Darwin Initiative: Final Report

*To be completed with reference to the "Writing a Darwin Report" guidance: (http://www.darwininitiative.org.uk/resources-for-projects/reporting-forms). It is expected that this report will be a **maximum** of 20 pages in length, excluding annexes)*

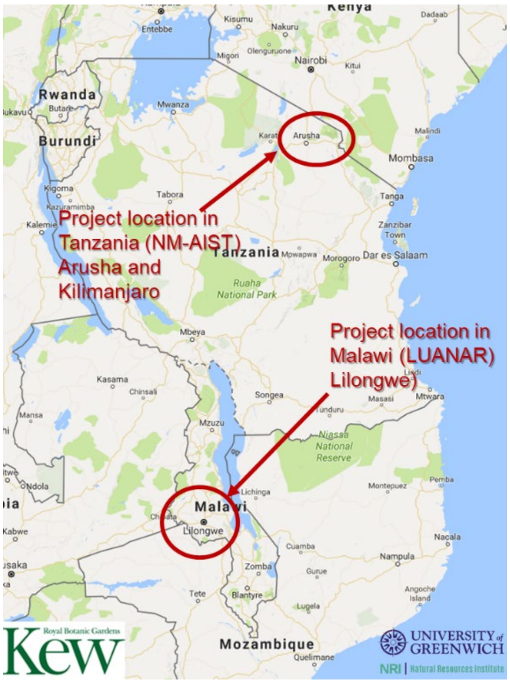
Darwin Project Information

Project reference	**22-012**
Project title	**Harnessing agricultural ecosystem biodiversity for bean production and food security.**
Host country/ies	**UK, Tanzanian and Malawi**
Contract holder institution	**Royal Botanic Gardens, Kew**
Partner institution(s)	**Nelson Mandela African Institution of Science and Technology (NM-AIST)** **Natural Resources Institute, University of Greenwich (NRI)** **Lilongwe University of Agriculture and Natural Resources (LUANAR)**
Darwin grant value	**£288,762**
Start/end dates of project	**01/04/2015 – 31/03/18**
Reporting period	**April 2015-March 2018 Final Report**
Project Leader name	**Prof Philip C Stevenson**
Project website/blog/Twitter	**@chickpeaman @sejarnold www.agriculturalecosystems.org**

1 Project Rationale

Expected world population growth to 9 billion, and the 60% increase in food required to support this, is increasing pressure worldwide on food security and the natural resources that underpin production [1]. Severe pest damage of crops continues to be a major global food security challenge [2] while pollinators, required for most crops are declining in intensive agricultural systems [3]. Conventional agricultural intensification (AI), which relies on agrochemical inputs (pesticides, fertilizers), has enhanced production over several decades, but in recent years has failed to track food demand and is now widely recognised to degrade the ecosystem services underpinning production. Strong recent evidence has shown that land use change and AI can result in severe declines in invertebrate biodiversity [4]. Arable land is finite so future growth in production must come from *sustainable intensification* (SI); the production of more food from the same or less cultivated land with reduced inputs minimising adverse environmental impacts. The most cost-effective change can be achieved through ecological intensification (EI); the management of ecosystem services underpinning production, an approach being adopted in developed economies illustrated by changes in pesticide regulation and subsidies for supporting or enhancing ecosystem services underpinning production. The proposed action will create new knowledge about EI in Africa with a focus on natural pest regulation (NPR) and pollination, two key ecosystem services for EI, but which are rarely considered together. EI is a knowledge-intensive pathway to improve food production that is economically and environmentally sustainable. Investments in EI for smallholder farmers can deliver transformative change [5], generating resilient agriculture that enhances livelihoods of the world's poorest and buffers production against future threats and risks. The target countries for this action were Tanzania and Malawi, both OECD DAC recipient nations suffering high rates of chronic malnutrition with 34% and 37% stunting respectively [**6**]). Tanzania's national poverty reduction strategy paper in 2014 highlighted that food poverty exceeded 18% and that agriculture was central to reducing this. The step-change production increases required to achieve poverty reduction are realistic since yields of key crops including the target of this action, common beans, are presently so low (500-700 kg/ha). Consequently, millions of farmers, particularly women (the primary bean growers in Malawi and Tanzania) and their households, are

[1] Godfray, et al. 2010 *Science* 327, 812 **[2]** Poppy et al. 2014 *Phil. Trans. R. Soc. B* 369, 2012027 **[3]** Potts et al. 2016 *Nature*, 540, 220. **[4]** Uchida & Ushimaru 2014. *Ecol. Monographs*, 84, 637-658, Zhao, et al., 2015. *Sci Rep*, 5, 8024. Senapathi et al., 2017. *Functional ecology*, 31, 26-37. [5] Garibaldi et al.2016 *Science*, 351, 388 **[6]** World Bank (2015) https://tinyurl.com/y9vbdtu8



at risk of nutritional deficiency and food insecurity. Potential yields are, however, >3000 kg/ha. Insects are major constraints for beans and were co-identified with our African partners as target for developing environmentally benign pest management and improving SI of beans. Pesticides can control insects but may be avoided for reasons of economics and availability. Biodiversity underpins ecosystem services and ultimately food security, livelihoods and economic development by augmenting natural enemies and reducing pest impacts, while bean yields may improve by optimising pollination. Biodiversity in smallholder ecosystems, however, can be poor in East Africa. Biodiversity surveys from this action aimed to identify plant species that support beneficial invertebrates and enhance ecosystem service and resilience and enable farmers to grow beneficial plants within their cropping systems to improve food security and alleviate poverty. The knowledge about the plant species will enable better land management to support insect biodiversity that delivers pollination services on which beans rely for optimal yield and quality and NPR to sustainably manage the pests and improve crop resilience and food and nutritional security for millions of farmers. Reducing reliance on pesticides reduces expenditure, widely acknowledged negative environmental impacts and exposure to counterfeit/banned products that can put users and consumers at risk and reduce market potential of produce [TEEB (2015) TEEB for Agriculture & Food: an interim report, UNEP, Geneva].

2 Project Partnerships

The project partnership had been working together on other actoivities led by NRI under McKnight Foundation and EU funding through the ACP Science and Technology Programme, so an effective working relationship already existed prior to this action. This is the first time as a partnership we have tackled large scale ecosystem surveys, and this was originally challenging to set up. However, owing to our track record and good working relationship we managed to make excellent progress in all areas. As mentioned above the research aims were co-designed and implemented through a fully cooperative and equitable process. We also engaged the services of an external socio-economics consultant who designed, helped undertake and analysed the outcomes of baseline and end-line surveys which we report on in full here (Annex 7). All partners have been engaged in the writing of the final report and contributed significantly to the data presented. Partners intend very strongly to keep in touch. Stevenson/Arnold (NRI), Ndakidemi (NM-AIST) and Tembo (LUANAR) are partners on a recently funded BBSRC-Global Challenges Research Fund (BBSRC-GCRF) project under the Sustainable Agriculture in Sub-Saharan Africa (SASSA) call addressing natural enemies of pests in orphan crop legumes. Partners are involved in a UKRI-GCRF Research Hub proposal led by Stevenson (NRI). No significant issues were encountered within the partnership.

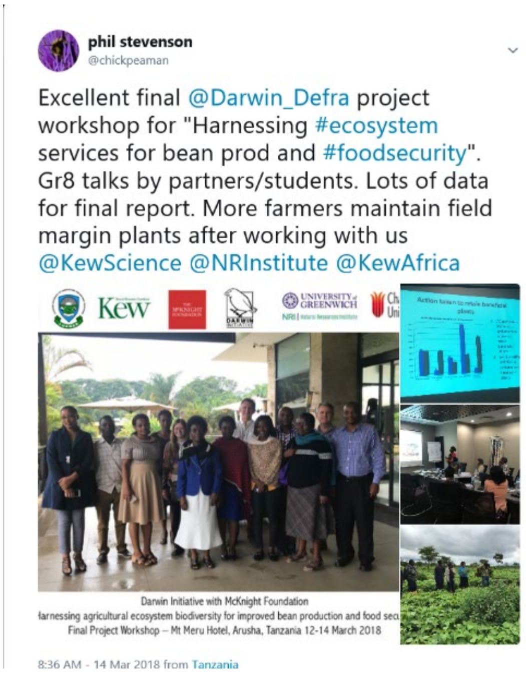
3 Project Achievements

3.1 Outputs

Overall planning and delivery. Project inception workshop (Arusha 22-25 Sept 2015) was hosted by NM-AIST and attended by Dr Iain Darbyshire (RBGK), Dr Sarah Arnold (NRI), Prof Patrick Ndakidemi (NM-AIST), Dr Kelvin Mtei (NM-AIST), Ms Julie Tumbo (Consultant Socio-economist), and Tanzanian students and was used to plan activities for the whole project including the baseline survey and implementation of field sampling. Two outcomes from the workshop included a survey methodology and a baseline survey tool (Annex 7). **Principal Hypotheses for the project were defined**

1. Margin and arable weed plant diversity varies between fields and different ecological zones
2. Fields with higher plant biodiversity have higher insect biodiversity than those with lower plant diversity a) Higher pollinator abundance and diversity leads to more pollination services and higher fruit-set in crop b) Higher natural enemy abundance and diversity results in lower pest damage
3. Pollinator networks are more complex where plant diversity is high
4. Plant biodiversity and insect biodiversity change over the growing season. High plant biodiversity in flower before/after the main bean flowering season, supports higher pollinator diversity throughout the season and benefits pollination of beans

Additional field visits undertaken by Profs Stevenson (PI) and Gurr (Charles Sturt University) and Drs Sarah Arnold (NRI) and Iain Darbyshire (Kew) throughout the project to NM-AIST In Tanzania and LUANAR in Malawi were used to develop protocols for assessing plant-invertebrate species interactions, establishing methods for gathering information about impacts of research and building capacity among scientific collaborators, farmers and extension technicians. Two PhD research students from NM-AIST were guided through their research and writing as were 8 MSc students of whom 6 graduated during the project and 2 are still studying. Annual workshops (Arusha; March 2016 and 2017 hosted by NM-AIST were attended by key partners and post grads and used to review outcomes and outputs, plan activities for the year and provide training for students in sampling and monitoring and developing research proposals to investigate how manipulating ecosystems can optimise ecosystem services. A final project workshop (Arusha 10-16 March 2018) assessed achievements across all activities and identified key outputs and outcomes for reporting; likely next steps; remaining research gaps and approaches to effective dissemination and outreach. This was attended by all key Tanzanian, UK and Malawian partners. See plate of the tweet to inform about the meeting with photo of participants, the workshop and the associated field visit.



phil stevenson
@chickpeaman

Excellent final @Darwin_Defra project workshop for "Harnessing #ecosystem services for bean prod and #foodsecurity". Gr8 talks by partners/students. Lots of data for final report. More farmers maintain field margin plants after working with us @KewScience @NRInstitute @KewAfrica

8:36 AM - 14 Mar 2018 from Tanzania

3.1.1 Output 1. Ecosystems & plant spp. that are habitats for key natural enemies of bean pests identified.

Plant biodiversity surveys were undertaken across 24 farm locations in Arusha and Moshi in 3 ecological zones: low (c. 800m), mid (950-1100m) and high altitudes (1500-1600m) with 8 sites (fields) per zone during years 1 and 2. In year 2 these were supplemented with data from 8 further sites in Malawi. All sites grew beans, either as a main crop or intercropped with maize. Sites varied in size and landscape with some large fields up to 100m but with most <50m along the edge. One site per zone was allocated to intensive survey and the other seven were 'minor' sites receiving less intensive monitoring. Each site was surveyed for data about plant and insect diversity (Survey Methods included in Annex 7). These sites were surveyed up to 6 times over the season to coincide with pre-ploughing/cleaning, immediately after planting seeds, seedling stage, bean flowering, bean podding and finally, post-harvest. Plant diversity and insects' visits to plants were recorded to provide data for interaction networks to help determine which species were the most important for beneficial invertebrates. The identification of plant specimens from diversity surveys were undertaken at the National Herbarium of Tanzania in Arusha and verified at RBG Kew.

We identified ~50 plant species of which 30 were abundant and important field margin species from surveys (Fig 1). The most abundant species for pollinators based on interactions included *Ageratum conyzoides*, *Commelinna benghalensis* and 2 *Bidens* spp. (including *pilosa*) (all 3 genera are noteworthy as being exotic weeds, abundant in several locations, supporting large numbers of bees, while *Bidens* and *Ageratum* have known pesticidal properties – see Output 4 below Annex 7 and Amoabeng et al., 2013 *PLoS One*)). Natural enemies of bean pests, including tachinid flies, long-legged flies, robber flies & assassin bugs were observed to be restricted to just one indigenous plant species, *Phaulopsis imbricata* in preliminary field trials reported in year one but data from the full surveys show natural enemies were abundant on a variety of species. Invertebrate surveys showed the insect assemblage changed across growing season and from one location to the next. Fourteen functional groups of invertebrates were identified as most common members of the natural assemblage of insects (mutualists and antagonists) that interacted with the field margin species (Fig 2.).

Several bean field margin plants were exotics or pantropical / palaeotropical species with unclear origins such as *Drymaria cordata* and *Commelina benghalensis*) and so may be seen in a negative light, particularly as some are potentially invasive and may be agricultural weeds. This unexpected outcome will require further work beyond this action to understand the trade-offs of supporting potential agricultural weeds as field margin flowers. Training of 2 graduate students and project staff in Malawi in the diversity survey techniques (insect surveys and associated plant surveys) was also undertaken as part of this work including developing a plant survey protocol and specimen collection (Annex 7).

Data from Tanzania enabled analysis of whether number of plant species in flower at the same time as beans, or outside the bean flower season, was associated with more pollinator visits. However, neither measure significantly predicted visits to beans and the relationship appeared complex, with some sites (e.g. high zone) indicating a positive correlation but others (e.g. the mid zone) a negative correlation.

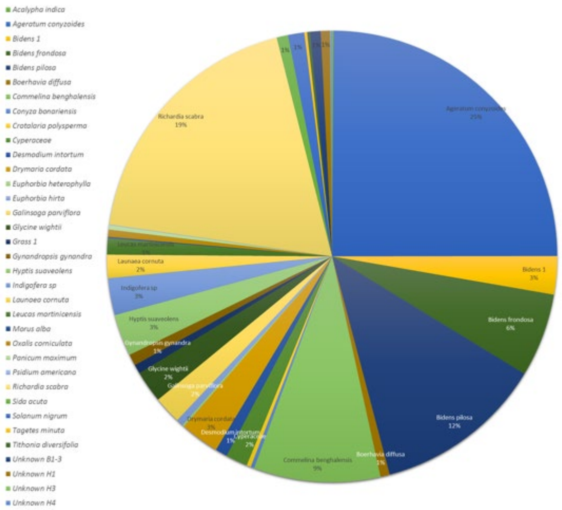


Fig. 1 Plant species recorded as visited by insects during the survey, across all sites, zones and seasons

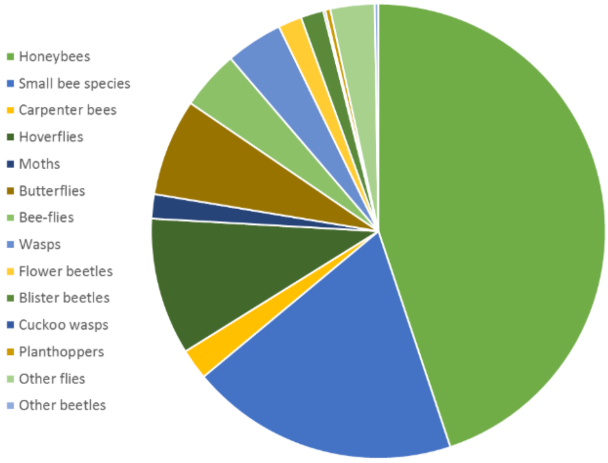


Fig. 2 Functional groups of flower visitors across all sites.

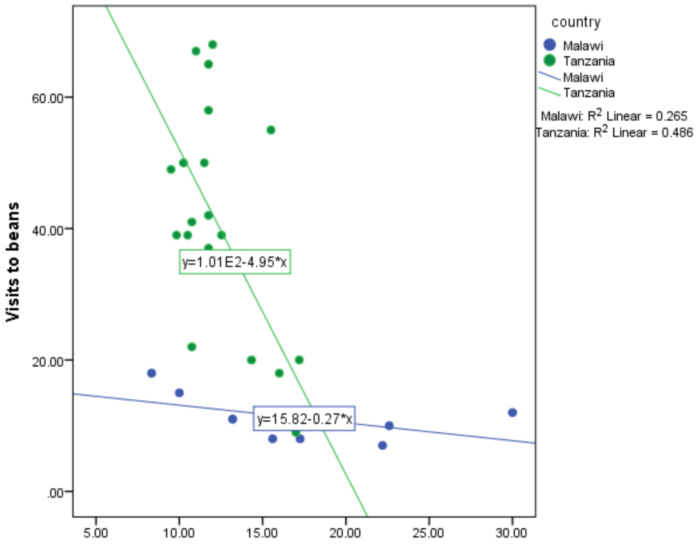


Fig. 3 Relationship between the plant species richness on each field (24 Tanzania + 8 Malawi) and the visits to beans recorded during the flowering period on each field.

