Biological Conservation 173 (2014) 42–52

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

A return-on-investment framework to identify conservation priorities in Africa

Timothy H. Tear [a,*], Bradford N. Stratton [b], Edward T. Game [c], Matthew A. Brown [d], Colin D. Apse [e], Rebecca R. Shirer [f]

[a] Grumeti Fund, P.O. Box 0, Mawalla Park, Olasiti Road, Arusha, Tanzania
[b] New York City Department of Parks and Recreation, Olmstead Center, Flushing Meadows-Corona Park, Flushing, NY 11368, USA
[c] The Nature Conservancy, West End, QLD 4101, Australia
[d] The Nature Conservancy, Plot # 16002 Mawalla Street, P.O. Box 13265, Arusha, Tanzania
[e] The Nature Conservancy, 14 Maine Street, Suite 401, Brunswick, ME 04011, USA
[f] The Nature Conservancy, 195 New Karner Road, Albany, NY 12205, USA

ARTICLE INFO

Article history:
Received 18 October 2013
Received in revised form 13 January 2014
Accepted 16 January 2014

Keywords:
Cost
Governance
Prioritization
ROI
Uncertainty
Ibrahim Index
Biodiversity

ABSTRACT

Environmental conservation activities must continue to become more efficient and effective, especially in Africa where development and population growth pressures continue to escalate. Recently, prioritization of conservation resources has focused on explicitly incorporating the economic costs of conservation along with better defining the outcomes of these expenditures. We demonstrate how new global and continental data that spans social, economic, and ecological sectors creates an opportunity to incorporate return-on-investment (ROI) principles into conservation priority setting for Africa. We suggest that combining conservation priorities that factor in biodiversity value, habitat quality, and conservation management investments across terrestrial, freshwater, and coastal marine environments provides a new lens for setting global conservation priorities. Using this approach we identified seven regions capturing interior and coastal resources that also have high ROI values that support further investment. We illustrate how spatially explicit, yet flexible ROI analysis can help to better address uncertainty, risk, and opportunities for conservation, while making values that guide prioritization more transparent. In one case the results of this prioritization process were used to support new conservation investments. Acknowledging a clear research need to improve cost information, we propose that adopting a flexible ROI framework to set conservation priorities in Africa has multiple potential benefits.

1. Introduction

1.1. Prioritization in conservation

The world's human population continues to grow, with estimates of 10 billion people by 2100 frequently cited and supported by demographers (e.g., UN, 2011). The provision of services and natural resources (e.g., food, water, energy, and raw materials) to sustain this global population has elevated both public and private interests to invest more in Africa due to its rich, relatively untapped natural resource base. In addition, Sub-Saharan Africa is the only region where fertility has not declined substantially enough for population stabilization to occur in the near term (Allendorf and Allendorf, 2012). Therefore, conservation in Africa will continue to face the vexing challenge of simultaneously increasing development and population growth pressures. When these pressures are applied to a region known for political and economic instability, there is greater urgency for conservation to more carefully assess where to further invest if the globally significant biodiversity values of the continent are to persist into the next century.

Fortunately, there have been significant advances in the methods, tools, and applications of resource prioritization to improve efficiency and effectiveness of conservation efforts, particularly in Africa (Brooks et al., 2001; Burgess et al., 2004, 2006; Moore et al., 2004; Thieme et al., 2005). However, there is still much room for improvement (e.g., McCreless et al., 2013; Game et al., 2013; Eklund et al., 2011; Wilson et al., 2009). In this paper, we identify conservation priorities that build upon the rich history of biodiversity information and prioritization developed for Africa, and for the first time we incorporate a simple return-on-investment approach to priority setting at the continental scale. Our approach includes

* Corresponding author. Tel.: +255 28 2622 074.
E-mail addresses: ttear2011@gmail.com (T.H. Tear), brad.n.stratton@gmail.com (B.N. Stratton), egame@tnc.org (E.T. Game), mbrown@tnc.org (M.A. Brown), rshirer@tnc.org (R.R. Shirer).

http://dx.doi.org/10.1016/j.biocon.2014.01.028
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the novel use of information on the security of conservation investments that explicitly include socio-political-economic context, as well as increased transparency about how value judgments of this process influence conservation priorities. We propose that this approach offers new insights to help prioritize conservation investments anywhere in the world, but particularly to conserve rich and globally significant African biodiversity.

1.2. Incorporating return-on-investment analyses into conservation prioritization

Return-on-investment (ROI) belongs to a broad class of economic assessments known as cost-effectiveness analysis, and is a general approach to prioritization that explicitly factors in cost when evaluating alternatives (Game, 2013). In conservation, ROI is a relatively new concept (Murdoch et al., 2007) although the critical steps to applying ROI in conservation have been established (e.g., Possingham et al., 2001; Mace et al., 2006). In its simplest form, ROI analysis is estimated by dividing the conservation benefit of a particular action by the cost of taking that action. In ROI analysis, it is preferable to explicitly include risks or uncertainties that influence the probability of success of these conservation interventions. These risks often include factors that are largely beyond the control of conservation management and yet are likely to influence the success of conservation interventions. These risks or uncertainties are incorporated into the ROI calculation as a probability of success according to the following equation:

$$\mathrm{ROI} = \frac{Conservation\ Benefit \times Probability\ of\ Success}{Cost}$$

The motivation for using ROI methods in conservation is to help improve the efficiency of conservation actions by achieving the most conservation possible for our investment. There are several additional strengths that an ROI approach can offer relative to other conservation planning approaches including: (1) explicit inclusion of costs early on in any prioritization process, (2) the assumptions behind prioritization are transparent and explicit (via the use of a mathematical equation), and (3) evidence (the data used to calculate ROI) is used in support of decision making.

A major challenge that has limited the greater use of ROI in conservation has been locating the information appropriate to estimate ROI. For example, it has been difficult to find appropriate and justifiable cost estimates for conservation actions and their alternatives (e.g., McCreless et al., 2013; Armsworth et al., 2011; Naidoo and Iwamura, 2007), as well as credible estimates of socio-political factors that impact the probability of success in conservation initiatives (e.g., Eklund et al., 2011; Knight and Cowling, 2007). In this paper, we present the use of an ROI approach to conservation priority setting for Africa. We propose that despite some inherent challenges faced with existing data, multiple potential benefits make this approach increasingly important and urgent as development and population pressures in Africa are expected to increase for the foreseeable future.

2. Methods

2.1. Units of analysis

For many global and continental conservation analyses, ecoregions are used as the unit of analysis. Ecoregions are large ecological units of land or water that share distinct assemblages of species and ecological communities, and vary with respect to climate, geology, topography, hydrology, soils, vegetation, and disturbance regimes (e.g., Dinerstein et al., 1995; Groves, 2003). We assessed biodiversity return and cost values by ecoregion relying on the existing standards for delineating ecoregions in each major environment type. For terrestrial ecoregions, we followed Olson et al. (2001) as the global standard, and Burgess et al. (2004) for Africa. For freshwater ecoregions, we used Abell et al. (2008) as the global standard, and Thieme et al. (2005) for Africa. For coastal marine ecoregions, we used Spalding et al. (2007) as the global standard, and the same for Africa as no Africa-specific coastal marine ecoregion assessments have been conducted to date. Countries were the unit of analysis for estimating the probability of success. To calculate ROI for ecoregions, we applied a proportionally weighted average to probability of success values based on the sections of countries within the ecoregion, and to calculate ROI values for countries we did the same via proportional weighting of biodiversity return and cost values for ecoregions.

