Darwin Initiative Main Project Annual Report

Submission Deadline: 30th April 2017

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 Institute for Science and Technology** **Natural Resources Institute, University of Greenwich (NRI)** **Lilongwe University of Agriculture and Natural Resources**
Darwin grant value	£ 288,762
Start/end dates of project	01/04/2015 – 31/03/18
Reporting period	April 2016-March 2017 Annual report 2
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Report author(s) and date	Philip C Stevenson 30/04/16

1. Project rationale

Tanzania's national poverty reduction strategy paper highlighted that food poverty exceeds 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 at risk of nutritional deficiency and food insecurity. Potential yields are, however, >3000 kg/ha. Insects and the plant diseases they vector are major biological constraints for beans. Pesticides can control insects but are rarely used for reasons of economics and availability. Biodiversity underpins agricultural ecosystem services and ultimately food security, livelihoods and economic development by augmenting natural enemies and reducing pest impacts, while bean yields are 40% lower without pollination. Biodiversity in smallholder ecosystems, however, can be poor in East Africa. Biodiversity surveys from this action will 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.

2. Project partnerships

The project partnership had been working on other actions together led by NRI under McKnight Foundation and EU funding, so an effective working relationship already exists. 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 have managed to make good progress in all areas. We have also engaged for the first time the services of a consultant who has designed, helped undertake and analysed the outcomes of a baseline survey which was slow to get up and running in year 1. The baseline survey was fully resolved in year 2 and is reported here (annex 4H). The agreement for the Malawi partner to come on board officially has been resolved and they have fully engaged with their required actions this year and have been executed effectively. While our Malawi partner LUANR was not expected to participate until year they provided useful information on invertebrate surveys for the year 1 report. This year activities in Malawi are underway as per project plan.

3. Project progress

3.1 Progress in carrying out project Activities

Field visits undertaken by Profs Stevenson (PI) and Gurr (Charles Sturt University) in May 2016 developed protocols for assessing plant - invertebrate species interactions around field sites in the Moshi area of Tanzania. Two Darwin affiliated PhD research students from NM-AIST were also guided on how to develop their research proposals to satisfy degree requirements. A second field visit was undertaken by Iain Darbyshire (Kew), Dr Sarah Arnold (NRI) and Prof Phil Stevenson (Kew) to Lilongwe University of Agriculture and Natural Resources in October 2016 set up field data collection on plant - invertebrate species interactions around field sites in Bunda, Lilongwe in Malawi. These data will supplement surveys in Tanzania and allow some landscape level assessments to be made and compared across countries. This also entailed training 2 graduate students in field sampling and recording techniques.

The annual workshop was held in Arusha in March 2017 hosted by the Tanzanian partner NM-AIST and attended by the 3 MSc students recryited in year 2, two PhD students already registered at NM-AIST our primary collaborating institute in Tanzania along with Prof Patrick Ndakidemi our project partner in Tanzania. UK participants were Dr Sarah Arnold and Dr Steve Belmain (Both NRI). This meeting was used to train the students in sampling and monitoring techniques and develop research proposals to undertake trials to investigate how manipulating ecosystems can optimise ecosystem services (Annex 4 I)

Output 1. *Ecosystems & plant species that are habitats for key natural enemies identified*.

Plant surveys were undertaken at 24 locations at 3 zones and across 2 seasons in Tanzania as proposed in original work plan. Plant diversity and insects visits to plant 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 are in the process of being verified at Kew having (finally) been received at Kew the end of March 2017. Export of these specimens to Kew was hindered by local bureaucracy but has now been resolved. We will assign authoritative names for the species that we have shown to be important forage or refuge for key beneficial insects.

We identified 30 species of plants that are abundant and potentially important field margin species from surveys with a further 5 determined as distinct species but not yet identified (Fig 1). The most abundant plant species for pollinators based on interactions included *Ageratum conyzoides*, *Commelinna benghalensis* and 2 *Bidens* spp. (including *pillosa*) (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). 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 are abundant on a wider variety of species. Invertebrate surveys showed the insect assemblage changed across growing season and from one location to the next. Fourteen functional groups (or species) 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 of the beneficial plant species of bean field margins are 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 will be considered in drafting farmer's information sheets. These will primarily stress the importance of beneficial insects to overcome clear problems with farmer recognition of these but will provide a similar section on beneficial plants but stressing potential issues as weeds. Training of 2 graduate students and project staff in Malawi in the diversity survey techniques (insect surveys and associated plant surveys) was also undertaken including writing a protocol for the plant surveys and specimen collection (Annex 4A).

Output 2: Key invertebrates of beans ecosystems and their habitat established. Invertebrate biodiversity in field margins was estimated (**Annex 4 B**) 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 (e.g., Figure 3). 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) with scope for commercial propagation (Babere and Stevenson, 2017 in review Annex 4) and has been reported as a habitat/shelter for predators of agricultural pests (Liang & Huang 1994). Various species of *Bidens* and *Tridax* contributed a further 21% of interactions. The high frequency of interactions recorded is due both to the prevalence of these plant species at sites and their attractiveness to flower visitors. Their dominance can be inferred from the quadrat/plant diversity datasets for these sites to provide a stronger indication of their relative attractiveness considering their abundance. *Hyptis suaveolens*, which has medicinal properties, was visited frequently by honeybees on some sites, 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 be supporting large populations of pest insects. However, interactions with minor pests including blister beetles leaf hoppers were recorded. The most frequently recorded flower visitor was the honeybee *Apis mellifera*, which was responsible for 44.8% of the total visits (Fig. 2). Bees in general were the most common flower visitors, but hoverflies were also often recorded. Apart from the known pollinators (hoverflies and bee-flies) other Dipterans were pooled for analysis. The number of insect-flower interactions observed in total increased with increasing elevation (Fig. 3). 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, and this will be the focus of a subset of the analyses.