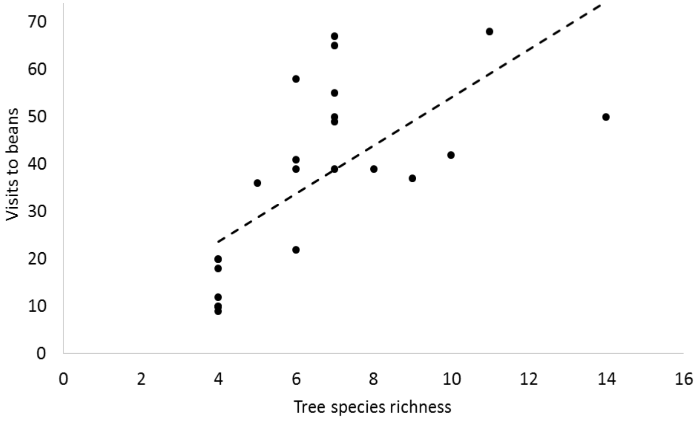


Fig. 4 Increased numbers of tree species on a site is predictive of higher visits to beans by pollinators

Somewhat surprisingly, both countries showed an inverse relationship between the plant diversity on farms and the number of visits received by bean plants (Fig. 3). This even applied when single visitor taxa were considered (such as important pollinators). It is possible that abundance of flowers rather than diversity may be a key predictor of ecosystems services since florally rich habitats were associated with greater insect diversity (see output 2 below). The major message from this finding is that management plans promoting plant diversity indiscriminately may not necessarily benefit all ecosystem services; the traits and nature of the plants may play a more important role.

Ecological or biodiversity assessments of landscapes evaluating potential to support beneficial insects often concentrate on forbs. However, trees offer potentially very large quantities of food in nectar and pollen for pollinators and natural enemies and nesting sites too and should be considered as important components of the supporting landscape for beneficial insects. Analysis of associations between beneficial insects and landscapes showed that diversity of tree species predicted greater numbers of floral visits by pollinators (Fig. 4).

We secured support from in-country partners at the National Herbarium of Tanzania (NHT) with verification at RBG Kew for all plant species, using herbarium vouchers. This had the advantage that the species records were all verifiable. We also established a mini-herbarium at NMAIST which can be used as an identification tool for similar future actions thus an important outcome from the plant identification was a verified bespoke herbarium with 50 species of plant species related to field margins of beans and this continues to provide the foundation of ongoing actions including our new BBSRC-GCRF SASSA Project.

3.1.2. Output 2. Key invertebrates of beans ecosystems and their habitat established.

Invertebrate biodiversity in field margins was evaluated (Annex 7) using transect walks at pre-ploughing, flowering, podding, harvest and post-harvest. All flower-insect interactions were recorded and assigned to functional groups. Detailed analysis was carried out in R using the package bipartite. Almost 2000 insect visits to flowers were recorded across the 24 sites during the cropping season in 2016. The most frequently visited plant species throughout these assessments were *A. conzyzoides* and *Richardia scabra*, which together accounted for 44% of all interactions (Fig. 1). Both are exotic species, native to the neotropics. *A. conyzoides* is also pesticidal (Output 4 and Amoabeng et al., 2013 *Crop Protection*) with scope for commercial propagation (e.g., Babere and Stevenson, 2017 or Annex 7) and has been reported as a habitat/shelter for predators of agricultural pests (Liang and Huang, 1994). Various species of *Bidens* and *Tridax* contributed a further 21% of interactions. The high frequency of interactions recorded is due to the prevalence of these plants and attractiveness to flower visitors. Their dominance can be inferred from the quadrat/plant diversity datasets for these sites to indicate relative attractiveness considering abundance. *Hyptis suaveolens* was visited frequently by honeybees, while two pesticidal plants *Tagetes minuta* and *Tithonia diversifolia* received relatively fewer visits. Interactions were not recorded with the main pests of beans (aphids and Lepidoptera) **suggesting that current field margin plants do not support populations of pest insects**. However, interactions with minor pests (e.g., blister beetles & leaf hoppers) were recorded. The most frequently recorded flower visitor was the honeybee *Apis mellifera*, (44.8% of the total visits). All bees were the most common flower visitors in Tanzania but hoverflies were also often recorded. Other flowering visiting Dipterans were pooled for analysis. The number of insect-flower interactions observed in total increased with increasing elevation (Fig. 6). However, it should be noted that the observations in the lower and mid zones were made during the flowering and podding stages, but the high zone was observed during the pre-ploughing and flowering stages. Thus, data are available for all sites only for the flowering stage.

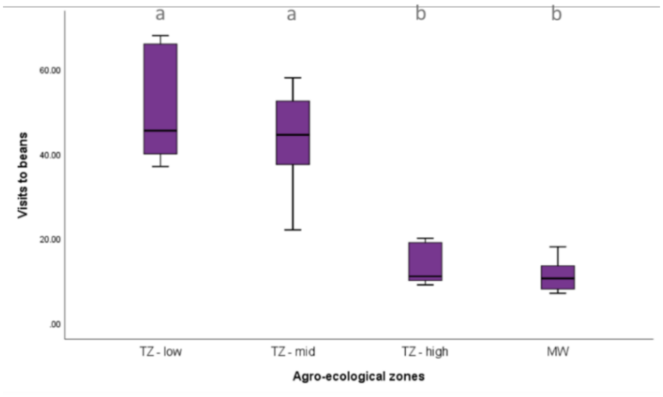


Fig. 5 Flower Visitor numbers to crop by zone (low-High) in Tanzania and in Malawi.

The zones differed in terms of the visits made to beans by potential pollinators (Fig. 5). The low and mid zones in Tanzania received significantly more visits than the high elevation zone (above 1500m) and Malawi. This indicates a pollination deficit in these zones in particular. This is somewhat surprising given the high plant and insect diversity recorded in the high zone of Tanzania. The composition of flower visitors by group changed with ascent up Kilimanjaro – honeybees became more dominant towards the higher elevations, with beeflies and moths recorded less frequently. However, blister beetles which are probably a net pest became rarer. Malawi displayed a very different flower visitor composition, with honeybees contributing much less and many more butterfly visits. All zones had similar percentage of carpenter bee visits – these are likely to be one of the most effective pollinators.

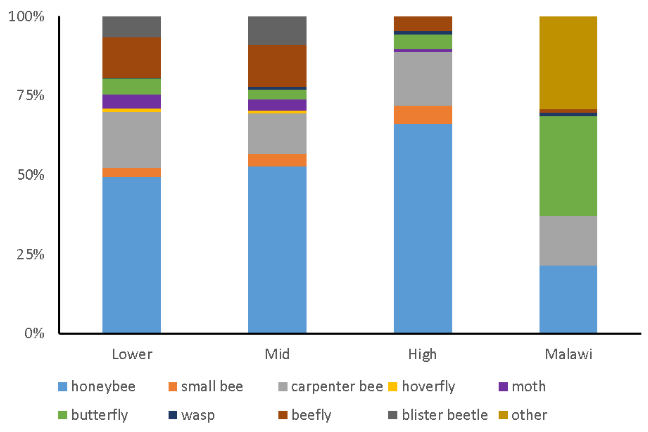


Fig. 6 Flower visitor composition by zone (low-high) in Tanzania, and Malawi).

Functional group richness was higher in the high and mid zones (14 of the target groups observed in each) compared to the lower zone (only 11 groups observed). During the flowering period, when all sites produced some data and the bean crop was blooming, the proportion of interactions involving bee species was highest in the lower zone and decreased in the mid/high zones. Significantly more butterfly- and bee-fly interactions occurred in the mid-zone compared with the lower and high zones (GLM, $F = 9.00$ and 4.79,

$p = 0.002$ and 0.019 respectively) (Fig. 6). The mid zone had the largest number of flowering species visited by the seven main functional groups of insects during the monitoring (25 species) followed by the high zone (19 species), with the smallest visited plant species abundance at the time of bean flowering observed in the low zone (16 species).

The 3 ecological zones were similar, but the lower zone was generally less biologically diverse coinciding with more pesticide use. The most prominent pollinators were honeybees, but there was also a large abundance and likely diversity of small bees, including sweat and stingless bees. *Ageratum conyzoides*, *Bidens* sp. and *Hyptis suaveolens* all recorded frequent interactions with beneficial insects and have pesticidal properties, so could be suited to multi-functional field margin management but their potential trade-offs as weeds must be considered. Additional surveys were undertaken at Bunda (Malawi). This compared plant diverse and plant depauperate field margins. The number of beneficial insects recorded from pre-planting to podding was higher in plant diverse field margins with >250 insects identified compared to <150 in poor field margins, with respect to long legged flies, hoverflies and wasps (Annex 7).

Figure 7(a) shows the interaction networks for plants and natural enemies of pests in the botanically diverse landscape in northern Tanzania while 7(b) shows plant-flower visitor networks in intensive agricultural landscapes near Lilongwe (Malawi) with very low plant diversity. These data show contrasting effects on the diversity of beneficial insects under different landscapes.

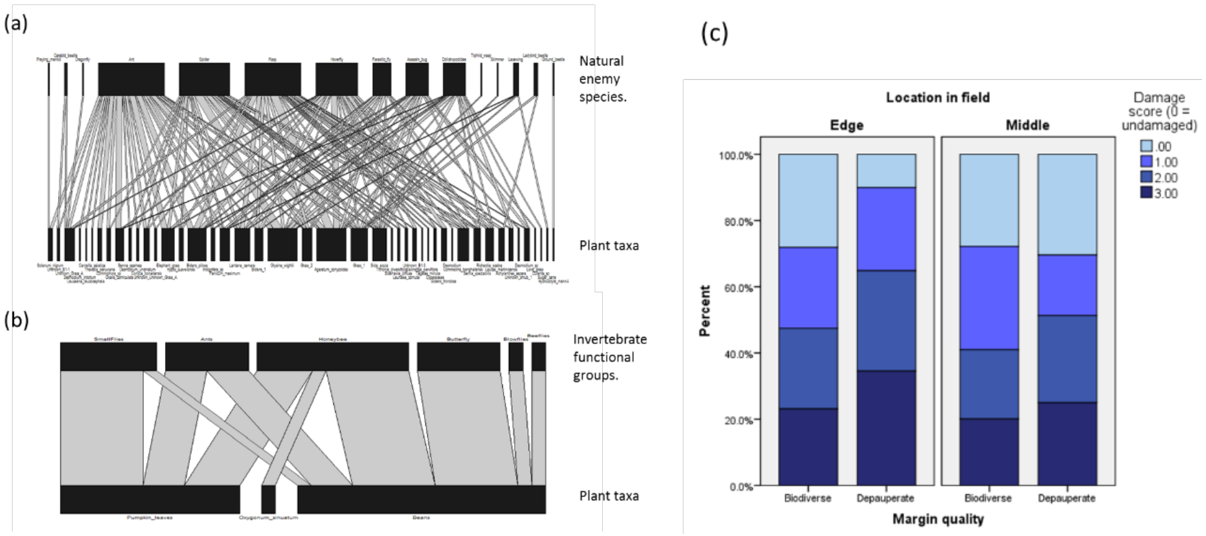


Fig 7. Plant invertebrate interaction networks in (a) a high plant diversity and (b) a low plant diversity location and (c) levels of crop damage at field edge bordering botanically rich and depauperate field margins. Plant diversity in field margins is strongly associated with greater invertebrate diversity and reduced damage, however, without greater knowledge of key plant and beneficial insect taxa it is not possible to optimize natural pest regulation, e.g., as demonstrated in other cropping systems (Gurr et al., 2016)

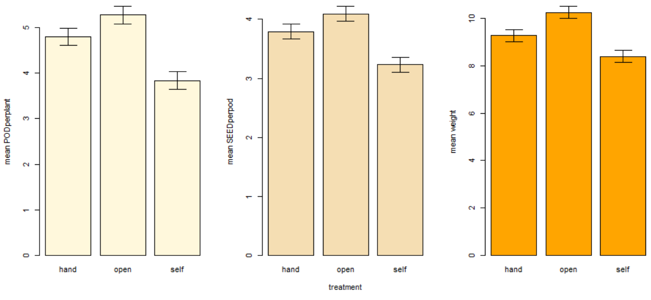


Figure 8: Bean yields parameters means (±SE) for three pollination treatments. The treatments are: Insect/natural-pollination (open), Hand-pollination (hand) and Self-pollination (self)

These differences can impact service delivery for both pollination and natural pest regulation. For example, Malawian fields with any level of semi-natural margin contained 2.5 times more plant species than fields with no set-aside margin area at all and supported twice as many total plant-insect interactions. The biodiverse margin plant-natural enemy network exhibited more specialization (H2 index of 0.362 compared to 0.288), and a higher complexity (linkage density; 7.833 compared to 5.566). The diverse margin network was also more robust (0.8897 compared to 0.7960). Figure 7(c) shows the penalty farmers with poor plant diversity in field margins suffer in Malawi: crops grown in fields with no or minimal margins suffer significantly more damage ($F = 9.112$, $p = 0.003$) and have fewer undamaged beans around the edges of their fields ($F = 6.579$, $p = 0.011$). This is particularly relevant to small holder systems where fields are small so vulnerable to edge effects which may impact the whole field. However, it is not known what distance influence specific field margin plants have in supporting the food and refuge needs of key beneficial insects, but these will be established in recently funded GCRF-SASSA project Natural Pest Regulation on Orphan Crop Legumes in Africa (NaPROCLA) (BB/R020361/1) sets out to understand this among other objectives.

An additional indication of the benefit derived from diverse insect populations from our data is illustrated by a yield benefit in open-pollinated plants relative to bagged plants illustrating the importance of pollinators for food security. By 3 measures (mean pods per plant, mean beans per pod and mean seed weight), open pollinated plants exhibited significantly superior performance (Fig 8). When combined as a single value of seed weight per plant, this showed yield increases of more than double at all three altitudes (>100% increase which exceeded our best expectations of 40% increase indicated in the proposal) in Tanzania, illustrating how important maintaining habitat for beneficial insects is and reducing the use of pesticides. Indeed, open pollination yields were higher even than hand pollination. The details of financial benefits to farmers are presented under output 4.

3.1.2 Output 3: Capacity of 400 lead farmers increased by information and guidance on exploiting and maintaining agricultural biodiversity for improved crop yield.

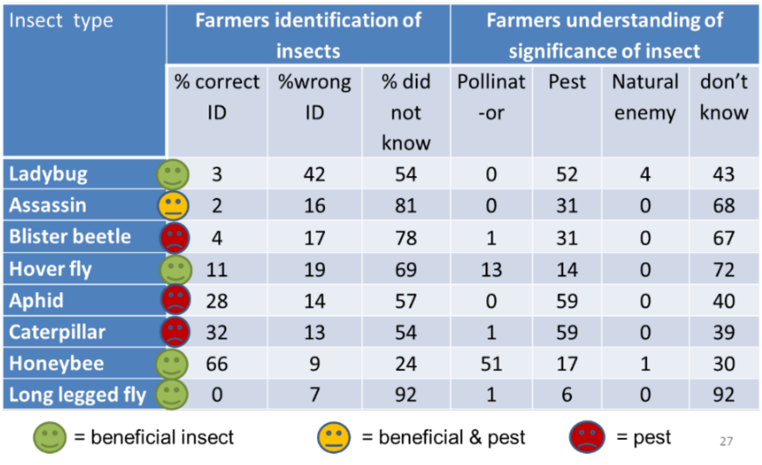
The project theory of change assumed that farmers had inadequate knowledge and skills on how to control pests and, consequently, struggle to maximise bean productivity and quality. Through the project, the farmers were also provided with information and knowledge on managing pests and improving their bean yield and quality. Therefore, the first module that was tracked by the end-line survey was the initial level and gradual improvement over time in the farmers' knowledge and attitudes. It is also believed that once the farmers' knowledge and attitudes had been enhanced, then they will gradually adopt sustainable farm management practices leading to improved yield and quality of beans on their farms. Therefore, the second module tracked by the end-line survey was improvements in the farm management practices employed by the farmers.

