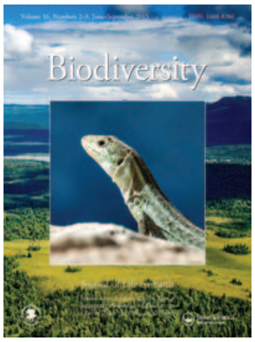


Taylor & Francis
Taylor & Francis Group

Biodiversity

ISSN: 1488-8386 (Print) 2160-0651 (Online) Journal homepage: http://www.tandfonline.com/loi/tbid20

Overcoming the challenges to conservation monitoring: integrating data from in-situ reporting and global data sets to measure impact and performance

P.J. Stephenson, Neil D. Burgess, Laura Jungmann, Jonathan Loh, Sheila O'Connor, Thomasina Oldfield, Will Reidhead & Aurélie Shapiro

To cite this article: P.J. Stephenson, Neil D. Burgess, Laura Jungmann, Jonathan Loh, Sheila O'Connor, Thomasina Oldfield, Will Reidhead & Aurélie Shapiro (2015) Overcoming the challenges to conservation monitoring: integrating data from in-situ reporting and global data sets to measure impact and performance, Biodiversity, 16:2-3, 68-85, DOI: 10.1080/14888386.2015.1070373

To link to this article: http://dx.doi.org/10.1080/14888386.2015.1070373

Published online: 27 Aug 2015.

BIODIVERSITY, 2015
Vol. 16, Nos. 2–3, 68–85, http://dx.doi.org/10.1080/14888386.2015.1070373

Overcoming the challenges to conservation monitoring: integrating data from *in-situ* reporting and global data sets to measure impact and performance

P.J. Stephenson[a]*, Neil D. Burgess[b], Laura Jungmann[c], Jonathan Loh[d], Sheila O'Connor[a], Thomasina Oldfield[e], Will Reidhead[a] and Aurélie Shapiro[f]

[a]*WWF International, Gland, Switzerland;* [b]*UNEP-WCMC, Cambridge, UK;* [c]*WWF Market Transformation Initiative, Zeist, Netherlands;* [d]*Zoological Society of London, London, UK;* [e]*TRAFFIC, Cambridge, UK;* [f]*WWF-Germany Remote Sensing Centre, Berlin, Germany*

(*Received 31 March 2015; final version received 5 July 2015*)

If parties to the Convention on Biological Diversity (CBD) and their partners are to report effectively on progress against national, regional and global biodiversity conservation goals, data will need to be collected at multiple levels. Global data sets, many gathered using remote sensing, offer partial solutions but need to be complemented by field-level observations to provide the resolution necessary to track conservation measures in a meaningful way. This paper summarises efforts made by the conservation organisation WWF, working with partners, to integrate 10 indicators of relevance to CBD parties into its global monitoring system and to use global data sets and data from field programmes to determine progress against multi-level goals and to assess programme performance and impacts. Integration of *in-situ* and *ex-situ* data into reporting dashboards tailored to WWF's needs allowed some degree of assessment of progress and adaptive management of the programme portfolio. Indicator trends were most favourable (on track) for protected area (PA) coverage and market share of sustainable commodities, and least favourable (worsening) for species offtake, species populations, wildlife trade, habitat fragmentation and Ecological Footprint. The most useful indicators – which could be disaggregated to provide trends at local levels relevant to WWF field programmes – were species populations, habitat cover and fragmentation, PA coverage and PA management effectiveness. However challenges remain if local and global monitoring objectives are to be aligned, including the need for increased collection of data by field projects, improved harmonisation of indicators, and greater sharing of data in formats of use to practitioners. We advocate wider adoption by governments and civil society organisations of indicators with the dual function of tracking delivery of CBD Aichi Targets as well as monitoring national, regional and ecoregional level conservation programmes, and urge more NGOs and academic bodies to support capacity building and data collection.

Keywords: Aichi Targets; biodiversity; CBD; indicators; monitoring; WWF

Introduction

Parties to the Convention on Biological Diversity (CBD) are striving to attain biodiversity goals for the year 2020 as defined in the Aichi Biodiversity Targets (Secretariat of the Convention on Biological Diversity 2014). In order to monitor delivery of the Aichi Targets globally and nationally, a set of pressure-state-response-benefit indicators has been developed (see, e.g., Butchart et al. 2010; Secretariat of the Convention on Biological Diversity 2014). Monitoring biodiversity and the impacts and outcomes of conservation projects at national, transboundary and global levels is also an essential challenge for conservation organisations supporting government efforts and the NGO (non-governmental organisation) and science community has been developing appropriate planning and monitoring methods (e.g. CMP 2013; Kapos et al. 2008).

If governments and their partners are to report effectively on progress against biodiversity conservation goals, data will need to be collected at multiple levels from multiple sources. Global data sets offer partial solutions, and in some cases national statistics are available (see, e.g., Mwangi et al. 2010). Satellite remote sensing provides a consistent, cost-efficient way to observe ecosystems on large scales (Secades et al. 2014) and has an underexploited potential to help with biodiversity monitoring (e.g. Nagendra et al. 2013; Pereira et al. 2013). Eleven of the 20 Aichi Targets could be at least partially monitored using remote sensing (Secades et al. 2014) and there is increasingly open access to global data sets (Scholes et al. 2012). Additional data sets and associated indices used to monitor biodiversity, levels of protection and threats at global levels include the World Database on Protected Areas (WDPA; Juffe-Bignoli et al. 2014), the Living Planet Index (Loh et al. 2005), the Global Database on Protected Area Management Effectiveness (GD-PAME) (Coad et al. 2013), and the Red List Index derived from the IUCN Red List of Threatened Species (Butchart et al. 2006). New databases are

*Corresponding author. Email: pjstephenson@wwfint.org

also emerging around, for example, oceans (Halpern et al. 2012), tropical forests (Hansen et al. 2013) and commodity production and trade (e.g. FAO STAT http://faostat.fao.org/).

Some efforts have been made to disaggregate global data sets to make them useful nationally (e.g. Han et al. 2014; Szabo et al. 2012). However, most conservation projects on the ground will need to collect their own data at levels relevant to their goals if they are to provide the resolution necessary to track conservation measures in a meaningful way. There is thus a potential disconnect between data being used to track the Aichi Targets nationally and globally, and data being gathered by conservation programmes at sub-national or ecoregional scales.

This paper summarises efforts made by the conservation organisation WWF and its partners to integrate global data sets with data collected by field staff to determine progress against multi-level organisational goals and to assess conservation impacts and programme performance. Lessons are presented that may be of use to CBD parties and their partners.

Methods and approaches

The WWF network (http://wwf.org/) has thousands of projects worldwide, but most contribute to 70 large-scale programmes designed to deliver on a set of global goals around 35 priority places (Figure 1), 13 species (Table 1) and key footprint areas (Table 1). During 2013, WWF adopted a new system for monitoring its global conservation programme, aiming to empower local adaptive management whilst informing global decision-making (Stephenson and O'Connor 2014; Stephenson and Reidhead 2014). The system involves programme teams

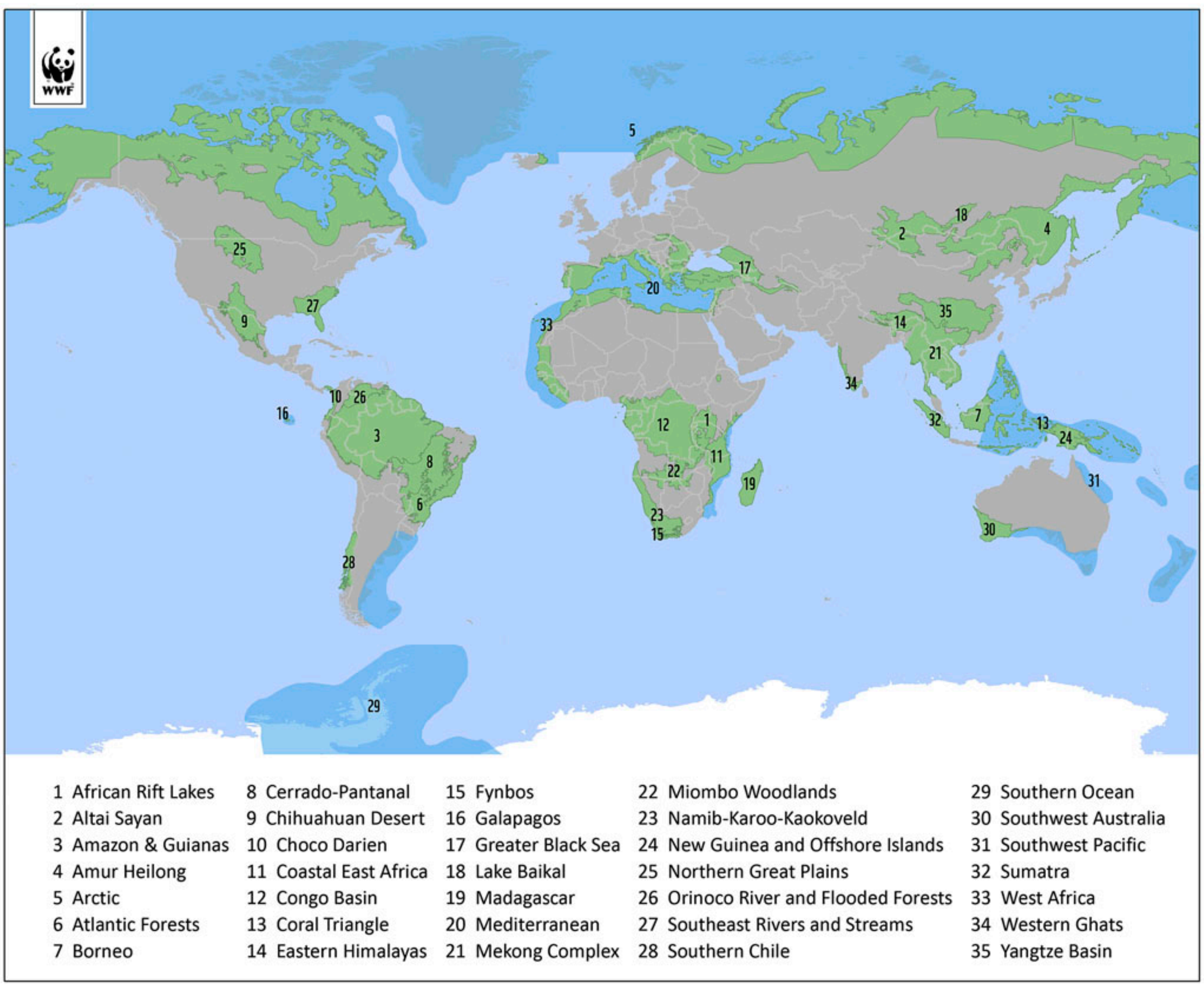


Figure 1. Map showing WWF global priority places.

