SCIENTIFIC REPORTS

OPEN

SUBJECT AREAS:
CONSERVATION
AGRI-ECOLOGY

Received
29 October 2013

Accepted
7 May 2014

Published
17 June 2014

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Prioritising *in situ* conservation of crop resources: A case study of African cowpea (*Vigna unguiculata*)

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Conserving crop wild relatives (CWR) is critical for maintaining food security. However, CWR-focused conservation plans are lacking, and are often based on the entire genus, even though only a few taxa are useful for crop improvement. We used taxonomic and geographic prioritisation to identify the best locations for *in situ* conservation of the most important (priority) CWR, using African cowpea (*Vigna unguiculata* (L.) Walp.) as a case study. Cowpea is an important crop for subsistence farmers in sub-Saharan Africa, yet its CWR are under-collected, under-conserved and under-utilised in breeding. We identified the most efficient sites to focus *in situ* cowpea CWR conservation and assessed whether priority CWR would be adequately represented in a genus-based conservation plan. We also investigated whether priority cowpea CWR are likely to be found in existing conservation areas and in areas important for mammal conservation. The genus-based method captured most priority CWR, and the distributions of many priority CWR overlapped with established conservation reserves and targets. These results suggest that priority cowpea CWR can be conserved by building on conservation initiatives established for other species.

As the world population increases, the need for long-term food security of high-yielding, highly nutritious crops becomes ever more critical. Increasingly, plant breeders are turning to the wider crop gene pool to find the diversity required to cope with the changing biotic and abiotic environment while sustaining food security[1–3]. Crop wild relatives (CWR) are taxa that are closely related to crops, many with the ability to contribute beneficial traits to their related crops such as resistance to biotic and abiotic stresses and higher, more stable yields[4–6]. Although recent advances in biotechnology offer techniques for direct genetic modification of crops, conventional breeding methods offer a more accessible and reliable option for crop improvement[7], particularly for breeders without access to the resources required for high-investment breeding. Thus, the most valuable taxa in conventional breeding are the priority CWR, the taxa that are most closely related to the crop and so have the highest potential to produce successful crosses[8].

As interest to integrate CWR into crop breeding has increased, CWR conservation has become critical to maintaining these resources for future use[9]. Despite the calls for their identification and conservation in both international and regional policy instruments[10–14], CWR conservation has historically been widely neglected[8,9,15,16] and CWR research is gravely under-represented in the general conservation literature[17]. This deficit in both research and action may reflect a lack of awareness in the wider conservation research community or the societal value of CWR conservation and their role in underpinning provisioning ecosystem services.

The plans that do exist for the *in situ* conservation of CWR are generally based on distributions of all taxa in the crop genera[18–21] (and recent strategies for *ex situ* CWR conservation by the Consultative Group on International Agricultural Research, http://gisweb.ciat.cgiar.org/GapAnalysis/). However, the difference between the best localities to conserve the priority CWR and the best localities to conserve an entire genus could be quite dramatic, especially if the crop genus is large. Using genus diversity as a surrogate for priority CWR diversity may mask the specific conservation requirements or miss important opportunities for the efficient conservation of the priority CWR and, therefore, many of the most useful resources to plant breeders. Furthermore, priority CWR conservation may be more efficiently conducted by searching within established protected areas or by building upon conservation targets for other taxonomic groups. Here we use the African cowpea (*Vigna unguiculata* (L.) Walp.) as a case study to explore the use of taxonomically and geographically prioritised conservation planning approaches to identify an efficient set of locations for the conservation of priority CWR.

Like all conservation efforts, CWR conservation will always be hampered by the limited availability of funds, which could explain why most current CWR conservation is limited to *ex situ* efforts, storing seeds in local and global seed banks. *Ex situ* conservation is cheaper than establishing and maintaining *in situ* activity, and agricultural agencies have limited responsibility for wild species conservation. Furthermore, ecological conservation agencies tend to prioritise specific habitats or rare, endemic, threatened or charismatic species. Although plant resources can be safely conserved *ex situ* in seed banks, *in situ* conservation is an important compliment because it allows populations to continue natural adaptation to changing conditions[22,23]. *In situ* approaches are especially important in CWR conservation since many of their traits that are beneficial in crop breeding are relevant to adaptation to particular environmental conditions (e.g., drought tolerance, salt tolerance). The future needs of crop improvement are dynamic, so maintaining CWR diversity *in situ* ensures that future use value is maximized.