The theory of change assumed that good farm management practices led to an improvement in the yield and quality of beans produced from the farms. Consequently, the third module tracked through the end-line survey was the yield, while the fourth module tracked was the quality of beans produced from the farms. The theory of change then concluded that the improved bean yields and quality lead to improved livelihood, living standards and general welfare of the farmers and their families. It is noted that the time-frame for the project period was too short for the farmers to realize tangible long-term changes in their livelihood because of the project activities. Therefore, the end-line survey was limited to provide comments on the potential for longer-term outcome changes in livelihood, welfare and living standards of the farmers and their families because of the activities they undertook. However the benefits of maximising pollination services were used to show financial benefits to farmers while increases in income from beans were recorded of 13% across the year between base line and end-line.

This end-line survey reports for Uganda and Tanzania (Annex 7) contains the benchmarks on data concerning the main milestones within the project theory of change. The end-line survey report presents changes from baseline to date, for the following main milestones: farmers' knowledge and attitude regarding bean farming; farm management practices applied in the beans farms; the yield of beans in the farms targeted by the project; income earned from the targeted beans farms; and the usage of income from beans farms.

Data were collected from over 400 farmers in Moshi and Himo and >200 in Malawi at baseline and from 300+236 farmers at end line (Annex 7). The principal objective was to obtain evidence and information on how improved pest control and management practices in bean farming lead to increased quality and yield and improved living standards for bean farmers. Along with economic information and agricultural practice pertinent to livelihoods the full reports (Annex 7) on what farmers knew about insects and whether they can distinguish between beneficial insects and antagonists (pests). Key findings about use of pesticides and their limitations or negative impacts are poorly understood by farmers beyond health risks to themselves and consumers. At the outset most farmers (>95%) were unaware of natural enemies in the baseline survey and only ~50% could recognise honeybees and hoverflies as pollinators (Table 1). Farmers typically identified natural enemies as pests (e.g., identifying ladybird beetles as the flower pest *Ootheca* spp.). Most farmers were unable to name insects and did not know the importance of field margins for supporting beneficial insects but believed they harboured pests. This prompts farmers to clear margins of plants. Our data (as reported above) suggest they do not

Table 1 Farmer knowledge of beneficial insects at baseline



Insect type		Farmers identification of insects			Farmers understanding of significance of insect			
		% correct ID	%wrong ID	% did not know	Pollinat-or	Pest	Natural enemy	don't know
Ladybug	☺	3	42	54	0	52	4	43
Assassin	😐	2	16	81	0	31	0	68
Blister beetle	☹	4	17	78	1	31	0	67
Hover fly	☺	11	19	69	13	14	0	72
Aphid	☹	28	14	57	0	59	0	40
Caterpillar	☹	32	13	54	1	59	0	39
Honeybee	☺	66	9	24	51	17	1	30
Long legged fly	☺	0	7	92	1	6	0	92

☺ = beneficial insect 😐 = beneficial & pest ☹ = pest

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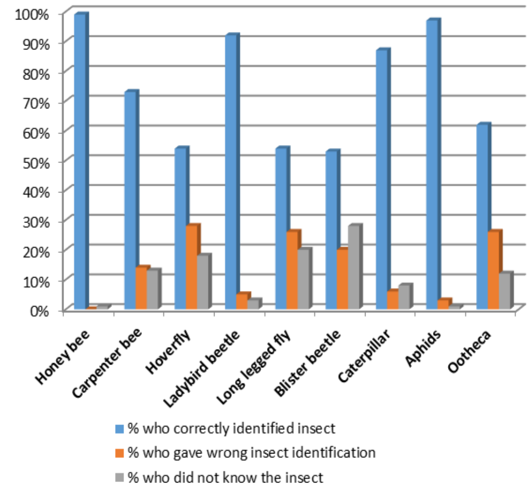


Fig. 9 Farmers' knowledge of key beneficial insects at baseline.

support key pests. Some farmers use synthetic pesticides but are poorly trained in their use, relying entirely on suppliers' advice which may not be appropriate or in their best interests. Some bean varieties were considered by farmers to harbour more insect pests. Most farmers highlighted the need for education to apply best practices to help increase bean production. By the time the end line survey was carried out, the following changes were observed:

a. An increased proportion of farmers exhibited accurate knowledge about varieties of beans, pesticides, and related beneficial insects including pollinators and natural enemies of pests (Fig. 9 and 10), with correct identification increasing from near zero for many taxa to consistently 50% or, in the case of honeybees, 100%.

b. A higher proportion of farmers showed better knowledge of and a more positive attitude to plant-based pesticides and a more negative attitude to synthetics, including a better understanding of the associated advantages and disadvantages.

c. More farmers understood and adopted positive management practices in relation to field margins, beneficial plants and agricultural implements. Numbers of farmers burning field margins fell by > 50%.

d. Overall a better quality of bean yields and amounts of bean harvests were obtained per farmer.

e. Increased price and income earned were reported among farmers who sold their beans.

More specifically, the study found improvements in farmers' knowledge in the following main aspects: i) beans varieties that harbour natural enemies; ii) beans varieties harbouring insect pests; iii) types of synthetic, organic and plant pesticides; iv) types of insects and their significance for beans farming. This knowledge was in turn translated into more appropriate and positive attitudes of farmers regarding the advantages and disadvantages of using botanicals, organic and synthetic pesticides. However, it was noted that though more farmers largely could identify the harmful nature of synthetic pesticides, there was only was a negligible decrease in their use illustrating the challenge in changing farming practice at scale. This was primarily because synthetic pesticides were perceived by farmers as effective, easy to use and readily available as compared to the other options.

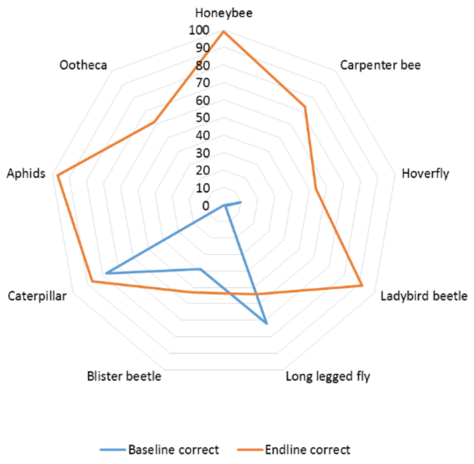


Fig. 10 Percentage of farmers from the high elevation zone identifying each insect taxon correctly at baseline (blue) and end line (orange), demonstrating an increase in familiarity with economically important insect groups over the project.

The end-line study also found improvements in farm management practices in various ways, including: more farmers reported that they took action to retain beneficial plants in their farms; more farmers reported using field margins for various purposes like planting animal feeds, pesticides and preventing erosion; there was a reduction in proportion of farmers who reported clearing field margins; fewer farmers cleared field margins by burning and more applied more appropriate clearing methods such as pruning and feeding to animals. Generally, a reduction in the number of farmers reported to be applying boosters and synthetic pesticides were recorded while more reported the use of compost and mixed farming approaches.

With the improved farming practices, the end-line survey found better quality, yield, prices, and income from the farmers who planted beans. The survey enumerators undertook an independent evaluation of the quality of beans provided from the farmer's yield. 63% of farmers at baseline and 94% of farmers at end-line provided bean seeds for the evaluation. The percentage of **good quality seeds rose from 57% at baseline to 70% at end line**, while the **% of bad seeds dropped from 12% to 9%.** By end-line, **31% of the farmers had reported an increase in bean harvest,** one of the reasons given for the increase was better attention to managing their bean farms stimulated by participation in our project. **Farmers interviewed at the end-line also reported a higher average of bean prices and income (up 13%) for their families**.

The main uses of beans as reported by farmers at end-line included selling, consumption at home, seeds for planting, school food and donation to relatives. The beans consumption and income spending patterns did not change much from baseline to end-line, with the main use of income from beans sales being on: school-related costs for children, food, household goods, shelter, clothing and medical care. Likewise, women remained involved in making decisions on how to use the beans and manage the beans farms from baseline to end-line.

Although the project has reported positive changes from baseline compared to end-line, there is a need for further investigation to ascertain and confidently verify the cause and effect relationship as assumed in the project theory of change. The main effort was limited to improving knowledge of the farmers through the field farmer schools and the informal interaction during the field experiments; it is possible that the positive changes in farmers' attitudes, practices, yield, and income could have been due to many other factors. Future action should undertake the following:

1) Provide more frequent and intense awareness, education and materials distribution to farmers on sound farm management practices. This could include working through social media platforms to reach well organized and mobilized local associations of farmers.
2) Mainstream and include environmental conservation and management, as well as health issues into the awareness and education sessions provided to farmers. The good health of farmers and a preserved environment are key influencers for the quality and quantity of beans yield.
3) Work out a mechanism to support production and supply chain for the organic pesticides to be generated by local groups. This would result in improved farming practices and building of local livelihoods at the same time.

Establish a rigorous system to track individual farmers and their farming practices, then verify and validate changes brought about by the same and having in place a treatment and control group.

A pilot study to develop a survey method to collect crop and pest observation directly from farmers was run from July to October 2016 in Tanzania in all 3 zones of Kilimanjaro providing info about state of crops, pesticides use and insects' occurrence via phone calls using an interactive voice response (IVR) system. 135 farmers provided data through weekly calls over 12 weeks during the cropping period (Thus t**otal farmers engaged in surveys = 435 in Tanzania and >200 in Malawi as against 400 proposed**). Data was combined with data from baseline surveys (Annex 7), including demographic information and was assessed for consistency, and compared, where possible to determine reliability. Farmers were recruited via community meetings to explain the project purpose, demonstrate the process and ensure questions were clear. Farmers were also recruited via automated telephone call. Participants received TSH10,000 via mobile money transfer for answering 8 or more phone calls. Participation rates of recruitment via community meetings did not differ from those recruited via automated phone call. Community meetings were, therefore, not a prerequisite for participation. Analyses to assess consistency and validity of data for which assumptions are made (e.g., that cropping phases were strongly correlated within each zone) finding ways to better ground-truth the collected data would be very useful to enable us to draw conclusions about the accuracy of data. As the data collection method has been shown to work, we fed back information to farmers to inform them but also supplement the survey of impact. During the call farmers received advice related to the answers they give; or weekly advice tailored to differing regions. Overall this approach to gather information and provide advice has a greater potential to upscale action and should be adopted in future activities to increase outreach.

To further provide training and advice to farmers we worked with McKnight Foundation (who co-funded the project's 2X PhD students) to make a training video about beneficial insects to farmers in collaboration. The video is available in English (https://www.youtube.com/watch?v=nTlFPt4BB_M&t=16s) Kiswahili which is the official language of Tanzania (https://www.youtube.com/watch?v=1o9C_6XZTTs) and Chichewa the official language in Malawi (https://www.youtube.com/watch?v=txkO_z5-zg8&t=16s).

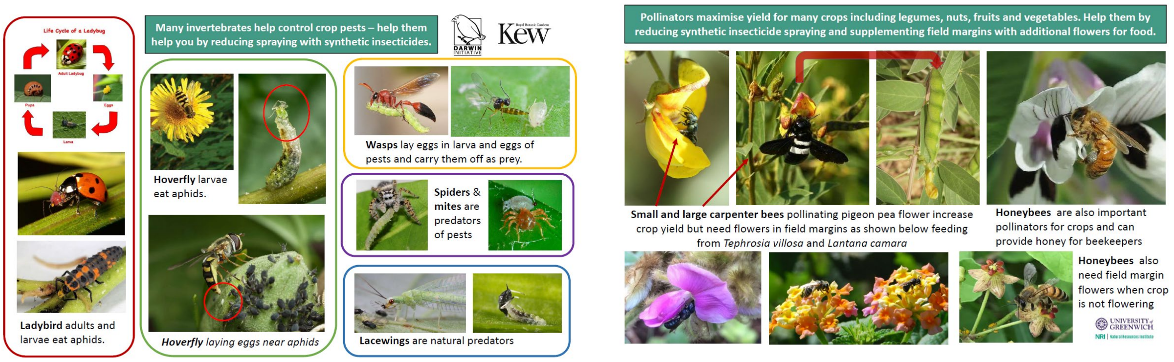
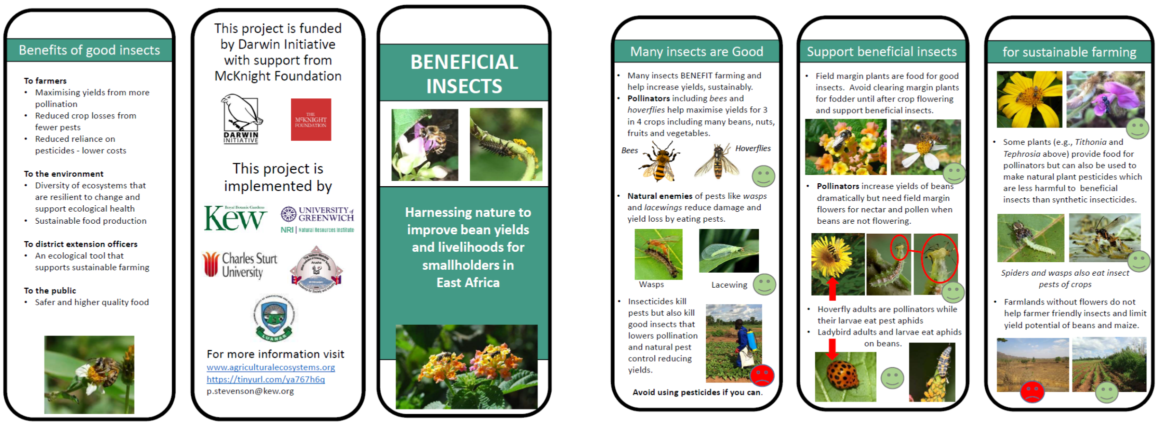


Plate 1. Farmer relevant information sheets about pollinators and natural enemies of pests emphasising the importance of field margins for supporting these insects (also in local language – see appendix 7)

We also made training tools through farmers research networks developed in cooperation with McKnight Foundation that comprise upwards of 8000 farmers across Malawi and Tanzania to whom fact sheets and technical leaflets were distributed in English, Kiswahili and Chichewa.

For farmers we produced an A4 double sided sheet that provided pictures and information about pollinators and natural enemies of pests. For technicians and policy makers and influencers we produced a tri-fold pamphlet. See Plate 1 and Plate 2



Benefits of good insects

To farmers
- Maximising yields from more pollination
- Reduced crop losses from fewer pests
- Reduced reliance on pesticides - lower costs

To the environment
- Diversity of ecosystems that are resilient to change and support ecological health
- Sustainable food production

To district extension officers
- An ecological tool that supports sustainable farming

To the public
- Safer and higher quality food

This project is funded by Darwin Initiative with support from McKnight Foundation

This project is implemented by

For more information visit
www.agriculturalecosystems.org
https://tinyurl.com/ya767h6q
p.stevenson@kew.org

BENEFICIAL INSECTS

Harnessing nature to improve bean yields and livelihoods for smallholders in East Africa

Many insects are Good

- Many insects BENEFIT farming and help increase yields, sustainably.
- **Pollinators** including *bees* and *hoverflies* help maximise yields for 3 in 4 crops including many beans, nuts, fruits and vegetables.

Bees *Hoverflies*

- **Natural enemies** of pests like *wasps* and *lacewings* reduce damage and yield loss by eating pests.

Wasps Lacewing

- Insecticides kill pests but also kill good insects that lowers pollination and natural pest control reducing yields.

Avoid using pesticides if you can.

Support beneficial insects

- Field margin plants are food for good insects. Avoid clearing margin plants for fodder until after crop flowering and support beneficial insects.
- **Pollinators** increase yields of beans dramatically but need field margin flowers for nectar and pollen when beans are not flowering.
- Hoverfly adults are pollinators while their larvae eat pest aphids
- Ladybird adults and larvae eat aphids on beans.

for sustainable farming

- Some plants (e.g., *Tithonia* and *Tephrosia* above) provide food for pollinators but can also be used to make natural plant pesticides which are less harmful to beneficial insects than synthetic insecticides.

Spiders and wasps also eat insect pests of crops

- Farmlands without flowers do not help farmer friendly insects and limit yield potential of beans and maize.

Plate 2. Trifold information sheet for agricultural technicians and policy maker about pollinators and natural enemies of pests emphasising the importance of field margins for supporting these insects (also In local language – see appendix 7)

Well informed agricultural officers are key as our end line survey revealed that they were the main source of knowledge and information for famers (Fig 11). Other ways of interacting with farmers that facilitated knowledge transfer included Demonstration (Farmer Field School), seminars, mobile, visits by agricultural experts, fliers, education at primary level. At the end line survey (Annex 7) several interesting developments were established that indicated farmers benefitted from participation in this action in ways that would improve their understanding of their agricultural landscape. Farmers had a much better understanding of beneficial insects (Fig. 8) because of training and interaction with the team conducting experimental work in fields with all farmers recognising honeybees (50% at baseline) and most farmers identifying hoverflies and wild bees as beneficial. Similarly, >90% farmers recognised ladybirds as beneficial compared to <5% in the baseline (where they were misidentified as the *Ootheca* spp of leaf beetle). This shows a massive improvement in understanding of insects and that effective interaction with farmers can change understanding and knowledge about insects and help support ecological approaches to sustainable agriculture.