Table 1. Summary of common indicators used by WWF in 2013–14 that are relevant to the indicators used to track CBD Aichi Targets.

WWF global goals	WWF indicator categories	Similar Aichi indicators	Aichi Targets
Biodiversity goals – conservation of 35 priority places (Fig. 1) and 13 flagship species groups (African elephants, African great apes, African rhinos, Asian big cats, Asian elephants, Asian rhinos, cetaceans, giant pandas, marine turtles, orangutans, polar bears, threatened marsupials in families Macropodidae & Potoridae)	Habitat cover	Extent of forests and forest types	Aichi Target 5: Loss of habitats
	Habitat fragmentation	Fragmentation (in development)	
	Habitat loss and degradation		
	Protected areas coverage	Coverage of protected areas	Aichi Target 11: Protected Areas
	Protected area management effectiveness	Management effectiveness of protected areas	
	Species populations Living Planet Index	Living Planet Index Red List index	Aichi Target 12: Preventing extinctions
	Offtake of species	Red List Index	Aichi Target 4: Use of natural resources
	Wildlife trade	Red List Index for species used for food or medicine	Aichi Target 14: Essential ecosystem services
Footprint goal – humanity's global footprint falls in the areas of energy/carbon footprint, commodities (crops, meat, fish and wood) footprint and water footprint	Ecological Footprint	Ecological Footprint	Aichi Target 4: Use of natural resources
	Sustainable production of commodities: – hectares certified (timber, pulp and paper) – metric tonnes certified (fish, seafood, crops such as soy, cotton, sugar, etc.) – percentage market share (uptake) for key commodities (i.e. % of total production certified)	Number of MSC certified fisheries Area of forest under sustainable management: certification	Aichi Target 6: Sustainable fisheries Aichi Target 7: Areas under sustainable management

establishing measurable goals and objectives and monitoring delivery through appropriate indicators, following best practices as defined in the Open Standards for the Practice of Conservation (CMP 2013). Annual reports are produced for each programme summarising progress and sharing data collected *in-situ*. Data on programme indicators are reported in a standard monitoring table and a Conservation Achievement Key Performance Indicator (KPI) is calculated (a summary score between a low of 1 and a high of 7 of how well the expected results for the year were delivered).

In 2013 and 2014, in addition to *in-situ* data collected and submitted by 56 and 57 programmes respectively, data were collated from external data sets on pressure-state-response indicators (*sensu* Sparks et al. 2011) to support meaningful aggregation and analysis of outcomes and impacts across the global conservation programmes. The indicators were chosen by the WWF network for their relevance to multiple programmes using the same conservation strategies.

In this paper we assess the 10 indicators used by WWF which are also of relevance to CBD (Table 1): three state indicators (habitat cover, habitat fragmentation, species populations); three pressure indicators (Ecological Footprint, habitat loss and degradation, offtake of flagship species) and four response indicators (protected areas (PA) coverage, PAME, wildlife trade, sustainable production of commodities). Data were sourced locally by programmes or from global data sets (Table 2). The *in-situ* and *ex-situ* data, and analyses conducted by relevant programmes, were compiled by a central team (the Conservation Strategy and Performance Unit at WWF International) to produce an overarching summary of progress towards global goals and lessons from the whole portfolio. Data are presented in dashboard format (Figures 2–4) to facilitate interpretation. Most of the indicators and data sources are the same as those used to track Aichi Targets (Tables 1 and 2) (Leadley et al. 2014).

Lessons for future development of the system are identified from application of the monitoring system in 2013 and 2014. We assess how well the process for *in-situ* and *ex-situ* data collection and analysis worked and to what extent it provided WWF and its partners with a means of tracking progress at different scales and how well it facilitated adaptive management. Indicators measured with similar methods are clustered together in the analysis of approaches and challenges.

Table 2. Summary of *in-situ* and *ex-situ* data sources and analyses for indicators used by WWF for which data were available in 2013–2014 and which are relevant to CBD Aichi Target monitoring.

Indicator	Global data sources (*ex-situ*)	Programme data sources (*in-situ*)	Notes on data analysis	Data completeness	Age of data used
State					
Species populations	Flagship species: Living Planet Index (WWF/ZSL)*; IUCN SSC specialist groups; government census reports; scientific papers (e.g. CIRVA 2014).	WWF species programme reports.	Some time series data were extracted from reports of programmes working on species and places, many of which used external sources such as IUCN SSC groups and government statistics. Most came from the LPI.	Time series data for all target species groups. Trends identified (which species declining, stable or increasing)	2014 (e.g. vaquita) to more than 15 years old (e.g. some ape, polar bear, tiger, cetacean populations)
	Species in priority places: Living Planet Index (WWF/ZSL)*; IUCN SSC specialist groups; government census reports; scientific papers.	WWF species and places programme reports	Data were charted for full species population (e.g. vaquita), regional populations (e.g. African elephant) or more local levels (e.g. loggerhead turtle, beluga, polar bear).	Data found for only 13/32 places. Sample too small to make conclusions on overall trends across the places.	2014 (e.g. black footed ferret, Northern Great Plains) to 18 years old (bonobo, Congo Basin)
Habitat cover	University of Maryland analysed by WWF-Germany Remote Sensing Centre.	Some programmes accessing data directly	We used monthly Vegetative Continuous Fields (VCF) data (MODIS44B) which estimates vegetative cover in 250 m pixels from 0 to 100% (Townshend et al. 2011).	Time series data for 24/32 places.	Up to 2010
Habitat fragmentation	University of Maryland analysed by WWF-Germany Remote Sensing Centre.	Not needed – global remote sensing (RS) data used	Changes in coverage of natural habitat were estimated by mapping areas of significant increase and loss in vegetative cover. We combined all observations with a minimum of 3 good quality data points in a year and removed cloud pixels using the provided quality data (buffering all pixels neighbouring clouds to remove shadows). All available cloud-free pixels above a specified VCF threshold to identify forest were assessed to determine persistent forest cover between time periods and significant increases and decreases in VCF (similar to Hansen and DeFries 2004).Forest fragmentation was assessed using neighbourhood analysis (Riitters et al. 2000) to calculate connectivity of a central pixel based on its neighbours. This defines core, interior and exterior edges of forest/non-forest data derived from the MODIS VCF. The percentage of edge versus core forest cover is used to evaluate the loss of intact forest and degradation over time.	Time series data for 24/32 places.	Up to 2010

(*Continued*)

Table 2. (*Continued*).

Indicator	Global data sources (*ex-situ*)	Programme data sources (*in-situ*)	Notes on data analysis	Data completeness	Age of data used
Pressure					
Habitat loss and degradation	University of Maryland analysed by WWF-Germany Remote Sensing Centre.	Not needed – global RS data used	See above (habitat cover and fragmentation).	Time series data for 24/32 places. Trends in rate of loss identified in and between places.	Up to 2010
Offtake of flagship species (number or proportion illegally killed)	CITES, including the MIKE programme analyzed by TRAFFIC; IUCN/SSC specialist groups.	Some species programmes also provided data on illegal killing.	MIKE programme collates information from the field on the proportion of elephant carcasses found that have been killed illegally (poached) rather than died of other causes in order to calculate PIKE (Proportion of Illegally Killed Elephants). These figures allow a comparison of poaching pressure over time. We also used raw figures for illegally killed animals. For African rhinos, offtake figures came from reports to CITES from range state governments and NGOs.	Time series data for 5 species groups (African and Asian elephants, African and Asian rhinos, tigers).	2013
Ecological Footprint	The Ecological Footprint Network*	Not relevant – global data used.	Total global Ecological Footprint was extracted directly from the Living Planet Report (WWF 2014) to provide a measure of progress against WWF's long-term goal for reducing footprint.	Global trend identified but data lag.	2010
Response					
Protected areas coverage	UNEP-WCMC World Database on Protected Areas* analysed by WWF-Germany Remote Sensing Centre.	WWF programme reports	We used geographical information systems (GIS) to compute total protected areas coverage by analysing the designation year of all protected areas in WWF places (terrestrial and marine were treated separately) and quantifying the increases in area from one year to the next. Duplicates were effectively dissolved or removed, so that only new area was calculated. Where available, information on PA downgrading, downsizing and degazettement were included as subtractions in PA coverage (Mascia and Pailler 2011). The analysis was computed automatically in ArcGIS 10.2 and can be re-processed as new versions of the WDPA come online.	Time series data for 30/32 places.	2013

Protected area management effectiveness	PAME database managed by UNEP-WCMC, IUCN WCPA, Universities of Queensland and Oxford*	In 2014 got new data from 12 places	UNEP-WCMC used data from the PAME database to assess the status of effectiveness assessments and trends in effectiveness in WWF priority places (based on analysis by Burgess et al. 2014; updated and informed by more detailed analyses in some WWF priority places such as Knights et al. 2014).	Baseline (though dates vary); limited time series data.	Some 2014
Wildlife trade (estimated illegal trade in products)	CITES; ETIS; TRAFFIC.	Some species programmes also reported trade data.	Data on seizures of illegally traded ivory recorded by TRAFFIC in the Elephant Trade Information System (ETIS) were used; analysis and modelling with subsidiary data allowed the trends in illegal trade to be determined. TRAFFIC surveys provided less thorough data for seizures of rhino horn (e.g. Milliken 2014).	Time series data on 2 wildlife products (ivory and rhino horn)	Rhinos 2014 Elephants 2012
Percentage market share for key commodities (i.e. % of total production certified)	WWF Market Transformation Initiative report sourced data from external sources: Aquaculture Stewardship Council, Better Cotton Initiative, Bonsucro, Forest Stewardship Council, Marine Stewardship Council, Roundtable on Sustainable Biomaterials, Roundtable on Sustainable Palm Oil, Roundtable on Responsible Soy.	WWF programme reports provided the analysis of externally sourced data.	Data extracted directly from databases of key agencies, and mapped over time for WWF priority commodities.	Time series data for all 10 target commodities with active certification schemes (aquaculture salmon, biomaterials, cotton, palm oil, pulp, soy, sugar, timber, tuna, whitefish).	2014

Note: Sources marked with an asterisk are the same as those used for global CBD reporting.

