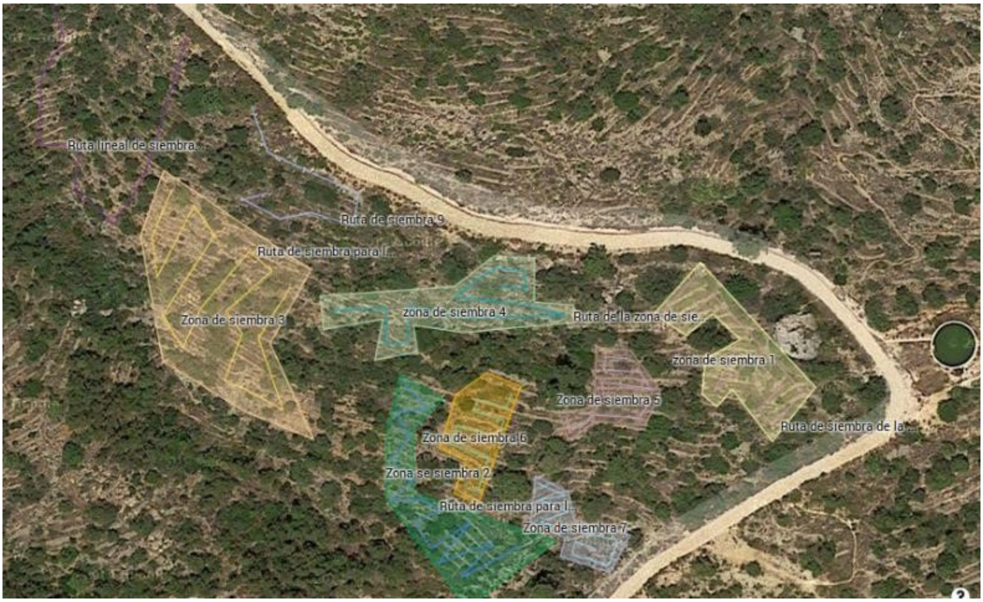

Figure 8.1 - Aerial image and seed dispersal plan of Montgo Natural Park, western flank, September 2015

Figure 8.2 - 3D-Robotics' Y6 hexacopter adapted to carry two seed dispensers

Chapter 7

AERIAL ROBOTICS FOR FOREST MANAGEMENT AND SEEDING

Lot Amorós[1] and Jesus Ledesma[2]

ABSTRACT

Dronecoria is a reforestation project that uses customized DIY drones to disperse seeds ("dronechory") in clay balls. Unlike traditional aerial seeding techniques, which often depend on exorbitantly expensive air craft and support facilities and personnel, dronecoria relies on low-cost mechanisms, borrowed from cybernetics, robotics, permaculture and digital manufacturing, to sow seeds from inexpensive drones, with wooden recyclable frames. Using drones to scatter seeds allows accurate positioning of seeds, to potentially maximize seed germination and seedling survival.

Key words: Drones, UAV, quadcopter, mapping, aerial seeding, nendo dango, permaculture, Masanobu Fukuoka

SOCIO-ECOLOGICAL BACKGROUND

Rising to 753 m above sea level, Montgó mountain is home to some of the most unusual flora and fauna in Spain. Part of the Cordillera Prebética Range in Alicante Province, the mountain is a national park, renowned for its rock formations, cliffs, caves and natural harbours. In May 2014, 39.5 ha of the western flank of the mountain, near Barranc de l'Hedra, caught fire and the vegetation was destroyed. Several organizations were mobilized to restore vegetation to the burnt areas. Foundation "Embracing the World", was created in La Marina Alta (Alicante) and took charge of the restoration work. Initial goals were to:

1. assess the state of the ground after the fire,
2. prepare the area for restoration,
3. create tools to assist in the ecological restoration and
4. plant native forest tree species.

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SITE DESCRIPTION

The project was implemented on 1 ha of the 2,057 ha of Denia municipality, “Monte de Utilidad Publica Montgó II”, cadastral parcel No. 177, Denia polygon 11 on predominately Cretaceous substrates, with some Triassic and Quaternary sub-strates also present, on loamy limestone. Annual temperatures average about 17˚C and annual rainfall averages about 700 mm, with most occurring during the fall, although in recent years, rainfall has decreased, resulting in droughts.

