystem Disturbance Adaptive Processing (LEDAPS) system has applied cloud and cloud shadow removal, as well as automatic atmospheric correction, to a collection of Landsat 5 and Landsat 7 scenes. This harmonisation of cloud screening and atmospheric correction methods results in a consistent set of pre-processed Landsat imagery. These scenes are available through the USGS Earth Explorer site under the Landsat CDR option in the Datasets list. On demand pre-processing of any Landsat scene is now possible through the LEDAPS system.

4.1.11 Specific limitations of remote sensing in terrestrial ecosystems

The terrestrial domain has not yet developed a joined up approach, involving multiple disciplines, to gain a greater understanding of the global terrestrial system, as has been done in the marine environment (Infoterra, 2007). For example, The World Meteorological Organization (WMO) and the Intergovernmental Oceanographic Commission (IOC) of UNESCO have developed a joint working group for a global met-ocean observing network in which remote sensing observations play a crucial role (JCOMM, 2013). This has hindered the development of terrestrial simulation/prediction models which have been more widespread in the marine and atmospheric domains (Infoterra, 2007). Terrestrial ecosystem variables derived from remote sensing can play a key role in model development.

Typical terrestrial habitat variables include tree, shrub or grass species composition, canopy cover, tree size distribution, density of dead trees, three-dimensional forest structure, understory characteristics, vegetation architecture and the timing and duration snow and ice cover (Green *et al*, 2011). The benefits of UAVs in mapping and monitoring these variables at close range are discussed in detail in Annex 3. However, their use in terrestrial environmental applications to date has been limited by restrictions imposed by civil aviation authorities, as well as cost. UAV technology is easier to apply to marine applications, whereas airspace management over land is more complex (Infoterra, 2007).

A challenging area for EO is to supply adaptable landcover products which can answer specific biodiversity and conservation research questions at a suitable spatial resolution, with sufficient spatial coverage, accuracy that can be updated when and where change occurs. Global land cover mapping at low resolution is challenging and has not always produced comparable results. For example, there are inconsistent cover estimates between GLC-2000, MODIS and GlobCover, especially for cropland, which introduces uncertainty in end user applications. Ways to overcome these challenges in future global landcover products include increasing data sharing efforts and the provision of more *in situ* data for training, calibration and validation (Fritz *et al*., 2011).

It is also challenging to translate landcover to habitat type, though it is often used as a proxy for habitat, the assumption that they are equivalent is questionable. However, mapping habitat directly from remote sensing imagery has been achieved using medium resolution satellite imagery, in the Phase 1, national-scale habitat map of Wales for example (Lucas *et al*., 2011). The method was based on object-oriented, rule-based classification coupled with multi-temporal, multi-sensor imagery and shows considerable promise in providing habitat-specific change updates. Such continual monitoring of habitat change, at the national scale, is not possible with current static landcover maps.

Landcover is not the only EO variable in use to infer habitat characteristics. Habitat variables such as species diversity and species richness can be estimated from spectral information alone (Rocchini *et al*. 2010, 2004). Variables such as VCF and fCover (see Annex 2) offer an alternative approach to global landcover mapping. Instead of considering discrete borders between landcover types, the VCF product estimates a continuous field of woody vegetation cover. This is a more realistic interpretation of gradients in spatial landcover variability (DeFries *et al*., 1999). Products such as fCover and VCF could potentially be one of several layers in an adaptable landcover map that could be routinely updated. However, understanding how EO products translate across different scales has been noted as a limitation in the terrestrial system (Infoterra, 2007). For example, LAI, FAPAR and fCover all demonstrate variable sensitivity to scale (Weiss *et al*., 2000), and LAI is scale dependent, while fCover is not (Baret *et al*., 2011). In addition, generating continuous-field land cover datasets at Landsat-resolution and on a global level is challenged by the difficulty of acquiring suitable reference data for validation. Local LiDAR measurements of tree height could be a potential solution to bolstering ground-based validation efforts (Sexton *et al*., 2013).

4.1.12 Specific limitations of remote sensing in aquatic ecosystems

Remote sensing and spatial analysis techniques used to study aquatic ecosystems differ from those used in terrestrial systems (Strand *et al*., 2007). This is largely due to the nature of reflectance from water bodies which reflect sunlight in different wavelengths to those from terrestrial surfaces, e.g. water bodies appear very dark in satellite images due to almost total absorption of near infrared radiation (Campbell, 2006).

The typical satellite sensor used in marine environments is therefore different in design and instrumentation to that used in terrestrial areas. For example, SAR systems such as Radarsat-1, Envisat ASAR and ALOS PALSAR, are mainly intended for marine applications such as oil-spill monitoring, ship detection, shallow-water bathymetry mapping, sea-ice monitoring and sea surface state (Infoterra, 2007). Other satellite sensors such as the NOAA AVHRR and METEOSAT are dedicated to marine meteorology and tracking extreme events such as hurricanes.

The two great benefits of EO-based monitoring of oceans and water bodies is the synoptic view of the spaceborne sensors and their regular repeat cycles which allow dynamic processes to be monitored on a regular and repeatable basis (Campbell, 2006). The aquatic environment and the wider hydrological cycle demonstrate unique challenges to EO-based monitoring, however. For example, ocean colour monitoring sensors such as SeaWiFS and Envisat MERIS measure slight changes in colour which are easily attenuated by atmospheric interference. Highly dynamic surface features such as ocean currents and the movement of suspended sediment can occur at a rate not measurable by polar orbiting sensors. The recently launched Geostationary Ocean Color Imager (GOCI) has been designed to monitor short-term and regional oceanic phenomena in order to address this problem (He *et al*., 2013).

Within the marine community, the use of EO data for monitoring biodiversity is relatively widespread and there is a core set of global and regional products to serve user needs (Infoterra, 2007). Such products are underpinned by a good scientific understanding of many of the processes in the marine environment. This has led to well established fields of research, such as remote sensing for monitoring individual marine species, using telemetry (e.g., Blumenthal *et al*. 2006), or factors controlling their distribution, such as algal blooms (e.g., Burtenshaw *et al*. 2004). However, it is worth noticing that remote sensing is more typically used in mapping tropical rather than temperate marine areas as the visibility through the water column is generally better due to lower a lower volume of suspended sediment (Strand *et al*., 2007).

For aquatic environments, key environmental parameters required by the conservation community have been listed as "biological productivity of marine areas (critical for all marine spatial distribution models), sea surface temperature, frequency of marine and freshwater algal blooms, plankton density, seasonality of extent of sea ice cover, including polynas, sediment type of intertidal zones, bathymetry of intertidal zones (and hence the duration of tidal coverage), the mobility of intertidal mud and sand flats, volume and seasonal pattern of river flows and species identity of emergent marsh vegetation" (Green *et al*., 2011).

However, not all of these variables are routinely monitored by satellite sensors. For example, more data are needed on carbon storage and sequestration value in oceans – similar to those which are used to generate maps of terrestrial carbon (Green *et al*, 2011). However, there are currently large discrepancies between satellite-based and model-based estimates. Furthermore, satellite-based estimates tend to suffer from wide error margins. For example, the Southern Ocean CO_2 sink in 1997/1998 was estimated at −0.08 GtC yr−1 with an error of 0.03 GtC yr−1 (Rangama *et al*. 2005) which was approximately 38% smaller than that based on *in-situ* measurements and climatological data of the same area (Takahashi *et al*., 2002). Some of this uncertainty can be explained by the weak correlation between *in-situ* and RS-derived measures of the same surface variable, e.g. chlorophyll-a, which are used in the estimation of CO_2 flux (Chen *et al*., 2011).

There is less understood on habitat fragmentation and connectivity in marine habitats than for terrestrial ecosystems (Strand *et al*., 2007). High-resolution measurements based on LiDAR can offer spatial, structural as well as thematic information on localised coastal habitats (Collin *et al*., 2012), while offshore benthic habitat mapping can be achieved with a combination of ship-based sonar devices and LiDAR (Costa *et al*., 2009). However, it is challenging to acquire the same level of information on a broader scale due to logistical constraints and financial cost. Therefore, mapping the connectivity of the marine habitat is not straight forward as different remote sensing platforms are employed and are not always compatible in producing seamless habitat maps.

4.1.13 Specific limitations of remote sensing in the intertidal zone

Intertidal habitats such as mangroves, sea grasses and salt marshes exhibit both terrestrial and marine characteristics. However, satellite and airborne mapping methods for these habitats are less developed than those for purely terrestrial or marine (Green *et al.*, 2011) and the selection of appropriate imagery is constrained by tidal regime where the surface cover is frequently inundated by water. Spatiotemporal variation in substrate, i.e. sand, mud and gravel and dynamic processes such as coastal currents and tides also make the intertidal zone difficult for ground validation work. Therefore, for satellite image selection or for planning an airborne survey, a balance must be achieved between tidal regime, cloud cover, vegetation seasonality, timing with field visits and the need for very high spatial resolution imagery (Murphy *et al.*, 2008). Furthermore, airborne surveys tend to be expensive and logistically challenging and therefore not suitable for operational monitoring. Field-based methods such as diver survey, underwater videography and acoustic techniques such as sonar can be used in a complimentary fashion in mapping shallow coastal habitats but suffer from error in interpolation of mostly point measurements (Dekker *et al.*, 2005). A nested approach, employing observations at multiple scales, combining *in-situ* and airborne mapping methods, appears to be the future for high resolution mapping of intertidal zones.

4.2 KEY CHALLENGES IN THE USE OF REMOTE SENSING FOR INDICATOR DEVELOPMENT

4.2.1 Knowledge transfer and capacity building

Knowledge transfer in remote sensing education is a particular challenge for the developing world as traditional expertise in the topic is located in western institutions. Despite some access limitations, the benefits of Internet access for knowledge exchange in the field of remote sensing are numerous. Firstly, access to geospatial data is almost on demand, secondly, access to a network of scientists and practitioners who can assist each other remotely, and thirdly, development of EO-based data sets that are coordinated locally, e.g. in citizen science initiatives (Global Marketing Insights, 2009).

In addition, a lack of capacity is of particular importance in developing countries where there is rarely access to commercial software, appropriate educational material or university-based education in remote sensing. North-South knowledge transfer has been promoted with approaches such as that adopted by ESA, whose EO projects have a strong capacity building component, covering both basic education on remote sensing theory and training courses on particular EO products. South-South cooperation will also be key to improving capacity at national level. In this regard, Brazil, through the INPE, has led the way in making remote sensing courses available to professionals in Latin America since the mid 1980s (Sausen, 2000).

4.2.2 Product accuracy

Accuracy of EO data is an issue in several themes of the discipline, e.g. in landcover mapping and land cover change detection, and in recording position-accurate geospatial data in the field and accurate EO-derived inputs for modeling work (Infoterra, 2007). As EO data are prone to error, uncorrected data are limited in their utility for ecological applications (Kerr and Ostrovsky, 2003). In a survey of nature agencies involved in management and monitoring of NATURA 2000 sites, it was found that thematic accuracy of EO-based habitat maps is seen as the most important measure of quality (Vanden Borre *et al.*, 2011). According to the CEOS Societal Benefit Area on Biodiversity, a critical drawback of EO data is spatial accuracy and alignment (Leidner *et al.*, 2012). Therefore, an EO-based approach to indicator development will be hindered by issues of reliability unless steps are taken to address error and uncertainty in input data.

The abstraction of remote sensing data in geographical information systems from lower to higher levels tends to propagate error and accumulate uncertainty (Gahegan and Ehlers, 2000). The challenge of product accuracy might be addressed on two fronts, firstly by promoting methods which produce the least error (harmonization of methodologies will play a key role in this) and by limiting the number of processing steps performed on raw EO data (quantifying error at every transformation step can help calculate overall error). Thorough documentation of error and highlighting the limitations of EO-based products must become mandatory if EO-based biodiversity indicators are to be used with confidence.

4.2.3 Uncertainty in long-term continuity

Ensured long-term (decadal) continuity of earth observations is a key requirement for user organizations interested in biodiversity change. Therefore, uncertainty in long-term continuity is a key challenge to increasing the use of remote sensing in monitoring biodiversity as it restrains some organizations to invest in EO projects and development. Initiatives such as ESA/EC Copernicus Sentinel missions that are envisaged to guarantee a long term continuity of earth observations for future decades (+25 years) will be very beneficial.

4.2.4 Dialogue between EO community, biodiversity practitioners and decision makers

Greater dialogue between the remote sensing community, biodiversity practitioners and decision makers has often been called for. Within the scientific community, dialogue between earth observation and biodiversity experts has significantly improved over the last years, as demonstrated by the substantial increase in biodiversity related EO publications. The major gap seems to be insufficient dialogue with decision makers. Improved dialogue can have many positive results. For example, clearer user requirements can be expressed, data and options for image processing can be thoroughly evaluated, unrealistic expectations can be moderated or refined, and the cost effectiveness of different options discussed take place (Kennedy *et al*., 2009).

The CEOS Group on Remote Sensing for Biodiversity and Conservation is an example of such an initiative as well as the LPV sub-group of the CEOS Working Group on Calibration and Validation. The latter initiative is particularly important as it requires validation of the spatial and temporal consistency of EO products using *in-situ* data gathered by field experts.

5. CONCLUSIONS

- Remotely sensed data and derived-measures, combined with appropriate validation and modelling, have improved insights into the ecological processes and anthropogenic disturbances that influence biological diversity, and have shown potential to fill gaps in the suite of indicators that could be used to track the implementation of the Strategic Plan for Biodiversity 2011-2020 and the achievement of the Aichi Biodiversity Targets. With a large number of examples to demonstrate this potential, remote sensing and biodiversity experts are beginning to explore these opportunities. However, caution should be taken not to oversell the promise of remote sensing for monitoring biodiversity. It is **not a fit-for all solution**, and despite the important contribution it has the potential to provide to any biodiversity monitoring system, validating the remotely sensed data with ground truth data and traditional methods of inventorying and assessing biodiversity will still be required.

- As explored throughout this review, there are potentially many areas for **future development** of remote sensing products experts could focus on. However, human and financial resources are limited and therefore priorities must be established. As part of an enhanced dialogue between the different stakeholders, priorities should be driven by end users needs. A significant requirement of the conservation community is for **long-term Land Cover Change** (LCC) products. Current global landcover products are too coarse in resolution, single-date or infrequently updated, although the recently announced 30m global forest change product (Hansen *et al*., 2013) will be a significant step forward in this regard. Consistent and repeatable land cover products over time, adopting a standardised hierarchal classification scheme, e.g. the Land Cover Classification System (LCCS), can address this need. As landcover changes such as agricultural expansion have been identified as major drivers of biodiversity loss, monitoring landcover change over time can identify where the pressures are occurring and how likely they are to impact the current status and future trends in global biodiversity. The success of conservation interventions can also be measured by assessing landcover change in and around protected areas. However, it is vital that the spatial resolution of such products are commensurate with the scale of conservation units (e.g. ecoregions and units smaller than these).

- Monitoring forest cover change has been the area of most intense research in global analyses of land cover change to date. There are numerous reasons for this. Firstly, forests are most easily distinguished in satellite imagery than other vegetation cover types, such as croplands or urban areas. Forest reserves are important conservation areas and are global in distribution. Monitoring forest cover change has important implications for carbon accounting, biodiversity monitoring, and other issues such as illicit logging. However, there is a need to address this bias in land cover monitoring. **Other terrestrial ecosystems such as open grasslands, savannah, peatlands and wetlands also need to be considered in land cover change studies**. They provide ecosystem services such as carbon storage, clean drinking water, fuel and shelter and are important habitats. Although marine ecosystems are not as readily monitored as terrestrial ecosystems for biodiversity purposes, inshore and intertidal ecosystems are also important landcover types. However, these are considerably challenging landcover types to monitor as their discrimination is difficult, and therefore require further research and development of routine and robust monitoring methods.

- Remote sensing products are a useful tool **to assess the effectiveness of conservation interventions**. However, most of the work done to date has focused on forested protected areas. Further habitats types and broader sets of data need to be included in future studies to expand the use of remote sensing in monitoring implementation of the Strategic Plan for Biodiversity 2011-2020.

- To date, dialogue between data providers and end users has been limited. There is a disconnection on the awareness of what is available, what can be done and what is expected. A **closer relationship between the earth observation community and potential users** in the biodiversity policy and management communities would help to enhance understanding, align priorities, identify opportunities and overcome challenges, ensuring data products more effectively meet user needs. Initiatives for biodiversity information like the global GEO BON or regional approaches like EU BON (European Biodiversity Observation Network) are key processes to link data providers and the user community from policy and conservation management.

- Developing indicators to monitor biodiversity in general, and the Aichi Biodiversity Targets in particular can be challenging and heavily data consuming. Most biodiversity indicators need a variety of data streams, from several sensors and often including non-remotely sensed sources. It can become a challenge to have all of them available at the required time, spatial coverage and temporal resolution. It only takes a blockage in one of the data streams to prevent execution and development of the indicator. This complexity makes it even more necessary to nurture a **productive dialogue** among all data providers and end users in order to facilitate and align priorities.

- The link between remotely sensed derived measures and the development of indicators for high-level policy making is still poorly developed. There is a lack of common standards regarding the measures required by the biodiversity community and the products provided by the remote sensing community. In addition, a full harmonization of methodologies and data collection at national and international level and a delivery approach that works across different landscapes is still not in place. An agreed **set of minimum requirements and common standards** from biodiversity monitoring practitioners would help focus the efforts of the Earth Observations' experts. Initiatives such as the development of EBVs led by GEO BON could offer the necessary conceptual framework to bridge the gap between both communities and map the pathway from primary remote sensing observations to the delivery of high-level indicators. Closer collaboration between the GEO BON community on the establishment of EBVs and the BIP work on biodiversity indicators could contribute to this.

- Bottlenecks in data access are a key limitation for the expansion of remote sensing for biodiversity monitoring. Free open access data policies have been adopted and implemented by various space agencies and national institutions to date, proving effective for increasing the use of remote sensing in biodiversity monitoring, as well as enhancing policy implementation and law enforcement in some cases. Free open data access schemes should continue to be the international trend among data providers to support the democratization of access to remotely sensed data. **Free and open access to all taxpayer-funded satellite remote sensing imagery** will address this significant constraint.

- However, free open access data policy does not necessarily translate into **easy and fast data access.** This might be due to unfriendly data search and order systems, limited bandwidth and internet constrains, or related to a hierarchical approach to prioritizing data dissemination among different user groups. A concerted international action to secure easy access to remotely sensed data should be implemented, especially to ease access for developing countries.

- Enhanced access to data will only be effective if Parties have the sufficient technical and human capacity to make use of it. The international trend of including a **major capacity building** component in space agencies' Earth Observations projects will play an important role. In addition, better mechanisms should be established to support the participation of Parties in space agencies' projects.

- Uncertainty in the long-term (decadal) continuity of Earth Observations from satellites and other remote sensing missions is a key challenge for the funding of projects as it restrains funders from investing in Earth Observation projects, affecting further research and development on remote sensing. More initiatives to **guarantee a long term continuity of Earth Observations** are needed.

- Accessing comprehensive information on Earth Observations is often difficult for Parties since it is still very scattered, hosted by different organizations, space agencies and national agencies, and across a wide range of projects. Therefore, what is missing for Parties to the CBD and other international Conventions and MEAs is to have a unique reference point they can consult on Earth Observation matters in relation to biodiversity (much as the BIP represents for information on biodiversity indicators). Such a reference entity that would act as a **hub to concentrate and coordinate existing information and is easily accessible globally** could be a key component to facilitate greater use of remotely sensed data and products in biodiversity monitoring. This hub would require significant work to constantly offer the most updated information due to the fast pace of development of the EO field.