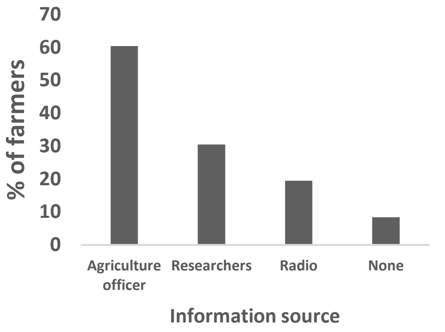


Fig 11 Main sources of information used by farmers

Awareness of the importance of field margin supporting beneficial ecosystems services or providing plants that could be used and adopted for use as pesticides also improved through training and farmers project interactions. While the number of respondents who had beneficial field margin plants was 7% at baseline the number who recognised field margin plants as beneficial in the end line survey was 40%. The number of farmers claiming to take some action to retain plants in field margins also increased dramatically from 7 to 67% between the baseline and end line survey. These data indicate that through our training programmes and interactions farmers are better placed to understand that field margin plants have benefits that may include use as forage for beneficial insects or as plant pesticides. The primary use of field margin plants was still perceived to be as animal fodder although those noting the value of margins as a source of pesticidal plants increased from 2 to 23% and there were increases in farmers reporting the value of field margins in controlling erosion and attracting beneficial insects.

Table 2: Bean yields under open pollinated and pollinator exclusion (self-pollinated). (1Ha = 200K plants)

Treatment	**Pods/plant**	**Seeds/pod**	**weight/30 seeds (g)**	**Pods Ha^{-1}**	**Seeds (ha^{-1})**	**yield (kg ha^{-1})**
Open/natural pollination	5.3	4.1	10.2	1,060,000	4,346,000	1,477.64
Self-pollination	3.8	3.2	8.4	760,000	2,432,000	680.96

We extrapolated data from output 2 showing the value of pollination to bean yield to illustrate the benefit to farmers. The data showed that self-pollinated plants produced 680Kg/Ha which is a typical (low) yield for this crop **whereas open (insect) pollinated beans produced 1477Kg/Ha which was more than double the yield of the bagged plants**. This calculated to, on average, **a yield gain of 797Kg** so with an average price of TSh1500/kg we showed that **failing to optimise farm management for pollinators could cost farmers up to TSh1,200,000/Ha or $530/Ha**. Farm sizes ranged at low altitude between 0.25 and 2.5 and 0.25-2.0Ha at mid and high zones with mean area cultivated with beans = 0.81 (low), 0.58 (mid) and 0.6 Ha (high). So, with average land area planted with beans in Tanzania of between 0.58 and 0.81Ha our data showed **that pollination increases individual farm income by $300 to $430/annum or cropping cycle**. At low zones farmers can cultivate 2 crops per year so the benefits of pollinators to farmers can be more substantial.

Table 3: Comparisons of bean income between two treatments.

Pollination treatment	**Average bean yield (kg ha-1)**	**Average price kg-1 (Tsh)**	**Average Income ha-1 (Tsh)**
Open/natural pollination	1,477.64	1507.55	2,227,616.18
Self-pollination	680.96	1507.55	1,026,581.25

3.1.4 Output 4: Field margin plant species that support beneficial insects evaluated for their biological activity.

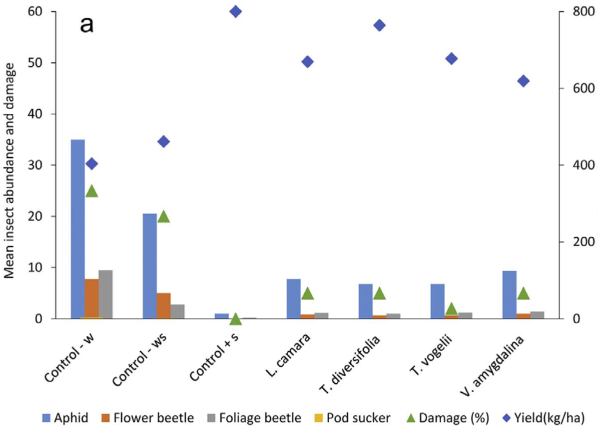


Fig 12. Pest abundance, crop damage and yield on bean plants in on-station field trials in Tanzania. Plant treatments are the average across the 3 concs. Aphid abundance is measured with a 0–5 index.

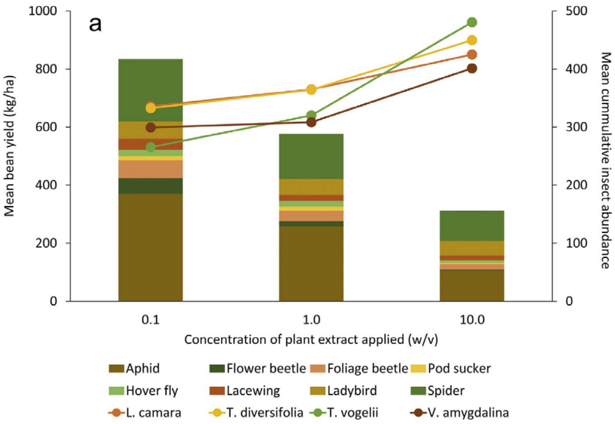


Fig. 13. Effect of pesticidal plant extract concentration on bean crop yield and key arthropod abundance in Tanzania. Aphid abundance is measured with a 0–5 index and is therefore a proxy for actual aphid numbers.

Plants with pesticidal properties have been investigated for decades as alternatives to synthetics, but only a handful have been commercialised and developed as non-food cash crops. One of the reasons why pesticidal plants are failing to deliver new pesticidal products is that they are often not evaluated under field conditions by farmers. Furthermore, many aspects of pesticide use related to environmental safety, such as their impact on beneficial organisms, are unknown. With a view to overcoming these bottlenecks, extracts made from six abundant field margin plant species found across Tanzania and Malawi (*Bidens pilosa, Lantana camara, Lippia javanica, Tithonia diversifolia, Tephrosia vogelii* and *Vernonia amygdalina*) were evaluated in on-station and on-farm trials over two years (2015 and 2016) on bean plants. All plant species offered effective control of key pest species that was comparable in terms of harvested bean yield to a synthetic pyrethroid. Furthermore, the plant pesticide treatments had significantly lower negative effects on natural enemies (hoverflies, lacewings, ladybird beetles and spiders). In all cases the commercial synthetic was the most effective, the untreated control always showed the greatest damage and insect numbers. Although not as effective as the synthetic the pesticidal plant treatments were typically more effective than the untreated plots. However, the pesticidal plant treatments typically performed as well as the synthetic in terms of bean yield despite them often having higher numbers of insects and damage throughout the cropping seasonIn addition to pest insect abundance, key predatory insect species were also monitored on a weekly basis. Consistent results across field trials showed very low abundance of predators on synthetic pesticide treated plots when compared to the untreated and pesticidal plant treatments (ANOVA, F= 13.6, df= 7, P < 0.01). In most cases abundance of predators was similar between the pesticidal plant treatments and the untreated control (Fig 12-13). Some significant differences in abundance were observed between mono-cropped and inter-cropped beans, particularly where hoverfly and lacewing abundance was relatively higher on the intercropped fields (ANOVA, F =3.5, df= 15, P < 0.01). However, this trend was not consistent for all predatory species and pesticidal plant treatments (see Mkenda et al., 2017 and Tembo 2018 Annex 7). Hoverfly adults are pollen feeders and our observations indicated that they were attracted to the abundance of Maize pollen that is produced at flowering (Plate 3). Thus, pesticidal plants were better able to support ecosystem services whilst effectively managing pests. Small holder farmer rankings on their perceived efficacy of the different plant species indicated that *T. vogelii* was the most preferred and effective, achieving bean yields as high as the synthetic, if not better. In Tanzania for example bean yields increased by 50-100% when field margin weeds were used as pesticides. (Full paper in Annex 7). Farmer training in how to use pesticidal plants for field applications was conducted in March 2017 with one of our trained MSc students from year 1 Angela Mkindi in 5 locations between Tengeru & Rombo, with 113 farmers trained. Further training has been implemented in Tanzania and Malawi through participatory trials. A major training exercise was also undertaken in January 2018 through established farmer research networks in Tanzania and Malawi. These were delivered top 200 lead farmers across the two countries who were responsible to then train locally reaching upward of 8000 farmers as part of farmer research networks.

Plate 3 Hoverfly feeding on maize pollen in maize-bean intercrop

3.1.5 Output 5: Post-graduates trained in conducting biodiversity surveys and carrying out field and laboratory based research.

The first pilot survey for invertebrates and plants was undertaken as described in last year's report. This year we have recruited 3 new MSc students under the supervision of Kew and NRI specialists and local partners and registered at NM-AIST. This work has established an on-station experiment to determine the contribution of 5 specific key field margin plants to ecosystems service delivery for pollination and natural enemies of pests on 5 X 5m plots comprising single species field margin plantings. Research protocols have been defined (Annex 7) and defended these at viva through the university process. Data collection is underway March – May 2017. Data focussed on evaluation of sentinel plants for natural enemies and flower bagging (to exclude pollinators) experiments for pollination service as described above. Research presentations by students reporting early results are available on request (too large to include). 2 PhD students who have undergone field training in monitoring and evaluating plant and invertebrate assemblage and interactions of plants and insects making collections and progress towards an institute reference collection also had a 3 month training visit to Charles Sturt University in Australia (Nov 2017 – March 2018). The students have submitted PhD proposals and passed preliminary examination by viva (proposals attached in Annex 7. Both are working on various research papers for requirements under NM-AIST university rules (Annex 7). They have focussed on pollinators and natural enemies respectively. Training was provided in May 2016 and March 2017. We have also recruited 2 graduate trainees to conduct surveys in Malawi. (Student trainees = 10 6 MSc, 2 PhD and 2 BSc).

All students have been supported to attend various formal training programs and conferences. E.g.,

- "2016 International Pollinator Biology, Health and Policy Conference" held from 17th-20th July 2016 at Penn State University, Pennsylvania, USA.
- "Research Methods Workshop organised by Southern Africa Community of Practice of the Collaborative Crop Research Program (CCRP)" held on 15th - 19th August 2016 at Giraffe Ocean View hotel, Dar as salaam, Tanzania.
- Experience in training 300 farmers during "Farmer Field School" in Moshi Rural District on proper farmland management and the importance beneficial insects found around bean fields. The training was held in October 2017.
- "Food-Water-Ecosystem Nexus Summer School" held from 12th-18th March 2018 in Kampala Uganda. It was organised by Bonn University, Germany and Makerere University, Uganda. Presentation by PhD student Philemon Elisante.

Output summary table.

Output 1: *Ecosystems and plant species that are habitats for key natural enemies of bean pests identified*. Comments

	Baseline	Change recorded by 2018	Evidence	
Ind 1.1 Plant biodiversity surveys across 25 locations in TZ by year 2	No info available about plant species important to bean farming	40 species identified as common to bean fields in region	Section 3.1 of report & Annex 7.	Surveys of plant diversity across TZ and MW completed.

Ind 1.2 Insect biodiversity surveys across 25 locations in TZ by year 2	No info available about insect species important to bean farming	Key beneficial insects identified and associations with climate and altitude recorded	Section 3.1 of report & Annex 7	Surveys of insect diversity across TZ and MW completed.
Ind 1.3 Associations between plant and invertebrate species diversity established	No info about plant and beneficial insect species important to beans	Associations between plants and insects determined and key species identified and benefits of beneficial insects evaluated in terms of yield and financial.	Section 3.1 for detail Annex 7	Field experiments undertaken in TZ
Ind 1.4 Plant species of importance to beneficials & with pest properties identified	No prior info about insect species known to NM-AIST and farmers	Some plant species identified in surveys as abundant and providing important forage for beneficial insects include known botanicals which were then tested for their activity in field trials.	Section 3.1 of report provides some detail	field and station experimental interventions undertaken in TZ

Output 2: *Key invertebrate pollinators of beans and their key habitat at 25 locations in 4 agro-ecological zones.* *Comments*

Ind 2.1 – 2.2 Five key natural enemies of bean pests and pollinators & key plant species identified	No info about beneficial insects known to NM-AIST and farmers at project outset.	>10 natural enemy species identified as common to bean fields in region. Key pollinators identified and associations with climate and altitude recorded	Section 3.1 of report and **Annex 7.**	Surveys completed with full report (annex 7)
2.3 5 key pests and key non crop habitats ID'd via abundance, perceived impact & lit.	No info about which non-crop plants are forage/refugee	5 key pests species that are influenced by enhanced numbers of beneficial insects established. *Ootheca* sp. X2 Aphids, Blister beetles, Leaf miners,	Section 3.1 of report provides some info & see **annex 7**	Surveys completed and data reported

Output 3: *Capacity of 400 farmers increased by information and guidance on exploiting and maintaining agricultural biodiversity for improved crop yield.* Comments (if necessary)

Indicator 3.1 and 3.2	No info about farmer knowledge of beneficial insects or how this might affect productivity.	Survey undertaken through interviews of 435 farmers in TZ and >200 in MW. Novel ICT pilot also informed data.	Findings summarised in 3.1 and details provided in **annex 7**	Baseline Surveys completed supplemented by novel survey tool using ICT.
Indicators 3.3-3.4	No info about how new knowledge could inform farmer practise	Development of training videos and info sheets reported above	Field and station expts evaluated impact of enhanced ecosystems to bean production and quality through intervention. Annex 7	

Output 4: *Field margin plant species that support beneficial insects evaluated for biological activity against pest insect species of beans and negative effects on natural enemies and pollinators determined*. Comments (if necessary)

Ind 4.1 Five species of importance as habitat and refuge for beneficial insects with potential pesticidal properties identified.	Previous lab and field testing of plants indicates measurable effects of field margin species - reduced impacts on beneficial.	Five potential pesticidal plant species identified in bean margins including pesticidal plants *Bidens* and *Ageratum* common in field margins and visited by pollinators. Two field margin species tested on storage pests	Section 3.1 of report detail also papers in review/published (Annex 7).	Surveys completed Field trials have been conducted that assess efficacy of pesticidal plants
Ind 4.2 - 4.4 Plant species evaluated for efficacy against pests and beneficial	No specific knowledge about species identified as relevant to bean field margins	6 species tested on beans in TZ and MW indicate pest management benefits of field margin spp. (e.g., *Bidens* a common in field margin plant and visited by pollinators.	Section 3.1 of report detail also papers in review/published (Annex 7).	Some species common to MW and TZ worthy of further investigation.

Output 5: *Post-graduates trained in conducting biodiversity surveys and carrying out field and laboratory-based research.* Comments (if necessary)

Ind 5.1 10 post grad trained and provided field experience in botanical surveys	None trained.	6 MSc students (3 F and 3 M) and two BSc grads (2F) now qualified through training gained from this project while 2 further MSc students (2 F) still studying. 2 X PhD	Annex 7 for papers published/in review and research proposals/reports.	Training ongoing and on track. several papers by students Annex 7

		students in final year using data from this project (1f and 1M)		
Ind 5.2 10 post grads trained and provided field experience in invertebrate surveys	None trained	6 MSc students now trained in field survey techniques and experimental design plus 2 X PhD students and 2 BSc graduates.	Annex 7 for papers published/in review and research proposals/reports.	Training on track & several papers by students Annex 7
Ind 5.3 PhD 1 student	None trained	2 X PhD students now enrolled and conducting research on harnessing ecosystem services	Annex 7 for papers published/in review and research proposals/reports.	Training ongoing and on track. several papers by students Annex 7

3.2 Outcome

Proposed outcome: Smallholder farmers implement science-based methods for enhancing and restoring ecosystem services and biodiversity in agricultural systems that improve bean yield and quality, food security and rural livelihoods.

Our action has generated important new knowledge in understanding the importance of field margin plants in supporting beneficial insects in bean production in East Africa. We have also assessed the base line knowledge and circumstances of our farmers and shown significant improvements in a number of areas regarding understanding and action about ecological intensification. Farmers income from bean increased and we showed that pollination increase yields dramatically.

