KBA+

Assessing the ecosystem service values of Key Biodiversity Areas

Framework and Pilot Demonstration: Madagascar

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Executive Summary

Conservation strategies to address biodiversity and ecosystem services have typically been developed separately. Key Biodiversity Areas (KBAs), sites contributing significantly to the global persistence of biodiversity, have served as a guide for many biodiversity conservation strategies, investments and other governance mechanisms. With the support of the Critical Ecosystem Partnership Fund, Conservation International (CI)'s Betty and Gordon Moore Center for Science and Oceans and CI-Madagascar collaborated to develop "KBA+", a framework for assessing and documenting the ecosystem service values of KBAs and surrounding areas.

This document discusses the proposed framework, which consists of a recommended process (a set of steps), as well as suggested technical methods for assessing key ecosystem services. It also describes a pilot demonstration of the framework, an assessment of the ecosystem service values of KBAs in Madagascar.

The KBA+ methodology includes seven steps:

1) Scope key ecosystem service values within and around KBAs
2) Develop narrative description of ecosystem service values
3) Identify criteria for assessing important areas
4) Apply criteria to identify and map important areas within and around KBAs
5) Summarize ecosystem services values for KBAs
6) Review and refine results
7) Develop recommendations and integrate into CEPF profile

This pilot analysis in Madagascar utilized a literature review, expert consultation, and GIS analyses using existing global and national datasets. We first identified a set of ecosystem services that were identified as important in the literature and by experts, and for which data were available. These included several provisioning services (wild sources of food; and fresh water for domestic use, irrigation, and hydropower), regulating and maintenance services (cyclone storm surge and flood risk), climate mitigation (biomass carbon stock and potential avoided emissions from deforestation), and cultural (ecotourism) values. We developed a narrative description of the importance of ecosystems for providing these services, as well as tabular results and maps from GIS analyses that show the relative importance of KBAs for various ecosystem services.

Our analysis shows that KBAs within Madagascar provide important ecosystem services supporting local livelihoods and the country's economy. The literature review and expert consultation suggested that virtually all remaining natural ecosystems are important to nearby local communities in Madagascar.

Different KBAs are important for providing different services, depending on the types of ecosystems they contain and the ways people are dependent upon those ecosystems. In terms of provisioning services, and based on catchment data, coastal and marine KBAs provide fish for both commercial and small-scale fisheries. Some KBAs contain mangrove and coral reef ecosystems that support these fisheries, as well as provide protection of populations living in the coastal areas from storms by regulating water surge and wind energy. Protected areas, such as National Parks, are providing important recreational and ecotourism values. Ecosystems that are currently unprotected, on the other hand, are likely providing important services to people who are food insecure, such as hunting, fishing, and fuel wood collection. Unprotected sites may be subject to unsustainable levels of harvest. This makes the argument for sustainable management even stronger, because they may currently be exploited for food and fuel, but they also may be highly threatened.

The dense humid forests of the eastern highlands are important for climate mitigation, flood control, and provision of fresh water for domestic use, irrigation, and generation of hydropower. The situation is somewhat different in the water-scarce north and southwest of the country, where ecosystem services are critical for provision of fresh water for domestic use and irrigation for a relatively smaller population. Understanding precisely how critical these services are to the well-being of the local population in those areas was beyond the scope of this study. Evidence from other studies suggests that dry and spiny forest ecosystems are extremely threatened in Madagascar, and have been under-represented in past conservation investments. Therefore, while they may not appear to have the highest values in terms of the provision of services, these ecosystems may be also critical for conservation. Additionally, coastal areas in the east that have lost their mangroves could be prioritized for restoration because of the amount of potential protection from cyclone storm surge.

This was a pilot test of the KBA+ framework. As such it relied on existing datasets, rapid desktop analyses, and relatively limited expert consultation. Many gaps in the data were identified. With additional resources and time, a more complete application of the KBA+ framework could include more sophisticated modeling or new data collection to fill in some of the identified gaps. In Madagascar, data gaps could be filled through new research or analyses during the implementation of the CEPF profile, or could be prioritized for future research. For future CEPF profiles, we recommend holding more comprehensive workshops specifically focused on ecosystem services, with a broader group of stakeholders including representatives of government agencies, development organizations, and academic experts on freshwater, climate change, food security, ecotourism, and cultural sites to ensure a more successful application of the KBA+ framework.

Introduction

Background

Ecosystem services can be defined as the contributions of ecosystems to benefits used in economic and other human activity (European Environment Agency 2013). The Common International Classification of Ecosystem Services (CICES, EEA 2013) includes three broad categories of ecosystem services:

- *Provisioning services*, all nutritional, material and energetic outputs from living systems.
- *Regulating and maintenance*, the ways in which living organisms can mediate or moderate the ambient environment that affects human performance.
- *Cultural services*, all the non-material, and normally non-consumptive, outputs of ecosystems that affect physical and mental states of people.

Natural processes are interconnected across different ecosystems. Therefore it is safe to assume that all ecosystems provide some form of services – even heavily modified habitats could provide valuable services in the form of soil carbon storage, nutrient cycling, water and air infiltration, or other benefits. The value of ecosystem services could significantly vary across space because of the inherent heterogeneity of biophysical characteristics of different ecosystems and uneven distribution of service beneficiaries. For example, human populations are often clustered along coastlines, near bodies of water, or along transportation corridors. Recognizing this spatial variation, and identifying ecosystems that provide relatively higher values to key beneficiaries, is an important step toward targeting effective conservation actions.

Biodiversity can be defined as the diversity of life on earth, at all levels – from the genetic level, to the level of species and ecosystems. Biodiversity encompasses functional, compositional and structural attributes. Most commonly, we think of biodiversity from a compositional perspective, primarily the distribution of species and ecosystems. Biodiversity has a complex relationship with other ecosystem services (Mace et al. 2012). There is an increasing recognition of the functional aspects of biodiversity as a habitat service, and that it underpins many ecosystem services by supporting processes such as nutrient cycling, water and air purification, and pollination of crops. Biodiversity could be also considered as a “final” ecosystem service (e.g., food provision), and a good (e.g., ecotourism) that is subject to valuation.

Conservation strategies to address biodiversity and ecosystem services have typically been developed separately. In some cases this has been for good reasons. For instance, management strategies that focus primarily on ecosystem services may not be the most effective for biodiversity conservation, because the priorities for management different in spatial distribution or in type of intervention (Chan et al. 2006). Yet there is much to gain through integration of strategies for biodiversity and ecosystem services. Planning based on multiple values of ecosystems can engage a broader range of stakeholders and constituencies, consistent with the multiple roles ecosystems play simultaneously. Integrated strategies consider both biodiversity and ecosystem services, their synergies and trade-offs (Nelson et al. 2009, Rogers et al. 2010).

Key Biodiversity Areas (KBAs) were developed as an important tool for biodiversity conservation (Langhammer et al 2007). They serve as a guide for implementation of a number of important conservation strategies, investments and other governance mechanisms (e.g. conservation investments made by the Critical Ecosystem Partnership Fund – see below). KBAs are defined as "sites contributing significantly to the global persistence of biodiversity" (IUCN 2012). KBAs are identified using standard criteria, based on their importance in maintaining biodiversity. In this respect, governments, intergovernmental organizations, NGOs, the private sector, and other stakeholders can use KBAs as a tool for identifying national networks of internationally important sites for conservation.

In the past, identification of KBAs has not included an assessment of ecosystem services. However, the importance of ecosystem services has been recognized in the most recent version of the KBA guidelines (IUCN 2012). The guidance states that when possible, ecosystem service values of KBAs should be documented, communicated, and incorporated into subsequent decision making.

The *Critical Ecosystem Partnership Fund* (CEPF) provides grants for nongovernmental and private sector organizations to help protect biodiversity hotspots, Earth's most biologically rich yet threatened areas. CEPF develops ecosystem profiles that outline the overall conservation targets or "outcomes," major threats and the policy, civil society and socioeconomic context, as well as funding gaps and opportunities. This information is used to determine the CEPF niche and investment strategy included in each ecosystem profile. One of the primary tools used within their ecosystem profiles to define targets are KBAs.

CEPF has become increasingly interested in understanding the role that KBAs play on the provision of services that are important to people, particularly to the poor. When defining the plan for the development of the Ecosystem Profile for the Madagascar and Indian Ocean Islands (MIOI) Hotspot, CEPF approached Conservation International's *Betty and Gordon Moore Center for Science and Oceans* (MCSO) to explore opportunities of mapping these services and using this information as part of the prioritization process for the areas where CEPF will invest in the MIOI hotspot. MCSO houses CI's global science and oceans expertise, and has experience with ecosystem service assessment.

Goals of KBA+

With the support of CEPF, MCSO and CI-Madagascar collaborated to develop KBA+, a framework for assessing and documenting the ecosystem service values of KBAs and surrounding areas. This document discusses the proposed framework, which consists of a recommended process (a set of steps), as well as suggested technical methods for assessing key ecosystem services. The audience for this guidance is primarily CEPF, but it can also be useful to other institutions interested in understanding ecosystem service values of biodiversity priority areas.

This document also describes a pilot demonstration of the framework, an assessment of the ecosystem service values of KBAs in Madagascar. Note, in this assessment, we refer to ***ecosystem service values*** strictly in non-monetary terms (e.g., the relative importance of ecosystems for supporting food security, or providing protection from climate-related events.) Valuation of ecosystem services in monetary terms was beyond the scope of this analysis.

The ecosystem service values identified through KBA+ were included in the ecosystem profile used by CEPF to guide investments. With KBA+, ecosystem services can be considered when identifying conservation investment strategies, and can help leverage additional funding opportunities. Specifically, information from KBA+ can be used to:

1) Assess the ecosystem service values of areas within and around KBAs. Such areas are not necessarily restricted to the boundaries of the KBAs themselves, and can include corridors between KBAs, watersheds surrounding KBAs, rivers linking KBAs to downstream beneficiaries, or other relevant units.
2) Document the importance of KBAs for providing benefits to people, and distinguish which KBAs are important for providing specific ecosystem services. Some KBAs might provide important freshwater services for local communities, while others might provide global climate mitigation values by sequestering and storing carbon.
3) Identify potential conservation interventions that can complement biodiversity conservation efforts by also maintaining or enhance ecosystem service values.

This framework provides general guidelines for documenting ecosystem services values based on qualitative information and quantitative data (both spatial and non-spatial). It is designed to be flexible to varying situations of information and data, varying scales (e.g. small island countries to larger regions) and can be applied anywhere.

As previously mentioned, biodiversity, as an ecosystem service, is complex and strategies for dealing with biodiversity conservation are often different from those for ecosystem services. With KBA+ we did not assess biodiversity conservation values and strategies; we left that to the existing CEPF profiling process.

Links to other tools

To develop this framework we reviewed previous approaches for assessing ecosystem service values to support conservation planning (including Egoh et al. 2007, Chan et al. 2011, and Tallis and Polasky 2009). One particularly relevant tool is "Toolkit for Ecosystem Service Site-based Assessment (TESSA)", which has a similar goal of identifying ecosystem service values around sites of global biodiversity importance such as Important Bird Areas (IBAs), a subset of KBAs (Peh et al. 2013). TESSA was explicitly developed for biodiversity priority areas, and has been applied in an assessment of the ecosystem service values of Important Bird Areas (IBAs) in Nepal (BCN and DNPWC 2012).

TESSA is not a single approach, rather it is a toolkit of possible approaches ranging from qualitative assessment of ecosystem services based on expert opinion, to field-based sampling of flows of freshwater or other services. Where possible, we have incorporated the TESSA approach into the KBA+ framework to ensure consistency.

However, TESSA is, by definition, site-based. In geographies where there are relatively few KBAs, a site-by-site approach is feasible. However, in many geographies (including Madagascar), there are so many KBAs that a site-by-site assessment of ecosystem services would be prohibitively expensive or impractical. Thus for KBA+, we have attempted to identify methods that can be used to assess ecosystem services across an entire region, then “clipped” to relevant spatial units (KBAs, watersheds, management units, or other relevant units.) Nonetheless, our framework includes some of the same tools as those included in TESSA, such as freshwater modeling using existing global datasets.

KBA+ Methodology

The KBA+ methodology includes seven steps (Figure 1), which we describe in detail below. Engagement with stakeholders, including conservation and development NGOs, relevant government agencies, research institutions, and local communities, is a cross-cutting component of this methodology and is therefore integrated into each step. In this document, we describe each step and provide guidance for undertaking it.

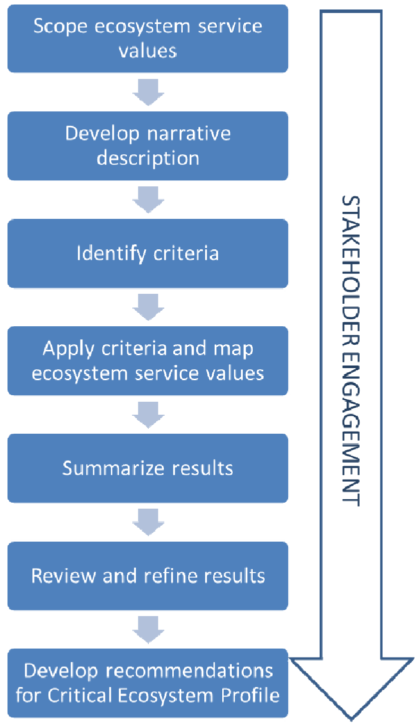


Figure 1. Process steps for assessing the ES values of KBAs

Step 1) Scope key ecosystem service values within and around KBAs

Identify key beneficiaries

Beneficiaries of ecosystem services include individuals, groups, or sectors that are dependent on natural ecosystems for food, freshwater, protection from extreme events, or other benefits. Key beneficiaries can include population centers, vulnerable groups such as poor communities or communities located in areas prone to climate-related disasters, communities that are food insecure, or traditionally marginalized groups such as indigenous and traditional communities. Beneficiaries can also include economic sectors dependent upon natural ecosystems, such as agriculture, forestry, or energy. Lastly, beneficiaries include the global population, who are dependent on natural ecosystems to regulate the global climate, or derive benefits (such as option values or existence values) from global biodiversity.

The benefits of a particular ecosystem might flow primarily to certain groups (such as coastal populations or smallholder farmers), and particular beneficiaries might be more vulnerable or in need of ecosystem services (for example, the rural poor). Information about benefits accruing to any population or group can potentially be an avenue for engaging stakeholders in the long-term protection of key ecosystems of interest. The KBA+ approach thus examines major benefits of ecosystems to a range of potential beneficiaries, providing a broad basis for developing strategies to conserve these areas.

Selected or “key” beneficiaries can be chosen based on the specific context and objectives of the KBA+ exercise.

Information about key ***dependencies***, or the specific ways ecosystem services are benefitting key groups or sectors, should also ideally be collected. Dependencies of people and sectors on natural ecosystems typically include needs related to food, raw materials, water, disaster risk reduction, income, recreation, and spiritual and cultural values. The specific dependencies in a given geography will depend on the local context.

Select relevant ecosystem services

Once the key beneficiaries and dependencies have been identified, it will be possible to identify which specific ecosystem services are most relevant in a given context. For example, it may be widely understood that people are dependent upon freshwater, but are they dependent upon it for drinking, for household use, for irrigation or watering their livestock? Is it the quantity of water important, the quality of that water, or the timing of floods and droughts?

Different beneficiaries may be utilizing water in different ways, so at this stage, it is useful to consider more detailed information about the particular pathways by which specific individuals, groups, or sectors benefit from each service. This can be done by referring to a global classification system of ecosystem services such as the Common International Classification of Ecosystem Services, or CICES (Table 1). Such a system provides a useful checklist to comprehensively evaluate all potential types of services relevant to the project. This information can also be collected from consultation with experts and stakeholders, from a literature review, or through data collection efforts.

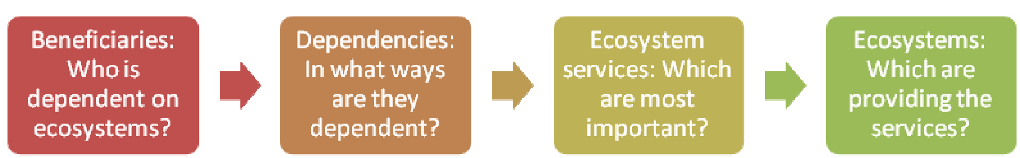
Table 1. Common International Classification of Ecosystem Services (CICES) V4.3 (January 2013) – 3-digit level (for a more detailed version of the table, see http://cices.eu/)

Section	Division	Group
Provisioning	Nutrition	Biomass
		Water
	Materials	Biomass, Fibre
		Water
	Energy	Biomass-based energy sources Mechanical energy
Regulation & Maintenance	Mediation of waste, toxics and other nuisances	Mediation by biota
		Mediation by ecosystems
	Mediation of flows	Mass flows

		Liquid flows
		Gaseous / air flows
	Maintenance of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection
		Pest and disease control
		Soil formation and composition
		Water conditions
		Atmospheric composition and climate regulation
Cultural	Physical and intellectual interactions with ecosystems and land-/seascapes [environmental settings]	Physical and experiential interactions
		Intellectual and representational interactions
	Spiritual, symbolic and other interactions with ecosystems and land-/seascapes [environmental settings]	Spiritual and/or emblematic
		Other cultural outputs

Identify ecosystems providing services

Once the beneficiaries, dependencies, and relevant ecosystem services have been identified, the next step is identifying which ecosystems are known or suspected to provide each service. For example, surface flows of freshwater typically originate in upstream areas, and then flow through streams and rivers to locations where they can be utilized by beneficiaries. The headwater ecosystems, which may include forests or wetlands, as well as the stream and river systems that link those ecosystems to downstream beneficiaries, are therefore providing the service of freshwater flows.



Information about which ecosystems are providing key services can be gathered by consulting experts and stakeholders, conducting a review of existing evidence about the services provided by different ecosystem types, ecosystem service modeling tools, reviewing lists or maps of ecosystem types (e.g., vegetation classifications, marine and coastal ecosystems) or collecting new data.

> **Link to the TESSA approach**
>
> TESSA involves a site-by-site assessment of which ES are relevant at each IBA. When possible this approach could also be utilized for KBA+, to identify key beneficiaries and relevant ecosystem services. In some geographies, such as Madagascar which has over 200 KBAs, a site-by-site approach is not practical. In this case it might make more sense to group KBAs based on similar characteristics (such as ecosystem type) in order to scope the relevant beneficiaries and ecosystem services of a set of KBAs collectively.

The spatial relationship between ecosystems and beneficiaries may be local, regional, or global. An example of an ecosystem providing a local service is a forested area that is directly used for firewood by a local community. That forest may also be located in the headwaters of a river basin that is supplying freshwater to people hundreds of kilometers away. Lastly, that forest may be sequestering and storing carbon that helps regulate the global climate, benefiting people everywhere.

Multiple services may be provided by a particular ecosystem, and have a different value to different groups of beneficiaries. Provision of some of the services may also be in conflict with each other. For example, a local community may be dependent upon a forest for timber to build their homes, leading to deforestation that affects downstream water quality, impacting the drinking water supply of a different community, and releasing greenhouse gases that contribute to global climate change. Therefore it is important to understand and document these conflicts, or tradeoffs, between different beneficiary groups and services. Though documenting and resolving these conflicts is beyond the scope of our study, our results quantifying the different benefits of ecosystems and different beneficiaries form the first step to understanding and resolving tradeoffs.

Step 2) Develop narrative of ecosystem service values

Based on the above exercise, it is now possible to develop a narrative summary of the qualitative and quantitative information gathered, including:

1) Key ***beneficiaries*** (e.g. coastal populations, the agricultural sector) and specific ***dependencies*** of those beneficiaries on ecosystems (e.g. for drinking water for or irrigation, nutrition, or crop yields)
2) Which specific ***ecosystem services*** are providing those benefits (e.g. stable flows of water, pollination services for key crops)
3) Which specific ***ecosystems or species*** are providing those services (e.g. high elevation wetlands, rivers) and their ecological functions (e.g. water regulation, soil retention)

Though beyond the scope of the current study, additional information that is useful to gather includes:

4) The capacity of ecosystem services to meet current or future demand and the sustainability of use
5) Tradeoffs between services, or conflicts between beneficiaries

6) Connectivity, or spatial relationships between the location of the ecosystems providing the service and the location of people or sectors benefiting from the service
7) Links to biodiversity; the specific contribution of biodiversity to each ecosystem service. This contribution can be direct, for example biodiversity that is consumed directly (provisioning services such as food or raw materials). The contribution can also be indirect, such as biodiversity that supports other ecosystem services (supporting or regulating services, such as soil quality maintenance or pollination.) Biodiversity can also contribute, directly or indirectly, to cultural or spiritual values (e.g. recreational bird watching, or sacred forests.)

Components 1–7 can be summarized in a narrative. Summary tables can also be a useful way to capture information from scoping exercises (Table 2).

Table 2. Results of a scoping analysis of important ecosystem services in Madagascar, based on a literature review and expert consultation

Section	Division	Key Ecosystem Services in Madagascar
Provisioning	Nutrition	Fish
		Bushmeat
		Edible plants
		Medicinal plants
		Water flows for domestic use
		Water flows for irrigation
	Materials	Construction materials (wood, thatch)
		Materials for artisanal products (wood, sedges)
		Water flows for mining
	Energy	Fuelwood
		Charcoal
		Water flows for hydropower
Regulation & Maintenance	Mediation of waste, toxics and other nuisances	Water quality for household use
		Water quality for irrigation
		Water quality for hydropower
	Mediation of flows	Flood regulation
		Drought regulation
	Maintenance of physical, chemical, biological conditions	Carbon storage and sequestration
		Protection from cyclones
		Genetic material
Cultural	Physical and intellectual interactions	Ecotourism

Section	Division	Key Ecosystem Services in Madagascar
	with ecosystems and land-/seascapes	Existence value (biodiversity)
	Spiritual, symbolic and other interactions with ecosystems and land-/seascapes	Cultural and spiritual identity

Step 3) Select criteria for identifying important areas

Once all the scoping steps have been completed, and a narrative description of the key beneficiaries, ecosystem services, and ecosystems has been developed, it will be easier to identify criteria for identifying areas that are more important for providing ecosystem service values.

As described above, every place provides ecosystem service values, but the magnitude of the services provided, and the benefits derived from them, vary across space. It is possible to distinguish areas that are more important than other areas for specific ecosystem services or for specific beneficiaries. The specific criteria used to distinguish "more important" from "less important" will depend on the service. Examples of criteria include:

1) Importance to beneficiaries (e.g. dependence of certain groups of people or sectors on an ecosystem; irreplaceability of an ecosystem in providing a service)
2) Types of beneficiaries that are dependent (e.g. vulnerable communities, important economic sectors)
3) Importance for meeting global, national, or stakeholder objectives (e.g. Aichi biodiversity targets, emissions targets, CEPF objectives)
4) Degree of overlap with other values (e.g. multiple benefits)

If information is available, other criteria can be used to distinguish important areas:

5) Scarcity of the resource being consumed (e.g. current or future unsustainable level of exploitation)
6) Level of threat to the underlying ecosystems (e.g. from deforestation or other habitat change, from climate change, or from other threats)
7) Tradeoffs with other values (e.g. conflicting uses)

Several additional criteria, including the cost of conservation intervention, the feasibility or opportunity of implement conservation interventions are important to include, but are considered in other steps in the CEPF Profiling process.