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LIST OF ACRONYMS AND ABBREVIATIONS

ALOS	Advanced land Observing Satellite
APEX	Airborne Prism Experiment
APRSAF	Asia Pacific Regional Space Agencies Forum
ASAR	Advanced Synthetic Aperture Radar
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATSR	Along Track Scanning Radiometer
AVHRR	Advanced Very High Resolution Radiometer
AVIRIS	Airborne Visible/Infrared Imaging Spectrometer
AWFI	Advanced Wide Field Imager
BIP	Biodiversity Indicators Partnership
CBD	Convention on Biological Diversity
CBERS	China-Brazil Earth Resources Satellite
CCRS	Canada Centre for Remote Sensing
CDOM	Colored dissolved organic matter
CDR	Climate Data Records
CEOS	Committee on Earth Observation Satellites
CHRIS	Compact High Resolution Imaging Spectrometer
CNES	French National Space Agency
CORINE	Coordination of Information on the Environment
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAAC	Distributed Active Archive Center
Defra	UK's Department of Environment, Food and Rural Affairs
DEM	Digital Elevation Model
DETER	Detection of deforestation in near real time
DGVM	Dynamic Global Vegetation Model

DHI	Dynamic Habitat Index
DLR	German Aerospace Center
DMP	Dry Matter Productivity
DOPA	Digital Observatory for Protected Areas
EBV	Essential Biodiversity Variable
ECV	Essential Climate Variable
EEA	European Environment Agency
Envisat	Environmental Satellite
EO	Earth Observations
EPS	EU Metsat Polar System
EROS	Earth Resources Observation and Science
ESA	European Space Agency
	Science Enterprise
ESI	Environmental Sensitivity Index
EU BON	European Biodiversity Observation Network
EVI	Enhanced Vegetation Index
FAPAR	Fraction of Absorbed Photosynthetically Active Radiation
FAO	Food and Agricultural Organisation
fCover	fraction of Green Vegetation Cover
fPAR	fraction of Photosynthetically Active Radiation
FOEN	Swiss Federal Office for the Environment
GEO BON	Group on Earth Observations Biodiversity Observation Network
GFW	Global Forest Watch
GIS	Geographic Information System
GLC	Global Land Cover
GLCF	Global Land Cover Facility
GMES	Global Monitoring for Environment and Security

GOCI	Geostationary Ocean Color Imager
GOSAT	Greenhouse Gas Observation Satellite
GPS	Global Positioning System
GRACE	Gravity Recovery and Climate Experiment mission
HyMAP	Airborne Hyperspectral Imaging Sensor
INPE	Brazilian National Institute for Space Research
ICARUS	International Cooperation for Animal Research Using Space
IOC	Intergovernmental Oceanographic Commission
IOOS	Integrated Ocean Observing System
IPBES	Intergovernmental Platform on Biodiversity and Ecosystem Services
IRS	Indian Remote Sensing satellite
ISRO	Indian Space Research Organisation
JAXA	Japanese Aerospace Exploration Agency
JRC	Joint Research Centre
J-BON	Japanese Biodiversity Observation Network
LAI	Leaf Area Index
LCCS	Land Cover Classification System
LEDAPS	Landsat Ecosystem Disturbance Adaptive Processing System
LiDAR	Light Detection and Ranging
LPV	Land Product Validation
MAPSAR	Multi-Application Purpose Synthetic Aperture Radar
MEA	Multilateral Environmental Agreement
MERIS	Medium Resolution Imaging Spectroradiometer
MISE	Multi-angle Imaging Spectroradiometer
MLS	Microwave Limb Sounder
MODIS	Moderate Resolution Imaging Spectrometer Sensor
MOPITT	Measurements of Pollution in the Troposphere
MWIR	Mid-Wave Infra Red
NASA	National Aeronautics and Space Administration
NBSAP	National Biodiversity Strategy and Action Plan
NIR	Near Infrared
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Association
NPP	Net Primary Productivity
NVDI	Normalized Difference Vegetation Index
OAPS	Ocean Acidification Product Suite
OCO	Orbiting Carbon Observatory
OLI	Operational Land Imager
OMPS	Ozone Mapping and Profiler Suit
OSCAR	Ocean Surface and Current Analysis
PALSAR	Phased Array Synthetic Aperture Radar
PAR	Photosynthetically Active Radiation
PIC	Particulate Inorganic Carbon
Radar	Radio Detection and Ranging
RCM	Radarsat Constellation Mission
SANBI	South Africa National Biodiversity Institute
SANSA	South Africa National Space Agency
SAR	Synthetic Aperture Radar
SDM	Species Distribution Model
Sonar	Sound Navigation and Ranging
SPM	Suspended Particulate Matter
SPOT	Systeme Pour l’Observation de ka Terre (French satellite)
SSS	Sea Surface Salinity
SST	Sea Surface Temperature
SWV	Surface Wind Vector
TERN	Terrestrial Ecosystems Research Network
TIRS	Thermal Infrared Sensor
TOMS	Total Ozone Mapping Spectrometer
TRMM	Tropical Rainfall Measuring Mission
UAV	Unmanned aerial vehicle

UNEP-WCMC	United Nations Environmental Programme World Conservation Monitoring Centre
UNESCO	United Nations Educational, Scientific and Cultural Organization
USGS	United States Geological Survey
UV	Ultraviolet
VCF	Vegetation Continuous Field
VCI	Vegetation Condition Index
VPI	Vegetation Productivity Index
VHR	Very High Resolution
VIS	Visible Spectrum
WFI	Wide Field Imagery
WMO	World Meteorological Organization
WRI	World Resources Institute

ANNEX 1. THE BASICS OF REMOTE SENSING IN BIODIVERSITY MONITORING

1.1 WHAT IS REMOTE SENSING?

There are many possible definitions of the term Remote Sensing. Remote means away from or at a distance and sensing means detecting a property or characteristics. Therefore, Remote Sensing could be very broadly defined as the science of collecting and interpreting information about an object without actually being in contact with it.

Remote sensing instruments can be classified according to the supporting vehicle or carrier (called platform). According to the height of platforms, remote sensing can be classified into three levels:

Table 1.1. Remote sensing classification according to the height of sensor-borne platforms

Level	Operational range	Height	Pros
Ground	Short range	50-100 m	- Panoramic mapping - Millimeter accuracies - High definition surveying
	Medium range	150-250m	
	Long range	Up to 1km	
Airborne	Aircraft	Up to 20km	- Last minute timing changes can be made to adjust for illumination from the sun, the location of the area to be visited and additional revisits to that location. - Sensor maintenance, repair and configuration changes are easily made to aircraft platforms. Aircraft flight paths know no boundaries except political boundaries - Quantitative measurement of ground features using radiometrically calibrated sensors - Semi-automated computerised processing and analysis - Unique way of covering a broad range of altitudes for *in-situ* or remote sensing measurements in the stratosphere - Opportunity for additional, correlative data for satellite based measurements, including both validation and complementary data - Important and inexpensive venue for testing instruments under development. - Relative low cost - Flexibility in the frequency and time of data acquisition - Ability to record spatial details finer than current satellite technology
	Balloon based	Up to 40 km	
Spaceborne	Space shuttle	250-300km	- Large area coverage - Frequent and repetitive coverage of an area of interest - Quantitative measurement of ground features using radiometrically calibrated sensors - Semi-automated computerised processing and analysis
	Space stations	300-400 km	
	Low level satellites	700-1500 km	
	Geostationary satellites	36000 km	

Aircraft based airborne remote sensing can be further categorised to manned aerial vehicle remote sensing and UAV remote sensing according to the platform. The name UAV covers all vehicles which are flying in the air with no person onboard with the capability of controlling the aircraft. Thanks to GPS and communication technology, UAVs can be remotely controlled or flown autonomously based on pre-programmed flight plans or more complex dynamic automation systems. The benefits of UAVs mainly lie in the ease, rapidity and cost of flexibility of deployment that lends itself to many land surface measurement and monitoring applications, especially those requiring access to higher altitudes and longer times on station (i.e. longer flight times). Although conventional airborne remote sensing has some drawbacks, such as altitude, endurance, attitude control, all-weather operations, and monitoring of dynamics, it is still an important technique for studying and exploring the Earth's resources and environment.

1.2 AN OVERVIEW OF REMOTE SENSING SOURCES AND APPLICABILITY FOR MONITORING BIODIVERSITY

Remote sensing systems can be classified in two major groups: passive and active sensors. The following pages contain a brief and simple description for each system, which is adopted throughout this review. The more technical aspects, as well as detailed discussion of advantages and drawbacks of each sensor have not been included since it is not the nature of this report to provide this level of technical information, which can be easily found in the available literature.

1.2.1 Passive remote sensing

Remote sensing systems that measure energy that is naturally available are called passive sensors. The way to use passive sensors to examine, measure and analyse an object is called **passive remote sensing or optical remote sensing**. Measurable energy takes the form of electromagnetic radiation from a surface, either as a reflection (reflected light) or as an emission (radiation emitted from the surface itself). For all reflected energy, this can only take place during the time when the sun is illuminating the Earth as there is no reflected energy available from the sun at night. Energy that is naturally emitted (such as thermal infrared) can be detected day or night.

Optical remote sensing is based on different areas of light's spectrum. For example, the visible spectrum (VIS) is the portion of the electromagnetic spectrum from about 0.39 to 0.7 μm that is visible to the human eye. The VIS is often displayed through the use of three spectral bands: blue band (0.45-0.515 μm) is used for atmospheric and deep water imaging, and can reach up to 50m deep in clear water; green band (0.515-0.6 μm) is used for imaging of vegetation and deep water structures, up to 30m in clear water; and red band (0.6-0.69 μm) is used for imaging of man-made objects, in water up to 9m deep, soil, and vegetation, and it is sensitive to chlorophyll. Infrared light occurs at longer wavelengths than red light, hence the name, infra- red. The near-infrared spectrum (NIR) ranges from about 0.7 to 1.1 μm that lies just out of the human vision, which is used primarily for imaging of vegetation. The NIR can be used to discriminate plant species. Short-wave infrared (SWIR) light is typically defined as light in the 1.1 – 3.0 μm wavelength range. One major benefit of SWIR imaging is the ability to image through haze, fog and glass. The SWIR is known to be very sensitive to leaf water content (Tucker, 1980), which therefore can enhance plant species identification. Mid-wave infrared spectrum (MWIR) ranges from about 3.0 to 5.5 μm and thermal infrared (TIR) ranges from 8 to 14 μm. Both MWIR and TIR imaging can capture the intrinsic heat radiated by objects (i.e. the objects' thermal emission): warm objects stand out well against cooler backgrounds e.g. warm-blooded animals become easily visible against the environment at night.

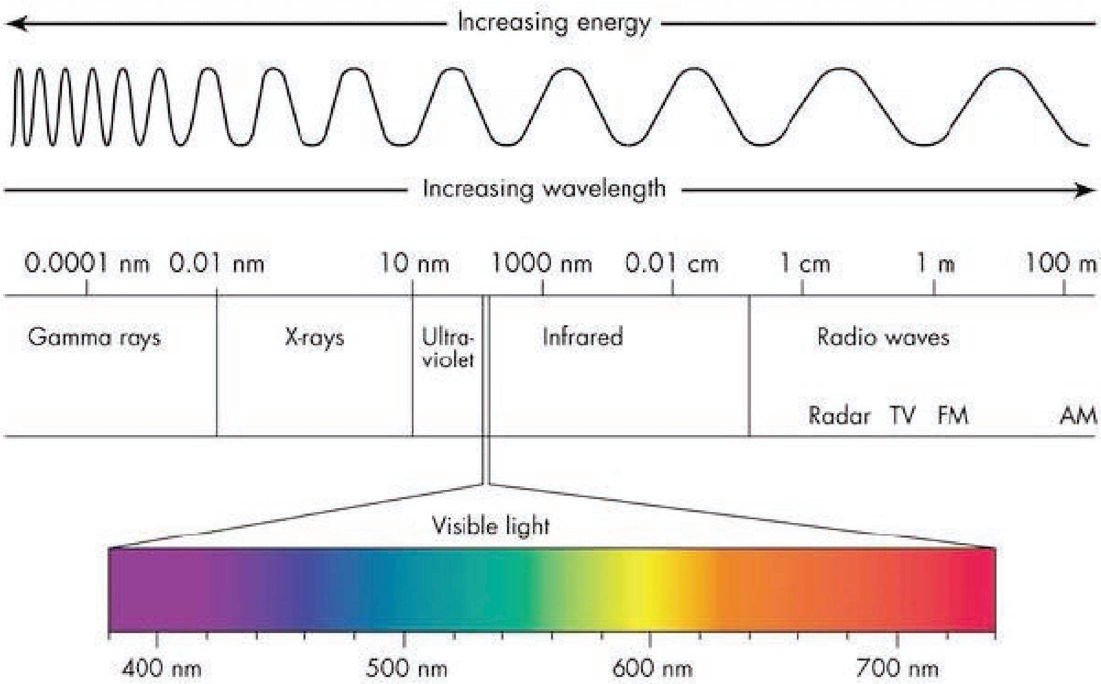

Figure 1.1 Diagram of the light's electromagnetic spectrum, showing the different wavelengths of visible light (Lumenistics, 2012)

There are two methods to collect data using passive sensors:

Multispectral

Multispectral remote sensing collects data in a few relatively wide and noncontiguous spectral bands, typically measured in micrometers or nanometers (1 micrometer = 1000 nanometers) These spectral bands are selected to collect radiation in specifically defined parts of the spectrum and optimised for certain categories of information most evident in those bands. Different spectral behaviour allows detailed classification of specific types of land surfaces (depending on the spatial, spectral and radiometric resolution of the used sensor). The remotely sensed spectral heterogeneity information provides a crucial baseline for rapid estimation or prediction of biodiversity attributes and hotspots in space and time.

Hyperspectral

Hyperspectral sensors or imaging spectrometers measure energy in many narrow, contiguous bands -often as many as 200 or more. A reasonable criterion, to be considered in a rather flexible way, is that the hyperspectral remote sensing collects at least 100 spectral bands of 10-20 nm width. The numerous narrow bands of hyperspectral sensors provide a continuous spectral measurement across a wider portion of the electromagnetic spectrum than multispectral instruments and therefore are more sensitive to subtle variations in reflected energy and have a greater potential to detect differences among land and water features. For example, multispectral imagery can be used to map forested areas, while hyperspectral imagery can be used to map tree species within the forest, contingent upon appropriate spatial resolution.

1.2.2 Active remote sensing

Active remote sensing sensors provide their own energy source for illumination. The active sensor emits radiation which is directed toward the target to be investigated. The radiation reflected from that target is detected and measured by the sensor. Using active sensors to examine, measure, and analyse an object is called active remote sensing. Active sensors can be used for examining wavelengths with insufficient energy provided by the sun, such as microwaves, or to better control the way a target is sensed. Advantages of active microwave sensors include the ability to obtain measurements anytime, regardless of the time of day or season. However, active systems require the generation of a fairly large amount of energy to adequately sense targets.

Radar

Radar is an acronym for "radio detection and ranging", which essentially characterises the function and operation of a Radar sensor. Radar works by sending out microwave (radio) signals towards the target and detects the backscattered portion of the signal. By measuring the amount of time it takes for the signals to return, it is possible to detect the location, speed, direction and altitude of an object. It also serves as a useful tool for the study of bird migration patterns and behaviours, as well as alerting researchers to any changes in those patterns and behaviors (Liechti *et al.* 1994; Hilgerloh 2001; Ruth *et al.* 2005; Ruth 2007; Benkert *et al.* 2008). An important advantage to using airborne and spaceborne Radar systems is that they can penetrate thick clouds and moisture, which would not be possible using optical remote sensing. This allows scientists to accurately map areas such as rain forests that are otherwise too obscured by clouds and rain. For these reasons, high resolution Radar is well suited to mapping and monitoring wildlife habitat in tropical and sub-tropical humid zones. The system can provide regular information on the location of changes, such as changes in the forest canopy through logging or landslides, (illegal) clearing of areas (for agriculture, mining, oil palm plantation) and encroachment patterns, expansion of road networks, fire impacts and vegetation development (Bergen *et al.* 2007; Swatantran *et al.* 2011).

LiDAR

LiDAR stands for "Light Detection And Ranging" and is very similar to the better known Radar except that a laser pulse, not a microwave signal, is sent out of a transmitter and the light particles (photons) are scattered back to the receiver. The photons that come back to the receiver are collected with a photodetector and counted as a function of time. As the speed of light is known, distance to the object can be easily calculated.

LiDAR is a remote sensing technology that is now becoming more widespread in ecological research. The metrics derived from airborne or spaceborne LiDAR measurements can be used to infer forest canopy height and/or canopy structure complexity. Its ability to accurately characterise vertical structure makes LiDAR a valuable and cost-effective approach for estimating forest attributes that are related to important ecological characteristics. In this regard, an attribute of particular interest is 3-dimensional or volumetric habitat heterogeneity, which reflects the variability in both horizontal and vertical forest structure (e.g. stem, branch and foliage density and distribution). This structural variability may be correlated with species richness and other biodiversity metrics, which are central components to understanding, modeling and mapping patterns of biodiversity (Clawges *et al.* 2008; Bergen *et al.* 2007; Goetz *et al.* 2007).

Sonar

Sonar – short for "Sound navigation and ranging" - is a technique that uses sound propagation (usually underwater, as in submarine navigation) to navigate, communicate with or detect objects on or under the surface of the water. Sonar works in a similar manner as Radar. However, instead of sending out radio waves, Sonar sensors send out sound waves. By measuring the time it takes for these sound waves to travel towards an object, bounce off of it, and then return, it is possible to calculate distances.

Two types of while active Sonar emits pulses of sounds and listens for the echoes. Sonar sensing may be used as a means of acoustic location and of measurement of the echo characteristics of targets in the water. Active Sonar allows scientists to accurately map the two thirds of the Earth that is under water. In addition, Active Sonar has been used to investigate the population dynamics of both deep and shallow water fish populations. Passive Sonar sensors that receive underwater sounds help overcome many of the limitations experienced with visual surveys.

Both passive and active Sonar have been incorporated into survey methods to improve animal abundance estimates, especially for cetacean surveys. For example, passive Sonar sensors have successfully been used in abundance estimates for several cetacean species including right whales, beaked whales, sperm whales, humpback dolphins, and finless porpoises (Akamatsu *et al.* 2007; Van Parijs *et al.* 2002; Barlow *et al* and Taylor 2005; Mellinger and Clark 2006). The use of passive Sonar sensors may allow for more animal detections across larger ranges than would be obtained from visual methods alone, and facilitate the detection of animals that spend a large amount of time under water.

1.3 HOW TO USE REMOTE SENSING TO MONITOR BIODIVERSITY?

There are several possible approaches to use remote sensing to monitor biodiversity. Which approach is most suitable depends on the environment in which biodiversity is to be monitored; the characteristics of relevant species that occur in these ecosystems and the availability of remote sensing data. Twomajor approaches can be distinguished:

1.3.1 Direct measurements of individuals and populations

Direct measurements of individuals and populations are possible with very high resolution imagery, such as RapidEye (5m), WorldView (≤2m), GeoEye (<2m), Pleiades (<1m) or IKONOS (3.2m). A key feature of very high resolution imagery is the ability to detect and classify individual tree canopies. Direct measurement of animal populations is constrained to situations where the animals or their traces (such as burrows) can be easily detected. This means a limited vegetation cover, or a vegetation cover that is less high than the species involved. Examples where this kind of monitoring has been successfully implemented include elephants, wildebeest and zebra in the Serengeti, (Yang 2012), marmots in Mongolia (Velasco 2009) or emperor penguins in Antarctica (Fretwell *et al*., 2012). In the 1980's Wombat burrows were identified from medium resolution Landsat MSS imagery (Löffler and Margules 1980). The breeding distribution of the Emperor penguin in Antarctica has been mapped by spectral characterisation of breeding colonies on snow in Landsat imagery (Fretwell & Trathan, 2009).

1.3.2 Indirect proxies of biodiversity

Indirect proxies involve approaches where derived information from the reflectance values that are recorded by satellite sensors is used to infer information about biodiversity on the surface that was monitored. Such proxies can be based on variability along three potential axes, a spatial, a temporal and a spectral axis. The sensor at hand determines to great extent which proxies can be generated. Sensors with high spatial resolution offer a possibility to look at variability in the reflectance in neighborhoods of small size, i.e. with great detail. But satellite borne sensors of this kind are normally limited in their spectral and temporal dimensions. Likewise, sensors with high temporal resolutions (e.g. NOAA AVHRR or MODIS) are limited in their spectral and spatial resolution. Which combination offers the best solution to monitor biodiversity depends heavily on the ecosystem and target species to be monitored. Recent literature suggest that spectral resolution would be preferred over spatial resolution (Rocchini *et al*. 2010 and references therein). The minimal size of homogeneous units within the system determines to a large extent which pixel size is acceptable. Likewise, the difference in phenology of key species in the system determines whether variation over the temporal axes can help in identifying changes in biodiversity (Oindo and Skidmore 2002).

Indirect proxies can often be derived from satellite data that have direct biophysical meanings, such as altitude from digital elevation models, green biomass from NDVI products, vegetation cover, or surface temperature. These data sometimes can have a direct link to diversity (Baldeck and Asner 2013) and be used as a proxy value. In addition they are often used as explanatory variables in species distribution modeling (SDM), which in turn can be used for species diversity assessments, as described below. Nevertheless, diversity in ancillary data, such as altitude also provides information about species diversity at intermediate scales because it can represent heterogeneity in available niches (Allouche *et al*. 2012).

1.3.2.1 Inputs to Models

Remotely sensed data can also be used as an essential input to several kinds of models that predict diversity, such as SDMs where empirical relationships between observed occurrences of species and remotely sensed environmental conditions are used to extrapolate potential species distributions. These models are often implemented to map the distribution of single species, but they can be also be aggregated to map areas with high probabilities of many species (i.e. hot spots) and few species (i.e. cold spots). Often this does not involve raw satellite reflectance signals, but further refined products such as indirect proxies (see above) that have a logical relationship with species survival such as surface temperature, rainfall data, NDVI or seasonality of NDVI. These are often important parameters for most species that try to find an optimum in a multidimensional optimisation of environmental conditions.

Another type of model worth mentioning in the context of this review is the bottom-up models that describe ecosystem dynamics, from which biodiversity can be inferred. These models, called Dynamic Global Vegetation Models (DGVMs), stimulate changes in potential vegetation and their impacts on hydrological and biochemical cycles, often using satellite based climate data as input.

1.4 DEVELOPING BIODIVERSITY INDICATORS FROM REMOTELY SENSED DATA

The development of biodiversity indicators involves a two stage process. Firstly it needs to be determined which biodiversity variables are needed to capture the status of the system. Secondly, a suitable remote sensing product has to be selected that can be linked to this variable. Many methods exist to derive information from remote sensing data, but depending on the system under monitoring and the required level of detail, a choice has to be made. In Annex 2 a summary of existing operational EO products and their applications in biodiversity monitoring can be found.

It is worth noting that satellite-derived information is not in a format which can be readily used as a biodiversity indicator but requires some modification in order to become an indicator (Strand *et al*., 2007). GIS-based analysis of remotely sensed information, supported by ground validation, is usually required before the data can become a usable indicator. This process of refining remote sensing information to the level of a biodiversity indicator is not straightforward and there are sometimes limits to the type and complexity of the indicators which can be developed. This applies to both terrestrial and marine environments which demonstrate unique challenges to indicator development (see sections 4.1 and 4.2 for further details).

1.5 WHY USE REMOTE SENSING TO MONITOR BIODIVERSITY?

1.5.1 Traditional *in situ* methods

A variety of traditional *in situ* methods exist to survey (and then monitor) biodiversity. Their adequacy strongly depends on the target taxon. Common methods for sessile organisms (plants, fungi) are quadrant and transect sampling, where a square frame or rope, respectively, delineates the plot horizontally. Scientific methods to collect mobile species include canopy fogging (insects; e.g. Paarman & Stork 1987, Yanoviak *et al*. 2003), netting (birds: e.g. Dunn & Ralph 2004, Arizaga *et al*. 2011); bats: e.g. Larsen *et al*. 2007, Kalko *et al*. 2008; and fish: e.g. Lapointe *et al*. 2006, Achleitner *et al*. 2012, pitfalls (e.g. herpetofauna: Ribeiro-Júnior *et al*. 2008, Sung *et al*. 2011), pheromones or light insects: e.g. Baker *et al*. 2011) and camera traps (e.g. Linkie, M. *et al*. 2013). Occasionally artifacts (e.g. pellets, dung, larval pupae) serve as evidence too (Hill *et al*. 2005), and for some species, other measurements may suffice for identification (e.g. acoustic monitoring of bats and birds Jones *et al*. 2009).