2.2. Estimating biodiversity return values for ecoregions

We drew from a recent assembly of global datasets conducted by Hoekstra et al. (2010) to create for the first time a comprehensive set of comparable biodiversity return information for all three major environments (terrestrial, freshwater and coastal marine) for Africa. To develop biodiversity significance values for each environment type, we relied on the extensive published work of the World Wide Fund for Nature (WWF) for terrestrial (Burgess et al., 2004, 2006) and freshwater (Thieme et al., 2005) ecoregions and adopted their biological distinctiveness index (BDI). This index was based primarily on species richness (number of species) and endemism (uniqueness of species), as well as other globally outstanding criteria such as ecological phenomena (e.g., large population assemblages), wilderness areas, evolutionary phenomena, and rare habitats, primarily identified via expert review and inputs.

To classify the biodiversity significance of coastal marine ecoregions consistently with the terrestrial and freshwater counterparts, we adopted Thieme et al.'s (2005) methodology for estimating BDI for freshwater ecoregions. We generated coastal marine species richness values for each of three taxonomic groups including vertebrates (marine mammals and seabirds), invertebrates (corals), and plants (seagrass and mangroves). Consistent with Thieme et al. (2005), we used Jenks natural breaks to rate marine ecoregions on a scale of one (low) to three (high) for each taxonomic group, then summed the three groups to create a coastal marine species richness rating used to develop a coastal marine ecoregion BDI value.

One of the strengths of ROI analyses in conservation is that it requires being explicit and transparent about value judgments (Game, 2013). The extent to which biodiversity distinctiveness and other ecological considerations influences biodiversity return metrics used to set conservation priorities encompasses one set of value judgments. Having a strong preference to conserve globally distinctive ecoregions is reasonable, but the role that value judgments (as opposed to objective scientific assessment) play in this preference should be clearly recognized. To ensure that value judgments were treated in an explicit and transparent fashion, staff involved in the prioritization were asked as a group to sketch curves that reflected how they believed different variables should influence conservation priorities (Fig. 1). These sketched functions were then turned into mathematical expressions (Fig. 1a and b). The habitat and management variables were normalized to a 1–10 scale before all input variables were transformed using one of these functions into a relative conservation value before being combined (via multiplication) to create a final biodiversity return value for each environment type. Due to space restrictions, we will not attempt to describe the value judgments associated with developing the extensive BDI information, but instead acknowledge their influence our results, and encourage others to refer to the primary data sources for more information.

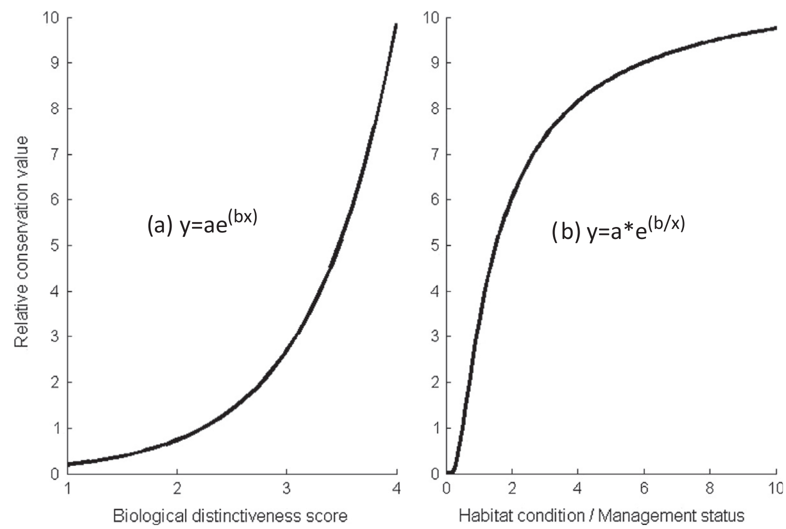

Fig. 1. Functions used to transform the variables that contributed to the calculation of biodiversity return. Curve (a) was used for biological distinctiveness data, and curve (b) was used for habitat condition and conservation management status. The curves reflect value judgments about how each of the variables influences conservation priority in Africa. In (a), the numbers correspond to the four rating categories defined originally by Burgess et al. (2004), where globally outstanding biodiversity value (4) was weighted most important. In (b), values for habitat condition and management status were converted to a uniform 1–10 scale. Higher values for habitat condition were related to greater intactness, less fragmentation and measurable stresses, while higher values for management corresponded to greater percentage of the ecoregion in protected status.

Table 1
Ecological information used to generate biodiversity return values for identifying global conservation priorities in Africa.

Biodiversity return category	Ecoregion type	Description	References (link)
Biodiversity significance	Terrestrial	WWF terrestrial biological distinctiveness index	Burgess et al. (2004, 2006)
	Freshwater	WWF freshwater biological distinctiveness index	Thieme et al. (2005)
	Coastal/marine	Marine mammal richness	Hoekstra et al. (2010) and The Nature Conservancy (2009)
	Coastal/marine	Seabird species richness	Harrison (1983)
	Coastal/marine	Area of mangrove forest	Spalding et al. (1997, 2008, 2010)
	Coastal/marine	Mangrove species richness	Spalding et al. (1997, 2008, 2010)
	Coastal/marine	Seagrass species richness	Green and Short (2003) and Spalding et al. (2003)
	Coastal/marine	Coral richness	UNEP-WCMC (2010) (http://www.unep-wcmc.org/global-coral-reef-distribution-2010_125.html)
	Coastal/marine	Coral abundance	UNEP-WCMC (2010) (http://www.unep-wcmc.org/global-coral-reef-distribution-2010_125.html)
Habitat condition	Terrestrial/freshwater	Percent of natural landcover	Globcover (2005) (http://www.gofcgold.wur.nl/sites/globcover.php)
	Terrestrial/freshwater	WCS Human Footprint	WCS (2008) (http://sedac.ciesin.columbia.edu/data/set/wildareas-v2-human-footprint-geographic/data-download)
	Coastal/marine	Human Footprint	NCEAS (2008) (http://www.nceas.ucsb.edu/globalmarine)
	Freshwater	River fragmentation Disruption of natural river flows	Nilsson et al. (2005)
	Freshwater	Water stress	Alcamo et al. (2003)
Conservation management	Terrestrial/freshwater	Percent of area within IUCN world database on protected areas categories I–IV	WDPA (2009) (http://www.wdpa.org/AnnualRelease.aspx)
	Coastal/marine	Percent of marine protected area on shelf	Spalding et al. (2007, 2008)

A detailed list of the ecological information used to define biodiversity return for all three environment types is available in Table 1. We standardized variables, applied a mathematical function, and then multiplied values for all three categories of information (i.e., biodiversity significance, habitat condition, and management status) to obtain an overall biodiversity return value for each environment type. For example, to create biodiversity significance values terrestrial and freshwater ecoregion BDI values were transformed using Fig. 1a function. The use of this function emphasized the importance of ecoregions categorized with globally outstanding BDI values – consistent with the values of the team's parent global organization – The Nature Conservancy. Since there were no published BDI values for coastal marine ecoregions, the variables listed in Table 1 were first combined to create a coastal marine BDI value (following Thieme et al., 2005 methods), and then transformed using Fig. 1a to create a biodiversity significance value (as with the terrestrial and freshwater ecoregions).

Similarly, for all variables listed in Table 1 used to estimate (a) habitat condition value (such as percent natural landcover) and (b) conservation management status value (such as the percent of land area in IUCN protected area status I–IV), the function in Fig. 1b was applied. This function emphasized the team's values to maximize the potential for successful conservation investment based on environmental status. For example, emphasizing areas with the highest habitat quality ratings (e.g., greater intactness and less fragmentation) reflected the assumption that conservation investments would have greater chances of success than in more degraded areas. Similarly, we applied the assumption that ecoregions with a greater percent of the area under some level of protection status would be better places to invest than ecoregions with less area in designated conservation status, all else created equal. This assumption was based on the team's desire to work in and around established conservation areas rather than invest effort in creating new IUCN acknowledged protected areas. Of course, there are many other social, cultural, and economic factors that influence whether protected areas are managed well or not (e.g., McCreless et al., 2013), but these were addressed elsewhere under a broader context via estimating the probability of success (see Section 2.3 below).