Addressing threats

Identification and assessment of threats is already included in the CEPF profiling process; thus we do not provide detailed guidance for it here. However, general steps for threat assessment include:

- Identify threats and assess levels of threats, based on an assessment of drivers and actors of change, trends, and scenario development (e.g. deforestation modeling, or climate change projections)
- Incorporate threats identified in the broader CEPF profiling exercise, along with additional threats to ecosystem services that may not have been identified
- Compile spatially explicit data on threats, if available
- Threats can be something to target for conservation action (i.e. prioritization of highly threatened sites), or to avoid (i.e. prioritization of less threatened sites)
- See Rogers et al. 2010 for examples of site prioritization scenarios that prioritize high human-pressure areas and low human-pressure areas

Once the appropriate criteria for assessing importance have been selected, thresholds can be used to distinguish "more important" from "less important" areas. If multiple values are being assessed in combination for a general category of service (e.g., "value of freshwater provision for domestic consumption" and "value of freshwater provision for rice agriculture"), it will be necessary to assign weights to each type of service (either weighting all services equally or giving more weight to services considered more important, based on the above criteria.)

Step 4) Apply criteria to identify important areas within and around KBAs

Once criteria for identifying important areas have been selected, those criteria can be applied, ideally using quantitative spatial data, to develop maps of areas within and around KBAs that are important for providing ecosystem services.

Synthesize existing data

First, existing spatial data must be gathered to characterize the relevant ecosystem services, as well as any existing spatial data characterizing threats, patterns of land use, and areas that have been prioritized previously for biodiversity or other values (Table 3).

Table 3. Examples of datasets useful for assessing ecosystem service values.

Biophysical characterization	Socioeconomic characterization	Threats	Existing land use & priorities
- Species distribution - Land cover (including terrestrial, freshwater, and coastal/marine ecosystems) - Land use - Hydrology - Current climate (precipitation, temperature, storms, floods, droughts) - Soils - Topography	- Settlement locations - Population data - Poverty rate - Food insecurity (malnutrition, undernourishment) - Water source/supply data - Important economic sectors / contribution to GDP - Roads, bridges - Hydropower dams - Relevant studies – dependence on natural resources, ecosystem service assessments, climate vulnerability assessments	- Deforestation - Climate projections - Sea level rise - Disaster risk - Development plans / projections	- Agricultural areas - Fishing areas, catch data - Hunting areas, gathering areas, species collected - Concessions (mining, forestry) - Sacred natural areas - Ecotourism - Existing protected areas - Biodiversity priority areas

Additional spatial or non-spatial information can be gathered from a review of existing ecosystem service assessments, past priority-setting analyses, vulnerability assessments, studies of human dependence on natural ecosystems, or other relevant studies. In many regions, there have already been efforts to identify important places for ecosystem services; this information can be reviewed and, if the criteria align with the selected criteria, the results can be incorporated.

Identify and fill gaps

Gaps in existing information, including spatial and non-spatial datasets, should be identified. Where possible, new data collection or modeling can be used to fill gaps. Examples of relatively low-cost analyses include using remotely sensed global datasets to estimate biomass carbon (e.g. Saatchi et al. 2011) and habitat change (e.g. Hansen et al. 2013), hydrological modeling using tools such as WaterWorld (Mulligan 2013) or ARIES (Villa et al. 2014), and climate vulnerability assessments using downscaled climate projections such as Climate Wizard (www.climatewizard.org/) and expert workshops.

Table 4 summarizes several existing tools for modeling ecosystem services. For a more complete comparison of tools, see *Decision Guide: Selecting Decision Support Tools for Marine Spatial Planning* (Center for Ocean Solutions 2011).

Additional information on the capacity of ecosystems to meet demand, the sustainability of use of key ecosystem services, and tradeoffs between services can also inform decisions about the relative "importance" of different places.

Table 4. Comparison of several tools for modeling ecosystem services, from Peh et al 2013: TESSA: A toolkit for rapid assessment of ecosystem services at sites of biodiversity conservation importance

Approach/tool*	Description	Feature				Capacity/resources requirement				
		Scope	Data demand	Resolution	Valuation focus	Computing skill	Specialist technical knowledge	Time	Man-power	Cost
Toolkit for Ecosystem Service at Site-based Assessment[a] (TESSA)	A practical suite of tools for measuring and monitoring ecosystem services at a site scale	Landscape	Low–High	Low–High	Low–High	Intermediate	Low	Low	Low	Low
Assessment and Research Infrastructure for Ecosystem Services[b] (ARIES)	A modelling approach for quantifying environmental services and factors influencing their values, in a geographical area and according to needs and priorities set by its users	Landscape – Global	Low–High	Low–High	Low	Intermediate–High	Low–High	Low	Low	Low
Corporate Ecosystem Services Review[c] (ESR)	A series of questions for developing strategies to manage risks and opportunities arising from the company's dependence on natural resources	Landscape – Global	Low	Low	Low	High	High	Low	Low	High
Integrated Valuation of Ecosystem Services and Tradeoffs[d] (InVEST)	A computer-based platform for assessing how distinct scenarios might lead to different ecosystem service and human-wellbeing related outcomes in a geographical area	Landscape – Global	Low–High	Low–High	High	High	High	Low	Low	High
Multi-scale Integrated Models of Ecosystem Services[e] (MIMES)	A suite of models for assessing how distinct management scenarios might lead to different ecosystem service and human-wellbeing related outcomes	Landscape – Global	Low–High	Low–High	High	High	High	Low	Low	High
Natura 2000[f]	A tool for assessing the total overall socio-economic benefits and value of a site, and for determining more monetary values of individual benefits provided by the site.	Landscape	Low	Low	High	Intermediate	Low	Low	Low	Low

* The list is not exhaustive

Tip for low data environments:
Developing general mapping rules based on qualitative information

Where dependencies of people on ecosystems are known or suspected, but no spatial data exists, it is possible to develop general mapping rules based on qualitative information. This information might be gathered from existing case studies, expert judgment, and established theory. For example, if research shows a high level of dependency of rural populations on natural resources, it might be reasonable to assume that natural ecosystems within a certain distance of rural population centers are likely to be important for providing multiple services. A general mapping rule could be applied using existing land cover data to identify potentially important areas. For example, natural ecosystems (such as forests, wetlands, mangroves, or coral reefs) that are within a certain distance of rural settlements with known dependencies on natural sources of food, water, or fuelwood could reasonably be assumed to be important. Other mapping rules based on known dependencies could include natural ecosystems that are:

- In proximity to population centers of a certain size
- In proximity to rural population centers
- In proximity to areas with relatively high poverty or food insecurity rates
- Upstream of irrigated agriculture
- Upstream of hydropower facilities
- In areas prone to severe climate-related events (floodplains, steep slopes, arid regions, coastlines, etc.)

Assumptions used to develop such mapping rules should be documented, and the uncertainty associated with the results should be clearly communicated.

Apply criteria

A desktop spatial analysis should then be used to identify areas that meet the selected criteria. Depending on the available resources and expertise, this can be done using desktop software for geographic information systems (GIS), such as ArcGIS or Idrisi. It can also be done using web-based tools such as WaterWorld (http://www.policysupport.org/waterworld) or Co$ting Nature (http://www.policysupport.org/costingnature). Multi-objective decision support tools such as Marxan (www.uq.edu.au/marxan/) can help identify networks of spatial units that meet multiple criteria.

Results from the desktop analysis should be reviewed and refined by stakeholders. Ultimately, this process aims to accomplish the three goals outlined in the Introduction.

Step 5) Summarize ecosystem services values for KBAs

A summary of the ecosystem service values for KBAs can now be developed, including the narrative description, summary tables or diagrams, maps and data gathered for the analysis, a description of methods, sources of information, and key information gaps. Maps illustrating the ecosystem service values of individual KBAs can be developed (for examples, see Results from the Madagascar pilot demonstration, below.)

Another useful way to summarize information is using graphs or diagrams that show the relative importance of various KBAs for providing various services. An example from an assessment in Nepal is provided in Figure 2, below.

In geographies with many KBAs, such as Madagascar, ecosystem services values across sets of KBAs with similar characteristics could be summarized. For example, KBAs with similar ecosystem types that are located near the same population centers may provide similar services to those areas.

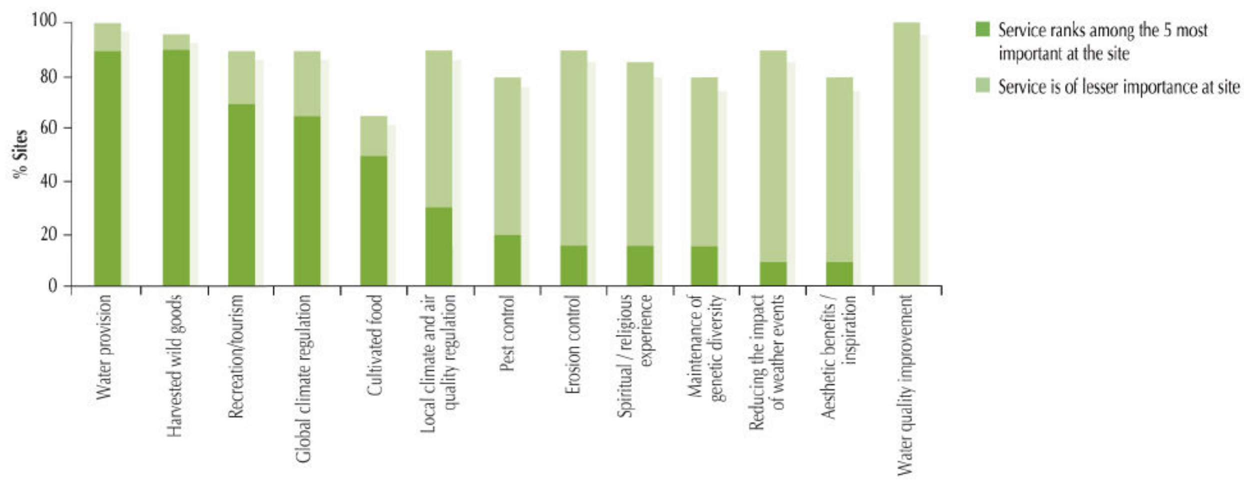


Figure 2. Proportion of Important Bird Areas (IBAs) delivering different ecosystem services and their relative importance. Figure taken from an assessment of ecosystem service values of IBAs in Nepal, based on information provided at an expert consultation workshop (BCN and DNPWC 2012).

Step 6) Make recommendations and integrate into CEPF profile

Once the summary has been developed, it can be used to develop recommendations to be integrated with the CEPF profile. These recommendations can assist with the prioritization of KBAs, by highlighting which KBAs are providing critical services to particular beneficiaries. Recommendations can also be developed related to potential strategies for addressing ecosystem service values through specific types of conservation interventions or investments, e.g. mangrove restoration activities that simultaneously support biodiversity conservation, protection of coastal areas from climate-related events, and fisheries that support food security. This step should be integrated with the broader profiling process, including extensive stakeholder consultation to inform discussions of potential strategies, costs, and feasibility.

Madagascar Pilot Demonstration

With the support of the Critical Ecosystem Partnership Fund (CEPF), Conservation International's (CI) Betty and Gordon Moore Center for Science and Oceans (MCSO) and CI-Madagascar collaborated to assess the value of Key Biodiversity Areas (KBAs) and their surrounding areas for ecosystem services in Madagascar.

The pilot demonstration in Madagascar utilized existing data and limited new analyses to assess the three broad categories of ecosystem services, including 1) provisioning services (wild sources of food; and fresh water for domestic use, irrigation, and hydropower), 2) regulating and maintenance services (cyclone storm surge and flood risk), climate mitigation (biomass carbon stock and potential avoided emissions from deforestation), and 3) cultural (ecotourism and cultural values). These particular ecosystem services were selected because they are important in Madagascar (see below), but also because it was possible to assess them using existing data and tools.

This process in Madagascar supported the development of the KBA+ framework. This framework can be applied in the remaining areas in the Madagascar Indian Ocean Islands (MIOI) Biodiversity Hotspot and adapted for future Critical Ecosystem Partnership Fund profiles in other regions. The framework could also be used to identify the ecosystem service values of biodiversity priority areas for other purposes or audiences.

Objectives

The objectives of this KBA+ pilot demonstration were to:

1) Pilot a framework for assessing ecosystem service values of Key Biodiversity Areas using existing data from Madagascar
2) Develop a set of maps illustrating links between ecosystems and human well-being
3) Identify data gaps and potential strategies to address them during the CEPF implementation phase, or with support from other donors' initiatives
4) Provide guidance for incorporating ecosystem service value considerations across the Madagascar and Indian Ocean Islands hotspot
5) Refine the KBA+ framework and develop guidance for its inclusion in future CEPF profiles

Scope

For this KBA+ pilot demonstration, we focused on the island nation of Madagascar to develop a conceptual framework and guidance materials that can be applied throughout the Madagascar and Indian Ocean Islands (MIOI) hotspot and refined for future CEPF ecosystem profiles. Within Madagascar, the geographic scope includes KBAs. In the future, we would like to repeat this analysis to include surrounding landscapes such as corridors, watersheds, or spatial links to beneficiaries such as access routes or rivers.

Team and process

CEPF has become increasingly interested in understanding the role that KBAs play on the provision of services that are important to people, particularly to the poor. When defining the plan for the development of the Ecosystem Profile for the Madagascar and Indian Ocean Islands Hotspot, CEPF approached CI's MCSO to explore opportunities of mapping these services and using this information as part of the prioritization process for the areas where CEPF will invest in the MIOI hotspot.

CI-Madagascar led the updated CEPF Critical Ecosystem Profile, including updating the Key Biodiversity Areas (KBAs without the +). Staff from the Betty and Gordon Moore Center for Science and Oceans led the KBA+ project, in close consultation with CI Madagascar staff.

CI-Madagascar organized a series of stakeholder consultations, regional workshops, and advisory group meetings between September and November 2013. The KBA+ team held two in-country workshops in Madagascar to coincide with these stakeholder consultations, in order to share information, get feedback on the high-level KBA+ framework, and present and validate results from the Madagascar pilot demonstration.

Step 1) Scope ecosystem service values

This scoping exercise involved a literature review and expert consultation.

Literature review

There have been a number of assessments of ecosystem services in Madagascar at national and sub-national scales. There have also been numerous studies of the links between ecosystems and people in the region, even if they are not framed in the language of ecosystem services. We conducted a literature review of relevant publications to provide context for our assessment, as well as to identify existing information and analyses to be included in our current assessment. Our objective was to update these past analyses with more recent data, to fill gaps, and to use the results to inform the current CEPF ecosystem profile. Relevant articles were requested from key experts within MCSO, from CI Madagascar and partner organizations, and external researchers, or were identified using web searches (e.g. Google Scholar search for "climate adaptation Madagascar.")

In total, we reviewed 125 articles, primarily scientific papers and some unpublished reports (see Appendix 5). These included numerous studies on themes relevant to ecosystem services: biodiversity (46), water (13), climate mitigation and deforestation (12), climate adaptation (13), food (34), cultural services (9), and human well-being and poverty (33). Many articles (45) included reference to multiple themes. Below we highlight several studies that addressed multiple ecosystem services at the national scale (considered most relevant for the current analysis), and a number of sub-national studies, many of which addressed only a single theme.

Expert consultation

We consulted with key experts from CI Madagascar and partner organizations throughout this process, beginning with the collection of relevant literature, identification of relevant ecosystem services, methods for the desktop analyses (below), and collection of spatial datasets. We held two half-day expert workshops in Antananarivo on September 10 and November 18, 2013 to review the conceptual framework for KBA+, identify key ecosystem services for Madagascar, agree on methods for the desktop analyses, review preliminary results, and refine the analyses. Participants are listed in Table 5.

Table 5. Participants in KBA+ expert workshop

Name	Institution	email	Expertise
Andriamasimanana H Rado	Asity Madagascar	d.andriama@birdlife.mada.org	Biologist
Razafimpahanana Dimby	Rebioma, WCS	dimby@rebioma.net	Biodiversity, coordinator for GIS/spatial planning
Harison Randrianasolo	CI	hrandrianasolo@conservation.org	Biodiversity
Andriamaro Luciano	CI	landriamaro@conservation.org	Biodiversity, Fresh water
Razafinacrama Soloadal	ARFIE	arsie@moov.mg	
Tianarisoa Tantely Farmazana	Rebioma	tantely@rebioma.net	Technical specialist for Rebioma, plant biology, marine
Randrianarisoa Jeannicq	CI	jrandrianarisoa@conservation.org	Human well-being
Rasolohery Andriambilasoa	CI	arasolohery@conservation.org	Spatial analyst
Rachel Neugarten	CI	rneugarten@conservation.org	Geographic priority-setting
Miroslav Honzák	CI	mhonzak@conservation.org	Ecosystem services

Step 2) Develop narrative of ecosystem service values

Ecosystem Services and Human Well-being in Madagascar

The people of Madagascar, particularly its rural and poorer populations, have a high level of dependence on natural resources and a strong relation to nature and environment (Kiefer et al. 2010). According to the World Bank, 50% of Madagascar's wealth is in the form of natural capital (World Bank 2013). Overall GDP is driven by income from mining, tourism, and services. However, agriculture, livestock, and fishery sectors provide 95% of Madagscar's food supply and source of livelihoods for 75% of the rural population (IISD 2011). Biodiversity and ecosystem services are therefore intricately linked to poverty, political stability, and other elements of well-being:

> Madagascar's economy depends to a great extent on exported ecosystem goods such as seafood and spices, and increasingly on minerals derived by extractive industries... The condition and availability of biodiversity and ecosystem services seems to be interlinked with political stability... Global environmental and socio-economic changes, such as climate change or high population growth rates, increasingly have an influence on human wellbeing, which makes the access to, and availability of, ecosystem services a major concern. The integrity of biodiversity, hence, contributes to the extent of vulnerability of Madagascar's population and the reduction of dependences and poverty (Kiefer et al. 2010).

The poverty rate is very high, and increased from 70% (1993) to 77% (2010). Rural poverty is even higher (82.2%) in part due to environmental deterioration, exacerbated by the current political crisis. GDP per capita was well below the average of the poorest sub-Saharan countries in 2009 (Rabarison 2013). The households that have the most persistent poverty are largely not members of the dominant ethnic group; are land poor; live in remote areas; and are headed by uneducated individuals, most commonly women (Stifel et al. 2010). Poverty drives unsustainable land and natural resource use. According to one study, "Small scale agricultural households were hit particularly hard in the 1990s, and the data suggest that these are the very households that have been extending their land use by clearing and cultivating increasingly fragile lands" (Paternostro et al. 2001). These practices are driving the conversion and degradation of the very ecosystems that the Malagasy people depend upon.

National-scale ecosystem service assessments in Madagascar

Two studies have explored ecosystem service values at the national scale, with a specific focus on the links between ecosystem services and biodiversity priority areas. They are therefore the most relevant for this current analysis. For example, there is an existing assessment of the relative priority of unprotected KBAs based on data on human related threats, ecosystem services, and biological values (Rogers et al. 2010). The study focused on 70 KBAs that were unprotected at the time. The authors found that sixteen key biodiversity areas emerged as particularly important for both biodiversity and ecosystem services (Figure 3). This assessment focused only on hydrological services (provision of drinking water to downstream populations and irrigation of rice paddies), thus our current KBA+ analysis substantially adds to this past work by including numerous additional ecosystem services.

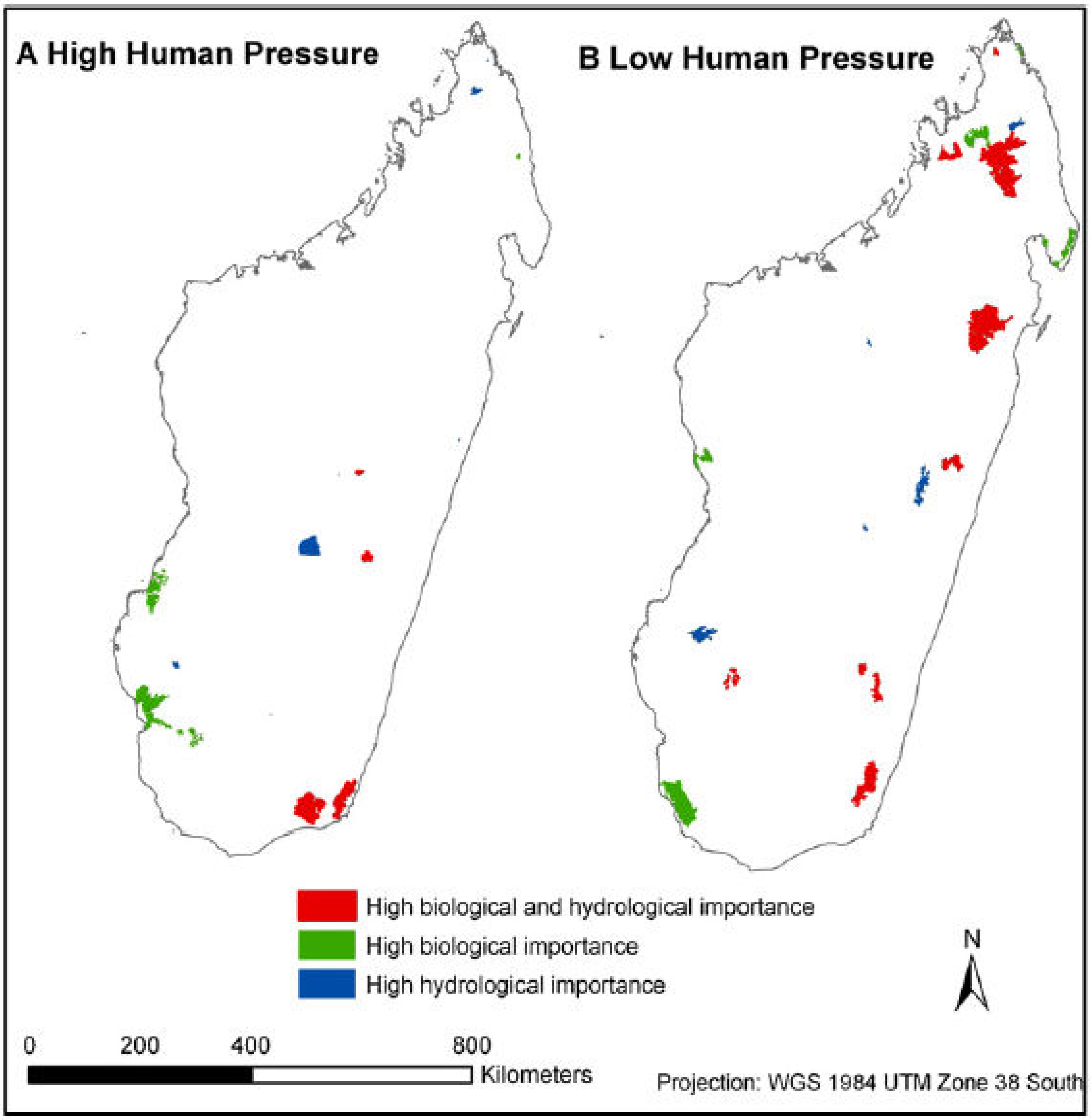


Figure 3. Priority scenarios for unprotected key biodiversity areas of highest biological and hydrological importance. (A) High-human pressure; (B) Low-human pressure. Reproduced from Rogers et al. 2010.