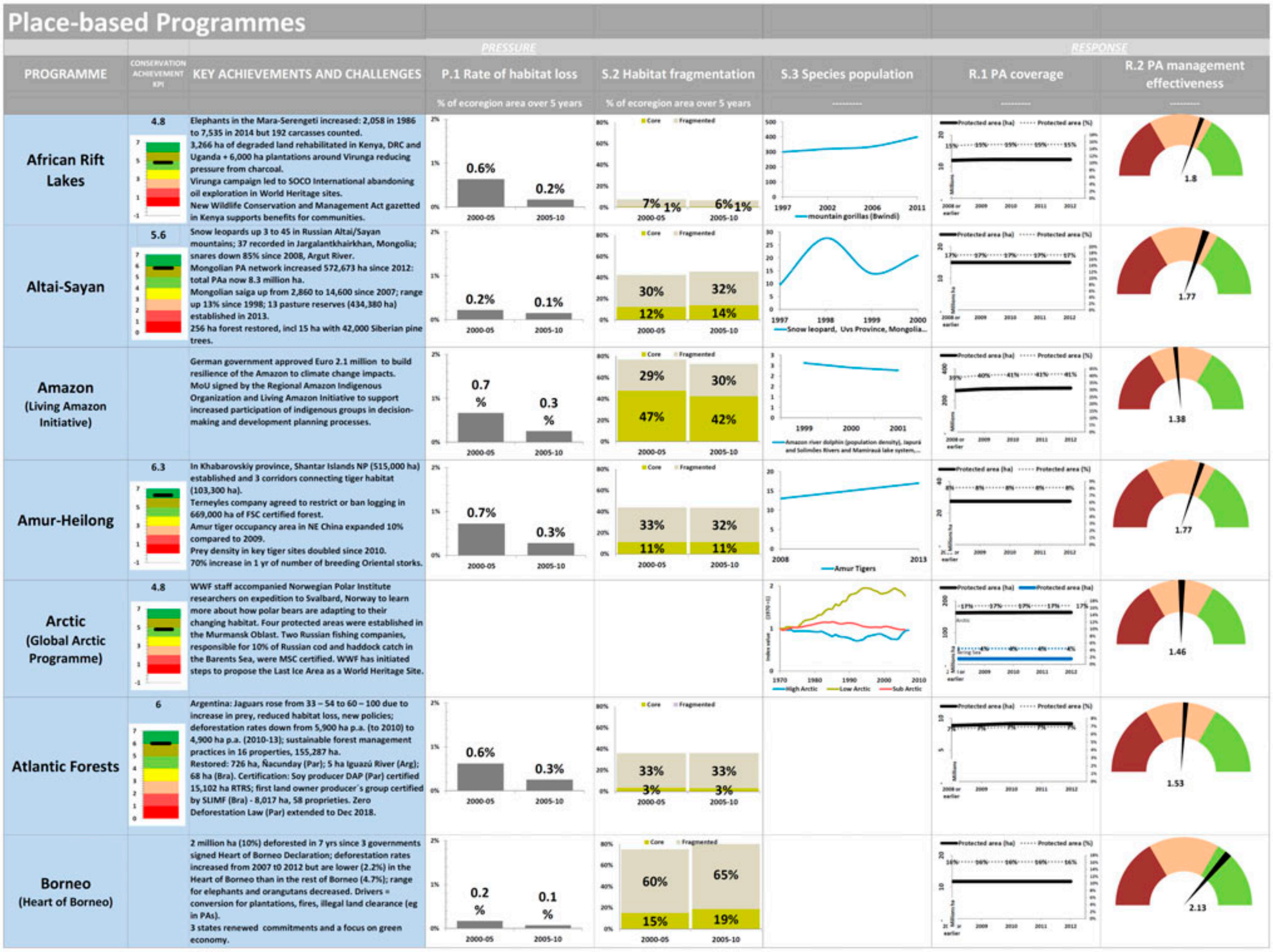


Figure 2. Sample elements of WWF place-based programme dashboard to demonstrate use of project data and *ex-situ* data. The Conservation Achievement KPI column is a graphic presentation of a rating of how well the programme delivered its annual objectives. Key achievements and challenges included text placing the KPI and impact data into perspective and highlighting any attribution of change where possible. The pressure-state-response-benefit indicators are then presented (where data are available), allowing comparisons across the portfolio.

Results and lessons learned

Data collection and analysis – approaches and challenges

Species population indicator

The Zoological Society of London (ZSL) continuously adds data to the Living Planet Index (LPI; Loh et al. 2005) using a global network of contacts including WWF teams. Numbers of records in the database have increased around 25% since 2010 and it now contains approximately 15,000 trends in populations for over 3500 vertebrate species. However, there are still temporal and spatial data gaps, including for WWF priority species (see list in Table 1). For example, data are inadequate (i.e. non-existent or patchy) for most cetaceans, most Asian big cats, African forest elephants, all great apes except mountain gorillas (*Gorilla beringei beringei*), many threatened marsupials and many marine turtle populations. In other cases, data are only available for single populations such as those in certain PAs, landscapes or seascapes (e.g. polar bear *Ursus maritimus*, beluga *Delphinapterus leucas*, loggerhead turtle *Caretta caretta*). Data for an entire population of a species – either in the LPI (e.g. giant panda *Ailuropoda melanoleuca*) or from programme reports (e.g. vaquita *Phocoena sinus*) – tend to be for species found only in one country.

There are logistical challenges in collecting data for wide ranging animals, especially aquatic species. Additional challenges include the lack of resources dedicated to species monitoring and inadequate capacity and expertise on the ground to use appropriate survey techniques.

Offtake of flagship species and wildlife trade indicators

The illegal wildlife trade is difficult to monitor so WWF and TRAFFIC strive to track all four stages of the

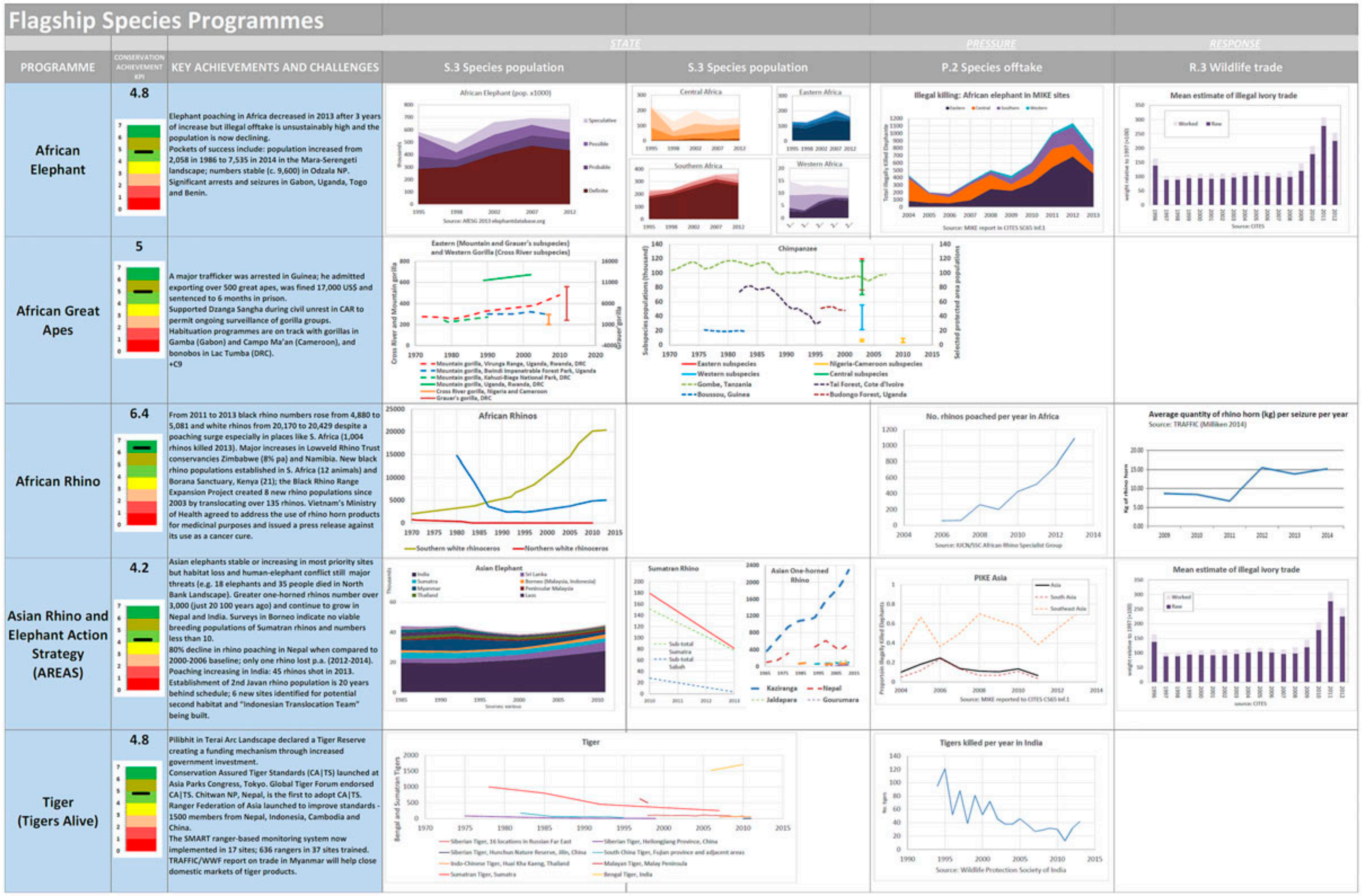


Figure 3. Sample elements of WWF species programme dashboard to demonstrate use of project data and *ex-situ* data.

