unique land use

Supported by:
Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection
based on a decision of the German Bundestag
IKI INTERNATIONAL CLIMATE INITIATIVE

Native Seedling Nursery Manual

Table of Contents

CONTENTS

INTRODUCTION

This manual is intended for practical use by nursery managers and staff. The following pages outline the key steps in developing and operating a best practice nursery for native seedlings.

This manual is a product of the project *"Ecosystem-based Adaptation in the North Central Coast of Vietnam: Restoration and Co-management of Degraded Dunes and Mangroves"*. The project is financed by the German International Climate Initiative (IKI). The German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) supports this initiative on the basis of a decision adopted by the German Bundestag. For more information about IKI visit www.international-climate-initiative.com.

The manual is based on the project's best practice nursery producing native seedlings for the restoration of sandy areas. It provides practical guidelines for how to establish and run a nursery for native seedling production.

This guide starts with advice on how to plan, prepare for, and construct a nursery that meets the material requirements for best practice operation. The manual then uses a best practice nursery developed in partnership with the project as an example of how a quality local nursery (the Cam Lo nursery) can develop their operations to enhance production efficiency and seedling quality. This is followed by a generic overview of the full native seedling production cycle in nurseries, from seed collection through to final seedling transportation. Finally, criteria for effective nursery maintenance, monitoring and management are outlined. Additional pages in the annex provide templates for managing nursery processes and guidelines for specific nursery tests or experiments.

This manual was made possible through a collaboration between staff at unique, local implementing partners, and the manager, owner and staff of the project's best practice nursery.

Supported by:

Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection

IKI INTERNATIONAL CLIMATE INITIATIVE

based on a decision of the German Bundestag

unique land use

Planning a nursery

CHAPTER 1

PLANNING CHECKLIST

Structured planning and preparation are vital to ensure smooth nursery development processes and positive outcomes. Before beginning nursery construction, key planning milestones must be completed, including:

Establish the Requirements

Determine key criteria and objectives of the nursery including its scale, the types and quantities of plants to be grown, and any specialized facilities or equipment needed.

Develop the Business Model

Establish the market potential and create a a framework for how the business will operate, generate revenue, and sustain profitability.

Secure Budget and Funding

Secure the necessary funding to cover nursery construction, start-up costs, and initial operating expenses before it becomes self-sufficient. Potential funding sources include grants, loans, and investments.

Choose the Location

Select a suitable location for the nursery, considering factors such as capacity needs, accessibility, proximity to both suppliers and customers, zoning regulations, and climate. Take into consideration mitigation of risks such as extreme weather.

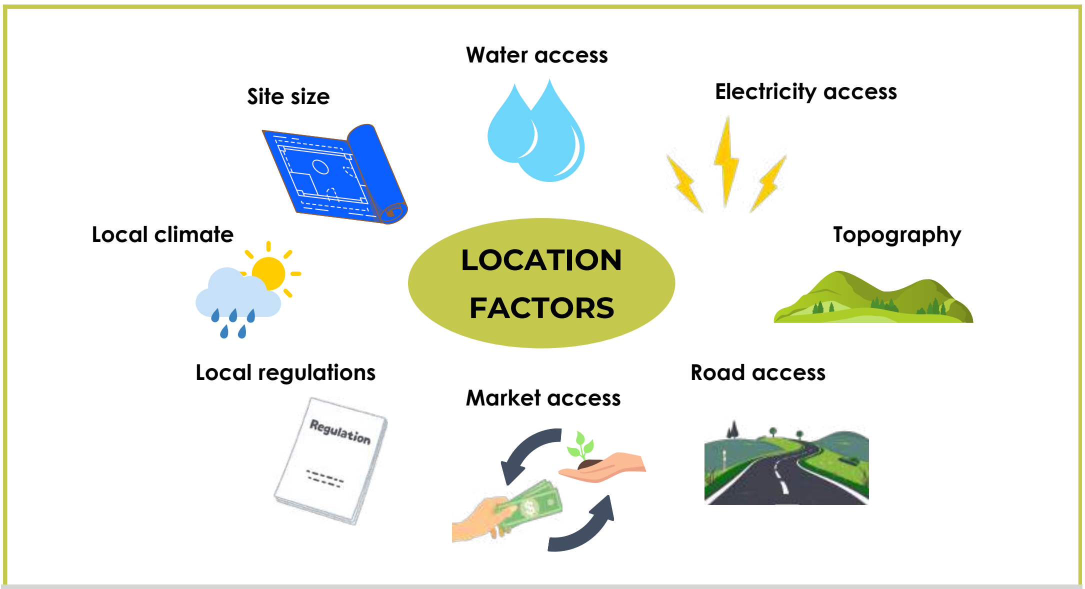
Design the Nursery Layout

Develop a layout plan for the nursery, including germination house structures, growing areas, storage facilities, and administrative spaces. Choose a design that optimizes efficiency and workflow.

Hire the Personnel

Secure skilled and motivated staff members, with expertise in plant care and other relevant areas, aligning with the nursery's capacity and operational needs.

LOCATION FACTORS



Factors to consider when choosing a nursery location.

Many contextual factors have implications on final nursery operations. These should be considered when either choosing the site for a new nursery or considering the redevelopment of an existing one. Factors that affect the suitability of a site include:

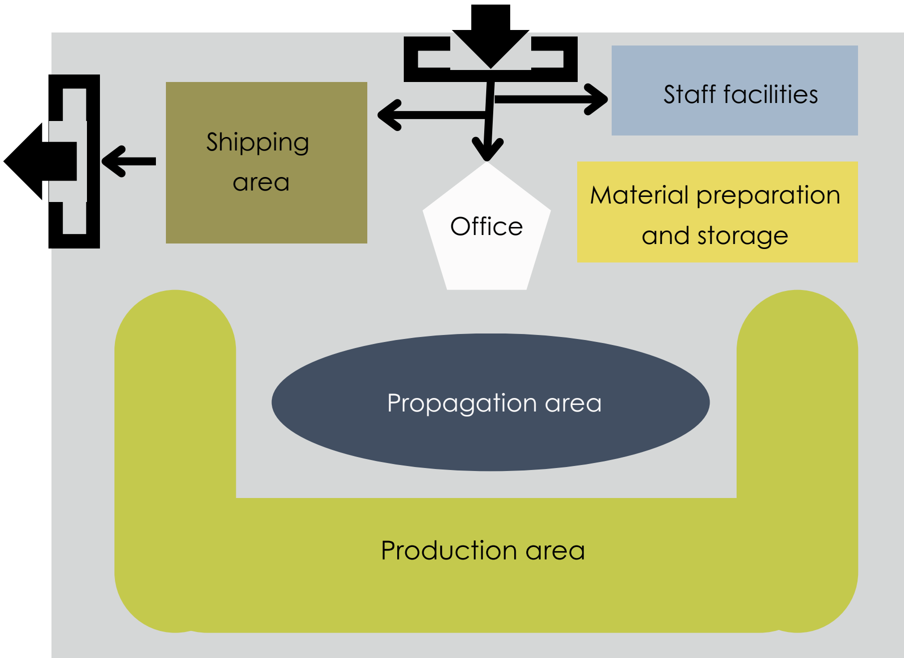
- Site size: This must reflect the nursery's planned capacity requirements and should consider future expansion potential.
- Fresh water: Vital for seedling irrigation and watering.
- Electricity access: For powering the facilities and any automated processes in the complete nursery. Though not vital, highly advantageous for nursery functionality.
- Topography: A 2-5° degree slope is recommended for drainage and ease of operations. Level terrain also increases ease of construction and cultivation.
- Road access: Good connectivity facilitates the transportation of supplies and products, tuck access is also essential for transportation of seedlings.
- Proximity to markets and utilities: increases efficiency and reduces material costs.
- Regulatory context: No restrictions that would affect construction and operation.
- Climate conditions: Information on prevailing wind patterns, temperature variations, precipitation levels, likelihood of storms, etc., should be considered and inform design decisions of the nursery.

LOGISTICS AND FOUNDATIONS

Quality nursery design involves careful planning of the key functional areas to ensure efficient work flows.

The layout of these features must be planned to facilitate smooth workflow and accessibility. Well maintained pathways should efficiently connect the different working areas in a design that minimizes unnecessary movement and maximizes productivity. When planned effectively, ergonomic design of nursery areas significantly increases productivity and reduces labor costs.

It is also vital to consider the logistics of transportation, and design the nursery so that large trucks are able to onload and offload without disruption to nursery activities. Equally, nursery design should always consider the possibilities for investing in further capacity and expansion.



Simplified nursery design, adapted from Russo et al., 2023

The different nursery areas should be defined and clearly marked, with pathways established. Nursery features should be built on level ground with a 2-5 degrees slope to facilitate drainage. Drainage channels should also be dug. Where applicable, secure fencing should be installed to prevent animal incursions or potential theft.

EXAMPLE NURSERY DESIGN

The following key features are recommended for nurseries to achieve best practice native seedling production:

- A germination zone (when required)
- A net house or production area
- An office
- Staff rest areas
- Water reserves and service points
- Storage area for tools and materials
- Soil dump and composting area
- A loading zone for transportation
- Washing stations (for cleaning pots or tubes)

In practice, nursery developers must work with the realities on the ground and seek to find ergonomic design that synchronizes work flows as much as possible.

One such example, based on the Cam Lo nursery's development for best practice, is demonstrated in the figure below.

Cam Lo nursery design plan example

unique land use

CHAPTER 2

Example Nursery Development

EXAMPLE NURSERY

Existing best practice nurseries provide examples of how processes can be improved across different contexts.

In 2018, the project *"Ecosystem-based adaptation on the northern central coast of Vietnam: restoration and co-management of degraded dunes and mangroves"* partnered with four local traditional nurseries to produce native species for sand dune restoration.

The target project sites posed many challenges for successful restoration efforts. They are highly exposed with dramatic variations between temperature and water availability, high soil salinity, and low nutrient value.

Native species are more suitable for restoration efforts, with many benefits over exotic species. Native species have adapted to local conditions, increasing their resilience, and supporting local biodiversity.

Degraded sand dunes, the sites of coastal restoration efforts

Nursery owner sorting seedlings in the new seedling production net house

A consistent supply of quality seedlings delivered for key planting windows is crucial to scale the project's proof-of-concept of native species coastal forest restoration.

To facilitate this need and improve restoration efforts, the project specifically invested in upgrading the top performing nursery of the four initially partnered with: Cam Lo, Quang Tri.

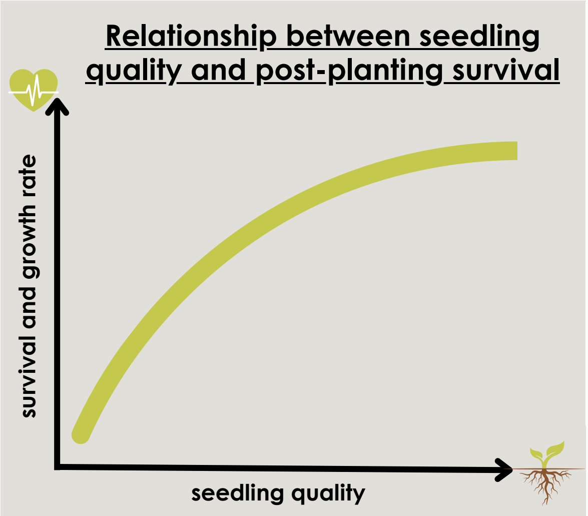
Leveraging the combined knowledge from unique, local partners, and investors, to develop a best practice nursery that incorporates traditional knowledge, implementing experience, and the latest scientific advancements in seedling production.

The result is a modern nursery with upgraded facilities and innovative practices.