The Rogers et al. (2010) assessment incorporated hydrological information from a more complete assessment that explored opportunities for bundling biodiversity conservation with carbon and water services (Wendland et al. 2010). (One of the authors of this report, Miroslav Honzák, was also a co-author of both the Rogers et al. and Wendland et al. studies.) The Wendland et al. (2010) analysis identified approximately 30,000 km^2 of natural habitat (out of a total of 134,301 km^2) that could potentially meet biodiversity conservation goals and also protect water and carbon services (Figure 4 and Figure 5). Results of this analysis were incorporated into our current KBA+ analysis; however, the information on carbon was updated using more recent (2010) forest cover data, and the fresh water analysis was updated using a more sophisticated, process-based ecohydrological modeling tool (WaterWorld).

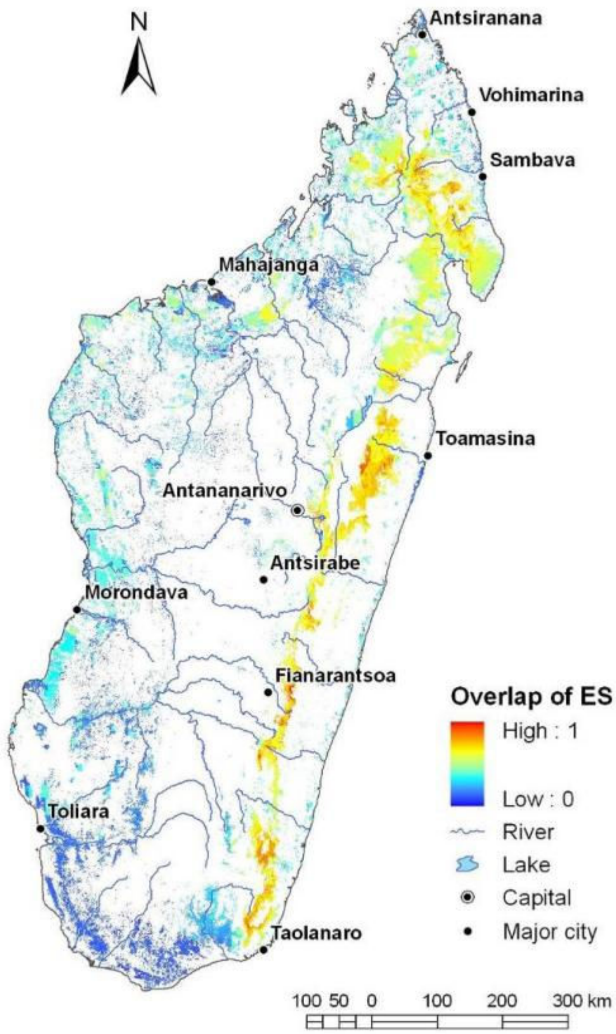


Figure 4. Overlap between multiple ecosystem services (ES) in forest and wetlands (the relative strength of the overlap is depicted in shades ranging from blue (low) to red (high)). Reproduced from Wendland et al. 2010.

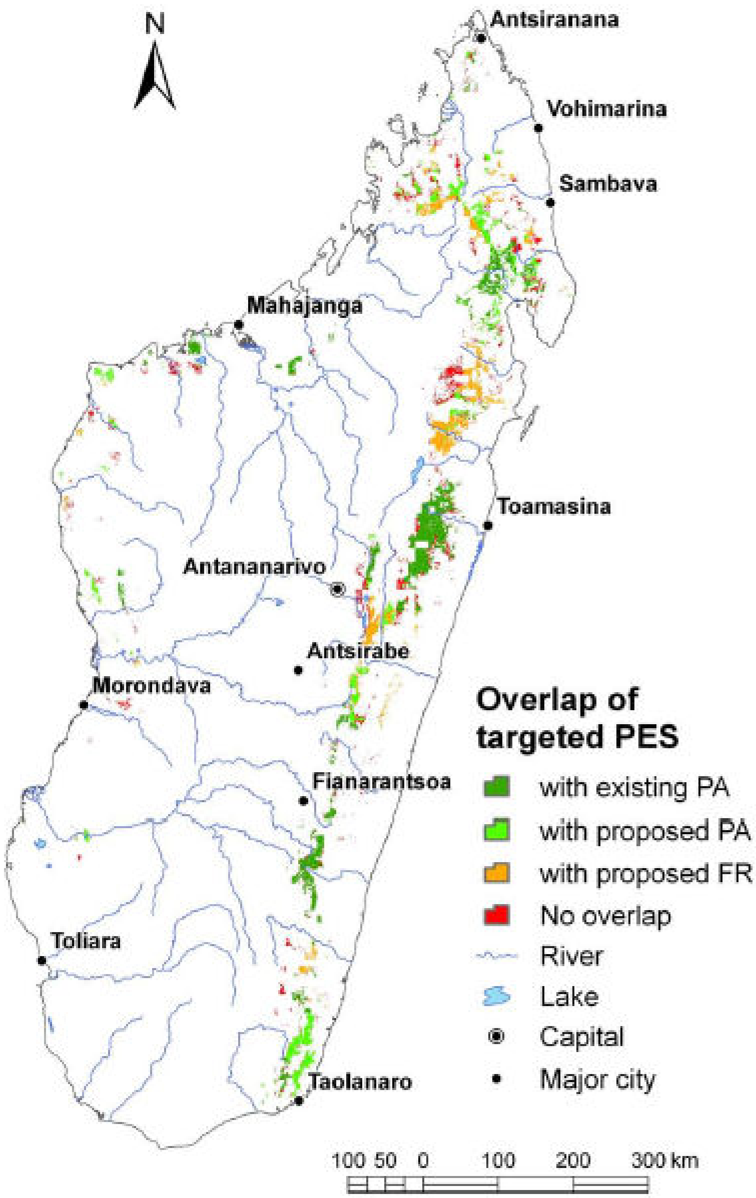


Figure 5. Overlap of ecosystem services and existing and proposed conservation interventions (PA = protected area, FR = forest reserve). Reproduced without permission from Wendland et al. 2010.

The Missouri Botanic Garden (2013) conducted a review of ecosystem service values of 51 Important Plant Areas (APAPCs for their French acronym), based on expert opinion. Results indicate that such sites provide a wide range of services to local communities: timber, wood for canoes and posts, fuel, food, materials for handicrafts, wild silk, traditional medicines, water for crop irrigation, cattle refuge, breeding grounds for fish and shrimp, social cohesion and identity, and religious values (Missouri Botanic Garden 2013).

Panegos (2011) conducted a review of ecosystem service values of Madagascar's 46 protected areas, based on a literature review, interviews with park officials, and a review of planning documents, websites, and other materials. She assessed whether or not the protected areas were important for providing hydrological services, climate regulation, genetic reservoirs, ecological connectivity, scenic beauty, cultural value, and ecotourism. The role of water was highlighted in most of the protected areas (30 out of 46). Fourteen protected areas were considered important for ecotourism. Eleven for ecological connectivity, eleven for scenic beauty, eleven for cultural services, eight were considered genetic reserves, and six were presented as having a role in regulating climate. This analysis, while useful, is based on a combination of quantitative analyses (past ecosystem service assessments) and qualitative information based on subjective opinion (interviews, planning documents, etc.) The results are therefore difficult to interpret and not applicable outside the boundaries of existing protected areas.

An economic evaluation of the value of ecosystem services of Madagascar's protected areas found that the national benefits of biodiversity conservation and ecotourism could be valued at US$5/hectare of protected areas per year (Carret and Loyer 2003). The same study found that water users downstream of protected areas (rice growers and consumers of drinking water) were willing to pay US$3 per hectare of protected area, increasing over time. This study is also useful but also does not apply outside of existing protected areas.

Sub-national & thematic assessments

There have been numerous studies about the relationship between nature and human well-being in Madagascar, many of them conducted at sub-national scales and around specific themes (such as the role of biodiversity in food security.) Below is a summary organized by thematic area: food, fresh water, climate adaptation, climate mitigation, and cultural values.

Food

Food security is a major issue in Madagascar. Overall, 84 percent of households experience a time during the year when they don't have enough cash or food (World Food Programme and UNICEF 2011). The Southern region of Madagascar showed the highest prevalence of households (92 percent) reporting this problem, followed by the West-South Western region (89 percent). The national population growth rate is 2.8% (Rabarison 2013), twice the rate of India, meaning every year there are even more hungry mouths to feed. There has been an overall decline in fish stocks and agricultural production, making it even harder for Malagasy people to feed themselves (IISD 2011). Natural ecosystems play a key role in food security, by providing wild sources of food (fisheries, e.g. Le Manach et al. 2012, and wildlife hunting, e.g. Brashares et al. 2011) as well as services that support agriculture, such as fresh water for irrigation (e.g. Bakoariniaina et al. 2006), soil quality, climate regulation, pest and pathogen control, and pollination (e.g. Bodin et al. 2006).

The Malagasy diet is based mainly on rice (on average, rice is consumed 6.2 times a week), vegetables (4.4 times a week) and tubers (mainly cassava, 3.9) (World Food Programme and UNICEF 2011). Vegetable and animal proteins are rarely consumed (once and 2.3 times respectively). Fish is the most popular animal protein, with an average weekly consumption of 1.3 days. The Southern zone appears to have the poorest diet. Here households eat cassava almost every day (6.1), followed by cereals, and vegetables (2.8).

Fisheries

Wild food sources, including fisheries, bushmeat, and wild plants, are critical to food security in Madagascar. One third of the population (34%) lives within 100 km of the coast (Rabarison 2013). It has been estimated that fish and fish products contribute about 20 percent of animal protein consumption of the total population (FAO 2008). The fisheries sector also plays a major socio-economic role in the country. Fisheries including aquaculture contribute 7 percent to the gross Domestic Product (GDP) and is also a provider of employment (FAO 2008). Approximately 194,000 direct jobs in the primary sector of which 33,365 as fish farmers and 3,000 indirect jobs have been created. In rural communities, fishing is the main source of income.

Thus coastal and marine fisheries provide critical sources of food as well as livelihoods, but are threatened by overharvest (Le Manach et al. 2012). Shrimps have been exploited industrially since the mid-1960s, while other invertebrates (notably octopus, lobster, crab and sea cucumber) and sharks are exploited for subsistence or on a semi-industrial scale. Sea turtles and small fish species are caught by small-scale fishers for local consumption. Several species of tuna (e.g., yellowfin Thunnus albacares, big-eye Thunnus obesus) are heavily targeted by illegal Asian and legal European fleets (Le Manach et al. 2012).

Small-scale fisheries are of fundamental importance to coastal communities, especially in the arid south-western region of the country where agriculture is largely unviable, and where many communities rely on food assistance (Le Manach et al. 2012). Data on small scale fisheries is limited and therefore the importance of this resource has historically been unreported or underestimated. The reconstruction of total catches by all Malagasy fisheries showed that total catches between 1950 and 2008 were twice the volume reported by national fisheries agencies, but signs of decline have been observed in several stocks (Le Manach et al. 2012). Recent studies suggest that traditional fishers are now migrating in unprecedented numbers to increasingly remote and isolated regions of the west coast as a coping mechanism in direct response to declining catches (Le Manach et al. 2012).

Data from a small-scale traditional invertebrate fishery in southwestern Madagascar showed that more than 34 taxa were caught, both for export and local consumption, but there are indications that the resources are being over-exploited (Barnes and Rawlinson 2009). A survey of 11 villages within the vicinity of Kirindy-Mite Marine Protected Area (Jones 2012) showed a high dependence on harvesting of marine resources, and low diversification of livelihood strategies. The traditional fishery of the Kirindy-Mite area is in marked decline, as a result of environmental stressors, such as cyclones and sustained high water temperatures leading to mass coral bleaching, as well as sustained fishing pressure from traditional, artisanal and industrial fishers. This situation leaves fishing communities of the Kirindy-Mite area highly susceptible to a potential future collapse of the traditional fishery.

Freshwater fisheries are also critical sources of food and income. Data from a RAMSAR site in western Madagascar, Manambolomaty Lakes, indicates that fisheries management has increased the annual local revenue by an estimated US$1,562 per fisherman per season, and the tax from the fish sales makes up 56% of the budgets of two local communes (Rabearivony et al. 2008). Endemic freshwater crayfish species are harvested for both subsistence use and small-scale trade, one study from eastern Madagascar indicated that more than half of households were directly involved in the harvest, contributing substantially to local incomes (Jones et al. 2006).

Wildlife hunting & edible plants

Tubers such as wild yams are considered a "famine food," critically important during the lean season between rice harvests (Ackerman 2004, Damson et al. 2010). Wildlife hunting and consumption (bushmeat) has been shown to increase when alternative livelihoods collapse in Madagascar and several other African nations, providing a safety net in times of crisis (Brashares et al. 2011). However, this net only exists for people who live near harvestable wildlife, and only lasts as long as the wildlife isn't hunted to extinction. Interviews with 1,154 households in 12 communes in eastern Madagascar showed that the majority of meals contain no animal protein, and bushmeat is not preferred over fish and domestic animals (Jenkins et al. 2011). Nonetheless respondents consumed a wide range of wild species; 95% of respondents had eaten at least one protected species, and nearly 45% had eaten more than 10. Traditional taboos have protected certain species, such as the Endangered Indri lemur, but there is evidence that such taboos are rapidly eroding. Wildlife consumption is also common in urban areas; a study from western Madagascar showed that bushmeat accounted for 10% of the meat consumed on a given day, including six wild mammals and five wild bird species, although fish and domestic animals were preferred and more affordable (Randrianandrianina et al. 2010). The authors state that it is likely that wildlife consumption is underestimated because of reluctance of interviewees to admit illegal activities.

Interviews from northeastern Madagascar revealed that 23 mammal species were hunted for consumption in that region (Golden 2009), but modeling results suggest that hunting is unsustainable. Evidence from a temporary camp in a national park in the northwest indicates that at least 49 unique wild animals were consumed for food, the majority of which are protected by law and are endemic to the island (Garcia and Goodman 2003). Even bats are consumed during periods of food shortage, but the level of collection surpasses the bats' breeding potential, which will likely result in extirpation of local populations over time (Goodman 2006). Frogs are also commonly collected for domestic consumption in restaurants as well as overseas export, providing important income for individual hunters, but potentially impacting frog populations (Jenkins et al. 2009). A study from a single restaurant in eastern Madagascar showed a delivery of 3,233 frogs over a five-month period, or an average of 249 per week, including one IUCN-listed critically endangered species (Jenkins et al. 2009). Wildlife consumption has also been shown to be a critical source of nutrition; one study in northeastern Madagascar links wildlife consumption to a 29% decrease in children suffering from anemia, with associated long-term health benefits (Golden et al. 2011). However, long-term depletion of the wildlife would lead to extinctions and therefore a loss of this critical resource.

Overharvesting of wildlife can lead to ecological changes to the forest with broader impacts on the services provided by these ecosystems. Past lemur extinctions brought about by humans likely had significant ecological ramifications for the ecosystems of southern and southwestern Madagascar (Crowley et al. 2011), and future losses may have far-reaching ecological consequences including impacts on forest structure and dynamics (Moses and Semple 2011).

Materials

Natural ecosystems also provide critical sources of materials and fuel that indirectly support food security. The majority of Madagascar's people are still reliant on wood from nearby forests for cooking and heating, even in the cities (Bertrand et al. 2010). Wood energy is used daily by more than 90% of the population and accounts for over 75% of primary energy consumption in the country, and is considered the cause of about 100,000 ha of deforestation (Ministry of Environment and Forestry, cited in Rabarison 2013).

Mangroves have particular importance for providing a diversity of materials in Madagascar (Jones 2013). A study from fishing areas along the northwest and western coasts shows that mangrove wood is used for making fishing traps, canoes, processing prawn and fish catch, and for domestic use including fencing, housing, and fuel for cooking (Rasolofo 1997). However, overexploitation has led to an increasing scarcity of forest species.

Medicinal plants

Ecosystems also provide numerous plant species that have huge current or potential value for medicine. One study from a single protected area indicated that 241 species are used as ethnomedicines (including 113 agricultural or weed species), providing an estimated value equivalent to 43-63% of median household income to local communities (Golden et al. 2012). The potential for developing novel biomedicines is even greater: the potential value from this watershed alone was estimated to be US$0.3-5.7 billion for American pharmaceutical companies. A separate study from forested areas in western and south-eastern Madagascar indicated 45 morphospecies, more than half of which were endemic to Madagascar, were used for medicine for gastrointestinal disorders, malaria/fever, rheumatisms, cold, skin illnesses, and inflammations (Norscia and Borgognini-Tarli 2006). Yet another study indicated that 68 plant species were used in traditional medicine in eastern Madagascar, many of which remain to be chemically tested and were in danger of being lost due to slash and burn agriculture (Novy 1997). Despite increasing access to western medicine, traditional healing using medicinal plants remains important and is complementary (Lyon and Hardesty 2005).

Ecosystems supporting agriculture

In Madagascar, the majority of the population is engaged in small-scale agriculture (75% of total population), and agriculture makes up 26% of GDP (World Bank 2013). The number of poor people engaged in farming is even higher:nine out of ten (Stifel et al. 2003). Natural ecosystems provide critical services that support agriculture, such as crop pollination (Bodin et al. 2006). Even the smallest forest patches were found to be essential for providing pollination services, as well as harboring lemurs that provide seed dispersal services critical for biodiversity maintenance (Bodin et al. 2006, Moses and Semple 2011). Such small patches are highly vulnerable to ongoing forest destruction, threatening the ongoing provision of ecosystem services.

Fresh water

Freshwater services (including water quantity, water quality, and flow regulation) are among the most important ecosystem services in Madagascar, and they link to other services such as food provision and protection from floods. Below is a brief summary of types of freshwater services that were frequently referenced in the literature: fresh water for domestic use, rice irrigation and sediment regulation, and flood regulation.

Domestic use

Many households in Madagascar, particularly the poorest households, are reliant on unimproved sources of fresh water (i.e. rivers, streams, ponds, and lakes). A 2000 survey of 552 households in the city of Fianarantsoa (Razafindralambo et al. 2004) showed that:

> 28% of households rely on private taps, 33% rely on public taps, and 22% use natural sources, with a few households using wells (6%) or a private connection in some other household (8%). Not surprisingly, the higher income categories rely on private connections (54% for income category 4 and 76% of income category 5). Households in the middle income category 3 rely most on public taps (44%), although some substantial portion rely on private connections (22%) and natural sources (30%). The poorest households rely on pubic taps (36%) and natural sources (54%).

Another study of household water use indicates that, similar to many places in the world, women and girls spend the most time gathering water (Boone et al. 2011).

Rice irrigation & sediment reduction

Irrigation schemes supply water to about 40 percent of all cultivated lands, but many are poorly maintained so crop yields are low (World Food Programme and UNICEF 2011). This is mainly because farmers are pushing into the hills in a bid to compensate for stagnating yields in lowland areas. But upper watershed land use is often based on unsustainable management practices leading to upland soil erosion and water surface run-off, causing sedimentation for downstream irrigation infrastructure and contributing to the flooding of crop fields in the rainy season and water shortages in the dry season (WFP and UNICEF 2011). Typically, households that grow rice as the main crop have more irrigated land (around 50% irrigated land) than households that cultivate cassava, maize, or yams as the main crop (15-20%).

Ecosystems such as Madagascar's largest lake, Lake Alaotra, supports the country's most fertile and productive rice fields (Bakoariniaina et al. 2006). However, past deforestation has reduced the original forest cover of Madagascar by 90%, causing siltation, which impacts agriculture and hydraulic infrastructure such as hydropower dams (Bakoariniaina et al. 2006, Rakotoarison 2003). In the past 30 years, silt from upstream deforestation has clogged the streams and rivers in the Lake Alaotra Basin, filling in most of the lake, causing it to shrink to 20% of its former size in 2000 (Bakoariniaina et al. 2006). This reduction has caused crop productivity in the basin to drop to about 40% of its former level. Existing GIS modeling and image analysis point to areas that are contributing the largest amount of silt so that remedial action can be taken.

Forests in Madagascar provide hydrological services that are important for agriculture. Not only do they produce water for the irrigation of rice fields and human consumption but they can also control the sedimentation and the erosion of watersheds (Rakotoarison 2003). Deforestation has been shown to cause siltation which decreasing productivity of irrigated agriculture, reduces the availability of drinking water, and raises costs of maintaining infrastructure such as hydroelectric dams. Collectively, these impacts result in "catastrophic economic consequences" for many economic sectors and communities (Rakotoarison 2003).

Alternatively, conservation of forests provides hydrological benefits that can be measured in monetary terms. Rakotoarison (2003) estimated economic benefits from forest conservation over 15 years to agricultural productivity $222-290 million, reduced repair costs of hydroelectric dams ($7 million), and improved drinking water quality ($6-102 million) (Rakotoarison 2003). A study of the ecosystem service values of the Ankeniheny-Zahamena Corridor (CAZ) (Portela et al. 2012) indicates that the forested corridor:

> Demonstrated the potential to sustain much greater water demand than did a non-forested comparison site, which already faces critical levels of water demand. In addition, water quality, measured as reduced sediment load, was estimated to be significantly better in CAZ than in a

non-conservation area. These results clearly highlight the role of forested areas such as CAZ in retaining precipitation in the form of usable water and in preventing sediment contamination of the water supply.

Flood regulation

One study examined flood alleviation benefits resulting from protection of upland forests in Eastern Madagsacar (Kramer et al. 1997). The authors looked at the relationship between changes in land use practices and the extent of flooding immediately downstream, as well as the impact of increased flooding on crop production in terms of lost producer surplus. They found that flooding (stormflow volume) was three times greater for a secondary forest catchment than for a same sized primary forest catchment. Catchments dominated by swidden (slash and burn) agriculture produced approximately 1.5 times more stormflow than secondary catchments. The authors concluded that land conversion from primary forests to swidden is likely to result in as much as 4.5 times more stormflow. However, forests have a decreasing ability to mitigate larger floods, and the largest (100 and 200-year) floods are less affected by land use.