The use of continuous benefit functions also avoided a number of known issues using categorical data during prioritization, such as the arbitrariness in the selection of thresholds based on limited justification (like quartiles), and the combination of categories (e.g., look-up tables) that can serve to hide value judgments and obfuscate the rationale for the prioritization (Game et al., 2013). In this process, the team's value judgments were not only transparent, but are relatively easy to modify should other teams want to use the same underlying information (which represents a significant body of work) but apply different values.

Finally, we categorized overall biodiversity return values for ecoregions within each environment type into four categories after the conventions developed by Burgess et al. (2004, 2006). Using a similar approach to the terrestrial and freshwater ecoregion overlap analysis conducted by Thieme et al. (2005) for Africa, we identified ecoregions in the highest biodiversity return categories across all three environment types as a unique set of global conservation priorities different from the continental priorities identified within each environment type. We used this categorical system to help identify and separate the global priorities from the others, and make a visual inspection (in all the figures) easier to compare across the vast number of countries and ecoregions. In addition, it provides for a direct comparison of ROI results with the previous efforts to identify Africa conservation priorities used in this assessment (i.e., Burgess et al., 2004, 2006; Thieme et al., 2005).

2.3. Estimating cost values for ecoregions

Estimated management costs for terrestrial conservation areas in Africa were calculated based on the methods of Moore et al. (2004). Estimates for the management costs of coastal marine conservation areas were calculated based on the method of Balmford et al. (2004). Terrestrial conservation management cost estimates were not applied to freshwater ecoregions based on the assumption that the vast majority of protected areas in Africa were not designed for freshwater conservation actions and therefore were not applicable. Instead, we used global data from Naidoo and Iwamura (2007) that used the value of agricultural lands as the opportunity cost of new conservation efforts outside of existing protected areas. We applied this agricultural-based opportunity cost to both freshwater and terrestrial ROI assessments. The two sets of cost data, protected area management and agricultural opportunity costs, were evaluated separately for terrestrial ecoregions.

2.4. Estimating probabilities of success for countries

We based our estimates of the probability of success for new conservation investments on two key assumptions: (1) the returns on new conservation investments are most likely to be measured over the long-term, and that (2) sociopolitical and economic context is a critical component of long-term success. We selected the Ibrahim Index of African Governance (IIAG and component indices – http://www.moibrahimfoundation.org/iiag/) as our proxy for probability of success as it provided the most detailed and credible assessment of governance for Africa. The IIAG is composed of international and continental databases assembled on an annual basis and organized according to four main categories: safety and rule of law, participation and human rights, sustainable economic opportunity, and human development. While it would be possible to select any one or combinations of variables in the IIAG to create a separate proxy, we chose to adopt the overall index as a first step to implementing an ROI approach to establish continental and global conservation priorities for Africa.

We acknowledge that global indices of governance exist for use in ROI assessments anywhere in the world. In particular, the Worldwide Governance Indicators (Kaufmann et al., 2010) has been used frequently to evaluate global conservation priorities (McCreless et al., 2013; Eklund et al., 2011; Garnett et al., 2013). However, it is known that continental and regional differences are profound, and Africa presents a special challenge to conservation (Eklund et al., 2011). For these reasons, as well as the ability to use more Africa specific information within the IIAG databases for future research, we chose the IIAG over other global datasets.

2.5. Assessing return-on-investment at the continental scale for countries and ecoregions

We generated two sets of ROI information based on different cost data. For countries that contained multiple ecoregions, ROI values were calculated for each portion of an ecoregion that fell within a country, and then area-weighted to estimate a mean value for the country. For ecoregions that spanned multiple countries, ROI values were calculated for each portion of an ecoregion that fell within a country, but were not area-weighted to estimate a mean value for the ecoregion. Instead, we only used the ROI values per ecoregion section as this information would be more accurate and appropriate to guide decision making within and across ecoregions. All data for countries and ecoregions used to calculate ROI values are available in Supplemental information.

In order to create a rating system highlighting the highest and lowest ROI values, the 0.9, 0.5, and 0.1 quantiles for ROI were used as category thresholds to define the bounds for a 4-part categorical rating system for each environment type. To evaluate how the input variables (benefit, cost, and probability of success) influenced placement in these ROI categories, we used the Wilcoxon rank test to compare the input variable between the top and bottom ROI categories for each environment type. This comparison was only done for the ROI calculated by ecoregions, since the sample size for countries was too small.

To illustrate how factoring cost and uncertainty early into a prioritization process potentially changes the outcome of the prioritization process, we compared two similar prioritization processes, both based on biodiversity return and ROI values, but applied in a different order. We counted the number of environment types for which a country occurred in either the top (highest) or bottom (lowest) 10 countries for biodiversity return and ROI values, respectively. In the first prioritization process, we followed a more traditional prioritization approach by selecting priority countries based on biodiversity return values alone, and then used ROI values to further evaluate these initial selections. In the second prioritization process, we selected countries based on ROI values alone, and then used biodiversity information to further evaluate these initial selections.

3. Results

3.1. Overlapping habitat priorities

Relative biodiversity return ratings for ecoregions in all three environments were used to identify *continental* conservation priorities (Fig. 2).

We selected only those ecoregions in the highest category (i.e., very high rating) from each environment as the top priority, and

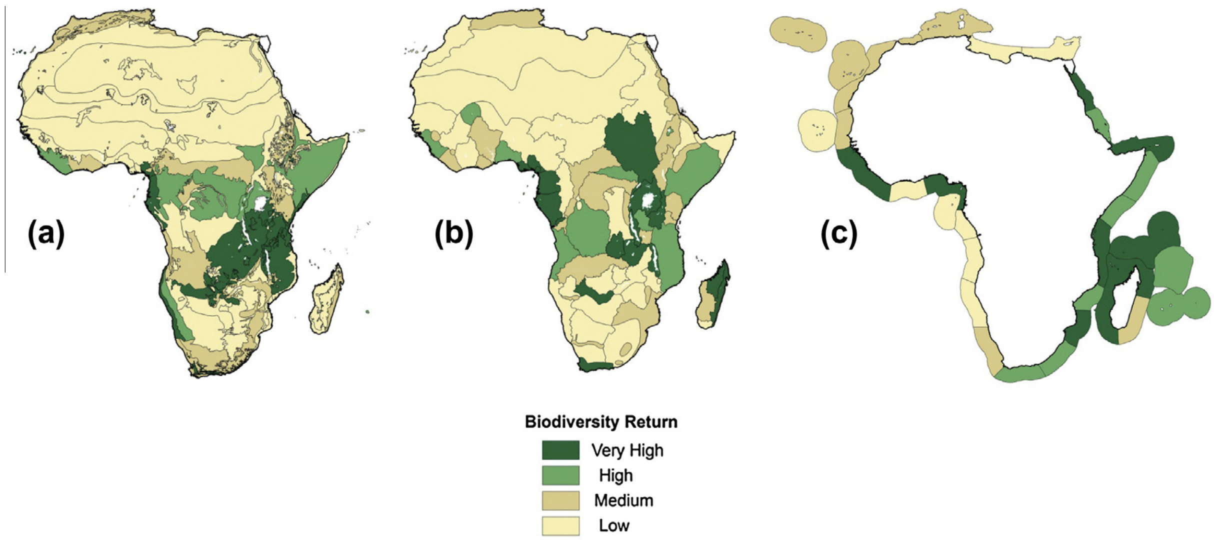

Fig. 2. Relative biodiversity return rating used in return-on-investment assessment for (a) terrestrial, (b) freshwater, and (c) coastal marine ecoregions.