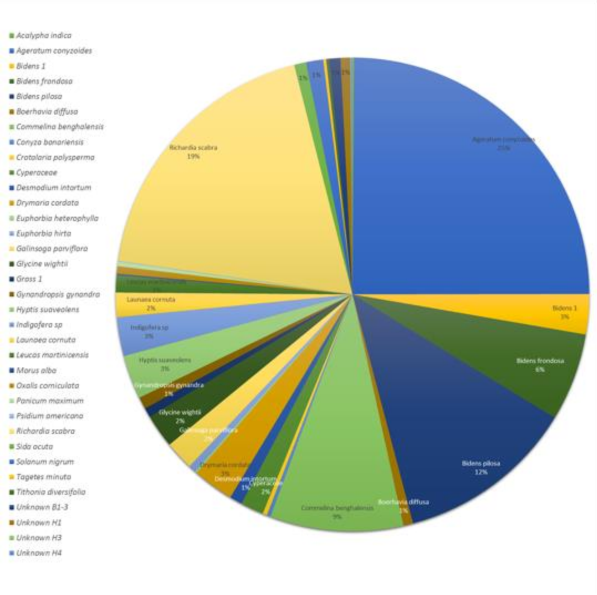


Fig. 1 Plant species recorded as visited by insects during the survey, across all sites, zones and seasons

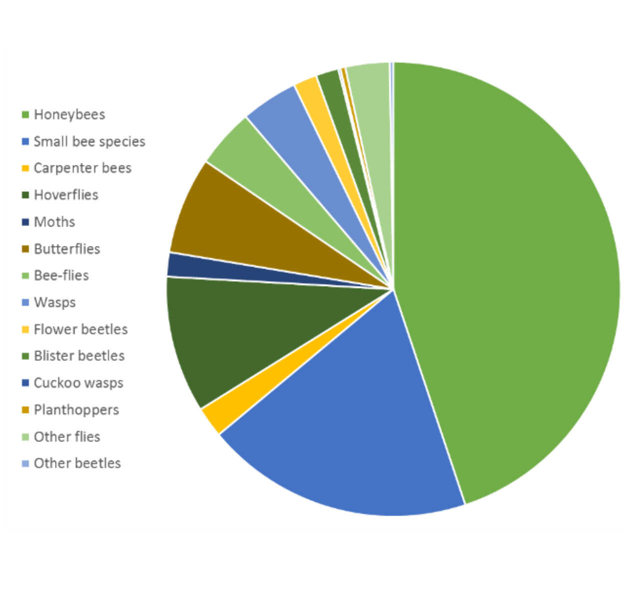


Fig. 2 Functional groups of flower visitors across all sites.

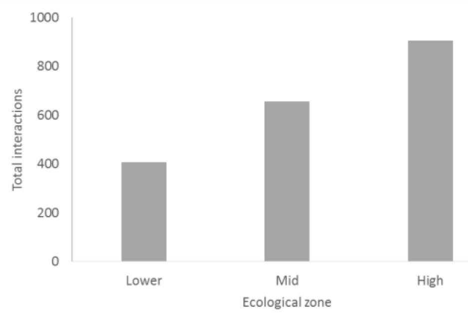


Figure 3 Trends in the number of interactions at different zones.

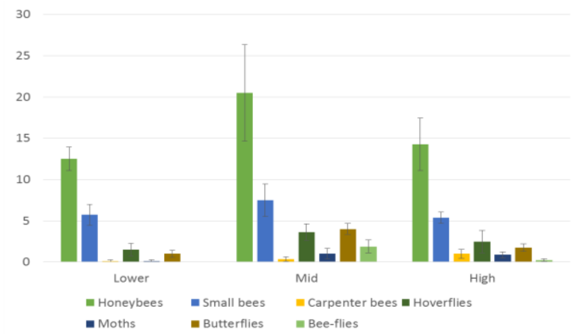


Fig. 4 Functional groups of the key floral visitors during the bean-flowering stage; data averaged per site and collated by zone

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. 4). 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 three agro-ecological zones were similar, but the lower zone was generally less biologically diverse coinciding with more pesticide use. More interactions took place in the higher and mid zones, which may also be accounted for by smaller fields on sloping land with more floristically diverse margins. Data about the rainfall and soil moisture in these areas will be beneficial and will be collected in year 3. The most prominent pollinators were honeybees, but there were also a large abundance and probably diversity of small bees, including sweat and stingless bees. Data suggested further focus on *A. conyzoides*, *Bidens* sp. and *H. suaveolens* is merited, as these have frequent interactions with beneficial insects and pesticidal properties, so could be suited to margin management but their potential as weeds must be considered.

Additional surveys were undertaken at Bunda in 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 less than 150 in poor field margins, with respect to long legged flies, hoverflies and wasps (Annex 4s Table 4).