Hydropower

Only 17.4% of people in Madagascar have access to electricity (World Bank 2013). For those that do, production of electrical energy is from hydropower (50.4%) and conventional thermal (49.6%) (reegle.info, no date). The hydroelectric potential of the country is around 7800MW, but only about 3% are operated with a national coverage rate of approximately 21% (Rabarison 2013).

Disaster Risk Reduction and Climate adaptation

Five million people, a quarter of the population, live in zones at risk of natural disasters (World Bank 2013). Tropical cyclones already occur at a rate of 3-4 per year, and on average 250,000 persons are affected and US$50 million worth of damage is caused by each event (World Bank 2013). Flooding often follows cyclones; between 1990 and 2011, five major flood events were recorded, affecting more than 135,000 people; however these figures do not account for the many smaller scale events, which can cumulatively impact many more lives (World Bank 2013). The southern region of Madagascar already has very arid conditions, with less than 500mm of rainfall per year; between 1988 and 2011, 5 major drought events (each lasting two to three years) were recorded that affected at least 2.5 million persons (World Bank 2013). A single event in 2010 caused conditions that led to 720,000 people to be in a state of food insecurity.

Climate change scenarios indicate that Madagascar will be subjected to increasingly frequent and intense cyclones, floods, and droughts, which will impact biodiversity, ecosystem services and human well-being (IISD 2011, MEWF 2010, World Bank 2013). Preliminary modeling of cyclone tracks for 2100 indicates that while the total number of cyclones affecting Madagascar is unlikely to significantly increase, the frequency of intense cyclones is likely to rise. There is evidence of increasing average temperatures over recent decades, and rainfall has become less predictable, with wetter wet seasons and prolonged periods of drought (IISD 2011). Preliminary modeling indicates that in the next 40 years, the national average annual temperature will increase by up to 3°C (World Bank 2013). Key concerns related to climate change in Madagascar are related to negative impacts on agriculture and livestock, public health (especially diseases such as malaria), freshwater resources, coastal resources, and the forestry sector (IISD 2011, MEWF 2010).

There are existing efforts to identify areas within Africa that are most vulnerable to climate change at the most detailed scale possible, using existing data on physical, socio-economic, and political insecurities (Busby et al. 2010). These past efforts can be used to identify areas within Madagascar that are also most vulnerable. This information can in turn be used to identify ecosystems that are potentially reducing impacts from climate change.

Some ecosystems, such as mangroves, have demonstrated value in terms of ameliorating specific climate change impacts, such as protection from storms and shoreline stabilization (Jones 2013). As described above, mangroves provide a variety of critical services that can also help local communities adapt to climate change, including 'provisioning': food (e.g., fisheries and aquaculture), fuel (e.g., wood) and alternative energies (e.g., wind and wave), natural products (e.g., construction materials, sand and pearls), genetic and pharmaceutical products, ports and shipping), 'regulating' (e.g. carbon sequestration, shore - line stabilization, storm and flood protection, waste filtration), 'supporting' (e.g. soil and sediment formation, nutrient cycling) and 'cultural' (e.g. tourism, recreation, education) services (Jones 2013). However, mangroves are extremely threatened in Madagascar; several of the country's largest mangrove ecosystems exhibited higher rates of loss than surrounding terrestrial forests (Jones 2013).

Coral reefs also have well-recognized value in terms of reducing impacts from climate change, both in terms of providing some protection from storm surge, and perhaps more importantly, providing critical sources of food and income that can help coastal populations cope with climate impacts (Cinner et al. 2009). However, coral reefs are themselves vulnerable to impacts form climate change. In 2005, 80% of the country's coral reefs in the northeast of the island experienced bleaching, associated with warmer ocean waters (IISD 2011).

One study examined the resiliency of coral reefs to climate change in the Madagascar and Indian Ocean Island region (Maina et al. 2008). The authors identified the northwestern Indian Ocean and some central Indian Ocean Islands as highly susceptible, and the islands east of Madagascar as low vulnerability regions. Half of the strictly no-take zones in the region are situated in locations with medium to high susceptibility, indicating that these protections might not be sufficient if the underlying corals are vulnerable to climate impacts. The authors recommend targeting more resilient coral reefs for marine protected areas.

Climate mitigation & deforestation

Madagascar's remaining forest cover also plays a key role in carbon sequestration and storage, which are important for mitigating the impacts of climate change. According to a study of the forested Ankeniheny-Zahamena Corridor (CAZ) (Portela et al. 2012):

> Carbon sequestration values are very high in CAZ, suggesting that the area has high value as a continued carbon pool and sink. However, results also showed the potential for high releases of carbon if the area is managed unsustainably. Livelihoods in this region are often based on unsustainable natural resource management practices, such as *tavy* (slash and burn) agriculture and illegal logging, both of which are associated with deforestation in CAZ. This could tip the balance and quickly turn the area into a significant source of carbon emissions.

Unfortunately, 90% of Madagascar's original forest cover is gone due to human activities (Hannah et al. 2008). Madagascar remains one of the countries with the highest rates of deforestation (ONE, DGF, FTM, MNP and CI 2013). Much of this deforestation is relatively recent: analysis of aerial photographs (c.1953) and Landsat images (c.1973, c.1990 and c.2000) indicates that forest cover decreased by almost 40% from the 1950s to c.2000 (Harper et al. 2008). This forest cover loss has real implications for climate change: globally, tropical deforestation releases 20 to 30% of anthropogenic greenhouse gases (Kremen et al. 2000).

A study of drivers of forest loss from 1990-2000 indicated that deforestation was correlated with roads and footpaths, and was not linked to population density or poverty (although the authors state that data shortcomings might explain the lack of a relationship to population or poverty) (Gorenflo et al. 2011). The authors also found that protected areas substantially slowed forest loss during the study period. The rate of deforestation within protected areas managed by Madagascar National Parks (MNP) was half the national rate (ONE, DGF, FTM, MNP and CI 2013).

Unfortunately, the effectiveness of protected areas to sustain forests may be declining. A recent study from Masoala National Park, the largest federal protected area in Madagsacar, found that the annual rate of forest change has increased, likely due to a 2009 coup d'etat and subsequent political crisis, which has resulted in increased illegal activities including logging of precious hardwoods in protected areas (Allnut et al. 2013).

Deforestation also has implications for biodiversity loss, of course. The remaining forest is highly fragmented, which means, among other threats, that there are few or no possibilities for species ranges to shift to adapt to climate change (Hannah 2008). A national-scale study of the impacts of climate change on the cost of forest conservation demonstrated that it is more cost-effective to maintain existing forest rather than invest in forest restoration, in order to conserve species (Busch et al. 2012). However, the costs and benefits of conserving forests don't accrue to the same actors, or at the same scales. One case study from Madagascar (Kremen et al. 2000) showed that "conservation generated significant benefits over logging and agriculture locally and globally. Nationally, however, financial benefits from industrial logging were larger than conservation benefits. Such differing economic signals across scales may exacerbate tropical deforestation."

Cultural values & ecotourism

Madagascar's biodiversity and natural beauty is its largest draw for tourists, providing aesthetic and recreational values for the tourists themselves as well as livelihoods and a large portion of the country's overall economic activity. 15% of Madagascar's GDP is in tourism and ecotourism, providing 31,207 jobs in 2011 (Rabarison 2013). As of 2003, approximately 60,000 of Madagascar's 200,000 annual visitors came expressly for tourism, and many others came for other reasons but included some touristic activities (Christie and Crompton 2003). National benefits of biodiversity conservation and ecotourism are valued atUS$5 per hectare of protected areas per year (Carret and Loyer 2003).

However, a study of one protected area, Ranomafana National Park, demonstrated that ecotourism created few work opportunities for local people and did not absorb job seekers who rapidly revert to survival techniques and more destructive use of resources, threatening the integrity of the forest and the long-term survival of ecotourism activities (Sarrasin 2013). Thus the author concludes that the role of ecotourism in the Malagasy economy, and the direct economic benefits of tourism at the local level, have been exaggerated.

The cultural identity of certain ethnic groups is also tied closely to their natural environment. As in many places, connections to the land (or sea) are fundamental aspects of well-being in Madagascar (Keller 2008). For example, the Vezo are fishing people of western Madagascar, and are considered "people of the sea, distinguished from the farmers around them by their economic specialism" (Astuti 2006). The Ankodida protected area in southeastern Madagascar includes a forest that is sacred to the Tandroy tribe because it is the former home of a precolonial Tandroy king (Gardner et al. 2008). The protected area is also inhabited by spirits that play an important role in the spiritual life of the tribe, as well as providing the bulk of household income for local populations.

The relationship between cultural values and conservation can be positive or negative. There is evidence that traditional protections or taboos can and have conserved certain ecosystems or species (Gardner et al. 2008, Jenkins et al. 2011). There is evidence that such traditional protections may be eroding, however (Jenkins et al. 2011). Also, the imposition of restrictions to human access and use of natural resources for conservation reasons can cause local hardship (Ferraro 2002, Golden et al. 2011) and actually undermine cultural connections to nature (Keller 2008).

Summary of key ecosystem service values in Madagascar

All ecosystems provide multiple ecosystem services; but the services that are most important in a given geography depend on the specific ecological and socioeconomic context. To reduce the complexity of analyses required, we used the literature review and expert consultation to identify a discrete number of important ecosystem services to include in the KBA+ assessment.

In order to identify the most important services, we first identified key ***beneficiaries*** (people or sectors that depend on ecosystems). Next, we identified key ***dependencies*** of those beneficiaries on ecosystems (the specific ways in which they depend on ecosystems - e.g. for food, water, protection from cyclones, or other benefits.) Lastly, we used those key beneficiaries and dependencies to select a set of important services around which to focus the analysis.

Based on the literature review and expert input, we identified the following key beneficiaries (Table 6). This list it is intended to identify the most important beneficiaries to be included in the ecosystem service assessment; it is not a comprehensive list of all beneficiaries. This list is specific to Madagascar, but these types of beneficiaries will be similar in other geographies.

Table 6. Key beneficiaries of ecosystem services in Madagascar

People	Important Sectors
• Population centers • Rural populations • Populations in areas at risk of climate change impacts • Global population (climate regulation & biodiversity values)	• Irrigated rice • Livestock • Aquaculture • Coastal fisheries • Hydropower • Mining • Ecotourism

Key ***dependencies*** of these beneficiaries on ecosystems in Madagascar include dependency for food, water, energy, protection from climate related impacts, livelihoods, and cultural and spiritual values (Table 7). Again, this list is intended to identify the most important dependencies, it is not comprehensive.

Table 7. Key dependencies of beneficiaries on ecosystems in Madagascar

Food & medicine	**Protection from climate impacts**
• Rice • Fish • Bushmeat • Edible plants • Medicinal plants	• Cyclones • Floods • Droughts
Water	**Livelihoods**

• Household • Irrigation • Hydropower • Fisheries	• Farming • Fishing • Ecotourism
Energy	**Cultural & spiritual values**
• Fuelwood & charcoal • Hydroelectricity	• Cultural identity • Existence values (biodiversity)
Materials	
• Construction • Artisanal	

Once the key beneficiaries and dependencies were identified, it was possible to identify important services provided by ecosystems to those beneficiaries (Table 8). The services are organized according to the Common International Classification of Ecosystem Services (CICES, http://cices.eu/). This list was reviewed by key experts from CI-Madagascar and partner organizations.

Table 8. Important ecosystem services identified in Madagascar

Section	Division	Ecosystem Service
Provisioning	Nutrition	Fish
		Bushmeat
		Edible plants
		Medicinal plants
		Water flows for domestic use
		Water flows for irrigation
	Materials	Construction materials (wood, thatch)
		Materials for artisanal products (wood, sedges)
		Water flows for mining
	Energy	Fuelwood
		Charcoal
		Water flows for hydropower
Regulation & Maintenance	Mediation of waste, toxics and other nuisances	Water quality for household use
		Water quality for irrigation
		Water quality for hydropower
	Mediation of flows	Flood regulation
		Drought regulation

	Maintenance of physical, chemical, biological conditions	Carbon storage and sequestration
		Protection from cyclones
		Genetic material
Cultural	Physical and intellectual interactions with ecosystems and land-/seascapes	Ecotourism
		Existence value (biodiversity)
	Spiritual, symbolic and other interactions with ecosystems and land-/seascapes	Cultural and spiritual identity

Step 3) Select criteria for identifying important areas; and Step 4) Apply criteria to identify important areas within and around KBAs

Desktop Analyses: Methods

Once the key ecosystem services had been identified through the literature review and expert consultation, we looked for existing information that could be used to assess the value of KBAs in providing these services. We collected spatial and non-spatial data on a large variety of biophysical and socioeconomic characteristics, threats, and existing land use and priorities (see Table 3, above, for the types of data we sought for this analysis). In general, the same data would be needed for applying the KBA+ framework in any geography. In Madagascar, low availability of up-to-date data at the national scale was overcome by using available global data (see Appendix 1 for a complete list of data sources).

Using existing data, past analyses, and limited new desktop analyses and modeling using GIS, we assessed the value of KBAs for the following key ecosystem services:

1. Provisioning services: Food
   1.1. Commercial fisheries: average landed values of fish catch
   1.2. Small-scale fisheries: number of food insecure people within 10 km of mangroves and coral reefs
   1.3. Wildlife hunting & non-timber forest products (NTFPs): number of food insecure people within 10 km of terrestrial & freshwater ecosystems (forests, mangroves, wetlands, and water bodies)
2. Provisioning services: Fresh water
   2.1. Relative importance for providing fresh water for domestic use
   2.2. Relative importance for providing fresh water for irrigation
   2.3. Relative importance for providing fresh water for hydropower dams
3. Regulating services: Climate mitigation
   3.1. Long-term carbon storage: average carbon stock per hectare and total carbon stock

3.2. Potential avoided carbon emissions from deforestation
4. Regulating services: Disaster risk reduction and climate adaptation
    4.1. People whose vulnerability to climate change-driven increases in storm surges is reduced by mangroves
    4.2. People whose vulnerability to climate change-driven increases in floods is reduced by forests
5. Cultural values
    5.1. Ecotourism: Number of visitors to national parks in 2012 (data limited)
    5.2. Cultural/spiritual values (data limited)

This list does not include every ecosystem service identified as relevant in Madagascar; we limited our analysis to 1-3 key ecosystem services per category, based on expert input and data availability. Summarized methods for each service are included below.

Provisioning: Food

Commercial fisheries: average landed values of fish catch

For this analysis, we assumed that KBAs with higher levels of landed fish catch values were relatively more important for commercial fisheries. A global dataset of average landed fish value (Swartz et al. 2012) was overlaid with KBA boundaries and average landed value within each KBA was calculated.

The criteria for assessing "relative importance" of KBAs in terms of landed values of fish catch are:

- Does a given KBA provide landed fisheries values (yes/no)?
- Does a given KBA provide a landed fisheries value that is relatively larger when compared to other KBAs?

Assumptions & limitations

- This analysis includes landed fish catch values, which focuses on commercial fisheries. It assumes that there is a link between commercial fisheries and food security. This might be true, for fish that are consumed domestically and/or where incomes from commercial fishing support local food security. However, commercially caught fish might be exported and revenues might not support local income.
- There is a lack of data on subsistence level fisheries in Madagascar: at least one study indicates that total catches are actually twice the volume reported by national fisheries agencies, due to missing information about small-scale fishing (Le Manach et al. 2012).
- There is also a limitation in this analysis due to the different resolution of the data layers included: KBAs in Madagascar tend to be quite small, and the global FAO landed values dataset is coarser, thus some KBAs are smaller than a single grid cell in the FAO dataset while other KBAs

intersect portions of multiple landed values cells. Therefore the average landed values per KBA should be interpreted with caution. This information might be more useful in identifying broad regions (clusters of KBAs) that have higher values, rather than comparing individual KBAs within the same region

Small-scale fisheries: relative number of food insecure people within 10 km of mangroves and coral reefs

For this analysis, we estimated the number of food-insecure people living within 10 km of mangrove and coral reef habitat that occurs within KBAs. We assumed that people who live closer to marine and coastal ecosystems are more likely to be benefitting from food and other resources from those ecosystems. We also assumed that people who are food insecure during part or all of the year would be particularly dependent on such resources to get them through the lean periods, as is described in the literature. Thus we used proximity to food-insecure people as an indicator of the importance of marine and coastal ecosystems.

Data on the location of mangroves and coral reefs came from two global datasets (Giri et al. 2011 and Burke et al. 2011, respectively.) Population data was based on LandScan 2011. Food insecurity rates were estimated using a commune-level census from 2007, which asked communities to self-assess food insecurity rates at the commune level (Moser et al. 2008). Focus groups in each commune were asked to estimate the percentage of people who were “poor” (defined as “Those who have problems with food safety seasonally, whether in a good or bad year”) and the percentage of people who were “destitute” (defined as “Those who do not have enough to eat throughout the year”).

The criteria for assessing “relative importance” for small-scale fisheries were:

- Does a given KBA contain marine habitats that are within 10 km of food insecure people (yes/no)?
- Does a given KBA contain marine habitats that are within 10 km of a relatively larger number of food insecure people, when compared to other KBAs?

Assumptions & limitations

- We assumed that certain ecosystem types (mangroves, coral reefs) provide food and other benefits (e.g. charcoal) to food-insecure populations
- We assumed that people living within 10 km of these ecosystems are able to access and benefit from those resources
- We assumed that people who are food insecure during part or all of the year would be particularly dependent on such resources to get them through the lean periods

- We reported results in terms of *relative* numbers of people (ranging from low to high) rather than absolute numbers, because the datasets we used are probably not precise enough to calculate absolute "counts" of people

Wildlife hunting & non-timber forest products (NTFPs): relative number of food insecure people within 10 km of terrestrial & freshwater ecosystems

For this analysis, we assumed that local populations probably benefit from natural terrestrial and freshwater ecosystems for wildlife hunting, collection of edible plants, medicinal plants, fuelwood/charcoal production, or other non timber forest products (NTFPs) as described by Golden et al. 2011, Brashares et al. 2011, Ackerman 2004, Damson et al. 2010, and others. We also assumed that people who are food insecure during part or all of the year would be particularly dependent on such resources to get them through the lean periods, as is also described in the literature. Thus we used proximity to food-insecure people as an indicator of the importance of terrestrial and freshwater ecosystems.

For this analysis, we relied on land cover data from Kew Royal Botanic Gardens (2007). The vegetation classes that we included are: water, mangroves, western dry forest, South western dry spiny forest-thicket, wetlands, western humid forest, humid forest, littoral forest, south western coastal bushland, western sub-humid forest, and tapia forest. Degraded forest types were excluded, as well as bare soil/rock, cultivated areas, and grasslands (we assumed most grassland in Madagascar is pasture.)

We excluded areas that were protected (data provided by CI-Madagascar). We then calculated the number of people who lived within 10 km of terrestrial and freshwater ecosystems using LandScan population data from 2008 multiplied by the estimated rate of food insecurity (Moser et al. 2008). We reported results in terms of relative numbers of people (ranging from low to high) rather than absolute numbers, because the numbers are useful as estimates but are probably not precise enough to calculate absolute "counts" of people.

The criteria for assessing "relative importance" for wildlife hunting & NTFPs are:

- Does a given KBA contain terrestrial or freshwater ecosystems within 10 km of food insecure people (yes/no)?
- Does a given KBA contain terrestrial or freshwater ecosystems that are within 10 km of a relatively large number of food insecure people, when compared to other KBAs?

Assumptions & limitations

- We assumed that terrestrial and freshwater ecosystems provide food and non-timber forest product benefits to food-insecure populations

- We assumed that people living within 10 km of these ecosystems are able to access and benefit from those resources
- We assumed that people who are food insecure during part or all of the year would be particularly dependent on such resources to get them through the lean periods
- We reported results in terms of *relative* numbers of people (ranging from low to high) rather than absolute numbers, because the datasets we used are probably not precise enough to calculate absolute "counts" of people

Provisioning: Fresh water

Relative importance for providing fresh water for domestic use

"Relative importance" of KBAs for providing fresh water for domestic (household) use was estimated using the average annual water availability in a KBA as a proportion of the overall water availability of a watershed, weighted (multiplied) by cumulative water demand downstream.

Water availability was estimated using surface water runoff calculated for current climate at 1 km^2 resolution using version two of WaterWorld (Mulligan 2013). WaterWorld is a framework that incorporates global spatial datasets at 1 km^2 and 1 hectare resolution, spatial models of biophysical and hydrological processes, and scenarios for climate and land use change. In its core, the FIESTA model is a process based spatially distributed model which uses variables such as vertical as well as wind driven horizontal precipitation, fog interception, infiltration rates and evapotranspiration losses to calculate water balance and surface runoff (Mulligan & Burke 2005).

The cumulative demand for fresh water for domestic use was estimated using the number of people living downstream (LandScan 2011) multiplied by average estimated annual domestic water use of 15.2 cubic meters per year per person (42.3 liters per day per person), and cumulatively summed upstream using surface water flow directions obtained from HydroSHEDS (Lehner et al. 2008). The annual per person domestic water use was based on a survey of 522 households in the city of Fianarantsoa, Madagascar (Razafindralambo et al. 2004). A buffer of 2.5 km was used to include water demand by people living alongside of major rivers (we used flow of >3 km^3/yr to define these rivers).

Area of high "relative importance" in this analysis, is defined as areas that provide relatively more water (as a proportion of the overall water availability of a watershed) and have a relatively higher level of cumulative water demand (based on population size and per-capita water use). Thus it simultaneously highlights areas that are important for large populations depending on surface water supply from relatively smaller watersheds in which natural vegetation can plays large role in regulating water quality and quantity. This role becomes marginal in larger watersheds due to the water dilution effect.

For all freshwater analyses, continuous "wall-to-wall" maps covering the entire country were generated, then KBAs were "clipped" and average per-area values for each KBA were calculated.