One way to improve the efficiency of *in situ* CWR conservation efforts is to focus taxonomically on the priority CWR, the taxa with the greatest potential for crop improvement. Based on breeding relationships or generic classifications, the priority CWR are 1) the wild forms of the cultivated taxa, or if breeding relationships are unknown, the infraspecific, uncultivated taxa; 2) taxa in the same taxonomic series or section as the crop; and 3) taxa in the same subgenus as the crop[6]. The priority CWR, should be the focus of CWR conservation, and have already been identified for a number of the world's major crops[8].

In addition to taxonomic prioritisation, conservation effort can be geographically focused by identifying existing protected areas where target taxa are likely to occur[24]. Identifying and accounting for species likely to occur in existing protected areas is a core principle of system conservation prioritisation[25]. An efficient set of *in situ* conservation sites might also include places of potential overlap with priority locations for other conservation action (e.g., important areas for endangered or critically endangered taxa from the same or different taxonomic groups[26]). The suitability of partnering CWR conservation with other conservation activities is relatively unexplored but may be a cost-effective way to achieve *in situ* conservation.

We use the African cowpea as a case study to demonstrate how to efficiently identify conservation targets for priority CWR using both taxonomic and geographic prioritisation. In sub-Saharan Africa, cowpea is one of the major grain legume and protein sources for subsistence farmers, valued for its high protein content, drought tolerance, and nitrogen fixing abilities[18]. Sub-Saharan Africa has the highest concentration of the most undernourished countries in the world[27], which makes the region an important target of the Millennium Development Goals in reducing the number of undernourished people by half[28]. Cowpea is one of the twenty most produced food sources in Western Africa[27], where many of the cowpea CWR are found[18].

Expanding and improving cowpea cultivation could help alleviate undernourishment in Western and sub-Saharan Africa. The conservation of the priority cowpea CWR is an important target for achieving this goal. Even though they offer the opportunity to increase production as well as biotic and abiotic resistance[18], CWR have not yet been widely exploited in cowpea breeding. The range of cowpea CWR diversity has not been adequately conserved for later use and is threatened by the by-products of human population expansion and urban sprawl continually threaten the maintenance of that diversity (i.e., irrigation practices and soil salinisation, deforestation, agricultural expansion, and the introduction of invasive species)[18]. Cowpea CWR populations are further threatened by climate change, which stands to deplete or change the patterns of natural ranges and habitats[29,30]. African cowpea is also a practical case study for demonstrating taxonomically-prioritised conservation plans for CWR since the priority CWR have already been identified[8].

In this study we identify the best locations to find and conserve the priority African cowpea CWR based on georeferenced herbarium and germplasm records. Of the over 100 taxa in the African cowpea genus, only 14 are considered priority wild relatives of cowpea[8], so the difference in best locations to conserve the entire genus versus the priority CWR could be quite large. Using the African cowpea genus as a case study, we first test the extent to which the best conservation sites identified by the known records of the entire genus adequately represent the conservation needs of the priority cowpea CWR. To design more practical conservation goals, we also identify where priority cowpea CWR in Africa are likely to occur in existing protected areas, and the extent to which they occur in places that are likely to be the focus of more traditional *in situ* conservation actions, in this case, focusing on the conservation of endangered mammal species. Finally, we use our findings to propose a series of localities for the *in situ* conservation of priority cowpea CWR in Africa. Although widely used to prioritise conservation efforts, these conservation planning techniques have not been applied to CWR conservation. We believe this case study provides a useful framework to identify efficient conservation targets that taxonomically and geographically prioritise the most important wild agricultural resources.

Methods

We started with a database of all collection localities of African *Vigna* taxa compiled from herbarium specimens and gene bank accessions[18]. We removed accessions collected before 1920 as older collection sites are less likely to reflect current distributions of taxa and since there was a general increase in *Vigna* collection after this time[18]. The resulting database included point locality records for 111 African *Vigna* taxa, including 13 of the 14 priority CWR taxa. We applied a 25 km radius buffer to each point locality record to account for possible error in the georeferencing of records in the database.