Mediterranean ecosystems are fire-prone, but this site is particularly so, due to a high density of Aleppo pines (*Pinus halepensis*) planted in the 1950s at higher densities than would occur naturally. However, in less than two years after the 2014 fire, perennial plants (e.g. carob, olives, mastic, Kermes oak, heather etc.) have resprouted. Dominant plant species include dwarf fan palm (*Chamaerops humilis*), mastic tree (*Pistacia lentiscus*), garden thyme (*Thymus vulgaris*), Aleppo Pine, carob (*Cerotonia siliqu*a) and various herbs e.g., *Psoralea bituminosa, Brachipodium retusum,* among others. We also found almond trees, together with *B. retusum* in beds of crushed litter, pioneer asparagus in stony areas and wild thyme, growing in an area covered with *Hyparrhenia* grasses.

UNMANNED AERIAL VEHICLES TO RESTORE A MEDITERRANEAN ECOSYSTEM

Due to the ecosystem properties and the possibilities provided by new technologies, we adopted a strategy of precise aerial seeding by drone of the 3 vegetation layers: i) the herbaceous layer (i.e., grasses and legumes, colonizers and ground cover), ii) shrubs of various sizes and in lower proportion iii) some trees, mainly of edible species.

Strategic seed-sowing is now possible by aerial robotics, because of the precision and control provided by GNSS (Global Navigation Satellite Systems) (Fig. 8.2).

Restoration protocol:

1. Carry out a pre-restoration site assessment: topography, flora and fauna, and water flow (Fig. 8.1).
2. Collect seeds, culture microorganisms, and produce seed pellets (nendo dango).

3. Develop a seeding plan (following a permaculture design) to determine the best combination of seed species for each part of the restoration site.
4. Plan shortest flights needed to deliver each seed species to its appropriate points.
5. Perform the seed dispersal flights.
6. Monitor seed germination and seedling growth across the site.

The Flone quadcopter as a tool for data collection

We used the open-source quadcopter, Flone[3] (Fig 8.3 & 8.6), to map the site, using a servo gimbal for nadir camera stabilization. Images were taken in the visible spectrum (Fig. 8.1), using a relatively inexpensive camera (Infragram Point-and-Shoot[4] from PublicLab[5]). Image resolution was largely determined by the elevation of the camera. Flights at 80-m altitude achieved resolutions of 3 to 5 cm/pixels. From these images, NDVI (Normalized Difference Vegetation Index) maps were constructed. The system was low cost, with the quadcopter costing approximately US$120 and the camera costing US$125. Since the system was self-built (DIY), it could be easily repaired on-site.

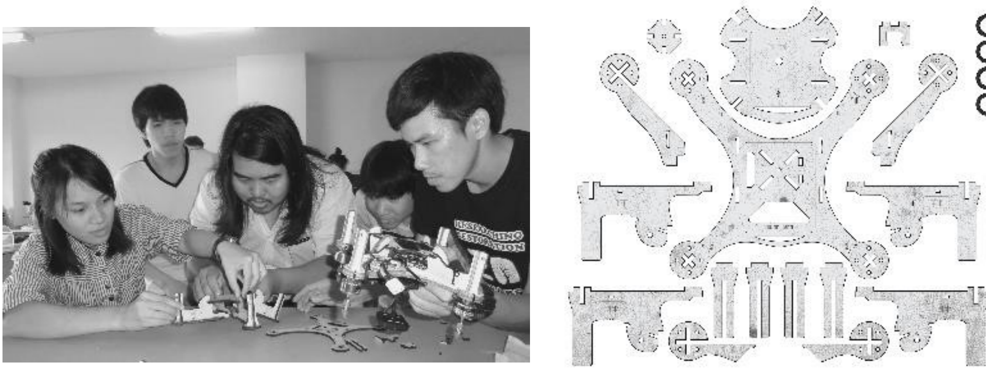

Figure 8.3 – The Flone frame comes as components, cut by laser into a sheet of plywood. Each part is pressed out from the sheet and assembled like a three-dimensional jigsaw. The frame is therefore cheap, easy to repair and biodegradable.