To obtain a representative sample of the examined habitat, a number of plots are typically required. To optimally allocate sampling effort in this respect, plots may be (systematically or randomly) stratified and/or clustered. In addition, often only a (random) subset of a quadrant is sampled, and observations along transects are recorded at predefined intervals only. Temporal variability of the target habitat may be as important to survey planning as spatial heterogeneity, because seasonality, daytime weather and irregular disturbances (e.g. fires) co-determines the presence and / or the ability to detect an organism. In such situations plots may require multiple sampling visits to avoid/reduce temporal bias.

Species accumulation curves (which plot sampling effort unit versus. species found) are used to assess the sufficiency of sampling effort in a given plot. Inventory results are typically summarised into various diversity indices (e.g. Simpson or Shannon-Wiener), which are calculated from the observed number of different species (richness) and their relative abundance per sample unit (evenness).

Monitoring biodiversity with traditional *in situ* methods often requires as much effort as compiling the initial inventory (see above), because repeat measurements should be based on (nearly) the same sampling design and methods to accurately detect changes. Some optimisation is possible though using occupancy modeling and power analysis (e.g. Sewell *et al*. 2012).

Especially in case of sparsely distributed organisms, as well as difficult to detect individuals (discussed e.g. in Mazerolle *et al*. 2007), traditional *in situ* sampling efforts may also become prohibitively expensive before a sample size is reached with sufficient statistical power to allow for estimates of (changes in) abundance.

Inaccessibility of some habitats within a study region (e.g. steep slopes, thick mangrove) but also practical considerations (e.g. proximity to roads or observer populations) may affect the comprehensiveness of results obtained with traditional *in situ* methods.

All sample site allocation schemes require a priori knowledge of the spatial (habitat) heterogeneity, which may be insufficient – especially at finer scales. Consequently some biodiversity values within the study region may remain undetected.

Insufficiently standardised sampling protocols may reduce the reproducibility of the initial inventory and thus inflate uncertainty of subsequent monitoring results (e.g. Braga-Neto *et al.* 2013).

Results cannot be extrapolated to the surrounding landscape or different temporal periods. At most, using expert knowledge and some generalized habitat maps, observed species-habitat relationships can be used to infer biodiversity in similar settings. The common practice however is to depict results of traditional *in situ* methods either as atlas grid cells or homogeneously for an entire examined area or strata.

1.5.2 Remote sensing

Remote sensing cannot replace traditional *in situ* methods for compiling initial inventories of species, except in case of very large species identifiable on airborne images, and very high resolution imagery collected by UAVs. However, remote sensing is a valuable large scale biodiversity monitoring tool at the level above species if coupled with quality ground data and likely to grow in value if embedded in a global, harmonized observation network (Pereira *et al.* 2013).

Remote sensing can be very useful for both planning surveys (and delineating strata in which initial surveys take place) as well as most importantly monitoring biodiversity changes thereafter. For example, remotely sensed imagery allows delineation of (spatial-temporal) habitat classes and strata within a study area, which is crucial for optimal sample site allocation. Remote sensing can also be used to identify habitat in space and time, which has not been examined yet with traditional *in situ* methods, and may harbor overlooked or yet unknown species. To meet the requirement of carrying out repeat measurements under spatiotemporal conditions similar to the initial inventory, remote sensing is extremely useful in identifying when and where to monitor.

If a robust relationship between ground truth observations and multivariate remote sensing data can be established, biodiversity conditions may be estimated for similar settings outside the study area – at species level by means of aggregated SDMs (e.g. Raes *et al.* 2009, Dubuis *et al.* 2011) or at ecosystem level (e.g. Duro *et al.* 2007, Rocchini *et al.* 2010). Using SDM techniques, remote sensing represents an efficient and cost-effective monitoring tool. To identify and calibrate reliable biodiversity proxies and indicators, permanent monitoring plots and standardised survey protocols are essential (e.g. Jürgens *et al.* 2012, Chawla *et al.* 2012, and Braga-Neto *et al.* 2013).

Table 1.2. List of some key advantages and disadvantages of airborne and spaceborne remote sensing compared to traditional *in situ* methods

Advantages	Disadvantages
Provide a continuous, repetitive, large-scale synoptic view relative to traditional point-based field measurements	Remote sensing instruments are expensive to build and operate
Practical way to obtain data from dangerous or inaccessible areas	Remote sensing data are not direct samples of the phenomenon and it must be calibrated against reality. The measurement uncertainty can be large
Relatively cheap and rapid method of acquiring up-to-date information over a large geographical area	Remote sensing data must be corrected geometrically and georeferenced in order to be useful as maps, not only as pictures. The difficulty of this varies.
Easy to manipulate with the computer, and combine with other geographic coverage in the GIS.	Remote sensing data interpretation can be difficult, which usually need to understand theoretically how the instruments are making the measurements, need to understand measurement uncertainties, and need to have some knowledge of the phenomena you are sampling.

ANNEX 2. OVERVIEW OF AVAILABLE REMOTE SENSING/EARTH OBSERVATION PRODUCTS

2.1 OPERATIONAL EARTH OBSERVATION PRODUCTS USED TO MONITOR BIODIVERSITY

On the following pages existing operational EO products are summarised according to their applications in biodiversity monitoring and their potential to support the Convention. To this purpose they have been mapped against the key Aichi Targets they have the potential to help tracking progress towards and the CBD operational indicators. In addition, candidate EBVs they could contribute to have been identified. Databases mentioned can be found in Annex 4, Tables 4.1 and 4.2. In addition, a more detailed mapping including secondary Aichi Biodiversity Targets these products could support, key features, summary of key features and available datasets can be found in Annex 4, Table 4.3.

2.1.1. Operational land-based EO products

Land cover and Land cover change

Land cover is the visible features of the Earth surface including vegetation cover as well as natural and manmade features that cover the surface of the Earth (Campbell, 2006). These are physical features of the Earth surface in contrast to land use which is an implied use of the feature, e.g. a field for agriculture. Physical features of the Earth's surface reflect solar radiation in different ways and therefore demonstrate unique spectral characteristics. The spectral characterisation of different land cover types allows land cover to be mapped over broad areas from EO satellite sensors. Land cover can be mapped at a range of spatial scales. At the local-scale ground surveys are often employed while aerial and satellite images are more commonly employed from regional to national scales.

Land cover maps are frequently used as a means of visually assessing broad-scale patterns in land cover across regions, countries or continents and relating these with species distributions or species richness (Cardillo *et al*., 1999) and identifying likely biodiversity hotspots through 'gap analysis' (Scott and Jennings, 1998). Such maps can also be useful to identify land cover change in and around protected areas and can contribute to improved management of existing protected areas (Jones *et al*., 2009). Land cover can be used as a variable to parameterise land use, agro-meteorological, habitat and climate models and as inputs to more complex EO-based products such as the MODIS LAI and FAPAR (Myneni *et al*., 2002).

Examples of operational land cover maps and some land cover data distributing centers are listed in the Annex 4. While these are open-access land cover maps, they have been created using different methodologies and classification systems which have been designed to satisfy different end user requirements and institutional needs. This makes integration of land cover maps very difficult. Furthermore, these tend to be static maps giving a snapshot of land cover in time although some have periodic updates, e.g. CORINE Land Cover (CLC) 1990, 2000 and 2006. The biodiversity community could benefit from an assessment of needs in relation to land cover mapping. This could help to focus efforts to produce a set of land-cover/use products that meet the needs of the biodiversity community.

Land cover and land cover change is most relevant to:

- CBD Aichi Biodiversity Target
  - ✓ Target 5. By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced
- CBD Strategic Plan for Biodiversity 2011-2020 operational indicators
  - ✓ Trends in extent of selected biomes, ecosystems and habitats (decisions VII/30 and VIII/15)
  - ✓ Trends in the proportion of natural habitats converted
- GEO BON EBVs
  - ✓ Ecosystem extent and fragmentation
  - ✓ Habitat disturbance

Fire

Fire scars provide a high contrast Earth surface target while the thermal radiation emitted by surface fires is readily detectable from EO sensors (Dozier, 1981). For example, the Along Track Scanning Radiometer (ATSR) sensor produces monthly fire maps based on land surface temperature data. The ATSR World Fire Atlas shows the spatial extent of burnt areas and the locations of active fire fronts (Arino *et al.*, 2005). However, spectral information in range of wavelengths, from the visible to infrared, can be potentially be used to detect active fires and separate them from non-burned areas, as has been done with MODIS (Roy *et al.*, 2005). Forest fire can rapidly alter ecosystem structure and change the nature of surface materials from living vegetation to charred organic matter and ash (Kokaly *et al.*, 2007).

Regularly-acquired fire data can contribute to understanding the temporal cycle of fire activity on a seasonal and annual basis and its impact on greenhouse gas emissions, in particular carbon dioxide (Zhang *et al.*, 2003). Operational fire products are produced at continental to global scales and updated in near real-time. The International Strategy for Disaster Reduction provides a comprehensive list of EO-based fire products. Fire products from 1999 to present are open access from the Global Land Service portal using SPOT/VGT data and MODIS products from the Land Processes Distributed Active Archive Centre (LP-DAACs). The MODIS Rapid Response System provides near real-time fire monitoring from a variety of EO sensors. The European Space Agency ATSR World Fire Atlas has monthly global fire maps from 1995 to present. While these data sources provide information on the spatial distribution of fires and their timing, understanding the cause of fires is important for conservation planning. A new tool for fire monitoring has been recently released by the Joint Research Centre to provide information on fire activity in the world protected areas. The information is derived from EO and it is presented in the form of environmental indicators and maps so that does not require specific remote sensing knowledge. This fire monitoring tool has been specifically designed for people working in protected areas.[4] It can support park managers and scientists in their conservation programs, decision-making activities, as well as the prevention, plan and control of fire.

The Fire Tool provides near-real time data derived from the Moderate Resolution Imaging Spectrometer Sensor (MODIS) observations and covers more than ten years from late 2000 to the present day, at global level. It can assist park managers in their conservation programs by providing up-to-date statistics and maps of the fire occurrence and also trends and anomalies based on the historical time series. Conservationists will be able to assess the alterations of the fire regimes in the natural habitats, analyse threats and pressures (for example some illegal activities associated with fire, such as poaching) and eventually evaluate the park management effectiveness. Anomalies in fire regime (e.g. change in fire frequency, seasonality) can be either an indicator of land cover change or habitat loss, or more generally an indicator of land use change. The possibility to access this information is therefore important to take the appropriate decisions for effective conservation.

Footnote

[4] *http://acpobservatory.jrc.ec.europa.eu/content/fire-monitoring*

Fire products are most relevant to:

- CBD Aichi Biodiversity Target
  - ✓ Target 5. By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced
- CBD Strategic Plan for Biodiversity 2011-2020 operational indicators
  - ✓ Trends in extent of selected biomes, ecosystems and habitats (decisions VII/30 and VIII/15)
- GEO BON EBVs
  - ✓ Disturbance regime

Biophysical vegetation parameters

There are two operationally-produced biophysical vegetation parameters, Leaf Area Index (LAI) and the Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) which are important in several surface processes, including photosynthesis, respiration and transpiration (Baret *et al*., 2013).

LAI is defined as the area of leaf surface per unit area of soil surface (Campbell, 2006) and is an important variable for surface-atmosphere interactions such as water interception, photosynthesis and evapotranspiration and respiration. FAPAR acts like a battery for the plant photosynthetic process measuring the plants ability to assimilate Photosynthetically Active Radiation (PAR) and generate green leaf biomass (Gobron *et al*., 2006). Both of these parameters are related as LAI is the biomass equivalent of FAPAR and both play a role in driving ecosystem process models. For example, FAPAR is an essential variable in light use efficiency models (McCallum *et al*., 2009).

LAI can be measured *in-situ* by measuring leaf area directly or through hemispherical photography while FAPAR can be inferred from measurements of incoming and outgoing solar radiation. However, both of these methods are labour intensive. Remotely sensed LAI and FAPAR products are generated at regional and global scale and produced operationally form sensors such as Envisat EMRIS (non-operational since 2012) and Terra MODIS. However, gaps due to cloud cover necessitate compositing daily data into regular intervals typically from 8 to 16 days. Time series of LAI and FAPAR can be used to monitor seasonal vegetation dynamics such as crop cycles and land surface phenology. For example, a slight global greening trend has been detected using a multi-decadal time series of LAI (Siliang *et al*., 2010).

The biophysical vegetation parameters are most relevant to:

- CBD Aichi Biodiversity Target
  - ✓ Target 5. By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced
  - ✓ Target 10. By 2015, the multiple anthropogenic pressures on coral reefs, and other vulnerable ecosystems impacted by climate change or ocean acidification are minimized, so as to maintain their integrity and functioning.
  - ✓ Target 14. By 2020, ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded, taking into account the needs of women, indigenous and local communities, and the poor and vulnerable.
- CBD Strategic Plan for Biodiversity 2011-2020 operational indicators
  - ✓ Status and Trends in extent and condition of habitats that provide carbon storage
  - ✓ Trends in primary productivity
- GEO BON EBVs
  - ✓ Net Primary Productivity (NPP)
  - ✓ Phenology

Vegetation Productivity Spectral Indices

A spectral index such as the Normalised Difference Vegetation Index (NDVI) is generic to any sensor recording electromagnetic radiation in the red and near infrared spectral bands. However, the shortcomings of NDVI, in relation to the influence of atmosphere and sensor-specific variation, have already been well documented (Pinty and Verstraete, 1992). Other spectral indices such as the MODIS Enhanced Vegetation Index (EVI) have been designed for specific sensors however. While the NDVI solely employs spectral information, indices such as the EVI are built on spectral information parameterised for sensitivity to green biomass and are therefore less likely to saturate in areas of dense biomass such as rainforest (Huete et al., 2002). The NDVI is a general indicator of vegetation presence or absence but is less stable than the EVI, particularly in time series analysis. However, both indices can show variation in vegetation productivity and condition when mapped spatially. These spectral indices can be used at any scale from local to global, particularly the NDVI as any sensor measuring radiation in the red and near infrared spectral bands is all that is required. However, there is a need for awareness of the strengths and weakness of these indices and caution in applying them to strictly quantitative rather than qualitative analyses (Campbell, 2006). The biophysical variables are best used in quantitative analysis of vegetation variables. These indices are best used as general indicators of the vegetation state and are useful to detect relative change in vegetation condition, in particular to detect where habitat disturbances are occurring and causes a reduction in the spatial extent of vegetated areas.

The Vegetation Condition Index (VCI) and the Vegetation Productivity Index (VPI) are operational global products based on NDVI. These products compare contemporary NDVI data with historic trends to identify vegetation growth anomalies, e.g. drought, and so are useful to monitor temporal change in vegetation condition. The VCI and VPI can be obtained from the Copernicus Global Land Service.

The biophysical vegetation parameters are most relevant to:

- CBD Aichi Biodiversity Target
  - ✓ Target 5. By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced

- CBD Strategic Plan for Biodiversity 2011-2020 operational indicators
  - ✓ Trends in condition and vulnerability of ecosystems
  - ✓ Trends in primary productivity

- GEO BON EBVs
  - ✓ Ecosystem extent and fragmentation
  - ✓ Habitat disturbance.

Vegetation Cover and Density

Vegetation Continuous Fields (VCF) and Fraction of vegetation Cover (fCover) are designed to measure the relative spatial coverage of vegetation in an image pixel. While the VCF estimate the relative proportions of vegetative cover types per pixel: woody vegetation, herbaceous vegetation, and bare ground (De Fries et al., 1999, Hansen et al., 2003), the fCover is a relative measure of the gap fraction in green vegetation (Baret et al., 2007). However, fCover has also been used as an input to climate models in separating the contribution of soil from vegetation (Baret et al., 2013).

They are also important components of land cover. For example, the continuous classification scheme of the VCF product may be more effective in characterising areas of heterogeneous land cover better than discrete classification. Regularly updating static land cover maps with measures of fCover can incorporate disturbance as a land cover variable producing more adaptable land cover products. Annual and global VCF data from Terra-MODIS (NASA) imagery are distributed by the Global Land Cover Facility (GLCF). The fCover product is accessible from the Copernicus Global Land Service.

Vegetation Continuous Field and fraction of green cover are most relevant to:

- CBD Aichi Biodiversity Target
  - ✓ Target 5. By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced
- CBD Strategic Plan for Biodiversity 2011-2020 operational indicators
  - ✓ Trends in proportion of degraded/threatened habitats
  - ✓ Trends in fragmentation of natural habitats
- GEO BON EBVs
  - ✓ Ecosystem extent and fragmentation
  - ✓ Habitat disturbance.

Biomass

Biomass is quantified in terms of the overall mass of plant material (Campbell, 2006). EO-based measures of biomass are calibrated and validated using local-scale *in-situ* measures of above-ground biomass (Saatchi et al., 2007), while below-ground biomass is a more challenging parameter for EO-based technology (Cairns et al., 1997). However, the total combined above-ground and below-ground biomass has been estimated from a synthesis of EO and airborne sensor data, as well as ground measurements, across Latin America, sub-Saharan Africa, and Southeast Asia (Saatchi et al., 2011). As there is currently no EO sensor directly monitoring biomass, remotely sensed methods of biomass estimation are indirect and inferred from estimates of vegetation canopy volume. Therefore canopy height estimation from airborne or satellite Lidar is an important first step in biomass calculations which are then extrapolated over large areas using a model based on coarser resolution satellite imagery such as MODIS (Saatchi et al., 2011).

As most of the global biomass is held in woody trees (Groombridge and Jenkins, 2002), biomass is frequently used as preliminary variable to assess forest carbon stocks. Satellite-derived estimates of above-ground woody biomass provide reliable indications of terrestrial carbon pools (Dong et al., 2003). Therefore, remote sensing of deforestation, land use change and global forest fires can contribute to improved models of the global carbon cycle. Changes in biomass are also likely to result in changes in biodiversity.

As biomass estimation methods are labour intensive and indirect, EO-based biomass products are not yet operational. However, Dry Matter Productivity (DMP) is produced operationally and can be accessed from the Global Land Service, GEONET Cast and DevCoCoast databases. DMP represents the daily growth of standing biomass (equivalent to the Net Primary Productivity) and is expressed in kilograms of dry matter per hectare per day. The European Space Agency mission, BIOMASS, due in 2020 and based on radar technology, will provide global measurements of forest biomass (Le Toan et al., 2011).

Biomass is most relevant to

- CBD Aichi Biodiversity Target
  - ✓ Target 5. By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced
  - ✓ Target 15. By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced, through conservation and restoration, including restoration of at least 15 per cent of degraded ecosystems, thereby contributing to climate change mitigation and adaptation and to combating desertification.
- CBD Strategic Plan for Biodiversity 2011-2020 operational indicators
  - ✓ Trends in primary productivity
  - ✓ Status and trends in extent and condition of habitats that provide carbon storage
- GEO BON EBVs
  - ✓ Habitat Structure
  - ✓ Net Primary Productivity (NPP)

2.1.2. Operational marine EO products

Ocean-based EO products differ in their method of retrieval and their spatial and temporal coverage from land-based products (Campbell, 2006). This difference is predominately due to the physical reflectance characteristics of land surfaces and water bodies. Water reflectance is determined by the state of the water surface, the amount and type of suspended material in the water column and the bottom substrate in areas of shallow water (Lillesand et al., 2008). Furthermore, dynamic ocean variables such as eddies and currents change at a more rapid rate than polar-orbiting sensors can sufficiently monitor (Campbell, 2006).

Nevertheless, satellite sensors (e.g. SeaWiFs, Envisat MERIS and NOAA AVHRR) have been optimised to retrieve ocean variables such as ocean colour (chlorophyll-a concentration in mg/m3) (Brewin et al., 2011), ocean Primary Productivity (Antoine et al., 1996), suspended sediment, sea surface wind speed (m/s), sea surface temperature (°C), sea surface salinity and sea surface state (Campbell, 2006). While these are important state variables of the oceans and routinely monitored to track climate change, they are also habitat parameters in themselves. For instance, oceanic variables can be correlated with sea bird density and species compositions (Hyrenbach et al., 2007), cetacean species ranges (Tynan et al., 2005), as well as the distribution of pelagic species and near shore fishes (Johnson et al., 2011). Measures of ocean colour can be related to the abundance and type of phytoplankton which has important implications for the marine food chain (Brewin et al., 2011). For climate change monitoring in the marine environment, satellite remote sensing has been used to track Arctic sea ice extent, sea level rise, tropical cyclone activity and sea surface temperature (IPCC, 2007). Global ocean colour, sea surface temperature and salinity are operationally produced and available for download from the NASA Ocean Color website or from the GMES My Ocean website. ESA have an operational data portal for Ocean colour products called Globcolour. The NOAA Ocean Surface and Current Analysis (OSCAR) provide near-real time global ocean surface currents maps derived from satellite altimeter and scatterometer data.

The marine EO products are ocean colour (chlorophyll-a concentration in mg/m3), ocean Net Primary Productivity (NPP), suspended sediment, sea surface wind speed (m/s), sea Surface temperature (°C), sea surface salinity and sea surface state. They are most relevant to:

- CBD Aichi Biodiversity Target
  - ✓ Target 5. By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced
  - ✓ Target 8. By 2020, pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity.

- CBD Strategic Plan for Biodiversity 2011-2020 operational indicators
  - ✓ Trends in condition and vulnerability of ecosystems
  - ✓ Trends in sediment transfer rates storage

- GEO BON EBVs
  - ✓ Ecosystem extent and fragmentation
  - ✓ Habitat disturbance
  - ✓ Net Primary Productivity (NPP)

2.1.3 EO products for pollution monitoring

Remote sensing has considerable potential in monitoring the spatial extent of polluting material both in the upper atmosphere, on the land surface and in the marine environment. Though this is a relatively new application of earth observation satellite technology, it is a promising field of development and potentially impacts on a number of EBV categories and in helping to chart the progress towards achieving the 2020 Aichi targets. The EO products related to pollution are not strictly operational in that these products are mostly in development or form part of larger data dissemination and early warning systems. Nevertheless, examples of EO-based information systems which are currently in use for monitoring and forecasting pollution events are listed below.

Atmospheric pollution and greenhouse gas emissions

Some atmospheric pollutants contribute to the greenhouse effect while others are directly harmful to life and can contribute to habitat degradation and biodiversity loss. The main greenhouse gases are carbon dioxide, methane and nitrous oxide (N_2O). Further information on these gases and their implication for climate change can be found online (Greenhouse Gas Online, 2013).