To explore whether the entire *Vigna* genus is a reasonable surrogate for identifying the best *in situ* conservation localities for the 13 priority CWR species, we first divided the continent of Africa into 100 km^2 planning units, and then summarised the occurrence of all *Vigna* species within each planning unit. We used the reserve design software Marxan[31] to identify the set of planning units that most efficiently represented at least one occurrence of all species in the *Vigna* genus, excluding the 13 priority CWR. Surrogates, especially based on point data, are likely to perform better using a complementarity approach than using a hotspot approach[32]. Performance is based on how well the surrogate represents the other species of interest. Within Marxan, we identified priority sites using both a basic Richness heuristic, and the more optimal Simulated Annealing algorithm[33]. Under the Richness heuristic, planning units that are likely to contain multiple *Vigna* taxa are selected preferentially. We repeated the Richness and Simulated Annealing prioritisations 100 times and identified the best set of sites to protect all non-priority cowpea CWR taxa. We also identified high priority sites, which were those sites selected in the best set of sites in at least 75 of the 100 runs. We then calculated the extent to which both the best set of sites and the set of high priority sites captured the 13 priority cowpea CWR, which were not considered in the selection of those sites. This approach to surrogacy testing is sometimes referred to as the selection method and is the most widely adopted approach[34].

Prioritisation analyses that are based on buffered point data, rather than the full distribution of each species, are sensitive to the size of the planning units used in the analysis. To test sensitivity to this effect, we repeated the analysis described above with 200 km^2 planning units and with 50 km^2 planning units.

To identify existing protected areas across the African continent that are likely to contain at least one of the 13 priority cowpea CWR, we overlapped the buffered locality records for priority species with data obtained from the World Database on Protected Areas[35].

To explore the extent to which conservation priorities driven by more charismatic species, the conventional focus of *in situ* conservation in Africa, could also include priority cowpea CWR species, we obtained the distributions of all 159 African mammal species listed as Endangered or Critically Endangered by the IUCN. As with the *Vigna* data, we summarised the occurrence of these 159 species within 100 km^2 planning units. We used the procedures described above to identify the best set of sites to represent at least one occurrence of each mammal species. We then calculated the extent to which these sites captured known occurrences of the 13 priority cowpea CWR.

Finally, we identified the best sites for *in situ* conservation of the 13 priority cowpea CWR in Africa. Again we used Marxan as described above but only considered the known occurrences of the 13 priority CWR species.

Results

Performance of Vigna genus as a surrogate for priority CWR species. The best conservation solution for the entire *Vigna* genus, not including the priority CWR, contained 32 planning units across Africa (Figure 1) and captured 12 of the 13 priority cowpea CWR. The only species not represented was *Vigna monantha*, known only from the coast of Somalia.

When we consider only the highest priority sites, those planning units selected more than 75% of the time, 10 of the 13 priority cowpea CWR are still captured (Figure 1). *Vigna monantha* was still not represented, along with *Vigna keraudrenii*, which is endemic to Madagascar, and *Vigna unguiculata* subsp. *baoulensis*, known from only two records in Côte d'Ivoire.

Using a simulated annealing algorithm rather than a simple richness heuristic delivered only a marginal improvement, reducing the total number of planning units required from 32 to 30. However, the best set of sites based on simulated annealing captured only 9 of the 13 priority CWR, 3 less than the richness heuristic. This result is explained by the fact that simulated annealing locates the most complementary set of sites to represent the genus, excluding the priority CWR species.

Doubling the planning unit size to 200 km^2 made little difference, with the best solution still capturing 11 of the 13 priority CWR, with *Vigna unguiculata* subsp. *baoulensis* missing in addition to *Vigna monantha*. The larger planning units were also less efficient, requiring 27 planning units or 1.08 million square km to represent the *Vigna* genus without the priority CWR, compared with 320,000 square kilometres for the 100 km^2 planning units. Halving the planning unit size to 50 km $\times$ 50 km proved the most efficient, still only requiring 32 planning units or 80,000 square km to represent the genera. The best set of 50 km^2 planning units also captured 12 of the 13 priority CWR, only missing *Vigna monantha*. This suggests that priority sites to conserve the *Vigna* genus *in situ* are extremely consistent and conservation efforts can be precisely targeted.