OPTIMAL NURSERY PERFORMANCE

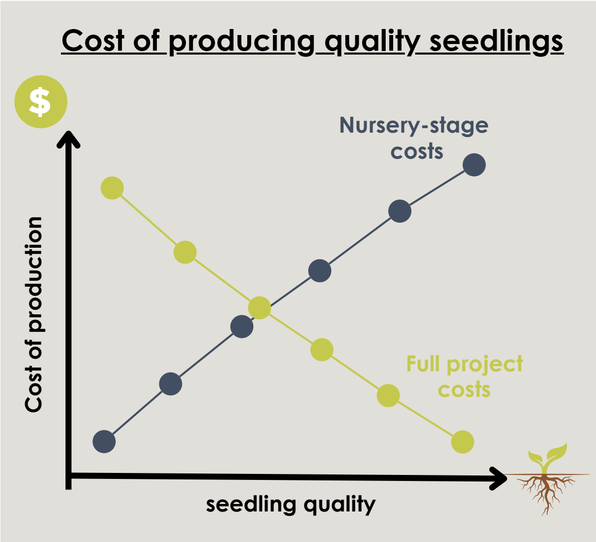
Nurseries must seek to balance cost-effectiveness and seedling quality.

The quality of seedlings a, if not the, determining factor of a restoration project's success. As seedling quality increases so does the survival and health of seedlings planted at restoration sits. This trend is especially pronounced in restoration projects operating in highly degraded and challenging environmental conditions.



Achieving seedling quality demands investment in nursery facilities and processes tailored to the specific needs of the nursery setting, target species, and conditions of the restoration site. Regrettably, many restoration projects balk at the costs of producing quality nurseries and instead prioritize quantity over quality in seedlings. This approach invariably leads to poor establishment, survival, and growth rates, particularly in the context of challenging environmental conditions. While reducing the project outgoings on nursery production produces apparent savings in the short term, this approach fails to account for the long-term costs incurred by using low-quality seedlings, which far outweigh the initial savings.

Take a hypothetical scenario where 500 high-quality seedlings, costing $3 USD each to produce, result in an 80% field survival rate. This totals $2000 USD, averaging $5 USD per surviving tree. When compared to and alternative production approach where 1000 low-quality seedlings, costing $0.50 USD each to produce, achieve only a 15% survival rate, total $1500 USD, averaging $10 USD per surviving tree. Despite the initial cost savings in the latter scenario, the overall cost per surviving tree is doubled (Haase, et al. 2021). Considering also the loss of project time and resources when poor quality, dead seedlings need to be replanted, the costs of investing in higher quality seedlings is more than recovered by their greater survival and performance in the field.

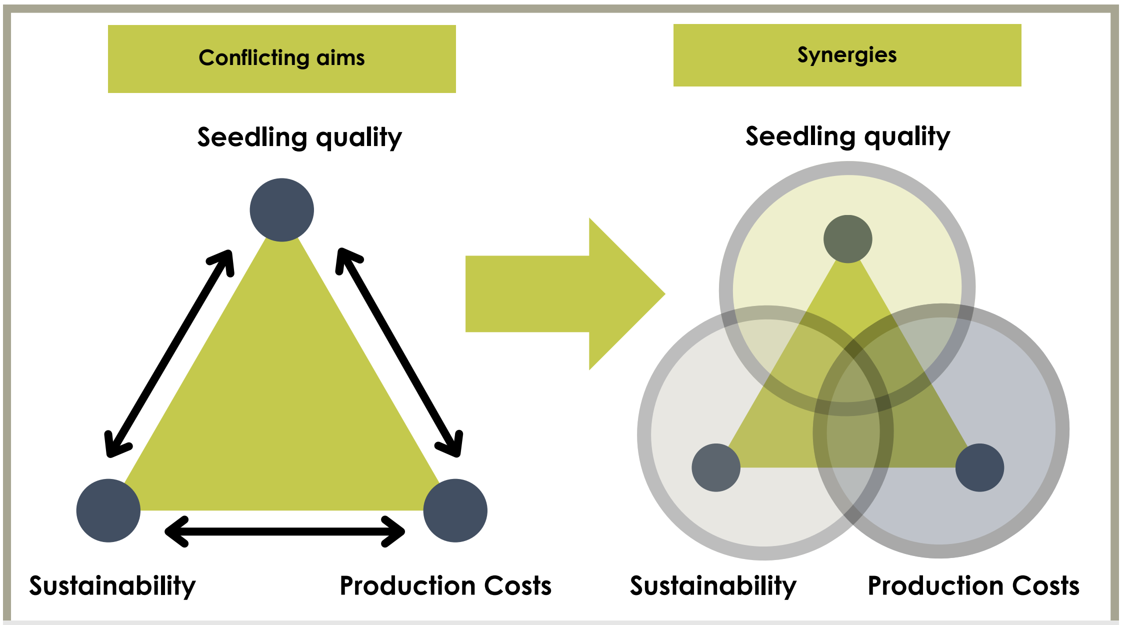


For nurseries that act independent of the restoration projects they are supplying, focusing on maximal production for minimal costs is a practical approach. However, in the context of restoration projects, the cost evaluation of the planting success (i.e., survival rate, growth performance, etc.) must be considered. For this reason, not only should the quality of seedling production become the priority, but developing full partnerships with local nurseries that extends their responsibility to overall project results also emerges as a vital aspect of restoration success.

NURSERY SYNERGIES

Nurseries work best when they prioritize seedling quality whilst working to find synergies with production costs and sustainability.

Nurseries should aim to achieve consistently high quality seedlings whilst also maximising the cost effectiveness and sustainability of nursery operations. Often these three objectives can appear to be contradictory to each other. Producing quality seedlings involves investing in nursery infrastructure. Depending on the nursery this may include the construction of a net house, switching from polybags to plastic tubes, the installation a sprinkler system, and other high cost investments. Some approaches to improving seedling quality can also be unsustainable, for example use of forest top soil can be unsustainable, and sprinkler systems can increase water waste.



Nursery development, from competing objectives to synergies

However, with careful planning and management, synergies can be found between these key objectives. For example, investing in the more durable plastic tubes, if well cared for, can be reused for around 10 years, reducing waste from single use plastic and increasing the cost effectiveness. Equally, Finding synergies between objectives supports effective nursery management, but achieving sustainability, seedling quality, and cost effectiveness will be an ongoing challenge that increases in difficulty in line with the size of the nursery. A philosophy of ongoing testing and experimentation should be adopted in order to discover more opportunities for nursery synergies.

Each nursery must develop a unique approach that reflects the specific context and aims in which it operates. With this in mind, the following chapters provides an overview of the design features, practices, and procedures adopted in the best practice project nursery in Cam Lo, for reference and inspiration.

GERMINATION ZONE

Germination is a stage where the seedlings are highly vulnerable to funghi and damage. Germination houses mittigate this risk by increasing control over climatic conditions.

Traditionally, seedlings were sown directly into sand in free areas of the nursery. Straw was often used to cover the sand to retain moisture.

The germination areas were outside and uncovered, with nursery staff choosing areas with tree cover to minimize exposure to the weather.

However, the seeds were highly vulnerable to weather fluctuations, mold, and being consumed or damaged by local wildlife.

Lack of infrastructure around germination beds necessitated manual watering limited protection of the seedlings. This lack of control over seed conditions increased the likelihood of problems arising during germination.

An established germination house gives nursery staff greater control over seedling conditions and protection from the elements.

Seedlings are no longer exposed to rainfall, and nursery staff can control the levels of moisture during germination via sprinklers.

Segmented soils are more easily monitored, sanitized and refreshed each season to help prevent funghi outbreaks.

Internal lighting and a perimeter wall help discourage invasions from local wildlife, reducing loss of seeds to squirrels and birds or damage from digging mamals.

Considerations:
Germination houses are most beneficial for nurseries germinating many species during peak rainy seasons and that require a large area for germination. Beds must be replaced or sanitized after each batch to maintain cleanliness. Positioning them near production areas, preferably as net houses, enhances efficiency. Weighing construction and energy costs against benefits is crucial.

PRODUCTION NET HOUSE

Using net houses during the maintenance stage of seedling development facilitates efficient production processes and tailored hardening processes.

Seedlings were shaded by established trees and handmade shelters.

Different levels of shading were catered for, but options were limited to full exposure and 2 levels of shade. This reduced the possibilities for gradual hardening of seedlings. Shade would be uneven between seedlings in the middle of rows and those at the edge.

Adjustment of shade for seedlings required manual repositioning of individual seedlings. This required additional physical labor, could often be overlooked, and reduced capacity to tailor shade for different species or growth stages.

Seedlings were spread across different beds all over the nursery, decreasing the efficiency of labor and making monitoring difficult.

By constructing a shade net house, the nursery staff have precise control of the seedlings' sun exposure. The structure provides even shade for the seedlings and precludes any "edge-effects".

Shade can also now be tailored based on the species and growth stage. Shade-nets of different colors and mesh sizes are managed via an automated system, with additional layers of shading also available manually. Easy adjustment of the shading reduces the manual effort, removing a potential barrier to effective shade management.

Through a gradual increase of sun exposure over the production cycle, the seedlings slowly increase their solar resilience without compromising their health. Concentrating seedling production into one, enclosed area also increases work efficiency.

Considerations:
The net house size should consider the final spacing and dimensions of planned features such as nursery tables. Different materials and designs should be chosen based on the climatic conditions. The net type and hardening progress depend on species, growth stage and season. An alternative, more labor intensive approach would be to divide the nursery into zones with fixed shading net houses, then moving seedlings outside for final hardening.

ELEVATED TABLES

Elevating the seedlings above the ground improves both seedling health and working conditions for staff.

Seedlings were closely stacked in beds on the ground. This heightened nursery capacity but required staff to spend extended periods bending down.

The traditional set up also increased the challenge of weeding, as weeds could access the seedling bags from the ground and were harder to spot.

During heavy rainfalls water logged due to poor drainage. Poorer seedling spacing also caused higher humidity and low airflow. These factors increased the risk of fungi. Spacing, selection and monitoring of the seedlings was challenging, decreasing the oversight of nursery staff on production outputs.

Strongly growing seedling roots would extend into soil, risking damage once picked up for transport, resulting in the delivery of wounded seedlings.

The tables are ergonomically easier for nursery staff to use and prevent discomfort from crouching over seed beds. They also provided a fixed grid for spacing and secure the seedlings in position.

The elevation and ordered spacing of seedlings supports good plant hygiene, drainage and improved airflow, as well as downward growth and air-pruning of roots. The table system also increases the ease of sorting, spacing, and nursery organization, making monitoring and management more efficient.

Placing weed mats under the tables is recommended to reduce the manual costs of removing weeds, which would otherwise obstruct airflow.

Considerations:
The table height must be adjusted to local workforce while other table dimensions and specifications must be compatible with the chosen pot or tray type. Table orientation, layout and access paths must reflect efficient work flows and facilitate easy transportation of seedlings. There must also be sufficient ventilation below the table to make them easy to clean and disinfect.

TUBES AND TRAYS

Choosing the right container is vital for seedling growth, health and survival in the field, as well as improving overall nursery efficiency.

The nursery utilized plastic polybags for growing seedlings due to their low cost, availability, and lightweight, facilitating easy transportation and capacity to be densely packed for space efficiency.

However, the smooth surface of polybags causes root spiraling and a concentration of root growth at the bottom of the bag, result in low fibrosity and volume. Roots frequently become spiraled, damaged or deformed. This reduced overall plant health and resilience, decreasing the likelihood of the seedling surviving after planting.

Polybags are ripped during planting, making them nonreusable, resulting in high plastic waste and loss rates.

One of the most costly but important investments, planting tubes promote strong, straight, downward root growth, aiding seedlings in water acquisition post-planting. Various tube sizes allow customization for different species, nursery durations, and substrate types.

