6 THE VALUE AND OPPORTUNITIES OF COMMUNITY- AND CITIZEN-BASED APPROACHES TO TROPICAL FOREST BIODIVERSITY MONITORING

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6.1 INTRODUCTION

Earth Observation (EO) refers to the direct and indirect measurement of the Earth's surface that can be undertaken using satellites, aircraft, on the ground and underwater using active and passive sensors (O'Connor et al., 2015). EO provides a valuable source of information for biodiversity monitoring of tropical forests (chapter 2; Turner et al., 2003; Gillespie et al., 2008; O'Connor et al., 2015), in particular from space-based platforms due to their extensive spatial and temporal coverage. With data from the new Copernicus Sentinel satellites now coming online and the planned Biomass mission of the European Space Agency (ESA), biodiversity monitoring could greatly benefit from these higher spatial and temporal resolution measurements.

The Group on Earth Observations Biodiversity Observation Network (GEO BON) has proposed a set of 22 Essential Biodiversity Variables (EBVs) (Pereira et al., 2013a). These EBVs provide quantifiable measures that can be used to monitor targets, e.g. the Aichi biodiversity targets, or they can be employed within conservation monitoring and research more generally. O'Connor et al. (2015) have surveyed experts in EO and biodiversity in order to identify a subset of EBVs, referred to as RS-EBVs, which can be entirely or partially monitored by remote sensing (RS). O'Connor et al. (2015) have shown that these RS-EBVs can aid in the monitoring of 11 out of 20 Aichi targets.

Although remote sensing has clear advantages for monitoring in terms of spatial and temporal coverage as mentioned previously, field level data are still needed to complement remote sensing if conservation measures are to be monitored in a meaningful way (Stephenson et al., 2015). From a remote sensing perspective, field level data are needed for calibration and validation of products derived from EO but also for those EBVs where remote sensing cannot be used for monitoring.

To fill this information gap, the participation by community members in monitoring and science (Bonney et al., 2009b; Chandler et al. 2016b) shows considerable potential for helping to collect ground-based data, that together with analysis, could contribute to international environmental agendas (Danielsen et al., 2014c). Several important factors have led to a dramatic increase in citizen science projects as well as interest in greater leveraging of citizen science (Theobald et al., 2015). The recent creation of professional associations dedicated to the advancement of the field of citizen science is helping to develop best practices, standards and lessons learned that will improve both ends of the equation - namely valuable data collected and meaningful participant experience. For example, the Participatory Monitoring and Management Partnership (www.pmmpartenrship.com) has been created to promote the dialogue between communities involved in natural resource and biodiversity monitoring as well as to document and disseminate best practices in community-based monitoring.

Another important advancement in citizen involvement has been driven by recent advances in technology and the proliferation of mobile devices, allowing more citizens to contribute to environmental monitoring and conservation at both local to global scales. Citizen science is now seen as being able to fill the perceived gap between an increased demand for monitoring and decreasing funding for professional staffing that traditionally performed in-situ monitoring, for government natural resource agencies. Additionally, citizen science can help boost civic engagement with a promise of building social capital that can be used to better inform and support management and policy initiatives, and empower individuals and communities (Constantino et al., 2012; Crain et al., 2014).

There are many examples of successful citizen science biodiversity monitoring projects across multiple ecosystem types (e.g. see http://scistarter.com/; http://www.earthwatch.org) including tropical forests. Many of these projects are focused on species occurrence and phenology, including invasive species. They range from very intensive projects (www.earthwatch.org), which require considerable training and commitment on the part of citizens, to easy-to-use mobile applications (e.g. iNaturalist)), or Do-It-Yourself (DIY) kits that anyone can download and use. GEO BON is also currently developing a BON in a BOX toolkit to support development of biodiversity observation systems at the country level, including tools for citizen science. The first region for the BON in a BOX toolkit will be Latin America hosted by Instituto Humbodt and GEO BON.

More recently, citizen science, in this case community-based forest monitoring, has been considered a viable approach in the framework of REDD+ (Reducing Emissions from Deforestation and Forest Degradation) for the monitoring of carbon (Danielsen et al., 2011, 2014a) and many new schemes are starting (Danielsen et al., 2013). Integrating biodiversity monitoring within community-based forest monitoring initiatives could therefore provide a potential source of calibration and validation data for products derived from EO. See section 8 for synergies between biodiversity monitoring and REDD+.

This chapter presents case studies of successful projects that have involved the community and citizen scientists in the monitoring of different biodiversity indicators and variables. We start with an overview of the various terms that can be found in the literature to denote the involvement of local people in monitoring activities including citizen science. This is followed by an assessment of the needs of the biodiversity community in terms of the variables of interest for monitoring and scientific research, the role of remote sensing in measuring these variables and what calibration and validation data are needed from ground-based measurements. The case studies serve to highlight what types of data are currently being collected by communities, how these relate to the key variables of interest and what gaps in ground-based monitoring exist.

Although citizen and community-based monitoring have considerable potential in supporting data collection for EO, the creation and development of a citizen science program is not a trivial task. Attracting, training and maintaining sufficient numbers of citizen scientists to meet monitoring needs is a significant endeavour (Chandler et al., 2016). There are many examples of programs where the cost of running the programs outweighed the benefits in terms of data collected, and in terms of the quality of the experience for the participants - ultimately resulting in a lack of sustainability of the programs. One key outcome from reviews of programs to date is the need to find a balance between the data gathering needs for the monitoring programs with delivering tangible (direct) benefits to the community members participating and contributing their time and effort (Chandler et al., 2016; Shirk et al., 2012). Thus, the final part of this chapter addresses these types of issues by providing guidelines for setting up a community or citizen-based project for tropical biodiversity monitoring, drawing upon experiences from many different past and ongoing projects around the world.

6.2 TERMINOLOGY

The term citizen science is often conceived by its practitioners in the broadest sense - i.e. the participation by the non-scientific public in scientific research and monitoring; see the review of typologies in Bonney et al. (2009b), Wiggins and Crowston (2011) and Haklay

(2015). The bulk of current projects labelled as environmental "citizen science" occur in temperate and western countries where many if not most participants engage in these projects as a hobby or in service of their "community" (Haklay, 2015). In practice and for the purpose of this chapter, it is useful to differentiate community-based monitoring as a distinct subset of citizen science. In the tropics, much of the important monitoring engages local community members, where many participants are and remain active users of their natural environment (Danielsen et al., 2005a; Haklay, 2015).

Evans and Guariguata (2008) have provided a meta-review of existing literature on participatory monitoring in tropical forest management as well as the lessons learned from these projects. Although many of these initiatives have been aimed at sustainable management of tropical forests rather than biodiversity monitoring, there are examples of where monitoring has included variables of interest to the biodiversity community (Ojha et al., 2003; Lawrence et al., 2006). Because of the importance of these works in considering how best to engage local communities in forest monitoring, we provide Table 6.2.1 which outlines the terminology that appears in Evans and Guariguata (2008) along with their original cited sources; we have expanded this to include community-based monitoring more generally and monitoring by citizen science programs.

Table 6.2.1: Summary of terminology

Term	Definition	Source
Participatory monitoring	The systematic collection of information at regular intervals for initial assessment and for the monitoring of change. This collection is undertaken by locals in a community who do not have professional training. The term is often used in the context of monitoring forests for their sustainable management but can be extended to other ecosystem services.	Guijt (2007); Evans and Guariguata (2008). See also Wikipedia (2015)
Locally-based monitoring	This is similar to participatory monitoring but monitoring can also be undertaken by local staff from government authorities.	Danielsen et al. (2005a)
Collaborative monitoring	Local monitoring that is embedded within resource management decision-making and part of an iterative learning cycle. The monitoring processes are also heavily driven by the need to be locally relevant.	Guijt (2007)
Participatory Assessment, Monitoring and Evaluation of Biodiversity (PAMEB)	Biodiversity monitoring, evaluation and assessment by non-specialists. Similar to the aims of many citizen science programs but with a specific emphasis on biodiversity.	Lawrence and Ambrose-Oji (2001); Lawrence (2010)
Joint monitoring or multi-	Monitoring by local people together with	Andrianadrasana et

Term	Definition	Source
party monitoring	local government authorities where the emphasis appears to be on enforcement.	al. (2005); Bagby et al. (2003)
Self-monitoring	The monitoring of activities by local people which are related to natural resource use, e.g. hunting or the harvesting of timber.	Noss et al. (2005); Constantino et al. (2008)
Event monitoring	The monitoring of events (e.g. fires, invasive species) by local people when they occur or as part of a census or other planned activity.	Stuart-Hill et al. (2005)
Community-based ecosystem monitoring	Monitoring involving non-specialists that are organized by government or conservation organizations in developed countries.	Whitelaw et al. (2003)
Community-based monitoring	Monitoring of environmental resources via the engagement of local communities to provide accountability, transparency, sustainability and inclusion in decision-making. Used also in the context of the monitoring of health programs and other public services.	Constantino et al. (2008); Wikipedia (2013)
Citizen science monitoring programs	The involvement of citizens in scientific research from data collection (**contributory**) to analysis and design (collaborative) to co-creation, in which citizens are involved in all stages of the scientific process. Also referred to as public participation in scientific research.	Bonney et al. (2009a, 2009b)

For the sake of clarifying important differences in approaches, we will focus on two forms of engaging community members in the data collection needed for monitoring and field research - community-based monitoring and “citizen science”. For the purpose of this chapter, we use ***community-based monitoring*** to denote the involvement of local community members in the data collection process, whether for the purpose of sustainable resource management, biodiversity monitoring or greater involvement in decision-making at the local level. We distinguish this from ***citizen science monitoring***, where participants participate in projects, often driven by external bodies, i.e. scientists, conservation bodies, etc., with participants both distant or local to the study area, often giving their time and resources by a shared passion for nature, or desire to help conserve nature in some way. It is important to state that there are many different approaches to citizen science, varying in the degrees to which participants lead, design or direct outcomes, and any generalisations will fail to capture the full variety of citizen science that exists.

A continuum exists in the degree of influence citizen science participants have in shaping the data collected, problem formulation, analysis and dissemination of results. Many community-based monitoring programs have some elements of being "co-created" or adapted to local circumstances (participatory sensing and civic/community science using Haklay (2015) terms), whereas many citizen science projects are "contributory" (sensu Bonney et al., 2009) where participants have little input to the creation of the programs or shaping of research or monitoring outcomes beyond data collection. Of course, there are many other kinds of important educational or social outcomes which both community-based monitoring and citizen science monitoring programs regularly achieve. In fact these "peripheral" or secondary benefits may outweigh any benefits derived from increased data gathering from the community's perspective. See Funder et al. (2013) for a good example of where the heightened involvement by community members in monitoring their forests was deemed of very high value because it led to a greater demonstration of occupancy and sense of control over "their" lands.

There will always be trade-offs between the information needs of the tropical biodiversity monitoring community and the needs of communities on the ground, so it is important to understand where the main data gaps are and how communities can also directly benefit from their involvement in data collection efforts.

In the sections that follow, we will demonstrate that both community-based monitoring and citizen science monitoring projects can provide valuable data for the calibration and validation of EO-derived products.

6.3 INFORMATION OF VALUE FOR BIODIVERSITY MONITORING IN TROPICAL FORESTS

Table 6.3.1 presents the variables of interest for biodiversity monitoring, which include relevant Essential Biodiversity Classes (EBC) and EBVs as published previously by Pereira et al. (2013a) as well as other variables of interest to biodiversity monitoring. The table also summarizes how these variables are measured in-situ, what training is required for in-situ measurement by communities and citizens, and whether these variables can be measured using remote sensing, thereby serving as potential calibration and validation data. There are many different types of in-situ measurement technique listed in Table 6.3.1 including field observations/presence surveys for groups of species or single species; patrol records; transects; species lists; village group discussions; camera traps; hair traps; footprints protocols; mist-nets; pitfall traps; nested vegetation plots, among others. The reader is referred to field manuals (Buckland et al., 2004; Silvy, 2012; Magnusson et al., 2013) and a considerable literature on nested vegetation plots (Shmida, 1984; Stohlgren et al., 1999, 1998, 1997, 1995) for more detailed explanations of these in-situ methods. See also chapters 4.2.2, 4.6.2, and 5.2.4 for more information on species mapping. See section 4.2 for more information on in-situ data.

Table 6.3.1 is shaded green when variables are observable by remote sensing and red when ground-based data are the only way to measure these variables. This shading has been informed by the survey of O'Connor et al. (2015) but is more focused on tropical biodiversity monitoring and is not linked to specific Aichi targets. This characterization indicates that four out of five EBCs can use remote sensing for monitoring all constituent EBVs while only the EBC Species Traits has some EBVs that require ground-based data exclusively.

6.4 CASE STUDIES OF COMMUNITY-BASED AND CITIZEN SCIENCE MONITORING

This section provides a series of case studies from citizen science and community-based monitoring projects for biodiversity and/or forest management. These case studies were chosen based on direct knowledge of EarthWatch projects and other community-based monitoring initiatives in order to provide a good geographical representation. These case studies are not meant to be a comprehensive selection but rather they each bring different approaches and lessons learned to the table.

Evans and Guariguata (2008) have provided an excellent review and resource of many community-based forest monitoring programs. The selection provided in Table 6.4.1 is complementary to Evans and Guariguata (2008) in that there are good examples of community-based forest monitoring programs but these are more up to date than the previous review. However, in contrast to Evans and Guariguata (2008), the emphasis of the case studies presented here is more on biodiversity monitoring rather than community-based forest monitoring, and it also covers citizen science programs. These 14 cases are summarized in Table 6.4.1 and then outlined in more detail in the sections that follow. In particular the link is made between what EBCs are captured through in-situ monitoring across the diverse set of case studies presented here.

Although the focus is not always on tropical forests, the case studies are still useful to illustrate good practice and lessons learned, some of which can be transferred to a tropical forest environment.

Table 6.3.1: Variables of interest for biodiversity monitoring organized by EBC and EBV. Shading is partly based on the characterization of O'Connor et al. (2015) of RS-EBVs, i.e. green is totally or partially observable by remote sensing and red is not observable, requiring ground-based data.