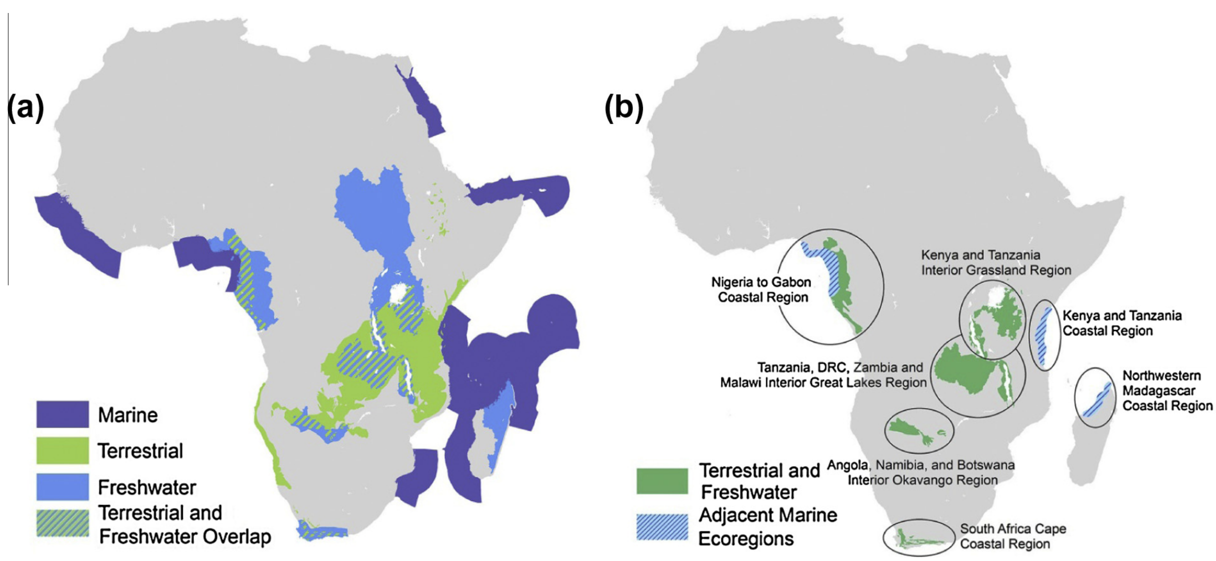

Fig. 3. Areas of overlap or intersection among the ecoregions with the highest biodiversity significance rating for (a) each major environment type and (b) corresponding regional descriptions.

compared the spatial distribution of all the top priority ecoregions for all three environment types (Fig. 3a). We emphasized areas of overlap (terrestrial and freshwater ecoregions) and adjacency (coastal marine ecoregions with either terrestrial or freshwater ecoregions) as *global* conservation priorities (Fig. 3b).

Seven areas emerged as global conservation priorities due to their continental ecoregional priority intersections (i.e., either overlapping or adjacent ecoregional priorities) (Table 2). These global priority areas included a mix of four coastal regions and three interior regions. Only one region captured the highest rated biodiversity return priorities for all three environment types – the Nigeria to Gabon coastal region.

3.2. Ecoregional return-on-investment assessment for major environment types

In all cases ROI values were not normally distributed, generally displaying a gamma or lognormal distribution with a concentration of low values and a long tail of a few very large values. The biodiversity return and cost variables were significantly different between the top and bottom ROI categories in all environments, while the probability of success variable was only significantly different in the marine environment (Table 3).

It was expected that all three variables included in the ROI calculation would influence the final rating, but these results suggest that the strong skew of the biodiversity return variable reduced the influence of the probability of success variable in determining which countries are included in the top quantile. Therefore, the top category of ROI of terrestrial and freshwater ROI assessments were characterized by high biodiversity return and low management cost values, but a wide range of success probabilities.

For terrestrial ecoregions, the use of the two cost variables resulted in differences in the final ROI prioritization. There were more similarities in the relative ROI rating in central, eastern, and southern Africa ecoregions than for northern and western Africa, where the differing cost estimates resulted in much greater divergence between higher and lower ROI values (Fig. 4a and b). However, there were more freshwater ecoregions than terrestrial

Table 2
Overlapping or adjacent African ecoregions of globally significant biodiversity value.

Region	Terrestrial priority ecoregion	Freshwater priority ecoregion	Coastal marine priority ecoregion
Nigeria to Gabon coastal region	• Cross-Sanaga-Bioko coastal forests	• Western equatorial crater lakes • Ogooue–Nyanga–Kouilou–Niari • Lower Congo rapids	• Gulf of Guinea central
Kenya and Tanzania interior grassland region	• East African montane moorlands • Serengeti volcanic grasslands • Eastern Arc forests	• Southern eastern Rift	
Kenya and Tanzania coastal region	• Northern Zanzibar Inhambane coastal forest mosaic		• East African coral coast
Northwestern Madagascar coastal region		• Northwestern Madagascar	• Western and Northern Madagascar
Angola, Namibia, and Botwana interior Okavango region	• Zambezian Baikiaea woodlands • Zambezian flooded grasslands	• Okavango	
Tanzania, DRC, Zambia and Malawi interior great lakes region	• Central Zambezian Miombo woodlands • Southern Rift montane forest–grassland mosaic • Eastern Miombo woodlands	• Lake Tanganyika • Rangweulu-Mweru • Upper Lualaba • Lake Malawi	
South Africa cape coastal region	• Montane fynbos and renosterveld	• Cape fold	

Table 3
Comparison of input variables between highest and lowest 10% ROI quantiles for ecoregions.

	Biodiversity return	Prob. of success (Ibrahim Index)	Management cost
Terrestrial ($N = 66$)	−6.984*	−1.670	5.087*
Marine ($N = 14$)	−3.080*	−3.097*	3.211*
Freshwater ($N = 50$)	−6.060*	0.875	5.387*

Wilcoxon rank test Z-score reported.
* Indicates significant differences ($p < 0.05$).

ecoregions with high ROI values in North Africa using the same cost data (Fig. 4b and c), suggesting these differences were primarily driven by biodiversity return values.

Many of the ecoregions identified as *globally* important due to their overlap or adjacency with another *continental* priority ecoregion (i.e., rated very high for biodiversity return) of a different environment type (Table 2) also achieved high ROI values. For example, continental priority terrestrial ecoregions in Equatorial Guinea, Gabon, Namibia, Botswana, and Zambia that overlapped with continental priority freshwater ecoregions also retained the highest ROI value rating independent of the type of cost data used. Similarly, continental priority freshwater ecoregions in Botswana and along the Nigeria to Gabon coastline that overlapped with continental priority terrestrial ecoregions also had the highest ROI value rating. Finally, several continental priority coastal marine ecoregions also have the highest ROI value ratings, especially in the Western Indian Ocean and along the East and Southern Africa coastlines of Kenya and Tanzania, including the global priority Kenya and Tanzania coastal region (Fig. 4d).

3.3. Return-on-investment for countries

To illustrate how this ROI information might be used to support conservation decision making, we conducted a simple analysis focused on the upper and lower ends of the ROI gradient for countries. We compared countries with very high ROI ratings to those with low ROI ratings. We focused at the country level because changes in conservation management (e.g., national parks and reserves) and global investments (e.g., World Bank, USAID) are frequently made at the national scale. Our intent was to identify countries where future investments were justified based on the criteria used here. Similarly, the lower end of ROI values signified countries where justification other than expected conservation return would need to exist before further conservation investments should be made there.