Stacking tubes in custom trays ensures even spacing, though it requires more space. This setup allows easy removal of individual tubes, adjusting seedling spacing for optimal airflow and hygiene. They are also easily lifted and carried to new areas of the nursery, supporting nursery organization and reducing the physical burden on staff.

Additionally, the tubes and trays are reusable, lasting over 10 years, offsetting initial costs and enhancing nursery sustainability.

Considerations:
Consider the initial investment in transitioning to tubes versus potential benefits in seedling quality and reusability. Polybags could still be used if regularly moved to prevent the roots from entering the ground. Choose tube/pot sizes and volumes according to species preferences and nursery duration. Account for the logistical aspects of installing the tube/pot system in nurseries and transporting seedlings to restoration sites. Typically, substrate in pots requires adjustments for optimal drainage, water retention, and ease of depotting.

WATER SUPPLY

A clean, reliable water supply is crucial for a nursery to function. Water quality, security, and reliability of access, must be prioritized in nursery development.

The nursery was well established with a stable water supply year-round water via two wells (40 m and 70 m deep).

An open air pond with a plastic base also facilitated everyday watering. Though affordable and of suitable size for the nursery's production capacities at the time, the pond was vulnerable to contamination and evaporation. The risk of spreading disease and fungus through polluted water was high. Frequent maintenance was needed to prevent run-off, leakage and litter.

Sunlight protection was required, and the pond could not support gravitational water transportation, precluding sprinklers and necessitating higher manual labor.

The nursery now also has a 10,000 liter capacity ground tank to facilitate all of the nurseries watering needs.

It is sealed from exposure to pollutants and the water passes through a double filtering system, one sand filter and one fine mesh filter, to ensure water quality for the seedlings.

A double pump system secures water access and maintains a stable water pressure at all times of year.

Gravitational water transportation is possible, supporting water hoes outlets (now installed in every zone) and a sprinkler system.

Considerations:
Installing enclosed water storage and pump systems is costly and requires careful alignment of dimensions between the different components. A reliable water supply in all seasons is a prerequisite. Different filters must be used for different filtering systems and these will need to be cleaned and maintained, as well as the water quality tested, regularly. Ensuring water pressure through backup pumps and/or manual watering options should be considered.

WATER APPLICATION

Managing seedling watering is a core determinant of overall seedling health and resilience. Watering systems should be adaptable and reduce staff labor.

Watering was manually delivered by nursery staff using watering cans, buckets, hoses supported by a small electric pump.

Staff used their experience to tailor water provision to the seedlings depending on their health and species. This necessitated a daily assessment of each seedlings watering needs.

However, this approach required extensive physical labor and was time intensive. Equally, though hand watering can be highly precise, there was also a higher risk of human error, and a less systemized approach that limited the potential for structured tailoring of water provision.

An automated watering system integrated into the net house reduces the manual burden of watering for nursery staff. Up to 50 tables can be watered at the same time, significantly improving efficiency.

Four sprinkler zones facilitate tailored watering of seedlings depending on the species and growth stage. Nursery staff can gradually reduce and adjust the watering to harden seedlings ready for periods of drought at the restoration site.

The system can be operated by an app-based adjustable automation system, facilitating remote watering if staff are unavailable. The time formerly spent watering can now be invested in sorting and care taking of the plants.

Considerations:
Sprinkler systems decrease water efficiency though increased water waste, so are not suitable in contexts where water is scarce. They are also expensive to install and require considerable maintenance. Quality, clean water is essential to prevent nozzles from clogging, (a double filter system is recommended). Strong water pressure and a reliable power source (electric- or fuel-based) are also prerequisites. Frequent calibration and testing of the system is required. Droplet size may need to be adjusted to plant size or wind conditions. Even with the automated watering system, monitoring and quality control of watering is required.

SUBSTRATE

Different substrates affect nutrient provision, water retention, and even plant microbiome development, key factors in influencing seedling health.

The nursery utilized locally available topsoil, sand, and clay to provide a nutritionally dense base for seedlings to grow from.

Topsoil is cost effective and exposes seedlings to mycorrhiza, supporting their assimilation to site restoration conditions.

However, topsoil is an inconsistent resource, with the balance of nutrients, salinity, etc., difficult to control. Weeds, fungal spores and diseases may also be present and undetectable at early stages, with significant risks to seedling health.

Topsoil is also a limited natural resource, exploitation of which takes generations to be replaced. As such, finding a nutritionally balanced, sustainable alternative was a key priority.

The nursery experiments with different potential substrate combinations and can tailor substrates to align with the needs of different species.

Substrate tests use varying percentages of locally available organic raw materials, including: cassava residuals, peanut husk, rice husk, coffee-cherries, cow dung, organic compost, coco peat, clay soil, river sand, and small amounts of forest top soil.

Simple tests on key criteria, such as water retention, are undertaken in the nursery before a substrate is implemented.

The performance of different species in different substrate mixes is also monitored, enabling the nursery to identify substrates in which different species grow best.

Considerations:
Determining the right substrate mixture balancing cost and performance is difficult and will require extensive testing and monitoring of plant growth. Possible substrate mixes are dependent on the local availability of raw materials, species needs, cost and compatibility with the selected pot system (de-potting characteristics, drainage capacity, etc.). When capacity allows, nurseries should seek to continuously experiment with substrate options. See annex 2 for more guidance.

NURSERY TOOLS

Nursery managers should reflect on which tools can best support the nursery's unique needs, taking both nursery efficiency and employee experience into account.

A range of nursery tools are available to increase nursery efficiency. Both high-tech and traditional tools were introduced into the best practice nursery to reduce the manual labor of staff and increase the efficiency of processes. Examples include:.

- Chopsticks: To create holes for seedling germination and to gently extract seedlings for transplanting.

- Seed dispensers: For the controlled distribution of seeds during germination.

- Transportation trailers: For easy movement of seedlings to appropriate areas of the nursery.

- Soil moisture detectors: To precisely monitor seedling water exposure at all stages, supporting informed watering practices and substrate decisions.

- Cement mixer: To increase the speed, efficiency and effectiveness of substrate mixing for consistent results and reduced labor

- Fridge: For storing suitable seeds collected from mother trees

- Scales and/or measuring cupes: To measure substrate ingredients, fertilizer dosing, and undertake water drainage tests

.... and many others.

Tools and equipment must be carefully stored, their use logged, and standards of practice developed as part of staff training.

Resistance to using new tools is common, particularly when the original practices are already producing good results (that the new tool could further improve) and when the new tool requires practice or adjustment to workflows. When introducing a new too, demonstrating its benefits to nursery staff, in terms of both results and the impact on their labor, is vital for effective uptake.

EXAMPLE TOOL: CEMENT MIXER

Cement mixers can dramatically improve the speed, quality, and ease of substrate mixing but their value must be proven to nursery staff.

Before

Mixing substrate materials was done by hand, either in large metal bowls or in wheelbarrows.

Vast quantities of substrate must be mixed for each production cycle, while only small amounts can be mixed at a time by hand, making the task highly costly in terms of both time and labor.

Mixing by hand is physically demanding and takes staff away from more skilled tasks such as weeding, transplanting, sorting and monitoring.

Mixing by hand also makes it very difficult to effectively break down the different substrate materials and ensure and even spread throughout the substrate mixture. This can lead to clumps, concentrations of materials, and an uneven allocation of nutrients for the seedlings.

After

Using a cement mixer to combine substrate ingredients results in a more complete and even distribution of the different materials. This provides consistent mixing results, key for quality production.

The mixer can be filled with the required ratios of materials and left running for a set period, freeing staff for more productive activities and reducing the physical labor of substrate creation down to filling and emptying the mixer.

The mixer also has a larger capacity than bowls or wheelbarrows so can mix large quantities at once. Mixed substrate can then be stored in a dry area for use later, helping to increase the efficiency and scope for effective time management in the nursery.

Considerations:
Cement mixers need an electrical or fuel power supply and manual labor is still required to fill the mixer with the substrate ingredients. Cement mixers are most helpful when large amounts of substrate need to be mixed so may not be required for smaller nurseries. A thorough and consistent substrate mix is particularly important if soil additives or low doses of fertilizer are part of the mix.

STAFF TRAINING AND COLLABORATION

Involving all stakeholders across al stages of nursery development should be prioritized.

Nursery manager delivering training on quality seedling selection.

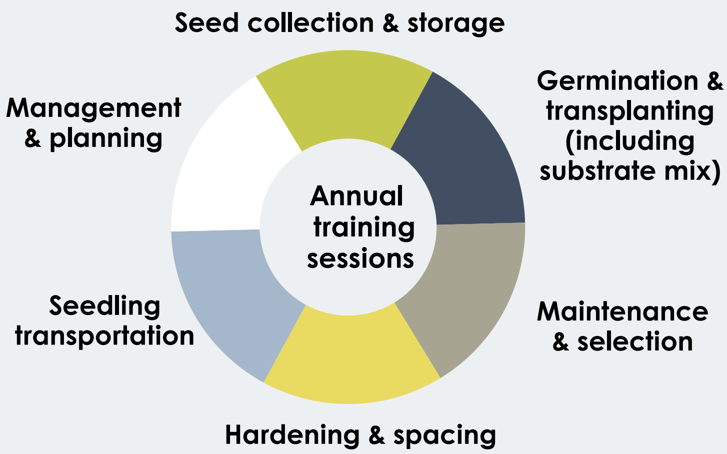
The new tools and processes for the nursery were introduced in partnership with the nursery owner and staff. Their input on preferred working methods and physical details, such as the distribution of seedling racks, informed nursery design decisions. Equally, their expertise in areas such as germination techniques and substrate characteristics advised key production processes.

The adoption of any new nursery practices necessitates training of staff on how to use new tools and apply new processes or techniques. Staff should also receive annual "refresher training" at key points in the production cycle to preserve best practice, e.g., on how to select seedlings or the ratios of substrate mixtures.

Broadly, there are 6 key periods in a seedling production cycle, each of which involves distinct tasks. Before going into a new stage in the production cycle, "refresher training" for all staff is important for 2 reasons:

1. To reiterate the important information and requirements of the production stage
2. To share any new information or changes to processes

Topics staff training sessions repeated for each production cycle



EFFECTS OF NURSERY UPGRADES

New (left) and old (right) seedlings

Through implementing the aforementioned nursery facility upgrades and developing best practices, the nursery has seen a significant change in the quality and characteristics of its native species seedlings. These changes have considerably improved the performance of seedlings planted in restoration sites.

Before

Seedlings raised in polybags prior often suffered growth deformities, especially in their roots (see image, right). Root spiraling at the base of the bag was common, leading to stunted growth. Additionally, roots frequently punctured the bag, risking damage during transplantation. A low root to shoot ratio (roots less than a third of stem length) increased plant stress, hindering the acquisition of resources for photosynthesis in the field. Low sorting rates (the result of uncomfortable working conditions) increased crowding and allowed poor-quality seedlings to remain in the batch. Limited options for hardening and species-specific care heightened the risk of planting shock. Transportation in polybags also posed risks, with seedlings prone to falling or being crushed and damaged in transit. These factors combined to produce seedlings with a reduced chance of survival in the field.

Old seedling in the field

After

Seedlings grown after to the nursery developments were significantly more likely to survive and demonstrate healthy growth at the restoration sites (see image, right). The strong, straight root growth cultivated through air pruning in the pots and trays production techniques translated to improved performance in the field. A good root to shoot ration resulted in healthier plants that are better equipped to support photosynthesis and strong plant growth. The plants were able to invest in developing new roots, establishing themselves in the restoration sites, and maintaining healthy leaves. Improved sorting and structured spacing of the seedlings facilitated by the new nursery infrastructure increased the quality standards of seedlings. The ability to tailor UV exposure and watering by species and growth rate enabled effective seedling hardening. Healthier, stronger seedlings are planted at restoration sites, significantly improving survival rates and seedling performance in the field.

