PRIORITIES FOR RESEARCH AND DEVELOPMENT IN THE MANAGEMENT OF POLLINATION SERVICES FOR AGRICULTURE IN AFRICA

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Abstract—It is increasingly recognized that a sustainable future for agriculture must build on ecosystem services. Pollination is an important ecosystem service in all agroecosystems. In much of Africa the main challenge is conserving pollinator biodiversity in traditionally "ecologically-intensive" agroecosystems that are changing to meet different demands for food security and poverty alleviation, rather than safeguarding pollination in transition from conventional agricultural systems, with a high reliance on purchased inputs, to "ecologically-intensive" agroecosystems using natural inputs provided by biodiversity. Priority issues for research and development in pollination services in Africa include, inter alia: quantification and documentation of pollination deficits and finding measures to address these; socio-economic valuation of pollinator-friendly practices; assessment of lethal and sub-lethal effects of farming methods, such as pesticide use, on crop pollinators; identification of habitat management practices that enhance synergies between pollinator lifecycles and crop growing patterns; and policy analysis in relation to drivers and trends in pollination services and management.

Keywords: agriculture in transition, ecosystem services, poverty alleviation, sustainable agriculture

INTRODUCTION

Numerous recent reviews of agricultural science and technology (FAO 2011, Royal Society 2009) call for increasing support for systems of food production that are based on "ecological intensification" - understood as a means of increasing agricultural outputs (food, fiber, agro-fuels and environmental services), while reducing the use and the need for external inputs (agrochemicals, fuel, and plastic), and capitalizing on ecological processes that support and regulate primary productivity in agro- ecosystems (Titonnell and Giller 2013). Pollination is of course a key ecological process supporting such productivity. In many regions of the world with high input, high output agricultural systems, the approach may be to restore such ecological processes while reducing external inputs. However, in much of Africa, the strategy may be quite different, to work within traditionally ecologically-intensive agroecosystems to meet changing demands for food security and poverty alleviation.

Both approaches are needed depending on the region and commodities farmed therein. Therefore the expectation is that Africa will have many unique challenges but will also be able to adapt practices introduced in other parts of the world.

Before the African situation can be compared with that in other regions certain basic questions need to be addressed. The purpose of this article is to highlight current priority issues for research and development in managing pollination services that will be applicable in Africa and gather data needed to assess the situation, compare it to global trends and set new priorities. The current priorities are: quantification and documentation of pollination deficits and development measures to address these; socio-economic valuation of pollinator-friendly practices; assessment of the negative impacts of farming methods, such as pesticide use on crop pollinators; identification of habitat management practices that enhance synergies between pollinators lifecycles and crop growing patterns; and policy analysis in relation to drivers and trends in pollination services and management.

POLLINATION SERVICES TO AGRICULTURAL PRODUCTION

Pollination service and poverty alleviation

Recent stressors on the global economy, such as financial instability, soaring commodity prices, energy crises and climatic changes have had negative impacts on human livelihoods, reflected in the fact that the number of undernourished people in the world now exceeds one billion (Gilland 2002; Ash et al. 2010). There are considerable

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pressures on the world food production system to intensify and expand agricultural systems to feed the human population, expected to reach 9.3 billion in 2050 (Lee 2011). Over the last fifty years, agriculture has intensified through the use of high-input, high-yielding crop varieties and livestock systems that are recognised to carry environmental consequences and vulnerabilities to farmers, along with increased production levels (Sachs et al. 2010; Pretty et al. 2010). Within the current production challenge lies opportunities to build food production systems less vulnerable to shocks impacting on those least able to withstand them, and more resilient and responsive to the ecosystem processes that support productivity.

Measures that can build resilience include incorporating ecological linkages and biological processes in agricultural systems, and enhancing the contribution of these over the use of agrochemical inputs (Bommarco et al. 2013). Agricultural systems, by design or by the nature of their development, may be relatively conducive to sustaining biological processes. This is the case in much of Africa, where due to the extensive nature of most farming systems and the relatively low use of inputs, such as fertilisers, most farmers currently rely on natural pollination services, the presence of natural enemies that control pests, and natural means of restoring soil fertility such as through fallow (Styger and Fernandes 2006). While yields are typically low, there are strong possibilities to increase yields through biological processes (Pretty et al. 2005).