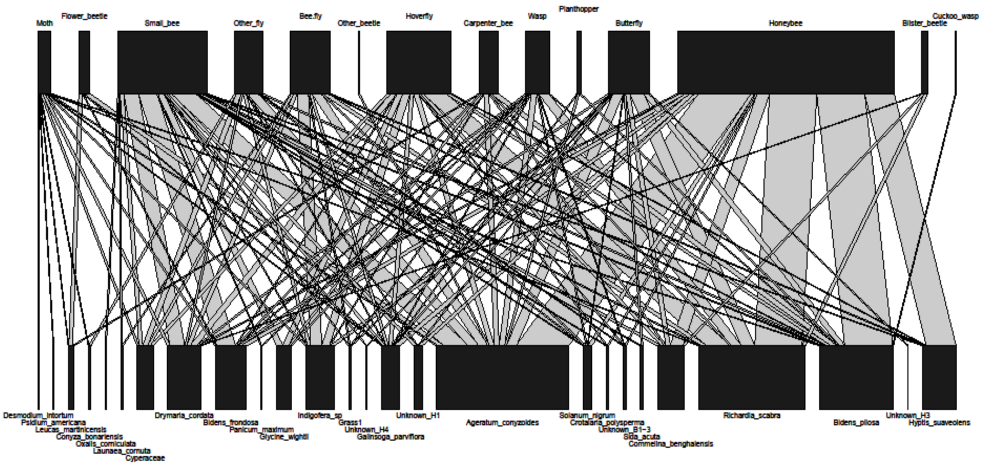


Fig 5. Illustrative pollination network (for high zone as example) showing relative frequency of visits to flowers by specific invertebrates, during bean flowering (visualised in R using the bipartite package). See **Annex 4B** for more details.

Output 3: *Capacity of 400 lead farmers increased by information and guidance on exploiting and maintaining agricultural biodiversity for improved crop yield.* Baseline data was briefly reported in year 1 but data collection continued into year 2 to capture responses from all farmers in all zones and now has reached the 300. The principal objective was to obtain evidence and information on how improved pest control and management practices in bean farming can lead to increased quality and yield and improved living standards for bean farmers. A full report including methodology and data is provided along with the survey tool in **Annexe 4 H**. Along with economic information and agricultural practise pertinent to livelihoods this reports on what farmers know about insects and whether they can distinguish between beneficial insects and antagonists (pests). Key findings about use of pesticides was already reported in year one but their limitations are poorly understood by farmers beyond health risks to themselves and consumers. **Most farmers are unaware of natural enemies while only ~50% could recognise honeybees and hoverflies as pollinators.** Farmers invariably identified natural enemies as insect pests (e.g., identifying ladybird beetles as flower beetles *Ootheca* spp.). Most farmers were unable to name insects and did not know the importance of field margins for supporting beneficial insects but believe they harbour pests. This prompts farmers to clear margins of plants. Our data suggest they do not support the key pests. Some farmers use synthetic pesticides but poorly trained in their use relying entirely on suppliers' advice which may not be appropriate or in the interest of the supplier. Agrovets education is key to reducing pesticides but unlikely without regulation since they may be more likely to encourage the use of pesticides. Some bean varieties were considered to harbouring many insect pests. Most farmers claimed the need of education to apply best agricultural practices that will help to increase bean production.

A pilot study to develop a novel 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 (**Total farmers engaged in baseline survey now = 435 as against 400 proposed**). Data was combined with data from baseline surveys Annex 4H), including demographic information and is being 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. So, community meetings are not a prerequisite for participation. Analyses to assess consistency and validity of data for which assumptions are made (e.g. that cropping phases will be 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. So, now that the data collection has been shown to work, we will feedback information to farmers to inform them but also supplement the survey of impact. During the call farmers can receive advice related to the answers they give; or weekly advice tailored to differing regions. Alternatively, we could provide information to civil/public actors such as extension services or research stations, but also private sector such as input suppliers which would help guide their activities. We are making a training video to inform about the importance of beneficial insects to farmers in collaboration with the McKnight Foundation. A video draft is available here http://tinyurl.com/k8ro529 but will ultimately be voiced in Kiswahili (Tanzania) and Chichewa (Malawi)

Table 1 Current farmer knowledge of beneficial insects

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 27

Output 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. On-station trial designed as recently published (Mkenda et al., 2015 *PLoS One*) 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 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 product. 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 industrial crops and products (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 4 I**. 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.

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 4 C to E**) and defended these at viva through the university process. Data collection is underway March – May 2017. Data will focus on evaluation of sentinel plants for natural enemies and flower bagging (to exclude pollinators) experiments for pollination service. Research presentations by students reporting early results are available on request (too large to include). We recruited 2 PhD students in year 1 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. The students have submitted PhD proposals and passed preliminary examination by viva (proposals attached in **Annex 4 F and 4 G**. Both are working on a review paper for requirements under NM-AIST university rules. 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).

3.2 Progress towards project Outputs

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

	Baseline	Change recorded by 2016	Evidence	
Ind 1.1 Plant biodiversity surveys across 25 locations in	No info available about plant species important to bean	40 species identified as common to bean fields in region	Section 3.1 of report & Annexe 4.	Surveys of 435 completed in TZ 100 more in

TZ by year 2	farming			progress Malawi
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 & Annexe 4	Surveys of 435 completed in TZ 100 more in progress Malawi
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	Section 3.1 for detail Annex 4B	field and station experimental interventions underway 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	Section 3.1 of report provides some detail	field and station experimental interventions underway 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 & their 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 4.**	Surveys completed with full report (annex 4)
2.3 5 key pests and key non crop habitats ID'd via abundance, perceived impact and literature.	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 4B**	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 300 farmers. Survey data from Malawi not yet available.	Findings summarised in 3.1 and details provided in **annex 4 H**	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 video underway	Field and station expts underway to evaluate impact of enhanced ecosystems to bean production and quality through intervention. Annex 4 C-E for expt protocols	
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 4).	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 Tanzania and Malawi indicate pest management benefits of field margin spp. (e.g., *Bidens* a common in field margin plant and visited by pollinators. 2 field margin species tested on storage pests	Section 3.1 of report detail also papers in review/published (Annex 4).	Some species common to Malawi & Tanzania, and 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 and two BSc grads now trained in field survey techniques – 2 X PhD students	Annex 4 for papers published/in review and research proposals/reports.	Training ongoing and on track. several papers by students Annex 4
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 4 for papers published/in review and research proposals/reports.	Training ongoing and on track. several papers by students Annex 4
Ind 5.3 PhD 1 student	None trained	2 X PhD students now enrolled and	Annex 4 for papers	Training ongoing

		conducting research on harnessing ecosystem services	published/in review and research proposals/reports.	and on track. several papers by students Annex 4