While no country achieved the highest ROI rating for all three environment types, Gabon and Equatorial Guinea obtained very high ROI ratings for both terrestrial and freshwater conservation investments (Fig. 5). Similarly, only two countries – Egypt and Cote D'Ivoire – achieved the lowest ROI rating more than once.

Following a more traditional process of selecting priorities based on biodiversity value, we used a simple count of the number of times a country occurred in the "top 10 countries list" for biodiversity value for all three environment types (Table 4). Of the 20 countries that occurred in these top 10 lists for biodiversity return value alone, five countries also occurred multiple times in the top 10 for ROI value (Cameroon, Equatorial Guinea, Gabon, Malawi, and Tanzania), and five more occurred once in the top 10 list for ROI values (Burundi, Kenya, Madagascar, Mozambique, and Zambia). Of these 10 countries that were selected first for high biodiversity value and second for high ROI values, five countries (Cameroon, Equatorial Guinea, Gabon, Malawi, and Tanzania) emerged as the highest priorities for future investment as they occurred multiple times in the top 10 lists for both biodiversity return and ROI values.

However, if cost and uncertainty were factored in at the beginning of the priority setting process, the outcome (i.e., the list of highest priority countries) would have been substantially different (20–40%) from the list of countries that would have been selected if biodiversity values alone were used to generate the list of priorities. For example, when we reversed the process and initially selected the top 10 countries for each environment type based solely on high ROI values, four countries (Angola, Botswana, Congo, and Namibia) were entirely absent from the initial list of 20 countries (or 20%) identified using biodiversity return values alone. Similarly, these four countries represented 40% of a smaller group of 10 countries that occurred multiple times in the top 10 lists for ROI values for multiple environment types. In addition, five countries (Congo–DRC, Equatorial Guinea, Guinea-Bissau, Liberia, and Sudan) occurred in the bottom 10 countries for ROI value, yet were well represented (27.5%) in the list of 20 countries in the top 10 for biodiversity value.

4. Discussion

A better accounting of the socio-political-economic-ecological context has been repeatedly stated in a host of conservation

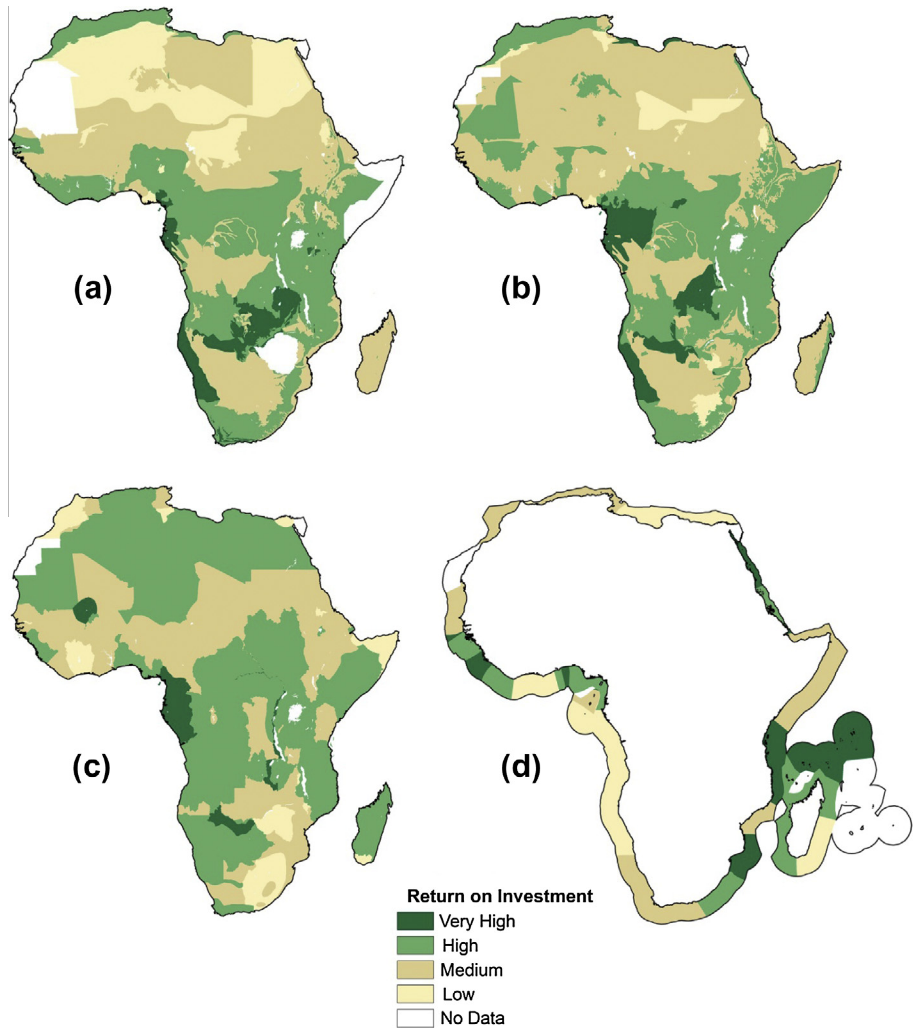

Fig. 4. Relative return-on-investment (ROI) rating for ecoregions using different cost functions most appropriate for each of three major environment types. Terrestrial ROI assessment was conducted with both (a) management costs within protected areas and (b) agriculture-based opportunity costs outside of protected areas. Freshwater ROI assessment was conducted only with (c) agriculture-based opportunity costs outside of protected areas, while the coastal marine ROI assessment was conducted only with (d) management costs within protected areas.

prioritization assessments (Eklund et al., 2011; Wilson et al., 2009; McBride et al., 2007). In addition, Africa presents substantial challenges to global conservation prioritization processes. Eklund et al. (2011) pointed out that continental and regional differences are significant when conducting global prioritization, and Africa is particularly challenging due to its high mammalian diversity, high threat levels, and high levels of corruption. In the developing world, weak governments and institutions have been identified as a critical barrier to conservation success (Barrett et al., 2001, 2006), especially in Africa (Fredricksson and Svensson, 2003; Smith et al., 2003). Using governance indices as the probability of success indicator within an ROI framework made it possible to explicitly factor in social, political, and economic uncertainties. Using the Ibrahim Index of African Governance (IIAG) incorporated the most comprehensive information available in an African context.

While our analysis integrated the IIAB into a ROI framework, there is much more potential to further utilize the rich IIAG information to better guide decision making. For example, Tanzania occurred multiple times in our top 10 lists for biodiversity return and ROI values. As context, over the last 6 years Tanzania has continuously improved in the IIAG's rankings, making it into their top 10 for the first time in 2012. Similarly, over the past 6 years, North Africa was the most imbalanced region in Africa across the four IIAG categories, experiencing the greatest regional governance decline since 2006. These factors contribute to explaining the paucity of terrestrial ecoregions identified with high ROI-values in North Africa, and that freshwater ecoregions with high ROI values were driven more by low agricultural opportunity costs for this very arid region, and not due to their high probability of success.