Transitioning from one agroecosystem to another, be it from either a high input or ecologically extensive system to an ecologically intensive system, implies an overall "package" of practices to replace previous systems. Yet farmers are rarely able to change to entirely new practices, nor are they inclined to, as they seek to reduce risks. Adopting new practices always entails some measure of trade-offs and decision making that weighs benefits versus costs, and often small but significant investments, for example in sourcing planting material that can sustain pollinators, natural enemies and/or build soil fertility. In some instances, ecologically intensive systems may favour lower yearly yields but longer sustained yields over time (Tilman et al. 2002). Benefits to farmers may accrue through better quality produce, less variability in yield over time and less input costs resulting in better overall profits, or higher incomes from access to specialised and restricted markets. Agricultural policy and support services can serve to structure those benefit and cost relationships, and access to investments that assist in transitions.

The availability of fruits and vegetables is a central component of measures that effectively deal with hunger and malnutrition. In subsistence diets of people below the poverty line there are often insufficient vitamins and minerals within limited caloric intake diets (Graham et al. 2007). Yet those calories contribute much more to health by providing essential micro-nutrients, than those from grains alone, which can lead to obesity and poor health (Ciati and Ruini 2012). Potential pollinator declines are likely to negatively impact the production of vitamin (e.g. vitamin C) and mineral (e.g. calcium and fluoride) rich crops like fruits and vegetables, leading to higher market prices, increasingly unbalanced diets and eventually health problems (Eilers et al. 2011). Globally, fruits and vegetables have never received the same price support and subsidies that grains have, and tend to be more expensive on a calorie-basis.

Horticulture, including fruit production, has been the fastest growing food sector worldwide, with production increasing from 495 million tonnes in 1970 to 1574 million tonnes in 2010 (318%) (FAOSTAT 2007). During the same period, the vegetable subsector alone grew at an impressive annual average rate of 3.8%, from 255 million tonnes in 1970 to 966 million tonnes in 2010 (FAOSTAT 2010). Taking Kenya as a specific, and perhaps leading, example within Africa. Horticulture is the fastest growing agricultural subsector in the country, ranked third in earnings from exports after tourism and tea (Gioè 2006). In recent years, Kenya has been the world's leading exporter of fresh green beans in terms of value (FAOSTAT 2010). Economic analyses have shown that horticultural production in Kenya is capable of producing substantially higher returns per hectare for farmers than staple food crop production; one crop of French beans can generate gross margins more than ten times greater than maize-bean intercropping (Gioè 2006). Of equal relevance is the contribution of pollinator-dependent crops to agricultural development. In Kenya as elsewhere it has often been the case that large-scale commercial growers have not been able to compete with smallholders who have lower labour costs and greater motivation to provide the careful husbandry that meets many of the quality standards required by exporters (Jaffee 2003).

Attempts at valuing the worldwide economic benefit of pollination services to crops have been published. A recent study estimated the pollination service to crop production at about USD 208 billion p.a. in 2005, or 9.5 percent of the total value of the world's agricultural food production (Gallai et al. 2009). This result is also reflected at smaller scales. For instance in Ghana , the overall contribution of pollination services to agricultural production is estimated at 11.1 % of the national agricultural production p.a. of circa US$ 7 million (Gallai and Vaissière 2009a, b) (Table 1). In addition to the overall economic importance of pollination services, the production value per unit farming area of insect pollinated crops is four times that of crops that do not need insect pollination (Gallai et al. 2009). Thus farmers can make more money and produce more nutritious foods if they cultivate high-value, often pollinator-dependent, crops. The value of pollination service is however higher than the current global estimates since the contribution of sugar-acid-ratios and fruit firmness which improve the shelf life thus fruit loss by 11% (Klatt et al. 2014).

Agricultural development programmes aiming at poverty reduction need to recognize the crucial role sufficient animal pollination plays in maintaining and increasing yields of horticultural crops and thus in improving human nutrition and food security.

TABLE 1. Economic impact of insect pollination on the 2005 agricultural production used directly for human food in Ghana (from Gallai and Vaissiere 2009a).

Crop category following FAO	Average value per metric ton in US$	Total value of crop (TVC) Price * Production in US$	Economic value of insect pollinators (EVIP) =TVC*%yield dependent on pollination (D) in US$
Cereals	422	821,267,900	0
Fruits	55	190,191,024	5,895,398
Oilcrops	141	400,822,900	30,717,694
Pulse	687	10,307,100	0
Roots and Tubers	286	4,356,036,458	0
Spices	1940	138,127,909	6,142,868
Stimulant crops	994	756,426,216	710,888,934
Sugar crops	28	3,981,600	0
Treenuts	466	6,060,990	3,296,046
Vegetables	617	396,491,526	31,505,314
TOTAL		7,079,713,622	788,446,253

The role of pollination in crop production

Animal pollination is being increasingly recognised as an essential ecosystem service, whose sufficient provisioning leads to overall increased and stabilized crop production (Garibaldi et al. 2011), and therefore sustained income levels and food security. For instance, coffee (Roubik 2002), avocado and mango (Johannsmeier 2001) which are all important crops for farmers' income and livelihoods in Africa. These crops benefit from insect pollination in terms of number of fruits produced and/or weight of fruits/seeds.