3.3 Progress towards the project Outcome

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.			Comments (if necessary)
	Baseline	Change by 2017	Source of evidence	
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 in Africa.	Baseline survey informed farmers about insects beneficial to bean production raising awareness about the project and farmer's intervention will be required in year 3 to demonstrate impact.	Annex 4H & section 3.1 of report	End of project survey *will* determine potential gains of intervention. See Annex H
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.	Currently acquiring information about the ecosystem management in experimental plots – too early to say exactly what yield increases might be achieved.	Section 3.1 and Annexe 4 C-E for proposed work	Trials underway to determine effects of intervention on yield & quality
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	Currently acquiring data from field trials about how interventions enhance ecosystem services – too early to report impacts achievable.	Section 3.1 and Annex 4 C-E	Field Experiments currently running
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.	Too early to say which species will be used to impact farming and yields. However – farmers participating in experimental work in field and farmer schools in year 3 will demonstrate impacts	Section 3.1 and Annex 4 C-E	semi field Experiment currently running
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	Baseline survey to assess levels of knowledge about ecosystem services and wealth have been carried out and info about	Section 3.1 and Annexes	Farmer Survey to be conducted at project end to determine impacts.

3.4 Monitoring of assumptions

An analysis of the assumptions has been undertaken as part of the monitoring and evaluation and those highlighted at the project outset remain valid. **Assumption 1** asserts that Farmers will adopt interventions that enhance the delivery of ecosystems services provided they are engaged appropriately and can be convinced of the benefits. Levels of engagement are higher than anticipated but their impact will be determined during the end of project survey although we have 300 direct participants in the baseline survey in Tanzania plus 135 telephone participants and 113 additional farmers engaged through training in use of pesticidal plants. The project will to provide as much information as possible in local languages through info leaflets where necessary to ensure farmers are fully informed of the interventions proposed and the benefits. **Assumption 2.** Findings will be taken up by agricultural policy makers. Policy briefs will be produced that highlight how ecosystems can be enhanced based on the findings in the project. **Assumption 3** Extreme weather conditions will not affect biodiversity sampling, particularly invertebrates. Weather has not hampered research so far.

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

Biological pest control and crop pollination benefit food production. Diverse agricultural ecosystems are healthier and resilient and enhance crop production through service provision so underpin food security in smallholder farming. However, basic information on ecological diversity to support beneficial invertebrates, and the key plant species for beneficial insects is not known. The level of pollinator contribution to yield and quality and impact of natural enemies is absent for almost all crops in Africa including beans. Recent evidence from Europe indicates pollinators play a major role in yield (40% increase) and quality in beans which are otherwise largely assumed to be self-pollinated, while ecological engineering of field margins augments natural enemies and improves food production in rice cropping systems in Asia. While many field margin plants are crucial in providing habitat, refuge and forage for invertebrates beneficial to crop production – e.g. nectar and pollen for parasitic wasps and bees, especially outside cropping seasons, and habitat for spiders and carnivorous beetles -many of these plant species such as *Ageratrum conyzoides* also have pesticidal properties that can be exploited for pest management. Currently the project is undertaking research towards obtaining the information required to progress farming towards a more ecologically aware approach that will deliver better yields. We have evidence that knowledge about beneficial insects is scant among farmer but now have the information about the key beneficial insects and which species support hem and can use this to demonstrate through field schools which will be implemented in year 3.

4. Contribution to the Global Goals for Sustainable Development (SDGs)

This project addresses in part 6 SDGs
End poverty in all its forms. By enhancing crops yields.
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. **Ensure healthy lives**. By providing alternatives to pesticides reducing exposure of users and consumers. **Achieve gender equality**. Supporting bean production which is typically managed by women. **Ensure sustainable consumption and production patterns** to Support developing countries to strengthen scientific and technological capacity for more sustainable patterns of consumption and production. **Protect and restore and promote sustainable use of terrestrial ecosystems** by providing farmers with knowledge and methods to support increased biodiversity.

5. Project support to the Conventions, Treaties or Agreements

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. 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 Dr. Aloysius Kamperewera Director, Environmental Affairs Department who have both been informed about this project and been invited to join an external advisory panel to evaluate relevance and progress of the action. We are also in communication with the Malawian ITPGRFA national focal point Lawrent L.M. Pungulani who is very supportive of the action (see accompanying correspondence). We have also notified Dr Fidelis Myaka, the National Focal Point in Tanzania for the ITPGRFA who also provided written support for the work.

6. 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 and the plant diseases they vector 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 will be admixed to stored beans enabling longer-term storage of beans worth up to 2 times more when supplies later in the year are depleted. The proposed project is directly and primarily relevant to the problems of the target developing countries and therefore is compliant with the OECD Overseas Development Assistance criteria. The action will be undertaken with the promotion of the economic development and welfare of developing countries as its main objective and seeks to develop zero cost interventions that increase yield and crop quality so are well suited and relevant to current farming strategies in bean production. Currently the project is undertaking research towards obtaining the information required to progress farming towards more ecologically approaches that deliver better yields. However, the evidence for this will not be produced until later in the project. We are still collating information on improved farming methods that consider the benefits of the field margin plants and invertebrates.

