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Collating and validating indigenous and local knowledge to apply multiple knowledge systems to an environmental challenge: A case-study of pollinators in India

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ABSTRACT

There is an important role for indigenous and local knowledge in a Multiple Evidence Base to make decisions about the use of biodiversity and its management. This is important both to ensure that the knowledge base is complete (comprising both scientific and local knowledge) and to facilitate participation in the decision making process. We present a novel method to gather evidence in which we used a peer-to-peer validation process among farmers that we suggest is analogous to scientific peer review.

We used a case-study approach to trial the process focussing on pollinator decline in India. Pollinator decline is a critical challenge for which there is a growing evidence base, however, this is not the case world–wide. In the state of Orissa, India, there are no validated scientific studies that record historical pollinator abundance, therefore local knowledge can contribute substantially and may indeed be the principle component of the available knowledge base. Our aim was to collate and validate local knowledge in preparation for integration with scientific knowledge from other regions, for the purpose of producing a Multiple Evidence Base to develop conservation strategies for pollinators.

Farmers reported that vegetable crop yields were declining in many areas of Orissa and that the abundance of important insect crop pollinators has declined sharply across the study area in the last 10–25 years, particularly *Apis cerana*, *Amegilla* sp. and *Xylocopa* sp. Key pollinators for commonly grown crops were identified; both *Apris cerana* and *Xylocopa* sp. were ranked highly as pollinators by farmer participants. Crop yield declines were attributed to soil quality, water management, pests, climate change, overuse of chemical inputs and lack of agronomic expertise. Pollinator declines were attributed to the quantity and number of pesticides used. Farmers suggested that fewer pesticides, more natural habitat and the introduction of hives would support pollinator populations.

This process of knowledge creation was supported by participants, which led to this paper being co-authored by both scientists and farmers.

1. Introduction

1.1. The methodological challenge

There is an important role for indigenous and local knowledge in a Multiple Evidence Base to inform decisions about the use of biodiversity and its management (Sutherland et al., 2013; Tengö et al., 2013). The Convention of Biological Diversity (CBD) refers to the knowledge of indigenous and local communities (article 8[j]) and more recently the Nagoya Protocol (2014) notes 'the importance of traditional knowledge for the conservation of biological diversity and the sustainable use of its components, and for the sustainable livelihoods of these communities'. Policy makers increasingly seek to ensure that policy regulating environmental management is evidence based and also recognize that

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the evidence may arise from parallel knowledge systems (IPBES, 2016). While there are materials available for collating Indigenous and Local Knowledge (ILK) and practices for specific challenges (Lyver et al., 2015), methods for integrating indigenous or local knowledge with the scientific evidence remain debated (Gratani et al., 2011).

There are instances where local knowledge has been successfully gathered and incorporated into decision making with the agreement of the local community (Maclean and Cullen, 2009) but there is also concern about the validity and utility of local knowledge (Bohensky and Maru, 2011; Usher, 2000). As a counter argument it has been pointed out that the process of validating indigenous or local knowledge with western scientific knowledge might be superfluous or misunderstands the epistemology of indigenous knowledge systems (Gratani et al., 2011; Matsui, 2015), and that poor tools may serve to alienate people further from participation (United Nations, 2013 http://unfccc.int/resource/docs/2013/tp/11.pdf accessed 23/02/2017). Although epistemological approaches in parallel knowledge systems may differ there is a need for a transparent tool to verify and validate evidence, one that does not alienate participants but which allows those co-creating policy to be confident that, within its own cultural framework, the knowledge is both valid and agreed.

Sutherland et al. (2013) outline a 3-stage process for collating and integrating parallel knowledge systems to support integrated analysis for decision-making. The first of these stages is to recognize that there are fundamentally different types of knowledge, each associated with different needs for different stakeholder groups. The second stage is to collate and validate indigenous and local knowledge and the third stage is to partly combine it with available information from conventional scientific knowledge, using formal consensus methods such as the Delphi technique (Mukherjee et al., 2015). We developed stage two of this methodology and applied it to a case where indigenous and local knowledge could contribute substantially and may indeed be the principle component of the available knowledge base. Our aim was to collate and validate local knowledge in preparation for integration with scientific knowledge, for the purpose of producing a Multiple Evidence Base to develop conservation strategies for pollinators.

1.2. The environmental challenge

There is a growing acknowledgement (Diaz et al., 2015) that pollinator decline is a global phenomenon (IPBES, 2016; Potts et al., 2010; Tylianakis, 2013) and evidence that declining pollinator diversity and abundance can affect food security (Chaplin-Kramer et al., 2014; Delaplane et al., 2013; Garibaldi et al., 2011; Garibaldi et al., 2016; Klein et al., 2007; Potts et al., 2016) although uncertainty remains over the extent of the impact (Tylianakis, 2013). This concern extends to India (Basu et al., 2011) where little is known about pollinator population trends and there are no published empirical data explicitly linking a change in crop yields to pollinator abundance. This is worth underlining as it has been suggested that decisions, even at national policy level, have been made on the basis of scant evidence (Sutherland, 2013). In India there are no validated scientific studies to elucidate recent trends in pollinator diversity or abundance. This presents researchers with a conundrum – how to determine whether change has already taken place in order to determine the direction of trends in pollinator abundance/diversity and to establish whether they are linked to changes in crop yield.