Game et al. (2013) highlight the need to expose hidden value judgments in conservation priority setting. In the ROI methodology employed here, all input variables were converted to continuous data and could therefore be transformed using mathematical functions. Constructing these functions required us to be explicit about our preference toward large, relatively intact, high quality and well protected ecoregions that capture globally significant biodiversity values. As McCreless et al. (2013) pointed out, international conservation prioritizations are inherently organization and context specific. While this analysis clearly represents the values of The Nature Conservancy, we contend that it would be easy to alter this analysis to reflect alternate value propositions by simply applying different mathematical functions to the initial dataset. While we emphasize the specific values introduced by this team as an important advancement, we also recognize that other values were introduced through the use of information produced by others. For example, the information used to create the BDI scores adjust

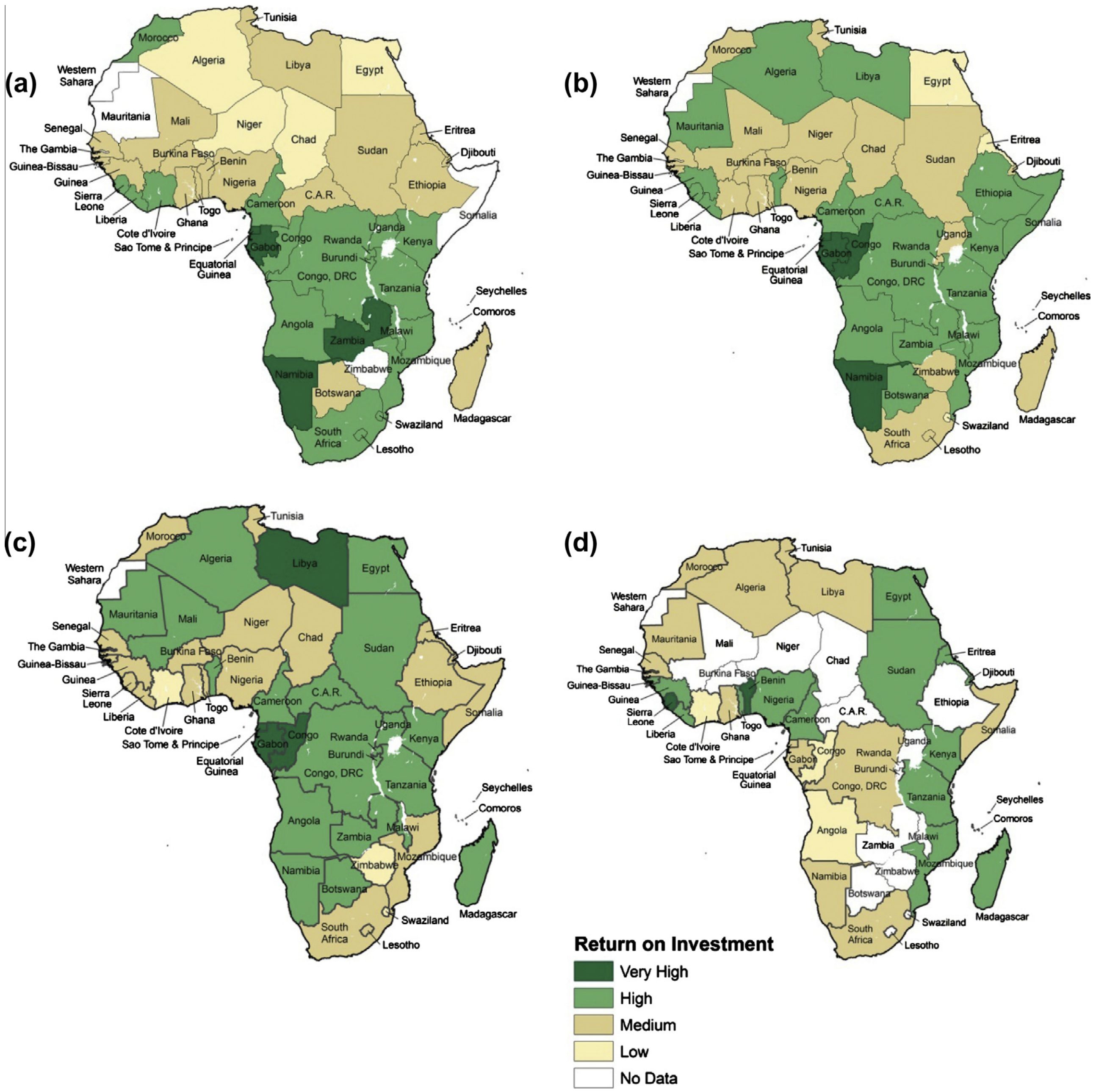

Fig. 5. ROI per country for conservation efforts based on different cost data for (a) terrestrial (using management costs), (b) terrestrial (using opportunity costs), (c) freshwater (using opportunity costs), and (d) coastal marine (using management costs).

species richness by area, and weight endemism highly. In addition, biases were likely introduced as similar metrics may interact across multiple indicators (e.g., percent natural land cover, the Human Footprint, and the percent of area in protection status). We believe any advances that result in greater transparency and flexibility are important for decision making, especially on the Africa continent as tradeoffs with development and human population pressures become more acute.

Wilson et al. (2009) called for the explicit incorporation of cost information early on in a planning process because it can change the selection of priorities. However, the use of cost information has been recently criticized, such as the limitations of management cost data (McCreless et al., 2013), or the use of cost information in isolation from other socio-economic factors (Eklund et al., 2011). In our assessment, we attempted to reduce some of these known limitations by relying on more than one type of cost estimate to inform decision making, and to purposefully balance cost information and separate it from socio-economic information in our ROI approach.

While McCreless et al. (2013) suggested that countries with low management costs might actually translate to higher conservation costs in the long-term due to the lack of political stability, Garnett et al. (2013) found that value for money outweighed corruption in potential investment decisions. McBride et al. (2007) found that where there was a probability that investments would fail (performance uncertainty), the optimal solution involved complex tradeoffs between immediate biodiversity benefits and the perception that the investment would last, and in general, regions with the greatest performance certainty were prioritized over other regions that were more highly threatened or greater biodiversity value.

Table 4
Number of times a country occurs in the top 10 or bottom 10 list for biodiversity return (BDR) or for return-on-investment (ROI) value for each major environment type.

Country	In top 10 BDR countries (#)	Country	In top 10 ROI countries (#)	Country	In bottom 10 BDR countries (#)	Country	In bottom 10 ROI countries (#)
Tanzania	3	Congo	3	Algeria	2	Burkina Faso*	3
Burundi	2	Equatorial Guinea	3	Chad	2	Chad*	3
Cameroon	2	Gabon	3	Egypt	2	Eritrea	3
Equatorial Guinea	2	Angola	2	Mauritania	2	Algeria	2
Gabon	2	Botswana	2	Niger	2	Djibouti	2
Liberia	2	Cameroon	2	Senegal	2	Libya	2
Malawi	2	Malawi	2	Congo, DRC	1	Egypt	2
Comoros	1	Namibia	2	Angola	1	Senegal	2
Congo, DRC	1	Tanzania	2	Central African Republic	1	Swaziland	2
Guinea	1	Zambia	2	Congo	1	The Gambia	2
Guinea-Bissau	1	Algeria	1	Cote d'Ivoire	1	Congo	1
Kenya	1	Benin	1	Djibouti	1	Equatorial Guinea	1
Madagascar	1	Burundi	1	Libya	1	Angola	1
Mayotte	1	Central African Republic	1	Mali	1	Namibia	1
Mozambique	1	Comoros	1	Morocco	1	Congo, DRC	1
Rwanda	1	Congo, DRC	1	Namibia	1	Liberia	1
Sierra Leone	1	Djibouti	1	Sao Tome and Principe	1	Sudan	1
Somalia	1	Kenya	1	Swaziland	1	Cote d'Ivoire	1
Sudan	1	Liberia	1	The Gambia	1	Ghana	1
Zambia	1	Libya	1	Tunisia	1	Guinea-Bissau	1
		Madagascar	1	Western Sahara	1	Mali	1
		Mauritania	1	Zimbabwe	1	Morocco	1
		Mozambique	1			Niger	1
		Seychelles	1			Tunisia	1
		Sierra Leone	1			Zimbabwe	1
		Sudan	1				
		Togo	1				

Countries can get a maximum value of three for biodiversity return (one for each terrestrial, freshwater, and coastal marine environment type, and a maximum value of four for ROI (as there were two ROI assessments conducted for terrestrial ecoregions using different cost data).
* Landlocked countries and therefore should be excluded.