7. Project support to gender equality issues

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 (http://www.researchintouse.com/nrk/RIUinfo/PF/CPP28.htm#L3) so by addressing the production of beans through environmentally benign approaches to yield increase this project is directly addressing women in agriculture. We will be particularly mindful of gender as the baseline survey data is assessed considering the project aims. Of the farmers interviewed in the baseline survey 76% are 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 households, and the sole or joint decision-maker about how the income from harvested beans are used in 86% of households, indicating that yield increases provide women with income, which is reportedly spent on female children in 48% of households.

8. Monitoring and evaluation

We are using a theory of change to monitor and evaluate the project success with respect to impact on livelihoods. The ToC assumes that farmers currently have inadequate knowledge and skills on how to control pests and, consequently, struggle to achieve increased bean productivity and quality through the exploitation of their ecosystems. The measures of achievement are based on how this knowledge has changed over the course of the project and whether farmers can implement changes to their farming practise that enhance ecosystem service delivery. Through the project, the farmers will be provided with information and knowledge on managing pests and improving their bean yield and quality. Therefore, the first module to be tracked by the survey will be the initial level and gradual improvement over time in the farmers' knowledge and attitudes.

Once the farmers' knowledge and attitudes have been enhanced through participation in field interventions that are currently underway, they will adopt sound farm management practices which could result in improved yield and quality of beans in their farms. Therefore, the second module to be tracked by the surveys will be improvements in the farm management practices employed by the farmers. The theory of change then predicts 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.

9. Lessons learnt

Owing to delays in appointment of students some training and survey work has been slower to 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. We established new targets and implementation plans which ensured that the project has progressed effectively. We are still largely on target to meet project output and outcomes.

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.

10. Actions taken in response to previous reviews (if applicable)

1. *It is unclear if the project is in discussions with a new partner institution in Malawi or a new project lead at LUANR. Please confirm. What impact will the delayed engagement in Malawi have on the project?* The participation of LUANR in field trials was always intended to be in years 2 and 3 so no delay. The confusion was over the recruitment of the original PI who moved off the project in year 1. This is now resolved and LUANR actions summarised in Annex 4 as per original plan.

2. *When will remaining postgraduate students be recruited and trained? There is mention of only 5 in the report against a target of 10?* We recruited 3 more MSc students in Tanzania this year and 2 grad students in Malawi to undertake the surveys. They were all trained in their respective actions as originally proposed. We anticipate recruiting 2 more MSc students in year 2.
3. *M&E does not seem adequate to monitor capacity building or gender equality (see section 7)*. *Students*: Monitoring of student capacity building will take place by ensuring students are meeting university targets and deadlines and discussing their data in workshops and via e-mail (weekly updates from PhD students). Key NM-AIST MSc/PhD milestones are publications (see Annex 4). We have 10 current or past trainees including 6 MScs and two BSc graduates and 2 PhD, of which 5 are female (50%) and who are monitored throughout degree. Ability to conduct expts. concept note presentation, research proposal defence, progress reports every three months. *Farmers*: In measuring capacity, we will assess the knowledge of farmers in the baseline and end line survey. In addition, during the farmer school fields, we will undertake a pre-test to assess farmers' knowledge prior to sessions and then undertake a post-test to assess change after the session. During outreach visits, the students normally assess what farmers know and provide the knowledge they require on farming - the students document the knowledge gaps and information provided. Regarding gender the baseline and end line surveys assess the decision making and privileges accorded to men, women, boys and girls in the farmers' households. Thus, we assess who decided on how the bean yield is used, who decides how beans income is used and who benefits from beans income - e.g. paying school fees for a female child. The end line survey will disaggregate data by gender where possible.
4. *Consultancy costs were 22% higher than budgeted. Why was more time needed to establish survey locations?* The original budget for the socioeconomic survey was evenly spread across 3 years but the main actions were baseline surveys and post project assessments. We deemed it appropriate to focus more in year 1. Year 2 Survey costs were lower to compensate so overall unchanged.

11. Other comments on progress not covered elsewhere

Owing to the seasonal nature of the target crop the April to April project time frame is not ideal. Planting starts in March in Tanzania so year 1 progress was limited to the tail end of a crop and the beginning of another. Also the time between approval and starting a project is very short giving little time to set up and organise budgets and funding allocations to partners who can do very little without.

12. Sustainability and legacy

Local scientists 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 lasting legacy. By supporting small-scale bean production through strategies that enhance biodiversity in Tanzanian and Malawian agriculture the project will ensure that DI funding has a significant impact for poverty reduction, human welfare and conservation.

High-level capacity development of 2 PhD and ultimately 8 Masters candidates to become leaders and change-agents, able to continue this work beyond the time frame of the project. The advanced training in research, allied to joint publications and presentations at scientific conferences, will make 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 will address poverty reduction and biodiversity conservation and support both countries CBD commitments. Nationwide agricultural policies that encourage ecosystem health and maintenance of biodiversity that improves 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 will develop through our surveys and interventions with farmers. 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.

13. Darwin identity

All communications regarding the project, both in Tanzania and Malawi and elsewhere make specific reference to Darwin Initiative funding (as a distinct project) and these will include a project blog posts. Year one has been a quiet in terms of publicising the project but now the project is up and running in all areas we will endeavour to make more outputs in the public domain. Some information has been provided through Twitter @chickpeaman & @sejarnold and http://www.agriculturalecosystems.org/ which was established as intended this year. There is also web presence on the Kew website here http://www.kew.org/science/projects/harnessing-agricultural-ecosystem-biodiversity-for-bean-production-and-food. 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 in supporting this action within in the host country.