Through a recently completed project (Defra Darwin initiative 19-024 http://www.darwininitiative.org.uk/project/19024/ accessed 23/02/2017) an important group of stakeholders were identified as smallholder subsistence farmers, including tribal people, who have personal and procedural knowledge of crop production. These subsistence farmers meet a large part of their nutritional needs through a variety of pollinator dependent vegetable crops (Chaplin-Kramer et al., 2014). The project included a participatory scheme, where local communities were engaged in pollinator monitoring efforts, thereby developing citizen science and incorporating valuable capacity building components, as exemplified by Community Based Monitoring and Information Systems (CBMIS) (Tengö et al., 2013). During the project the partners and stakeholders came to a consensual understanding of critical goals that addressed overlapping concerns. The farmers expressed a need to be aware of potential negative drivers of vegetable yields and a desire for a suite of practicable interventions to protect or increase those yields. Scientists (also stakeholders) hypothesised that pollinator populations are declining and that this may be an important driver of changes in vegetable yields. Pollinator-friendly management practices may help to increase yields but the base-line information to develop this is missing. The exercise was designed to address the shared aims of the stakeholders. At a larger-scale, this information will also contribute to a) our understanding of whether there could be a ‘pollinator crisis’ in India, as found in other countries; b) the global evidence-base on the status of pollinators.

Two clear knowledge gaps emerged from dialogue: 1) there was a lack of information on the diversity of crops that were grown and the trends in productivity (frequently not reflected in official databases, *Pers. Obs.*) in the study areas; 2) there was also a lack of information of pollinator identity and trends in abundance and diversity. To further understand whether there is a ‘pollinator crisis’ in India, it is important to know which pollinators are important for crop pollination and whether any changes in crop productivity are linked to changes in pollinator diversity or abundance.

This paper focuses on collating traditional and local knowledge that can be validated in a meaningful and respectful way (Gratani et al., 2014; Sutherland et al., 2013). Validity is interpreted as the extent to which observations reflect the phenomena or variables we are interested in (Kvale, 1995; Tengö et al., 2013). The process of validation involves verification (structural correctness of the knowledge) and evaluation (demonstration of the ability of the knowledge base to reach the right conclusion) (Vallejos and Morimoto, 2013). Here we present a novel method using consensual validation by peer groups of local knowledge holders, whereby knowledge is validated within its own cultural framework and carried out by individuals with the same mental model (Biggs et al., 2011). We suggest this is loosely analogous to the peer review process carried out by scientists to validate scientific data, thus standardising the quality of validation between farmers and scientists. It is in contrast to other methods where the traditional or local knowledge is presented as an environmental report and validated in technical reviews (Usher, 2000) or directly validated against scientific data (Gratani et al., 2011).

The aim of the knowledge gathering exercise was to establish whether farmer participants considered that the yields of pollinator dependent crops have changed in the last 10–20 years, whether pollinator abundance and diversity has changed over the same period via factual observations and then give their assessment of whether these phenomena (if they exist) are linked. A secondary aim was to identify possible mechanisms for any observed changes and potential interventions to conserve or restore crop yields and/or pollinator populations by asking farmers to make inferences based on their knowledge. We differentiate between factual observations and inferences; inferences are inferred mechanisms, causal links or theories, as distinct from factual observations. These can lead to hypotheses testable using experimental scientific approaches (Usher, 2000).

2. Method

The study sites were located in the East Indian state of Orissa and the study carried out in February 2014. The study sites were classified into three types representing different levels of farming intensity based on chemical inputs, vegetation cover, land cover and cropping intensity as described in (Chakrabarti et al., 2014): 1) an area of high intensification with large crop fields, low natural vegetation cover and relatively high chemical inputs; 2) an area of low intensification

Table 1
Questions asked in structured discussions with farmer participants.

Question	Purpose	Validation
1. Which crops do you grow?	Evidence gathering	Within group consensus
2. Is there any change in the yield in the crops you grow?	Evidence gathering	Validated with farmers from other groups
3. How do you know crops yields are changing?	Verification	N/A
4. In your opinion, why are crop yields changing?	Opinion scoping	Validated with farmers from other groups
5. Looking at these pictures, can you name these insects?	Verification	N/A
6. Do these species have a role in crop production?	Evidence gathering	Validated with farmers from other groups
7. How do you know that these insects you mention have a role?	Verification	N/A
8. Which crops do you see these insects visiting?	Evidence gathering	Validated with farmers from other groups
9. What do you understand by 'pollination'	Verification	N/A
10. Are there other insect pollinators not shown here?	Evidence gathering	Validated with farmers from other groups
11. Do crops need pollinators?	Inference	N/A
12. Why do you think crops need pollinators?	Inference	N/A
13. How do you know?	Verification	N/A
14. Which crops need pollinators the most?	Evidence gathering	Validated with farmers from other groups
15. Please rank the pollinators in the picture book according to their value as crop pollinators	Evidence gathering	Validated with farmers from other groups
16. How do you judge how important the insects are as pollinators?	Verification	N/A
17. Have there been any changes in the abundance of any of these pollinators in the last 5, 10, 20 years?	Evidence gathering	Validated with farmers from other groups
20. How do you know there has been a change?	Verification	N/A
21. Would it be useful to have more pollinators?	Inference	Validated with farmers from other groups
22. In your opinion, how could their abundance be increased?	Inference	Validated with farmers from other groups
23. Do pesticides affect pollinators?	Evidence gathering	Validated with farmers from other groups
24. How do you judge whether pesticides affect pollinators?	Verification	N/A