	Baseline	Change by 2018	Source of evidence	Comments (if necessary)
Ind 1. Roles and interactions of margin plant and beneficial invertebrates of agricultural ecosystems understood by farmers & technicians by project end	Little knowledge about importance of beneficial insects in bean farming.	Baseline and end-line survey informed farmers about insects beneficial to bean production raising awareness about the projects goals the value of field margin management and floral resources while field experiments have demonstrated impact.	Annex 7 & section 3.1 of report	End of project survey *showed actual major* gains of intervention. Particularly in financial return from optimised pollination See Section 3.1 and Annex 7
Ind 2. Management methodologies that maintain ecosystem services and augment natural enemies/pollinators developed to increase yields by 20% from baseline data without additional agricultural inputs.	Little known about the impact on yield of enhanced ecosystem services.	Evidence indicates that pollination is a major limiting step in bean production. Farming that supports pollinators and limits or excludes pesticides stands to more than double yields with increased benefits per farmer of $300-420. Crops grown in fields with minimal margins suffer significantly more damage and have fewer undamaged beans	Section 3.1 and Annex 7	Trials showed that supporting pollination service and natural pest regulation dramatically enhanced yield and reduced damage
Ind 3. Bean crop productivity and quality improved and monetary value of beans increased for 400 farmers by 20% by project end	Little known about impact on yield of enhanced ecosystems	Income generated from beans increased by 13% from the baseline to the end line while maximising pollination services in bean fields more than doubled yields far exceeding our prediction and showed that farmers could potentially reap income boost of up to USD 500/Ha	Section 3.1 and Annex 7	Benefits of natural pest regulation not measured in economic terms but evidence that field margins support lower damage produced.
Ind 4. Role of agricultural biodiversity in crop quality, enhanced yield and consequent poverty alleviating benefits demonstrated to key stakeholders through participatory field trials.	No knowledge about biodiversity in bean farming in Africa can be manipulated.	Most important plant species identified through surveys and show that exotic weeds are primary flowers for pollinators in Africa. This means that care must be taken in promoting wild flower strips ensuring trade-offs are understood.	Section 3.1 and Annex 7	Since the same exotic weeds occur widely similar management interventions will be relevant widely
Ind 5. Yield and poverty impacts of enhanced biodiversity demonstrated through individual farmer surveys for bean production that indicate increased income of 5-10%	yield increases by ecosystem services in bean production in East Africa unknown	Income generated from beans increased by 13% from the baseline to the end line while pollination in bean fields **more than doubled yields far exceeding our prediction and showed that farmers could potentially reap income boost of up to USD 500/Ha**	Section 3.1 and Annex 7	Benefits of natural pest regulation not measured in economic terms but evidence that field margins support lower damage (see 3.1).

3.3 Impact: achievement of positive impact on biodiversity and poverty alleviation

Impact statement: The harnessing of agricultural biodiversity in bean production systems of East Africa established and implemented widely to improve food security, reduce poverty and increase ecosystem resilience. In Africa, *Phaseolus vulgaris*, the common bean, provides about 15% of the total daily calories and 30% of the daily protein consumption so is critical for the livelihoods and food security of many millions of people. *P. vulgaris* is the main legume produced in Tanzania and Malawi our target country. This action was primarily a discovery project with the aim to identify the primary field margin plant species supporting beneficial arthropods for both pollination but also natural pest regulation through natural enemies. EI is a knowledge-intensive pathway to improve agricultural productivity that is economically and environmentally sustainable. Investments in EI for smallholder farmers can deliver transformative change, generating resilient agriculture that enhances livelihoods of the world's poorest and buffers production against future threats and risks. But it is the development and transfer of EI knowledge that is the first step to delivering this impact. We have evidence that supporting pollination through optimizing field margins can impact on yield and crucially farming practice that does not support pollinators will severely degrade food security and livelihoods.

Phaseolus vulgaris is a self-fertile species so will produce fruit in the absence of pollinators but yield benefits can be realised through pollination by insects. Pollination exclusion experiments conducted in year 2 & 3 in which the contribution of pollination to bean yield in a botanically rich landscape was evaluated by excluding pollinators from some beans, hand pollinated others (normally equates to 100% pollination as a control) and allowed others to received natural pollination services from the natural fauna. Beans open to pollinators produced more twice the yield as those from which pollinators were excluded. The findings are used to promote the value of pollination services to increase farmer income.

Our surveys showed that the project delivered increased empowerment and awareness among farmers to make biodiversity-supporting decisions about their farm management, and were more aware of the benefits of biodiversity. We showed that farmers have improved their attitude to field margins and are participating in more actions to preserve field margin biodiversity, including a decrease in farmers burning field margins (Details provided above in 3.1). During the same period, farmers saw increases in their bean quality and are getting higher mean prices for their beans.

4 Contribution to Darwin Initiative Programme Objectives

4.1 Contribution to Global Goals for Sustainable Development (SDGs)

By addressing sustainable agriculture through agro-ecological approaches that support nutritional, environmental and socio-economic security this project contributed to SDGs 1, 2, 3, 5, 12, and 15.
SDG 1 End poverty in all its forms. By enhancing crops yields**; SDG 2 End hunger, achieve food security and improve nutrition and promote sustainable agriculture**. By promoting sustainable agriculture via alternatives to pesticides, enhancing ecosystems services of farmlands and ensuring better understanding of ecosystem sustainability in farming among beans farmers. **SDG 3 Ensure healthy lives**. By providing alternatives to pesticides reducing exposure of users and consumers.
SDG 5 Achieve gender equality. Supporting bean production which is typically managed by women
SDG 12 Ensure sustainable consumption and production patterns to support developing countries to strengthen scientific and technological capacity for more sustainable patterns of consumption and production. **SDG 15 Protect and restore and promote sustainable use of terrestrial ecosystems** by providing farmers with knowledge and methods to support increased biodiversity

4.2 Project support to the Conventions or Treaties (CBD, CITES, Nagoya Protocol, ITPGRFA)

Project partner countries have ratified the CBD and this project supports CBD article 1 - conservation of biological diversity, sustainable use of its components and sharing of benefits arising out of use and article 6 - developing national conservation strategies and sustainable use of biological diversity into relevant programmes and policies. The project outputs will contribute to bean production which is an ITPGRFA Annex 1 crop (*Phaseolus* beans). Agricultural ecosystem services will be improved through augmentation of pollinators and natural enemies of pests in bean production also addressing several Aihchi-2020 targets (see below). Owing to the relevance of the project outputs to CBD we have established contact with CBD national focal points through NMAIST and LUANAR in Malawi and Tanzania. The current CBD national focal point in Tanzania is Mrs. Esther Shushu Makwaia, Principal Environmental Officer, Division of Environment and in Malawi is (who replaced Mrs. Tawonga Mbale-Luka who in turn replaced Dr. Aloysius Kamperewera). This level of turnover has made it more difficult to gain traction with CBD in Tanzania but the NFP have been kept informed of the project aims and overarching message about ecological intensification about this project and its outcomes specifically and been invited to support the promotion of the outcomes widely. We are also in communication with the Malawian ITPGRFA national focal point Lawrent L.M. Pungulani who is very supportive of the action and also notified Dr Fidelis Myaka, the National Focal Point in Tanzania for the ITPGRFA who also provided written support for the work at the outset.

4.3 Project support to poverty alleviation

Tanzania's national poverty reduction strategy paper highlights that food poverty exceeds 18% and agriculture is central to reducing this. Insects are the major biological constraint for beans. Beans are Tanzania and Malawi's primary legumes are produced on 1,500,000 ha and consumed by >20 million people in Tanzania and Malawi. Yields are chronically low (<500kg/ha in Malawi) but are potentially ~3T/ha. Yet beans are a critical protein and mineral source for poor rural households and income to farmers, particularly women - the major growers of this crop. About 35% of the production in Malawi, for example, is marketed, contributing about 25% of total household income for over 68% of the households who sell surplus. An increase in yield and quality of 20% could lead to a 5% overall increase in household income while increasing crop security and reducing food poverty. Farmers typically sell their beans after harvest when prices are low. As well as supporting natural enemies of field pests some field margin plant species can be admixed to stored beans enabling longer-term storage of beans which could be worth up to 2 times more when supplies later in the year are depleted. This project was directly and primarily relevant to the problems of the target developing countries and therefore was wholly compliant with the OECD Overseas Development Assistance criteria. The action promoted economic development and welfare of developing countries as its main objective and sought to develop zero cost interventions that increased yield and crop quality so was well suited and relevant to current farming strategies in bean production. Our action worked directly with 40-0 farmers in Tanzania 236 in Malawi plus a further 135 through ICT pilot. We also provided training in the use of pesticidal plants to a further 500 farmers of whom 200 were part of large farmer research networks in Malawi and Tanzania totalling more than 8000 farmers (far exceeding our projected reach of 3600 in the original proposal. We showed that pesticidal plants are an economically viable alternative to synthetic pesticides with a marginal rate of return of 5.5USD/Ha compared to synthetics and no treatments of 4.0USD/Ha (Mkinda et al., 2015 Annex 7). We demonstrated major yield benefits of more than double with maximised pollination service while overall farmers income from benas increased by 13% across one year from base-line

4.4 Gender equality

In our baseline survey the impact of enhanced biodiversity on bean production and poverty alleviation evaluated through surveys of ultimately >400 farmers in Tanzania and Malawi according to established measures, disaggregated for gender. Women are the primary growers of crops like beans (https://assets.publishing.service.gov.uk/media/57a08bdeed915d3cfd000fd0/CPP08.pdf) so addressing bean production through environmentally benign routes to yield increase this project is directly addressing women in agriculture. We were particularly mindful of gender as the baseline and end line survey data is assessed considering the project aims. For example, of the farmers interviewed in the baseline survey in Tanzania, 76% were women. These will be the same farmers engaged in project training in year 3. The survey also revealed that the adult female in the household was the sole or joint decision-maker about how the harvested beans are used in 88% of Tanzanian households and 58% of Malawian ones, and the sole or joint decision-maker about how the income from harvested beans are used in 86% of the Tanzanian households, indicating that yield increases provide women with income, which is reportedly spent on female children in 48% of households in the Tanzanian group. In terms of the project partners the NRI Project Leader Dr Arnold was female as was the LUANAR lead Yolice Tembo who took over management of the project after it was started.

4.5 Programme indicators

- **Did the project lead to greater representation of local poor people in management structures of biodiversity?**

This was not a stated aim of the project – however, the project has enhanced the relationship between the regional University sector and the farmers and farm leaders, with a clearer pathway between academics producing new knowledge and the regional agricultural officers and the farmers themselves.

- **Were any management plans for biodiversity developed?**

None formalised but have promoted widely the improved management of field margins through reduced clearing or recognising the potential value of those plants for supporting ES, botanical insecticides and as habitats for beneficial insects and these were adopted widely (Annex 7).

- **Were these formally accepted?**

Not formally but end line survey indicates significant behavioural changes in land management; for example, the number of farmers burning their field margins halved, and this behaviour was entirely voluntary on the part of the farmers. Through training provided to Farmer Research Network we predict that our message about the importance of beneficial insects and land management to support ES has reached more than 8000 farmers in Tanzania and Malawi.

- **Were they participatory in nature or were they 'top-down'? How well represented are the local poor including women, in any proposed management structures?**

Field trials testing botanical insecticides which trained farmers in the use of plant materials and the value of reducing synthetic inputs were farmer participatory and these data are presented in Tembo et al., 2018 and Mkindi et al., 2017 in Annex 7. We showed in these participatory trials that plant based pesticides were less harmful to beneficial insects. Baseline surveys established that many farmers wanted to know more about plant based biological pest control and this participatory trial and training was a direct response to their needs.

- **Were there any positive gains in household (HH) income as a result of this project?**

We have data showing that the income generated from beans increased by 13% from the baseline to the endline, and the percentage of high quality beans increased from 57% to 70%. More significantly, we also showed that pollination services contributed around $500/Ha to farmers' income and yield of beans doubled in the presence of a healthy pollinator population.

- **How many HHs saw an increase in their HH income?**

The end line survey was undertaken among 300 farmers in Tanzania and 236 in Malawi as opposed to 400 proposed at the outset. On average these farmers saw 13% increases in income from beans across about 1 year while all stand to benefit by much greater benefits from pollination service in the knwol3edge that their absence through poor land management or pesticides can more than halve yields.

- **How much did their HH income increase (e.g. x% above baseline, x% above national average)? How was this measured?**

HH income from beans was measured in Tsh at baseline and endline and increased by 13% among the target farmers over the project. This was measured by asking farmers to report during the survey. Empowerment and knowledge are also development currency – in a future action we will endeavour to conduct controlled trials implementing treatments that experimentally show how different approaches to land use can directly increase income from beans based on maximising pollination services and NPR. However, it can take several years for benefits to accrue.

4.6 Transfer of knowledge

Transfer of knowledge ensured a project legacy of skilled local scientists with capacity to continue supporting and developing ecosystem services and ecological intensification of agriculture. We trained students formally including 2 PhD students who are currently in their 3rd year of study. We provided research projects for 6 MSc students at NM-AIST, 2 BSc student at LUANAR who have been awarded their degrees and this included the publication of at least one research paper each (Annex 7). We have 2 current MSc students who are undertaking research on the project but have overlapped with the project end so are not yet qualified. Post grad Student trainees = 12 total compared to 10 proposed (8 MSc, 2 PhD and 2 BSc).

4.7 Capacity building

This project has provided major training opportunities within the limitations of the budget both in terms of technical skills but also professional scientific skills – e.g. science writing, proposal writing for 2 PhD students and 8 MSc students and experience at conferences and research methods programs and these are detailed elsewhere it his proposal in detail. Angela Mkindi who was an MSc student on an earlier collaboration between NRI and NM-AIST provided technical support in the early stages of the present action and was subsequently recruited to undertake a PhD as part of a follow-on action on pesticidal plants for which she is being supported by the McKnight Foundation. This in addition to 2 reported previously.

5 Sustainability and Legacy

Local scientists were trained in invertebrate and plant identification and collections based science. Insectary and herbarium established at NMAIST to provide academic project legacy. Outreach activities including farmer field schools with distribution of information is maximising this DI investment and will ensure the project leaves a legacy. By supporting small-scale bean production through strategies that enhance biodiversity in Tanzanian and Malawian agriculture the project ensures that DI funding has a significant impact for poverty reduction, human welfare and conservation.

High-level capacity development of 2 PhD and 8 MSc candidates to become leaders and change-agents, able to continue this work beyond the time frame of the project. Indeed, this is already happening as these persons are directly involved in new funded projects pursuing the optimising of natural pest regulation in leguminous crops (BBSCR-GCRF BB/R020361/1). The advanced training in research, allied to joint publications and presentations at scientific conferences, have made the African scholars competitive for funding schemes to further their professional development.

Bean production is a growth sector in Tanzanian and Malawian Poverty Reduction but cultivation is threatening ecosystems. Making bean production more efficient and more reliant on field margins will improve understanding of the importance of ecosystems for bean production. This project addressed poverty reduction and biodiversity conservation and supported both countries CBD commitments. Nationwide agricultural policies that encourage ecosystem health and maintenance of biodiversity that improved yields, ensuring greater food security and improved livelihoods for resource limited farmers. Our original exit strategy is still valid. Challenges to leaving a sustained legacy in farming systems and adoption of new approaches to farming in a short space of time are not without challenges. Influencing sustained change in land-use practices is complex and requires strong, convincing evidence coupled with positive engagement and sustained support. Our approach developed through our surveys and interventions with farmers was effective at encouraging changes in behaviour. Long-term uptake must become self-sustaining. We consider the priority in the short term to be maximising the likelihood of success of the 'demonstration' projects upon which future uptake will be built, and communicating those successes. We are working to engage these approaches into governmental programmes with the scope for future large-scale multiplication as part of follow on activities – e.g., BBSRC-GCRF-SASSA.

The commercialisation of biopesticides is the primary route to their sustainable use and wider uptake and within the current action we have widened the awareness around the use of biopesticides and established commercial value chains that will provide our farmers new income generating opportunities. Through the actions of the project PI Spanish biological pesticide company Kimitec is developing a value chain for farmers in East Africa to grow pesticidal plants that will support beneficial insects but also provide pesticidal plant material that can be processed in East Africa through another commercial company Botanical Extracts EPZ and exported providing an income generating opportunity for Tanzanian farmers.

6 Lessons learned

Owing to delays in appointment of students some training and survey work was slower to implement and get underway requiring a reallocation of funds from year 1 to 2/3 which was agreed. It is easy to approach a project with high expectations of achievement for year one when in fact much of year one is spent getting activities planned or up and running. We established new targets and implementation plans which ensured that the project progressed effectively. We largely met all targets for project output and outcomes with the exception of . We learned the necessity of incentivising attendance at meetings with refreshments and the importance of sufficient personnel to conduct surveys simultaneously. Encouragingly, we discovered that farmers engage in phone surveys even without in-person meetings providing an easier approach for further survey work. Innovative approaches to engaging with farmers at major training programmes helped with translating messages – perhaps the most fun and effective was the good insect or bad insect in which a series of pictures were shown of insects in a passive phase followed by then either 1. Pollinating, 2. Devouring or parasitizing a pest insect or 3 feeding on a plant. Farmers were asked to predict which the insect would be from the passive phase picture and then the truth revealed. This helped get a strong message across to hundreds of lead farmers that many insects are beneficial and in fact only a small number of insect species are actually pests. (See annex 7 for Powerpoint presented at the McKnight International Workshop in October 2017).