supply chain (species populations, illegal offtake, trade and consumer demand). Although data are ultimately sought for most flagship species groups, only those species of highest priority for WWF's wildlife trade work – elephants, rhinos and tigers – are currently tracked. In 2014, data were collected for species populations, illegal offtake (or poaching) and trade (Table 2).

Illegal offtake data were compiled by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (see CITES 2014). Data are collected for elephants by MIKE – the Monitoring of Illegal Killing of Elephants programme – and for African rhinos from range state government and NGO reports to CITES. Tiger poaching incidents are more difficult to quantify as, unlike with elephants and rhinos, the whole carcass is usually removed and no consistently measured global indicator of offtake is available.

Whilst data reported on ivory seizures are reported to CITES and recorded by TRAFFIC in the Elephant Trade Information System (ETIS), there is no such systematic, centralised or mandated system for monitoring and reporting seizures of rhino horn and tiger parts. Improved monitoring and the collection of subsidiary data are required for rhinos and tigers if trend analyses are to be conducted like those conducted regularly for ivory. In the meantime, data from survey reports (e.g. Stoner and Pervushina 2013) provided a partial picture of tiger trade in 2014 and it can be assumed that poached rhino horns are destined for trade (Milliken 2014).

Habitat cover, fragmentation, loss and degradation indicators

WWF uses remote sensing data to track indicators relating to forest cover and fragmentation. As WWF's priority places are huge (Figure 1), free data derived from the Moderate Resolution Imaging Spectrometer (MODIS) were used to provide quick results, reduce processing costs and cover large areas efficiently, as a proof of concept for simple, repeatable monitoring. This effort was made prior to the release of data by Hansen et al. (2013) and, despite the high quality and high resolution of the new information and its many applications, these data are not yet well suited for WWF's monitoring needs because: (1) there is a delay in publication, whereas WWF can analyse MODIS data collected in the current year; (2) the Hansen algorithm only assesses tree cover and, as presented, cannot be easily altered or amended in areas with low accuracy, or tailored to non-forest ecosystems; (3) data must be downloaded manually, and large data volumes constrain processing, making a tailored medium-resolution analysis more efficient for this type of large area mapping. Other MODIS analyses for deforestation, such as those presented by Global Forest Watch, are either limited in coverage or coarser resolution.

Automated change detection was performed by determining a significant decrease in MODIS Vegetation Continuous Fields value (VCF), as in Hansen and DeFries (2004), which correlated well with patterns of deforestation observed in Amazonia via high resolution imagery in Google Earth, providing gross validation. Auxiliary data, such as Google Earth imagery and Landsat data, were also used to determine the VCF tree cover definition of forest for the initial year of analysis. Stable forest was identified as forest areas with no significant change in VCF from one year to the next. Larger deforestation detection errors compared to Google Earth were observed in seasonal or dry landscapes, such as Coastal East Africa, where climatic variations between years in dry forests resulted in large areas of thresholded change not caused by land use change. In addition, despite twice-daily data coverage from MODIS, the presence of persistent clouds was still a challenge in many tropical regions, resulting in low valid data areas, notably in Gabon and Cameroon in the Congo Basin.

Forest fragmentation was estimated using a neighbourhood window analysis (Riitters et al. 2000; Vogt et al. 2007) to determine intact versus patchy and disconnected forest patches. This analysis assigns forest into core and various degraded classes (inner edge, outer edge, patch forest) as per Vogt et al. (2007). The advantage of this indicator is that it is easy to interpret and can be automated to assess fragmentation on any forest map, producing consistent assessments of core and degraded forest over time.

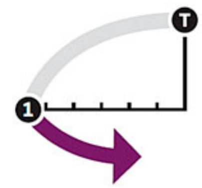
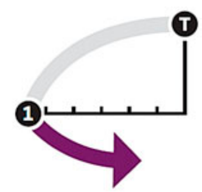
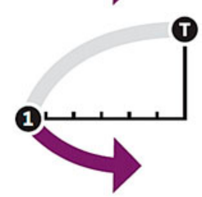
Ecological Footprint indicator

Challenges with this indicator include a delay in data availability: the 2014 WWF report could only access data for 2010. The Ecological Footprint is also heavily influenced by carbon footprint (currently 53% of overall footprint; Table 3), making it harder to detect trends in other components like cropland and infrastructure. A further challenge is disaggregating the data within WWF priority places or ecoregions, since the data are collated at national level.

Protected area coverage indicator

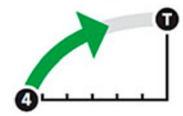
Protected area coverage over time in each WWF priority place was assessed using the WDPA (IUCN and UNEP-WCMC 2014), managed by UNEP-WCMC (United Nations Environment Programme – World Conservation Monitoring Centre). This database is an exhaustive collection of PA information, including IUCN category and year of designation, and allowed an assessment of coverage in all but two WWF priority places. However, there are some caveats with the database: areal changes over time may sometimes be due to more detailed or

Table 3. Summary of indicator trends for WWF priorities for which data were available in 2013–2014. Although many indicators do not yet have defined goals at the programme or global level, a preliminary assessment can be made of the trend in data based on the method of the Secretariat of the Convention on Biological Diversity (2014): 5 (exceeding expectations), 4 (on track), 3 (insufficient progress), 2 (no progress), 1 (getting worse).

Indicator (and the goals measured)	Results/trends	General trend
State		
Species populations (WWF biodiversity goals; Aichi Target 12 – preventing extinctions)	Populations declining in 47/56 priority species or subspecies; only 9 (16%) stable or increasing: black rhino (*Diceros bicornis*), white rhino (*Ceratotherium simum*), Asian elephant (*Elephas maximus*), Asian one-horned rhino (*Rhinoceros unicornis*), giant panda (*Ailuropoda melanoleuca*), Asiatic lion (*Panthera leo persica*), Western grey whale (*Eschrictius robustus*), Barents Sea Bowhead whale (*Balaena mysticetus*), Gilbert's potoroo (*Potorous gilbertii*).	
Habitat cover (WWF biodiversity goals; Aichi Target 5 – loss of habitats)	Net declines in 10/32 places but primary habitat likely to be declining in most places.	
Habitat fragmentation (WWF biodiversity goals; Aichi Target 5 – loss of habitats)	Highest levels found in Miombo Woodlands (40% of ecoregion area fragmented), Yangtze Basin (41%), Mekong Complex (46%), Southern Chile (51%) New Guinea and offshore islands (57%) Borneo and Southwest (SW) Pacific (65%), Increasing in 14/24 priority places, stable in 4 and decreasing in 6 (African Rift Lakes, Amur-Heilong, Cerrado-Pantanal, Coastal East Africa, Orinoco River and flooded forests, SW Australia).	
Pressure		
Habitat loss and degradation (WWF biodiversity goals; Aichi Target 5 – loss of habitats)	Highest rates of loss in Eastern Himalayas, Mekong Complex and SW Pacific (0.6% of ecoregion area over 5 years) and SW Australia (1.3%), Rate of loss declining in 15 places, stable in 3 and increasing in 5 (Choco Darien, Congo Basin, Eastern Himalayas, SW Australia, Yangtze Basin).	
Illegal offtake of species (WWF biodiversity goals; Aichi Target – use of natural resources)	Difficult trend to assess as it varies within and between species: African rhinos: continued increase African elephant: recent decline after several years of increase Asian elephant: erratic, but recent increase Asian rhinos: increased offtake in India, decline in Nepal. Tiger: recent rise in India after several years of decrease.	
Ecological Footprint (WWF footprint goal; Aichi Target 4 – use of natural resources)	Increasing steadily since 1961, especially for carbon (now 53% of overall footprint).	
Response		
Coverage of protected areas (WWF biodiversity goals; Aichi Target 11 – protected areas)	Increased coverage in 29/30 places. PA coverage in 13 places attained CBD goal of 10% for terrestrial areas or 17% for marine areas in African Rift Lakes, Altai-Sayan, Amazon & Guianas, Choco-Darien, Coastal East Africa, Fynbos, Galapagos, Lake Baikal, Miombo Woodlands, Namib-Karoo-Kaokoveld, Southern Chile, SW Pacific, Sumatra.	
Protected area management effectiveness (WWF biodiversity goals; Aichi Target 11 – protected areas)	PAs in only 4/27 places (Borneo, Choco-Darien, Sumatra, Western Ghats) scored 2 or above (performing well). In the 12 places with new data in 2014, average PAME scores were 1.62 (SD 0.45, n = 320) for sites where WWF was active, and 1.44 (SD 0.51, n = 1332) for sites not receiving WWF support.	

(*Continued*)

Table 3. (*Continued*).