(extensive sites) with small fields, high cover of natural vegetation and relatively low chemical inputs and 3) an area of intermediate intensification according to the same criteria. 80 farmers operating on the boundary of the Darwin Initiative project were invited to participate by local 'rural advisors' who knew them well (the three rural advisors who coordinated attendance are authors on this manuscript); the 50 farmers who took part had not received training in pollinator identification and were not directly associated with project activities. Discussion took place within each study area in three randomly assembled groups of between 5 and 7 individuals. The groups were interviewed concurrently, each working with a different researcher in a separate break out space. In total, nine groups of farmers engaged in the exercise. At the session start, the purpose, process and expected output were explained to participants, who verbally gave consent. Participation was voluntary. Conversations were structured around the questions shown in Table 1 and took place in the local language and dialect. Facilitators encouraged participants to expand on the questions and allowed additional discussion. Detailed notes of the discussions were scribed.

Before discussing trends in pollinator abundance or diversity it was important to confirm that farmers could identify insect pollinators and had a common understanding of pollinator identity; this was confirmed by using a pictorial guide and quiz (Question 7, Table 1), (Fig. 2). Farmers were asked 'what is this?' and 'can you name it?' Positive recognition was recorded if the (local) name was provided by more than one farmer. When each farming group identified an insect we asked "Which crops do you see these insects visiting?" (Question 8, Table 1). This information was discussed and validated within study areas.

Discussion lasted for between one and two hours, after which a number of statements were derived by the researchers; example statements are shown in Table 2. The participants regrouped and were asked to review each group's statements. All farmers had the opportunity to review the statements generated by other groups within their own study area.

Statements were read out and farmers had a brief discussion among themselves following which they were asked to either accept, reject or modify the statement — thereby providing internal validation and consensus for the statements made. In some cases there was a discussion about a particular point but in all cases agreement was reached through discussion. One set of agreed statements was produced from each of the three groups within each of the three zones (nine sets of statements). Farmers were not asked to verify statements from the six groups from the other two study areas.

2.1. Analytical approach

Differences in the number of crops grown in the study areas were tested using ANOVA (Genstat V 16). Other responses were collated and are here represented graphically. To interpret the answers to question 8 'which crops do you see these pollinators visiting?' we constructed a network ('anecdotal network') showing the linkages between the crop plants and the pollinators based on the anecdotal evidence from farmers.

2.2. Network analysis – constructing an anecdotal network

Mutualistic networks are frequently used to represent interactions between mutually-benefited taxa, however, the network we constructed represented plant pollinator interactions based on local understanding. The information from the three study areas was pooled to form a single network describing plant-pollinator interactions based on farmer perceptions. In our network the interaction strength (shown graphically by the width of the connecting lines) indicates the number of farmer

Table 2
Example statements that were generated in discussion with the farmer participants using the questions in a structured discussion. Statements were either detailed (type 1) and more general (type 2). Participants then discussed these and either a) agreed b) rejected or c) modified the statements.

Question	Statement Type 1	Statement Type 2
Is there any change in the yield in the crops that you grow?	Brinjal yield has declined by 25% in the last 10 years	All crops except cucumber have declined in yield in the last 10 years
In your opinion, why are crop yields changing?	Crop yields have changed due to a decreased fertility of the soil	
What do you understand by 'pollination'	In some plants the male and female flowers are on the same plant but they still need pollinators	Pollination means moving pollen from male to female flowers

groups that cited an interaction. We assumed that the more farmers that cited an interaction, the more confidence we could have that this interaction exists, therefore the line width can be seen to represent a proxy for confidence in the information. However, we acknowledge that this information is essentially biased because the chances of a farmer observing an interaction is influenced by detection probability based on size, insect rarity and visitation frequency. Therefore our network only provides information on positive interactions and it is not possible to draw inferences about lack of connections. A further bias is that farmers may misidentify closely related bee species; to minimise this effect we pooled data at genus level for all species except the two *Apis* species *Apis dorsata* and *Apis cerana* as these were readily distinguished by participants. Network analysis was performed by using "R" statistical software version 3.0.1(R_Core_Team, 2013) with "bipartite" (Dormann, 2013) and "SNA" (Butts, 2006) used to construct the network and "ggplot2" (Wickham, 2009) and "igraph" (Csardi and Nepusz, 2006) and packages used to visualise data.

3. Results

3.1. Crop diversity

Farmers reported that collectively they grew 41 crops (Table 3). The number of crops grown did not vary between study areas ($F_{2,8} = 0.07$, $P = 0.935$). Each of the nine groups reported that they grew between 17 and 29 crops between them (Table 3). Three crops were grown ubiquitously: brinjal, ladies finger and ridge gourd. Other commonly grown crops (recorded by at least five of the nine groups involved) included Curcubits (bitter gourd, bottle gourd, cucumber, pointed gourd and pumpkin), legumes (broad bean, cow pea, flat bean, mung bean) as well as chilli, maize, mustard, radish, rice and onion. Three crops were only grown by farmers in one group (banana, spiny gourd and water spinach). Only three of the crops mentioned by farmers are known not to be dependent on pollination services at all, these were banana, maize and rice.