The European Infrared Atmospheric Sounding Interferometer (IASI) measures the total column content of the main greenhouse gases, i.e., ozone, methane, nitrous oxide and carbon monoxide. These measurements contribute to an understanding of climate processes though their assimilation into global climate models. Products can be obtained from the IASI or associated sensors such as the EUMetsat Polar System (EPS). These products relate to temperature, humidity, ozone content and trace gas constituents of the atmosphere.

The NASA Microwave Limb Sounder (MLS) instrument measures passive microwave radiation from the upper atmosphere and derives estimates of atmospheric gases, temperature, pressure, and cloud ice. The MLS instrument is unique in its measurements of pollution in the upper troposphere as it can see through ice clouds that previously prevented such high altitude measurements. Such data can provide insights into the long-range transport of pollution and its possible effects on global climate. Near real time MLS products such as temperature, water vapor, ozone, carbon monoxide, water vapor, nitrous oxide, nitric acid and sulphur dioxide can be viewed online.

Nitrogen dioxide (NO_2) is a mainly man-made gas which forms nitric acid when oxidised creating acid rain. Acid rain has adverse impacts on soil, vegetation and can contribute to ocean acidification. Nitrogen oxides such as NO_2 are produced by emissions from power plants, heavy industry and road transport, along with biomass burning. NO_2 is important in atmospheric chemistry as it is responsible for the overproduction of tropospheric ozone, i.e. in the lower part of the atmosphere. A global NO_2 pollution map was produced by the ESA Envisat Sciamachy satellite in 2004 although this sensor was decommissioned in 2012. However, a variety of Sciamachy-based atmospheric products from 2002 to 2012 are available though registration with ESA on their data user portal. Upper atmosphere, stratospheric N_2O is inferred from measurements by sensors on board the US AURA and European MetOp satellite series.

The atmospheric EO products that relate to NO2 and ozone are most relevant to:

- CBD Aichi Biodiversity Target
  - ✓ Target 8. By 2020, pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity.
- CBD Strategic Plan for Biodiversity 2011-2020 operational indicators
  - ✓ Trends in nitrogen footprint of consumption activities
  - ✓ Trends in ozone levels in natural ecosystems
- GEO BON EBVs
  - ✓ Habitat disturbance

Ocean pollution

Oil spills such as the Prestige disaster of 2002, the Exxon Valdez in 1989 or the Deepwater Horizon oil rig of 2010 are a reminder of the threat posed to the marine environment of oil spills. Fortunately, large-scale surveillance of oil spills in the marine environment can now be readily achieved by satellite and airborne remote sensing (Leifer et al., 2012). Accidental, high-impact oil spills, and non-accidental incidental spills from marine vessels can be tracked in spatial extent and flow direction (Engelhardt, 1999). Remote sensing techniques are also used to localise point sources of oil slicks and for tactical assistance in emergency remediation.

SAR is the most frequently used satellite-based tool for oil spill detection since it operates at night time, penetrates cloud cover and is very sensitive to water surface roughness (Bern et al., 1993; Campbell, 2006). The smooth oil slick contrasts with the relative roughness of the surrounding surface water and appears as a dark patch on the SAR image.

CleanSeaNet is an example of an operation oil spill monitoring service based on EO technology which consists of oil slick imaging systems which also provide real-time sea state and weather information. This information is essential to track the rate and direction of slick movement. CleanSeaNet, which is operationally employed by marine authorities in EU member states, is part of the GMES initiative. Pollution alerts and related information is relayed to the relevant authorities 30 minutes after image acquisition for timely response. Currently, there are no operational open access products on ocean pollution events as they are relayed to relevant users as they occur and therefore need rapid delivery through formalised systems.

The impact of spills on biodiversity can be accessed through the integration of remote sensing imagery with other geographical layers such as marine and coastal protected areas and marine species ranges (Engelhardt, 1999). For example, the NOAA Office of Rapid Response and Restoration has produced an open-access Environmental Sensitivity Index (ESI) system, based on multiple data layers on biological and human land use of shorelines, for the U.S.A. This index is used to rank shorelines according to their sensitivity to an oil spill. The system is useful to planners for contingency planning before an oil spill occurs and for rapid response once it has occurred in order to direct resources to where they are most needed.

The oceanic EO products that relate to oil spill detection and shoreline sensitivity are most relevant to:

- CBD Aichi Biodiversity Target
  - ✓ Target 8. By 2020, pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity
- CBD Strategic Plan for Biodiversity 2011-2020 operational indicators
  - ✓ Trends in emission to the environment of pollutants relevant for biodiversity
- GEO BON EBVs
  - ✓ Habitat disturbance

ANNEX 3. EMERGING APPLICATIONS OF REMOTE SENSING IN THE CONTEXT OF THE CONVENTION

This section summarises emerging applications of remote sensing for both marine and terrestrial environments relevant for tracking progress towards the Aichi Biodiversity Targets, setting the basis for discussing on future directions.

3.1 NEAR REAL-TIME REMOTE SENSING FOR SURVEILLANCE

Operational near real-time imagery has a great potential as tool for surveillance and monitoring implementation of law and policies, which has been underused to date. Satellite imagery and derived products can have a short 'shelf-life 'when it comes to such applications as crop monitoring, deforestation monitoring or disaster response. The images are made available after an event or a potential hazard has occurred limiting their utility in disaster response and hazard mitigation. Operational near real-time availability of imagery is needed in such cases.

An example of this applicability is the monitoring of illegal deforestation in the Brazilian Amazonia. The Disaster Monitoring Constellation International Imaging Ltd (DMCii) is now providing imagery to the DETER service of the INPE in Brazil which uses regularly acquired MODIS satellite images to detect forest clearance (Hansen and Loveland, 2012). The DMCii imagery will provide INPE with medium resolution monitoring capabilities to overcome the ability of illegal loggers to go undetected at the 250m spatial resolution of the MODIS pixel. Further details can be found in section 3 of the review.

Fire surveillance also adopts near real-time monitoring systems based on EO data. For example, the Geoscience Australia Sentinel system uses daily MODIS imagery to monitor fires as they occur across the Australian continent (see section 3.1 for further details). This approach has also been adopted in different African countries.

Main CBD Aichi Biodiversity Target it supports:

- ✓ Aichi Target 5. By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced
- ✓ Aichi Target 7. By 2020 areas under agriculture, aquaculture and forestry are managed sustainably, ensuring conservation of biodiversity

3.2 POLLUTION AND ITS IMPACT ON BIODIVERSITY

The role of remote sensing in monitoring atmospheric gases in the context of climate change was discussed in Annex 2. However, there are considerable negative impacts of increased atmospheric nitrogen on biodiversity, in particular floristic diversity and plant health (Phoenix, et al., 2006). Although there are currently no direct ways to monitor the biodiversity impact of atmospheric nitrogen deposition using remote sensing, its impacts on plant vigour can be monitored using the vegetation products discussed in Annex 2.

Eutrophication of water bodies occurs with overload of plant nutrients, closely linked to land use/ land cover changes, and frequently result in ‘algal blooms’. The reflectance of water changes with chlorophyll concentration as water with high chlorophyll concentration is usually typified by high green reflectance and absorption in the blue and red spectral regions (Lillesand et al., 2008). Quantitative methods of algal bloom monitoring from aerial and spaceborne sensors use these reflectance properties to map and monitor their occurrence. Due to the spectral similarities between blue-green and green algae, narrow band sensors such as hyperspectral imagery or filtered airborne cameras are frequently used. More advanced methods relying on hydrodynamic–biogeochemical models which assimilate bio-optical measurements from ocean-observing satellites are being used for more accurate EO-based products for eutrophication assessment (Banks et al., 2012).

Ocean acidification has wide-ranging implications in marine ecosystems and has stimulated studies in areas ranging from biochemistry of calcareous shell-forming processes to the socio-economic impacts on marine fisheries, aquaculture, and other ecosystem services (Doney et al., 2009). Acidification happens when changes in seawater chemistry result from the oceanic uptake of anthropogenic CO_2. The change in pH levels has detrimental impacts for calcareous shell-building organisms such as foraminifera and pteropod molluscs (Fabry et al., 2008). Coral reefs are also at risk as the rate of coral reef calcification is projected to decrease by 40% by 2065 based on increased abundance of oceanic CO_2 (Langdon et al., 2000). Satellite remote sensing can play a role in monitoring this phenomenon, e.g. by measuring reflectance from calcium carbonate, also known as Particulate Inorganic Carbon (PIC), as measured by MODIS (Balch et al., 2005).

The NOAA Experimental Ocean Acidification Product Suite (OAPS) synthesises satellite and modelled environmental data sets to provide a synoptic estimate of sea surface carbonate chemistry which is updated monthly (OAPS, 2013). Satellite - based estimates of sea surface temperature based on the NOAA-AVHRR satellite are one of many parameters which contribute to the OAPS (Gledhill et al., 2009). Modelling of surface-ocean carbonate chemistry, using remote sensing as a tool, allows regional to basin wide trends in ocean acidification to be explored on seasonal to interannual time scales. This is very important for monitoring ocean-wide marine biodiversity impacts since ship-based measurement are limited in spatial scope and frequency of measurement.

Main CBD Aichi Biodiversity Target it supports:

- ✓ Aichi Target 8. By 2020, pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity
- ✓ Aichi Target 10. By 2015, the multiple anthropogenic pressures on coral reefs, and other vulnerable ecosystems impacted by climate change or ocean acidification are minimized, so as to maintain their integrity and functioning.

3.3 MONITORING THE SPREAD OF INVASIVE PLANT SPECIES

Spatial mapping of the spread of invasive alien plant species is a high priority for the conservation community and an area where a remote sensing-based approach could make a substantial contribution. There have been considerable advances in using remote sensing to map species that dominate forest canopies using remote sensing imagery. However, a large proportion of invasive plants in native forests occur in the understory where they are often obscured by the canopy. In addition, plant communities are often present in the form of mixed-species mosaics which can be difficult to separate using spectral data alone (Zhang et al., 2006). Indirect methods of mapping including the use of GIS data layers and modeling have been used in these cases. Besides passive sensor data, LiDAR has proved useful.

The key challenge the conservation community faces when monitoring invasive alien plant species is that species-level plant discrimination is not possible using current operational EO-based land cover or habitat products. Nevertheless, hyperspectral imagery has potential to provide species-level discrimination at the ecosystem level (Hestir et al., 2008). However hyper-spectral-based products are not operational and hyperspectral remote sensing is frequently limited to local-scale studies employing airborne hyper spectral sensors, e.g. the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) operated by NASA/JPL. Spaceborne hyper spectral sensors are the Hyperion sensor onboard EO-1 spacecraft and the Compact High Resolution Imaging Spectrometer (CHRIS) of ESA's Proba-1 instrument.

Further exploration and operational development of hyperspectral-based products from these sensors is a necessity for future site-level plant species mapping which will highly benefit monitoring the spread of invasive alien plant species. Airborne imagery and sub-metre resolution satellite imagery can also make a significant contribution to invasive species mapping.

Main CBD Aichi Biodiversity Target it supports:

- ✓ Aichi Target 9. By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment.

3.4 ASSESSMENT OF MANAGEMENT EFFECTIVENESS AND ESTABLISHMENT OF ECOLOGICALLY EFFECTIVE PROTECTED AREAS NETWORKS

Land use change around protected areas has been recognised as an important determinant of forest reserve health in tropical regions (Laurance et al., 2012). As observed from MODIS VCF data, up to 68% of protected areas in a wide-ranging, global sample of highly protected tropical forests had their cover reduced within a 50-km periphery of their administrative boundaries. Far fewer of those protected areas experienced loss of forest habitat within their administrative boundaries (De Fries et al., 2005). Such studies demonstrate the importance of considering land use dynamics at or beyond the boundaries of protected areas for more effective protected area management strategies.

Currently, large area monitoring of land cover change at medium spatial resolution predominately uses Landsat data due to the availability of a multi-decadal time series (Hansen and Loveland, 2012). Assessing protected area effectiveness requires change analysis methods which are consistent and repeatable over time, preferably at high to very high spatial resolution. Change mapping methods are therefore set to change from analyst interactions with individual scenes to automated processing chains which harness powerful computing to process large data volumes (Hansen and Loveland, 2012). Ideally, this would be combined with near-real time alert systems which are triggered by sudden change, as proposed by Verbesselt et al. (2012). This approach would increase sensitivity of alert systems to natural and anthropogenic disturbance events such as illegal logging and drought. Protected area level monitoring using EO-based tools is now possible with the DOPA, jointly developed by GEO BON and JRC. The DOPA has delivered a suite of informatics-based, we-enabled tools to conservation managers to monitor the state and pressures on protected areas globally (Dubois et al., 2011).

In Canada, candidate areas for protection status and existing protected area networks are being monitored through remotely sensed indicators on land cover, fragmentation, disturbance and snow cover. Areas sharing common environmental conditions using this approach can be used to assess the effectiveness of Canada's network of parks and identify sites requiring protection. More details of this approach can be found in section 3.3 of the review.

Main CBD Aichi Biodiversity Target it supports:

✓ Aichi Target 11. By 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes.

3.5 THE USE OF TERRESTRIAL AND MARINE MAMMALS AS SENSOR PLATFORMS

Technological advances in the last few decades have made animal telemetry a growing discipline. The objective of animal telemetry is to use animal-based tags to sample data such as position, movement, 3D-acceleration, and even physiological parameters like the heart rate of an individual animal.

However, there has been more limited use of terrestrial animal tags in comparison to those in marine ecosystems where tagging is frequently used to assess various attributes of movement. Commonly used methods for tracking animals in the terrestrial environment using individual tags are Global positioning system (GPS), Argos Doppler tags, very high frequency radio tags, light-level geolocator and banding or rings. However, not all of these rely on satellite sensor technology as acoustic devices are based on radio signals (Movebank, 2013). The International Cooperation for Animal Research Using Space (ICARUS) initiative is a new global animal movement monitoring system that is driven by end-users' needs, that upends the distinction between *in-situ* and remote-sensing methods by combining the advantages of both methods. It thereby provides the data needed for e.g. the EBV 'Migratory behavior' or the Operational Indicator 'Trends in distribution of selected species', both of high relevance for the Aichi Target 12.

The U.S.A. Integrated Ocean Observing System (IOOS) is making efforts to use data from electronic tags attached to marine animals to enhance understanding of the marine environment (IOOS, 2013). For example, movement of the hawksbill turtle in the Caribbean Sea has been characterised using telemetry, showing that they are more abundant in protected areas than previously thought (Scales et al., 2011). Animal-based tags are so useful because sensors can track individuals over long distances for multiple years, collecting sub-surface data from remote and difficult to reach environments. Conventional earth observation techniques are technically or economically unfeasible for monitoring movement and environmental conditions at the individual level.

Main CBD Aichi Biodiversity Target it supports:

✓ Aichi Target 12. By 2020 the extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained.

3.6 ECOSYSTEM SERVICES: CARBON STORAGE AND CLIMATE CHANGE

Remote sensing-based assessment of carbon stocks in terrestrial habitats is a major field of research and relies heavily on remote sensing for quantitative spatial data on vegetation biomass, among other variables such as Gross Primary Production (GPP). Remotely sensed surrogates of tree species diversity, such as the NDVI-based eco-climatic distance measure, have been related to carbon storage and sequestration in forests as well. This measurement demonstrates a strong relationship with tree-density, LAI and degree of deciduousness. Therefore continuous measurements over broad spatial scale can detect broad scale patterns of bio-diversity in forested landscapes and ecosystem services that can be used in conservation planning (Krishnaswamy et al., 2009).

The relation between biomass and carbon storage has already been discussed in Annex 2. In order to quantify above ground carbon content in forests, LiDAR is a frequently used tool, but is mostly used at a local scale owing to the small footprint of LiDAR instruments. In heterogeneous forests, LiDAR has been proven to be a more effective tool than ground-based methods in quantifying above ground carbon content (Patenaude et al., 2004). The forest carbon stock of areas the size of the Peruvian Amazon can be quantified at high resolution (0.1-ha) based on the integration of LiDAR, Landsat imagery and field plots (Asner et al., 2010). Landsat-derived NDVI is well correlated to carbon storage in urban forestry, based on field measurements, providing the potential for cost-effective and efficient regional forest carbon mapping (Myeong et al., 2006).

However, there are few studies of carbon stocks in ecosystems other than forest. Efforts to model the land-atmosphere exchange of CO_2 from high latitude, northern hemisphere peat lands using satellite remote sensing inputs are already well established (Schubert et al., 2010). Similar methods are employed to monitor grassland gross primary production and CO_2 uptake, but using *in-situ* spectral measurements of vegetation phenology combined with an estimation of radiation use efficiency (Migliavacca et al., 2011). The conservation community would find it especially useful to assess carbon stocks for grasslands and peat lands (Green et al., 2011). This would represent a worthwhile avenue for research in future carbon assessments based on EO data.

The role of remote sensing in monitoring the impact of climate change on ecosystems can be shared between observation data on primary and secondary indicators. Primary indicators include temperature, precipitation and FAPAR. A secondary indicator, vegetation phenology, is an essential component of ecosystem functioning (Thackeray et al., 2010), an important climate change indicator (Butterfield and Malström, 2009), and has been widely observed for several decades using ground-based methods.

Remote sensing of land surface phenology is now a well established field of research providing an objective and repeatable method of phenological observation that can contribute to climate change studies. However, remotely sensed phenological patterns are observed from multiple vegetation ecosystems and not a single plant or tree species resulting in incoherent phenology estimates with little consensus on how best to reconcile the different approaches. Finer scale ecosystem level observation are now possible using fixed-position, digital camera-based sensors, e.g. the Phenocam in selected forests in the U.S.A. (Sonnentag et al., 2012) or the Phenological Eyes Network in Japan (Nagai et al., 2013). Canopy-level monitoring of phenology has important implications for estimation of gross primary production of forested or grassland ecosystems. Therefore, phenological information gathered by *in-situ* sensors such as digital cameras, can be used in estimating local carbon sinks and sources.

Main CBD Aichi Biodiversity Target it supports:

✓ Aichi Target 15. By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced, through conservation and restoration, including restoration of at least 15 per cent of degraded ecosystems, thereby contributing to climate change mitigation and adaptation and to combating desertification.

3.7 ECOSYSTEM-LEVEL MONITORING USING UNMANNED AIRBORNE VEHICLES (UAVS)

The use of UAVs for remote sensing has become more widespread due to recent technical advances in miniaturisation, communication, the strength of lightweight materials and power supplies (Campbell, 2006). They offer near-surface observations in order to record complementary environmental information such as temperature, CO_2 and humidity. Their rapid deployment allows greater flexibility for use in dangerous and inaccessible environments permitting rapid change analysis while flights can be planned according to local weather conditions (Watts et al., 2010). As they operate below the cloud line, cloud-free observations are guaranteed and atmospheric correction of imagery is not required. UAVs can be considered as flexible sensor platforms as different sensors can be mounted giving them adaptability in different applications including aerial photography, optical, thermal and hyperspectral analysis. They are limited in spatial scope however and are frequently employed in site-level monitoring for which satellite or airborne sensors are too coarse in resolution or too infrequent in revisit time. Therefore UAVs are effective tools for modeling and monitoring biodiversity-related variables at a local scale.

UAV flights can be flown at the same time as satellite or other airborne sensors for coincident measurements (Campbell, 2006). Applications include invasive species mapping (Watts et al., 2010) and precision agriculture, to detect water stress and irrigation effectiveness in orchards (Stagakis et al., 2012, Zarco-Tejada et al., 2012) and to measure temperature at the plant canopy level using thermal remote sensing (Berni et al.,2009). UAVs are also used in the coastal zone (Malthus and Mumby, 2003) and in riparian habitats (Dunford et al., 2009). However, combining multiple images from different flight lines and dates can be problematic due to variability in solar illumination and sensor movement (Dunford et al., 2009).