Around three-quarters of food crops worldwide depend on animal pollinators (Klein et al. 2007), including primarily vitamin and mineral rich crops like fruits and vegetables. In Africa, pollinator dependent crops include numerous indigenous vegetables, such as African nightshades (*Solanum scabrum*), amaranths (*Amaranthus blitum*), spiderplant (*Cleome gynandra*), slenderleaf (*Crotalaria ochroleuca* and *Crotalaria brevidens*), African kale (*Brassica carinata*), jute mallow (*Corchorus olitorius)* and African eggplant (*Solanum macrocarpon* and *Solanum gilo*) (Abukutsa-Onyango et al. 2010). Also important are nuts (e.g. macadamia, Johannsmeier 2001) and wild fruits harvested from natural and semi-natural areas such as shea nuts *(Vitellaria paradoxa*). The vast majority of pollinators for these vitamin rich crops are insects such as bees, moths, flies, wasps and beetles (Klein et al. 2007), underlying the importance of insects in securing crop pollination services. Pollination services also contribute to other aspects of crop production. For example, strawberry producers and pollination researchers in Kenya demonstrated differences in their crop yields depending on whether the fields were located near bee hives. Increased insect pollination/visitation resulted in more uniform and marketable strawberries (Asiko 2012); and runner bean with good exposure to honeybees produced fewer "sickle shaped" pods that horticultural exporters refuse to accept (Vaissière et al. 2010). Insect pollination can also influence ripening speed, as is the case for chilli peppers (Bruijn and Ravestijn 1990), which means farmers are able to secure higher, off season, prices for their crop.

PRIORITIES FOR RESEARCH AND DEVELOPMENT IN AFRICA

Agricultural paradigms and practices

As noted above, pollination is a biological process in an agricultural system which can intensify production through sustainable agricultural development. There is a critical need to develop and expand agricultural paradigms and practices that sustain and increase crop yield and quality on existing cultivated land, to meet demands for higher agricultural production by current and future populations. These practices must increasingly rely on the key ecosystem services provided by biodiversity, such as nutrient cycling, pest regulation and pollination that enable the healthy functioning of the agricultural ecosystem. These functions ensure sustainability of agriculture as it intensifies to meet growing demands for food production. For high-value fruits and vegetables, harnessing the pollination services provided by biodiversity, along with companion services, such as soil nutrient cycling processes and natural pest control, is key to sustaining or increasing yields (Bommarco et al. 2013).

Status of pollinators and pollination services in Africa

While there is no solid documentation on the status and trends of pollinators in the African continent, the overall global trends of demands for pollination against anticipated supply is relevant in an African context. The area covered by pollinator-dependent crops has increased by more than 300 percent during the past 50 years (Aizen et al. 2008; Aizen and Harder 2009). A rapidly increasing human population will reduce the amount of natural habitats through an increasing demand for food-producing areas, urbanization and other land-use practices, putting pressure on the ecosystem service delivered by wild pollinators. At the same time, the demand for pollination in agricultural production will increase in order to sustain food production. Current trends, linked to the increase in the horticultural sector, show vastly greater increases in pollinator-dependent crops in