Finally, Eklund et al. (2011) highlighted that corruption can have complex positive and negative effects on biodiversity, and these effects are likely scale-dependent. They promoted the use of conservation planning frameworks that can account for any effect once these relationships are better understood. We believe the ROI approach presented here follows this advice and makes important advances, particularly in the explicit incorporation of socio-political context separately to cost estimates, the longer-time frame that the IIAB dataset presents for Africa, and a transparent method to incorporate new information as it becomes available.

In addition, we used ROI information in two ways to inform decision making, rather than expect ROI analysis will result in a final answer. First, we conducted a more traditional analysis based on biodiversity values alone and later interpreted those results in relationship to ROI information. In this context based on our team's values, priority areas with high ROI values were more likely choices for further investment, whereas areas with very low ROI values were viewed with much greater caution. Second, when the selection process was reversed and we used ROI-valued selections first, we could see that our team's values resulted in a very different suite of priority areas. When cost and probability of success were factored in from the beginning, entirely new areas for conservation investment were identified that were completely missed when prioritization was based on biodiversity-value alone (e.g., Angola, Botswana, Congo, and Namibia). In addition, other areas would have not been included due to poor ROI performance (e.g., Congo–DRC, Equatorial Guinea, Guinea-Bissau, Liberia, and Sudan). Each of these potential alterations accounted for a substantial proportion of the original list of biodiversity-valued priorities, highlighting that factoring cost and uncertainty early into prioritization can be very impactful on the final outcomes of the process.

We conducted our analysis at the scale of countries because for many international conservation groups and development organizations, this is the scale at which decisions about engagement are initially made, and it is also the scale at which most conservation management decisions are made (e.g., to create new national parks). While Halpern et al. (2006) pointed to the inconsistencies of non-governmental organizations matching funding with conservation priorities, The Nature Conservancy recently decided to open a new conservation program in Gabon (D. Banks, pers comm.). The results described in this paper, which consistently identified Gabon as a country with high biodiversity return and ROI values, were a major factor influencing The Nature Conservancy's decision to make this new conservation investment.

While this decision demonstrates the potential value of using an ROI approach to priority setting, we believe that there is much greater potential for using ROI at smaller spatial scales, such as within projects or within political regions within a country. At smaller scales, it may be possible to generate more accurate cost data to compare the ROI of potential interventions, where the majority of conservation investment decisions are made, and to better assess the added benefit over costs of new interventions. Armsworth et al. (2011) demonstrated that a combination of natural and socioeconomic factors explained only 50% of variation in management costs, with area size the most important determinant of management costs. We found two orders of magnitude difference between management costs and opportunity costs, creating some uncertainty as to their relative importance and resulting in our decision to avoid combining them into a single metric, or comparing ROI scores across environment types. More research is needed to improve cost data, better understand the relationships between social and economic factors and their influence on the probability of conservation success, and the relative influence of different spatial and temporal scales on ROI assessments. This will not only help to increase the use of ROI in decision making, but also build greater confidence in using ROI information to guide the initial selection of priorities as opposed to using it in a post hoc assessment to refine and revise priority lists based on biodiversity values alone.

The global comparison of terrestrial and freshwater ecoregional priorities by Abell et al. (2011) showed that tropical regions are particularly important areas of overlap as they capture the most biodiversity, especially in Africa. Building upon existing and extensive African databases (e.g., Burgess et al., 2004, 2006; Thieme et al., 2005), for the first time we identified a small set of global priority regions as the convergence of all three major environment types – terrestrial, freshwater, and coastal marine ecoregions. Abell et al. (2011) also suggested that areas of overlapping priorities might also hold great potential for the provision of ecosystem services. These areas with high biodiversity value create the potential to deliver multiple services (e.g., energy production, tourism revenue, pharmacology research, and protein generation) to the growing Sub-Saharan human population, and therefore we emphasize their higher quality and greater return on investment than areas with potential to deliver fewer ecological services. We suggest it is of global importance this service potential is not lost, and be given greater consideration when confronting more singular and destructive development decisions, such as conversion to industrial agricultural production or surface mining, that would place these areas at extreme risk.

5. Conclusion

Given the urgency that increasing development and human population pressures in Africa present for conservation, it is important to revisit the establishment of continental conservation priorities to include the most recent information and incorporate advances in prioritization processes. Our analysis generated the first set of comprehensive conservation priorities that span terrestrial, freshwater, and coastal marine ecoregions for Africa, included the novel use of governance data to reflect the likelihood of conservation success, and a method for making value judgments explicit and transparent. We describe a case where these ROI priorities were used to make a significant conservation investment decision for at least one organization, The Nature Conservancy. We believe that the priorities identified using an ROI approach offer significant improvements conservation priority setting and can support making more effective conservation investments in Africa.

Acknowledgements

We would like to acknowledge The Nature Conservancy, Africa Region for their complete support of this research, and especially D. Banks for initiating the effort. We also benefitted greatly from the cooperation and sharing of information from N. Burgess and M. Thieme providing access to the WWF datasets. T. Boucher helped access global datasets used for the Atlas of Global Conservation. S. Levental helped produce some of the illustrations. We also benefitted greatly from the comments of two anonymous reviewers.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.biocon.2014.01.028.

References

Abell, R., Thieme, M.L., Revenga, C., Bryer, M., Kottelat, M., Bogutskaya, N., Coad, B., et al., 2008. Freshwater ecoregions of the world: a new map of biogeographic units for freshwater biodiversity conservation. Bioscience 58, 403–414.

Abell, R., Thieme, M., Ricketts, T.H., Olwero, N., Ng, R., Petry, P., Dinerstein, E., Revenga, C., Hoekstra, H., 2011. Concordance of freshwater and terrestrial biodiversity. Conserv. Lett. 4, 127–136.

Alcamo, J., Döll, P., Henrichs, T., Kaspar, F., Lehner, B., Rösch, T., Siebert, S., 2003. Development and testing of the WaterGAP 2 global model of water use and availability. Hydrol. Sci. J. 48, 317–338.

Allendorf, T.D., Allendorf, K., 2012. What every conservation biologist should know about human population. Conserv. Biol. 26, 953–955.

Armsworth, P.R., Cantu-Salazar, L., Parnell, M., Davies, Z.G., Stoneman, R., 2011. Management costs for small protected areas and economies of scale in habitat conservation. Biol. Conserv. 144, 423–429.

Balmford, A., Gravestock, P., Hockley, N., McClean, C.J., Roberts, C.M., 2004. The worldwide costs of marine protected areas. PNAS 101, 9694–9697.

Barrett, C.B., Brandon, K., Gibson, C., Gjertsen, H., 2001. Conserving tropical biodiversity amid weak institutions. BioScience 51, 497–502.

Barrett, C.B., Gibson, C.C., Hoffman, B., McCubbins, M.D., 2006. The complex links between governance and biodiversity. Conserv. Biol. 20, 1358–1366.

Brooks, T.M., Balmford, A., Burgess, N.D., Fjeldså, J., Hansen, L.A., Moore, J., Rahbek, C., Williams, P., 2001. Toward a blueprint for conservation in Africa. BioScience 51, 613–624.

Burgess, N.D., D'Amico Hales, J.A., Underwood, E., Dinerstein, E., Olson, D., Schipper, J., Ricketts, T., Itoua, I., Newman, K., 2004. Terrestrial Ecoregions of Africa and its Islands: A Conservation Assessment. Island Press, Washington, DC, USA.

Burgess, N.D., D'Amico Hales, J., Ricketts, T.H., Dinerstein, E., 2006. Factoring species, non-species values and threats into biodiversity prioritization across the ecoregions of Africa and its islands. Biol. Conserv. 127, 383–401.