ANNEX 4. DETAILED MAPPING OF DATABASES, REMOTE SENSING SENSORS, TARGETS AND INDICATORS

TABLE 4.1. MENTIONED EXISTING GLOBAL DATABASES FOR THE MAIN EO PRODUCTS USED TO MONITOR BIODIVERSITY

Variable	Existing database	Institution	Satellite Sensors	Access
Land-based	Global Land Service	ESA/EC	SPOT- VGT	Open
	Distributed Active Archive Centers (DAACs)	NASA	MODIS	Open
Land, atmosphere and water based	Giovanni[5]	NASA Goddard Earth Sciences	Multiple	Open
Marine	Ocean Colour website	NASA	Multiple	Open
Land, atmosphere and ocean	Office of satellite[6] and product operations	NOAA	Multiple	Open
Atmospheric, ocean and land	GEONETCast website	Group on Earth Observation (GEO)	Space-based, air-borne and *in situ*	Open
Land-based (developing countries)	DevCoCast website	Global Earth Observation System of Systems (GEOSS)	Multiple	Open

TABLE 4.2 EXISTING LANDCOVER DATABASES AT DIFFERENT SPATIAL SCALES

Variable	Existing database	Year	Institution	Scale	Sensor
Landcover (and associated variables)	National Land Cover Database (NLCD)	1992, 2001, 2006	USGS Earth Resources Observation and Science (EROS) Centre	U.S.A.	Landsat
Landcover	Global Land Cover (GLC) 2000	2000	Joint Research Centre (European Commission)	global	SPOT-VGT
Landcover	GlobCover Portal	2006, 2009	European Space Agency (ESA)	global	MERIS
Landcover (and associated variables)	Africover database	Various	The Food and Agricultural Organisation (FAO)	National (African countries)	Various
Landcover	CORINE Land Cover (CLC)	1990, 2000, 2006	European Environment Agency(EEA)	Pan-European	

Footnote

[5] *The Giovanni data parameter database contains over 4,000 data parameters which are catalogued by their corresponding data product or sensor but are more restricted in terms of their spatial coverage, access rights and require more processing and user input. It has in-built analytical tools and is more of a scientific analysis tool than a download portal*

[6] *Spatial coverage is sometimes restricted to the United States*

TABLE 4.3. MAPPING OF EBVS, AICHI TARGETS, CBD OPERATIONAL INDICATORS AND RELEVANT EO PRODUCTS

Operational indicator	Candidate EBV	Most relevant Aichi target	Other Aichi Target supported	EO Product	Acronym	In-situ	Key features
Trends in climate impacts on population trends Status and Trends in extent and condition of habitats that provide carbon storage	Phenology (vegetation) phenology an EBV class, composed of EBVs such as LAI, fAPAR, etc. plus a trend model	15	8,14, 10	Leaf Area Index (for land surface phenology)	LAI	See CEOS LPV on standards to measure LAI or the Global Terrestrial Observing System (GTOS) (for canopy-level phenology)	Important in surface-atmosphere interactions such as photosynthesis, evapotranspiration and respiration
Trends in primary productivity Status and Trends in extent and condition of habitats that provide carbon storage		5 15		Fraction of Absorbed Photosynthetically Active Radiation (for land surface phenology)	FAPAR	Eddy covariance measurements (for canopy-level phenology)	Acts like a battery for the plant photosynthetic process
Trends in condition and vulnerability of ecosystems Trends in proportion of degraded/threatened habitats				Normalised Difference Vegetation Index (for land surface phenology)	NDVI	Flux towers and digital cams (for canopy-level phenology)	Spectral band ratio to detect differential reflectance in red and near infrared bands from green vegetation
Trends in primary productivity Status and Trends in extent and condition of habitats that provide carbon storage	Net primary productivity	5 15		Dry Matter Productivity	DMP	Quantifying dry matter content but not on a large scale	Directly related to NPP but customised for agronomic applications
Trends in condition and vulnerability of ecosystems		5		Ocean colour	n/a	Not measurable	Phytoplankton contain chlorophyll

Operational indicator	Variable measured	Spatial scale	Application to conservation	Access	Existing databases	Temporal coverage	Level of product development
Trends in climate impacts on population trends Status and Trends in extent and condition of habitats that provide carbon storage	The LAI [m^2/m^2] is geometrically defined as the total one-sided area of photosynthetic tissue per unit ground surface area	Global, 10°x10° tiles, Continental tiles	Input to Net Primary Productivity Models or as a correlate of other environmental variables understand vegetation-climate interactions. Phenology inferred from a time series combined with a trend model	Open access	Geoland 2	1999-present (version 1) 2009-present (version 0)	Operational
		Global, 10°x10° tiles					
		Africa and South America continental tiles			GEONET Cast	Near-real time only	
					DevCoCast website	Aug 2007-present (Africa) Jun 2010-present (S. America)	
Trends in primary productivity Status and Trends in extent and condition of habitats that provide carbon storage	It is not directly measurable, but is inferred from models describing the transfer of solar radiation in plant canopies, using remote sensing observations as constraints	Global, 10°x10° tiles, Continental tiles	Input to Net Primary Productivity Models or as a correlate of other environmental variables. Phenology inferred from a time series combined with a trend model	Open access	Geoland 2	1999-present	Operational
Trends in condition and vulnerability of ecosystems Trends in proportion of degraded/threatened habitats	Not a biophysical variable but an estimate of the vegetation amount	Global, 10°x10° tiles	Monitor vegetation state, health and disturbance. Phenology inferred from a time series combined with a trend model	Open access	Geoland 2	1999-present	Operational
		Africa and South America continental tiles			GEONET Cast DevCoCast website	Near-real time only Aug 2007-present	
Trends in primary productivity Status and Trends in extent and condition of habitats that provide carbon storage	Dry matter biomass increase (growth rate) expressed in kilograms of dry matter per hectare per day	Global, 10°x10° tiles	Identify anomalies in vegetation productivity and to forecast crop yields	Open access	Geoland 2	2009-present	Operational
		Africa and South America continental tiles			GEONET Cast DevCoCast website	Near-real time only Aug 2007-present	
Trends in condition and vulnerability of ecosystems	Chlorophyll-a	Regional seas, major oceans, major inland water bodies	Related to phytoplankton, primary production and marine food chain	Open access	GMES My Ocean NASA Ocean Color	Variable	Operational

TABLE 4.3. (CONTINUED)

Operational indicator	Candidate EBV	Most relevant Aichi target	Other Aichi Target supported	EO Product	Acronym	In-situ	Key features
Trends in condition and vulnerability of ecosystems	Net primary productivity	5	8, 14, 10	Sea Surface Temperature	SST	Marine weather buoy network	Depends on method , e.g. optical measures 'skin' temperature, radar penetrates sub-surface
Trends in distribution of selected species	Migratory behavior	12	5,6,9,10,11,12	Banding/ marking/ tagging and observation of individuals	International Cooperation for Animal Research Using Space (ICARUS)	Measurable	Satellite or radio tagging
Trends in extent of selected biomes, ecosystems and habitats (decision VII/30 and VIII.15)	Disturbance regime	5	7,9,10,11, 14,15	Burnt Areas	n/a	Not measurable	Fire detection
Trend in emission to the environment of pollutants relevant for biodiversity		8		Oil spill detection	Synthetic Aperture Radar (SAR)	Spatial extent not measurable	Tracking potential pollution events
Trends in condition and vulnerability of ecosystems		5		Vegetation Condition Index	VCI	Not measurable	Compares the observed NDVI to the range of values in same period in previous years
Trends in primary productivity		5		Vegetation Productivity Index	VPI	Quantifying gaseous exchange (FLUXNET sites globally)	Compares the observed NDVI to NDVI value from previous years over the same 10-day period
Trends in condition and vulnerability of ecosystems		5		Sea Surface State	n/a	Offshore weather buoys	Radar Scatterometry (wind) Radar Altimetry, e.g. Jason-2 (wave height)

Operational indicator	Variable measured	Spatial scale	Application to conservation	Access	Existing databases	Temporal coverage	Level of product development
Trends in condition and vulnerability of ecosystems	Temperature of water surface		Determines the distributions of marine plant and animal species	Open access	PO DAAC (NASA) GMES My Ocean ESA CCI SST	Variable	Operational
Trends in distribution of selected species	Global position but also physiological characteristics	All scales	Species range and habitat, foraging behavior, migration patterns	Open access	Movebank	Variable	Operational
Trends in extent of selected biomes, ecosystems and habitats (decision VII/30 and VIII.15)	Spatial extent of burnt scars	Continental, 10°x10° tiles	Temporal information on the fire season	Open access	Geoland 2	1999-present	Operational
		Global			MODIS Global Burned Area product	2000-present	
Trend in emission to the environment of pollutants relevant for biodiversity	Oil slicks, vessels and installations at sea	Local to regional	Marine pollution represents a habitat disturbance	Open access for maritime administration in EU member states	CleanSeaNet Data Centre	2007-present	Operational
Trends in condition and vulnerability of ecosystems	Good or bad vegetation state as a percentage of normal range	Continental, 10°x10° tiles	Identify areas of poor or improving vegetation state on a qualitative basis	Open access	Geoland 2	2013-present	Operational
Trends in primary productivity	Overall vegetation condition	Continental, 10°x10° tiles	Useful to monitor growing season in –progress i.e. As an early warning system for anomalous change	Open access	Geoland 2	2013-present	Operational
		Africa and South America continental tiles			GEONET Cast DevCoCast website	Near-real time only Aug 2007-present	
Trends in condition and vulnerability of ecosystems	Wave height, direction, length and frequency	Regional seas and major oceans	Monitoring of extreme weather events with potential for marine habitat disturbance	Open access	ESA Globwave (satellite and in-situ data) Aviso (altimetry products)	Variable	Operational

TABLE 4.4A. MAPPING OF THE ADEQUACY OF THE USE OF REMOTE SENSING FOR THE DEVELOPMENT OF THE INDICATORS CONTAINED IN DECISION XI/3, FOR THE STRATEGIC GOAL A OF THE STRATEGIC PLAN FOR BIODIVERSITY 2011-2020

Target	Code	Operational Indicator	Measurable by RS	Metric/Proxy	EO product	Additional non-RS data	Other requirements/ standards
1. By 2020, at the latest, people are aware of the values of biodiversity and the steps they can take to conserve and use it sustainably.							
	1	Trends in awareness and attitudes to biodiversity (C)	NO				
	2	Trends in public engagement with biodiversity (C)	NO				
	3	Trends in communication programmes and actions promoting social corporate responsibility (C)	NO				
2. By 2020, at the latest, biodiversity values have been integrated into national and local development and poverty reduction strategies and planning processes and are being incorporated into national accounting, as appropriate, and reporting systems.							
	4	Trends in number of countries incorporating natural resource, biodiversity, and ecosystem service values into national accounting systems (B)	NO				
	5	Trends in number of countries that have assessed values of biodiversity, in accordance with the Convention (C)	NO				
	6	Trends in guidelines and applications of economic appraisal tools (C)	NO				
	7	Trends in integration of biodiversity and ecosystem service values into sectoral and development policies (C)	NO				
	8	Trends in policies considering biodiversity and ecosystem service in environmental impact assessment and strategic environmental assessment (C)	NO				

		Global			Regional			National		
Target	**Code**	**Spatial**	**Temporal**	**Sensor**	**Spatial**	**Temporal**	**Sensor**	**Spatial**	**Temporal**	**Sensor**
1. By 2020, at the latest, people are aware of the values of biodiversity and the steps they can take to conserve and use it sustainably.										
	1									
	2									
	3									
2. By 2020, at the latest, biodiversity values have been integrated into national and local development and poverty reduction strategies and planning processes and are being incorporated into national accounting, as appropriate, and reporting systems.										
	4									
	5									
	6									
	7									
	8									

TABLE 4.4A. (CONTINUED)

Target	Code	Operational Indicator	Measurable by RS	Metric/Proxy	EO product	Additional non-RS data	Other requirements/ standards
3. By 2020, at the latest, incentives, including subsidies, harmful to biodiversity are eliminated, phased out or reformed in order to minimize or avoid negative impacts, and positive incentives for the conservation and sustainable use of biodiversity are developed and applied, consistent and in harmony with the Convention and other relevant international obligations, taking into account national socio economic conditions.							
	9	Trends in the number and value of incentives, including subsidies, harmful to biodiversity, removed, reformed or phased out (B)	NO				
	10	Trends in identification, assessment and establishment and strengthening of incentives that reward positive contribution to biodiversity and ecosystem services and penalize adverse impacts (C)	NO				
4. By 2020, at the latest, Governments, business and stakeholders at all levels have taken steps to achieve or have implemented plans for sustainable production and consumption and have kept the impacts of use of natural resources well within safe ecological limits.							
	11	Trends in population and extinction risk of utilized species, including species in trade (A)	YES	Intrinsic rate of increase,	laily surface water inundation fraction, surface air temperature, soil moisture, and microwave vegetation opacity	iIn-situ weather station data	
	12	Trends in ecological footprint and/or related concepts (C)	YES	Natural capital consumption, area units	Thematic classification		population model
	13	Ecological limits assessed in terms of sustainable production and consumption (C)	YES	USD/ha	Crop yield	ecosystem capacity	model - indirect
	14	Trends in biodiversity of cities (C)	YES	Green space - area unit, green infrastucture	Classification		Indirect
	15	Trends in extent to which biodiversity and ecosystem service values are incorporated into organisational accounting and reporting (B)	NO				

		Global			Regional			National		
Target	Code	Spatial	Temporal	Sensor	Spatial	Temporal	Sensor	Spatial	Temporal	Sensor
3. By 2020, at the latest, incentives, including subsidies, harmful to biodiversity are eliminated, phased out or reformed in order to minimize or avoid negative impacts, and positive incentives for the conservation and sustainable use of biodiversity are developed and applied, consistent and in harmony with the Convention and other relevant international obligations, taking into account national socio economic conditions.										
	9									
	10									
4. By 2020, at the latest, Governments, business and stakeholders at all levels have taken steps to achieve or have implemented plans for sustainable production and consumption and have kept the impacts of use of natural resources well within safe ecological limits.										
	11							Various	30d	Microwave AMSR-E, Landsat
	12	Low/medium	monthly/yearly	MODIS, Lansat, Sentinel 2	Low/medium	Monthly/yearly	MODIS, Landsat, Sentinel3	Low/medium	Monthly/yearly	MODIS, Landsat, Sentinel 4
	13				Low/medium	6months	MODIS/	Low/ medium	6months	MODIS/Landsat/ Sentinel3
	14						Landsat/ Sentinel2	High/ medium	Monthly/yearly	IKONOS, rapideye, Landsat/sentinel2
	15									

TABLE 4.4B. MAPPING OF THE ADEQUACY OF THE USE OF REMOTE SENSING FOR THE DEVELOPMENT OF THE INDICATORS CONTAINED IN DECISION XI/3, FOR THE STRATEGIC GOAL B OF THE STRATEGIC PLAN FOR BIODIVERSITY 2011-2020-

Target	Code	Operational Indicator	Measurable by RS	Metric/Proxy	EO product	Additional non-RS data	Other requirements/ standards
5. By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced.							
	16	Extinction risk trends of habitat dependent species in each major habitat type (A)	YES	NO			
	17	Trends in extent of selected biomes, ecosystems and habitats (A)	YES	Surface circulation features	Water surface vertical displacements		
	18	Trends in proportion of degraded/threatened habitats (B)	YES	Surface circulation features	Ocean Color, water surface vertical displacements		
	19	Trends in fragmentation of natural habitats (B)	YES	Area	Classification, change detection map		
	20	Trends in condition and vulnerability of ecosystems (C)	YES	Eco-environmental vulnerability index	Spatial principle component analysis		Elevation, slope, accumulated temperature, drought index, land use, vegetation, soil, water-soil erosion, and population density
	21	Trends in the proportion of natural habitats converted (C)	YES	Area	Classification, change detection map		
	22	Trends in primary productivity (C)	YES	NPP	fAPAR, NDVI		
	23	Trends in proportion of land affected by desertification (C)	YES	RUE	fAPAR, NDVI	Precipation	
	24	Population trends of habitat dependent species in each major habitat type (A)	YES	kg/km^2, mg/cu.m	Echosounder echograms, fish school density, chlorophyl pigments	Fish, seaweed samples	SST

			Global			Regional			National	
Target	**Code**	**Spatial**	**Temporal**	**Sensor**	**Spatial**	**Temporal**	**Sensor**	**Spatial**	**Temporal**	**Sensor**
5. By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced.										
	16									
	17	Large scale circulation features	Weeks to months	Radar altimeter	Large scale circulation features	Weeks to months	radar altimeter			
	18			LiDAR, radar altimeter			LiDAR, radar altimeter			LiDAR, radar altimeter
	19				Medium/high	Monthly/yearly	IKONOS, RapidEYE, GeoEYE, Landsat, Sentinel2	Medium/ high	Monthly/yearly	IKONOS, RapidEYE, GeoEYE, Landsat, Sentinel3
	20	Low	Year	Modis				High	Monthly	IKONOS, RapidEYE, GeoEYE.
	21				Medium/high	Monthly/yearly	IKONOS, RapidEYE, GeoEYE, Landsat, Sentinel2	Medium/ high	Monthly/yearly	IKONOS, RapidEYE, GeoEYE, Landsat, Sentinel3
	22									
	23									
	24				m to km		Echosounder, sonar, LiDAR, Aerial photography	m to km	Minutes to days	Echosounder, sonar, LiDAR, Aerial photography

TABLE 4.4B. (CONTINUED)

Target	Code	Operational Indicator	Measurable by RS	Metric/Proxy	EO product	Additional non-RS data	Other requirements/ standards
6. By 2020 all fish and invertebrate stocks and aquatic plants are managed and harvested sustainably, legally and applying ecosystem based approaches, so that overfishing is avoided, recovery plans and measures are in place for all depleted species, fisheries have no significant adverse impacts on threatened species and vulnerable ecosystems and the impacts of fisheries on stocks, species and ecosystems are within safe ecological limits.							
	25	Trends in extinction risk of target and bycatch aquatic species (A)	NO				
	26	Trends in population of target and bycatch aquatic species (A)	YES	kg/km^2, mg/cu.m	Echosounder echograms, fish school density, chlorophyl pigments	Fish, seaweed samples	SST
	27	Trends in proportion of utilized stocks outside safe biological limits (A) (MDG indicator 7.4)					
	28	Trends in catch per unit effort (C)	NO				
	29	Trends in fishing effort capacity (C)	YES	Number of Boats	Aerial images		
	30	Trends in area, frequency, and/or intensity of destructive fishing practices (C)	NO				
	31	Trends in proportion of depleted target and bycatch species with recovery plans (B)	NO				
7. By 2020 areas under agriculture, aquaculture and forestry are managed sustainably, ensuring conservation of biodiversity.							
	32	Trends in population of forest and agriculture dependent species in production systems (B)	YES	%, unit	Species map		
	33	Trends in production per input (B)	YES	usd/unit	Yield estimation		
	34	Trends in proportion of products derived from sustainable sources (C)	YES	%, loss of vegetation	Classification, land cover change		
	35	Trends in area of forest, agricultural and aquaculture ecosystems under sustainable management (B)	YES	area	Land cover map		Land tenure

Target	Code	Global			Regional			National		
		Spatial	Temporal	Sensor	Spatial	Temporal	Sensor	Spatial	Temporal	Sensor
6. By 2020 all fish and invertebrate stocks and aquatic plants are managed and harvested sustainably, legally and applying ecosystem based approaches, so that overfishing is avoided, recovery plans and measures are in place for all depleted species, fisheries have no significant adverse impacts on threatened species and vulnerable ecosystems and the impacts of fisheries on stocks, species and ecosystems are within safe ecological limits.										
	25									
	26				m to km		Echosounder, sonar, LiDAR, Aerial photography	m to km	Minutes to days	Echosounder, sonar, LiDAR, Aerial photography
	27									
	28									
	29									Airborne
	30									
	31									
7. By 2020 areas under agriculture, aquaculture and forestry are managed sustainably, ensuring conservation of biodiversity.										
	32							High res	Year	IKONOS, RapidEYE
	33							High res	Year	IKONOS, RapidEYE
	34							High res	Year	IKONOS, RapidEYE
	35	Low/medium	Year	MODIS/Landsat	Low/medium	Year	MODIS/Landsat	Low/medium	Year	MODIS/Landsat

TABLE 4.4B. (CONTINUED)

Target	Code	Operational Indicator	Measurable by RS	Metric/Proxy	EO product	Additional non-RS	Other requirements/ standards
8. By 2020, pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity.							
	36	Trends in incidence of hypoxic zones and algal blooms (A)	YES	phytoplancton concentration (mg/ m3),	Water leaving radiance, Ocean Color	Algal inventory	
	37	Trends in water quality in aquatic ecosystems (A)	YES	Water constituents	Water leaving radiance	Water samples	
	38	Impact of pollution on extinction risk trends (B)	NO				
	39	Trends in pollution deposition rate (B)	YES	meters	Bathymetry		
	40	Trends in sediment transfer rates (B)	NO				
	41	Trend in emission to the environment of pollutants relevant for biodiversity (C)	YES		SAR images, Ocean Color	Wind speed under certain threshold	Proper sun glint correction
	42	Trend in levels of contaminants in wildlife (C)	NO				
	43	Trends in nitrogen footprint of consumption activities (C)	NO				
	44	Trends in ozone levels in natural ecosystems (C)	YES	ppmv, Dobson unit	Ozone concentrations		
	45	Trends in proportion of wastewater discharged after treatment (C)	NO				
	46	Trends in UV-radiation levels (C)	YES	UV-A, UV-B	Ocean Color	use of a AERONET/OC network (CIMEL)	corection of aerosols

		Global			Regional			National		
Target	Code	Spatial	Temporal	Sensor	Spatial	Temporal	Sensor	Spatial	Temporal	Sensor
8. By 2020, pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity.										
	36	km^2	Weeks-month	MODIS, Sentinel 3(OLCI)	km^2	Weeks-month	MODIS, Sentinel 3	km^2	Weeks-month	MODIS, Sentinel 3
	37	km^2	weeks-month	MODIS, Sentinel 3(OLCI)	km^2	Weeks-month	MODIS, Sentinel 3	km^2	Weeks-month	MODIS, Sentinel 3
	38									
	39									airborne, bathymetric LiDAR
	40									
	41	10 cm to meters		SAR, Sentinel 1	10 cm to meters		SAR/Sentinel 1	10 cm to meters		SAR/Sentinel 1
	42									
	43									
	44		1 or 8 days	Total Ozone Mapping Spectrometer (TOMS), the Solar Backscatter Ultraviolet Spectrometer (SBUV), and the Global Ozone Monitoring Experiment (GOME).						
	45									
	46			CIMEL sensors			CIMEL sensors			CIMEL sensors

TABLE 4.4B. (CONTINUED)

Target	Code	Operational Indicator	Measurable by RS	Metric/Proxy	EO product	Additional non-RS	Other requirements/ standards
9. By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment.							
	47	Trends in the impact of invasive alien species on extinction risk trends (A)	YES	Area %	Time series, land cover map	Population dinamics model	
	48	Trends in the economic impacts of selected invasive alien species (B)	YES	USD/output	Time series, land cover map		Econometric model
	49	Trends in number of invasive alien species	YES	Area %	Land cover, species distribution maps		
	50	Trends in incidence of wildlife diseases caused by invasive alien species (C)	NO				
	51	Trends in policy responses, legislation and management plans to control and prevent spread of invasive alien species (B)	NO				
	52	Trends in invasive alien species pathways management (C)	YES	Area	Land cover map		
10. By 2015, the multiple anthropogenic pressures on coral reefs, and other vulnerable ecosystems impacted by climate change or ocean acidification are minimized, so as to maintain their integrity and functioning.							
	53	Extinction risk trends of coral and reef fish (A)	YES		SST, Ocean Color		
	54	Trends in climate change impacts on extinction risk (B)	YES	Celsius, W m -2 nm -1,	SST, Ocean Color	Wind speed	
	55	Trends in coral reef condition (B)	YES	Celsius, W m -2 nm -1,	SST, Ocean Color, Insolation, SAR, Ocean Surface	Wind speed	
	56	Trends in extent, and rate of shifts of boundaries, of vulnerable ecosystems (B)	YES	Area	Vector Winds		
	57	Trends in climatic impacts on community composition (C)	NO		Land cover		
	58	Trends in climatic impacts on population trends	NO				