3.2. Change in crop yields

Although there was general consensus between groups on the direction of change within each zone, trends of change in crop yield differed between zones (Fig. 1). In the extensive farming areas some crop yields were reported to have increased significantly, particularly

Table 3
Number of farmer groups reporting that they grew each crop.

Crop	Number of farmer groups	Crop	Number of farmer groups
Chilli	9	Cotton	4
Rice	9	Cucumber	4
Watermelon	9	Flatbean	4
Cauliflower	8	Ladies finger	4
Groundnut	8	Bean	3
Onion	8	Ginger	3
Potato	8	Khirai	3
Pulse	8	Peg Pea	3
Spiny Gourd	8	Rajma	3
Maize	7	Cori	2
Palong	7	Kolmi	2
Ridge gourd	7	Kundri	2
Sesame	7	Lemon	2
Brinjal	6	Mung	2
Pointed gourd	6	Musk melon	2
Pui	6	PD	2
Peas	5	Wheat	2
Pumpkin	5	Banana	1
Radish	5	Papaya	1
Tomato	5	Sunflower	1
Biri	4		

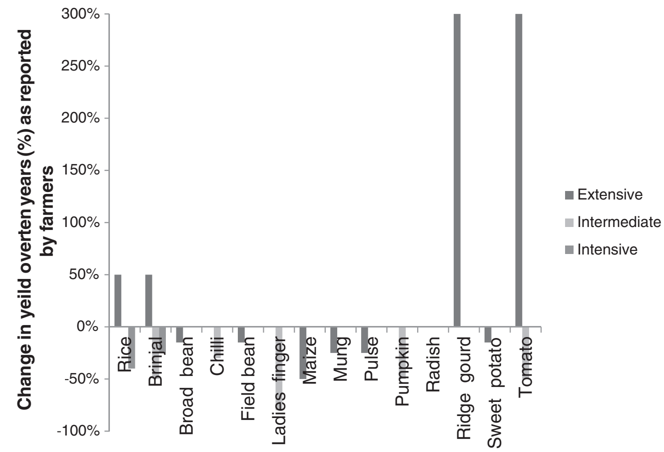

Fig. 1. Change in crop yield over ten years as reported by farmers in extensive, intermediate and intensive farming systems.

ridge gourd (+300%), tomato (+300%), brinjal (+50%) and rice (+50%), although others were reported to have declined including broad bean (−15%), field bean (−15%), maize (−50%), mung (−25%), pulse (−25%) and sweet potato (−15%). In the intermediate and intensive farming areas farmers consistently reported a trend towards lower yields. Farmers in the intensive zone only assigned values to two crops, rice (−40%) and brinjal (−25%) but agreed a broad statement that all other crop yields had fallen. Farmers in the intermediate areas were more detailed, agreeing that brinjal (−50 to −80%), chilli (−30%), ladies finger (−80%), pumpkin (−50%) and cowpea (no value assigned) had all declined. The farmers drew their information from notes on yields that they kept in farm diaries which is a common practice.

Where crop yield had increased farmers cited new products (pesticides and hybrid seeds), new training (in pesticide use and husbandry) and solutions to water management as important factors. The declines in crop yield were attributed to overuse of pesticides (five out of nine groups), declining soil fertility (four groups), increased pest damage (four groups), climate change (four groups), pollinator loss (one group), increased use of fertilizer (one group) and lack of crop specific expertise (one group). The large increases in yield in ridge gourd and tomato were attributed to improved plant quality and hybrid seeds respectively.

3.3. Recognition of pollinating insects

The most frequently recognised pollinators (eight out of nine groups) were *Amegilla* spp. (blue-banded bees), *Apis dorsata* (the rock

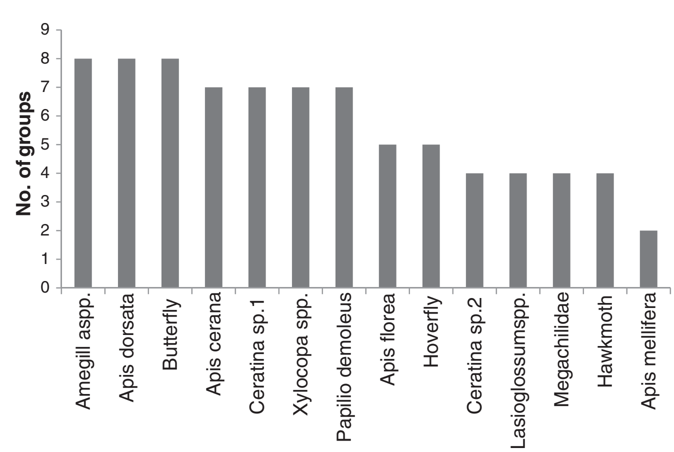

Fig. 2. Number of farmer groups that recognised common pollinating species.