Assumptions & limitations

- This analysis assumes that people are using surface water (from rivers and streams) for domestic water use. In Madagascar, this is often true, particularly for poorer households. However people also use water from wells (groundwater), piped water, or other water sources. For example, in a survey of 522 households in the city of Fianarantsoa (Razafindralambo et al. 2004):
    - "28% of households rely on private taps, 33% rely on public taps, and 22% use natural sources, with a few households using wells (6%) or a private connection in some other household (8%). Not surprisingly, the higher income categories rely on private connections (54% for income category 4 and 76% of income category 5). Households in the middle income category 3 rely most on public taps (44%), although some substantial portion rely on private connections (22%) and natural sources (30%). The poorest households rely on pubic taps (36%) and natural sources (54%)."
- This analysis assumes that every person requires 42.3 liters/day, which was the average per-person use. However, per-household use of water varied considerably with income:
    - "The lowest income-category [households] consume on average 13 liters per capita per day (for an average sized household), which is substantially below the WHO minimum recommendation of 20 liters a day per person. [Middle income-category households are] at the WHO minimum of 20 liters a day, and the higher income categories (higher for Fianarantsoa but still basically poor by international standards) are well above the 20 liters a day level standard".
- Availability of hydrological data (water availability, water quality, water demand or other data) is limited in Madagascar. This analysis is based on existing global datasets. Ideally, it should be validated using national or sub-national hydrological data, when available.

Relative importance for providing fresh water for irrigation

Similarly as for water for domestic use, "relative importance" of a KBA for water for irrigation was estimated using the average annual water availability in a KBA as a proportion of the overall water availability of a watershed, weighted by estimated cumulative irrigation demand. A calculation of the cumulative surface water demand for irrigation was based on maps of areas of irrigable agriculture and estimated water demand per hectare per year, adjusted for annual rainfall. We used an average water demand of 2000 mm per year (Portela et al. 2012) corrected for half of annual rainfall. Three agricultural land classes, found in BD500 digital maps (FMT 1998), were included: 1) rice paddies, 2) "culture" (monoculture), and 3) "mosaic de culture" (mosaic of crops).

Assumptions & limitations

- There is not high quality (up to date, fine-scale) spatial data on the location of irrigated agriculture in Madagascar. We used land cover data from the BD500 dataset (FTM 1998) and assumed that the three classes: 1) rice paddies, 2) “culture” (monoculture), and 3) “mosaic de culture” (mosaic of crops) contain irrigable agriculture.

- We assumed that areas that had rice paddies, monoculture, or mosaic crops, where those areas had low precipitation, were dependent upon surface water for irrigation at least for half of the year. Most rice in Madagascar is irrigated, but some other crops (such as maize, cassava, and yams) are primarily rain-fed (World Food Programme and UNICEF 2011). However, such crops are often rotated seasonally (i.e. rice during the wet season, then other crops when the soil is drier) or grown in a mosaic within a floodplain. Irrigation in Madagascar typically comes from surface water sources (e.g. small irrigation dams and channels); other sources (such as wells or pipes) are rare.
- Actual data on water demand of different crops in Madagascar was not available for this analysis. For this analysis, demand was estimated based on a single global statistic on the per-hectare water demand of rice assuming two rice harvests per year (Portela et al. 2012). However, demand varies considerably depending on numerous factors: latitude, temperature, soils, elevation, variety of rice or other crop being grown, number of harvests per season, and other factors.
- The above described estimation is a gross assumption which may be an overestimate of the real demand by including water demand generated by the mosaic of crops category from the BD500 dataset. On the other hand, it adjusts the demand of the crops grown on the eastern side of the island where the rainfall is over 2000 mm per year.

Relative importance for providing fresh water for hydropower dams

Similarly as for water for domestic use, “relative importance” of KBAs in terms of providing fresh water for hydropower was estimated using the average KBA’s contribution to the overall water balance in each watershed, weighted by demand for water to generate hydropower downstream. Cumulative power in MWH generated by hydropower plants (JIRAMA 2013) was used as a proxy for actual water demand (JIRAMA 2013). This is because we were unable to obtain actual water use data.

Assumptions & limitations

- Half of Madagascar's electric power comes from hydropower generation (reegle.info, no date). It is therefore safe to assume that the freshwater supply is critical for this sector. However, due to the lack of data on the actual water demand by each hydropower plant, we assumed that there is a positive linear correlation between produced electric power and water demand and used it as a proxy in the final analysis.
- In order to calculate the cumulative sum of power supplied by hydroelectric plants, we require that locations of these plants overlay directly with rivers supplying the water for their turbines. However, majority of the point locations supplied to us by JIRAMA did not align with spatial data on river locations. Therefore, we had to reassigning the locations by “snapping” them to the

nearest rivers (more precisely to grid cells with greatest runoff within a 5 km radius). As a result, in some cases, locations of the hydroelectric plants may have been moved up to 5 km. However, we feel that this procedure could not have significantly affected the overall results, unless point locations were snapped to different watersheds. Better data on the location of hydroelectric dams could resolve this issue.

- We do not know how reliable the numbers for the total power (MWh) generated by hydroelectric dams are. Many of the hydroelectric dams listed in the table provided to us by JIRAMA have either missing data or values that seemed too high or too low. Following up with JIRAMA could solve this issue.

Regulating: Climate mitigation

Long-term carbon storage: biomass carbon stock

Forested areas contain biomass that provides value in terms of long-term carbon storage that can help mitigate the impacts of climate change. Some areas contain forest with comparatively high carbon density – therefore regardless of their size, these sites provide a higher number of "tons of carbon per hectare" (tC/ha).

Based on a global biomass dataset (Saatchi et al. 2011) and a 2010 forest cover dataset for Madagascar (ONE, DGF, FTM, MNP and CI 2013, including Tapia forest, mangrove, and forest classes) was used to estimate the *average biomass carbon stock*, measured in tC/ha, for each KBA.

The criteria for assessing "relative importance" for long-term carbon storage are:

- Does a given KBA contain biomass carbon (yes/no)?
- Does a given KBA contain relatively more biomass carbon (average or total) than other KBAs?

Assumptions & limitations

- Calculations of carbon storage are based on a global dataset. Ideally, this data would be validated using ground-based sampling of biomass carbon stock.
- Forest cover data have a resolution of 28.5m. Biomass data have a resolution of 1 km. Biomass data are estimates for the entire grid cell, not just the forested part, and thus represent the average biomass of forest and non-forest cover within that cell. Thus, the biomass data are under-estimates if interpreted as values for forest only. This is a limitation of global datasets but only becomes a significant concern at the site level in fragmented-forest landscapes.
- For this analysis, we used biomass values at 1 km and multiplied them by the areas forest cover within the 1-km cell. This results in a conservative estimate of forest biomass for partially-forested cells, which has the largest impact in the more fragmented landscapes that are mostly in the drier eastern and southern zones.

Potential avoided carbon emissions from deforestation

For this analysis, we calculated the deforestation rate within each KBA from 2005-2010, based on a historic deforestation analysis of Madagascar (ONE, DGF, FTM, MNP and CI 2013). The deforestation rate was multiplied by the forest area within the KBA and divided by 5 (years) to calculate the future deforestation rate in hectares per year. The hectares per year deforestation rate is multiplied by the average biomass carbon stock (tC) of the KBA, and then converted into CO_2 equivalents (CO_2e) in order to get an estimate of the "potential avoided carbon emissions from deforestation." This refers to their *maximum* potential for emissions reductions (assuming deforestation is completely stopped, compared to a business-as-usual scenario based on the historical rate); feasibility studies would be needed to better estimate their actual potential for Reduced Emissions from Deforestation and Degradation (REDD+).

The criteria for assessing "relative importance" of KBAs in terms of potentially avoided carbon emissions are:

- Does a given area have a potential value in terms of avoided emissions from deforestation (yes/no)?
- Does the area have a relatively higher potential value in terms of avoided emissions, when compared to other KBAs?

Assumptions & limitations

- For now, we are using historic deforestation rate within the KBA (a percentage based on area deforested) as a proxy for potential future deforestation. However, this assumes that future deforestation will be at exactly the same rate as historic deforestation, which may or may not be true.
- This analysis is based on a global biomass carbon layer; ideally, this data would be validated with ground-based sampling of forest biomass carbon.

Regulating: Disaster risk reduction and climate adaptation

Relative number of people vulnerable to climate change-driven increases in storm surges that are near mangroves

There is mounting evidence that mangroves provide protection from storm surges generated by cyclones (Jones 2013), the frequency and/or intensity of which are projected to increase in the future in most ocean basins under climate change (IISD 2011, World Bank 2013). For this analysis, we used a global dataset that maps the number of people vulnerable to storm surges (the UNEP PREVIEW Global Risk Data Platform http://preview.grid.unep.ch). We also used global data on the location of mangroves (Giri et al. 2011). We omitted patches smaller than 1 hectare, buffered all remaining mangrove habitats by 2 km, then identified all people classified as being at risk of storm surge that fell within 2 km of mangroves, and hence who potentially derive some degree of protection (although see assumptions listed below). We then identified all KBAs that contain mangroves that are potentially protecting vulnerable people.

The criteria for assessing "relative importance" of KBAs for storm surge protection are:

- Does a given KBA contain mangroves within 2 km of people who are vulnerable to storm surge (yes/no)?
- Does a given KBA contain mangroves within 2 km of a relatively large number of vulnerable people, when compared with other KBAs?

Assumptions & limitations

- This analysis assumes that mangroves are capable of providing some degree of protection from cyclone-driven storm surges. The actual degree of protection afforded will depend on many characteristics of both the storm event and the biophysical context – e.g. wind speed, wind direction, duration of the storm event, structural characteristics of the mangroves, bathymetry, beach topography and other factors.
- This analysis assumes that people within 2 km of mangroves receive some form of protection from those habitats - the actual distance will depend on the factors listed above, and therefore may be smaller or greater.
- The dataset of people vulnerable to storm surges is coarse when compared to the mangrove dataset, thus it is possible that the vulnerable population is further from the mangroves than estimated, or in an unprotected position (e.g. adjacent).
- For all three reasons, this analysis might over- or under-estimate the number of people protected by mangroves. Thus like above, we reported results in terms of relative numbers of people (ranging from low to high) rather than absolute counts.

Potential flood risk reduction

For this analysis, we were interested in where ecosystems (particularly forests) may be providing flood regulation services. Similarly as for water for domestic use, "relative importance" of a KBA for mitigation of floods was estimated using the average annual water availability in a KBA as a proportion of the overall water availability of a watershed with a forested area, weighted by estimated cumulative sum of people downstream vulnerable to flooding. For forested areas, we used the 2010 forest cover (ONE, DGF, FTM, MNP and CI 2013). Estimates of people vulnerable to flooding were adopted from the GRID population database showing people physical exposure to flooding (UNEP 2013).

Assumptions & limitations

- The main premise for the method used here was that forested areas with relatively more runoff, located upstream of people vulnerable to flooding, are more important for mitigation of floods. In other words, if this forested area is deforested, the flooding effect may worsen for the people with physical exposure to flooding.
- The regulation of floods by forests has been demonstrated at small spatial scale from at least one location in Madagascar (Kramer 1997); however, it depends on the forest characteristics (e.g., primary forests provide more regulation than secondary forests, and both provide more regulation than agricultural land cover). It also depends on the flood magnitude; forests can better regulate small- to medium-sized floods, and are less effective at large (100- to 200-year) events.
- This analysis assumes that people downstream of forests benefit from those flood regulation services. This is based simply on location and not other factors such as the ability of people to move, engineering or infrastructural solutions, or other variables.

Cultural values

Ecotourism: Number of visitors to national parks in 2012 (data limited)
For this analysis, we used data on the number of visitors to National Parks (data from Madagascar National Parks) as a proxy for overall value for ecotourism.

The criteria for assessing “relative importance” for ecotourism are:

- Did a given KBA have visitors in 2012 (yes/no/data deficient)?
- Did a given KBA have a relatively large number of visitors in 2012, when compared to other KBAs?

Limitations

- This analysis only includes data on 32 protected areas managed by Madagascar National Parks and is for only a single year (2012).
- Many other KBAs likely also have ecotourism value, and the number of visitors likely varies year to year.

Cultural/spiritual values (data limited)
It is known that many sites throughout Madagascar have important cultural and spiritual values, but there has been no comprehensive, national inventory. There is an inventory of the cultural values of selected protected areas (Conservation International 2011). However, data is only available for 14 out of 220 total KBAs. Similarly, there is an inventory of the cultural (religious and social) values of 51 important plant areas, based on expert opinion (Missouri Botanical Garden 2013).

However, we chose not to include these datasets, because they are not comprehensive for the entire country, and therefore make it appear that some sites have cultural values while others do not. Additional investments in research are required to better understand the value of all KBAs for providing cultural and spiritual services.

Multi-criteria Analysis

We were also interested in examining areas that were important for multiple services. Multiple ecosystem services from terrestrial and freshwater ecosystems were combined in a multicriteria analysis based on several of the above results: 1) biomass carbon stock, 2) number of food-insecure people with access to terrestrial/freshwater ecosystems, 3) relative importance for providing fresh water for i) domestic use, ii) irrigation, iii) hydropower, 4) relative importance for flood risk, and 5) ecotourism. We were unable to run a similar analysis for marine/coastal ecosystems, because we had too little data.

For this analysis we used IDRISI Selva software (Eastman 2012) to scale the variables and assign them individual weights. All of the input datasets were prepared so that they had the same resolution and extent. The first step in the analysis was to make sure that all of the variables were in the same scale. For our analysis we chose to execute a simple linear stretch to fit the values for each variable between the range of 0 and 255. Then each variable was put into the Multi-Criterion Evaluation (MCE) module in IDRISI and assigned a weight.

The weights given to each of the values in the multi-criteria analysis are shown in Table 9. Weights were established with expert input. We decided to weight biomass carbon stock, food provision, and fresh water equally (30 out of 100) as these data are available for the entire country. For fresh water, we combined the four freshwater services (domestic use, irrigation, hydropower, and flood protection) so that they collectively added up to 30. We weighted ecotourism less (10 out of 100) because the data are available for only national parks. We tested slight variations in the weights and found similar results.

Table 9. Weights given to each of the terrestrial/freshwater ecosystem services included in the multi-criteria analysis.

Variable	Weight (out of 100)
Total biomass carbon stock (tC)	30
Food provision (# of food insecure people within 10 km of terrestrial & freshwater ecosystems)	30
Ecotourism (# of visitors to Madagascar National Parks in 2012)	10
Relative importance for fresh water (FW) (total):	30:
Relative importance of FW for domestic use	7.5
Relative importance of FW for irrigation	7.5
Relative importance of FW for hydropower	7.5

Relative importance of FW for flood protection	7.5
TOTAL	100

The multi-criteria analysis was also repeated, excluding carbon, in order to focus on places important for "local" terrestrial & freshwater ecosystem services (food provision, ecotourism, and freshwater.)

Step 5) Summarize ecosystem services values for KBAs

Desktop analyses: Results & maps

Below are results for several key ecosystem services (food provision, water provision, climate mitigation, disaster risk reduction/climate adaptation, and cultural values). A complete table listing the ecosystem service values of each KBA is provided in a separate Excel file which contains all the Appendices. A complete list of data sources is included in Appendix 1, at the end of this document.

1. Provisioning: Food

1.1 Commercial fisheries: average landed values of fish catch

Our analysis show that 21 coastal/marine KBAs provide landed fish values (Figure 6). Certain KBAs in the northeast, northwest, and west of Madagascar exhibited relatively higher values, including Antogil Bay, Barren Islands, Iranja-Ankazoberavina-Russes bays, Ambodivahibe Bay, and PK32-Ranobe. These sites could be prioritized for conservation investment and carefully managed to avoid overharvest (see Appendices for a complete list of sites).

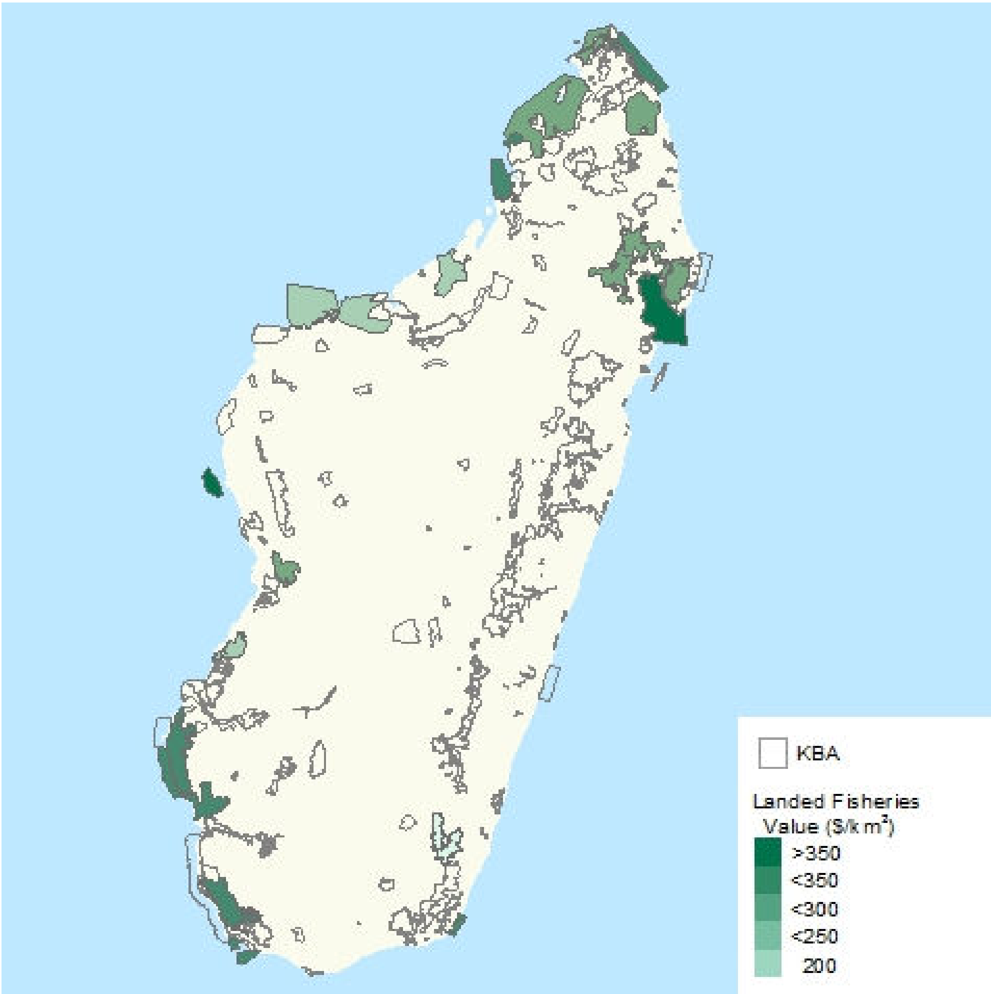


Figure 6. Landed value of fish in KBAs, expressed as US$/ km^2/yr (data: Swartz et al. 2012)

1.2 Small-scale fisheries: relative number of food-insecure people near coastal/marine ecosystems

Many coastal/marine KBAs contain ecosystems (coral reefs and mangroves) that may serve as important sources of food to food-insecure populations (Figure 7). We identified a number of KBAs (42 out of 221) that contain ecosystems and are near (within 10 km) populations of food-insecure people. Examples include Sainte Marie Island (Ambohidena), Three Bays complex, Antogil Bay, Southwestern Coastal Wetlands and Nosy Manitse Future SAPM Marine, and Ampasindava/Rigny Bay (Est). These sites could be prioritized and carefully managed to avoid overharvest. (See Appendices for a complete list of sites.)

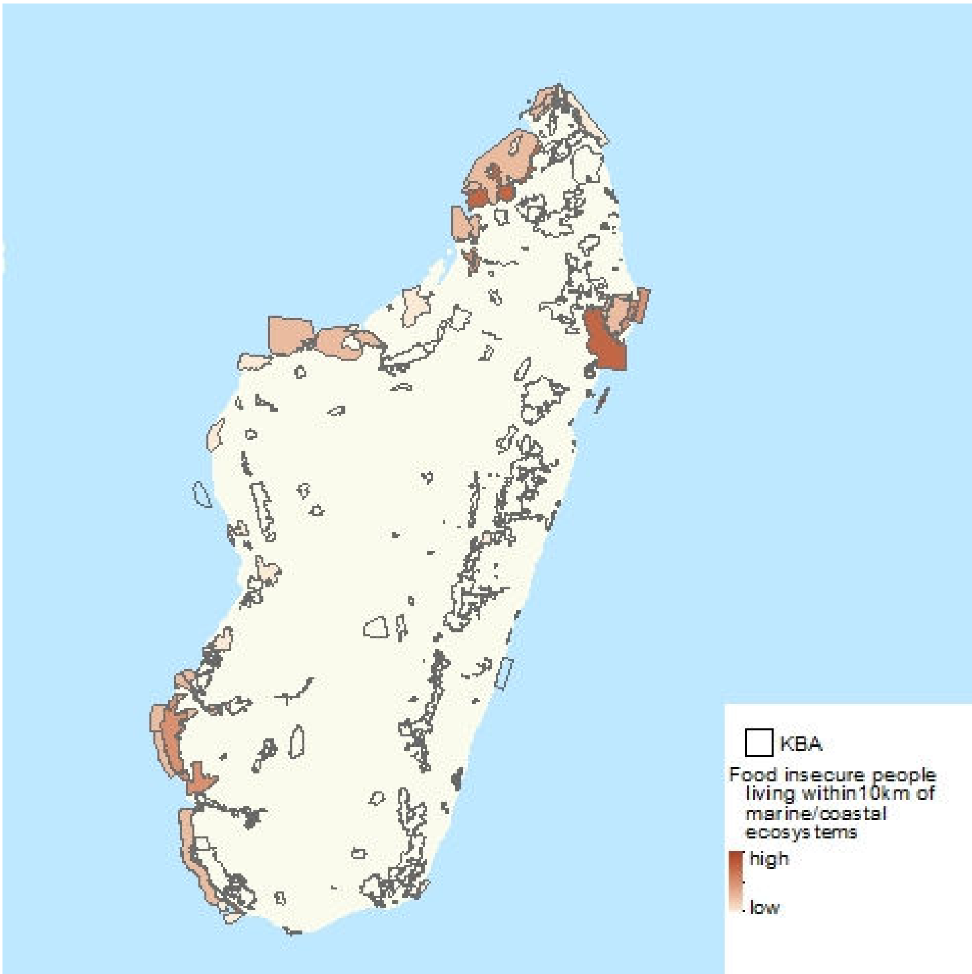


Figure 7. Relative number of food insecure people living within 10 km of mangroves and coral reefs (mangrove data from Giri et al. 2011, coral reef data from WRI Reefs at Risk Revisited (Burke et al. 2011); population data from LandScan; food insecurity data from Moser et al. 2008)

1.3 Wildlife hunting & non-timber forest products (NTFPs): relative number of food-insecure people near terrestrial & freshwater ecosystems

All terrestrial KBAs contain ecosystems (forests, mangroves, wetlands, and water bodies) that may serve as sources of food or non-timber forest products (NTFPs) to food-insecure populations (Figure 8). Most KBAs (193 out of 221) contain ecosystems that are near (within 10 km) food-insecure people. Examples include: Nankinana (Ambodibonara-Masomeloka), Manjakatompo-Ankaratra Massif, Namorona-Faraony River, Anja communuty Reserve, and Ankavia-Ankavana River (Antalaha). These sites might be prioritized if there is an interest in investing in sites that are potentially providing food and NTFPs to local communities. Such sites should be carefully managed to avoid overharvest. Mangroves were included in this analysis as well as the analysis above, as they cross the terrestrial/marine boundary.