New seedling in the field

unique land use

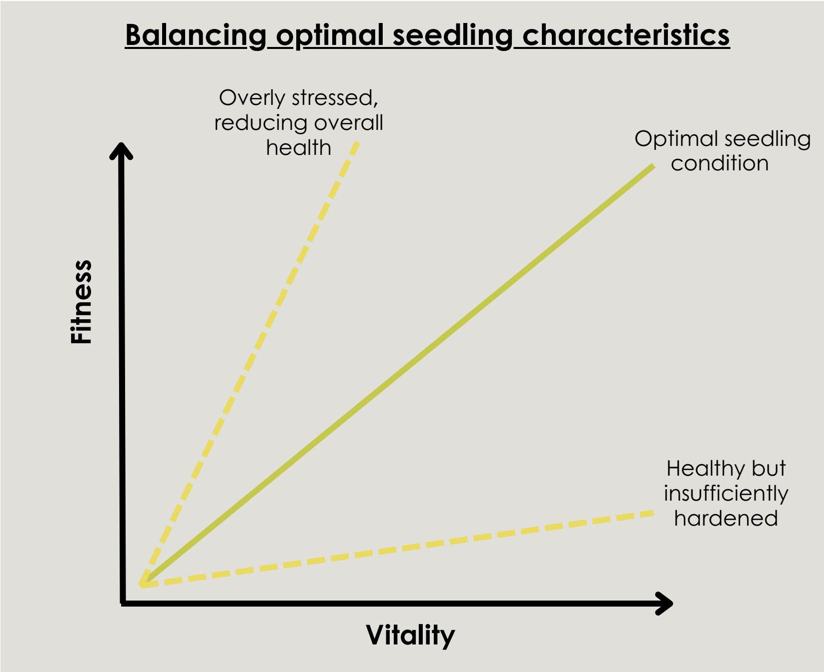
CHAPTER 3

The Production Process

SEEDLING PRODUCTION SUMMARY

The challenge for native seedling nurseries is to provide a reliable process for producing seedlings with the best possible chance for survival in an exceptionally harsh restoration environments.

Nursery's must tread the fine line between providing seedlings with a healthy start that gives them the strength to endure, and building their resilience to prepare them for the shock of planting in inhospitable conditions.



Initially, seeds are carefully selected, stored, and germinated in soils that are tailored to provide them with the perfect conditions for growth. Early-stage seedlings are optimally watered and provided with ample shade to protect them from excessive sun-exposure, allowing them to flourish and build up strength. The pot design and elevated tables encourage a strong downward root growth that will enable them to find fresh water deep in the dry soil of sandy sites, and regular weeding ensures no competition for nutrients.

As the seedlings grow, their conditions are carefully adjusted to increasingly reflect the harshness of their end destination. Shade is gradually peeled back and watering reduced, sufficient to harden the seedlings and encourage adaption but not enough to damage their overall health and stamina. Maintaining this delicate balance and achieving this sweet spot of seedling resilience should be the core aim of all nurseries serving restoration projects.

While the specifics of each nursery's approach will vary, the need to establish practices, production processes, and monitoring procedures that guide the nursery to this outcome are uniting factors across all nurseries serving restoration projects.

In the following pages, an overview of the different stages of seedling production, and the steps taken to hit this resilience sweet spot, are outlined with the aim to provide guidance and recommendations for nurseries pursuing similar goals.

SEEDS

The early stages of a production cycle set the foundation for seedling quality and smooth nursery management.

Seed source
- Select mother trees
- Identify seed collection season
- Collect seeds and transport to nursery
- Log seed and species quantity

Preparation & storage
- Develop production plan
- Prepare seeds for germination or storage
- Store reserve seeds
- Mix substrate for germination beds

Germination
- Activate seeds as per species requirements
- Plant seeds and begin gemination process
- Label beds with species and germination date

Monitoring & selection
- Track survival and growth rates
- Test different techniques
- Select seedlings for transplanting
- Prepare substrate and fill seedling pots

Restoration projects using native species encounter challenges due to the diversity of species types and lack of native species seed material available on the market. Because of these factors, nurseries are often required to source and process the seeds themselves.

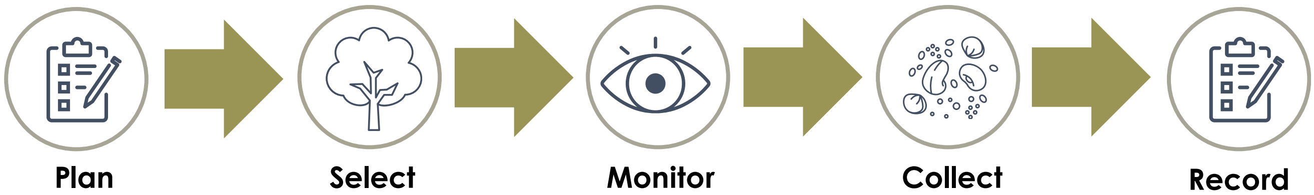
Seed storage makes production planning much easier, precise and reliable. However, native species production often involves working with Recalcitrant, Orthodox, and Intermediate seed types, of which only some have storage capacity and can be challenging to store. Lack of knowledge on the storage capacity of native species seeds further hampers native species nurseries' ability to plan production cycles. seeds being storable.

Effective monitoring and record-keeping are crucial for managing seed processes in nurseries and coordinating production cycles. In the context of vastly different species characteristics and growth cycles, record keeping and monitoring are vital for both nursery planning and maintaining an up-to-date oversight over the status of nursery production.

Regular testing of native species seeds' storage potential can aid in production planning and emergency preparedness. As nurseries evolve, experimenting with storage capacity of native species seeds could reveal previously unknown storage potential, and thus support nursery planning. Additionally, trialing different germination techniques can also reveal means of improving production. Documenting species-specific requirements and any discoveries is vital for continuous nursery improvement and smooth operations.

SEED SOURCING

Seed sourcing is the basis of seedling production, with mother-tree selection, careful timing, and effective record keeping are key aspects of the process.



It is important to establish the number of seeds to be collected for each species in advance. This helps to ensure the sustainability of seed collection and that a good balance of different species is produced. The actual number of seeds collected must also be recorded for effective nursery management.

Criteria for selecting mother trees include stage of maturity, exhibition of standard species characteristics, propensity for seed production, and being located witihn the region of the planting site. A wide range of mother trees should be used to maximize genetic diversity and reduce the pressure on specific donating strands. Nurseries must consider the relative scarcity of a species and take measures to avoid over-exploiting of the wild population.

Mother tree from a restoration site close to the nursery

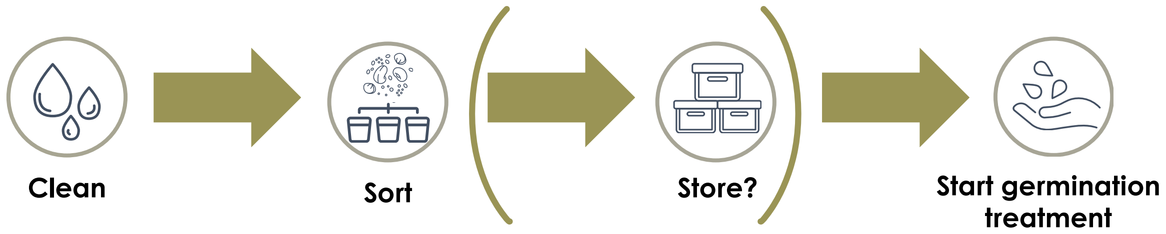
Nurseries must monitor the flowering of all mother trees to track when seeds are available for collection. As such, nurseries must also consider their own capacities and the geographical range they can cover. Often partnering with local communities to receive updates on the status of mother trees is necessary.

When ready, seeds should be gathered quickly, either from the ground or directly from the mother trees depending on the species. Before beginning a seed collection process, the necessary tools and techniques for extracting seeds must be sourced, agreed, and demonstrated to the responsible staff (typically in-house nursery employees).

The dates of seed collection and quantity of seeds collected for each species must be accurately recorded. These records facilitate detailed production cycle planning and ensure up-to-date knowledge of each species' flowering and seeding cycles (see examples in annex 1) . This tracking will also reveal fluctuations, trends and potential declines in seeds from mother trees, allowing for future planning.

SEED STORAGE AND GERMINATION TREATMENT

Seed preparation and storage capacities vary dramatically between species, creating challenges and opportunities for nursery management.



Upon arrival at the nursery, seeds should undergo cleaning and sanitization, with damaged or poor-quality seeds discarded. For some seeds species this will involve removing them from fruit, pods or capsules first, which may necessitate soaking in water.

Seeds must then be quantified (usually by weight and known seed/kg), recorded, and sorted. Sorting should be based on their specie and potential for storage or immediate germination.

Seeds that have storage potential should have a proportion of the seeds collected stored to help stagger production cycles. Species that do have known seed storge potential should be managed so that at least a proportion of the seeds are set aside for treatment and storage. These seeds can then be recruited in seasons where high losses occur. Seed storage typically involves drying seeds and storing them in a fridge at low temperatures.

Seeds are washed in preparation for germination

Seeds that cannot be stored, or with unknown storage potential, should be germinated immediately. Each species will also have unique pre-germination treatments that must be met. For example, some seeds may need to be pre-soaked in hot or cold water for differing periods of time. As species become more understood, experimentation with techniques such as stratification or scarification (via implement, acid, or scalding water) should also be tested.

As the nursery's experience with native species develops, gradually experimenting the storage capacity and pre-germination preferences of seeds is recommended. Increasing knowledge on native species would increase nurseries' ability to utilize both seed storage and seed preparation technique for better production cycle management.

GERMINATION

Germination is a crucial stage in the production cycle where seedlings are extremely vulnerable.

Two germination techniques are commonly available to nurseries, direct sowing and transplanting from germination beds. Different techniques should be implemented for different species with decisions based on the species characteristics and germination rates.

Direct sowing is where seeds are planted directly into the individual pots or tubes where they will reach maturity. Alternatively, seeds are sown into germination beds with the seeds that successfully germinate in good health picked out and transplanted to individual pots or tubes once they have sprouted.

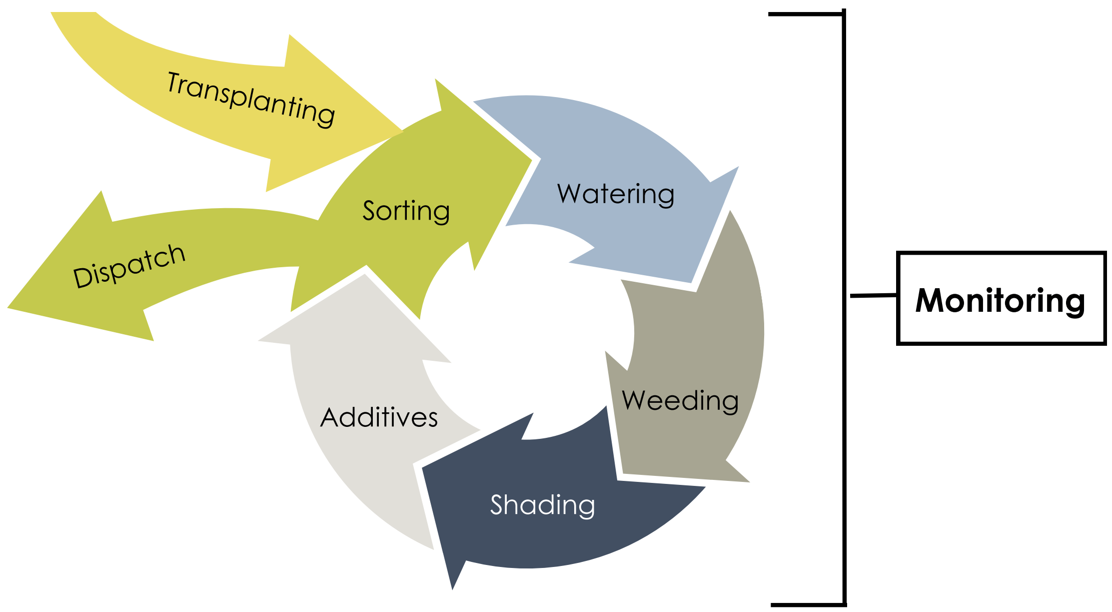
Preparing and managing individual germination pots can be significantly more costly and labor intensive than managing germination beds. Sowing into germination beds and later transplanting is the optimal approach when either there is a lack of pre-existing knowledge on the germination vigor, where germination rates are low, or where the complexity of the germination process is high.