14. Project expenditure

Table 1: Project expenditure during the reporting period (1 April 2016 – 31 March 2017)

Project spend (indicative) since last annual report	2016/17 Grant (£)	2016/17 Total Darwin Costs (£)	Variance %	Comments (please explain significant variances)
Staff costs (see below)			-3	Some additional days of worl required setting up new ICT socioeconomic survey using telephones that is a project add on through McKnight Foundation funding but will enhance data collection in end line survey.
Consultancy costs			24	To compensate for overpayment by £1000 to the socioeconomic consultant in year 1
Overhead Costs			-2	Directly because of increase staff costs above
Travel and subsistence			30	Travel for PI Phil Stevenson to Workshop was delayed owing to a bereavement the day before travel. This trip was rescheduled for end of April 2017. Kew Botanist wa unable to attend workshop owing to commitment to othe commissioned activities.
Operating Costs			18	Underspend on ELISA plates for field testing of insects owing to late germination of crop and no pre-testing achieved in short window between germination and en of year. ELISA plates will be used for monitoring insects visitation during April May and more will be purchased i year 3.
Capital items (see below)				
Others (see below)			0	
TOTAL	**A**	**B**	**6.00%**	

Highlight any agreed changes to the budget and **fully** explain any variation in expenditure where this is +/- 10% of the budget. Have these changes been discussed with and approved by Darwin?

Annex 1: Report of progress and achievements against Logical Framework for Financial Year 2016-2017

Project summary	Measurable Indicators	Progress and Achievements April April 2016 - March 2017	Actions required/planned for next period
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.		Surveys completed. Training and awareness raising of the potential value of ecosystems services to food production shared **with >500 farmers** through baseline survey (300), ICT survey (135) and pesticidal plants training (113).	Development of tool to determine how training, field trials participation and information exchange through field schools and outreach activities enhances farmer knowledge about beneficial insects and the importance of field margin ecosystems. This will be implemented among target farmer groups in year 3
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.	Roles and interactions of key plant and beneficial invertebrate species of agricultural ecosystems understood by farmers and agricultural technicians by end of project.	Several technicians (MSc & PhD students and others) trained in survey techniques, experimental design and data analysis and in the importance of beneficial insects. >500 farmers trained/awareness raised around the benefits of healthy ecosystem to support food production through environmentally benign approaches to horticulture.	Development and implementation of tool to determine how training and information exchange through field schools enhances farmer knowledge about beneficial insects and the importance of field margin ecosystems. This will be implemented among target farmer groups in year 3.
	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.	Field experiments are currently in progress that are evaluating various interventions or comparing different field margin types to determine how they influence insect diversity in bean field.	Continue field experiments into early year 3 and development of outreach tools to encourage farmers to implement those that enhance or support ecosystems services.
	Bean crop productivity and quality improved and monetary value of beans increased for 400 farmers by 20% by project end	Field experiments are currently in progress that are evaluating various interventions or comparing different field margin types to determine how they influence insect diversity in bean field.	Continue field experiments into early year 3 and development outreach tools to encourage farmers to implement those that enhance ecosystems services. Will also require data from post project survey to determine potential financial enhancements

	Role of agricultural biodiversity in crop quality, enhanced yield and consequent poverty alleviating benefits demonstrated to key stakeholders through participatory field trials.	Field experiments are currently in progress that are evaluating various interventions or comparing different field margin types to determine how they influence insect diversity in bean field. These will be used as example field sites for farmer field schools.	Feedback from farmers collated at field school and then at project end.
	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	Undertaking to develop a post project survey tool that understands how interventions improve yields and wealth.	Feedback from farmers collated at field school and then at project end.
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	Surveys **conducted at 25 locations** in Tanzania **and 8 in Malawi** and now complete. Key plants species and habitat types and associations with specific insects determined through analysis for survey data (see annex 4 for details). Completed. Two species with insecticidal properties and of significance as field margin species identified – *Bidens pillosa* and *Ageratum conyzoides*.	
Activity 1.1 Plant surveys to determine botanical biodiversity across 3 ecological zones undertaken across 25 farm locations in Arusha and Moshi.		Plant surveys completed in **25** locations at 3 zones.	
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.	
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.	
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.	Surveys completed in Tanzania and in Malawi but Malawi data awaiting full analysis.	

	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	
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.
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)
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.
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.
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	Baseline survey undertaken in Moshi – currently 300 farmers interviewed using a questionnaire as indicated in annex 4 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). 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.

	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 farmers through fields school and provision of information leaflets	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 data suggest they do not support the key pests. Farmers practice either mono cropping or mixed cropping mainly 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. A pilot to develop a method to collect crop and pest observations directly from farmers was run from July to October in Tanzania and involved farmers from lower, mid and higher zones of Kilimanjaro providing observations about state of crops, pesticides use and insects' occurrence in their fields but via phone calls using an interactive voice response (IVR) system. 135 farmers recruited and provided data through weekly calls over 12 weeks during the cropping period (Total farmers engaged in baseline survey now 435. Data collected has been combined with data from baseline surveys, including demographic information and GPS coordinates and is being assessed for consistency, and compared, where possible, to research field observations to determine reliability of the data. Farmers were recruited via community meetings during which the project was explained, and a demonstration of the process was given and discussed to ensure the questions were clear. In addition, farmers that did not attend the community meetings but participated in the baseline survey were recruited via automated telephone call. Participants receive 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, nor did their ability to answer the questions in the call. So, community meetings are not a prerequisite for significant participation. Open question were more challenging. The questions format about insect incidence/abundance/damage (more/less/the same amount compared to last week') made data analysis more difficult. High response rates and intuitive nature of process the time it takes to lose interests would be a useful metric (average call time for the survey was 3m46s). Currently we're conducting analyses to assess consistency and validity of the data for which assumptions are made (e.g. that cropping phases will be strongly correlated within each zone); finding ways to better ground-truth the collected data would be very useful be able to draw conclusions about the accuracy of the collected data