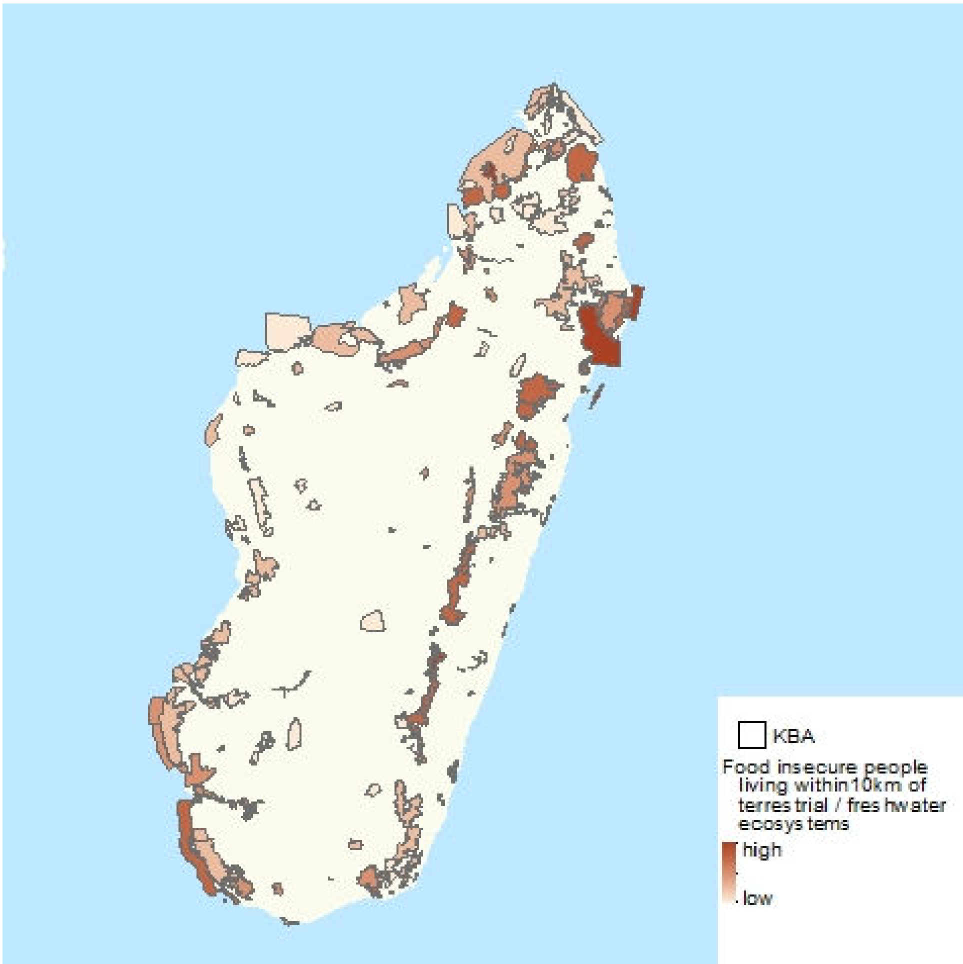


Figure 8. Relative number of food insecure people living within 10 km of terrestrial & freshwater ecosystems (ecosystems data from Kew Royal Botanic Gardens 2007; population data from LandScan; food insecurity data from Moser et al. 2008)

2. Provisioning: Fresh water

2.1 Relative importance for providing fresh water for domestic use

Most KBAs (203 of 221) are upstream of people and are likely to provide fresh water for drinking and other domestic uses (Figure 9 and Figure 10). "Relative importance" for domestic fresh water was estimated using the average annual water availability in a KBA as a proportion of the overall water availability of a watershed, weighted by estimated water demand downstream (see Methods). KBAs in the highlands, upstream of the largest numbers of people, and KBAs in the arid northeast and southwest, where water is most scarce, appear to be relatively more important. Throughout the rest of the country, the importance of KBAs for providing water is variable.

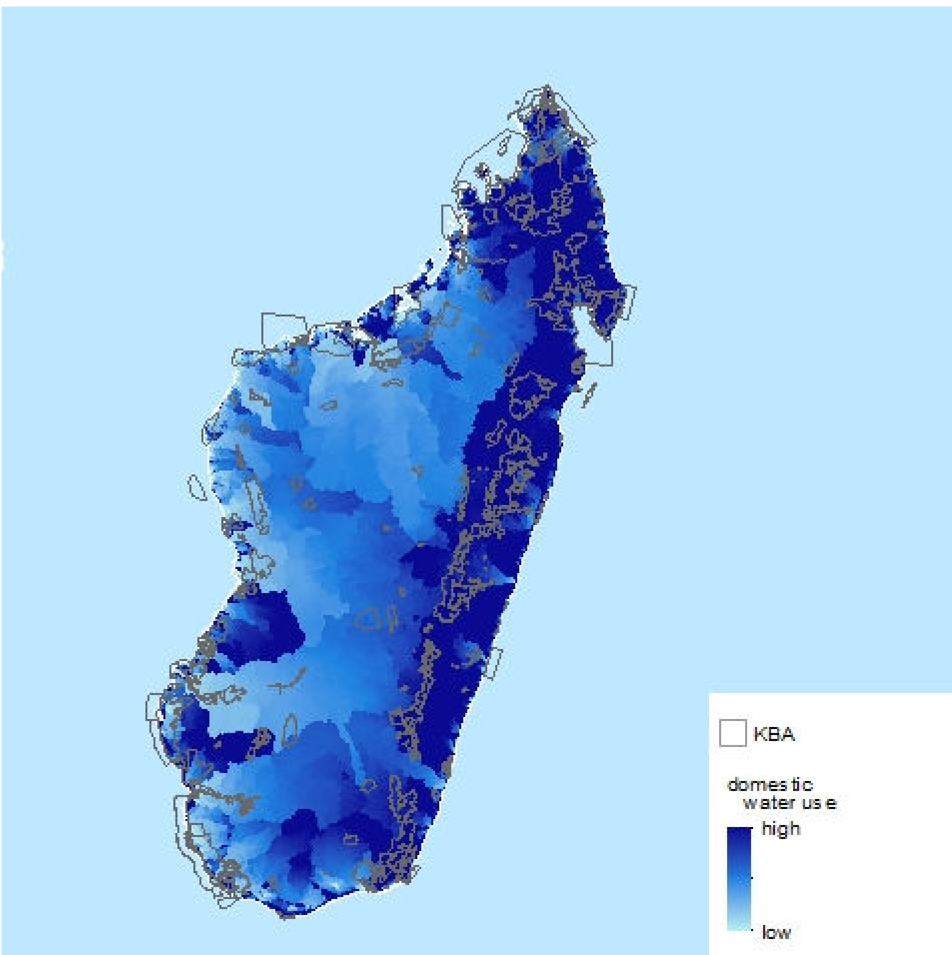


Figure 9. Relative importance for fresh water for domestic use. (Data: WaterWorld (Mulligan 2013), LandScan)

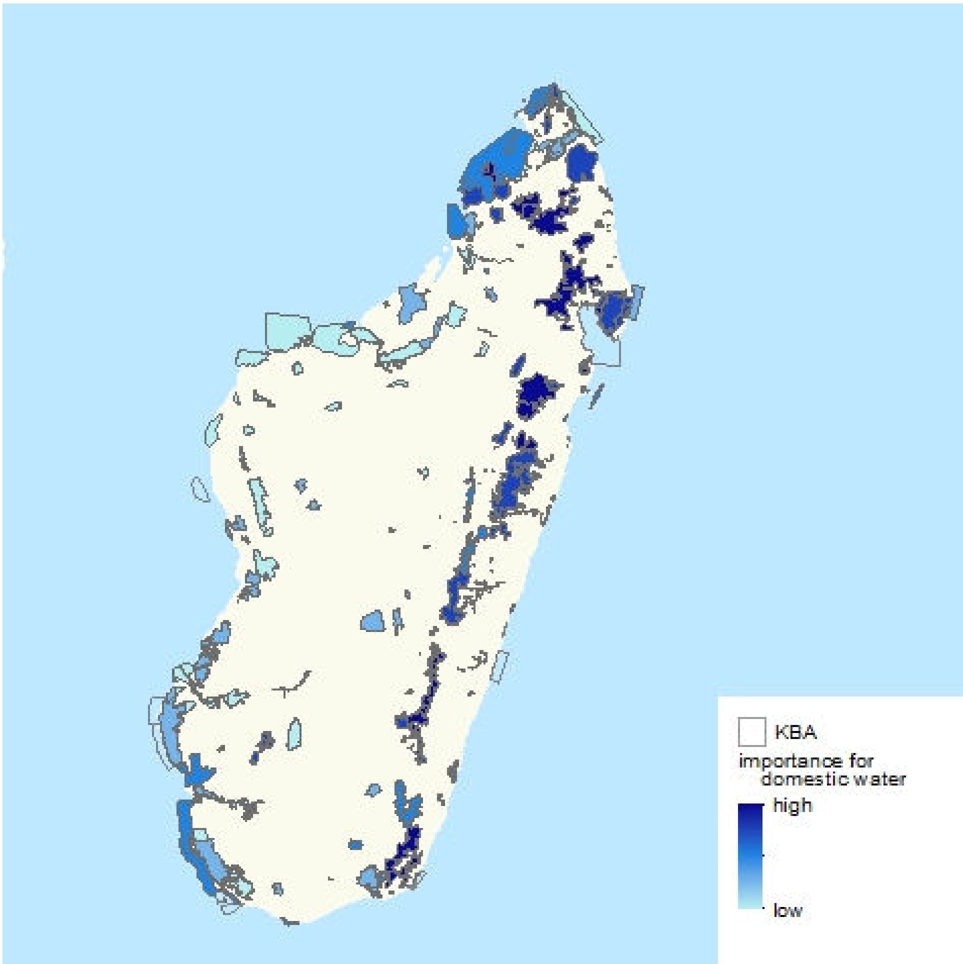


Figure 10. Relative importance of KBAs for fresh water for domestic use.

2.2 Relative importance for providing fresh water for irrigation

Similarly, "relative importance" of a KBA for provision of fresh water for irrigation was estimated using the average annual water availability in a KBA as a proportion of the overall water availability of a watershed, weighted by estimated irrigation demand (see Methods). Most KBAs (184 out of 221) are upstream of irrigated agricultural areas. Those with the highest relative importance are again located in the eastern highlands, where the largest number of people and highest concentration of irrigated rice agriculture occurs (Figure 11). But there are also relatively important areas in the east, north, and western part of Madagascar, regions characterized by larger areas of irrigated rice, as well as areas of higher aridity and lack of rain.

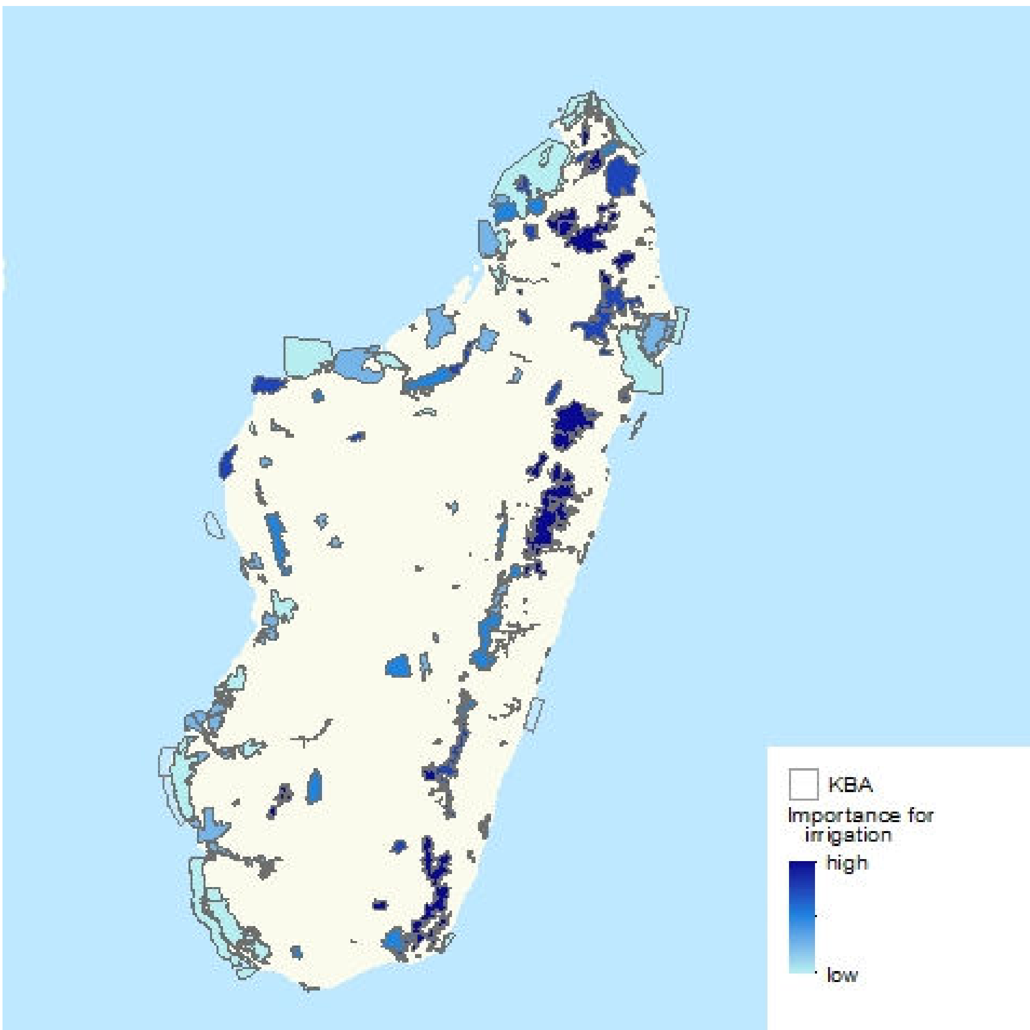


Figure 11. Relative importance of KBAs for fresh water for irrigation. (Data: Mulligan 2013 (WaterWorld), BD 500)

2.3 Relative importance for providing fresh water for hydropower dams

Relative importance of KBAs in terms of providing fresh water for hydropower was estimated using the KBA's contribution to the overall water balance in each watershed, weighted by demand for hydropower downstream (see Methods). Our analysis indicates that 38 KBAs are upstream of hydropower dams. Several KBAs in the east, north, and northwest appear to be relatively more important for hydropower (Figure 12). Examples include: Angavokely Forestry Station, Tsarasaotra Lake, Ankafobe, Manjakatompo-Ankaratra Massif, and Efatsy (Farafangana).

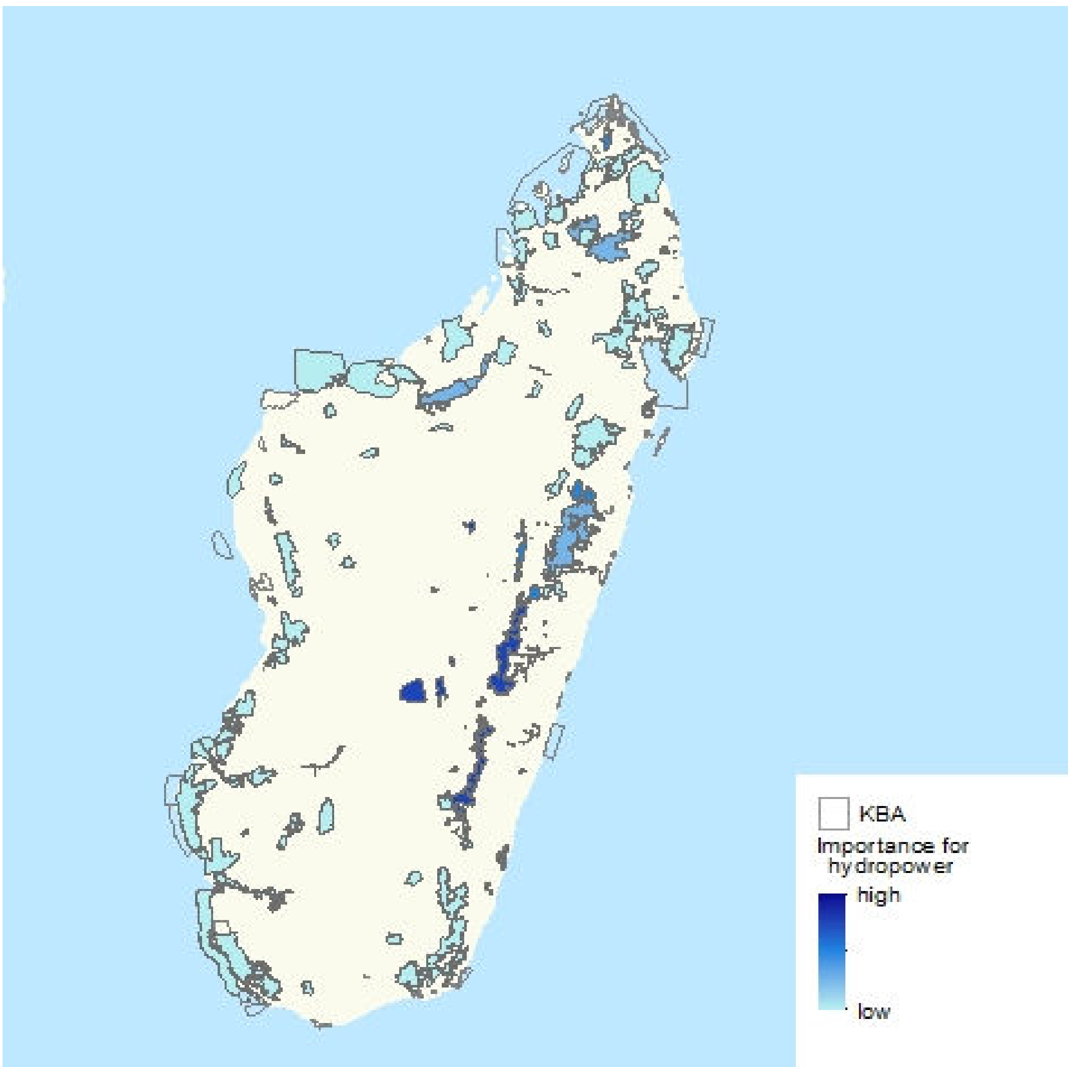


Figure 12. Relative importance of KBAs for fresh water for hydropower dams (Data: Mulligan 2013 (WaterWorld), JIRAMA)

3. Regulating: Climate mitigation

3.1 Long-term carbon storage: average biomass carbon stock per hectare

Virtually all of Madagascar's remaining forest is contained within KBAs; thus these areas in relative terms contain significant value in terms of forest biomass carbon stock compared to the rest of the land (Figure 13). All terrestrial, forested KBAs (180 out of 221 total KBAs) contain varying amounts of biomass carbon stock.

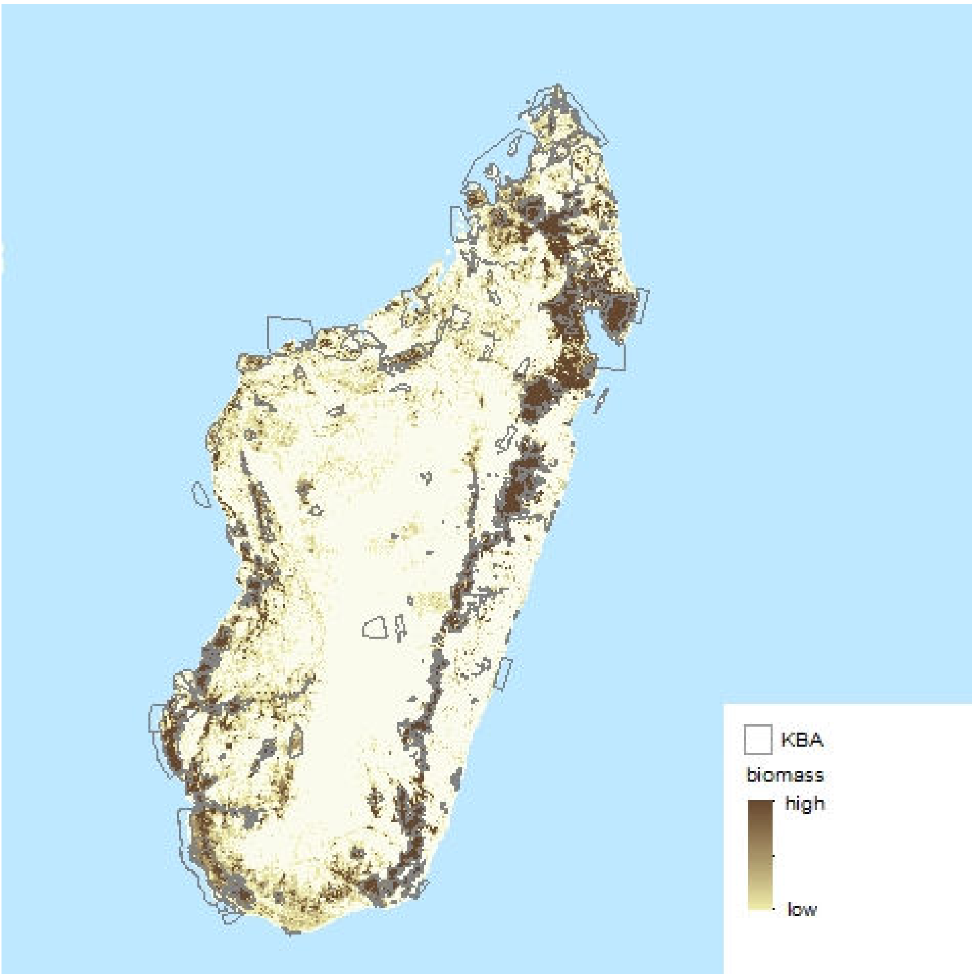


Figure 13. Total biomass carbon in Madagascar, overlaid with Key Biodiversity Areas (KBAs). Most of the remaining forest is contained within a KBA, and therefore most of the remaining biomass carbon stock exists within KBAs. (Data source: Saatchi et al.)

Some KBAs contain forest with comparatively high biomass carbon density as measured in tC/ha. The highest values are found in KBAs containing humid forest, particularly in the eastern highlands (Figure 14). Examples include Mananara-North National Park, Vohibe Ambalabe (Vatomandry), Ambatovaky Special Reserve, Analamay-Mantadia Corridor, and Masoala National Park.