However, transplanting from germination beds must be carefully timed, and has inherent risks of damage to the seedlings. Thus, where germination rates are high (>70%) direct sowing has greater advantages.

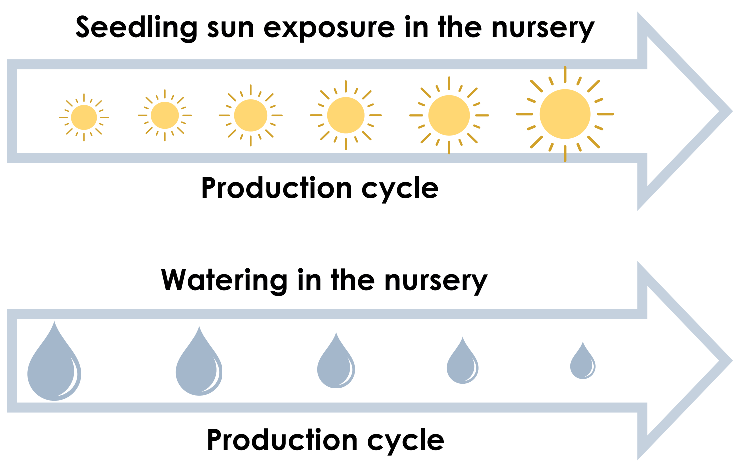
Method	Pro's	Con's
Direct sowing	Avoids transplantation shock. Mimics natural processes leading to stronger root systems. Improved monitoring and plant hygiene from individual tubes	Greater cost for each seed that does not germinate, so only suitable for species with high germination rates
Transplanting	Reduces cost of failed seeds and provides an additional stage of selection for quality. Suitable for species with low germination rate.	Must be carefully timed and executed with expertise to avoid damage to the seedlings. Risk of transplanting shock. Requires an extra step.

SEEDLING PRODUCTION CYCLE

From direct sowing or transplanting to dispatch, seedlings undergo an intensive growth and maintenance period. In this stage of the production cycle nurseries must carefully and consistently manage the many influencing factors that will determine the overall health and characteristics of the seedlings.



Overview of the seedling production cycle



Key aspects of seedling hardening

Towards the end of the production cycle, seedlings must also undergo a hardening process. Hardening helps prepare seedlings for survival outside of nursery conditions. Nurseries can develop their own complex hardening processes, but at a minimum they should involve a gradual change in sun exposure that reflects site conditions. Where periods of drought or water scarcity occur at the planting sites, water hardening is also a vital part of the overall hardening process.

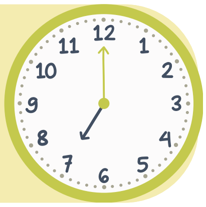
TRANSPLANTING

The seedlings are highly fragile and vulnerable during transplanting resulting in inherent risks to the process (e.g., shock, root damage, sun damage, etc.). Where possible, direct sowing is the preferred approach. When transplanting from germination beds is required it must be undertaken with great care. The following steps provide a guide to the process:

Monitoring Seedling Readiness: Seedlings are ready for transplanting when they have first developed the leaves after the cotyledons (the two "seed-leaves"). The transplanting window is short, so seedling germination must be closely monitored to ensure that it is not missed.

Preparation of Pots and Substrate: Before transplanting, ensure pots of the appropriate size for the species and planned duration in the nursery are ready. Fill the pots with the chosen substrate mix (specific to each species) the days or weeks before, stored dry, and watered just before transplanting occurs..

Timing: Young seedlings and their roots are delicate and susceptible to damage, particularly from UV exposure. To limit this risk, transplant early in the morning or late in the evening when the sun's intensity is lower and the humidity higher.



Select only strong seedlings: The cost of a seedling increases significantly upon entering the production house. Transplanting poor quality seedlings, that are likely to die or removed through selection later, is costly for the nursery. Being highly selective of which seedlings are transplanted is vital for cost-effectiveness and quality seedling production.

Extraction and Transport: Gently extract seedlings from the germination bed and place them into a bowl containing water. Once 50-100 seedlings are collected in the bowl, transport them to the production house and place the bowl in a shaded area.

Transplanting: To transplant a seedling, make a small hole in the substrate of the pot, deep enough to facilitate the root (typically 1-2cm). Carefully and gently place the seedling inside, ensuring the roots are covered and not bent, with the leaves uncovered. Fill the holes with the displaced substrate and compress the soil gently around the seedling so that it stands upright.

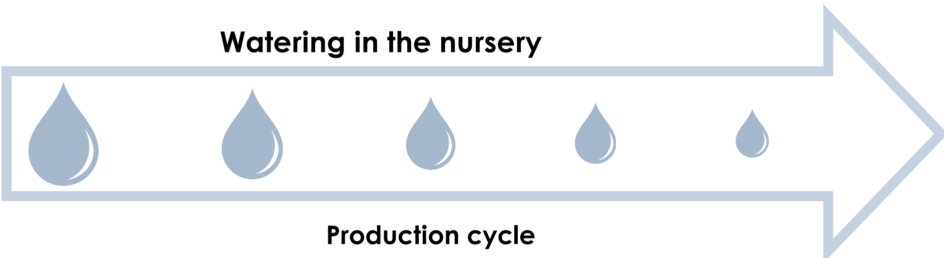
WATERING

To efficiently water plants in a nursery setting, it's crucial to consider their specific water needs (based on species, age, etc.), the season, substrate mix, and container sizes.

The best time to water seedlings is early in the morning and late in the afternoon. It is also important to remember that excess watering is as harmful as under-watering. Grouping plants with similar water requirements into separate irrigation zones helps conserve water and tailor watering strategies.

A Sprinkler system watering nursery seedlings

Several factors affect how much watering seedlings should receive. Variations between a rainy season and dry season can be extreme and require careful management to avoid over- or under-watering. Different native species have high variations in their water needs, which also change as the plants mature. Different substrates also have different water retention capacities and must be considered when planning watering application. Smaller containers dry out faster and need more frequent watering, while larger containers retain more water between irrigation events



Watering should be tailored first to meet optimal watering for each species and growth stage, then to facilitate a gradual hardening of the seedlings during their final months in the nursery. A gradual increase or reduction of watering, with careful monitoring of the plants' responses, allows seedlings to gradually adapt and prepare for periods of high or low water availability at the restoration sites. Proper container spacing is also vital for optimizing water use and plant growth, especially in overhead irrigation systems.

The watering system, whether sprinklers, irrigation, or manual watering, should be monitored closely with automated systems regularly tested to ensure they are functioning as intended. To accurately determine water needs, weigh plant containers one hour after irrigation and again 24 hours later to calculate daily water use. Comparisons between plant species can be made by weighing them simultaneously after watering to eliminate external factors. Soil moisture sensors can provide automated measurements for precise watering.

WEEDING

Weeds pose a consistent threat to seedling health that must be addressed through the development and implementation of a detailed weed management plan.

Weed control requires constant and thorough management as weeds can thrive in various conditions throughout the year and present a continuous challenge. Weeds compete directly with seedlings for vital resources such as water, nutrients, and light. They also prevent good ventilation and serve as hosts for pests and diseases, which threaten seedling growth, quality, and survival. To effectively manage weeds, nursery managers must develop a weed management plan that encompasses both preventive and reactive measures.

Nursery staff weeding together

Prevention is key, starting with thorough substrate selection, preparation and sanitation before planting. When selecting substrate, heated compost or materials such as peanut husk or coco peat do not contain seeds so should be chosen above top soil or openly stored materials. Establishing a weed-free environment is essential for the successful growth of nursery stock.

Additionally, a comprehensive ongoing weed management plan should be developed, using non-chemical approaches whenever possible. Physical methods such as mulching, sub-dressing fertilizer, and hand-weeding play crucial roles, especially in container nurseries where options may be limited.

Nursery staff weeding wearing gloves

Placing anti-weed foil below the tables is an option that can reduce ongoing labor cost. Nurseries can also work with cover layers in germination beds or pots to suppress other seeds. Some commercial nurseries commonly use physical or chemical treatments to kill of weeds and germs, however these are costly and chemical solutions should be avoided wherever possible.

Regular scouting and frequent hand-weeding can significantly reduce weed pressure, ultimately cutting labor costs and providing additional opportunities for monitoring of seedling performance. By implementing a holistic approach that combines preventive measures and non-chemical controls, nursery managers can effectively manage weeds and maintain clean, productive nurseries.

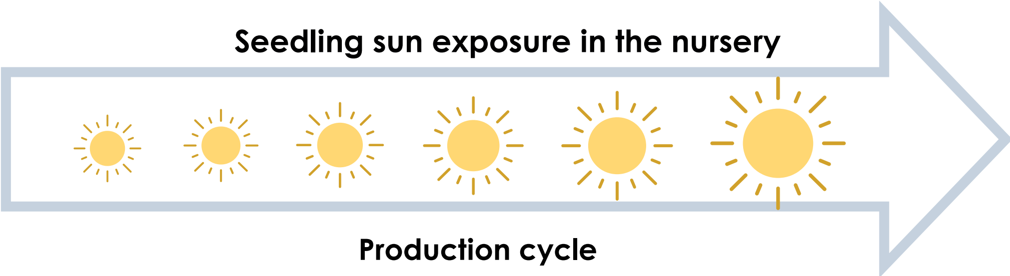
UV EXPOSURE

Gradually reducing the shade is essential for effectively hardening of native plant seedlings in nurseries.

Shade nets should be utilized to provide ample protection from direct sunlight, allowing seedlings time to adjust gradually. Shading plays a crucial role in the initial growth stages of native plant species within a nursery, providing protection from harsh sunlight. However, gradually reducing shading is equally important for the hardening process, which prepares seedlings for the challenging conditions they will face outside the nursery. Using shade nets facilitates this gradual hardening. During the hardening process, nursery staff must monitor seedlings for signs of excessive sunlight exposure, such as bleached or curled leaves, that indicate hardening is happening too quickly. Facilitating a gradual increase in sunlight is vital to harden successfully while avoiding these issues

Young seedlings are protected by shade in the net house

Seedling sun exposure in the nursery



Production cycle

Scheduling adequate time to allow for the hardening phase is an important aspect of management that can be overlooked and so should be factored into production cycle planning from the start. An automated shading system can help to regulate shading and follow a pre-determined schedule, as long as the climactic conditions and seedling health remain carefully monitored throughout. Seedling's can be hardened more rapidly in a nursery context, where a range of horticultural treatments are possible. However, caution should still be used to avoid overly stressing the plants, which can hinder their hardiness. Proper acclimation requires sufficient photosynthetic reserves, so shading and other accompanying hardening aspects should be carefully calibrated to support rather than overwhelm the plants.

PLANT NUTRITION

To enhance the performance of native plant seedlings in nurseries, various additives such as fertilizers, targeted nutrients, and mycorrhiza can be utilized.

Soil nutrients

While fertilizer offers a conventional approach, targeted application of essential nutrients is preferred for optimal results. Targeted nutrient supplementation, of both the foundational macronutrients (nitrogen, phosphorus, and potassium) and micronutrients, can help support healthy plant growth more effectively.