Indicator (and the goals measured)	Results/trends	General trend
Wildlife trade (WWF biodiversity goals, Aichi Target 14 – essential ecosystem services)	Trade in ivory and rhino horn higher now than in recent years, though with some recent drops.	
Percentage market share for key commodities (i.e. % of total production certified) (WWF footprint goal; Aichi Target 6 – sustainable fisheries; Aichi Target 7 – areas under sustainable management)	WWF goals met for 7/10 commodities. (On track: timber, pulp & paper, palm oil, cotton, tuna, whitefish, salmon aquaculture; Insufficient progress: soy, sugar, bioenergy).	

enhanced spatial data or missing data on designation year rather than any change in PA coverage. Sometimes it is difficult to correlate the data from the WDPA with data from programmes, since there can be a lag between a PA being created officially and its appearance in the WDPA.

Protected area management effectiveness indicator

Data were analysed for WWF by UNEP-WCMC from the Global Database on Protected Area Management Effectiveness (GD-PAME). PAME data are not yet freely available but UNEP-WCMC and IUCN, the managers of the WDPA and GD-PAME, aim to make the data open access when permissions from data providers are secured.

PAME tools have been applied more than 10,000 times across several thousand PAs globally (Coad et al. 2013). Recent data were added to GD-PAME for WWF-supported PAs in 12 priority places (Altai-Sayan, Amazon, Amur Heilong, Atlantic Forests, Borneo, Cerrado-Pantanal, Coastal East Africa, Congo Basin, Eastern Himalayas, Greater Black Sea Basin, Mekong Complex and Miombo Woodlands). Where such data were provided by programmes *in-situ*, analyses were possible to compare PAs where WWF is active with PAs where it is not, providing a first step towards attributing change to conservation action (Knights et al. 2014).

WWF helped devise the main tools used for measuring PAME – the Management Effectiveness Tracking Tool (WWF 2007) and the Rapid Assessment and Prioritization of Protected Areas Management Methodology (Ervin 2003). However, few WWF programmes measure PAME systematically and data gaps remain. Data are most abundant (above 30% of PAs assessed) in the Mediterranean, South America, eastern Africa, parts of Southeast Asia and parts of the Pacific, but weak in most other areas, including North America, Western Europe and Australia, despite dedicated efforts to compile available data (Coad et al. 2013).

Sustainable production of commodities indicator

WWF supports the multi-stakeholder development of standards for the sustainable production of key commodities. Therefore, progress towards WWF programme goals can be measured through the relative market share of commodities that are certified. Data were available for trade in all 10 priority commodities with active certification schemes in 2014 (Table 2).

Key challenges in measuring market share of sustainable production included competing certification systems for some commodities, different units used to measure conventional and certified production, the lack of transparency in some government production data, and a lag of about two years between the availability of certified production data and overall production data from FAO (the UN Food and Agriculture Organisation). Monitoring the steps companies are taking towards sustainable supply chains and towards meeting their commitments is a challenge, largely because commodity volumes that are purchased, traded or sold are usually proprietary information. One solution comes in the form of supply-change.org, which will start tracking the sustainability and deforestation-free commitments of more than 400 companies aligned with the Consumer Goods Forum.

The key assumption in promoting certification as a conservation strategy is that compliance with credible standards reduces the threats to biodiversity associated with commodity production, so it acts as a proxy indicator for improved conservation. Currently data are compiled at national and global levels, but ultimately the level of uptake (as well as the area under certification) needs to be measured at a priority place level and linked to biodiversity status.

Integrating in-situ and ex-situ data

Data collected from global data sets were not always up to date: for the 2014 WWF report, the latest data on habitat cover dated from 2010, most wildlife trade data from 2012, and commodity production and species offtake data from 2013. Some of the species data from the LPI were more than a decade old (e.g. for some cetaceans, apes, big cats and marine turtles) and data in WDPA and GD-PAME contain a time lag between PA creation or PAME assessment and entry into the databases. This inconsistent timing of data across programmes, as well as data gaps, prevented us from assessing any interrelationships between indicators.

Programme reports provided additional (*in-situ)* data on six indicators: species populations (e.g. vaquita, Sumatran rhino *Dicerorhinus sumatrensis*), offtake of flagship species (e.g. Asian rhinos), PA coverage (several newly gazetted parks and reserves), PAME (for 12 places), and wildlife trade (tiger *Panthera tigris*) (Table 2). Since these data were collected at the level of intervention, they often provided a more direct measure of programme progress than data from *ex-situ* sources. However, even for these indicators, most of the data used were derived from external data sets. PAME is the only indicator for which data from the field were integrated into the respective global database, allowing for a comparison between data from WWF sites of intervention and data from sites not worked in by WWF.

Barriers to the collection of more *in-situ* data included inadequate capacity and resources dedicated to monitoring. In some cases, there was a lack of harmonisation of programme indicators with global indicators (i.e. different indicators or different units of measurement were used). Motivation to collect and use data was enhanced where indicators reflected the needs of individual programmes and where dedicated capacity was available. For example, the WWF Asian Elephant and Rhino Programme was already tracking population levels and the habitats of its priority species. PAME data were abundant in east Africa largely due to staff from WWF and agencies such as the Global Environment Facility and IUCN seeing its value and having the capacity to use assessment tools.

Use of indicator data

What the data told us

In 2014, the Conservation Achievement KPI scores ranged from 3.9 to 6.7 out of 7 (mean 5.3; standard deviation 0.69). This suggests most programmes delivered well on their commitments in spite of worrying trends in impact and outcome indicators. This may be due to overly optimistic self-assessments, inappropriate or ineffective strategies, or a lag between action and impact.

The scale of the data accessed from *ex-situ* data sets (often global or national rather than ecoregional or species-level) meant that any change in trend could not generally be attributed to programmatic or policy actions. Nonetheless, the 10 indicators provided an important benchmark on the state of the areas, species, and pressures of relevance to programmes. Indicator trends were most favourable (on track) for PA coverage and market share of sustainable commodities, and least favourable (worsening) for species offtake, species populations, wildlife trade, habitat fragmentation and Ecological Footprint (Table 3).

In WWF priority places, on average only 32% of pressure, state and response indicators for which data were available showed positive trends (Table 4). In 18 out of 24 WWF priority places with data, habitat fragmentation was increasing; habitat cover had a net decrease in all but two of the 24 priority places assessed (New Guinea and Sumatra), though the rate of loss was generally declining (Tables 3 and 4). On average habitat loss was 0.39% (SD 0.26) of ecoregion area in 2000–2005 and 0.29% (SD 0.27) in 2006–2010 (n = 24). Only 16% of WWF priority species with available data showed stability or increases in populations (Tables 3 and 4). Illegal offtake in many elephant and rhino populations rose in recent years, correlated with an increase in illegal trade (e.g. a doubling of elephants killed annually and a threefold increase in the illegal

Table 4. Progress against WWF global 2020 goals calculated from available indicator data in 2014.

Indicator	Definition of progress (how an improvement was determined)	% showing progress	No. of programmes or species with data
Flagship species populations	Population stable or increasing	16.1%	56
Estimated progress against species 2020 goal (populations thriving)		16%	
Habitat fragmentation	Reduced fragmentation	25.0%	24
Habitat loss	Rate of loss decreased by 50% or more	50.0%	24
Protected area coverage	10–17% of place protected	37.1%	35
PA management effectiveness	METT score of 2.0 or above	14.8%	27
Estimated progress against places 2020 goal (all protected and well managed)		32%	