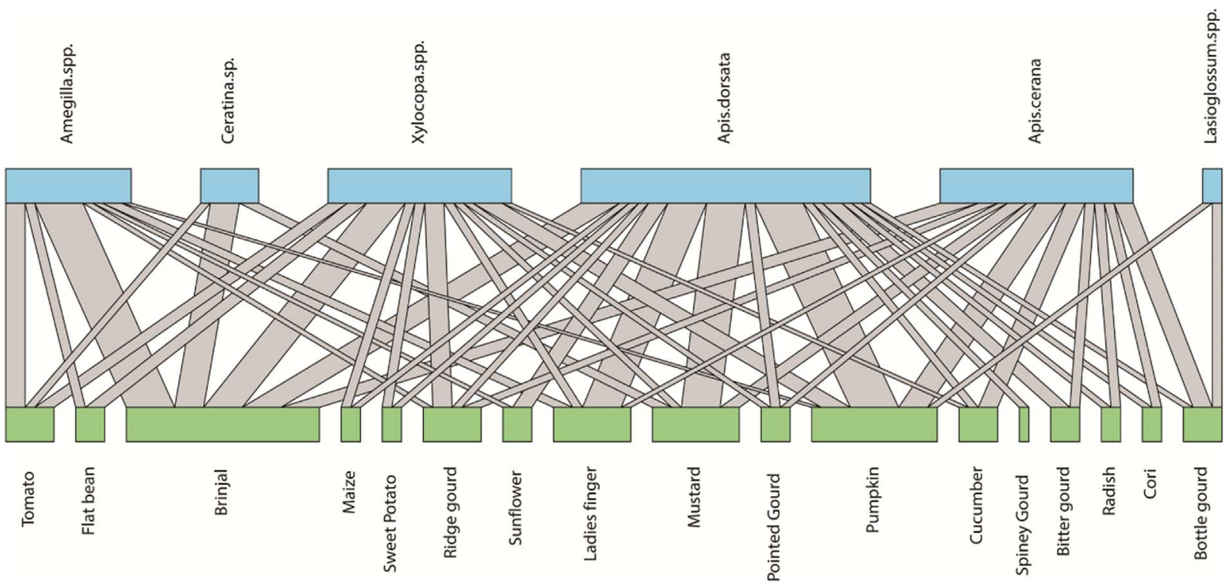

Fig. 3. An anecdotal pollinator visitation network constructed from farmer participant observations of bee visits to different crops.

honey bee) and an example of a potentially pollinating butterfly represented by the peacock pansy (*Junonia almana)*. *Apis cerana* (the Asiatic honey bee), one species of *Ceratina* sp. (a small carpenter bee) and *Xylocopa* sp. (carpenter bees) were recognised by seven of the nine groups as was the lime butterfly (*Papilio demoleus*), the larvae of which are a serious pest. The least well-recognised insect was the non-native *Apis mellifera* (the western honey-bee, which is not present in great numbers in Orissa).

3.4. Role of insect pollinators in crop production

Farmers were then asked if they thought that the insects played any role in crop production. *Apis dorsata*, *Apis cerana* and *Xylocopa* spp. were identified as pollinators by all groups that recognised them. However *Amegilla* spp. (blue-banded bees), *Ceratina* spp. 2 (green small carpenter bees), *Apis florea*, Megachilidae (leaf cutter bees) and hummingbird hawk moths were inaccurately identified as pests by at least one of the groups.

When asked how they gained their identification skills and knowledge of insect behaviour farmers answered that it was gained from personal observation (farmers in eight groups), knowledge passed down by elders (three groups) and text books (one group).

3.5. Anecdotal network based on participant understanding of pollinator visitation

The anecdotal visitation network is relatively simple, showing five bee taxa (including two species of *Apis*) visiting 17 crops (Fig. 3). *Apis dorsata* was the best connected species, visiting 15 crops (species strength = 6.86), *Lasioglossum* spp.were the least well connected (species strength = 0.33), reported as visiting only bitter gourd and pumpkin. Brinjal was known to be visited by most of the bees (five groups) and thus best connected (species strength = 1.43). Spiny gourd was least connected and only visited by *Apis dorsata* (species strength = 0.33).

3.6. Participant understanding of pollination

Pollination was understood to be the process of moving pollen from male to female flowers (reported by eight groups) or 'pollen exchange' (one group). All famers agreed that all crops need pollination (reported by 9 groups); one group emphasised that, even if the male and female flowers were on the same plant, pollination was still necessary. No additional species of pollinating insects were voluntarily suggested by the participants. Eight groups of farmers suggested that pollination was necessary to increase yield while two suggested pollination was important for quality. One group underlined the importance of pollination for brinjal yield and another group answered that crops need pollinators because 'God' has designed it so. None of the validating farmers disagreed with this last statement.

Farmers gained their understanding of the process of pollination by observing the increased yield or fruit quality after pollination (reported by five groups) or by observing the relationship between visitation and yield (reported by 2 groups), from 'books' (four groups), formal training (one group) and parents (one group).

The crops identified as needing pollination most were: brinjal, pointed gourd, ridge gourd, spiny gourd, ladies finger, cucumber, mustard, sunflower, and pumpkin. Pollinators were ranked in importance differently in each system (Table 4).

Farmers based this assessment on their observation of the number of bees seen flying (four groups, Table 5), observation of the behaviour of bees they saw (five groups), general 'observation' (one group); one group assigned the insect's importance as a pollinator according to the amount of honey produced.

3.7. Changes in pollinator populations

Farmers were then asked whether the abundance of pollinator populations had changed in recent years (statements were combined to give the Table 6). *Apis cerana* in particular was identified as having declined dramatically in all three farming systems. The only increase

Table 4
Ranked importance of pollinators for crop pollination as estimated by farmer participants.