Nurseries should seek to identify specifically what nutrients different seedlings are deficient in and address them directly. This could be achieved via changes to the substrate and soil mixture. Organic fertilizers like compost contribute organic matter and microorganisms, benefiting soil health. If additional fertilizer is added, careful application methods are essential to avoid over-fertilization. Alternatively, for container nurseries, nutrient uptake is better derived from various other sources including watering and microorganisms.

Microbiome

Nursery manager examining mycorrhiza on seedling roots

Mycorrhiza are increasingly recognized for their ability to acclimate seedlings to the microbiome of their planting site, thereby boosting their survival chances. The effects are particularly evident when applied early in a plant's life cycle. Incorporating mycorrhizal fungi into seedling containers or beds enhances young plants' resilience to drought by improving nutrient absorption through roots. This promotes the development of a robust root system, aiding quick establishment in field conditions. Such advantages are crucial in areas prone to unexpected or prolonged drought. Additionally, mycorrhizae augment microbial nutrition uptake and might offer protection against pathogens like root-knot nematodes. Use of mycorrhiza is particularly helpful when using sterile substrate, as is best practice.

However, mycorrhizal efficacy depends on the availability of affordable, high-quality supplies, and risks introducing harmful bacteria. Careful selection of strains and patience in observing effects are necessary, along with vigilance against low-quality products and complexities of soil variability. Wild mycorrhiza can also introduce harmful elements such to the seedlings and must be carefully monitored. As such, nursery's should conduct small-scale trials with seedlings, evaluating growth performance, and experimenting with forest soil samples in the absence of commercial mycorrhizae. Techniques for mycorrhizal application include seeding inoculation, seedling/transplant inoculation, and at-planting application, each ensuring effective symbiosis between plants and fungi. More information is available in annex 2.

SORTING AND SPACING

In nurseries, sorting and spacing seedlings are vital for ensuring high-quality plant production.

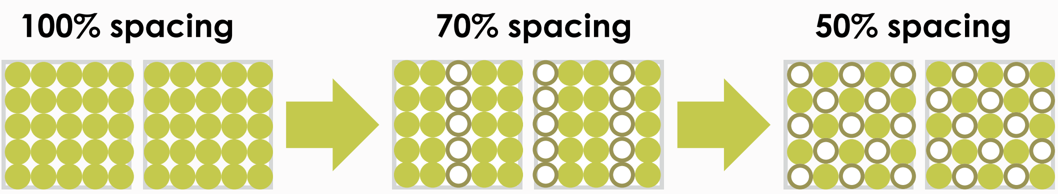
Sorting involves ongoing assessment, starting from seed collection and continuing through various stages like germination, transplanting, and final selection. Continuous sorting, along with meticulous record-keeping, helps maintain nursery performance and adapt processes accordingly. It's crucial to remove sub-par seedlings promptly, allowing ample spacing for healthy growth. This process not only ensures quality but also reduces costs, as only healthy seedlings are viable for restoration sites. Weak plants are also entry points for fungi, posing a risk to the entire production, so must be removed quickly from the nursery.

Tall, leafy seedlings are more widely spaced

Seedlings should be sorted out if they exhibit signs of poor health, such as disease, damage, deformities, abnormal size, few leaves, yellow or dry foliage, or thin stems. This proactive approach ensures that only robust native seedlings, capable of thriving in restoration conditions, are retained. By identifying and removing low-quality seedlings early on, nurseries can optimize resources and enhance overall seedling quality, reinforcing successful restoration efforts.

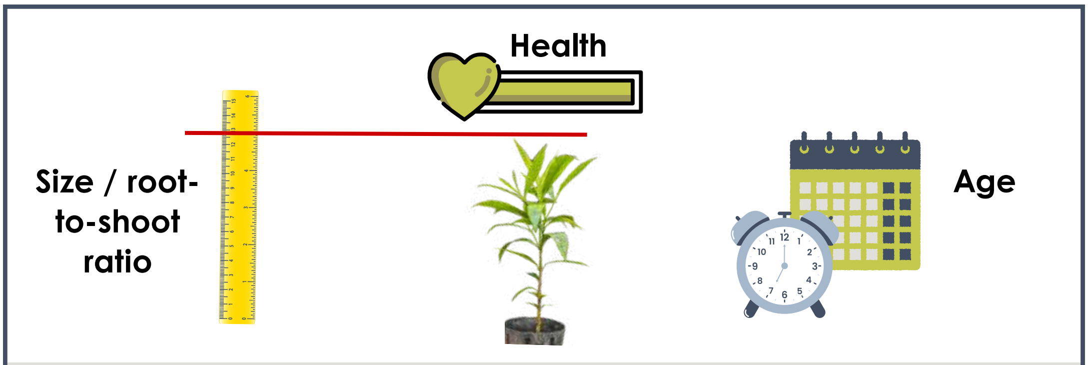
Spacing is necessary when seedlings reach the stage where their leaves start to touch and overlay with neighboring plants, preventing them from receiving sufficient sunlight. Spacing of seedlings ensures seedlings receive sufficient resources and facilitates easier monitoring. Spacing can be done by leaving a few inches of space in between two or three rows of seedlings in pots. When using the tubes and trays system, incorporating free rows or leaving every other pot space free can simplify the spacing process.

All species start at 100% spacing (i.e., no gaps between tubes). Not all species will need to be spaced, as this will depend on their growth rate and extent of foliage. Equally, while some species will be sufficiently spaced at 70% spacing, others will need up to 50% spacing before they leave the nursery. Spacing should be an ongoing and well managed process in order to maximize nursery space and seedling health. Awareness of the number of seedlings per square meter of the nursery when each species has reached their final spacing requirements is vital for effective planning of nursery space.



FINAL SEEDLING SELECTION

Selecting quality seedlings is essential for successful plant establishment and long-term growth in the field. Sending sub-quality seedlings risks low survival and high replanting costs.



Seedling selection criteria

The key indicator for seedlings leaving is the root-to-shoot ratio which should be between 1:1 and 1:2. Every species also has different optimal seedling heights for dispatch, but root growth is a greater indicator of survival.

Taller trees may appear stronger, but they have many disadvantages. Taller seedlings often have an unfavorable root-to-shoot ratio, causing reduced vitality or growth rigor. If planted, they tend to lose lower leaves and may bend over, increasing susceptibility to water loss and wilting, particularly in dry conditions. Another risk of taller plants is that, for most species, they are usually older. More mature seedlings face greater challenges in adapting to field conditions and may struggle to restart growth within the limited growth period after planting, affecting their overall health and survival rates.

Some fast-growing species may frequently overshoot this height range. Native seedling production timelines are highly challenging because of the wide variety between species seed availability, storage options, germination rates, growth rate, etc. In some of these instances, clipping tall seedlings a few weeks in advance of transportation can be used to reduce the risks of excessive height. This approach should be a last resort, only used when the seedlings are otherwise excellent quality and have sufficient time to recover before planting. It is also only suitable for a few of the highly regenerative species and must be tested on small samples first. Wherever possible, adjusting the production cycle to optimize species growth stage should be pursued over these remedial measures.

Nurseries should identify the optimum length of stay in the nursery for each species and select seedlings that match these. Lastly, the seedlings overall health criteria, as used throughout the nursery sorting process, apply to final seedling selection. Only seedlings with strong stems, good root-to-shoot-ratio, think root collars, no evident damage, and a good distribution of healthy, green leaves, should be selected for dispatch.

TRANSPORTATION

Transportation of the seedlings is a delicate operation that must be planned carefully to ensure no damage to the seedlings at this final stage of the production process.

Detailed Organization: Pre-plan and organize the allocation of seedlings from different species into appropriate planting clusters and site locations. Implement effective administrative processes to ensure the right number of seedlings reaches each site at a suitable rate for planting capacities.

↓

Preparation of Planting Sites: Plan and prepare the planting sites in advance. This includes clearing the area, arranging necessary equipment, and ensuring that all personnel are ready for the task. Avoid keeping seedlings at the planting site for more than a few days, as this can negatively impact their health and survival rates. It is recommended to establish temporary nurseries at the planting sites to care for the seedlings while they await planting. While the seedlings wait to be planted, barriers must be set up between the seedlings and the ground to prevent the roots from penetrating the soil prematurely.

↓

Selection and final watering of seedlings: Ensure that selected seedlings receive a thorough watering session before transportation. This ensures they are adequately hydrated for the journey and initial planting.

↓

Transportation: Organize transportation schedules to ensure seedlings are transported early in the morning, late in the evening, or on cloudy days to minimize heat stress. Use secure cases to transport seedlings, preventing movement and damage while maximizing space efficiency to minimize the number of required vehicles. If using the tubes and trays system, stack them securely in crates to optimize space while ensuring adequate protection for the seedlings. Ensure that seedlings are securely placed within transportation containers to prevent any falls or damage during transit.

Seedlings are secured in crates for transportation

PESTS AND PROBLEMS

Effective management of pests, fundus and diseases is an ongoing process that requires consistent monitoring and routine preventative measures.

Nursery's should develop an Integrated Pest Management (IPM) incorporating various techniques to suppress pests economically and environmentally responsibly. This involves management of nursery conditions, identification and monitoring of pest populations, and utilizing a combination of pest control measures.

Fundamental preventive measures include regular monitoring, spacing, and physical removal of pests. Sanitation is also an important measure, involving the use of pest-free plant propagation stock, sterilized media, and sanitizing equipment and surfaces using methods like steam or effective disinfectants. In some instances butterfly nets and insect traps may be appropriate measures at key points in the season. Even with these preventative measures in place, regular manual removal of pests will be a necessary part of nursert worker's routines.

Species of caterpillars, a common nursery pest

For fungus and plant diseases, prevention is better than cure due to a common due to the lack of effective cures. As with pests, Sanitation is a key preventative measure, including sterilization of tools, surfaces, and substrates to reduce the risk of spores and bacteria being introduced. n preparation of production cycles, air-drying substrate mixes in sunshine helps to sterilize it through UV exposure, after which keeping substrate stored in dry areas is vital.

Once planted, seedlings should be carefully monitored to avoid over-watering and creating an overly damp environment, particularly during rainy seasons. Nurseries should ensure careful monitoring of regular maintenance practices to ensure that the nursery environment does not support fungus and disease growth.

If a fungi outbreak occurs it must be rapidly addressed to avoid potentially devastating consequences. The imediate Removal of affected plants is vital. The substrate of infected plants must also be removed and all equipment thoroughly sterilized before being reused.

Seedling with damping off disease

unique land use

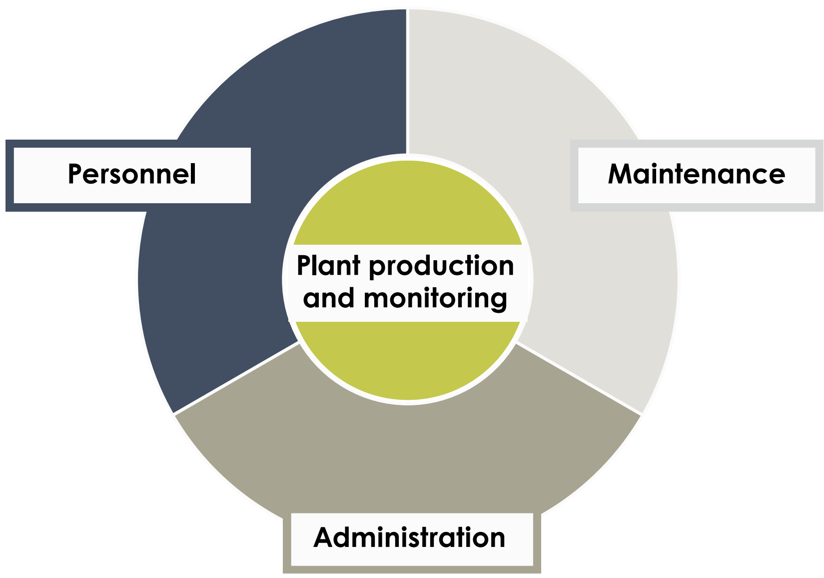
CHAPTER 4

Management

MANAGEMENT

Nursery management is multifaceted topic area that requires careful planning and organization.