EBC Class/ Variable of interest	EBV	Measurement in-situ	Training for in-situ data collection by community members	Can it be measured remotely by professional scientists?	Examples of data repositories or tools
Species populations **(SP)**	Species distribution	Field observations/ presence surveys for groups of species or single species; easy to monitor over an extensive network of sites with geographic representativeness. Via patrol records, transects, species lists, village group discussion, camera traps, hair traps, footprints protocols, mist-nets, pitfall traps	Training in patrol records, transects, species lists, village group discussion, species identification and training in protocols for collection of other animal/plant census data, collection of DNA samples for DNA barcoding, nested vegetation plots	Via aerial photos to count large mammals, reptiles or certain plants in less dense forests and woodlands. Potential role for incidental data from any spatial location. Via remote sensing imagery, including hyperspectral technology (Carlson et al. 2007). Native or invasive plant species classification and distributions (Gillespie et al 2008; Everitt et al., 2006). Potential role for incidental data from any spatial location.	Several case studies; see Giorgi et al. (2014). Examples of the use of: • patrol records (Brashares and Sam, 2005; Danielsen et al., 2010; Gray and Kalpers, 2005) • community-based transects (Andrianandrasana et al., 2005; Becker et al., 2005; Rovero et al., 2015) • community-based species lists (Bennun et al., 2005; Hockley et al., 2005; Roberts et al., 2005) • village group discussion (Poulsen and Luanglath, 2005; van Rijsoort and Jinfeng, 2005; Danielsen et al., 2014a)
	Population abundance	Population counts for groups of species; easy to monitor and/or	Training in patrol records, transects, species lists,	Via aerial photos to count large mammals, reptiles or certain plants animals in	Many examples in the row above

EBC Class/ Variable of interest	EBV	Measurement in-situ	Training for in-situ data collection by community members	Can it be measured remotely by professional scientists?	Examples of data repositories or tools
		important for ecosystem services and habitat quality assessment, over an extensive network of sites with geographic representativeness. Via patrol records, transects, species lists (presence or absence of species on fixed-time lists incl. 1-day index of abundance), and village group discussion.	village group discussion and nested vegetation plots. Quadrats, point counts, camera trapping, mist nets, with individual identification techniques (bands, tags) review and analysis of imagery	less dense forests. Via model inputs derived from remote sensing imagery, including hyperspectral remote sensing for native or invasive vegetation assessments and monitoring (Gillespie et al 2008; Carlson et al, 2007; Foody et al., 2005).	
	Population structure by age/size class	Quantity of individuals or biomass of a given demographic class of a given taxon or functional group at a given location, e.g. via forest vegetation plots for monitoring	Identification of size classes, dbh measurements, and from capture and release	Vegetation structure measurements via active remote sensing technology (e.g., LiDAR) and: Laser Vegetation Imaging Sensor (LVIS), an aircraft-mounted LiDAR sensor.	Examples of the use of community-based forest vegetation plots for monitoring forest biomass (Skutsch et al. 2011; Brofeldt et al. 2014; Torres & Skutsch 2015, Theilade et al. 2015) Examples of the use of community-based vegetation

EBC Class/ Variable of interest	EBV	Measurement in-situ	Training for in-situ data collection by community members	Can it be measured remotely by professional scientists?	Examples of data repositories or tools
		forest biomass and tree diversity			plots for monitoring tree diversity (Zhao et al. In review in PLoS ONE).
Species traits (ST)	Phenology	Record timing of periodic biological events for selected taxa/phenomena at defined locations. Examples include: timing of breeding, leaf coloration, flowering. Via patrol records, transects, and village group discussion	Identification of plant and animal species, their life cycles/stages; use common staging classification (e.g. NPN).	A range of remotely-sensed vegetation indicators can be used to determine phenology of some plant types, e.g. crops, annual plants, leaf-area index	Examples of the use of patrol records, community-based transects, and village group discussions provided above (row on species populations). Examples from temperate areas include: • National Phenology Network (section 6.4.8) (Kellermann et al., 2015) • Movebank (*www.movebank.org)*, • Project Budburst • Climatewatch.org • Phenocams (Crimmins and Crimmins, 2008) • try-db.org
	Body mass	Body mass (mean and variance) of selected species (e.g. under harvest pressure), at selected sites (e.g. exploitation	Animal population field methods. Measurements from capture & release, and examination of	No	Case study in Majete Wildlife Reserve, Malawi (section 6.4.9); Constantino (2015)

EBC Class/ Variable of interest	**EBV**	**Measurement in-situ**	**Training for in-situ data collection by community members**	**Can it be measured remotely by professional scientists?**	**Examples of data repositories or tools**
		sites).	harvested individuals		
	Natal dispersal distance	Record median/frequency distribution of dispersal distances of a sample of selected taxa.		No	Unaware of current examples
	Migratory behavior	Record presence, absence, destinations, pathways of migrant selected taxa, e.g. via patrol records and village group discussion	Train in the identification and field count methodologies for migratory raptors, butterflies	Use of radar imagery; satellite or radio tagging	An example of the use of patrol records and village group discussion for recording seasonal migration of ungulates include Topp-Jørgensen et al. (2005) Examples from temperate areas include: HawkWatch (hawkwatch.org); eBird (ebird.org); Movebank; Journey North (www.journeynorth.org)
	Demo-graphic	Effective reproductive rate	Measurements from capture and	No	Case study in Majete Wildlife Reserve, Malawi (section

EBC Class/ Variable of interest	EBV	Measurement in-situ	Training for in-situ data collection by community members	Can it be measured remotely by professional scientists?	Examples of data repositories or tools
	traits	(e.g. by age/size class) and survival rate (e.g. by age/size class) for selected taxa at selected locations	release studies		6.4.9); Freshwater turtle monitoring schemes in Zábalo, Ecuador, e.g. Townsend et al. (2005)
	Physiological traits	For instance, measurement of thermal tolerance or metabolic rate. Assess for selected taxa at selected locations expected to be affected by a specific driver.	Capture and rearing of insects for bio-chemical analyses (see Dyer et al. 2012)	No	See Dyer et al. (2012)
Community Composition (CC)	Taxonomic diversity	Multi-taxa surveys (including by morphospecies) and metagenomics at selected in-situ locations at consistent sampling scales over time, e.g. via patrol records, transects, species lists, and	Training in patrol records, community-based transects, species lists, and nested vegetation plots. Training in other survey techniques (mist nets, camera	Hyper-spectral remote sensing over large ecosystems	Case study in Loma Alta, Ecuador (section 6.4.2); Pacaya Samiria, Peru (section 6.4.1) Examples of community-based tools used in practice (Bennun et al. 2005; Danielsen et al.

EBC Class/ Variable of interest	EBV	Measurement in-situ	Training for in-situ data collection by community members	Can it be measured remotely by professional scientists?	Examples of data repositories or tools
		permanent forest vegetation plots	traps, etc.)		2014a, Rovero et al. 2015; Zhao et al. 2016; Dyer et al. (2012)
	Species interactions	Studies of important interactions or interaction networks in selected communities, such as plant-bird seed dispersal systems or of threats operating at local or larger scales. Via patrol records, transects, and village group discussions	Species identification of focal species and disturbances using survey transects and capture & release	Combined with multi-spectral remote sensing data, LiDAR offers potential for parametrizing predictive organism-habitat association models.	Case study in Pacaya Samiria, Peru (section 6.4.1) Case study in Majete Wildlife Reserve, Malawi (section 6.4.9) See Dyer et al. (2012). See also examples above (in the row on species populations)
Ecosystem function (EF)	Net primary productivity	Validation of measurement of net productivity for selected groups. For forest trees via permanent forest	Measure change in biomass in permanent forest vegetation plots and nested vegetation plots	Global mapping with modeling from remote sensing observations (fAPAR, ocean greenness) and selected in-situ locations (eddy covariance); calculated from NDVI (normalized	Examples of the use of community-based forest vegetation plots for net primary productivity (Skutsch et al. 2011; Brofeldt et al. 2014; Torres & Skutsch 2015) Case studies: San Pablo Elta;

EBC Class/ Variable of interest	EBV	Measurement in-situ	Training for in-situ data collection by community members	Can it be measured remotely by professional scientists?	Examples of data repositories or tools
		vegetation plots		difference vegetation index); ocean colour	MX for carbon assessment; and community-based monitoring for REDD+ (section 6.4.3); Casas de la Selav (section 6.4.4)
	Secondary productivity	Measurement of secondary productivity for selected functional groups, using in-situ methods or methods combining in-situ, remote sensing, and models. Example of functional groups include: bush meat;, fisheries; livestock; krill; herbivorous birds. Via patrol records, transects, and village group discussion		See above	Case study in Pacaya Samiria, Peru (section 6.4.1) for hunted and fished species, and in Lake Aloatra, Madagascar (section 6.4.10) for fish productivity. Examples of community-based tools used for monitoring production of non-timber forest products, fish, and freshwater turtle eggs (Danielsen et al., 2000, 2007; Poulsen and Luanglath, 2005; Topp-Jørgensen et al., 2005; Townsend et al., 2005)
	Nutrient	Ratio of nutrient output from the		Monitoring of crop cover to	Case study in Loma Alta, Ecuador on water capture

EBC Class/ Variable of interest	EBV	Measurement in-situ	Training for in-situ data collection by community members	Can it be measured remotely by professional scientists?	Examples of data repositories or tools
	retention	system to nutrient input, measured at selected in-situ locations. Can be combined with models and remote sensing to extrapolate regionally.		infer nutrient retention	(section 6.4.2)
	Disturbance regime (e.g. pest outbreak)	Type, seasonal timing, intensity and frequency of event-based external disruptions to ecosystem processes and structure. Flood regimes; fire frequency; windthrow; pests. Via patrol records, photo documentation, and village group discussions	Training in patrol records, photo documentation, and village group discussions. Species identification of key focal species and disturbances using survey transects and capture & release	Large and sudden changes might be identified through remote sensing (RS) but not smaller, slower outbreaks. Examples: sea surface temperature and salinity (RS); scatterometry for winds (RS); fire frequency (in-situ); burnt areas (RS); oil spills (RS); cultivation/ harvest (RS); monitor vegetation indices over time (RS)	Case study in Pacaya Samiria, Peru (section 6.4.1), Kafa, Ethipioa (section 6.4.13). Examples of the use of patrol records, community-based transects, and village group discussions for monitoring fire and other threats to forest ecosystems are listed above (the row on species populations). An example of the use of community-based photo documentation method to monitor threats is found in Danielsen et al. (2000)

EBC Class/ Variable of interest	EBV	Measurement in-situ	Training for in-situ data collection by community members	Can it be measured remotely by professional scientists?	Examples of data repositories or tools
Ecosystem Structure (ES)	Habitat structure	Via photo documentation, and forest vegetation plots. Data calibration of habitat structure (canopy height, habitat classification, etc.)	Training in photo documentation, and community-based forest vegetation plots and nested vegetation plots	Remote sensing measurements of cover (or biomass) by height (or depth) classes globally or regionally, to provide a 3-dimensional description of habitats. Different sensors can measure biomass globally or locally but this requires more calibration and validation data to improve the maps, especially globally.	Case study San Pablo Elta, Mexico (section 6.4.3) and Gazi Bay, Kenya (section 6.4.11). Examples of the use of photo documentation (Danielsen et al., 2000), community-based forest vegetation plots for monitoring forest biomass (Skutsch et al. 2011; Brofeldt et al. 2014; Torres & Skutsch 2015) and tree diversity: Zhao et al. 2016).
	Ecosystem extent and fragmentation	Local (aerial photo and in-situ monitoring). Some wetland areas can be identified using RS but remains problematic. Requires more calibration and validation data.	Mapping boundaries, e.g. of wetlands, and wetland identification	Global mapping (satellite observations) of natural/semi-natural forests, wetlands, free running rivers, etc.	Case study San Pablo Elta (section 6.4.3). Global map of wetland extent by Lehner & Döll (2004); new water occurrence product by JRC (Pekel et al., 2014)
	Ecosystem composition by functional	Functional types can be directly inferred from		Functional types can be inferred from remote sensing (translated from	N/A

EBC Class/ Variable of interest	EBV	Measurement in-situ	Training for in-situ data collection by community members	Can it be measured remotely by professional scientists?	Examples of data repositories or tools
	type	morphology.		land cover maps)	
OTHER	Land cover	Photo documentation	Knowledge of land cover definitions, protocols for collection, training in image interpretation	Land cover can be identified using automated and semi-automated classification methods but higher accuracies and higher temporal frequencies are needed. Requires more calibration and validation data.	See Halme and Bodmer (2006) for an example from Amazonian Peru
	Land use	Village group discussions. Photo documentation. Household surveys	Training in survey methods	Some land use types can be identified with RS but most are not discernible or require knowledge from the ground	Several examples of the use of village group discussions and photo documentation for monitoring land use can be found in Danielsen et al. (Danielsen et al., 2005b)
	Cultural and social heritage	Village group discussions	Training in participatory methods	RS could be used to identify change in an area but monitoring of cultural and social heritage requires ground-based data collection	Examples in Danielsen et al. (Danielsen et al., 2005b) Case study in Pacaya Samiria, Peru (section 6.4.1)

Table 6.4.1: Summary of case studies with relevance to Essential Biodiversity Classes

Section	Location	Types of participants	References	EBCs
6.4.1	Pacaya Samiria, Peru	Both	Bodmer et al. (2008; 2014)	SP, ST, CC
6.4.2	Loma Alta, Ecuador	Both	Becker et al. (2005)	SP, ST, CC, EF
6.4.3	San Pablo Etla, Mexico	Community-based		SP, EF, ES
6.4.4	Casas de la Selva, Puerto Rico	Citizen science monitors	Nelson et al. (2010; 2011)	SP, CC, EF, ES
6.4.5	Atlantic Forest, Brazil	Both	Giorgi et al. (2014)	SP, ST, CC
6.4.6	Project COBRA, Guyana	Community-based	Berardi et al. (2013); Mistry et al (2014)	SP, CC, ES
6.4.7	National Program for Biodiversity Monitoring, Brazil	Community-based	Pereira et al. (2013b); Nobre et al. (2014); Santos et al. (2015)	SP, ST, CC
6.4.8	National Phenology Network, North America	Both	Reports and scientific publications can be found at: https://www.usanpn.org	SP, ST
6.4.9	Majete Wildlife Reserve, Malawi	Both		SP, ST, CC, EF
6.4.10	Lake Aloatra, Madagascasar	Community-based	Andrianandrasana et al. (2005)	SP, ST, CC
6.4.11	Gazi Bay, southern Kenya	Both	Huxham et al. (2015)	SP, ST, CC, EF
6.4.12	REDD+ monitoring in China, Indonesia, Laos and Vietnam	Community-based	Brofeldt et al. (2014)	SP, ST, CC, EF
6.4.13	Kafa Biosphere Reserve, Ethiopia	Community-based	Pratihast et al. (2014: 2016)	SP, ST, CC, EF
6.4.14	Protected Areas, Philippines	Community-based	Danielsen et al. (2009)	SP, ST, CC

6.4.1 Pacaya-Samiria National Reserve, Peru

The Pacaya-Samiria National Reserve (PSNR) is one of the largest protected areas in Peru with an area of more than 20,000 km², situated between the confluence of the Marañon and Ucayali Rivers. The PSNR has around 20,000 people living within the reserve boundaries.

A biodiversity monitoring program was developed in 2001 for data gathering to be conducted by both local community members as well as international citizen scientists and students (e.g. Earthwatch volunteers, Operation Wallacea students). The current project is helping to conserve the biodiversity of the Amazon, and is working with local people to collectively better manage the rich resources from this region. The project is led by Richard Bodmer, a reader in Conservation Ecology at the Durrell Institute of Conservation and Ecology (DICE), UK, and also the president of FundAmazonia (www.fundamazonia.org).

The reserve was originally created in 1982 as an area with strict protection that largely excluded local people. This led to conflict between the reserve authorities and the local population who lost long-term interest in managing their traditional lands inside the reserve and reverted to overharvesting. The conflict escalated with the reserve authority battling to reduce harvesting and the local people taking as many natural resources as they could, as fast as they could. After violent confrontations, the Peruvian Protected Area Authority changed its management policy and in 1998, the local people actively participated in reserve management as a co-managed reserve. By 2006, the biodiversity monitoring program began to demonstrate that many animal populations along the Samiria River basin had recovered, e.g. woolly monkeys, black caiman, manatees, and turtle populations, after the change to include locals in management decision making (Bodmer et al., 2008). More recently, the project has been evaluating the impact of climate change events, especially severe droughts and extreme flooding on the biodiversity and local people, which have resulted in decreasing populations of resource use species. Bush meat species have largely disappeared as a result of the consistent extreme floods impacting the livelihoods of the local population (Bodmer et al., 2014).