Can you rank pollinators according to their importance for crop pollination?	Intensive	Intermediate	Extensive
1	*Apis dorsata*	*Apis cerana*	*Apis cerana*
2	*Apis cerana*	*Amegilla* spp.	Trigona spp.
3	*Xylocopa* spp.	*Xylocopa* spp.	*Xylocopa* spp.
4	*Ceratina* spp.	*Apis dorsata*	Lepidoptera
5	*Lasioglossum* spp.		*Apis dorsata*
6	Lepidoptera		
7	*Apis florea*		

Table 5
Farmer statements identifying the source of their knowledge on which pollinators are important for crop pollination. Numbers represent the number of farmer of groups that gave this statement.

How do you know which pollinators are the most important?	Intensive	Intermediate	Extensive
Observation - behaviour	2	1	1
Observation - abundance on flowers the species visits	3	1	1
Observation - abundance of species of pollinator	1		
Observation - honey production by the bee			1
Observation - improved crop yield linked to visitation		1	
Observation - general		1	

Species specific comments	
Apis cerana	Has a high vistation rate
Apis dorsata	Low visitation rate (ranked last, see Table 4)
Xylocopa spp.	Transfers pollen over large distances

Table 6
Participant perception of pollinator declines over three time periods in three farming systems.

Has pollinator abundance changed?	Intensive	Intermediate	Extensive
Apis cerana	Declined (rarely seen)[a]	− 40%[b]	− 70%[c]
Xylocopa spp.	− 75%[c]		− 70%[c]
Apis florea			− 60%[c]
Amegilla spp		− 60% and − 80%[3]	− 90%[c]
Apis dorsata		− 80%[c]	+ 300%[b]
General bees (in Mustard)		− 50%[b]	
Fewer pollinators generally	Agreed		

[a] Declined and not seen in the last 15–20 years.
[b] Declined and not seen in the last 10 years.
[c] Declined and not seen in the last 20–25 years.

was in *Apis dorsata* in the extensive zone, a trend that was independently suggested by two groups and was validated by all farmers from that zone.

Farmers were asked "what do you think has caused these changes in pollinator abundance?" (Table 7). Eleven drivers were suggested, the most frequently cited being pesticide use (seven groups), although this was qualified in the intensively farmed zone where farmers suggested that it was the number of different pesticides that were used that caused problems rather than quantity in itself (one group). In the extensive area farmers suggested that the social bees (*Apis dorsata* and *A. cerana*) were able to recover and would be seen in the fields a few days after pesticide application. When asked how they came to these conclusions (Table 8) farmers cited observations that included dead and dying bees following pesticide application and general observation of patterns of bee activity and abundance. In the extensive area farmers agreed that weather had changed in the last few years, with cyclones increasingly taking place in the flowering season which reduced bee food supply and killed crop plants.

When asked if it would be useful to have more pollinators all farmers responded 'yes'. The farmers were then asked to suggest ways to increase pollinators (Table 9); the interventions they suggested focused upon pesticide reduction, ranging from 'go organic' to 'use selective pest control' and use 'insect predators rather than pesticides'. Other interventions were focussed on habitat manipulation and also on importing pollinators by using bee boxes (managed hives).

The questions then focused on the use of pesticides and the farmers were asked whether pesticides affected pollinators. All farmers responded in the affirmative. They were then asked *how* pesticides affect pollinators (Table 10) and were then asked to say how they acquired that knowledge (Table 11). Farmers were clear that pesticides either killed pollinators directly or indirectly by disrupting their physiology; however, some more subtle variations emerged. *Apis dorsata* and *Apis cerana* were reported to recover after pesticide applications and, of these two, *A. dorsata* was considered the most resilient. Farmers gained knowledge by observing bee death and reported witnessing them flying

Table 7
The drivers of change in pollinator abundance as reported by farmer participants. Numbers represent the number of farmer of groups that gave this statement, validated by two other groups from their area.

What has driven changes in pollinator abundance?	Intensive	Intermediate	Extensive
Pesticides			
Pesticides negatively affect pollinators	2	3	2
The variety of pesticides(not excess quantity) affects pollinators	1		
Climate variables			
Climate change: cyclones during flowering season destroy pollinators		1	
Habitat destruction			
Pollinators have been destroyed by human activity		1	
No big trees left for pollinators to nest in	1		
Loss of nesting habitat in general means less pollinators	1		1
Selection felling affects pollinators negatively			1
Forest fragmentation affects pollinators negatively			1
Forest fire affects pollinators negatively			1
Apis dorsata may have increased because they are aggressive and this discourages human interference			1

Table 8
Participant statements identifying the source of their knowledge around the causes of pollinator decline. Numbers represent the number of farmer of groups that gave this statement.

How do you know?	Intensive	Intermediate	Extensive
Observation: After spraying there are no bees present		1	
Observation: Bees box colonies die after spraying		1	
Observation: Bees seen dead in front of hives after pesticide spraying		1	
Observation: Local people burn hives because they are scared of stings		1	
Observation – general	1		3
No response	2		

Table 9
Interventions suggested by famers to increase pollinator abundance. Numbers represent the number of farmer of groups that gave this statement, validated by two other groups from their area.