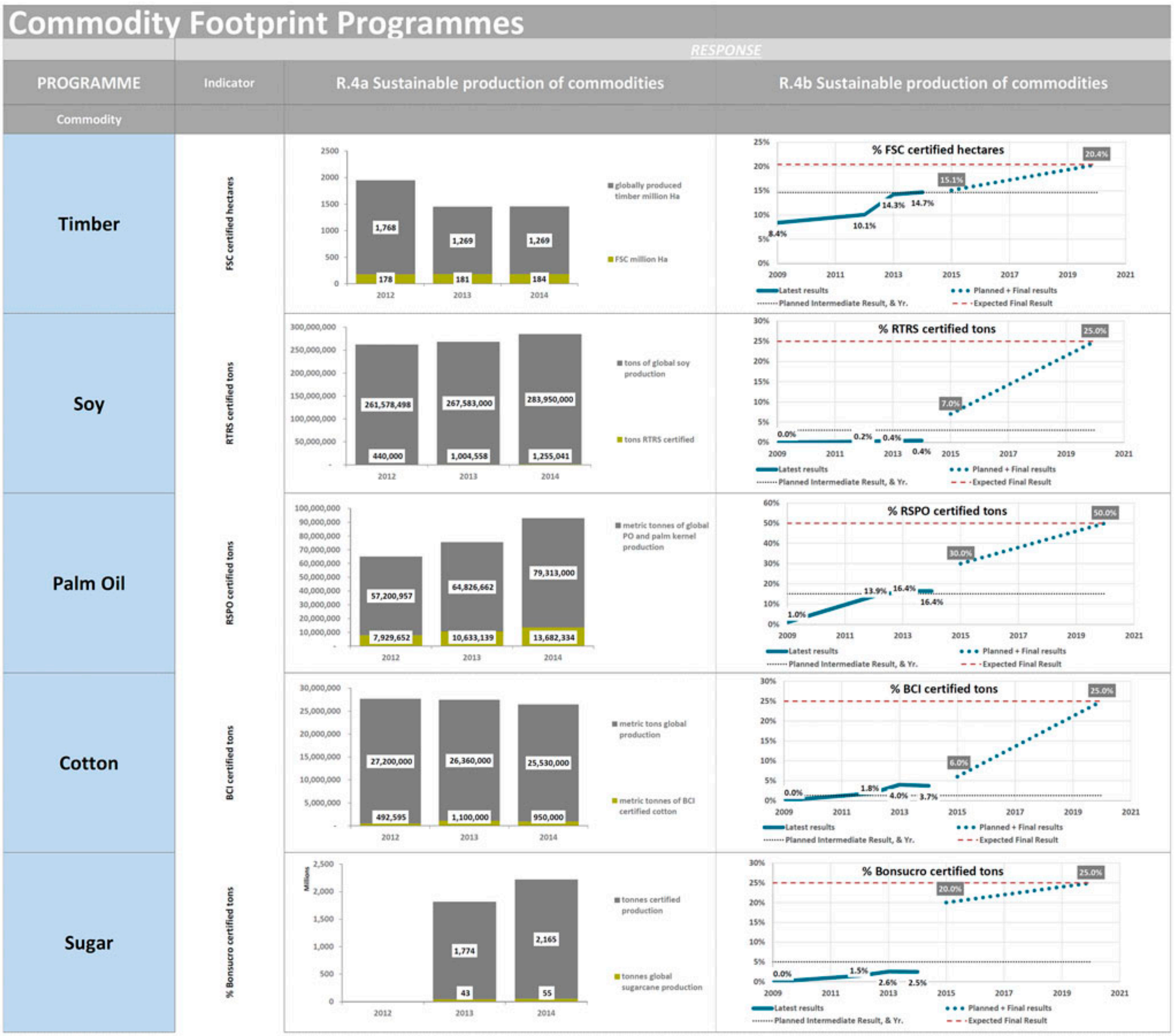


Figure 4. Sample elements of WWF commodities programme dashboard to demonstrate use of project data and *ex-situ* data.

ivory trade between 2008 and 2011). The steepest population declines were evident for the vaquita, Sumatran rhino and Yangtze finless porpoise (*Neophocaena asiaeorientalis asiaeorientalis*).

The average increase in PA coverage across WWF priority places (2008–2014) was 12.6% (SD 28.7, n = 30). Average PAME scores (where 3 is the highest level of effectiveness) in WWF priority places ranged from 1.29 to 2.28 (Burgess et al. 2014). Only four places out of 27 had average PAME scores over 2 (Table 3), suggesting most PAs could be better managed. A more in-depth assessment of data from Coastal East Africa showed differences in PAME between types of PA, with community-managed reserves generally scoring higher than equivalent PAs managed by government bodies (Knights et al. 2014).

Market share from sustainable sources met WWF goals for seven out of 10 commodities (Table 3), with the largest annual increase in 2014 occurring with whitefish (Figure 4).

Use of data to assess global goals

Analysis of available data allowed a preliminary assessment of progress against WWF global goals and suggested the organisation is between 16 and 32% towards achieving the conservation of its priority places and species (Table 4). However, broader indicator and data sets, with data at programme-specific scales, are needed before firm conclusions can be drawn.

Use of data for adaptive management

The dashboards summarised results in an easy-to-use format. Reading across a row allowed a holistic view of the status and trends of pressures, states and responses in a given WWF programme or priority place, and reading down the columns for a given indicator allowed identification of outlier programmes demonstrating strengths and challenges in specific areas, and regional, thematic, or species patterns. The evidence helped WWF think through its assumptions and strategy selection and to learn and adapt.

A range of adaptive management actions were triggered by the reports. For example, additional funding was allocated for vaquita and Sumatran rhino conservation and a renewed effort made in several programmes to collect data to fill gaps (especially for species numbers in priority places). Additional actions that might be expected in 2015 in response to the 2014 dashboards include increasing efforts to tackle negative trends (e.g. for high offtake and trade in elephants and rhinos), improving data collection to fill key gaps (e.g. broader use of PAME tools and species surveys), and learning from successful strategies (e.g. approaches that are increasing tiger and rhino numbers in India and Nepal and African rhinos in community-managed conservancies).

Discussion

WWF was able to use disaggregated data from *ex-situ* global data sets to monitor 10 biodiversity indicators of relevance to CBD to track its global priorities and to come up with a preliminary assessment of progress against its global goals. *In-situ* data collection against the indicators was limited but provided programme teams with information of relevance to their own goal delivery.

Trends detected in indicators for WWF priorities reflected those in reviews of global data sets for Aichi Target monitoring, such as downward trends in biodiversity state indicators (e.g. species populations and habitat cover), and upward trends in PA coverage and sustainable commodity production (Butchart et al. 2010; Juffe-Bignoli et al. 2014; Leadley et al. 2014; Secretariat of the Convention on Biological Diversity 2014; Tittensor et al. 2014; WWF 2014).

The presentation of indicator data in dashboards alongside text (summarising highlights and challenges, placing the indicators in context, allowing some attribution of change and reporting *in-situ* data) and a Conservation Achievement KPI (to assess annual results) allowed for an analysis of performance and impact by programme teams and managers and facilitated adaptive management decisions. The strongest indicators – that could be disaggregated to provide trends at regional or more local levels of relevance to WWF programmes – were species populations, habitat cover and fragmentation, PA coverage and PAME. Other indicators (e.g. species offtake, wildlife trade) require more comprehensive data sets to improve their usefulness. Ecological Footprint and sustainable commodity production posed challenges with disaggregation at a place level since they were collated nationally, though both helped measure global goal delivery. This suggests some indicators are more relevant to global than local monitoring.

In spite of some successes, a number of significant and ongoing challenges were identified which hinder effective monitoring across scales and the integration of *in-situ* and *ex-situ* data sets. Many global data sets were inadequate for our needs, reflecting acknowledged gaps in the geographic, taxonomic and temporal coverage of data for existing indicators (Butchart et al. 2010; Coad et al. 2013; Collen et al. 2009; Pereira et al. 2010; Walpole et al. 2009). Limited *in-situ* data collection reflected the challenges faced in the context of CBD where national reporting often lacks data (Bubb et al. 2011; Walpole et al. 2009).

The challenges identified have a number of root causes. Many conservation programmes have inadequate monitoring and evaluation systems (Stem et al. 2005), compounded by the absence of clear, measurable goals (e.g. Lindenmayer and Likens 2009; Stephenson and Ntiamoa-Baidu 2010). Improving monitoring methods and metrics is a key research topic (Sutherland et al. 2009), yet it is still not a priority for enough donors or academic bodies (Gibbons, Wilson, and Green 2011; Nichols and Williams 2006) and there is a general lack of funding and capacity for conservation monitoring (Martin, Blossey, and Ellis 2012).

The global biodiversity indicator set is incomplete (Tittensor et al. 2014; Walpole et al. 2009). Interlinkages between indicators are poorly understood (Sparks et al. 2011) and, although we found the pressure-state-response-benefit framework useful, as with many global assessments (e.g. Secretariat of the Convention on Biological Diversity 2014; Tittensor et al. 2014), we were not able to analyse any interrelationships between indicators. This avenue of analysis needs to be pursued more in future years. Significant challenges exist in sharing data (Bertzky and Stoll-Kleemann 2009; Tenopir et al. 2011), which for remote sensing include lack of capacity, cost of data acquisition, the need for data processing and derived products, and lack of harmonisation of methods (Secades et al. 2014; Turner et al. 2015). A lack of consensus about what to monitor (Pereira et al. 2013) further complicates data sharing.

Next steps

Lessons learnt from two years of using this monitoring system helped us identify some key actions which WWF and the world's conservation community need to take to address identified challenges in tracking conservation goals at multiple levels.

Continue to fill gaps in the indicator set

In addition to developing indicators required to monitor ecosystem services, demand for wildlife products, and how people participate in and benefit from conservation (Brown et al. 2014; Davies et al. 2013; Layke et al. 2012; Tierney et al. 2014; Tittensor et al. 2014), an ETIS-like system is needed for monitoring traded rhino and tiger products. Drivers linked to agriculture will account for 70% of the projected loss of terrestrial biodiversity in coming years (Secretariat of the Convention on Biological Diversity 2014) so it is vital to enhance monitoring of food systems and agricultural landscapes. New indicators must be developed primarily for use by national and regional programme management teams and linked to programme goals (Biodiversity Indicators Partnership 2010; CMP 2013; Jones et al. 2011).

Enhance and standardise data collection and sharing

Accessing the latest data in easy-to-use formats was not always easy for WWF. Efforts to standardise and share data (e.g. Chape et al. 2005; Pereira et al. 2010; Scholes et al. 2012) should be supported if local and global trends are to be assessed in comparable ways. Barrier-free approaches to data access, such as NASA's policy to share its USGS archive and Landsat data (Secades et al. 2014), should be encouraged, as should initiatives like ConservationEvidence.com that enhance understanding of the most effective conservation actions. For remote sensing, WWF will enhance its future forest cover change analyses by using MODIS annual best pixel composites to provide greater spectral resolution and complete cloud-free coverage at 250 m resolution. WWF will also integrate more global data sets (e.g. IUCN Red List of Threatened Species, Ocean Health Index) into its dashboards, especially where they help it harmonise with CBD and increase the opportunities for data sharing. However, ultimately more *in-situ* data collection is required by governments and their NGO and academic partners and more of the data fed into global data sets.

Use data in decision-making

Some of our results were used for adaptive management internally, but an 'effectiveness revolution' (Pullin and Knight 2001) in conservation will not be possible unless mechanisms are devised for incorporating the growing evidence base into decision frameworks to meet decision-makers' needs (Sanchirico et al. 2014; Segan et al. 2011), both in government and NGO structures. Developing derived products from global and local data sets, including dashboards like those used by WWF and others (e.g. Han et al. 2014) to enhance assimilation of information, could help support policy-making on governmental, corporate and financial levels, as would the use of indicators that respond predictably to policy changes (Costelloe et al. 2015; Jones et al. 2011).