Managing a plant nursery involves overseeing various aspects such as practical operations, scientific knowledge, technical expertise, interpersonal communication, and economic considerations. Key responsibilities include ordering supplies, maintaining facilities, scheduling tasks, and keeping records. Broadly, the many facets of nursery management fall under 4 categories. At the core is management of the seedlings themselves and the monitoring of ther development. However, management of the nursery plants can only be achieved through effective management of the nursery personnel, nursery maintenance, and nusery administration. Each of these 4 management aspects will be described in the following chapter.



Aspects of nursery management

Management of the plant production cycle, key maintenance and personnel activities, and important administrative steps such as seedling orders and supplies, should be planned at least 1 year in advance. Weekly planning sessions allow managers to assess immediate needs, prioritize tasks, and set long-term goals as well as guiding the daily tasks of nursery staff. A comprehensive checklist can help in managing daily, weekly, monthly, and seasonal tasks, ensuring the nursery runs smoothly. Flexibility is crucial due to varying environmental conditions and plant responses. Schedules and records are important, however nursery management must also have inbuilt flexibility to tailor tasks based on observed needs and conditions.

Regular observations by managers and staff are essential for effective planning. Reviewing daily logs and plant development records helps prioritize tasks and address potential issues like pests or growth delays. Planning sessions should encompass proactive activities aligned with the nursery's mission, such as public relations, education, and improving plant quality. By integrating these practices, nursery managers can ensure efficient operations and optimal plant care.

MANAGEMENT: PLANT PRODUCTION

Planning native species production for restoration projects is subject to significant additional challenges compared to "typical" or commercial seedling production.


Overhead view of nursery net house

Nurseries must produce native seedlings in bulk for specific planting periods and to stagger seedling production to match the capacities of planting teams. However, the period of a seedling's readiness for planting is small. Too developed and the trauma of planting could cause shock and death, not developed enough and the seedling usually does not have the strength or adaptation to survive. In the case of native species, nurseries often also face a lack of available species information or available stocks and supplies (of seeds, cuttings, etc.) on the market. Successfully navigating native seedling production is therefore fully dependent on robust and detailed planning.

Plant production planning needs to be at least 1 year in advance and detailed down to each week. Within this plan their also needs to be inbuilt flexibility and scope for mitigative actions if, for example, a species' mother trees do not flower as expected and an alternative species must be supplemented. Daily tasks like watering, record-keeping, and monitoring plant growth are vital for maintaining crop health and must also be planned and scheduled in advance.

At the top level, determining total production targets and the number of each species to be produced each cycle must be calculated based upon both demand and nursery capacities. Species choice must always seek to reflect a balance between high value species (as regards species richness and biodiversity) and species with greater reliability or stability as regards seed availability, planting success, etc. This mix should be planned in advance but have scope to adapt flexibly depending on the results of different stages of the production cycle. It is also important to factor in available knowledge on the species' production cycles (when seeds are ready, when they germinate, growth rate and final spacing) so as to calculate optimal nursery capacities across all nursery areas.

The key phases or production of each species, from seed collection through to transportation need to be planned and aligned so as to ensure sufficient capacity in germination and production zones, as well as to facilitate the synchronization of when each species reaches the optimal stage for planting. Where known, key periods of risks to a species, e.g., from pests or fungus, should also be included along with any planned mitigation methods. From these species plans, monthly, weekly, and daily tasks can be planned for each species depending upon their stage of development. By planning the production cycle for each species, potential bottle necks can be identified and mitigated, e.g., through seed storage and later germination of some species or clipping of others.

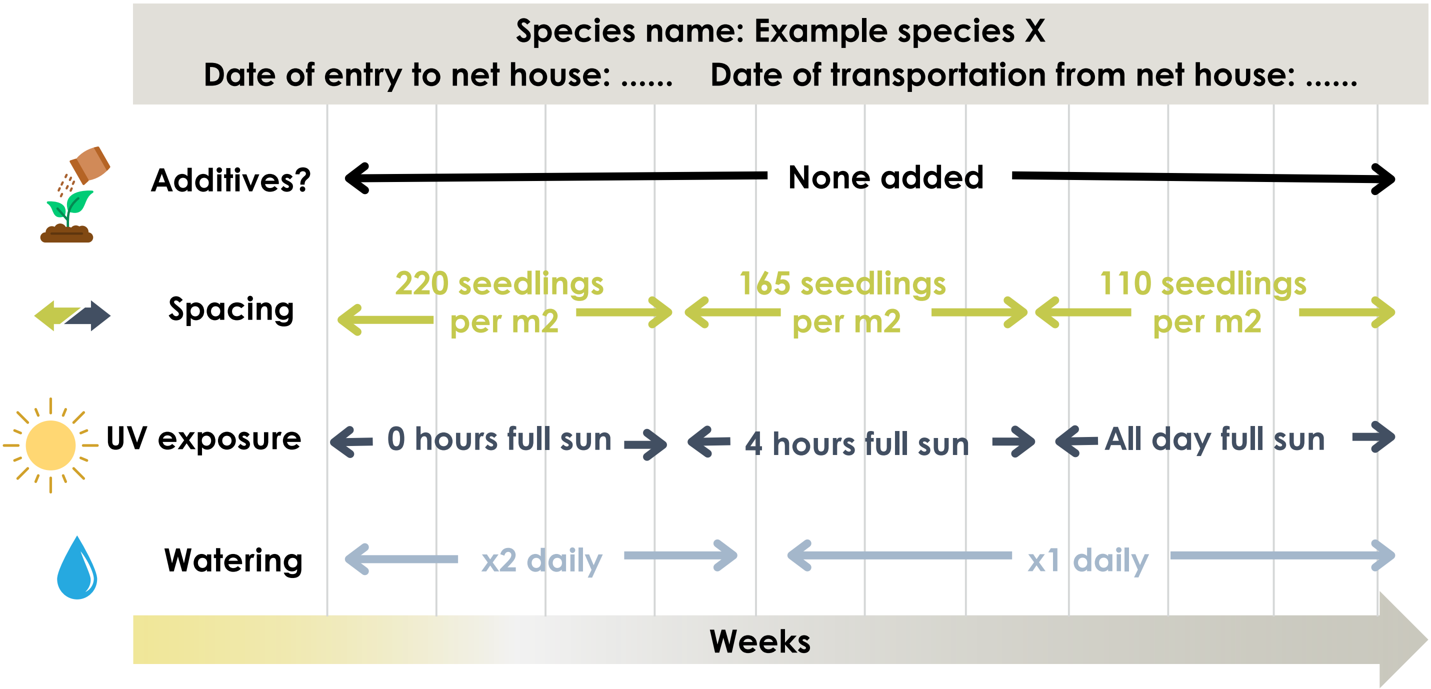
MANAGEMENT: PLANT MONITORING

Both planning and ongoing monitoring of plants as they go through the production cycle are vital for effective nursery management

Execution of the plant production plan must be combined with monitoring of the plants throughout the production cycle in order to facilitate effective management. Monitoring of each species across the production cycle allows nursery manager to track progress through the plan and identify where adaptations need to be made.

Monitoring, and comprehensive record keeping of the monitoring, is also vital in order to provide data and information for the panning of future production cycles. When detailed records are kept of the seedlings key metrics (germination rates, germination duration, selection rate, final spacing requirements, any pests or problems experienced, etc.) throughout the production cycle, trends and any required adjustments to the production approach can be easily recognized.

Overall monitoring of when each species reaches each stage of the production cycle should be supported by more granular monitoring of key aspects within each stage, such as in the example of a monitoring report for the net house stage.



Example of species monitoring sheet

Planning and monitoring of production cycles can be approached in a variety of ways, from online excel sheets to paper-based approaches, but the overall production plan must be understood and available to all nursery staff, with monitoring responsibilities clearly allocated and incorporated into routines effectively. Examples of production management templates can be found in annex 1.

MANAGEMENT: MAINTENANCE

In addition to managing the nursery processes, nurseries themselves require regular maintenance of the infrastructure and tools and facilities.

Overall nursery maintenance is important for maintaining efficiency and safety in the nursery. In particular, this means regular sweeping and weeding to keep pathways clear of debris, weeds, and obstacles, and well as overall policies of tidiness and proper equipment storage. Incorporating these tasks into daily or weekly schedules can minimize the time spent on these tasks in the longer term.

Maintenance of key nursery structures is also important. Nurseries that have invested in watering systems, net houses, storage facilities etc., should schedule regular maintenance checks to keep structures solid and in good condition. This may also involve the cleaning of glass or plastic panels, repairing leaks, clearing of drainage areas, or repairing any damage caused by extreme weather. Through planning in regular maintenance checks small issues can be identified an remedied before any broader structural damage occurs.

Weeds and debris are cleared from the drains around the net house

Similarly, management plans should include conducting routine maintenance checks on nursery equipment and tools. Equipment maintenance is vital to to prevent breakdowns, ensure optimal performance, and protect worker health and safety. Joints should be oiled, worn-out components replaced, and any damages noted and repaired.

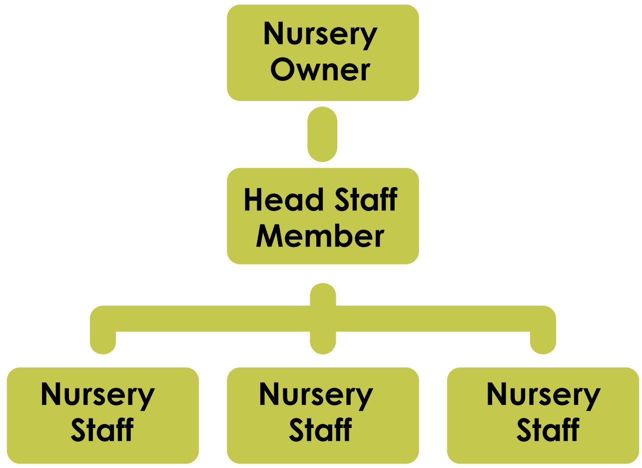
Finally, key nursery facilities, such as water and electricity systems, must be regularly tested and maintained. Nurseries depend on water to function and the watering system must be regularly tested across each aspect of it's operation. This includes testing water quality, monthly maintenance of filter systems, regular flow tests, pump maintenance (as per manufacture guidance), and cleaning of sprinkler heads. Scheduling these activities into monthly nursery tasks is vital to ensure they are not immitted and prevent failures of the watering system. Similar checks to other key facilities and systems, such as electricity, should also be planned. Nurseries with capacity may also seek to employ external experts to conduct yearly checks of these systems to ensure they are functioning well and pre-empt any necessary repairs.

MANAGEMENT: PERSONNEL

Personnel management includes establishing and overseeing the organizational structure, task allocation, staff training, and health and safety.

Each nursery should have a clear organizational structure with defined roles. The specifics of this structure will vary depending on the size and approach of each nursery, however a clear understanding of roles and responsibilities is vital for smooth nursery operation.

Typically, this will include a nursery owner who heads operations, and a senior member of staff who helps organize and oversee the team. In some cases it may also be appropriate to allocate specific roles based on expertise or qualifications related to equipment.



Basic nursery organizational structure

In all cases, nursery management requires the development, communication and reinforcement of this organizational structure to ensure that all employees understand their role, responsibilities, and who to approach for support. From this standpoint, tasks can be allocated on a daily, weekly, or monthly basis to appropriate team members based on their capacities and expertise, enabling management of responsibilities and accountability.