How to can we increase pollinator abundance?	Intensive	Intermediate	Extensive
Go organic		2	
Reduce pesticide use		1	
Use selective pest control			
Use insect predators rather than pesticides		1	1
Introduce bee boxes		1	1
Plant non-crop plants			1
Conserve natural habitat	1		1
Plant more big trees	1		

Table 10
Statements agreed by farmers in answer to the question 'How do pesticides affect pollinators?' Numbers represent the number of farmer of groups that gave this statement, validated by two other groups from their area,

How do pesticides affect pollinators?	Intensive	Intermediate	Extensive
Pesticides kill pollinators	2	1	2
Pesticides stop pollinators reproducing	1		
'After pesticide spraying bees lose coordination and can't find their way home'		2	
Pesticides are strong and kill both 'good and bad' insects			1
Coragen[a pyrethroid] is the most lethal pesticide		1	
Most pollinators are affected negatively by pesticides but *Apis dorsata* and *Apris cerana* recover after a few days			1
Apis dorsata is less affected by pesticides than *Apis cerana*	1		

Table 11
Participant statements identifying the source of their knowledge around the impact of pesticides on pollinators. Numbers represent the number of farmer of groups that gave this statement.

How do you know?	Intensive	Intermediate	Extensive
Observation in the field after application of pesticides	1		2
Observation: See good and bad insects dying after application			1
Observation: Witness bee death after application	1	2	
Observation: After spraying dead bees observed near water courses	1		
Observation: Seen hives 'dying' after spraying	1	1	
Observation: Seen bees flying away during spraying		1	
Observation: Seen that earthworms are also affected by pesticides (by dying)		1	1

away from pesticide sprays.

4. Discussion

4.1. Method

The aim of developing this method was to enable researchers to collate knowledge from indigenous and local knowledge systems to determine evidence-based management strategies in which local communities have their knowledge included, and in which they consequently have a voice. To test this method, we selected a case-study (pollinators in India), that was 1) an example of a system about which little information had been collected by scientists and for which local knowledge was likely to provide the principle evidence; 2) an urgent issue of both local and global concern ((IPBES, 2016).

Underpinning this approach is the assumption that the process collects factual information. This is distinct from work which attempts to represent whole knowledge systems (Brondizio, 2008). It is widely acknowledged that it is important that the evidence collated is validated by peers, as each knowledge system requires appropriate validation that is aligned with its own values (Tengo et al., 2014) and for this we opted to validate the acquired information from within the community using a consensual 'peer-review' approach (Sutherland et al., 2013). In the evidence gathering process we used metrics that could be construed as being rooted in a western scientific framework (Jordan and Kapoor, 2016), such as (Doran, 2002) the use of percentages, and linear cause and effect relationships. However, the aim was to arrive at a set of potentially different but ultimately comparable conclusions from a range of stakeholders and we were keen to capture evidence so that it can be used to facilitate the harmonisation of knowledge further upstream in the management/policy development process. Although no difficulties were encountered when asking about proportions or abundance in our case study, we acknowledge that there is a strong need to co-develop metrics between stakeholders and that this would increase the potential for equitable representation of stakeholder knowledge in management and policy development. Our aim was to gather evidence that would not only stand independently but also be ready for integration with evidence from other knowledge systems (Tengo et al., 2014).

There has been a debate over participatory approaches to research and authors raise concerns that even participatory methods can be exclusive and only give the illusion of participation (Jordan and Kapoor, 2016). However, others argue that this can be avoided by careful construction of the participatory process. This should be approached by developing dialogues 'in a problem solving a process (rather than a static arrangement) involving negotiation, deliberation, knowledge generation' (Berkes, 2009). It is within this kind of framework that method we suggest would work optimally.

4.2. Assessment of the evidence collated

The data collated provides the only information available on local crop yields and an indication of pollinator trends in Orissa. As there is no scientific information available on these issues from this region, it is a useful starting point for participatory research with famers. The overall message supported current understanding from global analyses that pollinators are declining (Potts et al., 2010) and suggests that there have been substantial declines in the last 10–25 years for some bee species which farmers reported as visitors of pollinator-dependent crop flowers. This is a warning sign that there is an issue which needs urgent attention.

Specifically, the evidence collated addressed the knowledge gaps identified in the participatory process adopted by the Darwin Initiative project (19–024). Declining yields were observed by farmers for insect-pollinated staple crops which were important in local diets, such as beans, pulses, brinjal (in the intensive and intermediate areas) and ladies finger (in all areas). These crops are known to provide important micronutrients, (Chaplin-Kramer et al., 2014). The extent to which pollinator imitation in these crops would actually deprive people of important nutrients from their diets would depend on exactly what they eat, and would require empirical analysis, as conducted by (Ellis et al., 2015).

It was suggested by the participants that curcubits (pointed gourd, ridge gourd, spiny gourd, pumpkin, cucumber), brinjal, ladies finger, mustard and sunflower were all dependent on pollination to maximise yield, something that is reflected in the literature. It is known that brinjal, mustard, ladies finger and sunflower all have a modest requirement for insect pollination and yields will increase by 10 to < 40% with insect pollination. Cucumber is more dependent — lack of insect pollinators can reduce yields 40 to < 90%; for other curcubits, insect pollination is essential — production will be reduced by ≥ 90% without animal pollinators (Klein et al., 2007).