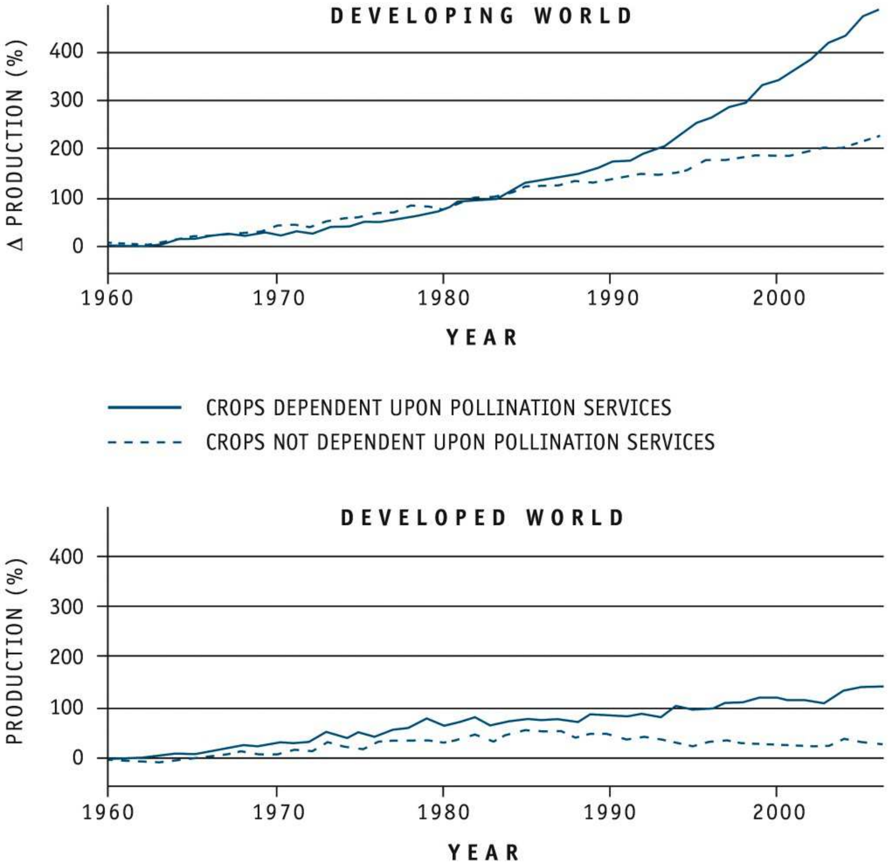


FIGURE 1. Temporal trends in total crop production from 1961 to 2006

developing regions of the world than in developed countries (Figure 1).

Use of managed honeybee colonies for crop pollination has been virtually the sole practice to increase levels of pollination service to agricultural production (e.g. apples in South Africa, Johannsmeier 2001). As with other ecosystem-service practices, future recommendations should focus on past experiences and present information. Honeybees can easily be managed, and their populations increased and moved around to match flowering periods (Radar et al. 2009). However, they are not always the most optimal pollinators (Westerkamp 1991), and can be susceptible to disease and degradation of the natural environment (Johannsmeier 2001). Recent research has shown that interactions between wild pollinators and managed honeybees may lead to more effective pollination than either alone (Greenleaf and Kremen 2007; Carvalheiro et al. 2011). A Recent global meta-analysis has shown that wild pollinators pollinate crops more effectively than honey bees, enhancing fruit set by twice as much as equivalent levels of visitation by honey bees (Garibaldi et al. 2013). Strategic crop pollination recommendations need to be developed, drawn from the possible contributions, benefits and costs of wild and managed pollinators as appropriate to specific systems.

Status of research on crop pollination services

The status of research on African pollination biology was reviewed in 2004 (Rodger et al. 2004) at which point it was noted that relatively little work had been done on pollination biology in Africa. Much of the research which had been done was of an evolutionary nature, with comparatively little focus on either agriculture or conservation. In a number of instances, results of African studies, although not unique, contribute to our understanding of pollination biology. For example, higher levels of dioecy are found in some African plant groups and floras than in comparable areas elsewhere (van Wyk and Lowry 1988; Steiner 1987). Marula, for example, is harvested from wild trees but villagers must know that they must conserve male trees even though they do not bear fruit. Unique pollination syndromes involving, amongst others, oil-collecting bees (Steiner and Whitehead 1996; Steiner 1999), long proboscid flies (Goldblatt and Manning 1999; Manning and Goldblatt 1997) and monkey beetles (Picker and Midgley 1996; Goldblatt and Manning 2000) point to the highly diverse nature of the pollinating fauna in southern Africa's arid regions. On the other hand, high plant diversity and specialized pollination syndromes in some environments has been attributed to a paucity of pollinators, with plants competing intensely, and thus diversifying, to attract the relatively rare visitors (Johnson 1996; Johnson and Steiner 2003).

Surprisingly little work has been carried out in Africa on the pollination of a number of crops that were domesticated on the continent, such as coffee and okra. For several crops important to horticultural production in Africa (e.g. aubergines, tomatoes, peppers, papayas and passion fruits among others) honeybees are not effective pollinators, e.g., they do not buzz-pollinate, do not trip Lucerne flowers and in some areas avoid onion. The focus where honey bees are not effective pollinators must be on alternative, wild species of pollinators. Equally, for those crops pollinated both by honeybees and other pollinators, studying African crops in Africa offers an excellent focus for better understanding the interactions between the two groups.