		(field visits at several points during the fieldwork period or collecting data about known or easily verified phenomena such as rain are two options for this). So, now that the data collection has been shown to work, we can start exploring how to use this data to provide feedback to farmers and potentially to inform them. This could be via information services, for example, during the call itself farmers receive advice related to the answers they give; or we set up a different call that provides advice once a week tailored to differing regions. Alternatively, we could work with organisations and agents working in the areas (if any relevant ones exist and are willing) to provide them with the data which would help guide their activities. This could be civil/public actors such as extension services or research stations, but also private sector ones such as input suppliers. Dissemination of knowledge to 3600 farmers will be implemented in year 3 and the information leaflets will be produced.
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 300 farmers by questionnaire and 135 by ICT in Tanzania. Primary findings summarised above and report in annex 4.
Activity 3.3 – 3.5		Impact of pollinators on bean yield and quality is being evaluated in field trials Comparing bagged versus unbagged beans and 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. Data will be available at the end of the current growing season in Tanzania (June/July 2017). Once these impacts are understood it will be possible to determine benefits to livelihoods of enhancing field margins for farmers.
Output 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.	5 Plant species of potential importance as habitat and refuge for beneficial insects and with potential pesticidal properties identified. 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 2. Pesticidal efficacy of plants evaluated in laboratory and screen-house against two key natural enemies. Farmer field trials evaluating efficacy of pesticidal plants to control bean pests and effects against key natural enemies and	On-station trials designed as reported recently (Mkenda et al., 2015 *PLoS One*) 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 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 *Industrial Crops and Products* (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 4 I**. 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 *Tithonia* and *Vernonia* is also submitted and included in **Annex 4 L**.

	pollinators by end of year 3. Potential of pesticidal plants to increase production and bean quality evaluated through impact assessments in year 3	
Activity 4.1 – 4.4 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. Pesticidal plants evaluated in laboratory and screen-house trials for efficacy against 3 pest species determined Pesticidal efficacy of plants from Activity 4.2 will be evaluated in laboratory and screen-house against two key natural enemies. Farmers in Tanzania and Malawi will be provided protocols to pesticidal plants to control bean pests and effects against key natural enemies and pollinators. Impact of pesticidal plants technologies to increases production and bean quality evaluated through impact assessments		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 4I. Additional trials underway during year 3 with farmers leading activities. Biological effects against beneficial insects determined through field trials reported above and show reduced effects of field margin species. Activities against beneficial in lab to be done in year 3. Farmers have been provided protocols to trials pesticidal plants and undertaken trials with project while 113 additional farmers trained in the use of pesticidal plants for pest control. Impact of pesticidal plants to increase production evaluated and reported in published research articles.
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	Three additional MSc students were recruited in TZ and 2 Graduate students in Malawi on to the project during year 2 (**making a total of 10 post graduate student's so far 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 will continue to receive training including a 3 month training visit to Charles Sturt University, Australia. 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 anticipate recruiting at least 2 more MSc students to the project in year 3.
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		Surveys completed and 10 graduates trained including 6 MSc students 2 BSc graduates and 2 PhD students

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 10 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 4. Students will continue to receive training in plant and invertebrate biology throughout the project and the two PhD students are still to make a training visit to Australia.

Annex 2: Project's full current logframe as presented in the application form (unless changes have been agreed)

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 assessments. 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 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	2.1-2.3 Research paper published in international refereed journals indicating most important invertebrates and their most important plant species habitats. 2.4 Habitat quality index used to quantity diversity and incorporated in paper indicated in 2.1 as methods component	Extreme weather conditions will not affect biodiversity sampling. Mitigation: Sampling will be undertaken across three seasons and at different times 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. 3.6 Impact of ecosystems on bean production disseminated to 3600 farmers through fields school and provision of information leaflets	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. Policy briefs produced for high level audience. Radio interview and Newspaper stories.	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.
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 of at least two plant species and two key beneficial insects by end of year 3	Graduate theses produced and research papers published by students reporting results. PhD thesis produced and interim reports	