Approaches Used and Data Collected

Over a number of years, the research team has developed rigorous protocols to train both local community members as well as international citizen scientists in collecting data on wildlife surveys using observational and capture and release techniques. Moreover, the project also trains local biologists in basic methodologies that provide essential support to the community-based monitors and international citizen scientists, and verification of data quality. Community-based observers and international citizen scientists are given a range of research tasks and responsibilities. These include carrying out censuses along transects for terrestrial mammals and game birds, point counts for macaws, capture and release studies of fish and caimans, aquatic transects of wading birds, river dolphins and turtles, and the setting and checking of camera traps to record large ground dwelling mammals, particularly carnivores, ungulates and edentates. A key to engaging local community members was the inclusion of species important for subsistence hunting and fishing since the beginning of the project, and species that provide economic benefits. Citizen scientists are interested in the project because of its broader implications for conservation of biodiversity in the Amazon and climate change.

The data collected during wildlife surveys involves field teams that are always composed of 1) local community members, 2) citizen scientists and 3) local biologists. Each type of person has a different role, which when combined, yields large verified data sets. The local community members are particularly adept at sighting animals in the physically complex forests. The citizen scientists are adept at data recording, measurements and data entry, and the local biologists are trained to verify data collected, including species identification, GPS locations, transect lengths, and measurements.

Adaptive management activities at the Samiria River basins are being incorporated as a result of the insights gained through Earthwatch and Operation Wallacea research. In 2007, a review of change occurring over the previous years found significant improvements for the wildlife, environment, and local people. Monitoring demonstrated increasing numbers of key species such as giant otters and primates and increased awareness of rare species using protected areas (e.g. manatees). The data have also helped to identify potential ecological interactions that may limit species response, e.g.

increases in large-bodied primates are correlated with decreases in small-bodied primates; increases in black caiman lead to a decrease in speckled caiman (Bodmer and Puertas, 2007).

Over the past 8 years the ‘citizen science’ monitoring program has shown how recent climate fluctuations are impacting biodiversity and the livelihoods of the local people. The historically high floods of 2009, 2011, 2012 and 2013 have resulted in population crashes of the ground dwelling species in the flooded forests, including white-lipped and collared peccary, red brocket deer, black agouti, paca, armadillos, giant anteater, among others. Many of these species were the favored bushmeat species of the Cocama indigenous people who can no longer rely on this subsistence resource (Bodmer et al., 2014). The monitoring data show that an estimated 2 million ground dwelling animals have died from the recent impacts of climate change in the northern Peruvian Amazon of Loreto. A co-benefit from engaging international citizen scientists is the first hand appreciation and increased awareness of the impact of carbon emissions and economic development on natural and human systems.

Successful Outcomes

Prior to establishing this model of protected areas, the regional government had taken the view that the PSNR was not functioning and had not looked to establish any more protected areas. However, monitoring by the “citizen science” program delivered quantitative results, demonstrating the success of the reserve (Bodmer et al., 2008). With the monitoring results in hand, the regional government was able to look at drafting new protected areas. Wildlife monitoring by the local community and international citizen scientists played an important role in helping to justify new protected areas in Loreto and increase the prevalence of community-based co-management systems.

The development of a biodiversity monitoring program for key wildlife species in and around the protected areas has been key to a more successful and comprehensive management program and helped create successful public-private partnerships with local people. The project has also led to increased economic input into the region with respect to the value of the reserve and its wildlife via international citizen science.

The impacts of climate change have been documented through the “citizen science” based program and present new challenges for the reserve and the local people living in the area. Threats are becoming obvious from the greater variations in water level, both in terms of droughts and intensive flooding. By working together, the reserve authority and local people are taking a collaborative and combined effort to overcome and adapt to the physical nature of climate change impacts.

6.4.2 Loma Alta, Ecuador

By 1994, most of the forest cover along the west coast of Ecuador had been cleared or selectively harvested, leaving less than 5% remaining (Becker, 1999). While looking at aerial photos, Dr. Dusti Becker was surprised and curious about large areas of forest remaining in the Colonche Hills near the community of Loma Alta. The land was communally owned, so tragedy of the commons should have made deforestation more likely. Why then were there thousands of hectares of fairly pristine intact cloud forest still there? In 1995, Becker put together a team of natural and social scientists from Indiana University, all influenced by the thinking of Dr. Elinor Ostrom a champion of the idea that local people can develop rules to sustain and manage natural resources independently of national government influence (and winner of the Nobel Prize in Economics in 2009 on this theme). With additional citizen scientists from Earthwatch, the Becker/Ostrom research team headed to Loma Alta to study the forest and interview community members to find out if the villagers had devised special rules or traditions to protect the forest.

The team discovered that the community had a strong system of local governance, but there were few rules explicitly in place to conserve the forest. The only rule that significantly slowed deforestation was a ban on timber exploitation by large forestry companies – only local community members were permitted to harvest trees and make them into boards for sale. These local wood-cutters didn't have the capacity to clear the forest quickly. Most of the forested land had been allocated to families for eventual use, but people were too poor to develop it. The most distant communal land had been stolen and cleared by another ethnic group who had cleared and burned about 200 hectares to encourage grass for cattle. By the end of our study, it was painfully clear that eventually, the Loma Alta forest would go the way of the other 95% as ranchers, local wood cutters and farmers expanded slowly cleared away the incredibly diverse and lush tropical montane forest (Becker, 1999).

While standing on the edge of the forest one foggy day, our team noticed that it seemed to be raining inside the forest but was only foggy in the cleared pasture. The forest was muddy, while the pasture soil was dry. Becker knew what the next citizen science effort had to be. We had to measure fog capture, report results to the villagers and hope that they would use their good governance to protect the forest for its valuable ecosystem service of providing water for all the activities in the lowlands.

In May 1995, several Loma Alta villagers were trained to monitor through-fall from fog capture, which is the quantity of water dripping off trees and other plants during the fog season (Jun-Nov). This water originates from fog and mist (locally known as garua) that forms over the Pacific Ocean, where it is intercepted by vegetation, and particularly on windward slopes of coastal mountain ranges. Monitoring by the community and Earthwatch volunteers during 1995 revealed that 2.24 million liters of water were trapped by trees per hectare on the slopes of Loma Alta. Equivalent to an Olympic pool/per hectare, fog-capture by the forest doubles the amount of water provided by rain in the Loma Alta watershed. The importance of the ecosystem service is further shown by the fact that a neighboring community in an adjacent watershed cleared its forest, their land became a scrub desert and they began purchasing water from Loma Alta. Despite these realities is was not until the Becker team reported on fog capture that the community became very proactive about forest conservation.

The data on fog capture enhanced local awareness about ecosystem services, leading them to alter their land use from the slowly extractive (and destructive) to protective, as they officially made an ecological reserve. As a result of the monitoring program pertaining to the water provisioning services by the forest, the community allocated more than half of the community lands to be a forest reserve. Many of the families who had lost rights to expand agricultural fields and cut timber were looking for new ways of making income. The community and Earthwatch volunteers decided to monitor bird diversity, hoping that findings and publications would encourage bird watching and ecotourism in the future. In 2004, the bird monitoring led to the entire Loma Alta watershed being declared an international Important Bird Area (IBA), because the Earthwatch and community monitoring teams had discovered 78 endemic species, 15 endangered species, and striking aggregations of hummingbirds.

Local awareness about the value of biodiversity has been greatly enhanced from none to a keen enthusiasm for local birds and wildlife and pride from local development of ecotourism. A small hotel and visitor cottages were built just outside the reserve while two small camps for visitors and researchers who come to enjoy the natural area or study birds have been set up inside, providing extra income to the local community. The project has also developed new and strengthened existing social connections at local, regional, national and international levels, and there have been positive impacts on how local people perceive themselves.

Starting around 2008 the community received "Socio-bosque" funding from the Ecuadorian government as part of international carbon sequestration payments to developing nations. The money, which is on the order of $ 20,000 to $ 30,000 USD/year, is used for protecting the reserve and for community development needs. Community rangers patrol the 7,000 acres of native vegetation, about half of which is recovering to mature cloud forest, and there are now only very rare cases of cutting and subsistence hunting, primarily because the community does not depend on exploitation of the forest for survival and needs the water provided by the intact forest ecosystem. The system is likely to be sustainable long into the future because most leaders and decision-makers in the community have a more "total" economic value for the forest now than they had in 1994. Now, it is clear to most everyone that the indirect values of ecosystem services and the option value associated with tourism far outweigh direct values of timber harvesting and farming in the cloud forest.

Originally conceived and led by Dr. Dusti Becker of Life Net Nature, with help from Aves de Ecuador, and Earthwatch Institute, avian monitoring and community-based conservation efforts are continued by Eve Astudillo Sanchez-Breon from University Espiritu Santo in Guayaquil, Ecuador. Dovetailing local indigenous efforts with capable well-educated citizens is far more sustainable than projects that rely on foreign-based conservation organizations. More details of this case study can be found in Becker et al. (2005).

6.4.3 San Pablo Etla, Mexico

San Pablo Etla (SPE) is a municipality in the Etla Valley of Oaxaca, Mexico, approximately 20 km northeast of the state capital. SPE abuts the Sierra Norte mountain range of southern Mexico, and maintains a 3,000 hectare forest reserve that includes large stands of oak, pine and mixed oak/pine forest. The community elects a Commission of Communal Resources to manage, protect and resolve disputes regarding the community's reserve. Commission members donate their time as community service for three-year terms. Although the reserve contains large stands of high quality timber species, in the early 1990s, SPE became a "Community Voluntarily Committed to Conservation," an official designation by the National Commission on Protected Natural Areas (CONANP). The community has declared the land off-limits for timber harvesting, hunting, destruction of plant life, and instead manages the lands for the provision of ecosystem services, including water provision, carbon storage, biodiversity, and eco-tourism. While the community has obtained some public and private grants to cover some of the costs of conserving the reserve, its sustainability will ultimately depend on whether or not it can receive payments from the end beneficiaries of its eco-services such as water provision to the Oaxaca City metropolitan area and carbon off-sets for standing timber.

Approaches Used and Data Collected

In 2011, UC Davis researcher, John Williams, worked with community members to conduct a carbon inventory of the SPE forest reserve. Using established carbon market measurement protocols (Pearson et al., 2005), Williams and local forest reserve staff established a series of forest biomass plots where they measured standing woody biomass volume for each of the three major forest types of the reserve. The sampling data were then input into a carbon calculator (Winrock International, 2006) to generate an estimate of carbon stored in aboveground woody biomass within the reserve. Forest conservation and data-supported estimates of aboveground woody biomass for the forest reserve will hopefully lead to carbon offset payments in the future.

In addition to the carbon storage study, community members and visitors have initiated a number of additional projects including: an orthorectified, geographic information system (GIS) based community map to support additional management activities and scientific research; a thorough year-round inventory and monitoring of the bird species found in the forest; camera-trap monitoring of wildlife populations; a collaborative weather monitoring effort with the Mexican Water Commission (CONAGUA) and the

National Research Institute for Forestry, Agriculture, and Livestock (INIFAP); reforestation of degraded lands in the lower-elevations of the reserve; an environmental demonstration and educational center "La Mesita," which includes a nursery for native plants and tree seed collection and propagation, erosion control techniques, water capture and usage techniques, and a series of award-winning landscape architectural design projects conducted in collaboration with the Real Architecture Workshop (RAW), a U.S.–based educational organization engaging volunteer architecture students.

Successful Outcomes and Lessons Learned

Multi-year bird diversity monitoring and data collection is undertaken that is input into the open-access eBird database managed by Cornell University and is available to scientific researchers, conservation managers, and bird enthusiasts worldwide. There is local participation in ecological research and biodiversity monitoring, resulting in several university level theses on themes including medicinal plants and uses, oak propagation techniques, and flora and fauna inventories.

There has been systematic education in the conservation education center of SPE, which has resulted in greatly increased community awareness about the municipality's natural resources, species diversity, and the connection between forest protection and the benefits people receive from healthy ecosystems. There is also local pride about the reserve and the community's environmental image, as well as increased local involvement in related projects.

Success has also spread to neighboring communities, which have recognized and been inspired by SPE's natural resource management achievements and have been inspired to develop similar types of projects. There has also been an increased awareness and tourism by Oaxacan, Mexican and international visitors, as well as an increased interest by scientists to conduct ecological research in the reserve, providing more opportunities for locals and visitors to participate in citizen science projects.

Currently, researchers from the Mexican National Polytechnic Institute are conducting a number of studies in the Reserve, including an investigation of the effects of climate change on the distributions of trees, rodents and butterflies, and one using bioacoustic techniques to examine how closely-related bird species establish territories and partition resources.

Community commitment to conservation that enables continuous efforts over many years and across sequential governing administrations is essential to achieving cumulative conservation progress. Incremental development of small projects leads to a critical mass-type of momentum that leads to greater community support and additional awareness and opportunities. No single theme (e.g., ecotourism, carbon offsets) will meet all the community's natural resource expectations, but a broad-spectrum approach with a diverse set of projects can be effective for raising awareness of conservation benefits and for building community support. Community collaboration with a broad-range of public and private organizations is essential for resource mobilization.

6.4.4 Casas de la Selva, Puerto Rico

Las Casas de la Selva is an experimental sustainable forestry and rainforest enrichment project begun in 1983 in southeastern Puerto Rico in the Cordillera Mountains. The 409 ha forest is located on steep slopes, at an average elevation of 600 m (2000 ft), receiving an average annual rainfall of over 3000 mm and an average temperature of 22 deg. C. Most of the land was logged, converted to coffee plantations and then subsequently abandoned, resulting in areas of severe erosion and a secondary forest which now covers the property. The project is managed by Thrity Vakil and Andrés Rua, with assistance from Dr. Mark Nelson on scientific papers and Norman Greenhawk, a herpetologist currently working on a Master's degree.

The Las Casas de La Selva project, undertaken by Tropic Ventures Research and Education Foundation (Patillas, P.R.) with consulting by the Institute of Ecotechnics (U.K., U.S.) has three principal objectives:

1- Restore and conserve the secondary forest ecosystem.
2- Identify and test the forestry techniques that provide the best ecological and economic outcomes as viable alternatives to conversion of the forest for agricultural and other uses.
3- Monitor the forest and its trees, key indicator animal species and the resource use to understand the ecological and socio-economic impacts of the project.

Foresty enrichment with line-planted valuable timber species was chosen as a method of providing economic returns without destroying the secondary forest on the land. Between 1984 and 1990 some forty thousand tree seedlings were planted in lines in about 25% of the secondary forest. Ninety percent of the seedlings were mahogany (mainly *Swietenia macrophylla x S.mahagoni)* while the other 10% was primarily mahoe *(Hibiscus elatus).* Seventy-five percent of the land including the steeper slopes of the forest were left untouched to minimize erosion and to provide areas to study natural regeneration and ecological succession of the forest. On the areas previously converted to grazing, more than a thousand fast-growing *Pinus caribaea* (Caribbean pine) were planted to hold the soil and mahogany and mahoe interplanted once the pines had established.

The hypothesis was that the program of line-planting, since overall forest conditions are minimally disturbed, would result in only small changes in both forestry parameters and in faunal populations. Small impact on tree and amphibian diversity was demonstrated by research after twenty years of the program (Nelson et al., 2010).

There are also studies, begun in 2009, of the "liberation thinning" technique to improve growth of valuable native trees in secondary forests (Wadsworth and Zweede, 2006). These are the first tests in Puerto Rico to see whether eliminating competitor trees will accelerate the growth of native hardwood species. If so, it will provide better economic returns and rationales for valuing and protecting secondary forests which are rapidly expanding on the island due to the abandonment of farming land.

More details of this project and its results on growth of the line-planted trees and its minimal ecological diversity impacts can be found in Nelson et al. (2011, 2010) and www.eyeontherainforest.org.