Over the last ten years, since the African Pollinator Initiative was established (API 2003), an expanding focus on the role of pollination in natural and agricultural systems has been seen. A document taking stock of the state of knowledge of pollinators in agricultural production in Africa was produced in 2005 (API 2005). A resource book to introduce the concept and needs for pollination management to global policy makers and practitioners was drafted and coordinated by the API (Ahmed et al. 2006). Progress has been made on making taxonomic information on African bees accessible to end-users, with a key to the African genera of bees (Eardley et al. 2010). There are also numerous revisions of groups of bees occurring in Africa, such as *Scrapter* (Davies et al. 2005), *Melitta* (Eardley and Kuhlmann 2006), *Andrena* (Eardley 2006), *Capicola* (Michez et al. 2007) and *Ceratina* (Eardley and Daly 2007) and listed in Eardley et al. (2010).

African researchers contributed a review article to a special issue of the journal Apidologie in 2009 (Eardley et al. 2009) devoted to bee conservation; the review concluded that, although Africa contains seven biodiversity hotspots, the bee fauna appears rather moderate given the size of the continent (Eardley et al. 2009). Several factors were proposed for this pattern, an important one being the dearth of bee taxonomists working in Africa and difficulties in carrying out research in many regions. Anecdotal observations suggest a very large number of undescribed bee species on the continent. A number of serious threats to this diversity were also noted to exist, especially habitat destruction and degradation (Eardley et al. 2009). Bee diversity in these regions is likely to be important for both agriculture and maintaining indigenous ecosystems, but is under-appreciated and relatively poorly researched. Reliance on conserved areas such as national parks will not be sufficient to preserve bee diversity in Africa and Madagascar because national parks are more geared to conserve vertebrates than invertebrate and all ecosystems are not adequately protected. Changes to land use practices and development of industries that facilitate conservation will be essential (Eardley et al. 2009) for conserving of pollinating species.

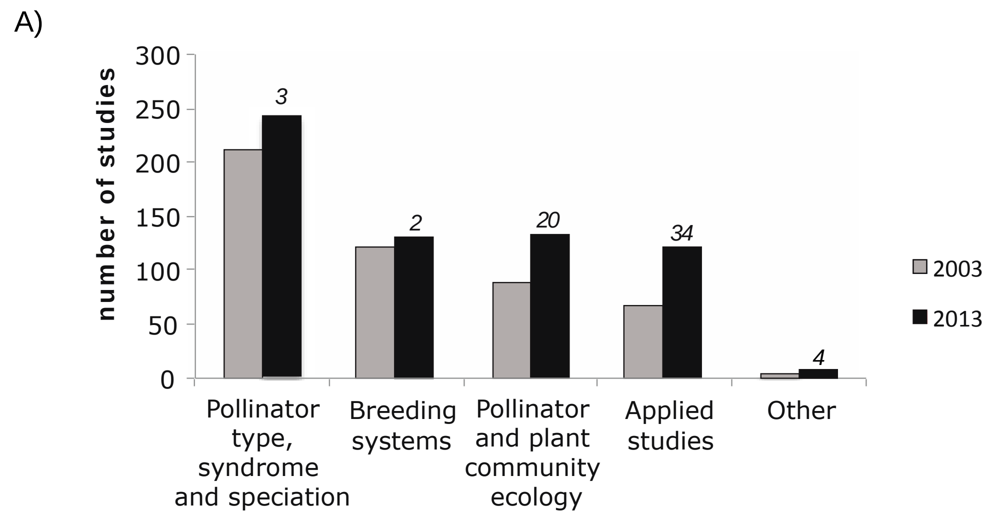
Recent research has described the pollination needs and dynamics of a number of important horticultural crops in Africa. The role of native bees and natural habitats to the pollination of eggplant has been documented (Gemmill-Herren and Ochieng 2007). The contributions of a diversity of pollinators to smallholder agriculture in western Kenya, and their economic benefits have been recorded (Kasina et al. 2009a, b). An important contribution to the economic valuation of pollination services has been made by South African researchers (Allsop et al. 2008). Amongst non-conventional pollinators, the role of hawk moths in papaya pollination has been shown to be of great significance (Martins and Johnson 2009), and in a more recent study hawk moths were found to also visit numerous indigenous plant species (Martins and Johnson 2013). An important study on cowpea pollination has documented gene-flow dynamics between cultivated and wild species (Pasquet et al. 2008). Nderitu and colleagues (2007, 2008) have detailed the detrimental effects of insecticides applied to sunflowers in Kenya on the diversity of bees and consequent seed yield. An interest in managing wild stingless bee species for both pollination and honey production has been published in recent articles (Cortopassi-Laurino et al. 2006; Kasina et al. 2009c). Interesting and unique syndromes of pollinator-plant interactions, such as strong associations of bees with grasses in Africa, have been reported (Bogdan 1962; Immelman and Eardley 2000; Gemmill and Martins 2004).