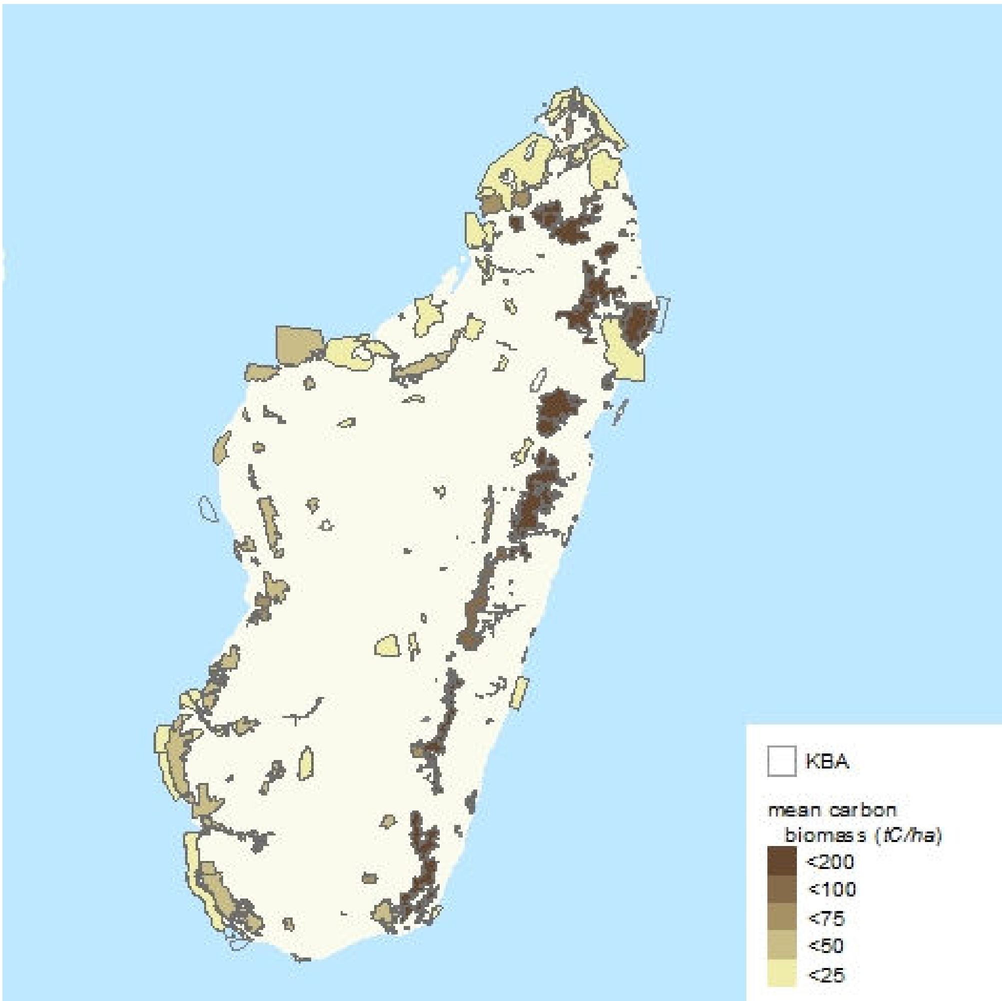


Figure 14. Average biomass carbon per hectare within KBAs (tC/ha). (Data source: Saatchi et al.)

3.2 Potential avoided carbon emissions from deforestation

Many KBAs (92 of 221) contain forest and have experienced historic deforestation. If conserved, these sites may have the highest estimated maximum potential for avoiding future carbon emissions from deforestation (Figure 15). This "estimated maximum potential" is based on the assumption that deforestation is completely stopped. Feasibility studies must be conducted if there is an interest in estimating the *actual potential* of sites for Reduced Emissions from Deforestation and Degradation (REDD+). Examples of KBAs with relatively higher estimated levels of potential avoided emissions are: PK32-Ranobe, Bidia-Bezavona Classified Forest, Ankeniheny-Lakato Future SAPM, Zahamena-Ankeniheny SAPM, and Mahafaly Plateau North Future SAPM.

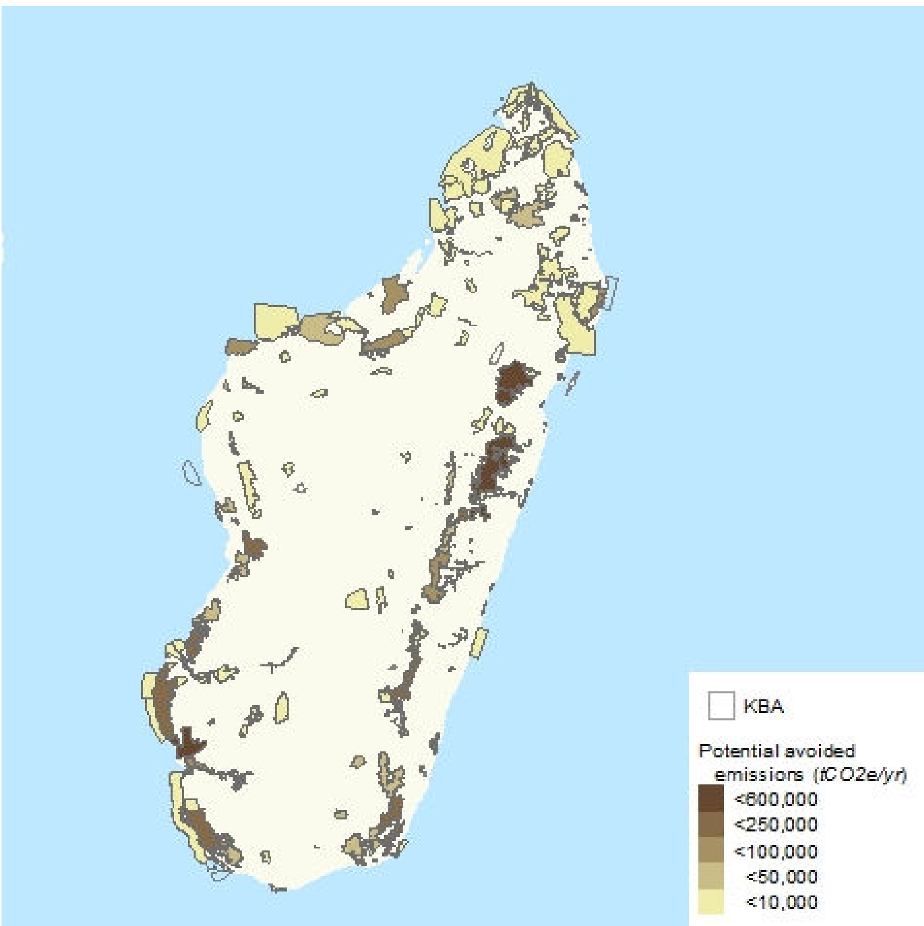


Figure 15. Potential avoided emissions within KBAs, estimated based on historic deforestation rates within KBAs. (Historic deforestation data from Conservation International and biomass data from Saatchi et al.)

4. Regulating: Disaster risk reduction & climate adaptation

4.1 Number of people vulnerable to climate change-driven increases in storm surges that are near mangroves

Twenty-eight KBAs contain mangroves within two km of people that are considered vulnerable to storm surges, based on historical cyclone events (Figure 16). This analysis uses historical occurrence of cyclones as a proxy for future risk, and assumes that proximity to mangroves provides some protection. Examples of KBAs that contain mangroves within two km of people who are vulnerable to cyclone surge include Amoron'i Onilahy et Onilahy River, Three Bays complex, PK32-Ranobe, Mikea Forest, and Diégo Bay. In Madagascar, cyclones primarily hit from the east and north; however remaining mangrove habitat exists primarily in the west. More research is required to understand the actual protection provided by mangroves, and the potential for mangrove restoration in the eastern part of the country.

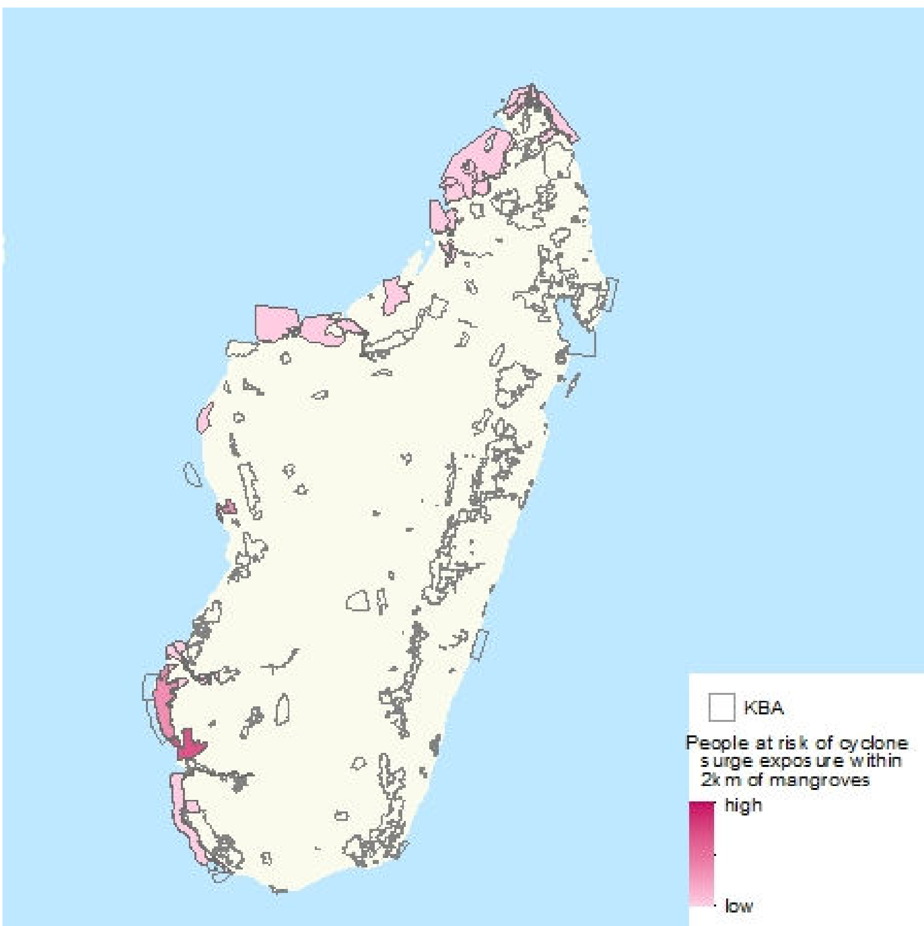


Figure 16. Relative number of people vulnerable to climate-change driven increases in storm surge, within 2 km of mangroves (Data sources: Human exposure to cyclone surge data from UNEP GRID, data on mangroves from Giri et al. 2011).

4.2 Potential flood risk reduction

Relative importance of KBAs for flood risk reduction was estimated based on identification of forest areas within KBAs that have a relatively high contribution to the overall water balance in each watershed, weighted by the number of people vulnerable to flooding downstream (Figure 17). Our analysis indicates that 123 out of 221 KBAs have potential flood reduction benefits. KBAs in the eastern and northeastern highlands showed up as relatively more important for flood risk reduction. Examples include: Angavokely Forestry Station, Anjanaharibe Sud Special Reserve, Ambohipiraka, Analalava-Analabe-Betanantanana (Ambatosoratra), and Zahamena National Park and Strict Reserve. This analysis assumes that forested areas provide some protection from flooding. There is evidence that forests provide some protection from small- and medium-sized floods; however, more research is required to better understand the role of forests in reducing floods in Madagascar.

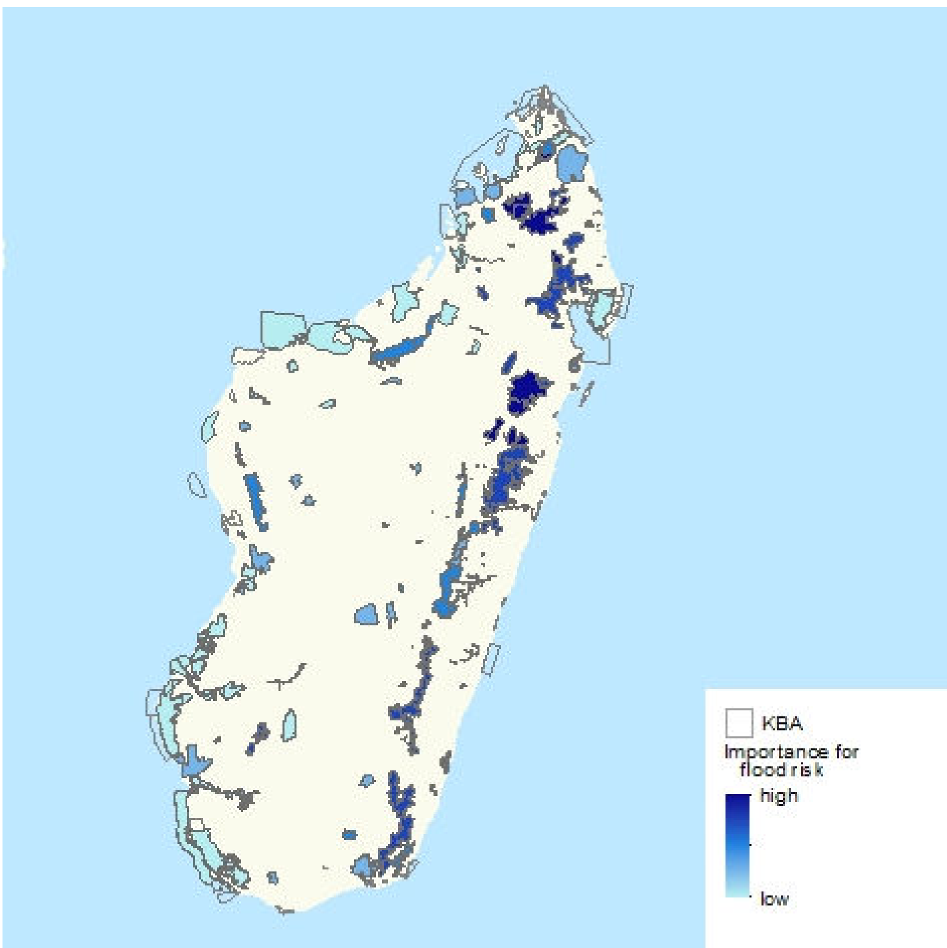


Figure 17. Relative importance of KBAs in terms of flood risk protection, based on relative importance of an area to regulate water weighted by number of people vulnerable to flooding downstream (Data: human physical exposure to floods from UNEP PREVIEW Global Risk Data Platform, water balance data from Mulligan 2013 (WaterWorld).

5. Cultural values and ecotourism

5.1 Ecotourism: Number of visitors to national parks in 2012 (data limited)

Data on ecotourism was only available for 32 protected KBAs managed by Madagascar National Parks. KBAs that had the largest number of visitors in 2012 include Isalo National Park, Mantadia National Park and Analamazaotra Special Reserve, Ranomafana National Park, Nosy Be and Satellites Islands (Nosy Tanihely), and Ankarana Special Reserve (Figure 18). Note that this data is limited to a single year. However, most ecotourism in Madagascar is centered on the national park system, thus while this dataset is incomplete, it is probably accurate to conclude that these national parks have relatively high values for ecotourism, when compared to other sites.

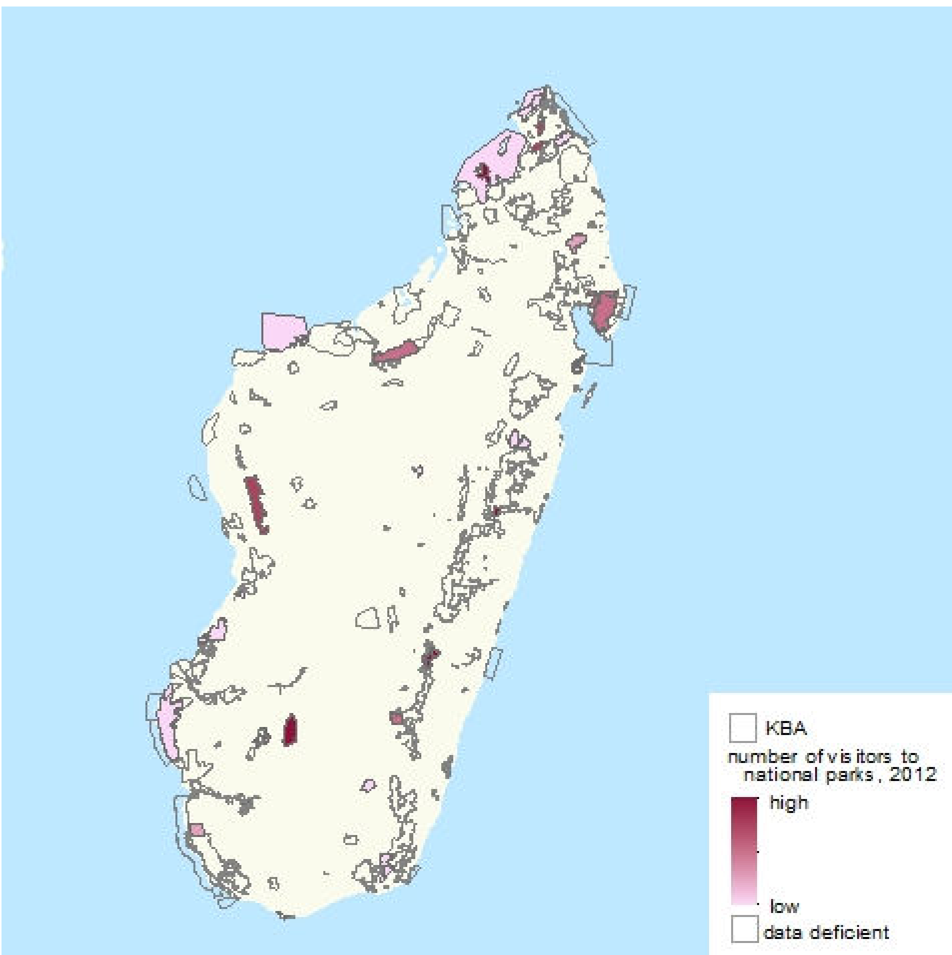


Figure 18. Number of visitors to protected KBAs managed by Madagascar National Parks in 2012 (data: Madagascar National Parks). Note that just because a site is data deficient does not mean that there were no visitors in 2012.

5.2 Cultural/spiritual values (data limited)

For this ecosystem service, data was only available for 14 out of 221 KBAs. These 14 sites were included in an inventory of community heritage areas of Madagascar (Conservation International 2011). The sites included: Ambodivahibe Bay, Andrafiamena, Bongolava Classified Forest (Marosely), Fandriana Marolambo Corridor, Ibity Future SAPM, Itremo Vakinakaratra Future SAPM, Manjakatompo-Ankaratra Massif, Montagne des Francais, Nosivolo Wetland, Vondrozo Classified Forest and surrounding areas, Zahamena National Park and Strict Reserve, and Zahamena-Ankeniheny SAPM. However; many sites throughout Madagascar have important cultural values, but were not included in this inventory. Thus a map of sites of known cultural/spiritual importance was not included because any such map would be incomplete. Additional investments in research are required to better understand the value of KBAs for providing cultural and spiritual services.

6. Multiple Terrestrial/Freshwater Ecosystem Services

Multiple ecosystem services from terrestrial/freshwater ecosystems were combined in a multi-criteria analysis based on several of the above results: 1) biomass carbon stock, 2) number of food-insecure people with access to terrestrial/freshwater ecosystems, 3) relative importance for providing fresh water for i) domestic use, ii) irrigation, iii) hydropower, 4) relative importance for flood risk, and 5) ecotourism (Figure 19). The highest value areas were found in the northeast and eastern highlands, with additional high-value areas on the southeastern side of the island. Examples include: Zahamena National Park and Strict Reserve, Mananara-North National Park, Andohahela National Park - Parcel I, Mantadia National Park and Analamazaotra Special Reserve, and Marojejy National Park. Note that this analysis includes only terrestrial and freshwater services, it does not include coastal protection, commercial fisheries, or small-scale fisheries. This map should be presented in combination with the above maps of coastal/marine services for a more complete picture. Note that areas important for providing multiple services are not necessarily “more important” than areas that are important for a single service. Thus this analysis may help to combine the above analyses, but it should not be presented in isolation.

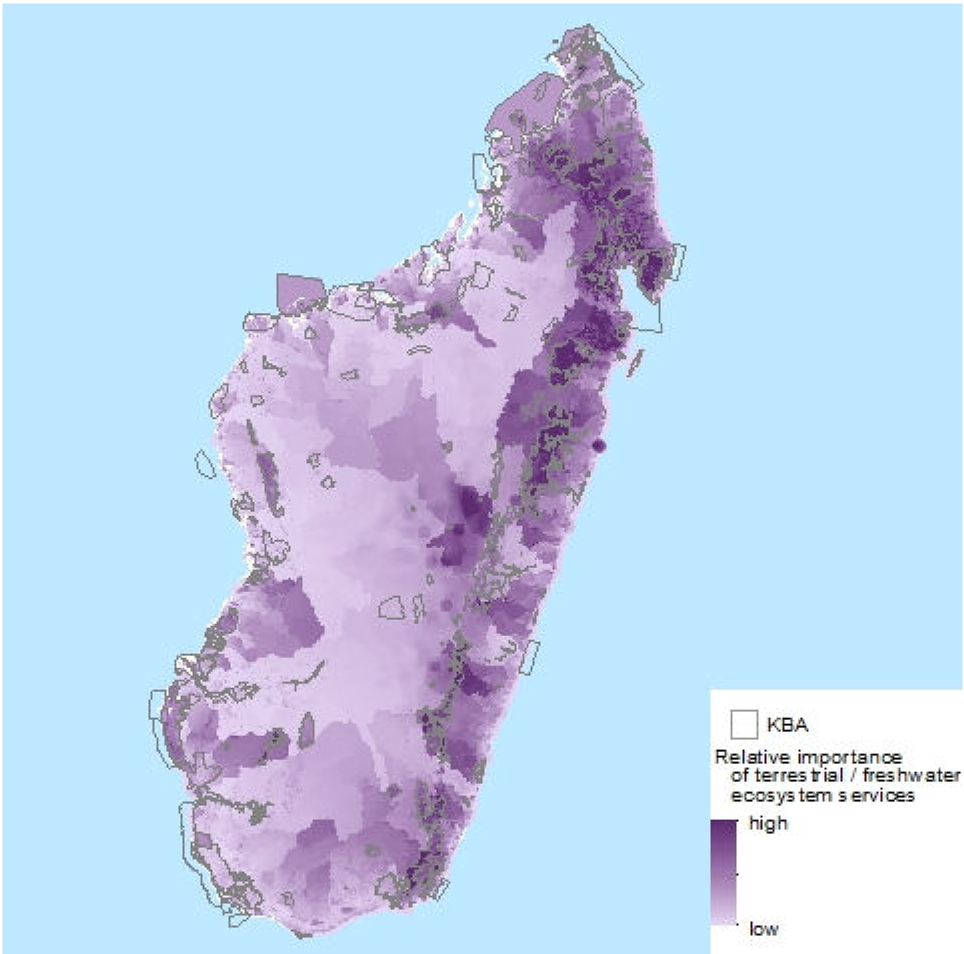


Figure 19. Results of a multi-criteria analysis of terrestrial and freshwater ecosystem services (carbon, food, freshwater, and ecotourism).