Approaches Used and Data Collected

The project staff includes some people with advanced or university training and also others who have learned forest management skills over several years through operating the project and collaborating with a wide diversity of scientists who have helped collect data. The data collection has also been helped by cooperation with the Earthwatch Institute, which has sent groups (i.e. citizen science monitors) since 2000, and also university classes and other volunteers.

The types of data that have been collected include:

- Measurements of tree survival and growth in the line-planted areas (basal area (BA), diameter at breast height (dbh), canopy, height, commercial height) and measurements of trees and biodiversity in the secondary forest areas compared to line-planted areas, in randomized geo-located plots.
- Measurements of tree seedling numbers in both line-planted and secondary forest.

- Impact of thinning on the line-planted areas in random plots and impact of liberation thinning on plots in the secondary forest compared with control plots (with advice from Dr. Frank H. Wadsworth, the developer of liberation thinning).
- Planting and monitoring of critically endangered endemic tree species for recovery and habitat enhancement. A shade nursery has been established for caring and sheltering of saplings of threatened endemic species until planting. The initial survival, growth rate, and success of the reintroduced material is monitored to ensure the best contribution to the recovery of the species.

With support from the USDA Forest service and the Puerto Rican Department of Natural Resources, Las Casas de la Selva has been conducting a Forest Products Assessment. This project has enabled Andrés Rúa, a member of the Las Casas management and a "citizen scientist" to visit sawmill owners all over the island, interview dozens of artisans who work with forest products, as well as large and small scale wood and product dealers. The project aims to investigate use of forest products in Puerto Rico; where the wood is coming from; what types of wood; who are the buyers; and what other forest products are in demand and use.

Herpetological studies have focused on identifying which species of reptiles and amphibians are present at Las Casas de la Selva in order to determine the population density, population fluctuations, microhabitat utilization, and the effects of forest management on the herpetofauna of the forest. Biodiversity and population studies of birds, vines and fungi have also been undertaken. Finally, basic meteorological data such as rainfall, temperature and relative humidity are recorded.

Successful Outcomes

The project would not have had the data to evaluate the overall program of forest enrichment nor its impact on natural biodiversity of the secondary forest without the extensive numbers and hours of research data collection. This has resulted in publication of several papers in forestry journals and helped project management evolve a program in response to the findings. In particular, it has quantified the success and rapid growth of the mahoe trees and other valuable native timber trees planted compared with the slower-growing mahogany.

The confirmation that the forest enrichment program has not significantly decreased tree or amphibian diversity has validated the project's main initial hypothesis and is helping make the project a model for sustainable forestry management on the island.

Coqui frogs are an important part of the forest food chain and were studied as key indicator species in the line-planted and untouched forest. Common coqui (*Eleutherodactylus coqui*) and melodious coqui (*E. wightmanae*) are the most commonly encountered frog species at Las Casas. Although relative abundance means were slightly greater in the undisturbed forest and during the wet season, there were no statistically significant differences which shows that line-planting did not significantly affect amphibian diversity (Nelson et al., 2010). In addition, several threatened and endangered frogs have been discovered in the property, extending their known range and anole lizards, another key part of the fauna have been unaffected by forest enrichment (Greenhawk, 2013, 2015).

Similarly, the line-planted areas had a slightly higher, but not statistically significant diversity, richness, and evenness of tree species than the control plots in the undisturbed forest. A multi-response permutation procedure (MRPP) showed statistically significant tree community composition differences between line-planting and control plots. But mean similarity among plots in both the line-planted and control plots was relatively low at less than 50% of shared species, indicating high diversity of vegetation in the overall forest area. Canopy cover by tree species greater than 3 cm in dbh was much higher in the undisturbed forest but as the young planted trees grow, this difference may be reduced. These data indicate that forest enrichment through line-planting of valuable timber species in secondary subtropical wet forest does not significantly affect tree diversity (Nelson et al., 2010).

Tree growth studied over 20 years since planting shows that mahoe had a BA increase over three times that of mahogany. In 57 years from planting, the mahoe trees will reach a mean stand BA of 0.20 m^2/tree, which correlates to a dbh 50 cm. The upper quartile of mahoe trees currently have a mean BA greater than 0.10 m^2/tree and are already being selectively harvested and marketed as a thinning of the stands. The BA annual increment for mahogany indicates that it will take 175 years from planting to achieve a mean stand BA of 0.20 m^2/tree for the best 25% of the mahogany trees. In trials with native species, Coccoloba pubescen, Calophyllum brasiliense and Cedrela odorata had the greatest percent increase in height with favorable survival rates, but longer term studies are needed to determine years to commercial size.

Because of the success, which has been validated by the enormous databases our citizen scientists have helped us collect, the project is also collaborating with a wide range of scientific institutions both in Puerto Rico (including the Institute of Tropical Forestry and the University of Puerto Rico at Rio Pedras) and elsewhere. It has also put Las Casas de la Selva in the forefront of a growing movement to promote a sustainable local timber/wood industry. Puerto Rico currently imports almost all of its commercial wood from the U.S. and Canada. Forest management for timber is still in its infancy despite the fact that the island has the greatest rate of secondary forest increase in the world. In another sign of the change of attitude towards its forests, the University of Puerto Rico has recently begun its first program in tropical forestry and silviculture.

6.4.5 Landscape Partnerships Project, Southern Brazil

The Brazilian Atlantic Forest (AF) is considered a major global biodiversity hotspot and is one of the most endangered ecosystems in the world (Myers et al., 1999; Mittermeier et al., 2004). The AF contains high biological diversity, including 1020 species of birds and 250 of mammals, with high numbers of endemic and threatened species. Additionally, the AF offers numerous ecosystem services to the Brazilian and global population, for example, providing drinking water for 60% of the Brazilian population and the sequestering of 2 billion tons of CO_2 (Calmon et al., 2011). The AF originally covered 16% of the Brazilian territory, but only 11.7% of the original forest cover is now left, where the majority of remnants are isolated patches embedded in a mosaic of secondary and anthropogenic forest tree plantations, pastures and agricultural crops (Ribeiro et al., 2009). These are subject to continued pressure from urbanization, agricultural expansion, and other threats associated with human presence, such as hunting and logging (Giorgi et al., 2014).

Ana Paula Giorgi and Thais Azevedo Vieira of the Earthwatch Institute in Brazil and Morena Mills of the University of Queensland in Australia lead the Landscapes Partnerships project. This project aims to map conservation opportunities with a focus on conducting restoration actions in the Southern AF based on recently changed Brazilian environmental legislation. It consists of a three-stage framework for conservation planning to conduct conservation and restoration actions. First, high resolution satellite imagery (0.5m) is used to analyze the impacts of Brazil's new Forest Code within the study region in order to identify areas at risk of deforestation and potential areas to be restored by mapping 15 watersheds (67,000 ha) throughout the Serra do Itajai National Park buffer zone. Second, interviews are conducted with local small-scale farmers to investigate motivations and barriers to participation in restoration initiatives, and to estimate the percentage of the population likely to adopt different programs and their adoption rate (Mills et al., submitted). Finally, biodiversity prioritization models are run to define priority areas for biodiversity conservation. The Landscape Partnerships opportunities map will be built by overlapping the results from these three stages.

Mapping conservation opportunities offers an understanding of the factors that contribute directly to effective actions and improves identification of candidate areas where conservation initiatives can be implemented feasibly.

Approaches Used and Data Collected

Citizen science monitors have been involved in carrying out censuses along transects as well as the setting and checking of camera traps to record terrestrial mammals. This research also includes the use of mist-nets, point counts for birds and bird banding. The citizen monitors help to check for footprints and set up the camera traps for mammal assessments, and for bird counts, they set up the mist-nets, and take the birds out of the nests to do biometric measurements. Since the start of the project in 2013, 180 small farmers/landowners have been interviewed regarding landscape perceptions and 67,000 ha have been mapped at a 1:3000 scale. In 2013, during only 17 days of field work for bird assessment and monitoring, the team of researchers and citizen scientists captured 485 birds from 94 species in the mist-nets. Of this number, 404 individuals were banded and released. When mist-nets and point count assessments were combined, the team identified a total of 199 species (18% of them are endemic to the AF) from 52 families living in one particular area of the study site. In 2014, while gathering bird data at a new site, citizen science monitors and researchers assessed 54 bird species, with 23 endemic to the AF and 45 listed in the IUCN Red List.

Two types of maps have been produced for the national park managers, the Brazilian Federal Government, and the Santa Catarina State Government for monitoring and enforcement: a map of priority areas for biodiversity; and an opportunities map showing where restoration and conservation actions should be focused.

Successful Outcomes

Detailed information on the mammal and bird communities throughout the National Park's buffer zone and surrounding water catchments has contributed to species population information. In addition, during the execution of the project, a potential Ecological Corridor, linking the two biggest protected areas of the Santa Catarina State, the Serra do Itajai National Park and the Serra do Tabuleiro State Park, was identified. The State Government invited the project coordinators to develop a proposal for such a corridor. Furthermore, a high number of birds are being banded, which will allow the team to include population dynamics and detailed ecological studies in the future, such as the effect of the fragmentation and different land-uses on the birds' movements and behavior. This will contribute to data on both species traits and collection of land use information.

6.4.6 Project COBRA, Guyana, South America

Jay Mistry of Royal Holloway University of London and Andrea Berardi of The Open University are key proponents of the COBRA project (Community Owned Best practice for sustainable Resource Adaptive management), which is funded by the European Commission's 7th Framework programme. The mission of COBRA is to "find ways to integrate community owned solutions within policies addressing escalating social, economic and environmental crises, through accessible information and communication technologies" in the Guiana Shield region of South America (see www.projectcobra.org). Starting in September 2011, the project has worked with various Indigenous communities in Guyana, Brazil, Suriname, Venezuela, French Guiana and Colombia (see http://projectcobra.org/communities for a description of each community). The aim of the project is to showcase Indigenous solutions for the management of natural resources and change development policies and projects so that they strengthen the position of Indigenous communities as stakeholders rather than undermine them, while inspiring other communities to take the initiative in facing up to global challenges.

Approaches Used and Data Collected

Project COBRA used accessible visual methods of Participatory Video (PV) and Participatory Photography (PP) to collect information about the social-ecological viability of Indigenous communities. Through a facilitated process, indigenous community members identified and recorded indicators that they perceived as allowing their community to survive in the face of a range of challenges. These were then documented through PV and PP where community researchers planned, filmed, screened and edited the indicator information into films and photostories through an iterative process of consultation and evaluation with community members. Indicators included how communities valued land rights in order to secure access to key resources, but also the ability to use new technologies in order to adapt to the challenges of an increasingly globalised world. Information on the status of all the indicators was collected by community members and used to identify 'best practices', i.e. local solutions which have been most successful at allowing communities to survive and thrive (see Table 6.4.6.1). These best practices were then documented through the PV and PP process for sharing with other communities across the Guiana Shield and policymakers at national and international levels. More details are available in Berardi et al. (2013), Mistry et al. (2015) and Berardi et al. (2015).

Table 6.4.6.1: Themes of the community owned solutions, or 'best practices' identified by each community.

Communities	Local community owned solutions
North Rupununi, Guyana	Traditional fishing practices Traditional cultural transmission Community radio Traditional farming techniques Local civil society organization Self-help practices
Antecume Pata, French Guiana	Traditional fishing practices
Katoonarib, Guyana	Forest island management
Kavanayén, Venezuela	Tourism cooperative
Kwamalasamutu, Suriname	Two-farm traditional system
Laguna Colorada, Colombia	Traditional cultural transmission
Maturuca, Brazil	Cattle raising to assert land rights

It is important to note here that the actual indicators and associated data collected through the community-led process focused on issues and practices that were of concern to the communities themselves, rather than the interests of external biodiversity scientists or policy makers. Indigenous communities highlighted indicators pertaining to land-rights, and access to key forest and river resources as essential to their existence. They identified the ability to continue with traditional rotational farming practices and the maintenance of a diversity of crops as important characteristics for giving them flexibility in a highly variable and unpredictable environment. They showed that indicators of community cohesion and self-help practices allowed them to function ideally in a situation of resource scarcity. They highlighted how advanced information and communication technologies allowed them to adapt to changing environmental conditions. But they also illustrated a range of indicators on how maintaining traditional culture and identity allowed them to resist deleterious change. Finally, they showed how partnerships with a range of organizations have enabled them to strengthen their responses in a range of initiatives, including the management of endangered species, such as the *Arapaima gigas*, the largest scaled freshwater fish species in South America.

Although the indicator selection on data recording did not fit neatly into the criteria often required for biodiversity monitoring and management (e.g. there were no indicators that focused on species abundance and distribution), the approach strongly suggests that addressing the concerns of Indigenous communities for maintaining their traditional livelihoods will have an indirect impact of also maintaining the natural habitats and species that biodiversity monitoring experts are so concerned with counting and preserving. Satellite data published on Global Forest Watch (Hansen et al., 2013) show almost intact forest cover and negligible deforestation over the 10 years within the immediate surroundings of the Indigenous communities with whom Project COBRA has worked. This is corroborated with other studies in the Amazon comparing Indigenous and non-Indigenous lands such as Nepstad et al. (2006) and Walker et al. (2014). The reasons why Indigenous territories seem to have higher levels of environmental protection are complex and may not always be linked to Indigenous cultures. For example, Indigenous territories tend to suffer from poor transport infrastructure, which makes the commercialisation and unsustainable exploitation of natural resources more difficult compared to better connected non-Indigenous areas. However, in our work, the overriding perception is that the identity and livelihoods of the Indigenous communities we engaged with were intimately linked with their local natural environment. As opposed to non-Indigenous people, community members felt that they had 'nowhere else to go' - if they unsustainably mismanaged their territories and were forced to leave, or 'sold out' to commercial interests, then they would lose everything: their livelihoods; their identity; their culture; and even their lives. Thus, identifying and sharing community owned solutions that strengthened the cohesiveness and cultures of Indigenous people more often than not has the indirect outcome of also protecting the local environment.

Successful Outcomes

Project COBRA has demonstrated that participatory approaches that allow local communities to identify, record and share what matters to them ought to be an essential component of effective natural resource management and biodiversity conservation. The participatory approaches used in Project COBRA not only engaged people directly in the research process, but also supported self-representation, encouraged reflection, collective involvement and empowered the individuals that are directly affected, and can react to habitat degradation and biodiversity loss. Supporting Indigenous communities in identifying and sharing their own solutions to conservation challenges constitutes one of the most ethically appropriate frameworks for research and interventions within Indigenous communities. Communities are becoming aware that the solutions to their challenges do not lie exclusively in the hands of professional experts, but also in people just like them.

6.4.7 National Program for Biodiversity Monitoring, Brazil

The Brazilian government, through the Ministry of Environment and the agency for biodiversity conservation and protected areas, Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio), has recently launched the National Program for Biodiversity Monitoring in protected areas. The 320 federal protected areas were design to conserve biodiversity under the management responsibility of ICMBio, and are categorized as conservation units that allow the use of natural resources, mainly by local communities, and conservation units that are strictly for biodiversity protection.

To improve their management capacity, the agency has been implementing different monitoring schemes addressing land cover change and management effectiveness of protected areas. The third pillar of information to manage the areas, however, was lacking until 2012 when the Program for Biodiversity Monitoring was established.

The program was built during three years of cooperation with the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), the Gordon and Betty Moore Foundation and Instituto de Pesquisas Ecológicas, using the lessons learned from 10 years of previous pilot programs, local initiatives and attempts to implement government-led biodiversity monitoring. Two major frontlines compose the program: on the one hand, it intends to provide continuous and systematic biodiversity information to support the management of the National System of Protected Areas; on the other hand, it was structured to also provide biodiversity information to support decisions at the level of single protected areas.