A reanalysis of the existing knowledge database on pollination in Africa, based on the original analysis of Rodger et al. (2004), has turned up a number of interesting insights (Figures 2a and b). First, and in part due to a Food and Agriculture Organization (FAO) coordinated project in Ghana, Kenya and South Africa that has supported national partners to database relevant studies, an additional 122 studies have been identified. Some of the studies come from more obscure sources as well as mainstream literature, and the facility to identify them now, as opposed to ten years ago, reflects the improvement in search functions and sharing of information over the Internet. Sixty-two of the new entries, however, are from new studies carried out between 2004 and 2013. The studies making the largest contribution (n=34) had an applied subject, always with an agricultural focus. The geographic location making the largest contribution over this period was East Africa (n= 39). Thus more attention needs to be given to pollination research in other areas of Africa.

Priorities for research and development

While considerable work has been undertaken to document the importance of pollinators to sustainable agriculture in Africa (i.e. studies mentioned above), work is still required to identify agricultural management practices that can increase the amount of pollination and thus yield of pollinator dependent crops. The next step will be to translate the knowledge base on pollination and other ecosystem services into a set of practices using biological processes that can be implemented to sustainably increase agricultural production in Africa. There is a strong need to understand how such ecosystem services can be enhanced and sustained, such that they provide a sustainable underpinning for production and livelihoods.

An important basis for such research is the recognition that considerable local knowledge already exists, making smallholder agriculture in Africa more efficient than large scale farms in some cases (Lele et al. 2010; Pinghali 2010). Interventions to sustain ecosystem services are likely to be highly site-specific and will need to be developed through a synthesis of existing, traditional knowledge and innovations by agricultural researchers. Specific development and research



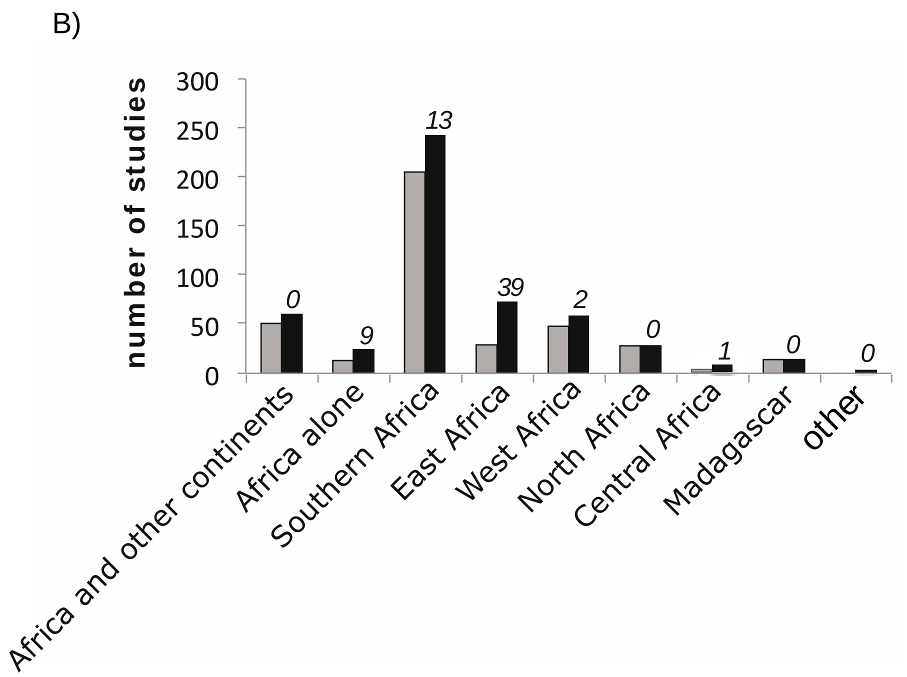


FIGURE 2. Classification of pollination studies carried out in Africa as identified in 2003, and in 2013. A total of 393 studies were identified in 2003, and 515 in 2013, with the increase in 2013 reflecting: (1) improved search ability and access to literature, including theses, (2) an FAO-coordinated project in Ghana, Kenya and South Africa that includes databasing the knowledge base and (3) 62 new studies published from 2004-2013. Numbers above the bars for 2013 results indicate the number of new studies in each class, from 2004-2013. A classification criterion is found in Rodgers, Balkwill and Gemmill (2004). A) Classified by subject matter. B) Classified by location of study

agendas that have been proposed as priority areas include the following:

First, there is need to develop a systematic assessment of the occurrence and consequences of pollinator declines to agricultural production over a range of crops all over the world. A protocol to assess pollination deficits has been developed through collaboration between FAO and the Institut National de la Recherche Agronomique (INRA) in France (Vaissière et al. 2010). The protocol should be applied to a range of cropping systems, both extensive and intensive, to detect and assess the extent to which insufficient pollination limits crop productivity across crops and across regions.