Target	Code	Global Spatial	Global Temporal	Global Sensor	Regional Spatial	Regional Temporal	Regional Sensor	National Spatial	National Temporal	National Sensor
9. By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment.										
	47							Medium/high	year	IKONOS, RapidEYE
	48							Medium/high	year	IKONOS, RapidEYE
	49							Medium/high	year	IKONOS, RapidEYE
	50									
	51									
	52							Medium/high	year	IKONOS, RapidEYE
10. By 2015, the multiple anthropogenic pressures on coral reefs, and other vulnerable ecosystems impacted by climate change or ocean acidification are minimized, so as to maintain their integrity and functioning.										
	53	10 cm to km^2	Days to months	MODIS, SAR	10 cm to km^2	Days to months		10 cm to km^2	Days to months	
	54	10 cm to km^2	Days to months	MODIS, SAR	10 cm to km^2	Days to months		10 cm to km^2	Days to months	
	55	10 cm to km^2	Days to months	MODIS, SAR	10 cm to km^2	Days to months		10 cm to km^2	Days to months	
	56	10 cm to km^2	Days to months	MODIS, SAR	10 cm to km^2	Days to months		10 cm to km^2	Days to months	
	57									
	58									

TABLE 4.4C. MAPPING OF THE ADEQUACY OF THE USE OF REMOTE SENSING FOR THE DEVELOPMENT OF THE INDICATORS CONTAINED IN DECISION XI/3, FOR THE STRATEGIC GOAL C OF THE STRATEGIC PLAN FOR BIODIVERSITY 2011-2020

Target	Code	Operational Indicator	Measurable by RS	Metric/Proxy	EO product	Additional non-RS data	Other requirements/ standards
11. By 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes.							
	59	Trends in coverage of protected areas (A)	YES	Area	Landcover	cadastral DB	
	60	Trends in extent of marine protected areas, coverage of key biodiversity areas and management effectiveness (A)	YES	Area	Time series		
	61	Trends in protected area condition and/or management effectiveness including more equitable management (A)	YES		Soil moisture, phenology		
	62	Trends in representative coverage of protected areas and other area based approaches, including sites of particular importance for biodiversity, and of terrestrial, marine and inland water systems (A)	YES	Area	Landcover		
	63	Trends in the connectivity of protected areas and other area based approaches integrated into landscapes and seascapes (B)	YES	Area	Landcover		
	64	Trends in the delivery of ecosystem services and equitable benefits from protected areas (C)	YES			Socio-economic data	Baseline data

		Global			Regional			National		
Target	Code	Spatial	Temporal	Sensor	Spatial	Temporal	Sensor	Spatial	Temporal	Sensor
11. By 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes.										
	59	Low/medium	Month/year	MODIS/Landsat/sentinel2	Low/medium	Month/year	MODIS/Landsat/sentinel2	Low/medium	Month/year	MOIDS/Landsat/ sentinel3
	60	Low/medium	Month/year	MODIS/Landsat/sentinel3	Low/medium	Month/year	MODIS/Landsat/sentinel3	Low/medium	Month/year	MODIS/Landsat/ sentinel4
	61	Low/medium	Daily	AVIRIS, WindSat, AMSR-E, RADARSAT, ERS-1-2, Metop/ASCAT	Low/medium	Daily	AVIRIS, WindSat, AMSR-E, RADARSAT, ERS-1-2, Metop/ASCAT	Low/medium	Daily	AVIRIS, WindSat, AMSR-E, RADARSAT, ERS-1-2, Metop/ASCAT
	62	Low/medium	Month/year	MODIS/Landsat/ sentines3	Low/medium	Month/year	MODIS/Landsat/sentinel3	Low/medium	Month/year	MODIS/Landsat/ sentinel4
	63	Low/medium	Month/year	MOIDS/Landsat/sentinel3	Low/medium	Month/year	MODIS/Landsat/sentinel3	Low/medium	Month/year	MODIS/Landsat/ sentinel4
	64	Low/medium	Month/year	MODIS/Landsat/sentines3	Low/medium	Month/year	MODIS/Landsat/sentinel3	Low/medium	Month/year	MODIS/Landsat/ sentinel4

TABLE 4.4C. (CONTINUED)

Target	Code	Operational Indicator	Measurable by RS	Metric/Proxy	EO product	Additional non-RS data	Other requirements/ standards
12. By 2020 the extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained.							
	65	Trends in abundance of selected species (A)	YES	mm	Landcover		Rainfall
	66	Trends in extinction risk of species (A)	YES	mm	Landcover, species composition		Rainfall
	67	Trends in distribution of selected species (B)	YES	Area	Landcover		Canopy structure, collard
13. By 2020, the genetic diversity of cultivated plants and farmed and domesticated animals and of wild relatives, including other socio-economically as well as culturally valuable species, is maintained, and strategies have been developed and implemented for minimizing genetic erosion and safeguarding their genetic diversity.							
	68	Trends in genetic diversity of cultivated plants, and farmed and domesticated animals and their wild relatives (B)	NO				
	69	Trends in genetic diversity of selected species	NO				
	70	Trends in number of effective policy mechanisms implemented to reduce genetic erosion and safeguard genetic diversity related to plant and animal genetic resources (B)	NO				

		Global			Regional			National		
Target	Code	Spatial	Temporal	Sensor	Spatial	Temporal	Sensor	Spatial	Temporal	Sensor
12. By 2020 the extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained.										
	65							1-30m	2-16d	casi, sentinel, LiDAR
	66							1-30m	2-16d	casi, sentinel, LiDAR
	67							1-30m	2-16d	slicer/elvis
13. By 2020, the genetic diversity of cultivated plants and farmed and domesticated animals and of wild relatives, including other socio-economically as well as culturally valuable species, is maintained, and strategies have been developed and implemented for minimizing genetic erosion and safeguarding their genetic diversity.										
	68									
	69									
	70									

TABLE 4.4D. MAPPING OF THE ADEQUACY OF THE USE OF REMOTE SENSING FOR THE DEVELOPMENT OF THE INDICATORS CONTAINED IN DECISION XI/3, FOR THE STRATEGIC GOAL D OF THE STRATEGIC PLAN FOR BIODIVERSITY 2011-2020

Target	Code	Operational Indicator	Measurable by RS	Metric/Proxy	EO product	Additional non-RS data	Other requirements/ standards
14. By 2020, ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded, taking into account the needs of women, indigenous and local communities, and the poor and vulnerable.							
	71	Trends in proportion of total freshwater resources used (A) (MDG indicator 7.5)	NO			Seasonal water levels of large catchments	
	72	Trends in proportion of the population using improved water services (A) (MDG indicator 7.8 and 7.9)	NO			Trends in national statistics	
	73	Trends in benefits that humans derive from selected ecosystem services (A)	YES	e.g. pollination potential	Land cover/land use	Species/population modeling	Food provision
	74	Population trends and extinction risk trends of species that provide ecosystem services (A)	NO				
	75	Trends in delivery of multiple ecosystem services (B)	YES	Delta/rate of change	Time series	Socio-economic data	
	76	Trends in economic and non-economic values of selected ecosystem services (B)	YES	NPP, area, fpar, par	Above ground biomass, seasonal productivity and carbon sequestration		
	77	Trends in health and wellbeing of communities who depend directly on local ecosystem goods and services (B)	NO			Health and socio-economic indicators, nutrition measures, food availability	
	78	Trends in human and economic losses due to water or natural resource related disasters (B)	YES	USD	Land cover	Socio-economic data	
	79	Trends in nutritional contribution of biodiversity: Food composition (B)	YES	Area	Land cover	Agricultural output	
	80	Trends in incidence of emerging zoonotic diseases (C)	YES	Area	Water bodies		Malaria
	81	Trends in inclusive wealth (C)	YES	Area, unit	Urbanization map	Socio-economic data	

Target	Code	Global			Regional			National		
		Spatial	Temporal	Sensor	Spatial	Temporal	Sensor	Spatial	Temporal	Sensor
14. By 2020, ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded, taking into account the needs of women, indigenous and local communities, and the poor and vulnerable.										
	71									
	72									
	73				Medium/high	30d	IKONOS, RapidEYE Landsat Sentinel2	Medium/high	30d	IKONOS, RapidEYE, Landsat, Sentinel3
	74									
	75	Low/medium	15,30,180,365D	MODIS Landsat Sentinel2	Low/medium	15,30,180,365D	MODIS Landsat Sentinel3	Low/medium	15,30,180,365D	MODIS/ Landsat/ Sentinel4
	76	Low/medium	Daily	MODIS	Low/medium	Daily	MODIS	Low/medium	Daily	MODIS
	77									
	78							vhr/high	1 day	aerial/ IKONOS
	79				Medium	30d	Landsat/Sentinel2	Medium	30d	Landsat/Sentinel2
	80				Medium	30d	Radar			
	81							High	Year	IKONOS, GeoEYE

TABLE 4.4D. (CONTINUED)

Target	Code	Operational Indicator	Measurable by RS	Metric/Proxy	EO product	Additional non-RS data	Other requirements/ standards
	82	Trends in nutritional contribution of biodiversity: Food consumption (C)	YES	Unit	Agriculture, yield		
	83	Trends in prevalence of underweight children under-five years of age (C) (MDG indicator 1.8)	NO			Time series of national statistics on children weight measures	
	84	Trends in natural resource conflicts (C)	YES	Unit, area	Mining map, deforestation map		
	85	Trends in the condition of selected ecosystem services (C)	YES	Area	Land cover, time series		
	86	Trends in biocapacity (C)	NO				
	87	Trends in area of degraded ecosystems restored or being restored (B)	YES	Area	Land cover, time series		
15. By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced, through conservation and restoration, including restoration of at least 15 per cent of degraded ecosystems, thereby contributing to climate change mitigation and adaptation and to combating desertification.							
	88	Status and trends in extent and condition of habitats that provide carbon storage (A)	YES	NPP, area, fpar, par	Land cover, species composition, ground biomass, seasonal productivity and carbon sequestration	Carbon model	
	89	Population trends of forest-dependent species in forests under restoration (C)	YES	Area %	time series, land cover map	Population dynamics model	
16. By 2015, the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization is in force and operational, consistent with national legislation.							
	90	ABS indicator to be specified through the ABS process (B)	NO				

		Global			Regional			National		
Target	Code	Spatial	Temporal	Sensor	Spatial	Temporal	Sensor	Spatial	Temporal	Sensor
	82				Medium	30d	Landsat Sentinel2	Medium	30d	Landsat Sentinel2
	83									
	84							Medium	Year	Landsat Sentinel2
	85							Medium	Year	Landsat Sentinel2
	86									
	87							Medium	Year	Landsat Sentinel2
15. By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced, through conservation and restoration, including restoration of at least 15 per cent of degraded ecosystems, thereby contributing to climate change mitigation and adaptation and to combating desertification.										
	88	Low/medium	Daily	MODIS	Low/medium	Daily	MODIS	Low/medium	Daily	MODIS
	89							Medium/high	Year	RapidEYE, IKONOS
16. By 2015, the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization is in force and operational, consistent with national legislation.										
	90									

TABLE 4.4E. MAPPING OF THE ADEQUACY OF THE USE OF REMOTE SENSING FOR THE DEVELOPMENT OF THE INDICATORS CONTAINED IN DECISION XI/3, FOR THE STRATEGIC GOAL E OF THE STRATEGIC PLAN FOR BIODIVERSITY 2011-2020

Target	Code	Operational Indicator	Measurable by RS	Metric/ Proxy	EO product	Additional non-RS data	Other requirements/ standards
17. By 2015 each Party has developed, adopted as a policy instrument, and has commenced implementing an effective, participatory and updated national biodiversity strategy and action plan.							
	91	Trends in implementation of national biodiversity strategies and action plans, including development, comprehensiveness, adoption and implementation (B)	YES	Area	Landcover	land tenure	REDD
18. By 2020, the traditional knowledge, innovations and practices of indigenous and local communities relevant for the conservation and sustainable use of biodiversity, and their customary use of biological resources, are respected, subject to national legislation and relevant international obligations, and fully integrated and reflected in the implementation of the Convention with the full and effective participation of indigenous and local communities, at all relevant levels.							
	92	Trends in land-use change and land tenure in the traditional territories of indigenous and local communities (B)	YES	Area	Landcover	land tenure, indigenous territories maps	REDD
	93	Trends in the practice of traditional occupations (B)	YES	Area	Landcover	land tenure, land use change analysis, changes in proportion of population engaged in traditional occupations,	REDD
	94	Trends in which traditional knowledge and practices are respected through their full integration, safeguards and the full and effective participation of indigenous and local communities in the national implementation of the Strategic Plan (B)	NO			Presence of indigenous organizations and linkages to national level decision making, number of laws protecting indigenous rights and resources at national level	
	95	Trends of linguistic diversity and numbers of speakers of indigenous languages (B)	NO			National level statistics, Number of indigenous languages included in national primary education systems	
19. By 2020, knowledge, the science base and technologies relating to biodiversity, its values, functioning, status and trends, and the consequences of its loss, are improved, widely shared and transferred, and applied.							
	96	Trends in coverage of comprehensive policy-relevant sub-global assessments including related capacity-building and knowledge transfer, plus trends in uptake into policy (B)	NO				
	97	Number of maintained species inventories being used to implement the Convention (C)	NO				
20. By 2020, at the latest, the mobilization of financial resources for effectively implementing the Strategic Plan for Biodiversity 2011-2020 from all sources, and in accordance with the consolidated							
	98	Indicators in Decision X/3	NO				

			Global			Regional			National	
Target	**Code**	**Spatial**	**Temporal**	**Sensor**	**Spatial**	**Temporal**	**Sensor**	**Spatial**	**Temporal**	**Sensor**
17. By 2015 each Party has developed, adopted as a policy instrument, and has commenced implementing an effective, participatory and updated national biodiversity strategy and action plan.										
	91							Low/medium	1y	MODIS Landsat Sentinel2
18. By 2020, the traditional knowledge, innovations and practices of indigenous and local communities relevant for the conservation and sustainable use of biodiversity, and their customary use of biological resources, are respected, subject to national legislation and relevant international obligations, and fully integrated and reflected in the implementation of the Convention with the full and effective participation of indigenous and local communities, at all relevant levels.										
	92							Low/medium	1y	MODIS Landsat Sentinel2
	93							Low/medium	1y	MODIS Landsat Sentinel2
	94									
	95									
19. By 2020, knowledge, the science base and technologies relating to biodiversity, its values, functioning, status and trends, and the consequences of its loss, are improved, widely shared and transferred, and applied.										
	96									
	97									
20. By 2020, at the latest, the mobilization of financial resources for effectively implementing the Strategic Plan for Biodiversity 2011-2020 from all sources, and in accordance with the consolidated										
	98									

TABLE 4.5. EXISTING SATELLITES AND REMOTE SENSING SENSORS AND THEIR POTENTIAL APPLICATIONS TO TRACK PROGRESS TOWARDS THE AICHI BIODIVERSITY TARGETS

Aichi Target	Category	Satellite	Sensors	Data Products (e.g. raw data or derived)	Uses specific to Aichi Targets	Sources
4,15	Optical/Passive Low Spatial High Temporal	Greenhouse Gas Observation SAT (GOSAT)	Thermal And Near infrared Sensor for carbon Observation - Fourier Transform Spectrometer (TANSO-FTS) Thermal And Near infrared Sensor for carbon Observation - Cloud and Aerosol Imager (TANSO-CAI)	Radiance Cloud cover Mapped CO2 & CH4 (abundance, vertical mixing, concentrations and vertical profile) CO2 flux and 3-D distribution concentration map) Normalized Difference Vegetation Index (NDVI) Global Radiance distribution Clear sky reflectance	Monitoring Impacts of use of natural resource consumption and production by combining monitoring of carbon emission and vegetation condition Measuring carbon stocks	Japanese Aerospace Exploration Agency (JAXA)
	Optical/Passive Medium Spatial and Temporal Resolution	Orbiting Carbon Observatory (OCO)	Three high-resolution grating spectrometers; specifics and other sensors TBA	Orbit granules of calibrated radiances Orbit granules of geolocated Xco2 Global Xco2 Global CO2 sources and sinks	Monitoring Impacts of use of natural resource consumption and production by combining monitoring of carbon emission and vegetation condition Measuring carbon stocks	National Aeronautics and Space Administration (NASA)
5,11	Optical/Passive Medium - High Spatial and Temporal Resolution	Satellite The Sino-Brazilian Earth Observation (CBERS) 1, 2, 2b, 3, 4, &4b	(1, 2 & 3) Wide Field Imager Camera (WFI); Medium Resolution Camera (CCD); Infrared Multispectral Scanner Camera (IRMSS) (3) High Resolution Panchromatic Camera (HRC) (3 & 4) Advanced Wide Field Imager Camera (AWFI); IRMSS; Panchromatic and Multiespectral Camera (PANMUX) (4b) TBA	Multispectral Images	Broad-Fine Scale Habitat Mapping Protected Area Monitoring	Instituto Nacional de Pesquisas Espaciais (INPE) Chinese Academy of Space Technology, China National space and Brazilian Space Agency

Aichi Target	Start Year / End Year (if completed)	Geographical Coverage	Repeat Viewing Frequency (days)	Spatial Resolution (meters)	Availability	Gaps/Limitations
4,15	2009 (expected to last 5 years)	Global - atmospheric	3	500 - 1,500	Freely Available: At present, only one ACOS product is publicly available - ACOS_L2S. It is a Level-2 product that contains full physics retrievals of column-averaged CO2 in units of dry-air mole fraction (Xco2). Restricted: Level 1B product (with calibrated radiances and geolocation), which is the input to the ACOS Level-2 production process, is currently restricted by cooperation agreements between JAXA and NASA.	-Not all data products are available -Primary objective is on atmospheric monitoring of GHGs, not Earth Observation; -Is not a stand-alone resource for biodiversity monitoring and needs to be used in conjunction with modelling and other RS and non-RS data
	2014	Global - atmospheric	16	TBA -medium/ moderate	Freely Available	-Initial launch failed in 2009, second launch was delayed form 2011 to 2014
5,11	(1) 1999-2003; (2) 2003; (2b) 2007-2010; 3 (2013); 4 (2014); 4b (2016)	Global	3, 5, 26	(1&2) 20 (2b) 2.7 (3&4) 5 (4b) TBA	Freely Available to all Chinese and Brazilian people	-Is not a stand-alone resource for biodiversity monitoring, needs to be used in conjunction with other data, modelling and field information; -Cloud cover and haze create also challenges for monitoring using optical sensor; -Very High Resolution (VHR) optical datasets have been exploited or tested to their full extent and even in cloud free images, present pixel mixing and shadowing challenges; -The lack of shortwave infrared band and provision of too much detail present noise in the data and challenges in extracting the desired metrics; -Limited availability, may be prohibitively expensive and time consuming to procure and process.

TABLE 4.4D. (CONTINUED)

Aichi Target	Category	Satellite	Sensors	Data Products (e.g. raw data or derived)	Uses specific to Aichi Targets	Sources
5,6,9,10, 11,12,14, 15	Optical/Passive Medium-High Spatial Resolution High Temporal Resolution	Landsat 1-5, 7-8	(1-7) Multispectral Scanner (4-5)Thematic Mapper (TM) (7) Enhanced Thematic Mapper Plus(TM) (MSS)(8) Operational Land Imager (OLI); Thermal Infrared Sensor (TIRS)	Climate Data Records (CDR) such as surface reflectance, land surface temperature Essential Climate Variables (ECV): leaf area index, burned area extent, snow covered area, surface water extent Normalised Difference Vegetation Index (NDVI) (4-5, 7) Bathymetry, ocean colour, SST	Protected Area Monitoring Habitat mapping and change detection -Capturing broad extent -Spatial patterns of fragmentation Assessing Habitat Degredation -Desertification -Ocean acidification Biodiversity Assessment -Indicators of overall species richness and diversity -Tracking species distributions Ecological Monitoring -Mapping ecosystems -Assessing the effectiveness of ecosystem Landcover / Landcover change -Quantifying the rate and extent of forest disturbance and re-growth Tracking pressures and threats -Identifying disturbance Restoration projects	US Geological Survey (USGS)/NASA/Global Land Cover Facility (GLCF)
		Terra	ASTER	Same as Landsat	Same as Landsat	NASA/Japanese Ministry of Economy, Trade and Industry (METI)

Aichi Target	Category	Satellite	Sensors	Data Products (e.g. raw data or derived)	Uses specific to Aichi Targets	Sources
5,6,9,10, 11,12,14, 15		ALOS	AVNIR2	Essential Climate Variables (ECV): leaf area index, burned area extent, snow covered area, surface water extent Normalised Difference Vegetation Index (NDVI) (4-5, 7) Bathymetry, Ocean colour	Same as Landsat	JAXA
		SPOT	(1-3) HRV (4) HRVIR (5) HRG	As above	Same as Landsat	CNES

TABLE 4.4D. (CONTINUED)

Aichi Target	Start Year / End Year (if completed)	Geographical Coverage	Repeat Viewing Frequency (days)	Spatial Resolution (meters)	Availability	Gaps/Limitations
5,6,9, 10,11,12, 14,15	(1) 1972 (4) 1982–1993, (5) 1994 (7) 1999	Global	(4-7) 16 days	(4-5) 30 meter+ (8) 15 meter+	Landsat 4-5: Freely Available Landsat 5 and 7: Commercially & Freely available Landsat 8: At least 400 scenes are collected daily, and placed into the USGS archive to become available for download within 24 hours after acquisition	-The Landsat surface reflectance CDR products are considered provisional; -Less effective at capturing good imagery in hyper-arid or snow-covered regions, areas with low sun angle conditions, coastal regions where land area is small relative to adjacent water and areas with extensive cloud contamination; -Users are strongly cautioned against correcting data acquired over high latitudes (>65 degrees North or South); -Less able to provide information on changes in habitat quality, species distribution and fine-scale disturbances, than spaceborne optical sensors Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs be used in conjunction with other data, modelling and field information; -Limited ecosystem monitoring capacity, using landcover as a surrogate and must be combined with other data.
	1999 - present	Global	16 days (pointable off nadir)	15 meter+	Commercially available	Same as Landsat

Aichi Target	Start Year / End Year (if completed)	Geographical Coverage	Repeat Viewing Frequency (days)	Spatial Resolution (meters)	Availability	Gaps/Limitations
5,6,9, 10,11,12, 14,15	2007-2011	Global	46 days (pointable off nadir)	10 meters	Commercially Available	Same as Landsat
	(1-3) 1986-1996 (4) 1998 (5) 2002	Global	26 days (pointable off nadir)	(1-3) 20 meters (4) 20 meters (5) 10 meters	Commercially available	Same as Landsat

TABLE 4.4D. (CONTINUED)

Aichi Target	Category	Satellite	Sensors	Data Products (e.g. raw data or derived)	Uses specific to Aichi Targets	Sources
5,9,11,12	Active Medium - High Spatial and Temporal Resolution	Multi-Application Purpose Synthetic Aperture Radar (MAPSAR)	L-band synthetic aperture radar (SAR)	Cloud free multi-spectral Images	Landscape Monitoring Monitoring Landscapes and Disaster Events Resource Surveying Protected Area monitoring Landscape Monitoring Habitat mapping and change detection -Discriminating structurally complex habitats (e.g., forests) based on 3D structure -Retrieving above ground biomass and structure (e.g., height, cover) -Assessing habitat condition Assessing habitat degradation -Even within structured environments (canopy) Biodiversity assessment -Floral and faunal diversity in habitats (e.g. forest) with complex three-dimensional structure Tracking pressures, threats and disturbance -Detecting dead standing trees -Patterns of clearing and other damage caused by fire	Instituto Nacional de Pesquisas Espaciais (INPE) & Deutsches Zentrum für Luft-un Raumfahrt eV (DLR)

Aichi Target	Start Year / End Year (if completed)	Geographical Coverage	Repeat Viewing Frequency (days)	Spatial Resolution (meters)	Availability	Gaps/Limitations
5,9,11,12	TBA	Global	7	3 - 20	TBA	-Unknown at this time but is likely to have similar limitations as other SAR sensors and will not be a stand-alone product for monitoring biodiversity but will need to be combined with other data, modelling and field information; -L-band SAR is incapable of simultaneously providing high resolution and wide coverage.