To answer the request at the national scale, the program is based on the information of a few, simple-to-collect biological indicators of biodiversity that every protected area has to provide through a standardized methodology that is easy to implement. Here, the program considers the involvement of local people in data collection, after participating in capacity-building courses. Therefore, representatives of communities that live in protected areas are participating in a national government-led program that provides information to manage biodiversity.

At the level of single protected areas, the program is open to a more comprehensive and intense involvement of local communities. In each protected area participating in the Program, communities participated in the design of the whole monitoring scheme. Together with the local staff they decide on the component of biodiversity that should be monitored, provide information to support and validate the design of the monitoring methodologies, select communities and members that participate, and collect the data. As such, the information produced is relevant for the local management of biodiversity both for the government as well as for communities living in the protected areas. Moreover, the core methods developed in one protected area have the potential to be adopted in others allowing for regional analysis and decision-making at broader scales.

Approaches Used and Data Collected

Given the size of the country, the elevated number and extension of protected areas, and the relative lack of financial and human resources to monitor biodiversity, the program opted to simplify things as much as possible since its design.

The two approaches developed in the Program are complementary and based on the principles that monitoring should be feasible to implement, and therefore, able to involve as many people as possible, independent of the level of formal education (Pereira et al., 2013b). Hence, four biological indicators, which provide complementary information on biodiversity, were selected to be monitored in every protected area engaging in the program: medium and large mammals, large birds, arboreal plants, and frugivorous butterflies. Simple methods were developed that allow local people to collect data on the number of mammals, birds, and butterflies, and the size of plants (Nobre et al., 2014). These data are used to estimate parameters of population, community structure and function. The program also designed two additional modules for each indicator that generate more complex information that can be adopted in protected areas that have partners willing to contribute, such as universities and research NGOs.

The technology for monitoring is intended to be applicable to as wide a variety of contexts as possible. Therefore, the option, in the first phase, was to use paper and pencil to record data. The program developed supporting material to facilitate the adoption and use of data collection protocols. The guides of data collection and identification were designed to facilitate the manipulation of local people and the information in them was expressed in drawings and photographs, instead of using words. Videos were also made to show the technical details of the data collection. Whenever communities in the protected areas are willing to participate in this part of the program, there are also capacity-building courses oriented to this audience (Santos et al., 2014).

The local approach was built on a series of meetings and workshops with community leaders and other members to design the monitoring. Although there were differences in the process depending on the protected area, the general overview and guidelines were maintained. The selection of monitoring target was defined after defining a question relevant to the management of biodiversity at the scale of the protected area. Usually, communities and government staff prioritized those targets that were included in the formal management agreement instruments of the protected areas (i.e. the management plan, the management agreement between communities living in protected areas of sustainable use and the state, and the term of commitment of communities using resources in protected areas of strict protection). Currently, communities in protected areas work with the government to monitor the status and use of Brazil nut trees, game species, peacock bass (tucunaré), and aquatic chelonians, as well as the effect of logging on large mammals and birds. Each monitoring target has specific methodologies, instruments, and technologies associated with it. Nevertheless, the methodological protocols were carefully developed to collect data with enough quality to support local management interventions with significant information. Moreover, a core group of data was defined for collection wherever these targets are monitored.

Successful Outcomes

The National Program for Biodiversity Monitoring is currently collecting data in 20 federal protected areas to provide information to manage the national system of protected areas. In addition, there are seven protected areas currently participating in the program, all in Amazonia, that are producing monitoring information for the local management of biodiversity. People living in communities in these protected areas participate in diverse ways and levels of engagement, being an essential part of the program. This program is a pioneer in recognizing local knowledge and promoting local engagement in a biodiversity monitoring program coordinated by a federal government to support local and national scale decision making. As it is now, the program is starting to provide nationwide continuous systematic information on trends of animal populations, and community structure and function.

Although the program is still in the first years of implementation, there is a strong effort to expand the activities. The Amazon Region Protected Areas Program of the Ministry of Environment is adopting the principles, including community involvement and the methodologies developed in the National Program for Biodiversity Monitoring. As a consequence, ICMBio is planning to include another 20 Amazonian protected areas in their program by the end of 2016. Moreover, state governments in Amazonia are interested in monitoring biodiversity in their protected areas according to these methodologies, and there is also interest in adapting the program for implementation in other indigenous lands across the country. In addition, ICMBio is expanding their network of collaborators to implement the more complex modules of biodiversity indicators in protected areas that already have the basic modules, and to develop a more traditional citizen science component.

6.4.8 Nature's Notebook: USA National Phenology Network

Nature's Notebook is led by the USA National Phenology Network (USA-NPN; www.usanpn.org), which was established in 2007 by the US Geological Survey in collaboration with other governmental and non-governmental organizations. The USA-NPN is a national-scale science and monitoring initiative focused on phenology – the study of seasonal life-cycle events such as leafing, flowering, reproduction, and migration – as a tool to understanding how plants, animals, and landscapes respond to environmental variation and change.

Formally launched in 2009, *Nature's Notebook* (www.nn.usanpn.org) is a ground-based, multi-taxa phenology observing program, which enables both professional and volunteer participants (typically contributory citizen science) across the USA to observe and record phenology of plants and animals according to standardized, published protocols via web or mobile applications.

The success of *Nature's Notebook* and the ability of USA-NPN to deliver a high-quality multi-taxa data resource hinges on the activity of the participants. Approximately half of the participants are volunteers. Therefore, without the efforts of the thousands of citizen scientists, it would be impossible to provide such a rich, deep phenology data resource.

Approaches Used and Data Collected

Participants in *Nature's Notebook* submit observations on the status of several phenological stages, or *phenophases*, during repeated visits over the course of a season (Denny et al., 2014). Status monitoring involves evaluating phenophase status (e.g., the presence or absence of leaves, flowers, or fruits for plants, and mating, feeding, or movement for animals) during a series of repeated observations over the course of a season. Observations are expressed as the question, "Do you see [phenophase]?" to which the observer answers "yes", "no", or "uncertain" for the presence of each phenophase. In addition, observers may record the intensity or abundance of each phenophase (e.g., number of flowers present, percentage of flowers open, number of robins feeding, etc.). The use of status-based monitoring is particularly suitable for tropical and sub-tropical systems where there is little seasonality, or where seasonal drivers typically considered important in more temperate regions, such as accumulation of warmth during spring, are unknown or of less importance. Status-based monitoring captures repeated bouts of flowering or leaf-out over the course of the growing season, which is common in tropical and aseasonal systems.

The data collected via *Nature's Notebook* directly supports the "phenology" EBV, and is suitable for documenting changes in species phenology as well as in synchrony of states or events between or among species (e.g. plant-pollinator interactions). Although primarily focussed on temperate climates of the coterminous USA, this type of citizen-based monitoring approach could easily be transferred to tropical forests.

Successful Outcomes

Nearly 7 million records (as of early 2016) of plant and animal phenology have been contributed to *Nature's Notebook* since the launch of the program in 2009, representing hundreds of species of plants and animals at over 8000 unique locations across the USA. These data have resulted in 21 peer-reviewed publications to-date (http://www.usanpn.org/biblio/%20contemporary-data) with several more under development. For example, data from the network have been used to improve models that predict onset of seasonal activity of important tree species in the eastern United States (Jeong et al., 2013), which has implications for local activities and economies, such as maple syrup production, honey production, allergy seasons, bird migrations, cultural festivals and harvesting of native herbs. Other models using data from the network indicated that 2012 was the earliest spring since 1900 (Ault et al., 2013), and illustrated how such a "false spring" increased susceptibility of agricultural crops (such as apples and grapes in Michigan) to frost, and may have exacerbated impacts of summer drought on regional agricultural productivity.

6.4.9 Majete Wildlife Reserve, Malawi

The 70,000 ha Majete Wildlife Reserve (MWR), at the tail-end of the Rift valley in southern Malawi, provides a home for many of Africa's iconic species: leopards, elephants, water buffalo, black rhinos, sable antelopes, eland, lions, leopards, and hyenas, among others. MWR was originally established as a game reserve in the southern section of the Great Rift Valley in 1955, and poaching became rampant during the late 1980s and 1990s. In March 2003, a decision was made to rehabilitate MWR through the establishment of a public-private partnership, between the Government of Malawi (Department of National Parks & Wildlife) and African Parks PTY Ltd. Since then, millions of dollars have gone into developing the reserve's infrastructure, primarily for ecotourism purposes and building up its staff component, with a current total of 135 full time staff, all employed from the surrounding communities. Tourism has been steadily increasing since African Parks took over management of the reserve. A 142-kilometer (88-mile) electric fence now surrounds the reserve, protecting the original 2,554 animals of 14 different species that were reintroduced to the reserve, along with their new offspring. Almost 10 years later, the project is gradually moving from its inception and rehabilitation phase into a conservation, monitoring and habitat management phase, including the provision of water, fire and visitor management, control of alien and invasive species, continued re-introduction and monitoring and translocation of animals and managing the rare and endangered species. Changes in animal numbers due to high breeding success rates and the predicted impact on vegetation brought about by the rehabilitation programme now require monitoring and measuring.

Dr Alison Leslie from the University of Stellenbosch (South Africa) and Earthwatch initiated a biodiversity research and monitoring program in 2013 to monitor key species and their ecological interactions in Majete Wildlife Reserve in Malawi.

Approaches Used, Data Collected and Successful Outcomes

Community-based monitoring and Earthwatch volunteers (i.e. citizen scientists) are being used to determine population trends of all 14 reintroduced species within the reserve. Fixed-point photography is used to monitor vegetation changes. Waterholes are monitored for the development of and an increase in the size of piospheres. Distance sampling monitoring, on foot and by vehicle, is undertaken for animal counts, camera trapping is conducted to determine presence/absence of species in different areas of the reserve and to determine species abundances and scat/dung is collected from herbivores and predators to determine the preferred seasonal diet of the various species.

The biodiversity observation monitoring program is providing data on key biodiversity indicators, including the status and trends of species, and identification of potential ecological interactions which may limit species response. The research team knew exactly how many individuals of what species were introduced (a rare situation) and are currently gaining a better understanding as to reproductive rates and population growth rates in general. All 14 reintroduced species are doing incredibly well (all species have reproduced since re-introduction) and using citizen scientists, Dr Leslie is studying actual rates of increase. Currently there are over 200,000 camera photographs of species presence/absence (habitat use) in areas of the reserve, which will use citizen scientists for identification. Thirty-two waterhole counts are carried out by citizen scientists per field season (June-December) totaling 384 hours. Fixed-point photography study is well underway with photographs taken every 3 months at 58 sites throughout the reserve, totaling 360 photographs per sampling session. Citizen scientists are responsible for sorting and collating all photographs. Additionally, citizen scientists undertake 512 hours of distance sampling, on foot and by vehicle per fielding season, contributing a huge amount of data to the research monitoring programme, which would otherwise be impossible to collect. The identification of potential ecological interactions which may limit species response include elephant impacts on habitat and habitat selection within the reserve, the development of piospheres around waterholes and the high number of wild fires. In the future, predator impact on herbivore populations will be studied.

The abundance, productivity and reproductive success of biological organisms can provide an indication of the overall health of an ecosystem. Monitoring of these variables provides key information for management decisions and will contribute to the overall success of one of Malawi's largest protected areas, and Malawi's only "Big 5" reserve. Monitoring has already indicated a higher number of elephants than expected and in late 2016, one of Africa's largest elephant relocation projects will be undertaken by African Parks. Results from this program will ultimately contribute towards a Management Plan for MWR, which will be provided to African Parks and the Department of National Parks and Wildlife, for implementation. This management plan may also assist other reserves within the country and further afield in the form of suitable monitoring protocols for a large number of re-introduced species of both predators and their prey. Additional outcomes of the research program include the training of numerous post-graduate students (including Malawian citizens), peer reviewed publications and ultimately the protection of some of the last remnants of Africa's eastern Miombo woodland.

6.4.10 Participatory Ecological Monitoring in Madagascar: The Case of Lake Alaotra New Protected Area

The Island of Madagascar (58.7 million hectares) is a biodiversity hotspot due to its exceptional rate of endemism and current environmental threats. All 103 species of primates (Mittermeier et al., 2006), 98% of amphibians (Glaw and Vences, 2007), 91% of reptiles, 52% of birds (Morris and Hawkins, 1998), and 80% of plants are endemic to the country. However, since the arrival of humans around 2,350 years ago, Madagascar has lost more than 90% of its original forest with a high annual rate of deforestation of 1.95%/year from 1990 to 2000 and 1.28%/year from 2000 to 2005 (Harper et al., 2007). Moreover, with a high multidimensional poverty index of 0.41 (Alkire et al., 2013), about 80% of people live in rural areas (INSTAT, 2010) and rely importantly on natural resources to survive. The main pressures on natural resources are slash-and-burn agriculture, tree felling for firewood and charcoal and illegal timber exploitation, causing loss and destruction of natural habitats. Due to lack of resources, the government has difficulty in controlling illegal timber exploitation. Therefore, many of the species are under serious threat of extinction.

Participatory ecological monitoring has been deployed by many conservation NGOs to help save Madagascar's wildlife. Lake Alaotra (17°02′-18°10′S, 48°00′-48°40′), where the Durrell Wildlife Conservation Trust introduced a participatory ecological monitoring approach for the first time in 2000, has been a key pioneering site. With a surface area of 20,000 hectares, and surrounded by a further 23,000 hectares of reed beds, Lake Alaotra was designated as a Ramsar site in 2003, and after receiving temporary protected area status in 2007, it was awarded an official permanent decree of protection n° 2015-756 on 23 July 2015

The main goals for the Lake Alaotra Protected Area are to conserve the lake and marsh area, their biodiversity including the Alaotran gentle Lemur *Hapalemur alaotrensis*, the carnivore *Salanoia durrelli* and indigenous fish and waterbirds, and to maintain the provisioning of ecosystem services to sustainably improve human well-being.

Approaches Used and Data Collected

Participatory ecological monitoring takes place yearly every rainy season when Lemurs and water birds are more active and the water level is high enough for travel by canoe (Andrianandrasana et al., 2005). The fieldwork lasts for 3-5 days per village. Monitoring teams at each site consist of up to 15 people: 8 villagers, 2 government representatives, 3 qualified Durrell Wildlife staff (all have university degrees) and 2 local technicians who have a secondary school education. Following a preparatory visit, participants are chosen at an initial meeting to which all members of the community are invited. Selection criteria include detailed knowledge of the marshes, interest in conservation, and literacy. Monitoring indicators were chosen with the local community through public village meetings. They include key species such as the Alaotran gentle lemur, the 50 species of water bird (Langrand, 1995), indigenous fish; the key habitat such as the reed beds and lake; and the main threats such as marsh fires, invasion of water hyacinth and snake-head fish, illegal fishing and rice farming. Indicators also cover some key environmental services such as fish productivity and hunting. Field data forms based on those indicators were developed with local monitors, authorities and government officials to make sure everyone understands the procedures of data collection and reporting. Participants who volunteer are paid around $3/person/day, less than the average income from fishing.

Since 2002, participating villagers, most of whom have had primary school education, have been given training in data collection.

The monitoring teams are divided into 5 subgroups. Each subgroup has the specific objective to observe lemurs and water birds along fixed canoe transects, and map out burned marsh areas using base maps and GPS. The subgroups that look at biodiversity and threats follow the existing tracks within the marsh area to record the name and number of mammals, reptiles and water bird species. They also visit the lake to check whether the selected no fishing zones already fenced with phragmites are respected. The group that is in charge of the fish productivity survey stays at the port to record the time spent by each fisherman and measure and identify the fish caught. They also record the type of fishing materials used by each fisherman. At the end of the annual participatory ecological monitoring, a big public meeting attended by government officials, local authorities and local associations is then organised in each village to discuss results of the observation. After some public speeches given by the authorities and government representatives that reminds the local people about the laws and the importance of natural resources for sustainable development, the monitoring teams give feedback about the results of their observation and discuss publicly the illegal activities. These review meetings are often animated by public quizzes and traditional dancing.