6.1 Monitoring and evaluation

For M & E we used a theory of change to monitor and evaluate the project success with respect to impact on livelihoods. Looking back over the life of the project, the M&E system was practical and helpful and provided useful feedback to partners and stakeholders on progress as reported (see 3.1). Evaluation of the changes was undertaken by a consultant socio-economist although who provided internal evaluation of the work which have been reported above and were useful for the project. The ToC assumed that farmers had inadequate knowledge and skills at the outset on how to control pests and, consequently, struggled to achieve optimum bean productivity and quality through the exploitation of their ecosystems. The measures of achievement were based on how this knowledge changed over the course of the project and whether farmers implemented changes to their farming practise that enhance regulating ecosystem service delivery. Through the project, the farmers were provided with information and knowledge on managing pests and improving their bean yield and quality. Therefore, the first module tracked by the survey was the initial level and gradual improvement over time in the farmers' knowledge and attitudes. Once the farmers' knowledge and attitudes had been enhanced through participation in field interventions, we recorded increased adoption of ecological farm management practices which led to improved yield and quality of beans in their farms. The second module to be tracked by the surveys was improvements in farm management practices employed by the farmers. The theory of change then predicted that ecologically sound farm management practice will lead to improvement in the yield and quality of beans produced from the farms. Therefore, the third module to be tracked through the surveys will be the yield; while the fourth module to be tracked will be the quality, of beans produced from the farms. The theory of change then concludes that the improved bean yields and quality will lead to improved livelihood, living standards and general welfare of the farmers and their families. Therefore, the status and longer-term outcome changes in livelihood, welfare and living standards of farmers and their families will be tracked through the post intervention surveys currently underway. Monitoring of activities and outputs is being conducted using the project log frame. See further discussion below in response to year 1 report reviewer comment.

6.2 Actions taken in response to annual report reviews

Only one piece of feedback was required for the final report. “The project management structure is unclear. How is the project being managed, how often do partners meet (in person or electronically) to monitor progress and make adaptive management plans?”
Response: Project was led by PI Phil Stevenson from Kew. NM-AIST activities led by Prof Ndakidemii supported by Dr Kelvin Mtei and then Dr Ernest Mbega with two PhD students (Elisante Philemon and Prisila Mkenda) and 8 MSc students. Work at LUANAR was led by Prof V Kabambe with Yolice Tembo and local technical staff. NRI activities were led by Dr SEJ Arnold and Prof Geoff Gurr contributed advice to PhD students. The Team communicated weekly about progress against objectives and updates of progress. An inception meeting, end of project workshop and two additional annual meetings were held to evaluate project horizons and progress. These were supplemented by additional field trips every 4-6 months by UK and Australian project partners to help develop approaches to monitoring.

7 Darwin identity

All communications make reference to Darwin Initiative funding. Some information has been provided through Twitter @chickpeaman & @sejarnold which linked back to the Darwin Defra twitter account and http://www.agriculturalecosystems.org/ and the project website features the Darwin logo and funding information prominently. The NRI communications team released several updates about activities via social media (see https://www.facebook.com/NaturalResourcesInstitute/videos/10155568720477017/, and https://www.facebook.com/NaturalResourcesInstitute/posts/10155474582362017 which received over 100,000 views and was “liked” over 3,000 times and linked back to the Darwin social media account. http://www.kew.org/science/projects/harnessing-agricultural-ecosystem-biodiversity-for-bean-production-and-food also provides a web presence via Kew website Within country for the partners and in all communications with representatives of the CBD, and other conservation organisations there is a clear understanding of the Darwin Initiative and its role and the UK Government’s contribution supporting this action within in the host country. We have publicised the activities at the Commonwealth Heads of Government (CHOGM) spouses event at RBG Kew including speaking directly to Philip May.
The project was recognised as a distinct project with a clear identity although was supplemented by smaller funds that were allocated because of the Darwin funding – e.g., from McKnight Foundation to support PhD students.

8 Finance and administration

8.1 Project expenditure

Project spend (indicative) since last annual report	2017/18 Grant (£	2017/18 Total Darwin Costs (£)	Variance %	Comments (please explain significant variances)
Staff costs (see below)			13	Recruitment delays for chemical ecologist on project in year 3 owing to FCO refusing visa 3 times (took 5 months)
Consultancy costs			0	
Overhead Costs			4.9	Reflects the underspend on salaries above.
Travel and subsistence			7.4	Shared flights \and trav costs with associated McKnight project
Operating Costs			4.1	
Others (see below)			35.2	Open access publication (one in review) at *Front Plant Sci* and 2 by NM-AIST who didn’t invoice Kew for costs (£1000).
TOTAL				

Staff employed (Name and position)	Cost (£)
Prof Phil Stevenson PI -	
Dr Iain Darbyshire Co-I RBG Kew botanist	
Research Fellow RBG Kew Chemical Ecologist	
Dr Sarah Arnold (NRI) Co-I NRI Entomologist	

Prof Patrick Ndakidemi Co-I NM-AIST Lead	
Prof Vernon Kabambe Co-I LUANAR Lead	
TOTAL	

Other items – description	**Other items – cost (£)**
Open Access Publication Costs	
TOTAL	

8.2 Additional funds or in-kind contributions secured

Source of funding for project lifetime	**Total (£)**
Charles Sturt University	
RBG Kew	
NRI	
McKnight funded PhD students	
TOTAL	
Source of funding for additional work after project lifetime	**Total (£)**
Genesis	
McKnight Foundation PP4FN	
BBSRC-GCRF (SASSA) Project code BB/R020361/1	
TOTAL	

8.3 Value for Money

Tanzania's national poverty reduction strategy paper highlights that agriculture is central to reducing food poverty[1]. Beans provide ~25% of the income for most farmers in Tanzania and Malawi so are a key to poverty alleviation. 90% of beans are produced on small farms <2ha with annual household yields ~250kg of which half is sold and worth between 150 and 250USD. We predicted that through yield increases of up to 20% equivalent to 50USD per household per annum, that this project would increase wealth of 400 participating farmers and a further 3600 via outreach, equal to increases in bean production worth 200,000USD per annum. We worked with over 700 farmers directly across two countries and have demonstrated measurable gains directly in income from beans (up 13% over 1 year) and shown that by supporting pollination services alone individual farmers benefit from £200-300/farmer/annum which from 700 farmers is up to £150-210K/annum or / cropping cycle for an initial investment of £288K across 3 years. This doesn't include the extension through farmer research network to 1000s more in Malawi and Tanzania. We also predicted and delivered an outreach program including farmer field schools with distribution of information briefs in local languages to maximise this DI investment and ensuring a legacy. By supporting small-scale bean production through strategies that enhance biodiversity in Tanzanian and Malawian agriculture the project ensured that DI funding impacted poverty reduction, human welfare and conservation. We also delivered and benefitted from the inputs of 2 rather than 1 PhD student who were funded through income from the McKnight Foundation awarded because of our Darwin action along with 10 Master candidates to become leaders and change-agents, able to work on related projects and address other agricultural challenges. Activities for MSc students at NM-AIST were also at no cost to the project other than the staff inputs from project partners and benefitted from important new knowledge that informed our understanding of regulating ecosystem services in East Africa.

The advanced training in research skills, allied to joint publications in international journals (this project published 10 research papers in international journals 50% of which have African women lead authors). We have 6 further papers in review or preparation (Annex 7). Presentations at scientific conferences including (International Congress of Entomology 2016), will make the African scholars competitive for funding schemes to further their professional development in the EU and Australia e.g., the Australian Government's Endeavour Scheme[2].

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[1] http://www.imf.org/external/pubs/ft/scr/2011/cr1117.pdf

[2] https://aei.gov.au/scholarships-and-fellowships/pages/default.aspx

Annex 1 Project's original (or most recently approved) logframe, including indicators, means of verification and assumptions.

Project summary	Measurable Indicators	Means of verification	Important Assumptions
Impact: The harnessing of agricultural biodiversity in bean production systems of East Africa established and implemented widely to improve food security, reduce poverty and increase ecosystem resilience.			
Outcome: Smallholder farmers implement science-based methods for enhancing and restoring ecosystem services and biodiversity in agricultural systems that improve bean yield and quality, food security and rural livelihoods.			
Outputs: 1. Ecosystems and plant species that are habitats for key natural enemies of bean pests identified.	1.1 Plant biodiversity surveys undertaken across 25 farm locations in Arusha and Moshi by year 2 1.2 Insect diversity surveys undertaken 25 farm locations in Northern Tanzania by year 2 1.3 Associations between habitat type and plant of invertebrate species diversity established by end of year 2 1.4 Plant species of importance to beneficial insects and with pesticidal properties identified	1.1 -1.4 Research paper published in international refereed journals reporting plant and insect biodiversity surveys and associations between habitat type and plant of invertebrate species diversity	Bean ecosystems at least in some locations provide adequate diversity (i.e. have not already been degraded) to prevent meaningful biodiversity assessments in adequate locations. Mitigation: During the IPM workshop funded by McKnight earlier in 2014 from which this project idea arose – the participants visited two field locations to make a pilot assessment. This suggested that at least in two ecological zones in our target area that plant species showed considerable diversity and both natural enemies and pollinators occurred in measurable numbers to enable a meaningful evaluation of biodiversity across the region.
2. Key invertebrate pollinators of beans and their key habitat (plants/ecosystems) established at 25 locations in 4 agro-ecological zones.	2.1 5 most important/abundant natural enemies of bean pests and their most important plant species habitats identified	2.1-2.3 Research paper published in international refereed journals indicating most important invertebrates and their most important plant species habitats.	Extreme weather conditions will not affect biodiversity sampling. Mitigation: Sampling will be undertaken across three seasons and at different times

	and target pest species determined by start of year 3. 2.2 5 key/abundant pollinators of beans and their most important non-crop species habitats identified by start of year 3. 2.3 5 most important pests identified and their most important non-crop habitats established through abundance, perceived impact and literature. 2.4 Habitat quality index developed to assess relative risk and provisioning in habitat for supporting beneficial invertebrates	2.4 Habitat quality index used to quantity diversity and incorporated in paper indicated in 2.1 as methods component	of the year – both during the cropping period and outside the cropping period to ensure that extreme weather events will not affect all data collection
3. Capacity of 400 lead farmers increased by information and guidance on exploiting and maintaining agricultural biodiversity for improved crop yield.	3.1 Impact of field margin variation across bean production systems or ecological interventions on populations of natural enemies, pollinators and pest insects determined in year 1. 3.2 Baseline evaluation of productivity and bean quality of 400 farmers in Malawi and Tanzania determined by end of year 1. 3.3 Field trials conducted to determine impact of field margin variation across bean production systems on bean yields and bean quality in year 2. 3.4 Impact of pollinators on bean yield and quality evaluated as a percentage improvement for each ecosystem and across the whole experimental area. 3.5 Impact of changes in field bean ecosystem biodiversity on livelihoods evaluated through post field trial surveys, monitoring benefits to farmers' livelihoods including effects on financial wealth, nutrition and health.	3.1 Project report showing impact of field margin species variation on bean production. Website produced to provide global reporting vehicle and networking tool. 3.2 Project report evaluating baseline productivity and bean quality of farmers in Malawi and Tanzania determined by end of year 1 – farmers survey reports. 3.3 Project report of Field trials conducted to determine impact of field margin variation on bean yields and bean quality – farmer survey reports. 3.4 Research paper reporting Impact of invertebrates on bean yield and quality evaluated as a percentage improvement across experimental area. 3.5 Impacts on wealth, nutrition and health incorporated in to paper in 3.4. 3.6 Production of 4000 information leaflets on the role of ecosystems in bean production.	Farmers commissioned to undertake independent field activities that evaluate various technologies that arise from biodiversity surveys conduct those evaluations effectively and without resorting to the use of pesticides. Mitigation: At the outset of farmer trials and during the course of the cropping season farmers will be visited regularly to encourage and enforce the specific requirements for those field trials. Farmers will be provided clear guidance on how to conduct field trials.

	3.6 Impact of ecosystems on bean production disseminated to 3600 farmers through fields school and provision of information leaflets	Policy briefs produced for high level audience. Radio interview and Newspaper stories.	
4. Field margin plant species that support beneficial insects evaluated for their biological activity against pest insect species of beans and negative effects on natural enemies and pollinators determined.	4.1 5 Plant species of potential importance as habitat and refuge for beneficial insects and with potential pesticidal properties identified. 4.2 Plant species of potential value as pesticidal evaluated in laboratory and screen-house trials for efficacy against pests and effects against two key natural enemies determined by end of year 21. 4.3 Pesticidal efficacy of plants evaluated in laboratory and screen-house against two key natural enemies. 4.4 Farmer field trials evaluating efficacy of pesticidal plants to control bean pests and effects against key natural enemies and pollinators by end of year 3. 4.5 Potential of pesticidal plants to increase production and bean quality evaluated through impact assessments in year **3**.	4.1-4.3 Research paper in international journal published reporting results. 4.4 Farmer field trials evaluating efficacy of pesticidal plants to control bean pests and effects against key natural enemies and pollinators by end of year 3. 4.5 Impact of pesticidal plants technologies to increase production and bean quality evaluated through impact assessments in year 3	
5.Post-graduates trained in conducting biodiversity surveys and carrying out field and laboratory based research.	5.1 At least 10 post graduate students trained and provided field experience in conducting botanical biodiversity surveys by end of project. 5.2 At least 10 post graduate students trained and provided field experience in conducting invertebrate surveys biodiversity surveys by end of project. 5.3 **Two** PhD student provided training in laboratory and field evaluation of suitability	Graduate theses produced and research papers published by students reporting results. PhD thesis produced and interim reports	

	of at least two plant species and two key beneficial insects by end of year 3		

Activities (each activity is numbered according to the output that it will contribute towards, for example 1.1, 1.2 and 1.3 are contributing to Output 1)

Output 1	
Activity 1.1	Plant surveys to determine botanical biodiversity across 3 ecological zones undertaken across 25 farm locations in Arusha and Moshi.
Activity 1.2	Invertebrate surveys to determine biodiversity among pollinators, natural enemies and pests across 4 ecological zones and undertaken across 25 farm locations in Arusha and Moshi, N. Tanzania.
Activity 1.3	Plant species occurrence and agroecosystem type correlated to establish key species in different locations.
Output 2	
Activity 2.1	Natural enemies of bean pests will be identified across experimental locations and the most important plant species identified and suitability of key plants species as habitat/refuge determined in laboratory and glass house experiments
Activity 2.2	Target pest species determined and likely natural enemies will be evaluated.
Activity 2.3	Insect surveys will be undertaken to identify the main pollinators of beans and through literature and field studies the most important plant species habitats determined across seasons to identify likely habitat outside the growing seasons.
Activity 2.4	Key pests species are already known for beans in East Africa so this activity will identify which plant species provide field margin refuge and habitat for all life stages of key bean pests e.g. for adults of Lepidoptera where their larvae are key pests.
Output 3	
Activity 3.1	Baseline evaluation of productivity and bean quality of 400 farmers in Malawi and Tanzania determined
Activity 3.2	Baseline field survey of the variation across bean production systems or ecological interventions on populations of natural enemies, pollinators and pest insects.
Activity 3.3	Field trials will be carried out in Malawi and Tanzania (200 farmers in each country) that will evaluate how specific field margin plant and natural enemy invertebrate species contribute to improved bean yields and bean quality.
Activity 3.4	Impact of pollinators on bean yield and quality evaluated will be evaluated through target field trials comparing bagged versus unbagged species and across locations to compare the absolute impact of pollinators sand the relative service delivery of pollination across different locations that differ in their plant and invertebrate diversity.
Activity 3.5	Impact of changes in field bean ecosystem biodiversity on livelihoods will be evaluated through post field trial surveys that compare production and quality at field locations and monitor absolute changes to farmers' livelihoods including increases in income, nutrition and health.

Activity 3.6	Production and dissemination of information leaflets to 3600 households.

Output 4	
Activity 4.1	During surveys species that are known through associated actions (See Q 15) field margin plant species of potential importance as habitat and refuge for beneficial insects but that also have pesticidal properties will be identified.
Activity 4.2	Pesticidal plants evaluated in laboratory and screen-house trials for efficacy against 3 pest species determined
Activity 4.3	Pesticidal efficacy of plants from Activity 4.2 will be evaluated in laboratory and screen-house against two key natural enemies.
Activity 4.4	Farmers in Tanzania and Malawi will be provided protocols to pesticidal plants to control bean pests and effects against key natural enemies and pollinators.
Activity 4.5	Impact of pesticidal plants technologies to increases production and bean quality evaluated through impact assessments

Output 5	
Activity 5.1	All plant diversity surveys will be undertaken as field trips for post graduate students on the Biodiversity and Ecosystems MSc at NMAIST providing training for 10 students in field collection in identification techniques as well as collection establishment.
Activity 5.2	Invertebrate diversity surveys will be undertaken as field trips for post graduate students on the Biodiversity and Ecosystems MSc at NMAIST providing training for up to 10 students in field collection techniques and identification and naming while a digital record of all taxa collected will be made.
Activity 5.3	A PhD student will be supervised to undertake training in specific laboratory and field evaluation of plants that determine the suitability of at least two plant species and two key beneficial insects that could be targets for ecological interventions. It is expected that this work will lead to information that identifies potential targets for propagation and distribution among bean farmers as a key environmentally benign input to improve production.