Protected area analysis. We found that 182 established protected areas across Africa are likely to contain at least one priority cowpea CWR (Figure 2, Table S1). In total, 9 of the 13 priority cowpea CWR are likely to be found in an existing protected area. Of these protected areas, 63 are likely to harbour multiple priority taxa (Table S2). Based on collection records, however, *Vigna monantha*, *Vigna unguiculata* subsp. *alba*, *Vigna unguiculata* subsp. *aduensis* and *Vigna unguiculata* subsp. *letouzeyi* are not likely to exist within any established protected areas.

Overlap with priorities for conservation of Endangered and Critically Endangered mammal species. The best conservation solution to represent all Endangered and Critically Endangered mammal species in Africa (Figure 2) required 61 planning units and captured 10 of the 13 priority cowpea CWR. The three species not captured were *Vigna monantha*, *V. unguiculata* subsp. *aduensis*, *V. unguiculata* subsp. *unguiculata* var. *spontanea*. Of these, *V. unguiculata* subsp. *aduensis* is recorded from Ethiopia in the planning unit adjacent to a mammal priority site, and *V. unguiculata* subsp. *unguiculata* var. *spontanea* is a widely distributed species, also with recorded occurrences in planning units adjacent to mammal priorities, particularly in South Africa. These results were indifferent to the use of simulated annealing or a richness heuristic.

Best sites for priority cowpea CWR species. Based on collection records, at least 8 *in situ* conservation sites are required to represent all 13 priority CWR from the African *Vigna* genus (Figure 1). Both the number and general location of the required sites were insensitive to changes in planning unit size or solution method. The 8 priority sites encompassed the following localities: the tri-border region of Côte d'Ivoire, Guinea and Liberia; northern Ethiopia; coastal

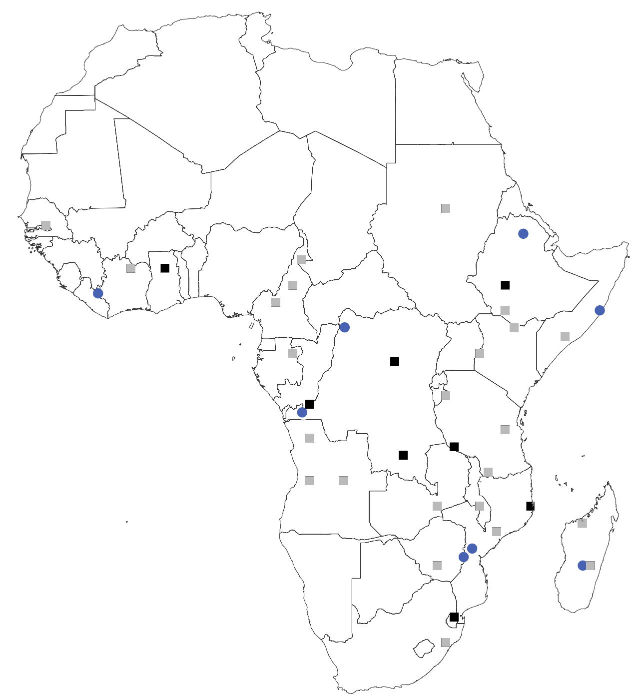

Figure 1 | The set of sites that most efficiently captures the *Vigna* genus excluding the priority crop wild relatives (CWR) (squares), compared with the set of sites identified specifically to represent the priority CWR (blue circles). The eight highest priority planning units from the *Vigna* genus set (identified in black) capture 10 of the 13 priority *Vigna* CWR. Eight priority CWR-specific planning units capture all 13 priority *Vigna* CWR taxa. Content for the maps was generated in Marxan 1.8.10 and the map images were generated in ArcGIS 10[38].