Between 2011 and 2016, Durrell has received financial support from the MacArthur Foundation, the Helmsley Charitable Trust, the Tusk Trust, the JOAC (Jersey Overseas Aid Commission), and the GEF UNDP MRPA (Managed Resources Protected Areas) to expand and reinforce participatory ecological monitoring in five sites including Lake Alaotra, Menabe dry forests, Lake Ambondrobe, Nosivolo River and Manombo rainy forest. The Ministry of the Environment and Forests approved the training of 468 local monitors, 96 of them in Alaotra, as well as the provision of uniforms and equipment including mobile phones and simple cameras.

Since April 2011, these local monitors have carried out patrols on a weekly basis to observe key species, their habitats and illegal activities within their local management area. Overall, the monitoring has provided useful data for decision making and started the process of building local pride in the environment as well as the ability to analyze the monitoring data locally.

The monitoring has supported wetland management by guiding amendments to, and increasing respect for, a regional fishing convention; by catalysing the transfer of marsh management to communities, by stimulating collaboration and good governance; and by raising awareness. Monitoring has revealed trends in natural resource management over time (e.g., changes in the extent and frequency of devastating annual marsh fires) and provided valuable fishery data. Surveys have also provided information on the levels of hunting of water birds and lemurs and the areas of lemur occupancy.

Data collected through participatory ecological monitoring has indicated stability in fish productivity from 0.23 kg/person/hour in 2002 to 0.25 kg/person/hour in 2005. That could be an impact of the reduction of marsh burning from 7,300 hectares in 2000 to 2,500 hectares in 2003 (Andrianandrasana et al., 2005). That stability was followed by a significant decrease in fish productivity until 0.09kg/person/hour in 2009, which has been confirmed by the massive decline in fish production from 2000 tonnes/year in 2004 to around 800 in 2011 (DRPRH, 2013)(DRPRH, 2013). Fish production and marsh burning may depend not only on overfishing and illegal rice farming but also on quantity of rainfall, climate change, and immigration and water quality issues. In addition to the lack of control of the use of illegal fishing gear, it seems that some of the more than 10,000 mosquito nets distributed in the area between 2010 and 2012 for reduction of malaria control have been used for fishing. At night, according to local monitors' reports, at least 10 seine fishing nets are still operated on the lake. Due to lack of resources and personnel, it is difficult to apply the national fishing regulations and the local fishing convention known as 'dinan'ny jono', which bans fishing of Tilapia less than 13cm length, *Ciprinus carpio* less than 15cm and eels less than 45cm. Furthermore, enforcement of the annual closed fishing season (15 November to 15 January) is often difficult especially if this coincides with political campaigning activity.

Successful Outcomes

The data collected through participatory ecological monitoring and local patrols are robust and have contributed to an understanding of the changes that have occurred across all the sites including Lake Alaotra. Contributions have been made to data on species populations and species traits as well as ecosystem structure through habitat monitoring. The data have also helped to develop management plans at each site and facilitated discussions during the process of developing management structures. The monitoring approach has contributed to achieving the government's objectives to expand the size of protected areas from 1.7 million hectares to six million hectares, most of which are under IUCN category V and VI that require the involvement of the local community in their management. In particular, Lake Alaotra, Menabe dry forest and Nosivolo River, and Lake Ambondrobe have become part of the official New Protected Areas, and have substantially succeeded in involving local people in their management.

The approach has worked well both in terms of involving villagers in the process of conserving biodiversity and improving collaboration between the communities and the local authorities responsible for sustainable management of natural resources. Although local monitors report on illegal activities, law enforcement is lacking and there is a little evidence of follow-through on these reports. This has had a negative effect on the reputation of the local monitors and dampened their enthusiasm for the hard work required to collect the data. The lack of law enforcement has also meant that there has been insufficient evidence to demonstrate the effectiveness of the participatory ecological monitoring approach at times although some positive changes of local people's attitudes are still evident. Overall, determining how best to monitor the effectiveness of the participatory approach remains an ongoing issue.

6.4.11 Community-led mangrove conservation and restoration in Gazi Bay, southern Kenya

For many coastal communities, such as those living around Gazi Bay in Kenya, mangrove ecosystems provide key services such as firewood and building poles, nursery provision for fish, coastal protection and opportunities for tourism. The forests also generate regional and global benefits, by protecting neighboring ecosystems such as coral reefs and through their exceptional ability to trap and sequester carbon, mitigating climate change. Whilst the mangroves of Gazi Bay have supported people for millennia, current patterns of use are unsustainable, with projections based on business as usual, suggesting that more than 40% of mangrove forests in southern Kenya will be lost in the next twenty years (Huxham et al., 2015).

A community-led mangrove conservation, restoration and research project is being led by Professor Mark Huxham of Edinburgh Napier University in partnership with Earthwatch Institute, James Kairo of the Kenya Marine and Fisheries Research Institute, Dr Martin Skov of Bangor University and the Kenya Forest Service. The aim of the project is to help sustain the supply of mangrove goods and services by linking mangrove management with direct community benefit. In particular, the project is pioneering the use of carbon credits as a new way to fund mangrove conservation and social development in the area, and has used scientific research conducted by international and local scientists and volunteers to underpin this work. Participants in the project include local stakeholders, students and early career scientists from Africa and Asia, corporate employees from major international companies, and self-funded volunteers recruited by Earthwatch. The engagement of a wide range of people and the building of trust over many years has proved critical to long term project success.

Approaches Used and Data Collected

In 2003, work began to research techniques to restore mangroves and associated marine ecosystems and to evaluate the carbon stocks they hold. In collaboration with Earthwatch, 253 individuals from 48 countries have taken part in the research and conservation activities. Tasks have included:

- planting trees as part of experimental studies and for general conservation and restoration purposes - over twenty thousand mangrove trees have been planted and measured over 20 years;
- monitoring established experimental stands to measure how trees are growing and surviving and which species combinations are best suited for restoration; and
- measuring the amounts of carbon accumulated above and below ground by different species of trees.

These data have led to a greater understanding of mangrove forests and their management – including effective restoration. The work has helped to clarify the role of mangroves in storing carbon and has used experiments to measure carbon losses arising from deforestation. The Mikoko Pamoja initiative ('Mangroves Together' in Kiswahili) was launched in 2009 to apply this research and use payments for ecosystem services (specifically, payments for carbon credits) to safeguard conservation gains and improve the quality of life of the local community. This research has led to the development of the first community mangrove conservation project to be funded by the voluntary carbon market, after gaining formal accreditation to sell carbon credits through the charity Plan Vivo. This project involves collaboration between local, national and international bodies:

- The Mikoko Pamoja Community Organization is run by nominated community representatives from Gazi Bay; all expenditure of project funds on local projects is determined following full community consultation.
- The Mikoko Pamoja Steering Group provides technical support and consists of staff from the Kenya Marine and Fisheries Research Institute, the Kenya Forest Service, the Tidal Forests of Kenya Project, Edinburgh Napier University and Earthwatch.
- The Association for Coastal Ecosystem Services is a charity registered in Scotland that facilitates the transfer of international funds, organises charitable fundraising and education and reports to the Plan Vivo Foundation (the organization that grants official accreditation of carbon credits).

Successful Outcomes

Specific project outcomes include: generation of new scientific knowledge in the form of 15 peer reviewed publications; increased technical skills and income to local people employed to assist with carrying out project functions; enriched opportunities for women through their representation within the village committee; training to 30 local school students and four master's students each year; investment in 12 future conservation leaders from developing countries each year through immersive training programmes and mentoring; improving sustainability of local fuel and timber sources through the planting of woodlots (which will also provide timber for sale to raise funds for community projects); enhancing ecosystem services through the protection of ~120 hectares of mangrove forests; locking away 2500 tonnes CO_2 per year, derived from avoided deforestation, prevented forest degradation and new planting; providing an income of ~£8000 each year from carbon credit sales, which is used to run the project and support community development; investing in community-led local livelihood projects such as beekeeping and tourism.

This pioneering carbon project is a triple win for community livelihoods, biodiversity conservation and climate change mitigation. More generally, the project at Gazi Bay has provided a greater understanding of sustainable mangrove utilization, and demonstrated the opportunities for community-based conservation of mangrove forests supported in-part by carbon credits. There is huge potential (and interest in) this model in Kenya and elsewhere, and the intention is to act as a catalyst and support for similar projects. The project has established a regional expert network to disseminate knowledge and help support similar initiatives: the East African Forum for Payments for Ecosystem Services, www.eafpes.org. Expansion at both the current site and other sites along the coastline will help to generate security in the face of fluctuating carbon markets, and bring benefits for local livelihoods, biodiversity and climate change mitigation.

6.4.12 Community-based Monitoring of Carbon Stocks for REDD+, Asian countries

Climate change has been identified as one of the biggest threats to society and our environment as a whole. Reducing CO_2 emissions can mitigate the threat of climate change. REDD+ is a proposed financial mechanism that can provide incentives to developing countries to reduce CO_2 emissions and increase CO_2 removal from the atmosphere by forests (Ghazoul et al., 2010). A "Monitoring and Measurement, Reporting and Verification" (MRV) system is needed for REDD+. Monitoring of forest carbon stocks can involve both remote sensing and in-situ measurement. The United Nations Framework Convention on Climate Change recognises that REDD+ may, in some cases, harm biodiversity and local livelihoods and has asked for safeguards to be implemented to ensure that REDD+ is consistent with the conservation of natural forests and biological diversity (Gardner et al., 2012). The Convention for Biological Diversity (CBD) is likewise calling for countries to identify potential indicators and monitoring mechanisms for assessing the biodiversity impacts of REDD+.

According to the REDD+ monitoring and implementation requirements, it is important to involve local community groups and societies to carry out forest monitoring, in particular, if there is any prospect of payment and credits for environmental services. There are several reasons why local communities should be involved in monitoring forest carbon stocks and biodiversity for REDD+ (Larrazábal et al., 2012; Boissière et al., 2014). Firstly, it is just and fair that local communities are informed of, and invited to participate in, activities pertaining to the forest areas that are central to their livelihoods (Skutsch et al., 2011; Danielsen et al., 2013; Butt et al., 2015). Secondly, it can help to address the concerns of local people that their existing forest use rights and benefits will not be undermined by top-down REDD+ implementation (Burgess et al., 2010). Thirdly, the participation of local communities can help link the monitoring to decision-making and this can lead to increased local forest management capacities (Gibson et al., 2005; Danielsen et al., 2007; Pratihast et al., 2013).

The role of community monitoring for REDD+ has been explored in several projects, including K:TGAL (Kyoto: Think Global, Act Local[30]; Skutsch, 2011), Land use and climate change interactions in Central Vietnam (LUCCi) and I-REDD+ (Impacts of Reducing Emissions from Deforestation and Forest Degradation and Enhancing Carbon Stocks) projects. This case study describes the approaches used by the I-REDD+ project, which was funded by the EU and led by the University of Copenhagen, NORDECO and partner organisations during 2010-2014[31]. One component of this project compared community-based and professional forest monitoring of forest biomass and biodiversity in forested landscapes in six field sites in China, Indonesia, Laos and Vietnam (Brofeldt et al., 2014).

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[30] http://www.communitycarbonforestry.org

[31] http://www.i-redd.eu; www.monitoringmatters.org

[3] http://www.lucci-vietnam.info/

Approaches Used and Data Collected

The I-REDD+ project worked with local partner organisations which, in the spirit of Free, Prior and Informed Consent (United Nations, 2008), contacted local communities living close to the forest and dependent upon forest resources for their livelihood. Communities choosing to become involved in the project participated in mapping and zoning of the local forest and proposed a stratification that reflected forest type and tree density (Brofeldt et al., 2014). A network of permanent circular plots for structured random sampling was established within each stratum. After a short training session, the community members established plots and measured all trees with diameter at breast height (dbh) > 10 cm within those plots. Some of the participating communities agreed to try to identify the species of all the measured trees. Carbon estimates were calculated using the dbh measurements and appropriate allometric equations. Professional foresters measured the same trees and the results of community monitors and professional foresters were compared.

Successful Outcomes

The I-REDD+ project built, to a large extent, on the lessons learned in the K:TGAL project, which had shown that local communities using hand-held computers could monitor forest carbon stocks in relatively simple-structured forests (Peters-Guarin and McCall, 2011). The I-REDD+ project took this a step further by excluding the use of computers in the field and assessing carbon stocks of complex, species-rich old-growth forests (Danielsen et al., 2011, 2013). The rationale was that reliance on the use of hand-held computers (Peters-Guarin and McCall, 2011; Pratihast et al., 2012) may represent a constraint to community involvement and the broad-scale implementation of local community monitoring of forest condition because capacity is limited in some communities (Howell, 2012). Employing low-tech field approaches, such as recording of data using pen and paper, measuring using ropes marked at relevant points, and utilizing other feasible protocols for local communities, may greatly enhance the application of the local approach to monitoring forest condition. The results showed that members of rural communities can monitor and measure levels of carbon stock even in complex, old-growth forests without the use of electronic devices (Brofeldt et al., 2014; Torres and Skutsch, 2015). An overview of who is involved in community-based monitoring of forests and where they are working is provided on the Forest COMPASS website[32] .

Combining REDD+ and Biodiversity Monitoring

There has been limited attention on how local communities can become involved in monitoring the biodiversity impacts of REDD+ (Gardner, 2010; Gardner et al., 2012; Swan, 2012; Enright, 2014; Hawthorne and Boissière, 2014; Latham et al., 2014; McCall et al., 2014). A central question is whether data on biodiversity can be collected while community members are already gathering carbon stock data. We know of three examples of this. Firstly, community members that meet regularly to discuss forest-related issues such as REDD+, the use of forest products and forest management can be encouraged to discuss trends in biodiversity, using the Focus Group Discussion method. Focus groups have the potential to provide results that are similar to results obtained from monitoring by professional scientist (Danielsen et al., 2014b). Focus groups are particularly useful in providing early warnings of changes in biodiversity. Secondly, community members can be encouraged to take notes on any encounter with selected rare but easily recognisable species (howling gibbons, hornbills heard flying above the canopy, calling pheasants, bear markings on trees, etc.; Padmanaba et al., 2013). Thirdly, permanent plots for monitoring carbon stocks, as done by community members in the K:TGAL and the I-REDD+ projects, can also be used to provide valuable biodiversity information. They can be used to provide data on forest type and structure (density and size of trees) (Theilade et al., 2015) and, in some cases, even on tree species diversity (Zhao et al, 2016). If funding permits, additional biodiversity monitoring

[32] http://forestcompass.org

activities can be undertaken, similar to the activities described in other sections of this chapter. See section 8 for synergies between biodiversity monitoring and REDD+.

6.4.13 Community-based Monitoring of Activity Data for REDD+, Kafa Biosphere Reserve, Ethiopia

The Kafa Biosphere Reserve is located in the south western part of Ethiopia. Expanding around 700K ha in size, the reserve achieved UNESCO recognition in 2011. This area contains some of the last remaining forests in Ethiopia, which are comprised of large areas of mountainous afromontane cloud forest (Pratihast et al., 2014). Kafa Biosphere Reserve is very important from an ecosystem service point of view as the wild coffee Arabica originates in this area. Wild coffee, as well as high value spices and honey, obtained from these forests are important for the livelihoods of the local communities. However, increasing pressure from the expanding Small-holder agriculture continues to threaten the forest (Pratihast et al., 2014) while, at the same time, climate change could drastically reduce the areas where wild coffee can grow in the future (Davis et al., 2012).

