Sacred church forests as sources of wild pollinators for the surrounding smallholder agricultural farms: a unique combination of religion and crop pollination in the Lake Tana basin, Ethiopia

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Church forests in Ethiopia

- Wild pollinators require natural areas like forest habitats in agricultural landscapes that can provide floral resources and nesting habitats (1).
  - ✓ Sacred church forest habitats significantly contribute to crop pollination and yield.
- Church forests scattered across intensified agricultural fields provide pollination services for nearby smallholder crop fields.

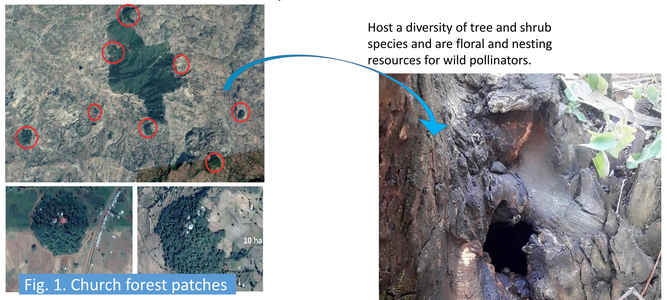

Fig. 1. Church forest patches

Host a diversity of tree and shrub species and are floral and nesting resources for wild pollinators.

Wild bees in tree cavities

Bees on crop flowers

This study assessed the local-scale pollination service with distance decay from church forest habitats using field-based data, remote sensing and spatially explicit empirical models.

Materials and methods

Church forest ecosystems

- The study area located in northwestern Ethiopian highlands
- Home to old Afromontane forests
- The area of each church forest ranges from 5 – 1,000 ha

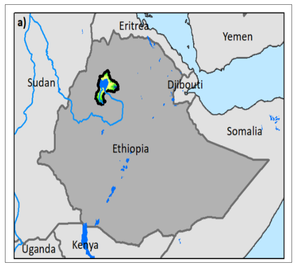

Fig. 2. Map of the study area

- Field data were collected during summer 2020 (Mid July to October)
  - ✓ Floral tree inventory in the 15 sampled church forest patches (69 plots of 20 by 20 m)
  - ✓ Crop flower visitation rate data on four major pollinator-dependent crop types (72 sampling plots of 2 by 2 m)
  - ✓ Land use data surrounding the 15 church forest patches (within 1500 m)
  - ✓ Interview with church custodians about church forest age

The 3 Methodological steps:

1) Spatially characterizing forests & croplands
   - ✓ Land cover mapping ➔ Sentinel-2 and PlanetScope images of 2020
   - ✓ Land cover configuration ➔ forest patch size (ha), cropland area (ha), crop field proximity to forest patches
2) Assess functional diversity index based functional traits floral trees and their abundance
3) Model crop flower visitation using GAMMs model
   - ✓ Six spatial predictors include: forest patch size, forest floral functional richness, forest age, distance buffers from the nearest forest habitat, crop field proximity index to surrounding forest patches, and crop types.

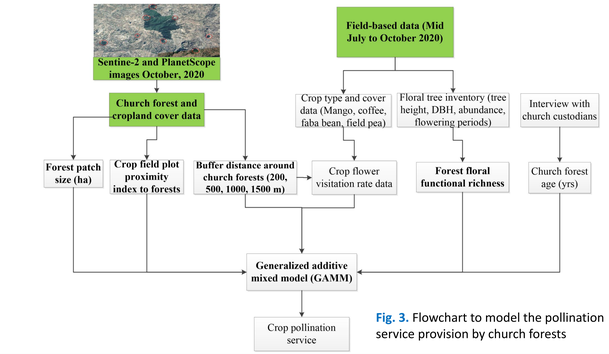

Fig. 3. Flowchart to model the pollination service provision by church forests

Results

1) Spatial characteristics of church forests and pollinator crops

- A total of 1,058 patches of church forests were identified based on church building shapefiles in the entire study area
- Covering a total area of aprox 12.6 thousand ha ≈ 1 % of the terrestrial landscape.
- Cropland area within the 1,500 m radius of all church forests was 700 thousand ha (76.4% of the study area)
- Of which about 196 thousand ha (28.0 % of the cropland) include croplands that at least partly benefit from wild pollinators (mango, coffee, faba bean, and field pea).