Annex 2 Report of progress and achievements against final project logframe for the life of the project

Project summary	Measurable Indicators	Progress and Achievements
Impact: The harnessing of agricultural biodiversity in bean production systems of East Africa established and implemented widely to improve food security, reduce poverty and increase ecosystem resilience.		New knowledge about the Key beneficial and pest arthropods (insects and spiders) was generated for bean fields in East Africa, the most important field margin plant species on which they depend for nectar and pollen were identified and their relative importance to supporting key ecosystem services was established. The extent to which these species might be limiting steps for successful delivery of ecosystems was determined through comparison of data from different landscapes, altitudes and countries. Farmers surveys were undertaken with >500 farmers in total for end-line baseline comparison and identified how our work with farmers has changed perspectives pre and post project about their understanding of the importance of beneficial insects, field margins and ecological intensification. This also showed increased income from bean farming and how supporting pollination services can more than double yields compared to farming systems that use excessive pesticides and do not support pollinators with field margin species. Farmers income from beans increased by 13% while evidence from pollination experiments showed that in the absence of pollinators yields were less than half and farmers stand to gain up to USD 500 by maximising pollination service
Outcome Smallholder farmers implement science-based methods for enhancing and restoring ecosystem services and biodiversity in agricultural systems that improve bean yield and quality, food security and rural livelihoods.	**Outcome level indicators** 1 Roles and interactions of key plant and beneficial invertebrate species of agricultural ecosystems understood by farmers and agricultural technicians by end of project.	Roles and interactions of key beneficial invertebrates was established in two countries at different altitudes enabling several technicians (MSc & PhD students and others) to be trained in survey techniques, experimental design and data analysis and in the importance of beneficial insects. >700 farmers trained/awareness raised around the benefits of healthy ecosystem to support food production through environmentally benign approaches to horticulture with indirect reaching >8000 through farmer research networks. Knowledge of farmers about beneficial insects and importance of field margins among other changes recorded through end line survey.
	2 Management methodologies that maintain ecosystem services and augment natural pest enemies and pollinators developed and implemented to increase yields by 20% from baseline data at project outset without additional agricultural inputs.	Baseline data indicated that farmers do not recognise field margins as important for supporting beneficial insects. With respect to pollinators we showed experimentally that excluding pollinators reduced yields by more than half at a cost of USD 500/ Ha compared to open pollinated in botanically rich- landscape where pesticides did not damage populations of insects. Farmer income from beans increased by 13% but yield potential for fully supported pollination more than 100% yield benefit.

	3. Bean crop productivity and quality improved and monetary value of beans increased for 400 farmers by 20% by project end	Farmers yield increases associated with maximising pollination services increased on average by >100% with a value of between USD 320-400 ($500/Ha) although increases between end line and baseline of income generated was 13% suggesting pollination deficits are lower than expected due to florally rich landscapes of Himo and Moshi.
	4. Role of agricultural biodiversity in crop quality, enhanced yield and consequent poverty alleviating benefits demonstrated to key stakeholders through participatory field trials.	Participatory field trials and associated training saw significant changes in 1. Farmers understanding of the concepts of beneficial insects. 2. what farmers could do to support beneficial insects 3. Changes to how farmers managed and understood the value of field margin plant species. Participatory trials saw farmers understand through their own experience the yield benefits of using plant based pesticides compared to synthetic pesticides and the evidence is published or in review for publication (Annex 7)
	5. Yield and poverty impacts of enhanced biodiversity demonstrated through individual farmer surveys for bean production at project outset and project end that indicate increased income of 5-10% per household	Over the course of the year between the end of the base line survey and the end line survey farmer income increased by 13%. On top of this we showed that at least with pollination yield benefits of more than 100% could be achieved through protecting the pollination services in beans farming. This amounted to between $320 and $400/farmer/cropping cycle as opposed to the conservative estimate of $50 in the proposal.
Output 1. Ecosystems and plant species that are habitats for key natural enemies of bean pests identified.	1.1 Plant biodiversity surveys undertaken across 25 farm locations in Arusha and Moshi by year 2 1.2 Insect diversity surveys undertaken 25 farm locations in Northern Tanzania by year 2 1.3 Associations between habitat type and plant of invertebrate species diversity established by end of year 2. 1.4 Plant species of importance to beneficial insects and with pesticidal properties identified	Extensive biodiversity surveys have been undertaken in a total of 32 sites across Malawi and Tanzania. These have revealed association patterns and interactions between plants and insects and identified the most important plant species for pollinators and natural enemies. This information forms the foundation of knowledge required to implement a margin management approach to optimise their value to pollinators and natural enemies of pests. We found a high level of exotic plants in Tanzania on all sites which means the trade-off of weedy species encroaching on the crop need to be established. A key finding was that tree-rich sites had higher levels of pollination. Many interactions between flower visitors and *Ageratum conyzoides* and *Bidens* sp. were noted, both of which are pesticidal plant taxa (Annex 7 and Amoabeng et al., 2013 *PLoS One*). Several plant species showed high interaction with natural enemies, including *A. conyzoides* and neem trees.
Activity 1.1 Activity 1.1 Plant surveys to determine botanical biodiversity across 3 ecological zones undertaken across 25 farm locations in Arusha and Moshi.		Plant biodiversity available across 3 agro-ecological zones, highlighting a very high number of exotic plant species are present on most sites.

Activity 1.2. Invertebrate surveys to determine biodiversity among pollinators, natural enemies and pests across 4 ecological zones and undertaken across 25 farm locations in Arusha and Moshi, N. Tanzania.		Invertebrate surveys completed in **25** locations at 3 zones and 8 further locations in Malawi. Insect diversity was surveyed on the sites both using pan-trapping and also standardised transect walks to record plant-insect interactions.
Activity 1.3 Plant species occurrence and agroecosystem type correlated to establish key species in different locations		Key plant species for pollinators and beneficial insects determined for different ecological zones in Tanzania, data awaiting complete analysis from Malawi. Analysis has indicated tree rich habitats are associated with higher pollination services
Activity 1.4 Statistical calculations of invertebrate and plant species diversity and their interlinkage, and assessment of provisioning quality in terms of ecosystems services on 25 farm sites with analysis for effects of management types.		Several candidate species have been identified via analysis of pollination networks.
Output 2. Key invertebrate pollinators of beans and their key habitat (plants/ecosystems) established at 25 locations in 4 agro-ecological zones	2.1 5 most important/abundant natural enemies of bean pests and their most important plant species habitats identified and target pest species determined by start of year 3. 2.2 5 key/abundant pollinators of beans and their most important non-crop species habitats identified by start of year 3. 2.3 5 most important pests identified and their most important non-crop habitats established through abundance, perceived impact and literature. 2.4 Habitat quality index developed to assess relative risk and provisioning in habitat for supporting beneficial invertebrates	Several taxa identified, including parasitoid wasps, spiders, hoverflies, lady beetles, lacewings Species include honeybees, carpenter bees, moths/butterflies, small solitary bee species and hoverflies Species include *Ootheca* sp., aphids (*Aphis* sp. and *Macrosiphum* sp.), stem borer and blister beetles. This has proven to be extremely complex, as the results have shown relationships with plants and habitats relate to certain traits more than particular species. These indicators were suitable, although 2.4 proved unfeasible given the complexity of factors.
Activity 2.1. Natural enemies of bean pests will be identified across experimental locations and the most important plant species identified and suitability of key plants species as habitat/refuge determined in laboratory and glass house experiments		Primary natural enemies in field margins of bean field identified and determined in Tanzania and Malawi. Several taxa identified, including parasitoid wasps, spiders, hoverflies, lady beetles, lacewings. Work has been carried out in Africa and Australia in terms of understanding use of natural enemies to control key pests.
Activity 2.2. Target pest species determined and likely natural enemies will be evaluated		Primary pest species in bean field identified and determined in Tanzania (25 field sites) and Malawi (8 field sites). Species include *Ootheca* sp., aphids (*Aphis* sp. and *Macrosiphum* sp.), stem borer and blister beetles.

Activity 2.3. Insect surveys will be undertaken to identify the main pollinators of beans and through literature and field studies the most important plant species habitats determined across seasons to identify likely habitat outside the growing seasons		Main pollinators occurring in bean field margins determined in Tanzania and pollinators of beans determined in Malawi. Species include honeybees, carpenter bees, moths/butterflies, small solitary bee species and hoverflies. Bagging experiments have indicated their overall contribution to food production to more than doubling yield. A cage trial by an MSc student indicated a potential, if small, role for stingless bees as bean pollinators.
Activity 2.4. Key pest species are already known for beans in East Africa so this activity will identify which plant species provide field margin refuge and habitat for all life stages of key bean pests e.g. for adults of Lepidoptera where their larvae are key pests		Interactions between key field margin plant species and pests determined. Surprisingly the main pests (aphids and spider mites) are not found on field margin plants although *Ootheca* do occur on some and blister beetles. Field trials have indicated damage to beans around the edges of fields, but that this is ameliorated by presence of field margin, indicating the margin is not aggravating pest damage.
Output 3. Capacity of 400 lead farmers increased by information and guidance on exploiting and maintaining agricultural biodiversity for improved crop yield	3.1 Impact of field margin variation across bean production systems or ecological interventions on populations of natural enemies, pollinators and pest insects determined in year 1. 3.2 Baseline evaluation of productivity and bean quality of 400 farmers in Malawi and Tanzania determined by end of year 1 3.3 Field trials conducted to determine impact of field margin variation across bean production systems on bean yields and bean quality in year 2. 3.4 Impact of pollinators on bean yield and quality evaluated as a percentage improvement for each ecosystem and across the whole experimental area. 3.5 Impact of changes in field bean ecosystem biodiversity on livelihoods evaluated through post field trial surveys, monitoring benefits to farmers' livelihoods including effects on financial wealth, nutrition and health. 3.6 Impact of ecosystems on bean production disseminated to 3600	Particularly notable case study from Malawi, showing differences between fields that have some sort of semi-natural margin compared to fields with no margin at all. Natural enemy-plant interaction networks were more complex on fields with rich margins compared to depauperate margins. Baseline survey undertaken in Tanzania and Malawi (>500 farmers) using a questionnaire as indicated in annex 7 and data now analysed. Additional 135 farmers interviewed with a novel ICT approach using an automated telephone service. Overall farmers are using various synthetic pesticides but their uses have limitations. E.g., they can't be used during flowering stage because its poison can last for a long time even after harvest that makes bean seeds poisonous to consumers (but this will also kill pollinators which were whon to be critical to increasing yield). Synthetic pesticides have health problems as it's toxic and according to farmers, it causes flue and breathing problems when sprayed as the farmer doesn't wear protective gear. Some farmers are using both plant (especially leaves of neem trees) and organic (especially ash and cattle's urine). However, farmers report that it is time consuming to prepare plants and not as effective in eradication of insect pests. Most farmers were unable to name insects but broadly recognised most insects as pests regardless of their function. Farmers did not know the importance of field margins for supporting beneficial insects but believe they harbour pests and prompts farmers to clear margins. Our baseline data suggest they do not support the key pests. Farmers practice either mono cropping or mixed cropping mainly

	farmers through fields school and provision of information leaflets	due to season or insufficient land. Some farmers use synthetic pesticides though do not know their names because when they go to the agro-vet shops, they just explain what is happening with their crops and then the seller will advise on the 'appropriate' chemical to be used. Sometimes farmers can collect a representative insect pest which they believe attack their beans and show to agro-vet specialists so that they can get appropriate pesticides. Most farmers claimed a need for agricultural education to apply best agricultural practices that will help to increase bean production. Dissemination of knowledge to >8000 farmers through direct interactions (>700) and Farmer Research Networks.
Activity 3.1 and 3.2 Baseline evaluation of productivity and bean quality of 400 farmers in Malawi and Tanzania determined and Baseline field survey of the variation across bean production systems or ecological interventions on populations of natural enemies, pollinators and pest insects		Completed for >500 farmers by questionnaire in Tanzania and Malawi and 135 by ICT in Tanzania. Primary findings summarised above and reports in annex 7. Baseline evaluation indicated less than 60% of beans in Tanzania were rated "good" quality. Data from Malawi show that damage rates are lower when margins are biodiverse.
Activity 3.3 Field trials will be carried out in Malawi and Tanzania (200 farmers in each country) that will evaluate how specific field margin plant and natural enemy invertebrate species contribute to improved bean yields and bean quality. Activity 3.4 Impact of pollinators on bean yield and quality evaluated will be evaluated through target field trials comparing bagged versus unbagged species and across locations to compare the absolute impact of pollinators sand the relative service delivery of pollination across different locations that differ in their plant and invertebrate diversity. Activity 3.5 Impact of changes in field bean ecosystem biodiversity on livelihoods will be evaluated through post field trial surveys that compare production and quality at field locations and monitor absolute changes to farmers' livelihoods including increases in income, nutrition and health.		Station trials have evaluated more than 6 different field margin plants for their impact on beneficial insects and bean yield/quality, including two *Lippia* species, *Tephrosia*, *Ageratum* and *Hyptis*. Impact of pollinators on bean yield and quality was evaluated in field trials across locations to compare the absolute impact of pollinators and the relative service delivery of pollination across different locations that differ in their plant and invertebrate diversity. These data reveal that pollination service can more than double yields and that this realises potential gains over pollinator poor farming of up to USD 500 / Ha. With average farm sized of 0.58-0.81 farmers can realise an increase in income of between 320-$400 per cropping cycle.
Output 4. Capacity of 400 lead farmers increased by information and guidance on exploiting and maintaining agricultural biodiversity for improved crop yield	4.1 5 Plant species of potential importance as habitat and refuge for beneficial insects and with potential pesticidal properties identified. 4.2 Plant species of potential value as pesticidal evaluated in laboratory and screen-house trials for efficacy against pests and effects against two key	The project chose to address some of these assessments via station trials, which allow a higher degree of control and lower risk as they are not risking interference with a livelihood crop. This also permitted MSc students to become more involved. On-station trials implemented in both Malawi and Tanzania. Six field margin species (*Bidens pilosa, Lantana camara, Tephrosia vogelii, Vernonia amygdalina, Lippia javanica, Tithonia diversifolia*) tested on 5x5 plots with 4 plot replicates of each treatment randomly across the field with each species tested at 3 concentrations (10%, 1% and 0.1% w/v) plus control plots. Trials also carried out

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<td></td>
<td>natural enemies determined by end of year 2. Pesticidal efficacy of plants evaluated in laboratory and screen-house against two key natural enemies
4.3 Farmer field trials evaluating efficacy of pesticidal plants to control bean pests and effects against key natural enemies and pollinators by end of year 3
4.4 Potential of pesticidal plants to increase production and bean quality evaluated through impact assessments in year</td>
<td>and run with support from the McKnight foundation project with farmers showed that the pesticidal plants broadly worked with some more effective than others but the impacts on beneficial insects was significantly lower than the synthetic pesticides. Yield of legumes was as good as the synthetic and all plant species led to better yields than the control. These data have been compiled in to a paper and submitted to the journal <i>Industrial Crops and Products</i> (Mkindi et al., 2017). Assessments of their impacts on beneficial insects are reported and a draft of the submitted manuscript is provided as an Annex 7. Farmer training in how to use pesticidal plants for field applications was conducted in March 2017 with one of our trained MSc students from year 1 Angela Mkindi in 5 locations between Tengeru & Rombo, with 113 farmers trained. A second paper looking at the biological effects of field margin pesticidal plants <i>Tithonia</i> and <i>Vernonia</i> is also submitted and included in Annex 7</td>
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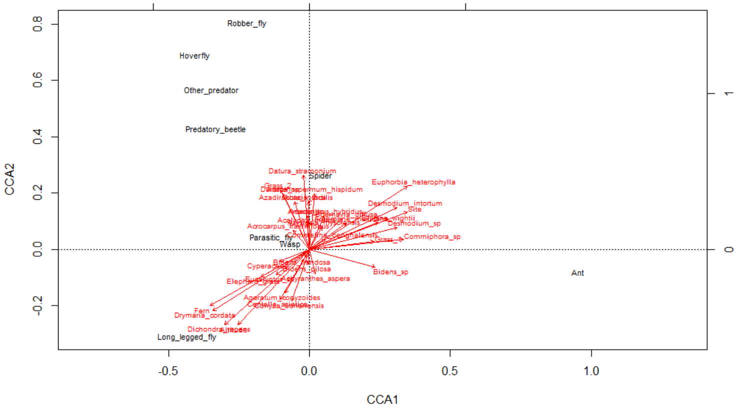
<td colspan="2">Activity 4.1 During surveys species that are known through associated actions (See Q 15) field margin plant species of potential importance as habitat and refuge for beneficial insects but that also have pesticidal properties will be identified</td>
<td>Pesticidal plants evaluated in laboratory and field trials demonstrate efficacy comparable with synthetic pesticides but reduced impacts on beneficial insects (Mkindi et al., 2017) Annex 7. We have identified various plant species with pesticidal properties as also providing resources for natural enemies (Fig. a), e.g. <i>Ageratum conyzoides</i> is associated with higher Dolichopodidae catches in traps; <i>Azadiracta indica</i> associates with higher predatory beetle and hoverfly catches.