TABLE 4.4D. (CONTINUED)

Aichi Target	Category	Satellite	Sensors	Data Products (e.g. raw data or derived)	Uses specific to Aichi Targets	Sources
5, 6, 10,11,15	Optical/Passive Course Spatial, High Temporal Resolution	Terra and Aqua	Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Clouds and Earth's Radiant Energy System (CERES) Multi-angle Imaging Spectroradiometer (MISR) Moderate-resolution Imaging Spectroradiometer (MODIS) Measurements of Pollution in the Troposphere (MOPITT)	Numerous data products measuring Land, Ocean, Atmospheric, Cryospheric and Calibrationi parameters from both Terra and Aqua Sensors:	Monitoring Earth's atmosphere, lands, oceans, and radiant energy including: -Measuring levels of gas in the lower atmosphere and tracking its source -Monitoring ocean parameters, circulation, temperature, colour, etc. Very Broad-scale Habitat Monitoring and Degredation -Early warnings of regional ecological change and climate change (photosynthetic activity) including: -Coral reef monitoring -Comparing plant productivity with carbon dioxide and other important greenhouse gases, as well as global temperature trends to better enable scientists to predict how changes in the climate will impact Earth's ecosystems. Tacking Pressures and Threats (fires and photosynthetic activity) -Identifying and monitoring ocean acidification -Measure how certain human activities, such as biomass burning and deforestation, may be contributing to climate change -Near real-time alerts of deforestation Protected Area Monitoring	San Diego State University (SDSU)/NASA

Aichi Target	Start Year / End Year (if completed)	Geographical Coverage	Repeat Viewing Frequency (days)	Spatial Resolution (meters)	Availability	Gaps/Limitations
5, 6, 10,11,15	Terra: 1999 Aqua: 2002	Global	16	ASTER (15-90) MISR (250-275) MODIS (250-1,000) CERES (20,000) MOPITT (22,000 at nadir)	Freely Available	-Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs to be used in conjunction with other data, modelling and field information; -Course resolution; -Cloud cover and haze create challenges for monitoring using optical sensors.

TABLE 4.4D. (CONTINUED)

Aichi Target	Category	Satellite	Sensors	Data Products (e.g. raw data or derived)	Uses specific to Aichi Targets	Sources
5,11,12	Active Moderate - High Spatial Resolution Moderate - Low Temporal Resolution	Advanced Land Observing Satellite - Phased Array type L-band Synthetic Aperture Radar (ALOS-PALSAR)	Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM); Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2); Phased Array type L-band Synthetic Aperture Radar (PALSAR)	PALSAR data are in dual Polarization, HH+HV, mode. Bands HH (red and green) and Band-HV (blue) can be used to visualize land use patterns. The backscattering coefficient or Normalized Radar Cross Section (NRCS) are also provided as gray scale images.	Monitoring Landscapes and Disaster Events Resource Surveying Protected Area monitoring Landscape Monitoring Habitat mapping and change detection -Discriminating structurally complex habitats (e.g., forests) based on 3D structure Assessing habitat degradation - Even within structured environments (canopy) Biodiversity assessment -Floral and faunal diversity in habitats (e.g.,forest) with complex three-dimensional structure Tracking pressures and threats -Detecting dead standing trees -Patterns of clearing and other damage caused by fire	Japanese Aerospace Exploration Agency (JAXA)

Aichi Target	Start Year / End Year (if completed)	Geographical Coverage	Repeat Viewing Frequency (days)	Spatial Resolution (meters)	Availability	Gaps/Limitations
5,11,12	Around 2007; completed 2011	Global	46	10	Freely Available	-Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs be used in conjunction with data, modelling and field information; -Incapable of simultaneously providing high resolution and wide coverage.

Aichi Target	Category	Satellite	Sensors	Data Products (e.g. raw data or derived)	Uses specific to Aichi Targets	Sources
5,10,11, 12,14, 15	Active Low Spatial and Temporal Resolution	ENVISAT	Advanced Synthetic Aperture Radar (ASAR); The Medium Resolution Imaging Spectroradiometer (MERIS)	GlobCover Bathymetry Sea Surface Height (SSH) sea colour (can be converted to chlorophyll pigment concentration, suspended sediment concentration and aero loads over marine areas) Cloud type, top height, and albedo Top and bottom indices of atmosphere vegetation Photosynthetically available radiation Surface pressure Water vapor total column content for all surfaces Aerosol load over land and sea Vegetation indices Fractional Absorbed Photosynthetically Active Radiation (FAPAR)	Protected Area monitoring Landscape Monitoring Habitat mapping and change detection -Discriminating structurally complex habitats (e.g., forests) based on 3D structure -Coral reef monitoring Assessing habitat degradation -Even within structured environments (canopy) Biodiversity assessment -Floral and faunal diversity in habitats (e.g.,forest) with complex three-dimensional structure Tracking pressures and threats -Detecting dead standing trees -Patterns of clearing and other damage caused by fire -Identifying and monitoring ocean acidification Ecosystem monitoring Disaster management -Detecting oil spills -Monitoring floods, landslides, volcanic eruptions -Aiding forest fighting	European Space Agency (ESA)

Aichi Target	Start Year / End Year (if completed)	Geographical Coverage	Repeat Viewing Frequency (days)	Spatial Resolution (meters)	Availability	Gaps/Limitations
5,10,11, 12,14, 15	2002/3-2012 Globcover 2005-2006; 2009	Global	35	300 meter	Commercially available from Radarsat International	- Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs be used in conjunction with data, modelling and field information; -Incapable of simultaneously providing high resolution and wide coverage (swath width).

Aichi Target	Category	Satellite	Sensors	Data Products (e.g. raw data or derived)	Uses specific to Aichi Targets	Sources
5,10,11, 12,14,15	Active High Temporal and Spatial Resolution	Light Detection and Ranging (LiDAR) Remote Sensing	Laser scanner and photodetector/optical receiver	Point Cloud: A 3-dimensional (3D) dense assemblage of points with precise location of individual points hit by the laser, height of the object in the lasers path and intensity of the laser return (similar to optical reflectance only more concentrated and not influenced by cloud or other atmospheric disturbance to as great an extent as optical sensors are).	Protected Area monitoring Habitat mapping and change detection -Discriminating structurally complex habitats (e.g., forests) based on vegetation canopy structure Assessing habitat degradation -even within structured environments (canopy) Biodiversity assessment -Floral and faunal diversity in habitats (e.g. forest) with complex three-dimensional structure Tracking pressures and threats -Detecting dead standing trees -Patterns of clearing and other damage caused by fire	Multiple

Aichi Target	Start Year / End Year (if completed)	Geographical Coverage	Repeat Viewing Frequency (days)	Spatial Resolution (meters)	Availability	Gaps/Limitations
5,10,11,12,14,15	Various	Regional (global data from GLAS available, but sparse sampling)	1+	0.1 - 10	Commercially and Freely Available on case-by-case basis. Sources of freely available data include USGS & university/institutional collections	-Not currently utilised widely, effectively or efficiently though it is growing in popularity around the world; -Not available at global scale; -Costly to obtain data if not already available as requires flying a plane and operating cameras, software, expertise, etc.; -Requires formatting, importing and process which can create huge transaction (computing) costs and technical challenges to process data, the larger the study area the more time consuming, costly and otherwise prohibitive to utilize; -LIDAR data handling software packages are not keeping pace with the LiDAR technology advancements, especially in automated classification and vegetation mapping; -Intensity must be calibrated when doing the flight campaign with targets and/or utilising correction algorithms for existing data as most LiDAR sensors are not calibrated for intensity; without calibrating intensity LiDAR is less useful for habitat and species monitoring; -Is not a stand-alone resource for biodiversity monitoring; the point clouds are used to generate other geospatial products, such as digital elevation models, canopy models, building models, and contours for monitoring/predicting trends in species changes, needs be used in conjunction with modelling and field information.

Aichi Target	Category	Satellite	Sensors	Data Products (e.g. raw data or derived)	Uses specific to Aichi Targets	Sources
5,11,12, 14,15	Active Low-High Spatial Resolution Moderate-High Temporal Resolution	Radarsat 1 & 2 Radarsat Constellation Mission (RCM)	Synthetic Aperture Radar (SAR)	Cloud free multispectral images with change detection capacity	Protected Area Monitoring Resource management -Forestry -monitoring growth and other changes Hydrology -Monitoring water use/ consumption Oceanography -Mapping sea ice distribution -Maritime surveillance - improving shipping navigation Geology Meteorology Ecosystem monitoring Disaster management -Detecting oil spills -Monitoring floods, landslides, volcanic eruptions -Aiding forest fighting Sustainable development Fine to Broad Habitat Mapping and change detection -Discriminating structurally complex habitats (e.g., forests) based on 3D structure Assessing habitat degradation -Within structured environments (canopy) Biodiversity assessment -Floral and faunal diversity in habitats (e.g.,forest) with complex three-dimensional structure Tracking pressures and threats -Detecting dead standing trees -Patterns of clearing and other damage caused by fire	Government of Canada / Canadian Space Agency

Aichi Target	Start Year / End Year (if completed)	Geographical Coverage	Repeat Viewing Frequency (days)	Spatial Resolution (meters)	Availability	Gaps/Limitations
5, 11, 12, 14, 15	(1) 1995-2012 (2) 2007 (7 year minimum duration) Constellation scheduled for 2018 launch	Global	RS-1 &-2 (24) RCM (12)	(RS-1) 8-100 meters (RS-2 & RCM) 3 -100 / 1 + in Spotlight Mode	Commercially Available	-Is not a stand-alone resource for monitoring/predicting trends in species changes, needs be used in conjunction with modelling and field information; -Often insufficient for the purpose of detailed habitat mapping over large areas b/c of a fundamental incapability to simultaneously providing high resolution and wide coverage VHR and high resolution datasets suffer from problems of shadowing from and within objects and mixed pixels, and can be expensive and time consuming to procure and process.

Aichi Target	Category	Satellite	Sensors	Data Products (e.g. raw data or derived)	Uses specific to Aichi Targets	Sources
5,9,10, 11,12	Optical/Passive High Spatial Resolution High Temporal Resolution	IKONOS	High resolution stereo imaging sensor (satellite based camera)	Images available as panchromatic (PAN) or multispectral (MS)	Protected Area monitoring Ecological monitoring Habitat mapping and change detection -Mapping successional fine scale homogeneous habitats, ecotones and mosaic areas (e.g. coral reefs) Assessing habitat degradation -Identifying fine scale degradation in forests Biodiversity assessment -Indicators of overall species richness and diversity -Delineation of tree crowns/ clumps to species level Tracking pressures and threats -Detection of fine-scale disturbances -Identification and monitoring of ocean acidification	GeoEYE

Aichi Target	Start Year / End Year (if completed)	Geographical Coverage	Repeat Viewing Frequency (days)	Spatial Resolution (meters)	Availability	Gaps/Limitations
5,9, 10,11,12	1999	Global	1–3	1 (PAN) - 4 (MS	Commercially Available	-Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs to be used in conjunction with other data, modelling and field information; -IKONOS imagery may incur a high purchasing cost to the user; -Specialist hardware/software for utilising data may be required; -IKONOS data needed lengthy processing; -Visual interpretation of the IKONOS image necessitated fieldwork; -IKONOS images are not great for creating accuracy of vegetation classes with high spectral variance (heterogeneous) -Often insufficient for the purpose of habitat mapping over large areas; -Cloud cover and haze create challenges for monitoring using optical sensors; -Very High Resolution (VHR) and high resolution datasets have not yet been tested or exploited to their full extent and suffer from problems of shadowing and mixed pixels; -Can be prohibitively expensive and time consuming to procure and process.

Aichi Target	Category	Satellite	Sensors	Data Products (e.g. raw data or derived)	Uses specific to Aichi Targets	Sources
5, 10, 11, 12,15	Optical/Passive and Radar/Active High to Low Spatial Resolution Moderate Temporal Resolution	Indian Remote Sensing Satellite (IRS) System	Multiple optical and radar based sensors on 11 satellites in operation - largest civilian remote sensing satellite constellation in the world	The main data products are images in a variety of spatial, spectral and temporal resolutions utilised for a variety of applications with climate monitoring & environmental monitoring among them. The latest satellite to add to the constellation, SARAL includes biodiversity protection as a focused use case, focused on oceanographic studies.	Landscape Monitoring Protected Area Monitoring Habitat mapping and change detection -Broad extent and spatial patterns Assessing habitat degradation -Broad scale loss (i.e., desertification) Biodiversity assessment -Indicators of overall species richness and diversity Tracking pressures and threats -Identifying disturbances -Monitoring desertification	Indo-French collaboration built by the French National Space Agency (CNES) and the Indian Space Research Organisation (ISRO)

Aichi Target	Start Year / End Year (if completed)	Geographical Coverage	Repeat Viewing Frequency (days)	Spatial Resolution (meters)	Availability	Gaps/Limitations
5, 10, 11,12,15	First satellite launched in 1988, The first of the still operational satellites in the constellation was launched in 2003 SARAL is scheduled for 2013	Global	various	various	Commercially Available	-Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs to be used in conjunction with other data, modelling and field information; -Limitations vary with individual satellites/sensors; SARAL will likely only benefit marine biodiversity monitoring; -Can be prohibitively expensive and time consuming to procure and process.

Aichi Target	Category	Satellite	Sensors	Data Products (e.g. raw data or derived)	Uses specific to Aichi Targets	Sources
5,10, 11,12	Active Moderate Spatial Resolution Low to High Temporal Resolution	European Remote Sensing Satellite 1 & 2	Synthetic Aperture Radar (SAR)	Radar Imagery	Protected Area monitoring Habitat mapping and change detection -Discriminating structurally complex habitats (e.g., forests) based on 3D structure -Coral reef monitoring Assessing habitat degradation -Even within structured environments (canopy) Biodiversity assessment -Floral and faunal diversity in habitats (e.g.,forest) with complex three-dimensional structure Tracking pressures and threats -Detecting dead standing trees -Patterns of clearing and other damage caused by fire -Identifying and monitoring ocean acidification	European Space Agency (ESA)

Aichi Target	Start Year / End Year (if completed)	Geographical Coverage	Repeat Viewing Frequency (days)	Spatial Resolution (meters)	Availability	Gaps/Limitations
5,10, 11,12	(1) 1991–2001; (2)1995–2001	Global	3/35/336	50	Freely Available	-Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs be used in conjunction with other data, modelling and field information; -Incapable of simultaneously providing high resolution and wide coverage (swath width).

Aichi Target	Category	Satellite	Sensors	Data Products (e.g. raw data or derived)	Uses specific to Aichi Targets	Sources
5,9,10,11, 12, 14	Optical/Passive High Spatial Resolution High Temporal Resolution	QuickBird	Panchromatic (PAN) and multispectral (MS)	Three levels of imagery ranging from least processed/corrected to orthorectified, GIS ready. 1) Basic Imagery - black and white or multispectral imagery available by scenes (not georeferenced) 2) Standard Imagery - black and white, multispectral or pan sharpened imagery (is georeferenced) available by area of interest 3) Orthorectified Imagery - in addition to the Standard Imagery corrections it is terrain corrected and comes GIS ready as an Image basemap in black and white, multispectral or pan sharpened option; available by area of interest.	Protected Area monitoring Ecological monitoring Habitat mapping and change detection -Mapping successional fine scale homogeneous habitats, ecotones and mosaic areas Assessing habitat degradation -Identifying fine scale degradation in forests -Rapid detection of clearing and degradation Biodiversity assessment -Indicators of overall species richness and diversity -Delineation of tree crowns/ clumps to species level Tracking pressures and threats -Detection of fine-scale disturbances -Identify and monitor ocean acidification	Digital Globe

Aichi Target	Start Year / End Year (if completed)	Geographical Coverage	Repeat Viewing Frequency (days)	Spatial Resolution (meters)	Availability	Gaps/Limitations
5,9,10, 11,12, 14	2001	Global	4	<1 (PAN) - 2.4 -2.8 (MS)	Commercially Available	-Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs to be used in conjunction with other data, modelling and field information; -Often insufficient for the purpose of habitat mapping over large areas; -Cloud cover and haze present challenges for monitoring with optical sensors: -Very High Resolution (VHR) optical datasets have not yet been exploited or tested to their full extent and even in cloud free images, present shadowing and mixed pixel challenges; -Can be prohibitively expensive and time consuming to procure and process.

Aichi Target	Category	Satellite	Sensors	Data Products (e.g. raw data or derived)	Uses specific to Aichi Targets	Sources
5,11,12, 14, 15	Optical/Passive Medium-High Spatial Resolution High Temporal Resolution	Système Pour l'Observation de la Terre (SPOT)	Panchromatic (PAN) and multispectral (MS), infrared and SWIR	A range of high resolution, multipspectral NIR and SWIR imagery with or without orthorectification	Protected Area Monitoring Ecological Monitoring Fine-scale Habitat Monitoring -Rapid detection of habitat and degradation Biodiversity assessment -Indicators of overall species richness and diversity Tracking pressures and threats -Identifying disturbances -Monitoring droughts and desertification Agricultural monitoring -Crop yields Oceanography Climatology	Astrium
5,6,10	Optical/Passive Low Spatial Resolution High Temporal Resolution	Sea-viewing Wide Field-of-view Sensor (SeaWiFS)	Optical scanner	Angstrom Exponent Aerosol Optical Thickness Chlorophyll-chromophoric dissolved organic matter (CDOM) proportion index Chlorophyll a Photosynthetically Available Radiation Particulate Inorganic/Organic Carbon concentration Sea Surface Temperature Quality Sea surface Reflectance Sea Surface Temperature	Monitor coral reefs and ocean acidification	GeoEYE

Aichi Target	Start Year / End Year (if completed)	Geographical Coverage	Repeat Viewing Frequency (days)	Spatial Resolution (meters)	Availability	Gaps/Limitations
5,11, 12,14,15	SPOT 1 (1986-1990) SPOT 2 (1990-2009) SPOT 3 (1993-1997) SPOT 4 (1998-2013) SPOT 5 (2002) SPOT 6 (2012) SPOT 7 scheduled for 2014	Global	1-4 Tasking optional with 1 day revisit	SPOT 1-4 (10-20) SPOT 5 (2.5-5) SPOT 6-7 (1.5)	Commercially Available	-Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs to be used in conjunction with other data, modelling and field information; -Cloud cover and haze present challenges for monitoring with optical sensors; -Very High Resolution (VHR) optical datasets have not yet been exploited or tested to their full extent and even in cloud free images, present shadowing and mixed pixel challenges; -Can be prohibitively expensive and time consuming to procure and process.
5,6,10	1997–2010	Global	1-2	1,100	Freely Available	-Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs to be used in conjunction with other data, modelling and field information; -Ocean focused; -Cloud cover and haze present challenges for monitoring with optical sensors; -Very High Resolution (VHR) optical datasets have not yet been exploited or tested to their full extent and even in cloud free images, present shadowing and mixed pixel challenges.