The second multi-criteria analysis excluded carbon in order to focus on "local" ecosystem services. Results indicate that again, areas in the eastern and northeastern Madagascar are important for multiple terrestrial & freshwater services, but also highlights some regions in the northwest and southwest (Figure 20). Examples of sites that are important for multiple "local" terrestrial and freshwater ecosystem services include: Zahamena National Park and Strict Reserve, Tsarasaotra Lake, Marojejy National Park, Angavokely Forestry Station, and Ankavia-Ankavana River (Antalaha). Again, this analysis excluded coastal/marine services, and this map should be presented in combination with the above maps for a more complete representation of ecosystem services in Madagascar.

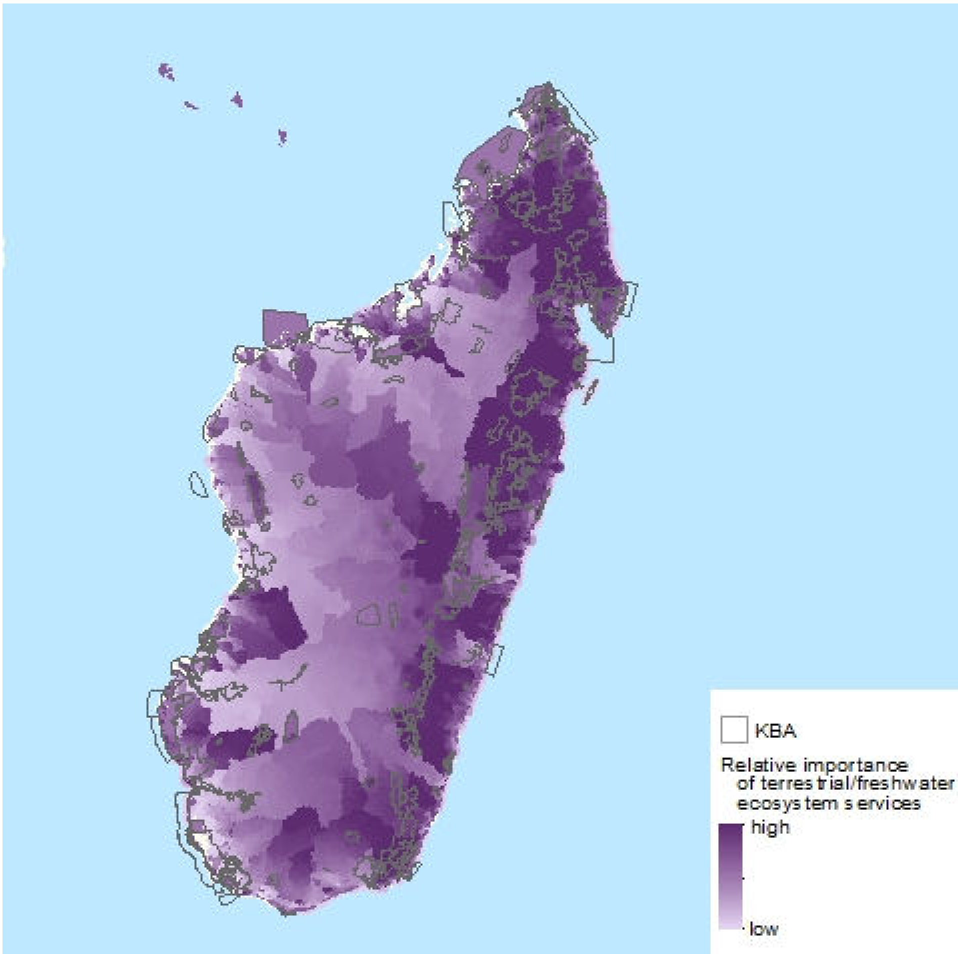


Figure 20. Multi-criteria analysis of "local" ecosystem services: freshwater, food provision, and ecotourism

Step 6) Make recommendations and integrate into CEPF profile

Discussion

Our analysis shows that KBAs in Madagascar provide important ecosystem services supporting local livelihoods and the country's economy. The literature review and expert consultation suggested that virtually all remaining natural ecosystems are important to nearby local communities in Madagascar. The value of nature for these communities ranges from provisioning and regulating services (food and water) to cultural and spiritual benefits. For example, inventories of important plant areas in Madagascar show that such sites provide timber, wood for canoes and posts, fuel, food, materials for handicrafts, wild silk, traditional medicines, water for crop irrigation, cattle refuge, breeding grounds for fish and shrimp, social cohesion and identity, and religious values (Missouri Botanic Garden 2013).

Different KBAs may be more important for providing different ecosystem services, however. In terms of provisioning services, based on the catchment data, coastal and marine KBAs provide fish for both commercial and small-scale fisheries. Some of them contain mangrove and coral reef ecosystems that support these fisheries, as well as provide protection of populations living in the coastal areas from storms by regulating water surge and wind energy. Protected areas, such as National Parks, are providing important recreational and ecotourism values. Ecosystems that are currently unprotected, on the other hand, are likely providing important services to people who are food insecure, such as hunting, fishing, and fuel wood collection. Unprotected sites may be subject to unsustainable levels of harvest, however. This makes the argument for sustainable management even stronger, because they may currently be exploited for food and fuel, but they also may be highly threatened.

The humid dense forests of the eastern highlands are important for climate mitigation, flood control, and provision of fresh water for domestic use, irrigation, and generation of hydropower. However, it is important to recognize that services obtained from ecosystems in KBAs in the more arid north and southwest of the country may be critical for provision of fresh water for domestic use and irrigation in these water-scarce regions. Understanding precisely how critical these services are to the well-being of the local population in those areas was beyond the scope of this study. Evidence from other studies suggests that dry and spiny forest ecosystems are extremely threatened in Madagascar, and have been under-represented in past conservation investments. Therefore, while they may not appear to have the highest relative values in terms of the provision of services, these ecosystems may be critical for conservation. Additionally, coastal areas in the east which have lost their mangroves could be prioritized for restoration because of the amount of potential protection from cyclone storm surge.

Limitations, data gaps, & lessons for future KBA+ analyses

This was a pilot test of the KBA+ framework. As such, it relied on existing datasets, rapid desktop analyses, and relatively limited consultation with experts and partner organizations in-country. It included key components of the KBA+ framework but was not a complete application of the framework. This pilot included a half-day scoping workshop with a few selected NGO partners to identify the suite of ecosystem services that are relevant in a given geography, and the datasets (both ecological and socioeconomic) to support those analyses. After the desktop analyses had been run, we held a second half-day workshop with those same partners, to review the results and gather feedback for finalizing the analyses.

A more comprehensive scoping workshop with a broader group of stakeholders, including representatives of government agencies, development organizations, and academic experts on ecosystem services would be preferable for application of the complete KBA+ framework. After the desktop analyses have been conducted, there should be a second workshop with this broader set of groups to present and validate results.

This exercise relied on existing datasets and rapid desktop analyses. Many gaps in the data were identified (see next section for details). Our analyses were also based on many assumptions, for example, that proximity of food-insecure people to natural ecosystems was an indicator of the importance of those ecosystems for food provision. With additional resources and time, a more complete application of the KBA+ framework could include additional analyses, modeling, or new data collection to check our assumptions and fill in gaps. In Madagascar, data gaps could be filled through new research or analyses during the implementation of the CEPF profile, or could be identified as areas for future research. More sophisticated modeling tools could be applied, for example, models of coastal protection provided by mangroves that take into account more detailed coastal mapping, wind direction, and wave height.

The level of threat to the underlying ecosystems (e.g. from deforestation or climate change) was not consistently addressed in all analyses. Identification of KBAs includes consideration of the level of threat to the species (IUCN Red List species). Thus all KBAs include threatened species. Threats from deforestation were included in one analysis (potential avoided emissions). Threats from cyclone storm surge and flooding, based on historic events, was included in those two analyses. In the future, a more systematic assessment of threat across all ecosystem service would be useful to identify most-threatened and least-threatened sites.

The level of sustainability of use of ecosystem services was also not included in this analysis. For example, ecosystems that are potentially providing important sources of food or fuelwood are likely being over-exploited in Madagascar, particularly in the most densely populated, food insecure areas. Understanding sustainable levels of use and identifying sites that are already over-exploited would be a useful next step.

Our analyses focus on relative values of ecosystem services, which are insufficient for monetary valuation. Data on the actual demand or use of ecosystem services would be necessary for valuation. This data is available for selected sites within Madagascar (e.g. Portela et al. 2012) and for selected ecosystem services (e.g. Rakotoarison 2003), but is not available for all ecosystem services at a national scale.

Identified data gaps

Key gaps in the data needed for this analysis include:

- ***Nationwide, fine-scale spatial data on poverty, access to safe water, and food insecurity***. This information was not readily available from national government agencies. It appears that the most recent information on food insecurity that is available is from the World Food Program / UNICEF Comprehensive Food and Nutrition Security and Vulnerability Analysis (2011). However the data is coarse scale (it is organized into 8 livelihood “zones” for the entire country).

Therefore, we used a slightly older (2007) dataset from Moser et al. 2008, which is finer-scale (commune scale).

- ***Nationwide, fine-scale data on the location of people vulnerable to climate impacts*** (cyclones, floods, droughts, or other impacts such as sea level rise). Fine-scale information was not readily available from national government agencies. It appears that nationwide data on the location, frequency and effects (in terms of mortality or economic costs) of cyclones, droughts, and floods has been gathered at the district scale. Therefore, for this analysis we used finer-scale (1 km^2) global data from UNEP PREVIEW Global Data Risk Platform (UNEP 2013).
- ***Data on biomass carbon stock values of different ecosystem types*** (forest and non-forest) from field sampling in Madagascar (to calibrate global models or validate estimated values)
- ***Data on carbon sequestration rates*** of different ecosystem types in Madagascar
- ***Up-to-date, fine-scale data on the location of rice paddies and other key agricultural crops***. To our knowledge, the best data available is from national vegetation mapping efforts, such as BD500 and the Kew Botanical Garden, conducted in mid-1990's and mid-2000's respectively. These maps are outdated and likely under-represent the total amount of rice paddies currently in the country.
- ***Information about environmental requirements of rice and other key agricultural crops*** that are supported by ecosystems (such as climate, fresh water, pollination, pest or pathogens, and soil quality) and, to our knowledge, is not available. Instead, generic FAO numbers were used to, for example, estimate fresh water requirement of irrigated rice (following Portela et al. 2012).
- ***Hydrological data, such as river and stream flow data and water quality measurements,*** from as many points as possible across the country. This information is not readily available from national government agencies and likely does not exist. Some data is available from JIRAMA but is coarse scale (districts or regions.) Data on groundwater, including water tables, well locations, and amount of water removed from dams for various uses, would also be useful.
- ***Historical meteorological data*** such as temperature and precipitation patterns, from as many points as possible across the country. Currently there are only a few meteorological stations located at airports, and we were unable to obtain historical records.
- ***Information about actual freshwater demand for domestic use, rice irrigation, hydropower, or other needs***. This includes water quantity demands (including, if possible, location of outtake and volume) and water quality demands (e.g. sediment levels that are damaging to irrigated crops or hydropower facilities, places that have been impacted by sedimentation or other water quality issues). This information was not readily available from national government agencies. For this analysis we used a single estimate of water demand for domestic consumption (42.3 liters per person per day), based on a single study from one city in Madagascar (Razafindralambo et al. 2004) and a single estimate of water demand for rice irrigation (2000 mm per year) (Portela et al. 2012).

- ***Nationwide information about places important for harvesting wild food and materials,*** including small-scale coastal fisheries, freshwater fisheries, important wildlife hunting areas, important areas for the collection of NTFPs. Currently this data is available at the site scale only.
- ***Information about the actual benefits of ecosystems in reducing climate-related impacts***, e.g. cyclone surges and floods, and which variables influence the provision of these benefits (e.g. spatial proximity, characteristics of the ecosystems, characteristics of the climate event, socioeconomic characteristics of the beneficiaries, infrastructural features such as dams and sea walls, etc.) Currently such information is available for only a few types of events (e.g. cyclone winds and floods) and from only a few sites within the country.
- ***Nationwide, multi-year information about places important for ecotourism*** including national parks, other protected areas, wildlife reserves, beaches, waterfalls, bird watching areas, or other sites. This would include both spatial data about the location of these places and also data about the number of visitors or associated economic revenues. For this analysis we were only able to obtain data from Madagascar National Parks and for a single year (2012).
- ***Nationwide information about the cultural/spiritual values of ecosystems in Madagascar.*** Currently the only available information is for selected sites.

Lessons from this pilot demonstration

The pilot demonstration of the KBA+ framework in Madagascar provided several valuable lessons. In particular:

- Presentation of results in the forms of maps was useful input to the CEPF prioritization process. Tabular results were also useful, however due to the large number of KBAs in Madagascar, and the large number of ecosystem services included in the analyses, the tabular results were too long to include in a report (except as a separate Excel file Appendix) or to present to stakeholders.
- It was difficult to understand the sustainable rate of ecosystem service extraction. Related, there was little time series data and therefore it was difficult to understand trends in ecosystem services and effectiveness of current management strategies. Finally, there was little specific information around dependencies on ecosystem services. More information on these factors would have helped understand prioritization of ecosystem services and their values.
- Interpretation of the maps should be done carefully, given the limitations of the data. In particular, maps that summarize several ecosystem services (i.e. multi-criteria analyses) should be presented in combination with other maps, because alone they omit key information. No single map tells a complete story.
- Expert consultation was absolutely essential to the success of this analysis. It is impossible to include every single ecosystem service, thus expert input is critical from the very beginning, to

identify a set of ecosystem services that are most relevant to include, to identify sources of data, and to review and refine preliminary results.

- Despite being a relatively rapid analysis, this analysis still required time and resources. In total, this project (developing the KBA+ framework and pilot testing it in Madagascar) required approximately 155 days of staff time. The budget (including ~110 days of staff time, travel for three staff from the US to Madagascar for in-country workshops, and indirect costs) was approximately US $100,000. This figure does not include staff time for CI-Madagascar staff, partners, or experts, nor workshop expenses, as those were all covered separately by CEPF. However, some MCSO staff time was co-funded by a matching grant from the Gordon and Betty Moore Foundation. In the future, application of the KBA+ framework in other geographies could be somewhat faster, as the framework has already been developed and tested. However, a significant amount of the time required involves data collection and expert consultation, and that time will also be required for other geographies. Larger, multi-country geographies, may in fact require more time for data collection and expert consultation.
- Alternative approaches based on qualitative information from literature reviews and expert opinion could be tested. For example, a key set of ecosystem services could be identified from a literature review and expert consultation. Next, qualitative information on the importance of various types of ecosystems (forests, mangroves, coral reefs) for those services could be collected, also based on the literature and expert consultation. Maps of ecosystem types and the locations of beneficiaries (e.g. population centers) could be used to infer ecosystem service values. Results could be refined with expert input, for example, using known locations of important freshwater resources or fisheries. This approach would require greater stakeholder consultation (and therefore more time/cost for consultation) but would require less spatial data and fewer GIS analyses (and therefore less time/cost for data collection and analysis, and less technical capacity). The results of such an approach could be less data-driven, less quantitative, and less spatially explicit. Depending on the level of knowledge of the experts, however, the results could be as accurate and useful as a more data-driven approach. Based on this pilot, however, we believe a combination of approaches (expert- and data-driven) are ideal.

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List of appendices

All appendices are included in a separate Excel file, unless noted

Appendix 1. Data sources (below)

Appendix 2. Binary results of desktop analyses of ecosystem service values provided by each KBA (0, 1, or data deficient)

Appendix 3. All results of desktop analyses of ecosystem service values provided by each KBA (binary, quantitative, and rankings)

Appendix 4. Economic and socio-cultural importance of Priority Areas for Plant Conservation (Missouri Botanical Garden 2013).

Appendix 5. Literature included in the literature review, organized by theme.

Appendix 1. Data sources

Spatial data layer	Global or national?	Source
Landed fish catch values	Global	Swartz, Wilf, Rashid Sumaila, and Reg Watson. 2012. Global Ex-vessel Fish Price Database Revisited: A New Approach for Estimating 'Missing' Prices. Environmental and Resource Economics.
Mangroves	Global	Giri, C., E. Ochieng, L. L. Tieszen, Z. Zhu, A. Singh, T. Loveland, J. Masek, and N. Duke. 2011. Status and distribution of mangrove forests of the world using earth observation satellite data. Global Ecology and Biogeography 20:154–159.
Coral reefs	Global	Burke, L., K. Reytar, M. Spalding, and A. Perry. 2011. Reefs at Risk Revisited. World Resources Institute. Washington, DC. http://www.wri.org/publication/reefs-risk-revisited
Population	Global	LandScan™ 2011 High Resolution global Population Data Set. Copyrighted by UT-Battelle, LLC, operator of Oak Ridge National Laboratory under Contract No. DE-AC05-00OR22725 with the United States Department of Energy. http://web.ornl.gov/sci/landscan/index.shtml
Food insecurity	National	Moser C., E. Ralison, J.F. Randrianjatovo, S. Ravelomanana. 2008. Enquête sur le suivi du recensement des communes de Madagascar Année 2007 (2007 Monitoring Census Survey of Madagascar Communes.) Final Report. February 2008. Fonds d'Intervention pour le Developpement (FID).

Fresh water (water balance)	Global	Mulligan, M. 2013. WaterWorld: a self-parameterising, physically based model for application in data-poor but problem-rich environments globally. Hydrology Research **44**:748.
		WaterWorld web site: http://www.policysupport.org/waterworld
		Analyses run with WaterWorld Standard version 2, 1 km2 resolution, for all Madagascar
Land cover	National	Kew Royal Botanic Gardens. 2007. Madagascar Vegetation Atlas. Editors: Justin Moat and Paul Smith. http://www.vegmad.org/
Rice paddies and irrigated agriculture	National	FTM (Foiben-Taosaritanin'i Madagascar). 1998. BD500. Les bases des données vecteur à 1/500 000. FTM, Madagascar.
Forest cover	National	ONE, DGF, FTM, MNP et CI (2013), Evolution de la couverture de forêts naturelles à Madagascar 2005-2010, Antananarivo.
Historic deforestation	National	ONE, DGF, FTM, MNP et CI (2013), Evolution de la couverture de forêts naturelles à Madagascar 2005-2010, Antananarivo.
Hydropower dams	National	JIRAMA. 2013. Data on hydropower dams (locations and production) sent via personal communication, Andriambolantsoa Rasolohery, Conservation International, October 10, 2013.
Biomass carbon	Global	Saatchi, S. S. et al. 2011. Benchmark map of forest carbon stocks in tropical regions across three continents. Proceedings of the National Academy of Sciences **108**:9899–9904.
Population vulnerable to cyclone surge	Global	United Nations Environmental Program (UNEP) 2013. PREVIEW Global Risk Data Platform. UNEP/GRID-Geneva. Supported by UNISDR. http://preview.grid.unep.ch
		PREVIEW contains the global risk information produced for the 2009 and 2011 Global Assessment Reports on Disaster Risk Reduction of the United Nations Strategy for Disaster Reduction (UNISDR)
		Cyclone surge – Physical Exposure: This dataset includes an estimation of the annual physical exposition to surges from tropical cyclones of Saffir-Simpson category 1. It is based on four sources: 1) A compilation of best tracks dataset from WMO Regional Specialised Meteorological Centres (RSMCs) and Tropical Cyclone Warning Centres (TCWCs). As well as personal communication with Dr. Varigonda Subrahmanyam, Dr. James Weyman, Kiichi Sasaki, Philippe CAROFF, Jim Davidson, Simon Mc Gree, Steve Ready, Peter Kreft, Henrike Brecht. 2) A GIS modeling based on an initial equation from Greg Holland, which was further modified to take into consideration the movement of the cyclones through time. 3) A Digital Elevation Model (SRTM) at 90 m of resolution. 4) A population grid for the year 2007, provided by LandScan™ Global Population Database (Oak Ridge, TN: Oak Ridge National Laboratory). Unit is expected average annual population (2007 as the year of reference) exposed (inhabitants). This product

		was designed by UNEP/GRID-Europe for the Global Assessment Report on Risk Reduction (GAR). It was modeled using global data. Credit: GIS processing UNEP/GRID-Europe. This dataset was generated as part of the Global Assessment Report on Disaster Risk Reduction (2009).
Population vulnerable to flooding	Global	United Nations Environmental Program (UNEP) 2013. PREVIEW Global Risk Data Platform. UNEP/GRID-Geneva. Supported by UNISDR. http://preview.grid.unep.ch *Floods – Physical Exposure:* This dataset includes an estimate of the annual physical exposition to flood. It is based on three sources: 1) A GIS modeling using a statistical estimation of peak-flow magnitude and a hydrological model using HydroSHEDS dataset and the Manning equation to estimate river stage for the calculated discharge value. 2) Observed flood from 1999 to 2007, obtained from the Dartmouth Flood Observatory (DFO). 3) The frequency was set using the frequency from UNEP/GRID-Europe PREVIEW flood dataset. In area where no information was available, it was set to 50 years returning period. 4) A population grid for the year 2010, provided by LandScan™ Global Population Database (Oak Ridge, TN: Oak Ridge National Laboratory). Unit is expected average annual population (2007 as the year of reference) exposed (inhabitants) . This product was designed by UNEP/GRID-Europe for the Global Assessment Report on Risk Reduction (GAR). It was modeled using global data. Credit: GIS processing UNEP/GRID-Europe, with key support from USGS EROS Data Center, Dartmouth Flood Observatory 2008.
Ecotourism	National	Madagascar National Parks (MNP) 2012. Visitors to Madagascar National Parks in 2012. Data sent via personal communication, Andriambolantsoa Rasolohery, Conservation International, October 7, 2013.
Cultural/spiritual values	National	Conservation International 2011. Inventaire des Aires du Patrimoine Communautaire a Madagascar [Inventory of Community Heritage Areas in Madagascar]. Antananarivo, 2011.
		Missouri Botanical Garden. 2013. Economic and socio-cultural importance of Priority Areas for Plant Conservation with Temporary Protection to vulnerable local stakeholders (only uses of major importance are noted). Table 6 in: Ecosystem Profile - Madagascar: Contribution to status of plant conservation and identificiation of important gaps. Personal communication from Chris Birkinshaw, Missouri Botanical Gardens, November 8 2013.