Second, the identification of habitat management practices that can best contribute to building up wild pollinator populations to service crop pollination needs. Farmers can supply pollinator foraging resources by encouraging the establishment of attractive indigenous plant species that flower throughout the year, or increase nesting sites (e.g. by providing wooden bee nests or empty reeds for solitary bees), and applying conservation tillage to safeguard ground nesting bees (Gemmill-Herren, Azzu and Biesmeijer in prep). Documentation is needed on flowering plants species that can be used in hedgerows, fallows and natural habitats adjacent to the farms to provide a source of nectar, food, nesting opportunities and shelter for wild pollinators.

It is recognized that for farmers to implement pollinator-friendly practices, the benefits accrued from improved pollination service they receive must outweigh the costs of such practices. Participatory methods could assist farmers in recording costs and benefits of their practices. Many pollinator-friendly practices may involve minimal costs, such as to encourage (or not weed) selected wild flowering plants that are not pernicious weeds, near crops and document floral visitors over time. Other measures, including taking some crop land out of production to allow for native plant restorations, or reducing applications of pesticides, involve more complex understandings of costs and benefits. Research on the barriers and incentives for the uptake of ecological intensification practices, including pollinator-friendly measures, is also needed to support a transition to a more sustainable form of agriculture built on the enhancement of ecosystem services.

Third, agricultural pesticides may adversely affect pollinators in a variety of ways. For example, high concentrations can cause direct mortality while sub-lethal exposures of bees to pesticides during field applications can induce changes in individual bee activities and colony performance (Fisher and Moriarty 2011). There is little information available about the effects of pesticides on pollinators in Africa (van der Valk et al. 2013). Studies are needed to provide basic information on lethal and sub-lethal effects of selected insecticides commonly used by farmers, on social and solitary bees (Martins 2011). For example, work on pesticides used in fishing has been shown to be detrimental to dragonflies (Martins 2009) and similar patterns are expected for pollinators.

Forth, determining the lifecycles of wild pollinators (generation time, number of generations in a year, timing of reproduction) and assessing how they interact with crops during growing seasons, e.g., pollinator availability during off-season cultivation through irrigation and alternative food plants for pollinators when crops are not in flower. Development of pollinator management strategies including inventories of wild pollinators requires detailed understanding of their phenology, life history and distribution in relation to crop growing patterns. For this purpose, the taxonomic capacity to identify pollinators, at least to morphospecies, needs strengthening because pollinator may only visit certain crops types, and not all flower visitors are pollinators.

POLICY ANALYSIS

Pollination rarely receives much attention in the policy arena, but the farming category to which it substantially contributes, horticultural production, is growing in importance in Africa. The supply of fruits and vegetables remains little addressed component in fighting hunger and malnutrition. Multiple drivers affect, and will increasingly impact the future of horticultural production in Africa, and the contribution of pollination services to production. Pollinators cannot be protected in nature reserves alone, and so there is need to establish policies that guide pollinator protection in all terrestrial ecosystems including urban areas due to the prevailing threats such habitat modification, pollution and use of chemicals pose.

Population growth and agricultural intensification

African governments recognize the need to increase food production to provide food security for growing populations. Increasing production may have many possible paths: it can lead to larger, more consolidated farm operations producing for commercial markets. Where there are markets with value chains that dictate standards, such standards can shape agricultural practices. For example, in some markets, fruit is only marketable if it is blemish-free, leading to increased use of pesticides for cosmetic purposes. In other instances, produce must not exceed limits of pesticide residues, leading to decreased use of pesticides. Alternatively, in consolidated operations, there is a growing recognition that smallholder farms may be significantly more productive than large farms in some situations (Pinghali 2010). With appropriate policies and support from the state, smallholder production sectors can be formidable engines for economic growth and poverty alleviation. Amongst these trends, small farm sizes and reduced pesticides usage are outcomes that are likely to benefit the provisioning of pollination service, and may be impacted by policy measures and voluntary standards.