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 3: Standard Measures

Table 1 Project Standard Output Measures

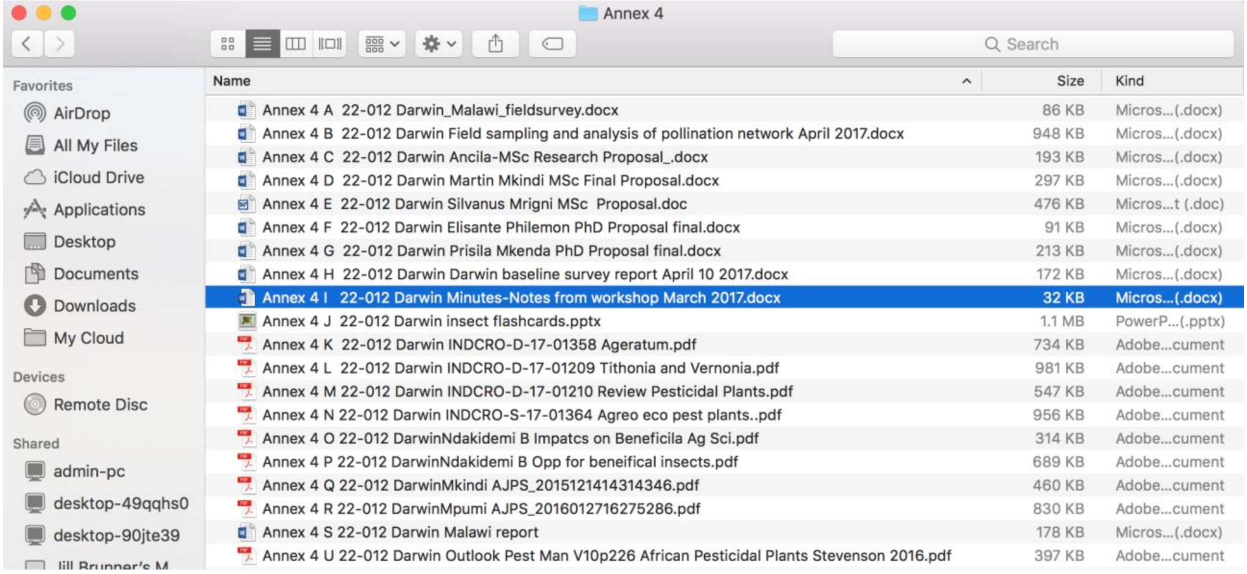
Code No.	Description	Gender of people (if relevant)	Nationality of people (if relevant)	Year 1 Total	Year 2 Total	Year 3 Total	Total to date	Total planned during the project
1B	PhD students appointed	1 male 1 female	Both Tanzanian	2	0		2	2
2	MSc student to undertake Masters project [in progress]	2 male 1 female	All Tanzanian	3	3		3	8
6A	Farmers trained in using field margin plants for pest management	Min 50% female	Tanzanian and Malawian	0	113		113	400
11A	Papers published peer review journals	One male one female senior author.	Tanzanian and UK	2	2		2	4
11B	Papers submitted peer review journals (this gets confused as some of these will move to 11a next year)				4		4	
12 B	Specimen databases enhanced in Tanzania			1	1		2	2
13 B	Malawian and Tanzanian species reference collections enhanced (botanical collections)			1	1		2	2
13 B	Malawian and Tanzanian species reference collections enhanced (insect collections)			1	1		1	2
14A	Conferences/seminars/workshops organised to disseminate findings			0	2		2	2
14B	Conferences/seminars attended to disseminate findings			0	4		4	4
15	National press releases in Tanzania and UK			0	0		0	3
16	Newsletters (including web-based blog posts, and website news items)			0	2		2	5
20	Estimated value (£'s) of physical assets to be handed over to host country			1500	0		1500	5000
22	Permanent field plots established			24 (TZ)	8 (MW)		32	25
23	Value of resources raised as indicated in proposal including in kind McKnight Foundation Charles Sturt University Natural Resources Institute **Total**				0			

Table 2 Publications

Title	Type (e.g. journals, manual, CDs)	Detail (authors, year)	Gender of Lead Author	Nationality of Lead Author	Publishers (name, city)	Available from (e.g. weblink or publisher if not available online)
The Potential of Common Beneficial Insects and Strategies for Maintaining Them in Bean Fields of Sub Saharan Africa*	Journal	**Ndakidemi**, B. Mtei, K., **Ndakidemi**, P.A., **2015**	M	Tanzanian	Scientific Research Publishing Inc.	http://file.scirp.org/pdf/AJPS_2016031015420060.pdf
Field margin weeds provide economically viable and environmentally benign pest control compared to synthetic pesticides*	Journal	**Mkenda, P.,** Mwanauta' R., **Stevenson, P.C. Ndakidemi' P.**, Mtei, K., and **Belmain, S.R**. **2015**	F	Tanzanian	Public Library of Science (*PLoS One*)	http://dx.doi.org/10.1371/journal.pone.0143530
Impacts of Synthetic and Botanical Pesticides on Beneficial Insects*	Journal	**Ndakidemi**, B. Mtei, K., **Ndakidemi**, P.A., **2015**	M	Tanzanian	Scientific Research Publishing Inc.	http://file.scirp.org/pdf/AS_2016061715061431.pdf
The Potential of Using Indigenous Pesticidal Plants for Insect Pest Control to Small Scale Farmers in Africa*	Journal	**Mkindi, A., Mtei, K.M., Njau, K.N., Ndakidemi, P.**	F	Tanzanian	Scientific Research Publishing Inc.	http://file.scirp.org/pdf/AJPS_2015121414314346.pdf
Pesticidal Plants in African Agriculture: from local uses to global perspectives*	Popular article	**Stevenson, P.C. and Belmain, S.R.**	M	UK	Research Information Ltd. *Outlook on Pest Managemen*	http://projects.nri.org/options/images/stevenson_and_belmain_opm.pdf
		Project partners indicated by embolden				

Annex 4 Onwards – supplementary material (optional but encouraged as evidence of project achievement)

See attached annexes in accompanying Zip file.



See below for illustrative photos provided by the Malawi team from year two surveys and sampling – **Annex 4T**

Checklist for submission

	Check
Is the report less than 10MB? If so, please email to Darwin-Projects@ltsi.co.uk putting the project number in the Subject line.	Yes
Is your report more than 10MB? If so, please discuss with Darwin-Projects@ltsi.co.uk about the best way to deliver the report, putting the project number in the Subject line.	No
Have you included means of verification? You need not submit every project document, but the main outputs and a selection of the others would strengthen the report.	Yes
Do you have hard copies of material you want to submit with the report? If so, please make this clear in the covering email and ensure all material is marked with the project number.	No
Have you involved your partners in preparation of the report and named the main contributors	Yes
Have you completed the Project Expenditure table fully?	Yes
Do not include claim forms or other communications with this report.	