Harness partnerships and engage civil society

WWF works with partners on the ground (e.g. government agencies, local communities) to collect *in-situ* data and a variety of institutions (e.g. IUCN, UNEP-WCMC, ZSL, etc.) to access *ex-situ* data. More partnerships are needed to advance indicator use (Balmford et al. 2005). Enhanced collaboration is needed between the earth observation community, biodiversity practitioners and decision-makers (Secades et al. 2014; Turner et al. 2015), as well as with organisations that monitor transparency. Local and international NGOs, as well as academia and local communities, have a major role to play in biodiversity monitoring (Danielsen et al. 2014; Stephenson and O'Connor 2014).

Creating the enabling environment

Several preconditions, such as project management standards and dedicated central capacity, were necessary for WWF to implement its monitoring system (Stephenson et al. 2015). Sustained investment in global biodiversity monitoring is also essential (Butchart et al. 2010). To use resources efficiently, we should prioritise where we monitor, focussing on populations and habitats, especially those at high risk (Balmford, Green, and Jenkins 2003; Noss 1990) or where monitoring capacity already exists (Pereira and Cooper 2006). Capacity and awareness need to be built, especially in relevant national institutions (Stephenson et al. 2015; Tittensor et al. 2014; Walpole et al. 2009), to ensure conservation programmes use best practices for planning, monitoring and data collection (e.g. CMP 2013).

Conclusions

The set of global indicators being used to help track progress towards the CBD Aichi Targets (Pereira et al. 2013; Walpole et al. 2009) is relatively robust and should be maintained and improved (Jones et al. 2011). WWF adopted many of these indicators and found them useful in tracking conservation delivery. Integration of *in-situ* and *ex-situ* data into dashboards allowed an assessment of progress at global and programme levels and facilitated adaptive management. However key challenges remain to be overcome if global and local monitoring objectives are to be attained.

Based on our experiences, we encourage government agencies, academic institutions, local and international NGOs and civil society groups to harmonise monitoring systems and indicator sets, to invest in data collection and analysis, to create enabling conditions for data sharing, and to use data in suitable formats for adaptive management at local to global levels. If the global indicator set is to meet everyone's needs, CBD Parties need support with capacity building and *in-situ* data collection and analysis. This will be even more relevant if some of the same indicators are adopted to measure environment-related Sustainable Development Goals, currently under development by the United Nations.

If the global conservation community can rally together to tackle the identified challenges, we expect to see not only improved monitoring of regional programmes and global goals but also improved mainstreaming of biodiversity data into decision-making and national policy frameworks, ultimately leading to greater conservation impacts.

Acknowledgements

We would like to thank the WWF teams who produced technical reports, and colleagues at TRAFFIC, UNEP-WCMC, WWF and ZSL for their help with data collection and management. Matt Walpole and Stephanie Mansourian provided useful feedback in the initial development of this paper, and comments from April Eassom, Diego Juffe-Bignoli and an anonymous referee helped improve the manuscript.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Balmford, A., R. E. Green, and M. Jenkins. 2003. "Measuring the Changing State of Nature." *Trends in Ecology & Evolution* 18 (7): 326–330.

Balmford, A., P. Crane, A. Dobson, R. E. Green, and G. M. Mace. 2005. "The 2010 Challenge: data Availability, Information Needs and Extra-terrestrial Insights." *Philosophical Transactions of the Royal Society B: Biological Sciences* 360 (1454): 221–228.

Bertzky, M., and S. Stoll-Kleemann. 2009. "Multi-level Discrepancies with Sharing Data on Protected Areas: what We Have and What We Need for the Global Village." *Journal of Environmental Management* 90 (1): 8–24.

Biodiversity Indicators Partnership. 2010. *Guidance for National Biodiversity Indicator Development and Use*. Cambridge: UNEP World Conservation Monitoring Centre.

Brown, C., B. Reyers, L. Ingwall-King, A. Mapendembe, J. Nel, P. O'Farrell, M. Dixon, and N. J. Bowles-Newark. 2014. *Measuring Ecosystem Services: guidance on Developing Ecosystem Service Indicators*. Cambridge: UNEP World Conservation Monitoring Centre.

Bubb, P., A. Chenery, P. Herkenrath, V. Kapos, A. Mapendembe, D. Stanwell-Smith, and M. Walpole. 2011. *National Indicators, Monitoring and Reporting for the Strategic Plan for Biodiversity 2011–2020: a Review of Experience and Recommendations in Support of the CBD Ad Hoc Technical Expert Group (AHTEG) on Indicators for the Strategic Plan 2011–2020*. Cambridge: UNEP-WCMC.

Burgess, N., M. Gonçalves de Lima, N. Kingston, S. Blythe, I. Tompkins, L. Coad, F. Leverington, et al. 2014. *Protected Area Management Effectiveness in WWF Global Priority Places*. Cambridge: UNEP-WCMC.

Butchart, S. H. M., H. R. Akçakaya, E. Kennedy, and C. Hilton-Taylor. 2006. "Biodiversity Indicators Based on Trends in Conservation Status: strengths of the IUCN Red List Index." *Conservation Biology* 20: 579–581.

Butchart, S. H. M., M. Walpole, B. Collen, A. van Strien, J. P. W. Scharlemann, R. E. A. Almond, J. E. M. Baillie, et al. 2010. "Global Biodiversity: indicators of Recent Declines." *Science* 328: 1164–1168.

Chape, S., J. Harrison, M. Spalding, and I. Lysenko. 2005. Measuring the Extent and Effectiveness of Protected Areas as an Indicator for Meeting Global Biodiversity Targets. *Phil Trans Royal Soc B: Biological Sciences* 360(1454): 443–455.

CIRVA. 2014. *Report of the Fifth Meeting of the 'Comité Internacional Para La Recuperación De La Vaquita' (CIRVA-5)*. http://www.iucn-csg.org/index.php/2014/08/02/the-vaquita-new-report-from-cirva-released/.

CITES 2014. "SC65 Doc. 42.1 Elephant Conservation, Illegal Killing and Ivory Trade: report to the Standing Committee of CITES." Sixty-fifth meeting of the Standing Committee. Geneva, Switzerland, 7–11 July 2014.

CMP. 2013. *Open Standards for the Practice of Conservation, Version 3*. Bethesda: Conservation Measures Partnership.

Coad, L., F. Leverington, N. D. Burgess, I. C. Cuadros, J. Geldmann, T. R. Marthews, J. Mee, et al. 2013. "Progress towards the CBD Protected Areas Management Effectiveness Targets." *Parks* 2013 (19): 13–24.

Collen, B., J. Loh, S. Whitmee, L. Mcrae, R. Amin, and J. E. Baillie. 2009. "Monitoring Change in Vertebrate Abundance: the Living Planet Index." *Conservation Biology* 23: 317–327.

Costelloe, B., B. Collen, E. J. Milner-Gulland, I. D. Craigie, L. McRae, C. Rondinini, and E. Nicholson. 2015. "Global Biodiversity Indicators Reflect the Modelled Impacts of Protected Area Policy Change." *Conservation Letters*. doi:10.1111/conl.12163.

Danielsen, F., P. M. Jensen, N. D. Burgess, R. Altamirano, P. A. Alviola, H. Andrianandrasana, J. S. Brashares, et al. 2014. "A Multicountry Assessment of Tropical Resource Monitoring by Local Communities." *BioScience* 64 (3): 236–251.

Davies, T. E., I. R. A. Fazey, W. Cresswell, and N. Pettorelli. 2013. "Missing the Trees for the Wood: why We Are failing to See Success in Pro-poor Conservation." *Animal Conservation* 17: 303–312.

Ervin, J. 2003. *WWF: rapid Assessment and Prioritization of Protected Area Management (RAPPAM) Methodology*. Gland: WWF.

Gibbons, D. W., J. D. Wilson, and R. E. Green. 2011. "Using Conservation Science to Solve Conservation Problems." *Journal of Applied Ecology* 48 (3): 505–508.

Halpern, B. S., C. Longo, D. Hardy, K. L. McLeod, J. F. Samhouri, S. K. Katona, K. Kleisner, et al. 2012. "An Index to Assess the Health and Benefits of the Global Ocean." *Nature* 488 (7413): 615–620.

Han, X., R. L. Smyth, B. E. Young, T. M. Brooks, A. S. de Lozada, P. Bubb, S. H. M. Butchart, et al. 2014. "A Biodiversity Indicators Dashboard: addressing Challenges to Monitoring Progress Towards the Aichi Biodiversity Targets Using Disaggregated Global Data." *PLoS ONE* 9 (11): e112046.

Hansen, M. C., and R. S. DeFries. 2004. "Detecting Long-term Global Forest Change Using Continuous Fields of Tree-cover Maps from 8-Km Advanced Very High Resolution Radiometer (AVHRR) Data for the Years 1982–1999." *Ecosystems* 7 (7): 695–716.

Hansen, M. C., P. V. Potapov, R. Moore, M. Hancher, S. A. Turubanova, A. Tyukavina, D. Thau, et al. 2013. "High-resolution Global Maps of 21st-Century Forest Cover Change." *Science* 342 (6160): 850–853.

IUCN and UNEP-WCMC 2014. *The World Database on Protected Areas (WDPA)* [On-line]. Cambridge: UNEP-WCMC. Accessed October 5, 2014. www.protectedplanet.net

Jones, J. P., B. Collen, G. Atkinson, P. W. Baxter, P. Bubb, J. B. Illian, T. E. Katzner, et al. 2011. "The Why, What, and How of Global Biodiversity Indicators beyond the 2010 Target." *Conservation Biology* 25 (3): 450–457.

Juffe-Bignoli, D., N. D. Burgess, H. Bingham, E. M. S. Belle, M. G. de Lima, M. Deguignet, B. Bertzky, et al. 2014. *Protected Planet Report 2014*. Cambridge, UK: UNEP-WCMC.

Kapos, V., A. Balmford, R. Aveling, P. Bubb, P. Carey, A. Entwistle, J. Hopkins, et al. 2008. "Calibrating Conservation: new Tools for Measuring Success." *Conservation Letters* 1: 155–164.