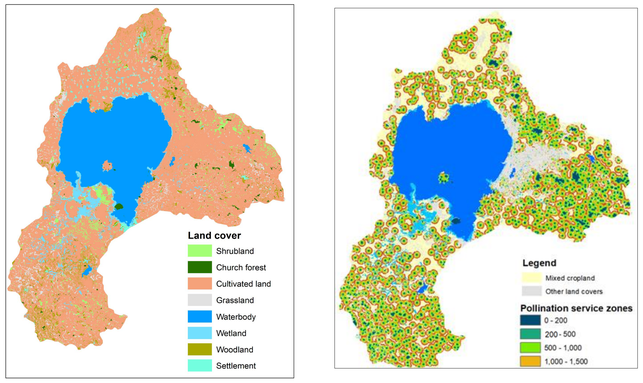

Fig. 4. Land cover map and pollination service zones of the study area

2) Floral characteristics

- 67% of the tree species surveyed in church forests provide floral resources and nesting habitat.
- The duration of floral flowering periods varied from 3 to 12 months.
  - ✓ Out of the crop growing season, floral resources are an important foraging resource (complementary to crop)

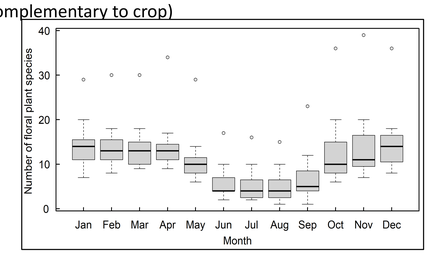

Fig. 5. Flowering calendar of important floral plant species in church forests

3) The GAMMs model outcomes.

- Effects of church forest habitats on pollination services would decays with distance.
- The effects of both pollinator providing church forests habitats and pollination service benefiting crop on the flower visitation rate investigated.

Table 1. flower visitation model

Explanatory variables	F-value	p-value
Distance from church forest: Coffee	24.808	***
Distance from church forest: Mango	64.491	***
Distance from church forest: Horse bean	14.001	***
Distance from church forest: Field pea	10.527	**
Crop field proximity index	44.246	***
Floral functional richness index	11.26	***
Church forest age	6.201	*
Forest patch size	5.316	*

Significant codes: '***' P<0.001; '**' P<0.01; '*' P<0.05; ' ' P<0.1.

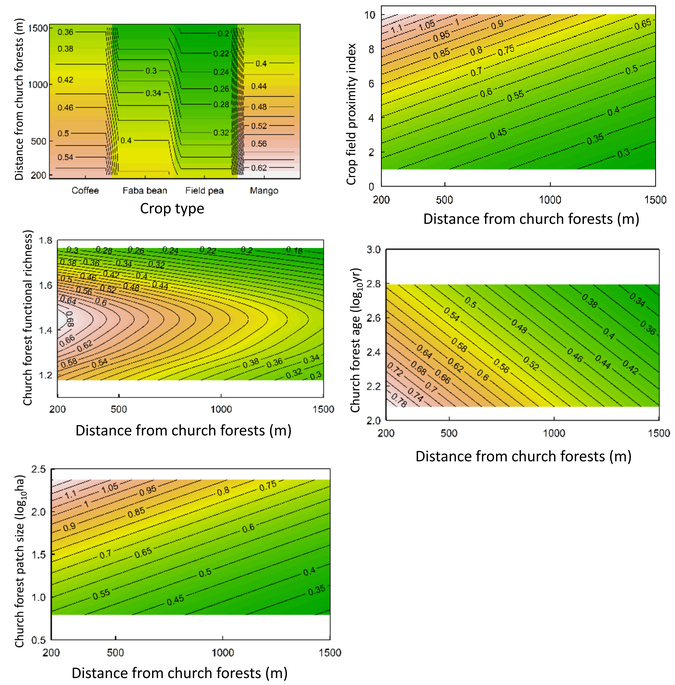

Fig. 6. GAMM plots of the relationship between crop flower visitation rate (visits/flower/15 min) and variables along distance gradients from church forests.

Key messages

- Clear empirical evidence that religiously conserved church forest habitats, by harboring wild pollinators, provide complementary pollination services to surrounding crop fields.
- Pollination is higher closer to the church forests.
- pollination service zone overlap exists in proximal church forest habitats
- Mango and coffee crops were most benefited from pollination.
- Integrating primary field data and RS imageries to empirically model pollination services are essential for land managers & decision-makers to develop appropriate mitigation & conservation strategies.
- Culturally protected sacred church forests play an important role in conserving the floral resources and wild pollinators, which support crop yield for food security and nutrition and income (cash crops).

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References
1. Williams, N.M., Kremen, C., 2007. Resource distributions among habitats determine solitary bee offspring production in a mosaic landscape. Ecol. Appl. https://doi.org/10.1890/06-0269