Community-based forest monitoring in the context of REDD+ is one mechanism for safeguarding local livelihoods, especially if this activity is linked to an incentive scheme such as payments or credits (Pratihast et al., 2013). Community-based monitoring can also play an important role in contributing to national-level forest monitoring systems (NFMS) for MRV as outlined in the previous case study (section 6.4.12), which focused on carbon stock data. This case study considers activity data referring to forest area change (generally measured in hectares) for MRV purposes. This is normally undertaken using remote sensing in combination with field measurements by professional surveyors. The main concern with community involvement in MRV is the lack of confidence in data collection procedures and unknown quality of such data set for their integration in the NFMS. To this aim, Arun Pratihast (and colleagues) at Wageningen University & Research, Mesfin Tekle of the Nature and Biodiversity Conservation Union in Ethiopia and community members made an approach to combine the use of high-resolution satellite imagery and forestry expert measurements to assess the accuracy and consistency of community monitoring data in Kafa Biosphere Reserves, Ethiopia in terms of spatial, temporal and thematic category. The results of the study shows that the local communities were capable of describing processes of change associated with deforestation, forest degradation and clearly demonstrated the value of community involvement in forest monitoring of activity data. Full details of the study can be found in Pratihast et al. (2014).

Approaches Used and Data Collected

The data collection task was undertaken by 30 community members. These community members were recruited within the frame of the project entitled “Climate Protection and Primary Forest Preservation—A Management Model using the Wild Coffee Forests in Ethiopia as an Example”. All selected community members were educated personnel, to a minimum of secondary level high school, and some fundamental understanding on forest management and conservation in the Kafa Biosphere Reserve. These community members were concurrently involved in activities such as the development of ecotourism, education and reforestation activities, and therefore had some basic experience of forest management. By ensuring that recruitment was geographically balanced across the 10 administrative districts in the area, a strong community representation was created.

Two mechanisms for data collection were employed: paper-based forms with separate GPS devices to capture location; and mobile phones using a survey-style app built from the open source ODK (Open Data Kit) Collect. Community members were trained through events that took place before and during the forest monitoring activities, and user-friendly training materials were provided. The community members collected data from

755 locations between January 2012 to December 2013; paper forms were used in 2012 while a shift to mobile phone data collection occurred in 2013.

Unlike other examples of community-based REDD+ projects (Danielsen et al., 2011, 2013; Shrestha et al., 2014), which have focused on measuring carbon stocks, the data collection here was centred on the monitoring of forest change processes. Three main categories of data were collected:

- Spatial category: Three aspects of the spatial category of the local experts' data were collected, including categorical location information, GPS location information and the estimated size of forest change. The deforestation areas were mapped on the ground while the central location and area affected were recorded for degradation.
- Temporal category: The time of forest change (day, month and year) was acquired under this category.
- Thematic category: The type of change (deforestation, degradation, reforestation), drivers of change (agricultural expansion, settlement expansion, charcoal and firewood extraction, intensive coffee cultivation, timber harvesting and natural disasters), with documentation consisting of photographs taken in four cardinal directions, were collected in this category.

As mentioned previously, a key component of this study was the assessment of data quality, in particular for MRV purposes and for potential scaling up to national level reporting. An accuracy assessment was performed across all categories of community acquired data sets. Field reference data were collected by a team of local and regional experts who revisited 140 randomly chosen sites at the end of 2013. A time series of high resolution imagery between 2005 and 2013 (including pan-sharpened SPOT and RapidEye images) were used to manually digitize areas and to identify the time of forest change.

Outcomes

In general, the results of the study show that community members were able to document forest change processes, where accuracy varied depending on the category of data collected. The spatial accuracy varied between 71 to 92% for different spatial categorizations of change (Administrative units, Distance to nearest village, Distance to nearest road and Distance to core forest). The positional accuracy (GPS errors) reported by community members compared with those reported in the reference data showed a slight systematic error on the order of 0.65 m.

For large change areas, i.e. greater than 2 ha, the community members systematically underestimated the size of the change. For the time of change, 33% of deforestation events were accurately reported when compared to the remote sensing analysis while 45% was reported 1 to 2 years later than indicated by remote sensing. Forest degradation, on the other hand, was reported earlier than remote sensing for 54% of degradation occurrences, reflecting the advantage of a ground-based approach over remote sensing. Finally, recognition of the type of change and the presence/absence of forest were documented with high overall accuracy (83 to 94%) while drivers of forest change, which were more complex to assess, were still documented to a reasonable accuracy of 69%, assuming that the experts monitoring represented the "truth".

Relevance for Earth Observation

The data collected through community-based monitoring represents a complementary data stream to remote sensing observation, where the latter will continue to have a clear role to play in forest change monitoring and detection. Remote sensing requires ground-based data for calibration and validation; community-based monitoring represents a cost effective way to acquire in-situ data on both forest cover and change over time.

However, it can also provide additional information on drivers of change and other land use information that is beyond the capabilities of remote sensing. In addition to land cover and land use (Table 6.3.1), this study documented drivers of change, which partly addresses the EBV of disturbance regime within the broader class of ecosystem function. It might also be possible to extend the types of data collected to other environmental monitoring variables such as biodiversity, plant species type and phenology. Thus, the integration of other environmental monitoring variables may have potential for including community-based monitoring in monitoring and benefit-sharing systems in REDD+ projects (Visseren-Hamakers et al., 2012).

6.4.14 Community-Based Monitoring of Philippine Protected Areas

Until the 1990s, the most protected areas in the Philippines existed only on paper. In 1992, a new protected area act, the National Integrated Protected Areas System Act (DENR, 1992), allowed for community participation in management of protected areas. In 1996, the World Bank and Danish aid (DANIDA) agreed to assist the Philippine government to operationalize the new act, and for three years they worked together to develop a simple scheme for monitoring protected areas based on observations undertaken and interpreted by community-members and protected area rangers.

Representatives of the local communities in each community helped the government select community participants on the basis of their interest in and experience with forest resources. The community participants included some of the most experienced collectors of forest products in each community. Most of the community participants had attended only primary school and had a limited ability to read and write; however, in each community there was at least one literate participant.

The scheme was intended to identify trends in important biodiversity assets and to use these trends to guide management action in protected areas. It was also intended to enhance participation of protected-area communities in management of the protected area.

The scheme was developed by the government's Biodiversity Management Bureau in cooperation with Nordic Foundation for Development and Ecology (NORDECO). It is a category 4 Collaborative Monitoring Scheme with Local Data Interpretation (*sensu* Danielsen et al., 2009). Foreign support to the scheme ceased in 2001 but the scheme continues at most of the sites where it was established.

Approaches Used and Data Collected

Data were collected by government rangers and volunteer community members. The aim of this monitoring system is to ensure better management and the involvement of local people rather than data-based falsification of scientific hypotheses concerning variation in biodiversity values. By allowing park staff to carry out the field assessments, this monitoring encourages them out of their offices and into the field and improves their understanding of park issues and thus their capacity for park management (Danielsen et al., 2000). In each park, monitoring focused on a list of 10–15 taxa and 5–10 signs of resource use (usually large terrestrial mammals, easily identifiable birds, crocodiles, marine turtles, fish and shellfish). The targets of the monitoring were selected by local community members together with protected area staff. Data were collected every 3 months. Data interpretation was undertaken locally by the protected-area staff and community members, and a small report was presented every quarter to the Management Council of each protected area. The report included the data set, a list of important observations of changes in species and resource use, and a list of proposed management interventions with a description of the issue identified, the location, and the proposed action to be taken by the protected-area council (Danielsen et al., 2005b).

Successful Outcomes
Before this monitoring scheme was established, there was little collaboration between local people and park authorities, and park monitoring was restricted to assessments of the quantity of extracted timber (Danielsen et al., 2005b, 2007). As a result of 2.5 years of operation of the scheme by 97 rangers and 350 community volunteers, 156 interventions were undertaken in terrestrial, marine, and freshwater ecosystems across 1.1 million ha of 8 protected areas in the Philippines (Danielsen et al., 2005b). The majority of these interventions were meaningful and justified, 47% targeted the 3 most serious threats to biodiversity at the site, and 90% were implemented without external support. By ‘‘the most serious threats’’, we mean the human activities with the most negative impact on the areas’ conservation values. Based on existing information on each park from other sources, the three most serious threats of each site were identified as industrial and road development (four sites), logging and timber poaching (four sites), small-scale agriculture (four sites), large-scale agriculture (three sites), and commercial marine fishing (three sites), along with gathering of non-timber forest and wetland products, grazing, wildlife hunting, and quarrying (one site each).

Many of the interventions were jointly undertaken by community members and the management authorities or consisted of local bylaws in support of park management. As a result of monitoring, schemes to regulate indigenous resource use were reestablished with government recognition in several parks. Monitoring led to more-diversified management responses on the part of the authorities, including a more socially acceptable and effective approach to enforcement. The findings by the community members closely correspond with findings by professional scientists (Danielsen et al., 2014a). The government has promoted the scheme as a standard management tool in protected areas, and it has spread to new sites. In 2012, there were 435 community member participants in the scheme (Jensen *in litt.*, 2013; Danielsen, 2016).

6.5 LESSONS LEARNED FROM COMMUNITY- AND CITIZEN-BASED MONITORING PROJECTS

One of the common themes found in the case studies, and certainly expressed in current reviews of citizen science (Azavea and SciStarter, 2014; Theobald et al., 2015) revolves around balancing the objectives of:

- increasing contributions to answering research questions pertaining to status and trends of key EBVs through accessible regional databases,
- enabling the application of management decisions based on sound monitoring, while
- maintaining relevance to key local partners and participants through the flexible and responsive development of projects that reflect local interests and perspectives.

Achieving potentially divergent goals (i.e. collecting standardized data for top down directed goals vs. meeting the identified needs of participants through bottom up project design) is, however, possible, as these case studies, and others demonstrate. One key approach that is common to most successful projects is that leaders of the monitoring program have sought to identify and incorporate benefits or local relevance for the different participants with whom they were working. Leveraging communication tools that allow for discovery, use or value generation by the participants is clearly a rich avenue to explore in fostering benefits for the participants. See, e.g., case studies Project COBRA (section 6.4.6), and the Natural Phenology Network (section 6.4.8) for communication tools for community-based monitors and citizen monitors, respectively.

Many of the case studies illustrate the power of building field research monitoring programs that leverage three distinct groups of participants: local community members, citizen science monitors (often away from their "homes"), and the field research team (scientists, resource managers (e.g. rangers) and often biology students) (see Figure 6.5.1).

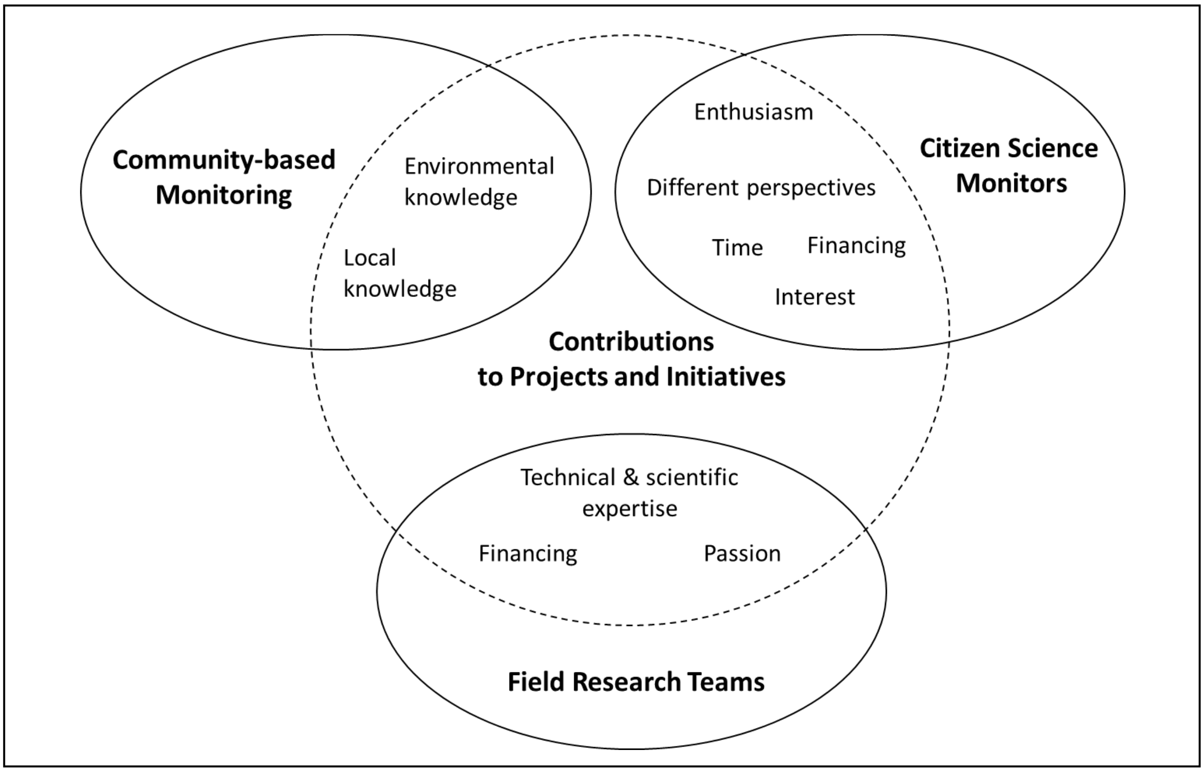

Figure 6.5.1: Synergies between groups of participants in contributing to projects and initiatives

Each of these groups brings important contributions to a successful monitoring program. For example, local community members bring knowledge about the environment derived from experience that is not otherwise available to the other two groups; citizen science monitors can bring additional resources (time, experiences, financing, interest) that extend the monitoring, and the research team brings technical expertise, and other resources, usually not found in the other two groups. It should be mentioned that there is at least one other avenue of support to biodiversity monitoring programs, i.e. the engagement of the public from their homes, who lend their time and online resources to make observations, review images, detect patterns, etc. that otherwise would overwhelm the limited number of highly trained monitoring staff (e.g. Ellwood et al., 2015). Zooniverse is one of the best examples of such programs.

Many of the outcomes identified through the case studies can be attributed to optimizing the synergies between community-based monitoring, citizen scientists and the research field team. For example, in the Pacaya-Samiria case study in Peru (section 6.4.1), the local community brought local knowledge and legitimacy, foreign citizen scientists (e.g. Earthwatch volunteers, Operation Wallacea students) brought additional hands in the field, enthusiasm, interest and financing, and the field research team (including trained Peruvian university students) brought technical know-how, helping to train and direct the monitoring programs. Each group contributed unique resources, but also derived important values from each of the other groups. In this case, the interest, energy and enthusiasm of the citizen scientists enhanced the commitment and attention to the monitoring program by the other two groups, as evidenced on teams where the citizen scientists were absent. Secondary benefits can emerge from such blended projects. In the Community-Based Monitoring project of Philippine Protected Areas (section 6.4.14), the blending of both park rangers and local community members not only increased the capacity of both groups in field surveys but enabled the development of a closer working relationship between the two groups which had heretofore not existed.

Successful use of community members or citizen scientists does not require the whole blending of these approaches, and most start with one group and then evolve over time. For example, in both the Loma Alta (Ecuador) (section 6.4.2) and the Pacaya Samiria (Peru) (section 6.4.1) case studies, the projects started by assessing characteristics that were of high value to the local community (water in Ecuador, hunted mammals in Peru) and then blended in other habitat and biodiversity monitoring subsequently.