Knights, K., I. Cuadros, C. Zamora, L. Coad, F. Leverington, B. O'Connor, M. Gonçalves de Lima, et al. 2014. "A Preliminary Assessment of Protected Area Management within the WWF 'Coastal East Africa' Priority Place, Eastern Africa." *Parks* 20 (2): 77–88.

Layke, C., A. Mapendembe, C. Brown, M. Walpole, and J. Winn. 2012. "Indicators from the Global and Sub-global Millennium Ecosystem Assessments: an Analysis and Next Steps." *Ecological Indicators* 17: 77–87.

Leadley, P. W., C. B. Krug, R. Alkemade, H. M. Pereira, U. R. Sumaila, M. Walpole, A. Marques et al. 2014. *Progress towards the Aichi Biodiversity Targets: an Assessment of Biodiversity Trends, Policy Scenarios and Key Actions*. CBD Technical Series No. 78. Montreal: Secretariat of the Convention on Biological Diversity.

Lindenmayer, D. B., and G. E. Likens. 2009. "Adaptive Monitoring: a New Paradigm for Long-term Research and Monitoring." *Trends in Ecology and Evolution* 24 (9): 482–486.

Loh, J., R. E. Green, T. Ricketts, J. Lamoreux, M. Jenkins, V. Kapos, and J. Randers. 2005. "The Living Planet Index: using Species Population Time Series to Track Trends in Biodiversity." *Philosophical Transactions of the Royal Society B: Biological Sciences* 360 (1454): 289–295.

Martin, L. J., B. Blossey, and E. Ellis. 2012. "Mapping Where Ecologists Work: biases in the Global Distribution of Terrestrial Ecological Observations." *Frontiers in Ecology and the Environment* 10 (4): 195–201.

Mascia, M. B., and S. Pailler. 2011. "Protected Area Downgrading, Downsizing, and Degazettement (PADDD) and Its Conservation Implications." *Conservation Letters* 4 (1): 9–20.

Milliken, T. 2014. *Illegal Trade in Ivory and Rhino Horn: an Assessment Report to Improve Law Enforcement under the Wildlife TRAPS Project*. Cambridge: TRAFFIC International.

Mwangi, M. A. K., S. H. M. Butchart, F. B. Munyekenye, L. A. Bennun, M. I. Evans, L. D. C. Fishpool, E. Kanyanya, et al. 2010. "Tracking Trends in Key Sites for Biodiversity: a Case Study Using Important Bird Areas in Kenya." *Bird Conservation International* 20: 215–230.

Nagendra, H., R. Lucas, J. P. Honrado, R. H. Jongman, C. Tarantino, M. Adamo, and P. Mairota. 2013. "Remote Sensing for Conservation Monitoring: assessing Protected Areas, Habitat Extent, Habitat Condition, Species Diversity, and Threats." *Ecological Indicators* 33: 45–59.

Nichols, J. D., and B. K. Williams. 2006. "Monitoring for Conservation." *Trends in Ecology & Evolution* 21 (12): 668–673.

Noss, R. F. 1990. "Indicators for Monitoring Biodiversity: a Hierarchical Approach." *Conservation Biology* 4 (4): 355–364.

Pereira, H. M., and D. H. Cooper. 2006. "Towards the Global Monitoring of Biodiversity Change." *Trends in Ecology & Evolution* 21 (3): 123–129.

Pereira, H. M., J. Belnap, N. Brummitt, B. Collen, H. Ding, M. Gonzalez-Espinosa, R. D. Gregory, et al. 2010. "Global Biodiversity Monitoring." *Frontiers in Ecology and the Environment* 8 (9): 459–460.

Pereira, H. M., S. Ferrier, M. Walters, G. N. Geller, R. H. G. Jongman, R. J. Scholes, M. W. Bruford, et al. 2013. "Essential Biodiversity Variables." *Science* 339 (6117): 277–278.

Pullin, A. S., and T. M. Knight. 2001. "Effectiveness in Conservation Practice: pointers from Medicine and Public Health." *Conservation Biology* 15: 50–54.

Riitters, K., J. Wickham, R. O'Neill, B. Jones, and E. Smith. 2000. "Global-scale Patterns of Forest Fragmentation." *Conservation Ecology* 4 (2): 3.

Sanchirico, J. N., M. R. Springborn, M. W. Schwartz, and A. N. Doerr. 2014. "Investment and the Policy Process in Conservation Monitoring." *Conservation Biology* 28 (2): 361–371.

Scholes, R. J., M. Walters, E. Turak, H. Saarenmaa, C. H. R. Heip, E. O. Tuama, D. P. Faith, et al. 2012. "Building a Global Observing System for Biodiversity." *Current Opinion in Environmental Sustainability* 4 (1): 139–146.

Secades, C., O'Connor, B., Brown, C. and Walpole, M. 2014. *Earth Observation for Biodiversity Monitoring: a Review of Current Approaches and Future Opportunities for Tracking Progress towards the Aichi Biodiversity Targets*. CBD Technical Series No. 72. Montreal: Secretariat of the Convention on Biological Diversity.

Secretariat of the Convention on Biological Diversity. 2014. *Global Biodiversity Outlook 4*. Montréal: Secretariat of the Convention on Biological Diversity.

Segan, D. B., M. C. Bottrill, P. W. J. Baxter, and H. P. Possingham. 2011. "Using Conservation Evidence to Guide Management." *Conservation Biology* 25: 200–202.

Sparks, T. H., S. H. M. Butchart, A. Balmford, L. Bennun, D. Stanwell-Smith, M. Walpole, N. R. Bates, et al. 2011. "Linked Indicator Sets for Addressing Biodiversity Loss." *Oryx* 45: 411–419.

Stem, C., R. Margoluis, N. Salafsky, and M. Brown. 2005. "Monitoring and Evaluation in Conservation: a Review of Trends and Approaches." *Conservation Biology* 19: 295–309.

Stephenson, P. J., and Y. Ntiamoa-Baidu. 2010. "Conservation Planning for a Widespread Threatened Species: WWF and the African Elephant *Loxodonta Africana*." *Oryx* 44 (2): 194–204.

Stephenson, P. J., and S. O'Connor. 2014. *A Case Study of Conservation Monitoring Related to Aichi Targets: experiences and Lessons from WWF*. Unpublished report. Gland: WWF International.

Stephenson, P. J., and W. Reidhead. 2014. "Portfolio Management: measuring Short and Long-term Results in WWF." In *Project Management Best Practices: achieving Global Excellence*. 3rd ed, edited by H. R. Kerzner, 602–606. New Jersey: Wiley and Sons.

Stephenson, P. J., S. O'Connor, W. Reidhead, and J. Loh. 2015. "Using Biodiversity Indicators for Conservation." *Oryx* 49 (3): 396. doi:10.1017/S0030605315000460.

Stoner, S. S., and N. Pervushina. 2013. *Reduced to Skin and Bones Revisited: an Updated Analysis of Tiger Seizures from 12 Tiger Range Countries (2000–2012)*. Kuala Lumpur: TRAFFIC.

Sutherland, W. J., W. M. Adams, R. B. Aronson, R. Aveling, T. M. Blackburn, S. Broad, G. Ceballos, et al. 2009. "One Hundred Questions of Importance to the Conservation of Global Biological Diversity." *Conservation Biology* 23 (3): 557–567.

Szabo, J. K., S. H. M. Butchart, H. P. Possingham, and S. T. Garnett. 2012. "Adapting Global Biodiversity Indicators to the National Scale: a Red List Index for Australasian Birds." *Biological Conservation* 148 (1): 61–68.

Tenopir, C., S. Allard, K. Douglass, A. U. Aydinoglu, L. Wu, E. Read, M. Manoff, and M. Frame. 2011. "Data Sharing by Scientists: practices and Perceptions." *PLoS ONE* 6 (6): e21101.

Tierney, M., R. Almond, D. Stanwell-Smith, L. Mc Rae, C. Zöckler, B. Collen, M. Walpole, and S. de Bie. 2014. "Use It or Lose It: measuring Trends in Wild Species Subject to Substantial Use." *Oryx* 48: 420–429.

Tittensor, D. P., M. Walpole, S. L. Hill, D. G. Boyce, G. L. Britten, N. D. Burgess, S. H. M. Butchart, et al. 2014. "A mid-term Analysis of Progress towards International Biodiversity Targets." *Science* 346 (6206): 241–244.

Townshend, J., M. Hansen, M. Carroll, C. DiMiceli, R. Sohlberg and C. Huang 2011. *User Guide for the MODIS Vegetation Continuous Fields Product Collection 5 Version 1*. Technical Report. Maryland: University of Maryland.

Turner, W., C. Rondinini, N. Pettorelli, B. Mora, A. K. Leidner, Z. Szantoi, G. Buchanan, et al. 2015. "Free and Open-access Satellite Data Are Key to Biodiversity Conservation." *Biological Conservation* 182: 173–176.

Vogt, P., K. H. Riitters, C. Estreguil, J. Kozak, T. G. Wade, and J. D. Wickham. 2007. "Mapping Spatial Patterns with Morphological Image Processing." *Landscape Ecology* 22 (2): 171–177.

Walpole, M., R. E. A. Almond, C. Besançon, S. H. M. Butchart, D. Campbell-Lendrum, G. M. Carr, B. Collen, et al. 2009. "Tracking Progress toward the 2010 Biodiversity Target and beyond." *Science* 325: 1503–1504.

WWF. 2007. *Management Effectiveness Tracking Tool: reporting Progress at Protected Area Sites*. 2nd ed. Gland: WWF International.

WWF. 2014. *Living Planet Report 2014: species and Spaces, People and Places*. Edited by R. McLellan, L. Iyengar, B. Jeffries and N. Oerlemans. Gland: WWF International.