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[3] Flone, open-source quadcopter, available at: http://flone.cc (Fig. 8.7)
[4] Camera documentation available here: https://publiclab.org/wiki/infragram-point-shoot
[5] The Public Laboratory for Open Technology and Science (Public Lab) is a community, which develops and applies open-source tools, for environmental exploration and investigation.

Planting plan development

Initially, we took photographs in the near-infrared, to increase visibility of plants, since they reflect mainly in the infrared spectrum. However, since the effects of erosion and burning were noticeably clear, in the end, near-infrared photos were not necessary. We analyzed the pictures and decided to seed the most vulnerable areas, i.e. those eroded by surface runoff and without vegetation cover.

Nendo dango

Aerial seeding by drone requires less effort than the conventional method of raising tree saplings in nurseries, transporting them to the site, hole digging and post-planting maintenance (weeding and fertilizer application). Even though the percentage establishment of aerially seeded plants is low (due to predation and desiccation), we found that the roots of those that *do* establish rapidly penetrate deep into the soil.

Our use of seed pellets was inspired by the agricultural practices of permaculture (ALLEN, 2006) and by those devised by Masanobu Fukuoka (FUKUOKA, 2013). Nendo Dango means "soul of the earth in your hands", representing the potential of life, concentrated in the clay pellets (Fig. 8.4).

Each of our pellets contained a few seeds, mixed with a cocktail of native micro-organisms and plant-based seed-predator repellents (e.g. pepper, chili powder, tobacco or thyme).

The ideal composition of the aerial Nendo Dango was:

- dry native microorganisms solidified,
- 1/4 of basaltic stone powder,
- 1/4 of seed mix (2% of the soil quantity approximately),
- a handful of predator repellents: black pepper, tobacco, chili and thyme,
- liquid binder (water or liquid microorganisms),
- clay powder to completely cover the seeds.

Clay proportion, strength and porosity

Tests were performed to ensure that the clay balls did not break up when dropped from a UAV. Experiments with mixing poultry manure and microorganisms with either rice husk or wheat bran, increase the porosity and elasticity of the clay balls were inconclusive; further tests are needed.

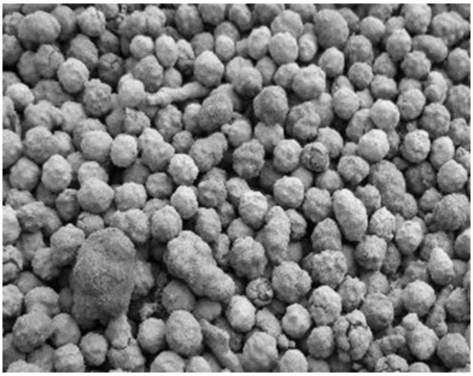

Figure 8.4 – "Nendo Dango"

Figure 8.5 - Surface microbiological culture

Basaltic rock powder

Being an igneous, volcanic rock, basalt has not been weathered or otherwise transformed by environmental processes. Therefore, the rock retains its full complement of minerals and plant nutrients, with no leaching of trace elements or micronutrients. This contrasts with the depleted substrate of the burnt and leached restoration site. Therefore, addition of basaltic rock powder to the Nendo Dangos might improve provision of plant nutrients to the germinating seedlings, although this needs additional testing and verification.

Microbiology

Forest soil supports a great diversity of the micro-organisms that are fundamental to soil ecology and plant development. The purpose of incorporating microbes into the Nendo Dango (Fig. 8.5) is to protect seeds from pathogens, increase their germination, to boost restoration, by breaking down organic matter and increasing plant nutrient availability. The microbial cocktail, prepared by J. Ledesma consists mainly of bacteria (*Lactobacillus* species, and fungi spores), particularly those species capable of decomposing pine-needle litter.

Seed species selection

After assessment of site conditions, we propose selecting a mix of seed species for habitat restoration that enhance soil fertility and ameliorate soil physical conditions, thus promoting establishment of woody plants and recolonization by wildlife (e.g. rabbits and partridges).