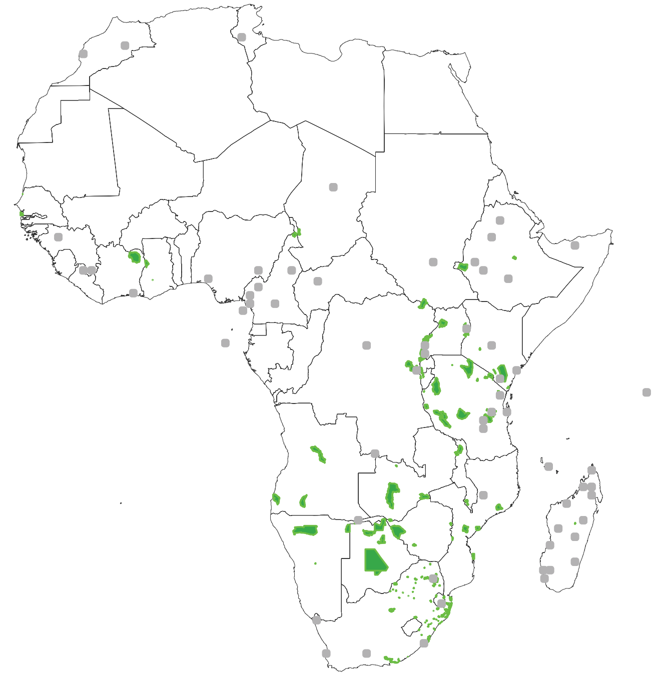

Figure 2 | Established protected areas where priority *Vigna* crop wild relatives may be found (green areas) and the best conservation solution to represent all Endangered and Critically Endangered mammal species in Africa (grey rectangles). 9 of the 13 priority CWR taxa are likely to be found in the established protected areas shown (see Supplementary tables S1 and S2 for details), and the set of sites that capture Africa's Endangered and Critically Endangered mammal species also capture 10 of the 13 priority cowpea CWR. Content for the maps was generated in Marxan version 1.8.10 and the map images were generated in ArcGIS 10[38].

Somalia; the tri-border region of the Democratic Republic of Congo (DRC), Central African Republic and Congo; the coastal border of DRC and Angola; the border of Zimbabwe and Mozambique; and central Madagascar (Fig. 1). Together, these eight sites also capture 27 of the 98 non-priority African *Vigna* taxa.

Discussion

By identifying the priority conservation sites for all taxa in the African cowpea genus, we were also able to capture 12 of the 13 of the most important CWR analysed in this study. This result suggests that the whole cowpea genus acts as a reasonable surrogate for identifying conservation sites for priority CWR. However, for other crop genera, the whole genus may not be a suitable surrogate for the priority CWR. Because CWR are vital resources for future crop improvement and sustainability, it is important to conduct a similar analysis on other important crop genera to ensure that the conservation needs of priority CWR are identified. While this study focuses on identifying conservation targets for the priority CWR, an important aspect of the methodology is exploring both genus-wide and priority CWR-specific conservation needs, as focusing solely on the priority CWR may overlook the unique needs of non-priority taxa.

Based on occurrence data for 13 of the 14 priority cowpea CWR, we identified over 100 established protected areas where priority cowpea CWR may be located and conserved, many of which are likely to harbour multiple priority taxa (see Tables S1 and S2). Locating and initiating conservation activity within protected areas is likely to be an efficient and cost-effective strategy for protecting priority CWR. We also found that three African cowpea CWR are not found in established protected areas, so extra effort will be needed to locate and conserve these priority taxa. Although we use cowpea as a case study, the conservation goals for other CWR may also be met by building on established conservation initiatives[36].

Additionally, we found that a number of the best localities for Endangered and Critically Endangered mammal conservation overlap with occurrence data for many of the priority cowpea CWR. This suggests that there is potential for CWR conservation efforts to build on or partner with active conservation activities focused on other species. An example of such partnership is the inclusion of conservation goals for fynbos vegetation in South African conservation efforts originally motivated by fauna conservation[37].

Our analysis was based on herbarium specimen and seed collections, not on modelled distributions. Modelling expected distributions of the priority CWR would be useful in conservation planning to reduce the extent to which site selection is biased by sampling effort. However, distribution modelling would only be possible for a small subset of cowpea CWR taxa, since some taxa are known from fewer than 5 records. It is an unfortunate paradox that it is these lesser-known species that would benefit most from distribution modelling, and yet there would be little confidence in the modelled distributions. The results presented here represent conservative but reliable geographic targets for initial, cost-effective conservation of the priority cowpea CWR.

Although we find that the African cowpea genus acts as an adequate surrogate for CWR conservation planning, this may not be the case for all CWR. It would be useful to analyse multiple crop genera using similar methodologies to investigate the generality of the results presented here. Where possible, identifying the priority CWR and using their distributions as a guide for conservation effort is likely to lead to the most efficient conservation of priority CWR. Furthermore, we recommend fully exploring the conservation needs of the entire genus and the priority CWR to ensure that the specific needs of threatened or remote taxa are identified.