Fig. a Canonical correspondence analysis showing association between plants on Tanzanian farms and guilds of natural enemies</td>
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Activity 4.2 Pesticidal plants evaluated in laboratory and screen-house trials for efficacy against 3 pest species determined.		Additional trials undertaken in year 3 with farmers leading activities and on station.
Activity 4.3 Pesticidal efficacy of plants from Activity 4.2 will be evaluated in laboratory and screen-house against two key natural enemies		Biological effects against beneficial insects determined using station trials, applying pesticidal plants and/or growing them as companion plants alongside crops. Findings showed that impacts were varied, but it is important that margin plants do not compete excessively with the crop for resources.
Activity 4.4 Farmers in Tanzania and Malawi will be provided protocols to pesticidal plants to control bean pests and effects against key natural enemies and pollinators		Farmers have been provided protocols to trials pesticidal plants and undertaken trials with project while hundreds of additional farmers trained in the use of pesticidal plants for pest control. Leaflets have been produced with information about field margins. An instructional YouTube video was produced about use of pesticidal plants and translated into local languages.
Activity 4.5 Impact of pesticidal plants technologies to increases production and bean quality evaluated through impact assessments		Impact of pesticidal plants to increase production evaluated and reported in published research articles Annex 7.
Output 5. Post-graduates trained in conducting biodiversity surveys and carrying out field and laboratory based research.	At least 10 post graduate students trained and provided field experience in conducting botanical biodiversity surveys by end of project At least 10 post graduate students trained and provided field experience in conducting invertebrate surveys biodiversity surveys by end of project One PhD student provided training in laboratory and field evaluation of suitability of at least two plant species and two key beneficial insects by end of year 3	Successful – in terms of students trained and a high percentage were female. Targets were exceeded in terms of PhD students. A **total of 10 post graduate student's inlcluding 2 PhDs were recruited on the project compared with the predicted 8 MSc and 1 PhD at outset**) and received training in designing and implementing plant and invertebrate surveys and experimental design for evaluation the ability of field margin plants to harness ecosystem services and as a plant based pesticide against pests. Some work published subsequently (see above and Annex 4). 2 PhD students recruited and trained up in survey techniques, and laboratory experiment and including a 3 month training visit to Charles Sturt University, Australia with [project partners Prof Geoff Gurr So total of 8 post graduates trained on project with 2 additional BSc graduates receiving training and undertaking field work in Malawi under supervision of project partners. We recruited 2 more MSc students to the project in year 3 who are still undertaking their work. 8 Students attended Research Methods Workshop organised by East and Horn of Africa and the Southern Africa Community of Practice of the Collaborative Crop Research Program (CCRP) in August 2016 and 2017 at Giraffe Ocean View hotel, Dar as salaam, Tanzania. This helped students develop their experimental design and analyses of data.

Activity 5.1. All plant diversity surveys will be undertaken as field trips for post graduate students on the Biodiversity and Ecosystems MSc at NMAIST providing training for 10 students in field collection in identification techniques as well as collection establishment	12 students received training in different aspects of botanical survey, including as part of MSc studies: Tanzania: 10 students/5 female Malawi: 2 students/2 female
Activity 5.2.. Invertebrate diversity surveys will be undertaken as field trips for post graduate students on the Biodiversity and Ecosystems MSc at NMAIST providing training for up to 10 students in field collection techniques and identification and naming while a digital record of all taxa collected will be made	Surveys completed and 11 graduates trained including 6 MSc students 2 BSc graduates and 2 PhD students.
Activity 5.3 PhD student will be supervised to undertake training in specific laboratory and field evaluation of plants that determine the suitability of at least two plant species and two key beneficial insects that could be targets for ecological interventions. It is expected that this work will lead to information that identifies potential targets for propagation and distribution among bean farmers as a key environmentally benign input to improve production	This activity is underway and reported in some detail above and in annex 7. Students will continue to receive training in plant and invertebrate biology throughout the project and the two PhD students received further training on a trip visit to Australia.

Annex 3 Standard Measures

We use these figures as part of our evaluation of the wider impact of the Darwin Initiative programme. Projects are not evaluated according to quantity. That is – projects that report few standard measures are not seen as being of poorer quality than those projects which can report against multiple standard measures.

Please quantify and briefly describe all project standard measures using the coding and format of the Darwin Initiative Standard Measures. Download the updated list explaining standard measures from http://darwin.defra.gov.uk/resources/reporting/. If any sections are not relevant, please leave blank.

Code	**Description**	**Total**	**Nationality**	**Gender**	**Title or Focus**	**Language**	**Comments**
Training Measures							
1a	Number of people to submit PhD thesis	2	Tanzanian	1M 1 F	Pollination and Natural Pest Regulation	English	Writing up
2	Number of Masters qualifications obtained	8	Tanzanian and Rwandan	3M 5F	Pollination and Natural Pest Regulation	English	6 qualified 2 currently studying
5	Number of people receiving other forms of long-term (>1yr) training	2	Malawian	2F	Pollination and Natural Pest Regulation	English	Technicians working on farm surveys in Malawi

	not leading to formal qualification (e.g., not categories 1-4 above)						
6a	Number of people receiving other forms of short-term education/training (e.g., not categories 1-5 above) Farmers trained in using field margin plants for pest management Indirectly through Farmer Research Networks in Tanzania and Malawi.	>500 through surveys ~200 through botanicals and ecosystems training 8000 indirectly through FRNs	Tanzanian and Malawian	Min 50% F	As part of survey farmers trained about beneficial insects and how to optimise Environmentally benign pest management and beneficial insects	English, Chichewa and Kiswahili	>8000 farmers reached through those trained in botanicals including distribution of training papers on beneficial insects (Annex X) via McKnight foundation FRNs
7	Number of types of training materials produced for use by host country(s) (describe training materials)						

Research Measures		**Total**	**Nationality**	**Gender**	**Title**	**Language**	**Comments/ Weblink if available**
9	Number of species/habitat management plans (or action plans) produced for Governments, public authorities or other implementing agencies in the host country (ies)						Participatory process?
10	Number of formal documents produced to assist work related to species identification, classification and recording.						
11a	Number of papers published or accepted for publication in peer reviewed journals	7	TZ, MW and UK	50:50 M:F	See Table below	English	See table 2 below.
11b	Number of papers published or accepted for publication elsewhere	1					

12a	Number of computer-based databases established (containing species/generic information) and handed over to host country						
12b	Number of computer-based databases enhanced (containing species/genetic information) and handed over to host country						
13a	Number of species reference collections established and handed over to host country(s)	2	Tanzanian, Malawian and cosmopolitan	Non-binary	Insect collection Herbarium	Latin (Scientific)	This is ludicrous
13b	Number of species reference collections enhanced and handed over to host country(s)						

Dissemination Measures		**Total**	**Nationality**	**Gender**	**Theme**	**Language**	**Comments**
14a	Number of conferences/seminars/workshops organised to present/disseminate findings from Darwin project work						
14b	Number of conferences/seminars/ workshops attended at which findings from Darwin project work will be presented/ disseminated.						

Physical Measures		**Total**	**Comments**
20	Estimated value (£s) of physical assets handed over to host country(s)		
21	Number of permanent educational, training, research facilities or organisation established		
22	Number of permanent field plots established		Please describe

Financial Measures	**Total**	**Nationality**	**Gender**	**Theme**	**Language**	**Comments**

23	Value of additional resources raised from other sources (e.g., in addition to Darwin funding) for project work McKnight Foundation Charles Sturt University Natural Resources Institute **Total**	£75,000 £34,000 £20,982 £**129,982**	Intl Australian UK	1 F and 1 M 1M 1M		English Swahili	

Annex 4 Aichi Targets

Please note which of the Aichi targets your project has contributed to.

Please record only the **main targets** to which your project has contributed. It is recognised that most Darwin projects make a smaller contribution to many other targets in their work. You will not be evaluated more favourably if you tick multiple boxes.

	Aichi Target	**Tick if applicable to your project**
1	People are aware of the values of biodiversity and the steps they can take to conserve and use it sustainably.	X
2	Biodiversity values have been integrated into national and local development and poverty reduction strategies and planning processes and are being incorporated into national accounting, as appropriate, and reporting systems.	X
3	Incentives, including subsidies, harmful to biodiversity are eliminated, phased out or reformed in order to minimize or avoid negative impacts, and positive incentives for the conservation and sustainable use of biodiversity are developed and applied, consistent and in harmony with the Convention and other relevant international obligations, taking into account national socio economic conditions.	
4	Governments, business and stakeholders at all levels have taken steps to achieve or have implemented plans for sustainable production and consumption and have kept the impacts of use of natural resources well within safe ecological limits.	
5	The rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced.	
6	All fish and invertebrate stocks and aquatic plants are managed and harvested sustainably, legally and applying ecosystem based approaches, so that overfishing is avoided, recovery plans and measures are in place for all depleted species, fisheries have no significant adverse impacts on threatened species and vulnerable ecosystems and the impacts of fisheries on stocks, species and ecosystems are within safe ecological limits.	
7	Areas under agriculture, aquaculture and forestry are managed sustainably, ensuring conservation of biodiversity.	X
8	Pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity.	
9	Invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment.	X
10	The multiple anthropogenic pressures on coral reefs, and other vulnerable ecosystems impacted by climate change or ocean acidification are minimized, so as to maintain their integrity and functioning.	
11	At least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes.	
12	The extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained.	

13	The genetic diversity of cultivated plants and farmed and domesticated animals and of wild relatives, including other socio-economically as well as culturally valuable species, is maintained, and strategies have been developed and implemented for minimizing genetic erosion and safeguarding their genetic diversity.	X
14	Ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded, taking into account the needs of women, indigenous and local communities, and the poor and vulnerable.	X
15	Ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced, through conservation and restoration, including restoration of at least 15 per cent of degraded ecosystems, thereby contributing to climate change mitigation and adaptation and to combating desertification.	
16	The Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization is in force and operational, consistent with national legislation.	
17	Each Party has developed, adopted as a policy instrument, and has commenced implementing an effective, participatory and updated national biodiversity strategy and action plan.	
18	The traditional knowledge, innovations and practices of indigenous and local communities relevant for the conservation and sustainable use of biodiversity, and their customary use of biological resources, are respected, subject to national legislation and relevant international obligations, and fully integrated and reflected in the implementation of the Convention with the full and effective participation of indigenous and local communities, at all relevant levels.	X
19	Knowledge, the science base and technologies relating to biodiversity, its values, functioning, status and trends, and the consequences of its loss, are improved, widely shared and transferred, and applied.	X
20	The mobilization of financial resources for effectively implementing the Strategic Plan for Biodiversity 2011-2020 from all sources, and in accordance with the consolidated and agreed process in the Strategy for Resource Mobilization should increase substantially from the current levels. This target will be subject to changes contingent to resource needs assessments to be developed and reported by Parties.	

Annex 5 Publications

Provide full details of all publications and material that can be publicly accessed, e.g. title, name of publisher, contact details. Mark (*) all publications and other material that you have included with this report

Type * **(e.g. journals, manual, CDs)**	**Detail** **(title, author, year)**	**Nationality of Lead Author**	**Nationality of institution of lead author**	**Gender of Lead Author**	**Publishers** (name, city)	**Available from** (e.g. weblink or publisher if not available online)
Journal X	The Potential of Common Beneficial Insects and Strategies for Maintaining Them in Bean Fields of Sub Saharan Africa* **Ndakidemi**, B. Mtei, K., **Ndakidemi**, P.A., **2015**	Tanzanian	Tanzanian	(M)	*American Journal of Plant Sciences* Scientific Research Publishing Inc., Wuhan, China.	http://file.scirp.org/pdf/AJPS_2016031015420060.pdf
Journal	Field margin weeds provide economically viable and environmentally benign pest control compared to synthetic pesticides* **Mkenda, P.,** Mwanauta, R., **Stevenson, P.C. Ndakidemi, P.**, Mtei, K., and **Belmain, S.R. 2015**	Tanzanian	Tanzanian	(F)	Public Library of Science (*PLoS One*)	http://dx.doi.org/10.1371/journal.pone.0143530
Journal	Impacts of Synthetic and Botanical Pesticides on Beneficial Insects* **Ndakidemi**, B. Mtei, K., **Ndakidemi**, P.A., **2015**	Tanzanian	Tanzanian	(M)	*Agricultural Sciences* Scientific Research Publishing Inc., Wuhan, China.	http://file.scirp.org/pdf/AS_2016061715061431.pdf
Journal	The Potential of Using Indigenous Pesticidal Plants for Insect Pest Control to Small Scale Farmers in Africa* **Mkindi, A., Mtei, K.M., Njau, K.N., Ndakidemi, P. 2015**	Tanzanian	Tanzanian	(F)	*American Journal of Plant Sciences Scientific* Research Publishing Inc., Wuhan, China.	http://file.scirp.org/pdf/AJPS_2015121414314346.pdf
Journal	Pesticidal plants in Africa: a global vision from local uses. **Stevenson, P.C.,** Isman, M.B., Belmain S.R. (2017)	UK	UK	(M)	*Industrial Crops and Products.* 110, 2-9.	https://www.sciencedirect.com/science/article/pii/S0926669017305459

Journal	Potential of goat weed (*Ageratum conyzoides* l.) as a non-food crop for increased food productivity and ecosystem balance among smallholder farmers: a review. Rioba NB and **Stevenson P.C.** (2017)	Kenya	Kenyan (F)	*Industrial Crops and Products.* 110, 22-29.	https://www.sciencedirect.com/science/article/pii/S0926669017304545
Journal	The Toxicity, Persistence and Mode of Actions of Selected Botanical Pesticides in Africa against Insect Pests in Common Beans, *P. vulgaris*: A Review. **N. Mpumi**, **Mtei, K.,** Machunda, R., **Ndakidemi, P.A**.,	Tanzania	Tanzania (M)	*American Journal of Plant Sciences Scientific* Research Publishing Inc., Wuhan, China.	http://dx.doi.org/10.4236/ajps.2016.71015
Journal	Invasive weeds with pesticidal properties as potential new crops, **Mkindi, A.,** Mpumi, N., **Tembo, Y., Stevenson, P.C., Ndakidemi, P.A., Mtei, M.,** Machunda, R., **Belmain, S.R**. (2017)	Tanzania	Tanzania (F)	*Industrial Crops and Products.* 110, 113-122	https://doi.org/10.1016/j.indcrop.2017.06.002
Journal	Insecticidal Activity of *Tithonia diversifolia* and *Vernonia amygdalina*. Green, PWC, Belmain, S.R., **Ndakidemi, P.A**., Farrell, I.F., **Stevenson, P.C.,**	UK	UK (M)	*Industrial Crops and Products.* 110, 113-122	https://doi.org/10.1016/j.indcrop.2017.08.021
Journal	Pesticidal Plants in African Agriculture: from local uses to global perspectives* **Stevenson, P.C. and Belmain, S.R.**	UK	UK (M)	*Outlook on Pest Management* Research Information Ltd.	http://projects.nri.org/options/images/stevenson_and_belmain_opm.pdf
Handbook	Anjarwalla P., Belmain S., Sola P., Jamnadass R., **Stevenson P.C.** (2016). Handbook on Pesticidal Plants. ISBN: 978-92-9059-397-3	Kenya	Kenya (F)	World Agroforestry Centre (ICRAF), Nairobi, Kenya	
Videos	English/Kiswahili/Chichewa language videos for farmers on using botanical pesticides to control insect pests without harming the environment and strong	Tanzanian/ UK	Tanzanian/Malawian/UK (MX2 and FX2)		https://www.youtube.com/watch?v=nTIFPt4BB_M&t=16s

	emphasis on impacts against beneficial insects. 2017				
	Project partners indicated by embolden				

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Ref No	22-012
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Checklist for submission

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Have you involved your partners in preparation of the report and named the main contributors	Yes
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