The green manure seed mix, use at Montgó, consisted of *Avena* spp and *Vicia* spp, applied in a ratio of 2:1. The former are oats (grasses), whilst the latter are vetches (legumes); nitrogen-fixing herbs. Although indigenous, wild, green-cover species, such as *Psoralea bituminosa* and *Brachipodium retosum* (a ground covering grass), were preferred, their seeds were not available. Other recommended seed species included Buckthorn (*Rhamnus alaternus*), kermes oak (*Quercus coccifera*), lavender (*Lavandula dentata*), Phoenician juniper (*Juniperus phoenicea*), dwarf fan palm (*Chamaerops humilis*), madrone (*Arbutus unedo*), heather (*Erica sp.*) and wild thyme (*Thymus mastichina*).

Mass production

The mechanical process of making the seed pellets was derived from Fukuoka (2013), using a "nendodanguera". We adapted a concrete mixer without the blades. The seeds were placed in the mixer and moisture was gradually added by spraying, along with the clay powder and the rest of the materials. Within a few seconds, the clay was deposited around the seeds, resulting in nendo dangos, which were then left to dry in the sun for storage and prevent germination.

Flight planning

Flight paths were designed with the open-source software DroidPlanner, available for Android devices. Once the areas to cover were defined by drawing spots, lines, or areas, the resulting flight paths were uploaded to the drone and executed.

Seed-dispersal flights

3D-printed seed-release system

Together with Salva Serrano[6], we designed a 3D-printed seed-release system (Fig. 8.7) attached to a re-used PVC drinking bottle, analogous to a screw tap. Bottles were used for storing nendo dango pellets and for aerial dispersal by drone. The release mechanism was in the neck of the bottle, with an automatic aperture controlling the flow rate of the seeds.

[6] https://salva-serrano.com

Monitoring

Although monitoring was not done for this project, monitoring should be done by flying at low altitudes to increase the resolution of the pictures in order to determine if germination and plant establishment is achieved and the resultant extent of vegetation cover. In this study area, the ideal time to perform monitoring will depend on when the dispersed seeds typically germinate.

Table 8.1 - Species sown the 10th October 2015

Scientific Name	Common Name	% Mix*	Growth Form	Ecological Function
Avena sativa	Oat	45	Herbaceous grass	Provides carbon, food, plant cover.
Vicia spp.	Vetches	25	Herbaceous legumes	Nitrogen fixation, food and shelter, seed and soil protection
Clematis vitalba	Old-man's beard	5	Vine	Long flowering; attracts biodiversity
Colutea arborescens	Bladder senna	5	Small shrub	Perennial legume with nitrogen fixation capacity
Viburum tinus	Laurus	5	Tall shrub	Bird food, protects arboreal species
Juniperus oxycedrus	Juniper	5	Tall shrub	Bird food, protects arboreal species, construction material
Cerationia siliqua	Carob	5	Tree	Improves soil, carbon fixation, food
Pistacia lentiscus	Mastic	5	Small tree	Protection and food for birds and other fauna

** percentage of seeds of each species*

CONCLUSIONS

Sowing is not a hardware problem anymore

Aerial seeding using low-cost, DIY UAVs is no longer limited by hardware. The technologies of multirotor UAVs have been tested and improved considerably over recent years, making such vehicles both more controllable and affordable. The other main factor increasing the feasibility of UAV-seeding is availability of seed-release systems. Open-source hardware and software are creating new opportunities for ecological management and green activism.

Two strategies of aerial seeding with UAVs

We identified two strategies for aerial seeding, using UAVs: i) indiscriminate vs. ii) precision sowing. Indiscriminate sowing over large areas does not need detailed pre-restoration surveys, but many seeds will fall into unsuitable micro-habitats, so seed germination would likely be low and seedling mortality high. To compensate for these high losses, the numbers of seeds sown per unit area could be increased, provided seed supply is sufficient. Conversely, precision sowing can increase seedling establishment rates and so fewer seeds need to be dropped. However, this approach requires detailed knowledge of microhabitats and detailed mapping and research.

Optimization of aerial sowing missions

UAVs can release seeds at very high rates and can move up to 60 km/h. In order to increase the flight time and capacity of the payload of seeds, UAV batteries must be lightweight. Ideal seed sowing strategies would involve short, fast flights, avoiding long flights with heavy payloads.

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Figure 8.6 – Controlled by mobile phones with open-source software and constructed from open-source hardware, with biodegradable wooden frames, “flones” are inexpensive and easily repaired. Thus, they are ideal UAVs for citizen-based ecological actions.

Figure 8.7 - 3D-printed seed-release system