Although *in situ* conservation of critical crop resources is an economic and humanitarian priority[12,28], it has been largely ignored by the conservation movement. Here we demonstrate that the African cowpea CWR distribution overlaps with both established protected areas and existing conservation initiatives that target other taxonomic groups. This finding suggests that much *in situ* CWR conservation can be accomplished by utilising existing resources, yet will have a huge benefit to humanity.

1. Hajjar, R. & Hodgkin, T. The use of wild relatives in crop improvement: a survey of developments over the last 20 years. *Euphytica* **156**, 1–13 (2007).
2. Feuillet, C., Langridge, P. & Waugh, R. Cereal breeding takes a walk on the wild side. *Trends. Genet.* **24**, 24–32 (2008).
3. Nevo, E. & Chen, G. Drought and salt tolerances in wild relatives for wheat and barley improvement. *Plant Cell Environ.* **33**, 670–685 (2010).
4. Prescott-Allen, R. & Prescott-Allen, C. *The First Resource: Wild Species in the North American Economy.* (Yale University Press, 1986).
5. Hoyt, E. *Conserving the Wild Relatives of Crops.* (International Board for Plant Genetic Resources (IBPGR), International Union for the Conservation of Nature and Natural Resources (IUCN), and Worldwide Fund for Nature (WWF) 1988).
6. Maxted, N., Ford-Lloyd, B. V., Jury, S., Kell, S. & Scholten, M. Towards a definition of a crop wild relative. *Biodivers. Conserv.* **15**, 2673–2685 (2006).
7. Burke, J. M., Burger, J. C. & Chapman, M. A. Crop evolution: from genetics to genomics. *Curr. Opin. Genet. Dev.* **17**, 525–532 (2007).
8. Maxted, N. & Kell, S. P. *Establishment of a global network for the in situ conservation of crop wild relatives: status and needs.* (FAO, 2009).
9. Ford-Lloyd, B. V. *et al.* Crop Wild Relatives—Undervalued, Underutilized and under Threat? *BioScience* **61**, 559–565 (2011).
10. FAO. *Global Plan of Action for the Conservation and Sustainable Utilization of PGRFA.* (Food and Agriculture Organization of the United Nations, 1996).
11. FAO. *International Treaty on Plant Genetic Resources for Food and Agriculture.* (Food and Agriculture Organization of the United Nations, 2001).
12. CBD. *Strategic Plan for Biodiversity 2011–2020, including Aichi Biodiversity Targets.* (Secretariat of the Convention on Biological Diversity, 2010).
13. Heywood, V. H., Kell, S. P. & Maxted, N. in *Crop Wild Relative Conservation and Use* (Maxted, N. *et al.*) 653–662 (CABI, 2008).
14. Planta Europa. *Sustainable Future for Europe; the European Strategy for Plant Conservation 2008–2014.* (Plantlife International and the Council of Europe, 2008).
15. Heywood, V., Casas, A., Ford-Lloyd, B. V., Kell, S. & Maxted, N. Conservation and sustainable use of crop wild relatives. *Agric. Ecosyst. Environ.* **121**, 245–255 (2007).
16. Maxted, N., Scholten, M., Codd, R. & Ford-Lloyd, B. V. Creation and use of a national inventory of crop wild relatives. *Biol. Conserv.* **140**, 142–159 (2007).
17. Honnay, O., Jacquemyn, H. & Aerts, R. Crop wild relatives: more common ground for breeders and ecologists. *Front. Ecol. Environ.* **10**, 121–121 (2012).
18. Maxted, N. *et al. An ecogeographic study: African Vigna.* (International Plant Genetic Resources Institute, 2004).
19. Al-Atawneh, N., Amri, A., Assi, R. & Maxted, N. Management plans for promoting in situ conservation of local agrobiodiversity in the West Asia centre of plant diversity in *Crop Wild Relative Conservation and Use* (Maxted, N. *et al.*) 338–361 (CABI, 2008).
20. Maxted, N., Dulloo, E., Ford-Lloyd, B. V., Iriondo, J. M. & Jarvis, A. Gap analysis: a tool for complementary genetic conservation assessment. *Divers. Distrib.* **14**, 1018–1030 (2008).
21. Ramírez-Villegas, J., Khoury, C., Jarvis, A., Debouck, D. G. & Guarino, L. A Gap Analysis Methodology for Collecting Crop Genepools: A Case Study with Phaseolus Beans. *PLoS ONE* **5**, e13497 (2010).
22. Schoen, D. J. & Brown, A. H. The Conservation of Wild Plant Species in Seed Banks. *BioScience* **51**, 960–966 (2001).
23. Meilleur, B. A. & Hodgkin, T. In situ conservation of crop wild relatives: status and trends. *Biodivers. Conserv.* **13**, 663–684 (2004).
24. Ford-Lloyd, B. V., Kell, S. P. & Maxted, N. Management plans for promoting in situ conservation of local agrobiodiversity in the West Asia centre of plant diversity in *Crop Wild Relative Conservation and Use* (Maxted, N. *et al.*) 110–119 (CABI, 2008).
25. Pressey, R. L., Humphries, C. J., Margules, C. R., Vane-Wright, R. I. & Williams, P. H. Beyond opportunism: Key principles for systematic reserve selection. *Trends Ecol. Evol.* **8**, 124–128 (1993).
26. Groves, C. R. *Drafting a conservation blueprint: A practitioners guide to planning for biodiversity.* (Island Press, 2003).
27. FAO. *FAOSTAT.* (Food and Agriculture Organization of the United Nations, Rome). at <http://www.faostat.fao.org> Date of access: 01/09/2012.
28. UN. *Millennium Development Goals.* (2000). at <http://www.endpoverty2015.org> Date of access: 01/09/2012.
29. Jarvis, A., Lane, A. & Hijmans, R. J. The effect of climate change on crop wild relatives. *Agric. Ecosyst. Environ.* **126**, 13–23 (2008).
30. Burke, M. B., Lobell, D. B. & Guarino, L. Shifts in African crop climates by 2050, and the implications for crop improvement and genetic resources conservation. *Glob. Environ. Change* **19**, 317–325 (2009).
31. Ball, I. R., Possingham, H. P. & Watts, M. E. Marxan and Relatives: Software for spatial conservation prioritization in *Spatial Conservation Prioritization: Quantitative Methods & Computational Tools* (Moilanen, A., Wilson, K. A. & Possingham, H. P.) 185–210 (Oxford University Press, 2009).