Aichi Target	Category	Satellite	Sensors	Data Products (e.g. raw data or derived)	Uses specific to Aichi Targets	Sources
5,10, 11,14	Optical/Passive Low Spatial Resolution High Temporal Resolution	Advanced Very High Resolution Radiometer (1-3)	AVHRR 1 included a 4 channel radiometer AVHRR 2 include 5 channel radiometer AVHRR 3 includes a 6 channel radiometer	Imagery available in four data sets: The Global Area Coverage (GAC) data set The Local Area Coverage (LAC) data set High Resolution Picture Transmission (HRPT) is real-time downlink data Full Resolution Area Coverage (FRAC)	Very Broad-scale Habitat Monitoring and Degredation -Early warnings of regional ecological change and climate change (photosynthetic activity) -Near real-time alerts of deforestation Tacking Pressures and Threats (fires and photosynthetic activity) Protected Area Monitoring Ecological Monitoring -Coral reefs and ocean acidification	National Oceanic and Atmospheric Association (NOAA)
5,10, 15	Optical/Passive Low Spatial Resolution High Temporal Resolution	Aquarius	Specialised radiometer	Sea Surface Salinity (SSS)	Monitor coral reefs and ocean acidification supplements observations of precipitation, evaporation, soil moisture, atmospheric water vapor, and sea ice extent	National Aeronautics and Space Administration (NASA)

Aichi Target	Start Year / End Year (if completed)	Geographical Coverage	Repeat Viewing Frequency (days)	Spatial Resolution (meters)	Availability	Gaps/Limitations
5,10, 11,14	1978-? 1981-? 1998-?	Global	6	1,100	Freely Available	-Not particularly useful for habitat mapping; -Not useful for change detection or biodiversity assessment; -Limited ecosystem monitoring capacity, using landcover as a surrogate and must be combined with other data; -Early data products suffered from difficulties with sensor calibration, orbital drift, limited spectral and directional sampling; -Is not a stand-alone resource for biodiversity monitoring needs to be used in conjunction with other data, modelling and field information; -Cloud cover and haze present challenges for monitoring with optical sensors; -Very High Resolution (VHR) optical datasets have not yet been exploited or tested to their full extent and even in cloud free images, present shadowing and mixed pixel challenges.
5,10, 15	2011	Global	7	150	Freely Available	-Is not a stand-alone resource for biodiversity monitoring needs to be used in conjunction with other data, modelling and field information; -Cloud cover and haze present challenges for monitoring with optical sensors; -Ocean focused

Aichi Target	Category	Satellite	Sensors	Data Products (e.g. raw data or derived)	Uses specific to Aichi Targets	Sources
5,6, 10, 11	Optical/Passive Moderate Spatial Resolution High Temporal Resolution	Seawinds: Quikscat	Specialised radiometer	Surface Wind Vector (SWV)	Monitor coral reefs and ocean acidification ocean response air-sea interaction mechanisms annual and semi-annual rainforest vegetation conditions daily or seasonal ice edge/ice pack movement and changes	National Oceanic and Atmospheric Association (NOAA)
5,9, 11, 12	Optical/Passive - Hyperspectral High Spatial Resolution High Temporal Resolution	WorldView-2	Multispectral sensor (MS)	High resolution Panchromatic band and eight (8) Multispectral bands; four (4) standard colors (red, green, blue, and near-infrared 1) and four (4) new bands (coastal, yellow, red edge, and near-infrared 2), full-color images	Protected Area monitoring Ecological monitoring Habitat mapping and change detection -Mapping successional fine-scale homogeneous habitats, ecotones and mosaic areas Assessing habitat degradation -Identifying fine scale degradation in forests Biodiversity assessment -Indicators of overall species richness and diversity -Delineation of tree crowns/clumps to species level Tracking pressures and threats -Detection of fine-scale disturbances	DigitalGlobe

Aichi Target	Start Year / End Year (if completed)	Geographical Coverage	Repeat Viewing Frequency (days)	Spatial Resolution (meters)	Availability	Gaps/Limitations
5,6, 10, 11	1999-2009	Global	1	12.5-25	Freely Available	-Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs to be used in conjunction with other data, modelling and field information; -Cloud cover and haze present challenges for monitoring with optical sensors; -Ocean focused
5,9, 11,12	2009	Global	1	0.46 (PAN) 1.84 (MS)	Commercially Available	-Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs be used in conjunction with other data, modelling and field information; -Cloud cover and haze present challenges for monitoring with optical sensors; -Very High Resolution (VHR) optical datasets have not yet been exploited or tested to their full extent and even in cloud free images, present shadowing and mixed pixel challenges; -Can be prohibitively expensive and time consuming to procure and process.

Aichi Target	Category	Satellite	Sensors	Data Products (e.g. raw data or derived)	Uses specific to Aichi Targets	Sources
5,9, 11,12	Optical/Passive - Hyperspectral High Spatial Resolution High Temporal Resolution	Airborne	Airborne Hyperspectral imaging sensor (HyMAP)	Hyperspectral imagery spanning 126 spectral bands	Habitat mapping and change detection -Distinguishing habitat types in low-contrast environments, and identifying forest successional classes Assessing habitat degradation -Based on changes in chemical composition of vegetation Biodiversity assessment -High precision classification of plant communities -Mapping top canopy trees to species or genus level - Identifying invasive species -Relating spectral heterogeneity to species richness and diversity Tracking pressures and threats -Identifying disturbances based on changes in foliage color, and fine-scale modifications due to disturbance	Spectronics

Aichi Target	Start Year / End Year (if completed)	Geographical Coverage	Repeat Viewing Frequency (days)	Spatial Resolution (meters)	Availability	Gaps/Limitations
5,9, 11,12	1999	Airborne	Airborne	5	Commercially available	-Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs be used in conjunction with other data, modelling and field information; -Often insufficient for the purpose of detailed habitat mapping over large areas; -Cloud cover and haze present challenges for monitoring with optical sensors; -Very High Resolution (VHR) optical datasets have not yet been exploited or tested to their full extent and even in cloud free images, present shadowing and mixed pixel challenges; -The shape and orientation of tree crowns, solar illumination, and sensor geometry, topography and spectral variation exert enormous influence over airborne spectroscopic signatures; -Very high-performance airborne HiFIS are needed at spatial resolutions that can resolve individual tree crowns, which is necessary for species-level determinations; -Can be prohibitively expensive and time consuming to procure and process.

Aichi Target	Category	Satellite	Sensors	Data Products (e.g. raw data or derived)	Uses specific to Aichi Targets	Sources
5,9, 11,12	Optical/Passive - Hyperspectral High Spatial Resolution High Temporal Resolution	Airborne	Airborne Visible/Infrared Imaging Spectrometer (AVIRIS)	Calibrated images of the upwelling spectral radiance in 224 contiguous spectral channels (bands) with wavelengths from 400 to 2500 nanometers.	Habitat mapping and change detection -Distinguishing habitat types in low-contrast environments, and identifying forest successioinal classes Assessing habitat degradation -Based on changes in chemical composition of vegetation Biodiversity assessment -High precision classification of plant communities -Mapping top canopy trees to species or genus level - identifying invasive species -Relating spectral heterogeneity to species richness and diversity Tracking pressures and threats -Identifying disturbances based on changes in foliage color, and fine-scale modifications due to disturbance	National Aeronautics and Space Administration (NASA)

Aichi Target	Start Year / End Year (if completed)	Geographical Coverage	Repeat Viewing Frequency (days)	Spatial Resolution (meters)	Availability	Gaps/Limitations
5,9, 11,12	First developed in 1983, updated in 2012	Airborne	Airborne	2	Freely and commercially available	- Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs be used in conjunction with other data, modelling and field information; -Only data from 2006-2013 is currently downloadable, pre 2006 data is processed on request if possible; -Often insufficient for the purpose of detailed habitat mapping over large areas; -Cloud cover and haze present challenges for monitoring with optical sensors; -Very High Resolution (VHR) and High Resolution optical datasets have not yet been exploited or tested to their full extent and even in cloud free images, present shadowing and mixed pixel challenges; -The shape and orientation of tree crowns, solar illumination, and sensor geometry, topography and spectral variation exert enormous influence over airborne spectroscopic signatures; -Very high-performance airborne HiFIS are needed at spatial resolutions that can resolve individual tree crowns, which is necessary for species-level determinations; -Can be prohibitively expensive and time consuming to procure and process.

Aichi Target	Category	Satellite	Sensors	Data Products (e.g. raw data or derived)	Uses specific to Aichi Targets	Sources
5,9, 11,12	Optical/Passive - Hyperspectral High Spatial Resolution High Temporal Resolution	Airborne	Airborne PRISM Experiment (APEX) http://www.apex-esa.org/	Radiance calibrated data in up to 520 spectral bands (380–2500 nm)	Only sensor worldwide to measure simultaneously leaf pigment concentration and chlorophyll fluorescence. Has been used to assess species diversity, pigment diversity, and plant functional traits	University of Zurich, VITO, and European Space Agency (ESA)
5,11,12	Active Radar High - Moderate Spatial and Temporal Resolution	TerraSAR-X and Tandem-X	Synthetic Aperture Radar (SAR)	WorldDEM: a homogenous, worldwide digital elevation model data (DEM) Additional individual image products	Protected Area monitoring Habitat mapping and change detection -Discriminating structurally complex habitats (e.g., forests) based on 3D structure Assessing habitat degradation -Even within structured environments (canopy) Biodiversity assessment -Floral and faunal diversity in habitats (e.g.,forest) with complex three-dimensional structure Tracking pressures and threats -Detecting dead standing trees -Patterns of clearing and other damage caused by fire	German Aerospace Center (DLR) and EADS Astrium

Aichi Target	Start Year / End Year (if completed)	Geographical Coverage	Repeat Viewing Frequency (days)	Spatial Resolution (meters)	Availability	Gaps/Limitations
5,9, 11,12	Operational since 2009	Regional	Airborne	1.5–5 m, depending on flight altitude	Data freely and/or commercially available	4th generation imaging spectrometer, with internal calibration source and absolute radiometric calibration. Standard processing includes traceable, calibrated radiances, including BRDF correction. Fully automated data processing scheme, delivery of end products to users. Creates very large data-sets,
5,11,12	TerraSAR - 2007 TandemX - 2010	Global	11 (3-4 at poles) Tasking 1-3	1-18 for individual products 2-10 for WorldDEM	Commercially Available	-Often insufficient for the purpose of detailed habitat mapping over large areas; -VHR and high resolution datasets suffer from problems of shadowing from and within objects and mixed pixels; -Incapable of simultaneously providing high resolution and wide coverage (swath width); -Can be expensive and time consuming to procure and process.

Aichi Target	Category	Satellite	Sensors	Data Products (e.g. raw data or derived)	Uses specific to Aichi Targets	Sources
5,9,11,12	Optical/Passive - Hyperspectral Moderate Spatial and Temporal Resolution	E0-1	High resolution hyperspectral imager capable of resolving 220 spectral bands (Hyperion) Advanced Land Imager (ALI) Linear Etalon Imaging Spectrometer Array (LEISA) Atmospheric Corrector (LAC)	Hyperion - High resolution hyperspectral images ALI - panchromatic and multispectral	Habitat mapping and change detection -Distinguishing habitat types in low-contrast environments, and identifying forest successional classes Assessing habitat degradation -based on changes in chemical composition of vegetation Biodiversity assessment -High precision classification of plant communities -Mapping top canopy trees to species or genus level - identifying invasive species -Relating spectral heterogeneity to species richness and diversity Tracking pressures and threats -Identifying disturbances based on changes in foliage color, and fine-scale modifications due to disturbance	National Aeronautics and Space Administration (NASA)

Aichi Target	Start Year / End Year (if completed)	Geographical Coverage	Repeat Viewing Frequency (days)	Spatial Resolution (meters)	Availability	Gaps/Limitations
5,9, 11,12	2000	Global	16	30	Freely available	-Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs to be used in conjunction with other data, modelling and field information; -Cloud cover and haze present challenges for monitoring with optical sensors.

Aichi Target	Category	Satellite	Sensors	Data Products (e.g. raw data or derived)	Uses specific to Aichi Targets	Sources
5,11,12	Active Radar Moderate Spatial Resolution Low Temporal Resolution	JERS-1 SAR	An L-band (HH polarization) synthetic aperture radar (SAR); A nadir-pointing optical camera (OPS); A side-looking optical camera (AVNIR).	Radar and optical Imagery data available spanning seven bands from the visible region to short wave infrared band and is capable of stereoscopic data in NIR	Protected Area monitoring Habitat mapping and change detection -Discriminating structurally complex habitats (e.g., forests) based on 3D structure Assessing habitat degradation -even within structured environments (canopy) Biodiversity assessment -Floral and faunal diversity in habitats (e.g.,forest) with complex three-dimensional structure Tracking pressures and threats Land surveys Agricultural-forestry-fisheries Disaster prevention and monitoring Coastal surveillance Locating natural resources.	Japanese Aerospace Exploration Agency (JAXA)

Aichi Target	Start Year / End Year (if completed)	Geographical Coverage	Repeat Viewing Frequency (days)	Spatial Resolution (meters)	Availability	Gaps/Limitations
5,11,12	1992-1998	Global	44	18	Freely available	-No longer operational -Cannot easily differentiate between species in high heterogeneity habitats, shadowing and mixed pixels can present challenges for mapping detailed habitats over large areas; -Not great for change detection due to inactivity, low temporal resolution and inconsistency in classifying heterogeneous images; -May have difficulty finding complementary/supporting data sets (e.g. DEMs) in tropics; -The L-band is incapable of simultaneously providing high resolution and wide coverage.

Aichi Target	Category	Satellite	Sensors	Data Products (e.g. raw data or derived)	Uses specific to Aichi Targets	Sources
5,9, 11,12	Optical/Passive - Hyperspectral High Spatial and Temporal Resolution	Airborne	Compact Airborne Spectrographic Imager (CASI)	Multispectral imagery	Habitat mapping and change detection -Distinguishing habitat types in low-contrast environments, and identifying forest successioinal classes Assessing habitat degradation -based on changes in chemical composition of vegetation Biodiversity assessment -High precision classification of plant communities -Mapping top canopy trees to species or genus level - identifying invasive species -Relating spectral heterogeneity to species richness and diversity Tracking pressures and threats -Identifying disturbances based on changes in foliage color, and fine-scale modifications due to disturbance	Itres Research Ltd. of Calgary, Canada

Aichi Target	Start Year / End Year (if completed)	Geographical Coverage	Repeat Viewing Frequency (days)	Spatial Resolution (meters)	Availability	Gaps/Limitations
5,9, 11,12	Various	Airborne	Airborne	1+	Publically Available (may not be free)	-Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs to be used in conjunction with other data modelling and field information; -Often insufficient for the purpose of detailed habitat mapping over large areas; -Cloud cover and haze present challenges for monitoring with optical sensors; -Very High Resolution (VHR) optical datasets have not yet been exploited or tested to their full extent and even in cloud free images, present shadowing and mixed pixel challenges; -The shape and orientation of tree crowns, solar illumination, and sensor geometry, topography and spectral variation exert enormous influence over airborne spectroscopic signatures; -Very high-performance airborne HiFIS are needed at spatial resolutions that can resolve individual tree crowns, which is necessary for species-level determinations; -Can be prohibitively expensive and time consuming to procure and process.

Aichi Target	Category	Satellite	Sensors	Data Products (e.g. raw data or derived)	Uses specific to Aichi Targets	Sources
5,9, 11,12	Optical and Chemical Passive High Spatial and Temporal Resolution	Airborne	High-fidelity Imaging Spectrometers (HiFIS)	Two-dimensional image, but with a third dimension containing a detailed spectroscopic signature of plant canopies.	Habitat mapping and change detection -Distinguishing habitat types in low-contrast environments, and identifying forest successional classes Assessing habitat degradation -based on changes in chemical composition of vegetation Biodiversity assessment -High precision classification of plant communities -Mapping top canopy trees to species or genus level - Identifying invasive species -Relating spectral heterogeneity to species richness and diversity Tracking pressures and threats -Identifying disturbances based on changes in foliage color, and fine-scale modifications due to disturbance	Carnegie Airborne Observatory

Aichi Target	Start Year / End Year (if completed)	Geographical Coverage	Repeat Viewing Frequency (days)	Spatial Resolution (meters)	Availability	Gaps/Limitations
5,9, 11,12	Various	Airborne	Airborne	<1+	Publically Available (may not be free)	-Although HiFIS has come of age technologically, the theories and algorithms required to extract taxonomic information from the spectra remain in the early stages of development; -Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs to be used in conjunction with other data, modelling and field information; -Often insufficient for the purpose of detailed habitat mapping over large areas; -Cloud cover and haze present challenges for monitoring with optical sensors; -Very High Resolution (VHR) optical datasets have not yet been exploited or tested to their full extent and even in cloud free images, present shadowing and mixed pixel challenges; -The shape and orientation of tree crowns, solar illumination, and sensor geometry, topography and spectral variation exert enormous influence over airborne spectroscopic signatures; -Very high-performance airborne HiFIS are needed at spatial resolutions that can resolve individual tree crowns, which is necessary for species-level determinations; -Can be prohibitively expensive and time consuming to procure and process.

Aichi Target	Category	Satellite	Sensors	Data Products (e.g. raw data or derived)	Uses specific to Aichi Targets	Sources
4,5,10, 11,12, 14,15	Optical/Passive Low Spatial Resolution High Temporal Resolution	Proba V	Vegetation Instrument	Multispectral images: VNIR: -Blue(438-486nm) -Red(615-696nm) -NearIR(772-914nm) SWIR(1564-1634nm)	-Land observation with focus on vegetation -Environmental & agro-climatic conditions -Effects of extreme events as drought and floods -Natural resources (soil, water, rangeland) -Crop and livestock production; -Prevalence of diseases -Desertification	European Space Agency (ESA)

Aichi Target	Start Year / End Year (if completed)	Geographical Coverage	Repeat Viewing Frequency (days)	Spatial Resolution (meters)	Availability	Gaps/Limitations
4,5, 10,11,12,14, 15	2013	Global	1-2	100-350	Unknown - Contact ESA's Prova-V programme	-Primarily a technology test -Expected to have s short life span of 2.5 years -Is not a stand-alone resource for biodiversity monitoring/predicting trends in species changes, needs to be used in conjunction with other data, modelling and field information; -Cloud cover and haze present challenges for monitoring with optical sensors; -Can be prohibitively expensive and time consuming to procure and process.

ANNEX 5. RELATIVE COSTS OF USING REMOTE SENSING FOR BIODIVERSITY MONITORING.

A number of costs associated with an EO-based approach to biodiversity monitoring and reporting on the Aichi Targets are listed below. Taking these costs into consideration is an important part of planning for any project based partly or wholly on EO data. Despite the costs, certain types of remote sensing monitoring are considerably more cost effective than in situ monitoring. For the purpose of the Aichi Targets, a useful future exercise would be a comparative economic analysis of the two types of monitoring for each target

5.1. DATA PRODUCTION

Data can be produced by public institutions, such as space agencies and national geo-spatial agencies, or via commercial companies. Some spaces agencies have adopted an open access data policy, offering free data to virtually all users. Nonetheless, a full and open access data policy does not necessarily mean easy and fast data access, and sometimes distribution of imagery can be subject to a fee depending on the type of user agreement in place. For more details see section 4.1.2.

High resolution imagery is usually available via commercial companies and costs vary depending on the remote sense technology used, amount of imagery requested, and specific agreement with the data provider.

Costs of the most common and popular satellite products are summarized in table 3.1. Prices are in USA dollars ($) per image as estimated in mid-2013.[7]

Table 3.1. Costs of the most common and popular satellite products as of mid-2013

Satellite (sensor)	Pixel size (m)	Minimum order area (sq. km)	Approx. cost ($)
NOAA (AVHRR)	1100	Free	No cost
EOS (MODIS)	250, 500, 1000	Free	No cost
SPOT-VGT	1000	Free	No cost
LANDSAT	15, 30, 60, 100, 120	Free	No cost
ENVISAT (MERIS)	300	Free	No cost
ENVISAT (ASAR)	150	Free	No cost
SRTM (DEM)	90	Free	No cost
EO-1 (Hyperion)	30	Free	No cost
EOS (ASTER)	15, 30, 90	3600	100
SPOT-4	10, 20	3600	1,600 – 2,500
SPOT-5	2.5, 5, 10	400	1,300 – 4,000
SPOT-6	1.5, 6.0	500	1,000 – 3,000
RapidEYE	5	500	700
IKONOS	1, 4	100	1,000 – 2,000
QuickBird	0.6, 2.4	100	2,500
GeoEYE	0.25, 1.65	100	2,000 – 4,000
WorldView	0.5, 2, 4	100	2,600 – 7,400

Source. IKONOS, QuickBird, GeoEYE, WorldView and RapidEYE: Landinfo. SPOT 4 & 5: Astrium EADS. Aster: GeoVAR. SRTM DEM, Landsat, Hyperion, MERIS, ASAR, AVHRR, SPOT-VGT and MODIS: NASA, ESA and Land Cover Facility

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[7] *This price is for the buying of a single image. If large amount of images are bought, price per single image may decrease.*

5.2. DATA ANALYSIS

Data can be analysed either in-house or be outsourced. Space agencies most often analyse their own data as they have the required expertise. Agencies at the national, provincial and local level might outsource the process to commercial companies offering the service, which they cost according to the amount of work and level of complexity.

5.3. DATA VALIDATION

Companies or institutions creating the data would verify it as part of the creation process, but verification and updating may also be done by those experts who have knowledge of the specific area. The cost are usually incurred at the point of data editing, or in the case of the expert being requested for their input the cost incurred could be equal to that of their hourly rate.

5.4. OTHER COSTS

Besides the above costs, there are a number of other costs associated with the use of Earth Observation for biodiversity mapping and monitoring that need to be taken into account. The key categories to consider are:

- Hardware and software costs
- Training and support costs
- Age and frequency of the EO data required
- Type of EO product to purchase

The following examples illustrate the broad costs for each of the above categories in USA dollars ($), as estimated in mid-2013. However, it is an estimate, and advice from suppliers of services and products should be foreseen to refine the estimates. The estimates provided below reflect the basic versions of commercial products which could be used to support the various image processing and analysis requirements.

5.4.1. Hardware and software costs

Hardware requirements can/should include:

- Production based computer: $2,000 - $4,000
- Plotter (or large format color printer) – $4,500 – $13,500

Software requirements can include:

- Image processing package
  - ERDAS Imagine Professional - $13,500 for 1 license
  - Exelis ENVI (no versioning) – $4,500 for 1 license
- Desktop GIS package to allow integration of datasets, GIS analysis functions
  - ArcGIS 10 – $3,000
  - MapInfo – $2,000
- Free and open Source GIS software
  - ILWIS 3.8 – Open source and free of charge, http://52north.org/
  - GRASS GIS - http://grass.osgeo.org/
  - gvSIG - http://www.gvsig.com/
  - OpenJUMP GIS - http://www.openjump.org/
  - MapWindow GIS - http://www.mapwindow.org/
  - QGIS - http://www.qgis.org/en/site/
  - uDig - http://udig.refractions.net/

5.4.2 Training and support costs

Depending on the complexity of the earth observation monitoring using remote sensed data with support of field data should be 2-4 person weeks of effort (also depending on size of area). In addition:

- GIS and Remote Sensing expertise would be required
- Training can be provided, or personnel can be hired

A key factor influencing the decision to hire specialists or to invest in-house is whether the inventory and future monitoring is going to be done frequently or not. For short duration work, perhaps only performed every three years, it is likely that consistent product quality will not be possible using in-house personnel that are infrequently using their skills. Instead, hiring external services and working with them closely to ensure the quality will yield the best results.

5.4.3. Age and frequency of the EO data required

Data costs are affected by:

- Urgency - emergency services - the faster you need it, the higher the cost.
- Age of the data - the older the data, the less expensive it is.
- Spatial resolution - the higher the spatial resolution, the higher the cost.
- Level of the product – the higher level image processing, the higher the cost.