Dinerstein, E.D., Olson, M., Graham, D.H., Webster, A.L., Pimm, S.A., Bookbinder, M.P., Ledec, G., 1995. A Conservation Assessment of the Terrestrial Ecoregions of Latin America and the Caribbean. World Wide Fund and the World Bank, Washington, DC.

Eklund, J., Arponen, A., Visconti, P., Cabeza, M., 2011. Governance factors in the identification of global conservation priorities for mammals. Philos. Trans. R. Soc. B: Biol. Sci. 366, 2661–2669.

Fredricksson, P.G., Svensson, J., 2003. Political instability, corruption and policy formation: the case of environmental policy. J. Public Econ. 87, 1383–1405.

Game, E.T., 2013. Identifying conservation priorities using a return on investment analysis. In: Simon, A.L. (Ed.), Encyclopedia of Biodiversity, second ed. Academic Press, Waltham, pp. 185–198.

Game, E.T., Kareiva, P., Possingham, H., 2013. Six common mistakes in conservation priority setting. Conserv. Biol. 27, 480–485.

Garnett, S.T., Joseph, L.N., Watson, J.E.M., Zander, K.K., 2013. Investing in threatened species conservation: does corruption outweigh purchasing power? PLoS ONE 6, e22749.

Globcover, 2005. <http://www.gofcgold.wur.nl/sites/globcover.php> (17 October 2013).

Green, E.P., Short, F.T., 2003. World Atlas of Seagrasses. University of California Press, Berkeley, USA.

Groves, C., 2003. Drafting a Conservation Blueprint: A Practitioner's Guide to Planning for Biodiversity. Island Press, Washington, DC.

Halpern, B.S., Pyke, C.R., Fox, H.E., Hanye, J.C., Schlaepfer, M.A., Zaradic, P., 2006. Gaps and mismatches between global conservation priorities and spending. Conserv. Biol. 20, 56–64.

Harrison, P., 1983. Seabirds: An Identification Guide. Christopher Helm, London.

Hoekstra, J.M., Molnar, J.L., Jennings, M., Revenga, C., Spaulding, M.D., Boucher, T.M., Robertson, J.C., Heibel, T.J., Ellison, K., 2010. In: Molnar, J.L. (Ed.), The Atlas of Global Conservation: Changes, Challenges, and Opportunities to make a Difference. University of California Press, Berkeley, 234pp.

Kaufmann, D., Kraay, A., Mastruzzi, M., 2010. The Worldwide Governance Indicators: Methodology and Analytical Issues. <info.worldbank.org/governance/wgi/index.asp> (21 March 2014).

Knight, A.T., Cowling, R.M., 2007. Embracing opportunism in the selection of priority conservation areas. Conserv. Biol., 1124–1126.

Mace, G.M., Possingham, H.P., Leader-Williams, N., 2006. Prioritization choices in conservation. In: MacDonald, D. (Ed.), Key Topics in Conservation Biology. Oxford University Press, UK, pp. 17–34.

McBride, M.F., Wilson, K.A., Bode, M., Possingham, H.P., 2007. Incorporating the effects of socioeconomic uncertainty into priority setting for conservation investment. Conserv. Biol. 21, 1463–1474.

McCreless, E., Visconti, P., Carwardine, J., Wilcox, C., Smith, R.J., 2013. Cheap and nasty? The potential perils of using management costs to identify global conservation priorities. PLoS ONE 8, e80893.

Moore, J., Balmford, A., Allnut, T., Burgess, N., 2004. Integrating costs into conservation planning across Africa. Biol. Conserv. 117, 343–350.

Murdoch, W., Polasky, S., Wilson, K.A., Possingham, H.P., Kareiva, P., Shaw, R., 2007. Maximizing return on investment in conservation. Biol. Conserv. 139, 375–388.

Naidoo, R., Iwamura, T., 2007. Global-scale mapping of economic benefits from agricultural lands: implications for conservation priorities. Biol. Conserv. 140, 40–49.

NCEAS, 2008. <http://www.nceas.ucsb.edu/globalmarine> (17 October 2013).

Nilsson, C., Reidy, C.A., Dynesius, M., Revenga, C., 2005. Fragmentation and flow regulation of the world's large river systems. Science 308, 405–408.

Olson, D.M., Dinerstein, E., Wikramanayake, E.D., Burgess, N.D., Powell, G.V.N., Underwood, E.C., D'Amico, J.A., Strand, H.E., Morrison, J.C., Loucks, C.J., Allnutt, T.F., Lamoreux, J.F., Ricketts, T.H., Itoua, I., Wettengel, W.W., Kura, Y., 2001. Terrestrial ecosystems of the world: a new map of life on earth. BioScience 51, 933–938.

Possingham, H.P., Andelman, S.J., Noon, B.R., Trombulak, S., Pulliam, H.R., 2001. Making smart conservation decisions. In: Orians, G., Soule, M. (Eds.),

Research Priorities for Conservation Biology. Island Press, Washington, DC, pp. 225–234.
Smith, R.J., Muir, R.D.J., Walpole, M.J., Balmford, A., Leader-Williams, N., 2003. Governance and the loss of biodiversity. Nature 426, 67–70.
Spalding, M.D., Blasco, F., Field, C.D., 1997. World Mangrove Atlas. International Society for Mangrove Ecosystems, Okinawa, Japan.
Spalding, M.D., Taylor, M.L., Ravilious, C., Short, F.T., Green, E.P., 2003. Global overview: the distribution and status of seagrasses. In: Green, E.P., Short, F.T. (Eds.), World Atlas of Seagrasses. University of California Press, Berkeley, USA, pp. 5–26.
Spalding, M.D., Fish, L., Wood, L.J., 2008. Towards representative protection of the world's coasts and oceans – progress, gaps and opportunities. Conserv. Lett. 1, 217–226.
Spalding, M.D., Kainuma, M., Collins, L., 2010. World Mangrove Atlas. Earthscan, London, UK.
Spaulding, M.D., Fox, H.E., Allen, G.R., Davidson, N., Ferdana, Z.A., Finlayson, M., Halpern, B.S., Jorge, M.A., Lombana, A., Lourie, S.A., Martin, K.D., McManus, E., Molnar, J., Recchia, C.A., Robertson, J., 2007. Marine ecoregions of the world: a bioregionalization of coastal and shelf areas. BioScience 57, 573–583.
The Nature Conservancy (TNC), 2009. World Atlas Database. <http://maps.tnc.org/globalmaps.html> (17 October 2013).
Thieme, M.L., Abell, R., Stiassny, M.L.J., Skelton, P., Lehner, B., Teugels, G.G., Dinerstein, E., Toham, A.K., Burgess, N., Olson, D., 2005. Freshwater Ecoregions of Africa and Madagascar: A Conservation Assessment. World Wildlife Fund, Island Press, Washington DC, USA.
UN 2011. United Nations World Population Prospects: The 2010 Revision. United Nations, Department of Economic and Social Affairs. Population Division. New York.
UNEP-WCMC, 2010. Global Coral Reef Distribution. <http://www.unep-wcmc.org/global-coral-reef-distribution-2010_125.html> (17 October 2013).
WCS, 2008. Human Footprint Data. <http://sedac.ciesin.columbia.edu/data/set/wildareas-v2-human-footprint-geographic/data-download> (17 October 2013).
WDPA, 2009. World Database on Protected Areas. UNEP-World Conservation Monitoring Centre, Cambridge, UK. Digital Media. <http://www.wdpa.org/AnnualRelease.aspx> (17 October 2013).
Wilson, K.A., Carwardine, J., Possingham, H., 2009. Setting conservation priorities. Ann. NY Acad. Sci. 1162, 237–264.