Climate change

Climate change is expected to lead to fluctuating and frequently reducing, crop yields in Africa, as El-Niño-like events increase as is predicted in most climate models (Stige et al. 2006). Cultivating drought tolerant annual fruits and vegetables is one of the options that have been proposed for farmers adapting to climate change (Lobell et al. 2008). Horticultural crops such as melons (cucurbits) and vegetables generally produce over a shorter period than grain crops, and thus can fit into requirements for later start dates, when rains are delayed, or early harvest dates when rains are curtailed. Certainly, drought and consequent water deficits are likely to pose greater resource limitations, than pollination but both merit consideration under changing climates and changing crop options. Little is known about how pollinators may adapt their life history strategies when growing seasons are either shorter, or lengthened with irrigation, and research addressing this is needed. However, long-term irrigation is likely to disrupt biological processes of ground nesting bees especially in natural arid and semi-arid regions.

Farmers may select different crops, and thus change the distribution of crops in response to climate change, but wild pollinators cannot be so easily transplanted. Maintenance of reserves and habitat corridors between reserves, may enable some pollinators with long foraging ranges to readily disperse to new areas in response to different temperature and rainfall regimes.

Changes in diets

Economic development has been identified as one of the drivers of diet change in many economies (Caballero 2002). The pace of shifts in diets has recently accelerated (Popkin 1998; 2002), and these trends may have strong impacts on demands for pollinator-dependent fruits and vegetables. In many societies, as threats of famine recede, the consumption of fruits, vegetables, and animal protein increases, with starchy staples becoming a smaller percentage of food consumed (Drewnowski and Popkin 1997; Popkin 2002). As the consumption of processed foods, high in total fat, cholesterol, sugar and other refined carbohydrates and low in polyunsaturated fatty acids and fiber increases along with more sedentary lifestyles, dietary disorders such as obesity may also increase. But a third dietary trend is emerging, associated with desires to avoid dietary disease and promote health, this trend focuses on the importance of good nutrition for children and a return to fruits, vegetables, pulses and less processed food (Nestle 2006). This latter trend may be instituted and encouraged by consumers or by government policy. The impacts of this can be seen in countries such as Kenya, where products that incorporate flours from pulses into meal flours are increasingly popular for child nutrition, urban demands for fresh fruits and vegetables per capita are increasing, and soft drink providers are introducing products that incorporate fruits as a base (Gioè 2006; Gikungu pers. communication).

Local market access

Diversification into horticultural crops is becoming an avenue to poverty alleviation amongst many farmers around the world (Weinberger and Lumpkin 2005). For farmers to benefit from expansion into horticultural production, market access is critical. Fruits and vegetables are traditionally sold in regularly convened markets in centers of population. Although the presence of supermarkets in developing countries is a rapidly increasing phenomenon, horticultural produce tends to be largely locally sourced (McCullough et al. 2008). Supermarkets can still offer favourable access for farmers growing horticultural produce. In addition, urban consumers tend to be more concerned and conscious of how their fruits and vegetables have been grown (for example whether there may be pesticide residues in their food), thus there may be a potential for capturing price premiums for crops grown under sustainable practices (Onozaka et al. 2006).

An important aspect of market access for producers of pollinator-dependent crops, however, is that many of these crops (fruits in particular, but also vegetables) are highly susceptible to spoilage. It is increasingly recognized that food waste has tremendous impacts on both food security, farmer livelihoods, and natural resource use (Food Wastage Footprint and FAO 2013); thus more investment in efficient supply chains has multiple benefits. Recent publication may have found a way of ameliorating this problem by the increased shelf-life contributed by pollination in strawberry (Klatt et al. 2014) and by extrapolation other crops.

Globalization of trade

The profound changes in the nature of the international economy with the advance of globalized trade brings both threats and opportunities to agricultural production in Africa. Given the large and growing trade of horticultural products from Africa to Europe, it can be argued those countries that import horticultural crops from the continent are as vulnerable to pollinator losses in Africa as in their own countries (Gallai et al. 2009). Thus, pollination deficits may be matters for supra-national policy concerns.

CONCLUSION

Yields from agricultural production in Africa are amongst the lowest in the world (Tittonell and Giller 2013). There are strong expectations that intensifying farming systems will contribute to addressing issues of hunger and poverty throughout the continent. If productivity is not increased, the rate of natural habitat loss and degradation may be accelerated, resulting in a further decrease in food security. A tremendous opportunity exists to instead use sustainable intensification methods to build on and enhance the natural wealth and ecosystem services underlying most African ecosystems, rather than to intensify through greater reliance on anthropogenic inputs. Pollination services and their contribution to the production of horticultural crops, may serve as an excellent flagship area of research and development in African agriculture as sustainable agricultural solutions are sought for the continent.

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