Five pollinating taxa were identified as having changed in abundance in the last 10–25 years: *Apis cerana*, *Apis dorsata*, *Apis florea*, *Amegilla* spp. and *Xylocopa* spp. With the exception of *Apis dorsata*, which was reported to have increased in the extensively farmed areas, all bee species were estimated to have declined in abundance. Unlike the other species *Apis dorsata* is a migratory species which may respond to wider level landscape changes (Woyke et al., 2012). In some cases, the decline in abundance was reported to be dramatic (*Amegilla* spp. abundance was said to have declined by 90% in the extensive zone).

We used a network to visualise the pollinator visitation information provided by farmers. The majority of visits were ascribed to *Apis* *dorsata*, *Apis cerana*, *Xylocopa* spp. followed by *Amegilla* spp. — suggesting that the declines in these species could have a significant impact on food security. *Ceratina* spp. and *Lasioglossum* spp. were also mentioned but connected with only two and three of the crops respectively. The crops that were identified as being visited by the greatest diversity of insects were brinjal, pumpkin, ladies finger and mustard. Although visitation does not confirm that pollination is taking place it is suggestive of it and the network provides a basis for further work.

In other studies, concerns have been raised that non-experts are unable to provide good information due to poor ability to identify bees (Kremen et al., 2011). In our study the larger bees were well recognised by the majority (but not all) of the farmers. However, the smaller honey bee *Apis florea* and the solitary bee species belonging to the genus *Lasioglossum* and the family *Megachilidae* were less well recognised. In general it is has been observed that smaller species are less likely to be noticed or identified even by relatively experienced people (Stuart Roberts, (*pers. comm.*)). Bees are not generally well recognised without training which means that more confidence can be placed on information relating to common species.

Farmers used inferred knowledge to provide informed opinions as to why crop yield had changed but did not link crop yield to pollinator visitation. Only one group suggested that a lack of insect pollinators was driving crop yield losses, despite all groups later showing enthusiasm for encouraging pollinators. Nevertheless, participants understood the process of pollination, and although farmers were less sure of the role of specific insects in crop production, the larger bees (*Apis dorsata*, *Apis cerana* and *Xylocopa* spp.) were all identified as pollinators by the groups that commented. The smaller solitary bees such as *Lasioglossum* and *Megachilidae*, along with hoverflies and hawkmoths, were less frequently recognised as pollinators. We suspect that this could represent a detection bias in the knowledge base. Furthermore, some of the smaller species such as *Apis florea* and even *Amegilla* spp. were identified as crop pests by some of the participants. The effectiveness of the majority of pollinating species has been poorly studied in science and, in many studies, bees other than honeybees, bumblebees or carpenter bees are classed together (based on size) despite having diverse life-histories and physiology. For example in (Kremen et al., 2002), *Lasioglossum* species are included in a category called ‘small and stripy’.

There has been much discussion in the scientific literature about the impact of pesticides on pollinators in both scientific literature (Godfray et al., 2015) and in the public domain. The farmers in all study zones considered that pesticides had a negative impact on pollinators, using observations from their fields to support this assertion. One group identified a specific pyrethroid (known as Coragen – active ingredient: chlorantraniliprole) as having a great impact on bees, also confirmed by scientific research (Ceuppens et al., 2015).

Drawing on their experience famers suggested possible interventions to conserve or restore pollinator populations which included reducing pesticide use, managing natural pest predators, conserving or restoring diverse natural habitats and introducing bee boxes (managed hives). The approaches for interventions suggested by the farming community are echoed by the FAO (http://www.fao.org/family-farming/en accessed 6-9-16). Our findings highlight the importance for maintaining diverse non-crop habitats in agricultural landscapes for improved pollinator health. Other authors also underscore the need for researchers, policy makers and farmers to collaborate to mainstream pollinator conservation and management (Rose, 2015). The suggestions made by the farming community in the present study are useful; not only are they practical and testable but show a willing engagement on behalf of the farming community and can be considered a good basis for participatory research, indicating scope for co-producing management guidelines for pollinators.

The evidence collected suggests that pollinator populations are threatened in the study area, particularly in intensively farmed areas. This requires immediate attention from policy makers to consider the management of both farmland and adjacent natural habitats that may support pollinators. The farmers suggested that a reduction in the use of pesticides would be beneficial and therefore alternative strategies for pest control need to be developed and can be considered a priority for research.

In summary, our paper tests a new approach to validate factual and inferential indigenous and local knowledge in the context of an environmental issue that is both local and global in nature. This process will increase the opportunities for communities to contribute to evidence based management strategies. In our case study, there is as yet little relevant scientific knowledge to integrate with the indigenous and local knowledge locally – there is a large scientific knowledge gap relating to trends in pollinator abundance in India and there is little information on key crop pollinators for vegetables. The validated indigenous and local knowledge represents the majority of what we know. This is likely to be the case for many environmental issues, when considered at specific locations and for human livelihood.

A lack of long-term data on pollinator abundance and distribution typifies the situation in much of the world. In areas where data are poor, local knowledge will form the basis of the evidence for determining local conservation needs and strategies. Using this method we captured valuable data that can be used to inform strategies for both policies and management, despite there being little scientific data available, and initiated a shared platform for farmers and scientists to begin to work on a problem that affects us all.

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