32. Lewandowski, A. S., Noss, R. F. & Parsons, D. R. The effectiveness of surrogate taxa for the representation of biodiversity. *Conserv. Biol.* **24**, 1367–1377 (2010).
33. Game, E. T. & Grantham, H. S. *Marxan user manual; for Marxan version 1.8.10.* (The University of Queensland and Pacific Marine Analysis and Research Association, 2008).
34. Grantham, H. S., Pressey, R. L., Wells, J. A. & Beattie, A. J. Effectiveness of Biodiversity Surrogates for Conservation Planning: Different Measures of Effectiveness Generate a Kaleidoscope of Variation. *PLoS ONE* **5**, e11430 (2010).
35. IUCN-UNEP. *The World Database on Protected Areas (WDPA).* (UNEP-WCMC, 2010). at <http://www.protectedplanet.net> Date of access: 01/09/2012.
36. Stolton, S., Ford-Lloyd, B. V., Kell, S. P. & Dudley, N. *Food Stores: Using Protected Areas to Secure Crop Genetic Diversity.* (WWF, 2006).
37. Reyers, B., Fairbanks, D., Van Jaarsveld, A. S. & Thompson, M. Priority areas for the conservation of South African vegetation: a coarse-filter approach. *Divers. Distrib.* **7**, 79–95 (2001).
38. ESRI. ArcGIS Desktop: Release 10. (Redlands, CA: Environmental Systems Research Institute, 2011).

Author contributions

N.M. proposed the study and provided the data. C.M. and E.G. designed and performed the analyses. All authors wrote and reviewed the manuscript.

Additional information

Supplementary information accompanies this paper at http://www.nature.com/scientificreports

Competing financial interests: The authors declare no competing financial interests.

How to cite this article: Moray, C., Game, E.T. & Maxted, N. Prioritising *in situ* conservation of crop resources: A case study of African cowpea (*Vigna unguiculata*). *Sci. Rep.* **4**, 5247; DOI:10.1038/srep05247 (2014).