The rest of this section considers a number of key issues relevant to citizen science projects and community-based monitoring, including setting up a project; considerations around recruitment, training and sustainability; the management and sharing of the data collected by the communities and citizen volunteers; the quality of the data, which continues to be a key issue within citizen science (Nature, 2015), and mechanisms for communication and feedback. Guidance on these issues from the published and grey literature are provided along with relevant lessons learned from both the case studies and author experiences.

6.5.1 Setting up a project

A significant number of resources exist for developing citizen science projects, whether to start a project of your own or building on what others have done. The same basic standards and principles apply to engaging citizens in biodiversity monitoring. Resources for developing projects can be found at:

- http://www.birds.cornell.edu/citscitoolkit/toolkit/manual
- http://www.ceh.ac.uk/products/publications/documents/citizenscienceguide.pdf
- http://www.birds.cornell.edu/citscitoolkit/publications/CAISE-PPSR-report-2009.pdf/view

A large number of model projects are available from:

- http://scistarter.com/
- http://earthwatch.org/expeditions
- http://www.birds.cornell.edu/citscitoolkit/projects

Furthermore, http://www.citsci.org has a platform for developing citizen science projects that includes standardized templates and support for data collection, storage and mapping, among other features.

One important consideration when setting up a citizen science project is the desired scale of the project. Haklay (2015) reviewed citizen science projects in Europe and found the infrastructure needed to scale up from local to regional is significant and often beyond the means of many smaller scale organizations.

6.5.2 Recruiting, training and maintaining participants

Key aspects for successful project development include:

- identifying the needs, e.g. the numbers, time commitment needed (both total amount of hours but also when), the kind of data to be collected, etc.;
- who the participants will likely be (local community members, visitors, etc.);
- what the likely motivation for participating is; and,
- why the research or monitoring goals of the program might be relevant to the participants.

Identifying the appropriate communication "tools", processes and feedback systems is of particular importance to keeping the alliance between "project leads" and the participants, be they communities or citizen scientists "external" to the region being studied. The use of cameras or videos for monitoring can be extended by community members to include indicators of specific interest to the monitoring project as well as others that may also be of principal interest to the participants (e.g. see the case study on Project COBRA in section 6.4.6).

Projects that focus on ***community-based (ecosystem) monitoring*** often emphasize sustainable resource management, biodiversity monitoring and greater involvement in decision-making at the local level (e.g. community forest reserves, Pacaya Samiria and Loma Alta case studies in sections 6.4.1 and 6.4.2). Evans and Guariguata (2008) have reviewed many examples of approaches taken in the creation of successful community-based monitoring of forests. Many if not most rural community members adjacent to tropical forests will likely have little formal education, and have little time or financial wealth to dedicate to hobbies. Here we assume that the primary motivational factors for community participation are clear benefits to them in terms of improved management of key resources that they will benefit from - in terms of sustainability and access to these resources, jobs, etc., or valuable co-benefits including improved overall surveillance of their community lands with the potential of warding off other detrimental incursions on their lands. Typically, community-based monitoring initiatives are only successful if they are co-designed together with key community members to ensure that the language, goals, and end products of the program are internally consistent with the community as well as the end users of the data.

Projects that focus on ***citizen science monitoring*** typically include participants that are both local and distant to the study area and share an enthusiasm for being outdoors (see e.g. the Natural Phenology Network case study in section 6.4.8). These projects are directed by external institutions, i.e. scientists, government agencies, etc. The main driver for those who are leading these projects is the need for data collection to assess status and trends of natural resources of interest, with secondary goals being greater education or engagement of the general public. Many (if not most) participants to these contributory citizen science projects have above average income (or their parents do) and formal education, and dedicate time and resources to nature-based hobbies (e.g. birding, hikers, etc.). Typically participants do not directly depend on the biodiversity observed for their livelihoods (e.g. Cornell's Lab of Ornithology Backyard Birds), and their primary motivation is to help some management authority or science institution to better understand the state of the environment and thereby enable better decision making in a way that is consistent with their beliefs. Reflecting the diversity of potential citizen science participants is a diversity of motivations including just getting out into nature, having fun, meeting other like-minded people, contributing to science, helping monitor the state of the planet, etc.

Capacity building is often an essential need that enables the transfer of methodologies and communication across audiences and key stakeholders in such programs. A number of organizations are developing modules to train field leaders of citizen science projects. Earthwatch Institute trains senior field scientists and staff to successfully lead teams of public participants to ensure that project leads get the data they need, and participants have a meaningful and safe experience. Building capacity is essential to ensuring that both project leads but also the participants have the capability and confidence to carry out the tasks to the level needed for a successful project. The Citizen Science Academy trains educators to lead citizen science projects on a number of different kinds of projects (citizenscienceacademy.org) including phenology through project Budbust (www.budburst.org).

Finally, a clear understanding of the resources that are needed and available is essential. This includes any financial, technological, personnel, and infrastructure resources that would enable the project to succeed. Developing and sustaining citizen science projects requires a non-trivial amount of resources to succeed.

6.5.3 Data collection: management and sharing

The data management plan for programs, which include community and citizen participants, needs to emphasize several key components. Several useful resources for data management and sharing include:

- Data Policies for Public Participation in Scientific Research: A Primer, DataONE Public Participation in Scientific Research Working Group, August 2013 http://www.dataone.org/sites/all/documents/DataPolicyGuide.pdf

- Data Management Guide for Public Participation in Scientific Research, DataONE Public Participation in Scientific Research Working Group, February 2013 http://www.dataone.org/sites/all/documents/DataONE-PPSR-DataManagementGuide.pdf

- Primer on Data Management: What you always wanted to know but were afraid to ask, Carly Strasser, Robert Cook, William Michener, Amber Budden http://www.dataone.org/sites/all/documents/DataONE_BP_Primer_020212.pdf

- Citsci.org, which is an example of a useful data collection, storage and sharing platform. See Azavea and Scistarter's 2014 publication, which summarizes a review of platforms at:
  http://www.azavea.com/index.php/download_file/view/1368/

The purposeful sharing of data is a key criterion to be decided early on in the creation of a project. For example, will participants have access to their data, to the data of others, and how accessible will the data be to partners? What sort of attribution needs to be made to the data collectors when data are used and aggregated into other databases?

It is often thought that the motivation and maintenance of participants in citizen science projects can be tied to the relevance they see in the data that they collect. Visualizing their own data or the data that citizen scientists collect in some sort of summary format against monitoring questions of interest can help keep participants engaged. See Sheppard et al. (2014) to see some of the solutions for tagging volunteer-collected data as it migrates through databases.

6.5.4 Quality assurance

Participants can be trained to reliably collect a wide variety of data, covering most of the EBVs. Earthwatch supports many projects where scientists are able to train citizen scientists to collect trustworthy data on many variables (www.earthwatch.org). Danielsen et al. (2014a) studied the similarity in data on status and trends of tropical forests collected by both community members and scientists across 34 tropical forest sites and 4 countries (Madagascar, Nicaragua, Tanzania). In general they found high correlations for species counts as well as 5 types of resource use. Their findings concurred with their review of previous studies that suggested that community members can in fact report the same data as "scientists". Discrepancies only occurred when there was a notable separation in where samples were collected or if there was a significant time lag between data collection efforts. Similar positive correlations between community collected data and professional foresters on forest carbon stocks was reported by Brofeldt et al. (2014), who looked at 289 plots across four countries in South-East Asia.

The ability for non-specialists to collect reliable data depends greatly on the amount of training, and the kind of oversight and support that is provided. One key factor is the degree of confidence that the data collector has in their abilities (Buesching et al., 2014). There are several papers which discuss general approaches to training and motivation that enhance the quality and consistency of the data collected. See Newman et al. (2003); Wiggins et al. (2011); and Buesching et al. (2014) for examples of approaches.

Initially, citizen science monitoring projects may expect to invest more heavily in having "experts" to review the data collected by participants, verifying both outliers and novel observations, but also "normal" observations. This initial phase serves to identify problem points, enhance training and clarity of data collection tools, as well as building towards the next phase, which may include a more automated data quality reviewing process. This second phase often takes the shape of post data collection screening tools, whereby set criteria are used to identify potential anomalous data points, which can be reviewed by experts; atypical observations can then be verified or removed. This second stage should be less intensive on the time of the "experts".

A third stage for more developed programs (e.g. eBird) leverages models that are built to predict future observations against which new observations can be assessed.

Given that many citizen science programs remain in the first phase of data screening, setting appropriate expectations on the investment needed for "experts" to review and verify the data is important. This is one positive attribute of large scale programs such as iNaturalist and iSpot, which have developed a very large community of reliable observers to verify the observations.

6.5.5 Use of technological tools to enhance data collection.

There are several technology-enabled tools to facilitate the collection and sharing of biological observations. By combining mobile observation systems with communities of experts, the ability to greatly increase observations by the public is potentially unleashed. Given the increase in capable software programmers, ease of web hosting and the need for technology-enhanced data collection, storage and sharing, it is not surprising that many apps and websites exist to support field data collection, interpretation and sharing. It is beyond the scope of this chapter to review the strengths and weaknesses of the different programs. Instead, we share information about a small number that are well established globally in order to illustrate the potential.

iNat (www.iNat.org) and iSpot (www.ispotnature.org) are two examples of web and app enabled platforms that can be used across much of the globe to record observations that have established communities of "experts" who can identify or verify observations. Once verified, these observations are uploaded into the Global Biodiversity Information Facility (GBIF) where national inventories can access them for their reporting purposes. Whereas iNat and iSpot are open to all species, other platforms such as *eBird* are very much focused on specific taxa. In fact, *eBird* leverages the passion and enthusiasm of birders globally and is the single largest contributor of biodiversity observations to GBIF (http://ebird.org/content/ebird/news/gbif/). These established platforms have significant communities that support them. Their use is further refined by an ability to create one's own projects that help focus on specific regions of interest, including species lists, etc.

Furthermore, some of these programs can be enhanced by creating versions in local languages and tailored to local interests (see http://naturalista.conabio.gob.mx/ for a Mexican version of iNaturalist).

These technological tools are further enhanced by cross-linking to other web programs such as the Encyclopedia of Life (http://www.eol.org), which themselves are further repositories of information relating to species. For example, EoL has created Traitbank, which is a repository of traits associated with species, many of which are EBVs (http://eol.org/info/516), and GloBI, which provides access to biotic interaction datasets. Finally, there are other platforms that operate at scale or support the development of programs that seek scale. For example, there are many country-based platforms such as the National Biodiversity Network in the UK and the India Biodiversity Portal among many others, taxa-based platforms such as eBird or platforms that clearly contribute to a particular EBV such as Nature's Notebook and Project BudBurst, which focus on phenology.

Moreover, there are platforms that seek to support the development of local initiatives by providing common tools, database standards and interfaces. By creating common standards, programs such as citsci.org enable local efforts to share their data more widely and increase the value of these varied contributions. Most of these platforms remain, however, in English and are only accessible to users with smartphones or other expensive communication devices. The digital divide remains a real barrier to access.

Several new approaches are evolving to enable programs with fewer resources or in more remote areas to develop apps that are much more tailored to local audiences. Two examples of such approaches are OpenDataKit (ODK - http://www.opendatakit.org) at the University of Washington, and Sapelli (https://www.ucl.ac.uk/excites/software/sapelli), which is built on top of ODK, at the Extreme Citizen Science (ExCiteS) lab at University College London (http://www.ucl.ac.uk/excites). The list of example deployments for ODK is extensive, with several looking at supporting the monitoring of forests, agricultural fields and water sources among other (https://opendatakit.org/about/deployments/). The goal behind ODK is to provide relatively straightforward do-it-yourself kits to building data collection and sharing tools for local projects. ExCiteS has exciting new programs looking at building local apps for forest monitoring using the icon-based interface of Sapelli, which can serve both the local community needs, but also the needs of governments and corporations as well.

6.5.6 Communication and feedback

As emphasized by many of the case examples, communication is key to building and maintaining a monitoring program that is relevant to its contributors and users, whether they be community members or participants that live external to the location. Identifying the appropriate media, the content and the messaging that best engages the different audiences can be a challenge given the potential for multiple languages, interests, and varying access to different media. As such, this is a vigorous area of research in the field of citizen science to identify best practices and provide guidelines.

The Project COBRA case study (section 6.4.6) explores some interesting approaches to creating stories and feedback that enhance the value of the program to local communities. For more information, see the Project COBRA Handbook entitled: How to Find and Share Community Owned Solutions at: http://projectcobra.org/how-to-find-and-share-community-owned-solutions. This Handbook, available in English, Spanish, Portuguese and French, specifically shows how to engage community members in identifying their own indicators of social-ecological viability using participatory visual techniques. Examples of participatory films and photostories can be found on the MediaGate: http://projectcobra.org/media-gate.

Creating mechanisms to solicit feedback from key users, and demonstrating to users that the program is listening to them is one obvious means of engagement that can be very powerful. This requires dedicated investment in communication and feedback, and time and resources should not be underestimated. Ultimately the building of a supportive community is essential to the long term success of any citizen science project.

6.6 SUMMARY

This chapter illustrates a small number of approaches that can be undertaken to meaningfully engage the broader public in data collection activities that complement and contribute to Earth Observations. Many of the examples demonstrate the potential for citizen science projects to complement EO, especially around the Essential Biodiversity Classes of Species Populations and Species Traits. This is especially true for species occurrence and species trait data (e.g. tree dbh), and certain species with well-developed methodologies and interest groups (e.g. birds, butterflies, large mammals) or species of value to local communities (e.g. hunted or fished species). The spatial and temporal distribution of the power of the many people is especially effective and perhaps even essential to cover the large landscapes at the resolution necessary to corroborate data collected by EO. Programs such as eBird and iNaturalist are already the greatest contributors to GBIF observations for many species.

A number of citizen science programs are developed to cover large scales (e.g. Brazil's National Biodiversity Monitoring Program (section 6.4.7) and the National Phenology Network - section 6.4.8), as are the website-enabled programs using apps (e.g. iNaturalist; eBird, Naturalista). Moreover, there are large country-wide assessments of species occurrence for a number of taxa, particularly in Europe (http://butterfly-conservation.org/; http://www.ukbms.org/; Pocock et al., 2015). A large country-wide citizen science study of decomposition rates coordinated by university scientists was found to yield valuable data and was one-quarter the cost of doing the project with paid staff.

Nevertheless the great majority of citizen science projects are focused on a more narrow spatial and temporal scale and do require significant investment to be successful. The scaling up of citizen science to contribute to national level programs will require several key factors. First, careful attention to the needs and interests of the participants (in effect co-design for both top down (i.e. data needs) and bottom up (i.e. participant needs) benefits is essential to the development of sustained and successful programs. Projects that successfully blend different kinds of participants (e.g. community members, citizen science monitors, technical monitors and experts) will yield secondary benefits. Investment in the professional development or capacity building of key stakeholders across regions is essential to ensure standardization of data collection efforts. Careful design of data management including data interoperability and the sharing of data across the system and users is important to demonstrate the usefulness and value of the programs. Finally, citizen science is a social process. Programs that integrate regular gatherings and attentive communication with all users can build an army of support and contributors that can pay off multi-fold.

Citizen science and community-based monitoring can be considered as essential inputs to the collection of tropical biodiversity data, complementing EO and other tools. Emerging techniques and protocols are being developed that should increase the effectiveness and reliability of citizen science programs, and we look forward in particular to developments that leverage citizen science community-based monitors at scale.

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