Staff meeting to discuss sorting of seedlings

Regular communication with nursery staff is important to ensure positive working environment and communicate tasks. Nursery owners may seek to hold regular staff meetings on a daily or weekly basis to facilitate organization. Additionally, regular employee training must be organized on key processes and at key stages of the production cycle. Training will also be necessary when new equipment or processes are introduced, annual health and safety training particularly important.

Overseeing the health and safety of employees in general is also a key management responsibility. This involves setting up clear protocols, ensuring safe storage of tools and hazardous materials, and provision of safety equipment.

MANAGEMENT: ADMINISTRATION

Effective management of administrative tasks is essential for ensuring the smooth operation of a plant nursery.

The administrative aspects of a nursery's management underpin al other activities and are essential for its functioning. It is therefore vital that nursery managers have oversight over all administrative procedures and plan the required administrative tasks effectively. The administrative management of an individual nursery will vary, but key areas that must be managed in all contexts include:

Inventory Management: Maintain accurate records of plant inventory, including quantities, species/varieties, and stock levels. Implement inventory tracking systems to monitor plant movement, identify trends, and optimize stock levels to meet customer demand.

Order Processing: Handle incoming orders from clients, wholesalers, and suppliers efficiently. Ensure orders are processed accurately, and plants are selected, packed, and processed correctly for trasnportation.

Financial Management: Manage budgeting, invoicing, and financial transactions effectively. Monitor expenses, revenue, and profitability to ensure financial sustainability. Implement cost-saving measures and analyze financial data to identify areas for improvement.

Plant monitoring and nursery maintenance records: Maintain a clear picture of the state of the nursery as regards production targets, pest and disease issues, germination rates, transplanting, and sorting rates and duration, equipment condition, and nursery capacities (vital for the smooth running of the nursery and only possible through clear records). Compilation of this data to increase knowledge on each species and making adaptations to production plans.

Regulatory Compliance: Stay informed about relevant regulations, permits, and licenses governing plant nurseries. Ensure compliance with environmental regulations, plant health regulations, and workplace safety standards. Maintain accurate records and documentation to demonstrate compliance with regulatory requirements.

ACKNOWLEDGEMENTS

With thanks to University of Huế, HUSTA, and everyone at the Cam Lo Nursery, whose knowledge and insights made this manual possible.

References

Haase, D. L., Bouzza, K., Emerton, L., Friday, J. B., Lieberg, B., Aldrete, A., & Davis, A. S. (2021). The High Cost of the Low-Cost Polybag System: A review of nursery seedling production systems. *Land (Basel), 10*(8), 826. https://doi.org/10.3390/land10080826

Russo, C., Yeager, T. H., Ingram, D. L., & Steed, S. (2023). Layout and design considerations for a wholesale container nursery. EDIS, 2023(3). https://doi.org/10.32473/edis-ep034-2023

CONTACT

Unique Land Use
Schnewlinstraße 10, 79098
Freiburg im Breisgau

(+49) 0761 2085340
unique@unique-landuse.de

Supported by:
Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection
IKI International Climate Initiative
based on a decision of the German Bundestag

unique land use

unique land use

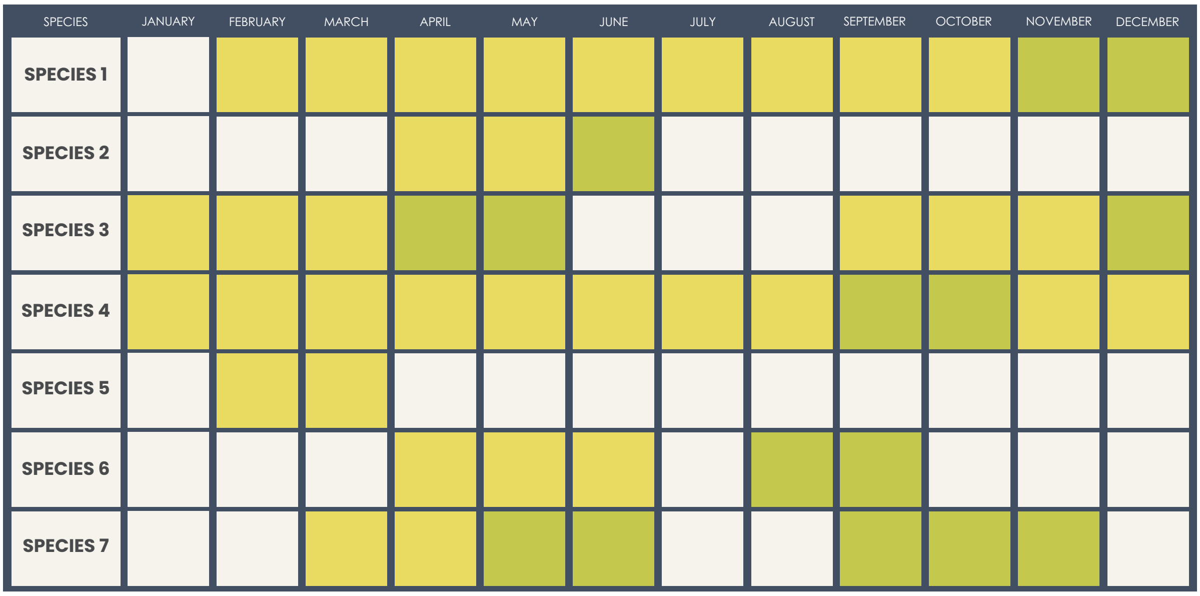
Monitoring and Managment Templates

ANNEX 1

SEED COLLECTION MONITORING

Keeping records of when the mother trees of each specie is flowering and seeding is vital to facilitate the collection of native species seeds in the wild. A demonstration of how species information could be tracked, and a demonstration of how the Cam Lo Nursery has tracked this information, are provided in the two tables below. These tables would need to be updated on a yearly basis, with records of each year kept, to facilitate a comparison of any seasonal changes to the species flowering and seedling cycles. A blank table template is also provided on the following pages for utilization by nursery managers.

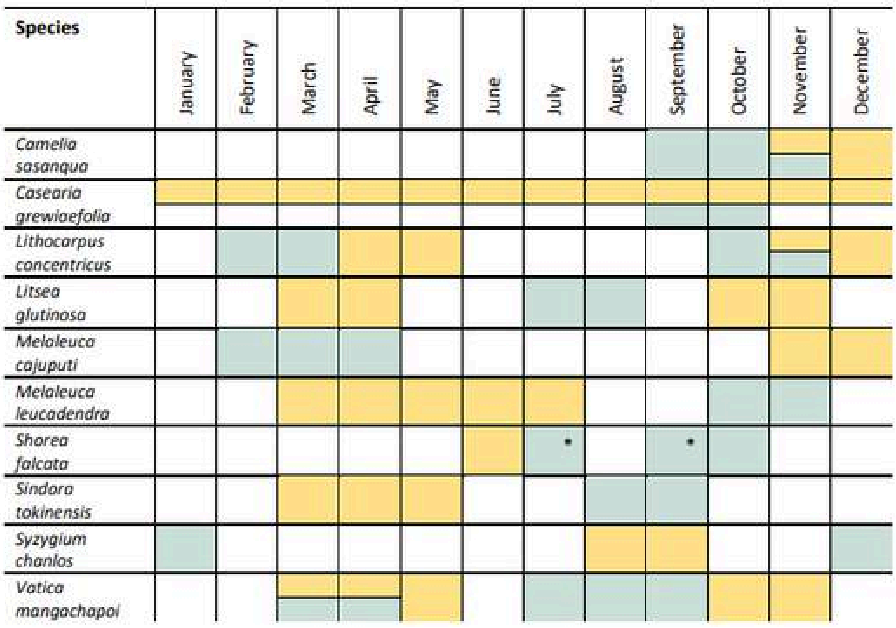
<u>Example table1</u>



Seeding

Flowering

<u>Example from Cam Lo nursery records</u>



Species	January	February	March	April	May	June	July	August	September	October	November	December
Camelia sasanqua												
Casearia grewiaefolia												
Lithocarpus concentricus												
Litsea glutinosa												
Melaleuca cajuputi												
Melaleuca leucadendra												
Shorea falcata							*		*			
Sindora tokinensis												
Syzygium chanlos												
Vatica mangachapoi												

Table 4: Seed collection periods for terrestrial species. Species flower in yellow colored and scatter seeds in blue colored months.

SEED COLLECTION MONITORING TEMPLATE

SPECIES	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
SPECIES 1												
SPECIES 2												
SPECIES 3												
SPECIES 4												
SPECIES 5												
SPECIES 6												
SPECIES 7												

Flowering

Seeding

SEEDLING AND NURSERY MONITORING

Throughout the seedling production cycle monitoring and management are required at various levels of operations. There are many ways that a nursery can approach nursery monitoring and nurseries should develop a record-keeping approach that reflects the specifics of the nursery operations and capacities.

Here, we provide an example of how the Cam Lo nursery maintains monthly records of the nursery status (inclusive of species data, nursery expenses, and labor. This if followed by a blank template with additional criteria that could be utilized as a basis for nurseries. This monitoring approach requires that the entire monitoring report be completed on a monthly basis, capturing data across numerous monitoring metrics. This information can inform decision-making for the following month which is then communicated to staff directly. The records should also be compiled and reviewed annually to identify changes for the next production cycle.

Additionally, nurseries should develop species-level monitoring of plant development. The plant development template provided would also need to be updated every month with key plant data, with the end result of a one-page record of the species' progress through the production cycle. This data can then inform key production cycle decision-making and enable increasingly tailored approaches for each species.

From the data collected on species, overall production cycle planning and management can be developed, such as in the final template provided. These production plans would need to be updated based on seasonal deviations to when each species reached every stage of the production cycle. These macro-level oversights are vital for planning nursery capacities across different zones.

In addition to the templates provided here, as nurseries become more established they should seek to experiment with key aspects of seedling production for each species, for example testing different substrates, germination treatments, hardening rates, etc. Developing clear records of the results of these experiments and incorporating different approaches within species will require increasingly complex monitoring and record keeping. However, the advantages for overall nursery outcomes make investing in developed nursery testing, monitoring, and management processes highly recommendable.

Nursery team recording data on key plant monitoring metrics

EXAMPLE OF MONTHLY NURSERY OVERVIEW TEMPLATE

unique land use

Cam Lo - Montly Nursery Report

February 2023

Weather

Precipitation	200 mm
Temperature avg.	18 °C
Humidity avg	90 %

Germination bed

bed no.	area (m²)	species	# seed	gemination date	size (cm)
1	12	Lithocarpus concentricus	15,000	02/02/2022	2
2	5	Melaleuca cajuputi	20,000	03/02/2022	3
3	8	Camelia sansanqua	4,000	12/02/2022	4.2
4	25	Melaleuca cajuputi	3,500	14/02/2022	3.1
5	4.5	Sindora tokinensis	1,700	20/02/2022	5.7
6					
Total			**44,200**		

Net house

batch	table no.	species	# seedlings	transplanting date	size avg. (cm)
1	1,3,5,7,9	Lithocarpus concentricus	16,000	01/06/2022	12.1
2	6,7,8	Lithocarpus concentricus	9,600	12/06/2022	16
3	11,12	Coccoloba uvifera	6,400	13/06/2022	4
4	14,15,16,17	Melaleuca cajuputi	12,800	14/06/2022	6.2
5	18,20	Melaleuca cajuputi	6,400	05/06/2022	6.8
6	21	Shorea falcata	1,600	06/06/2022	22
7	22	Camelia sansanqua	3,200	07/06/2022	23
8	23	Sindora tokinensis	3,200	18/06/2022	41
9	24,25	Vatica mangachapoi	5,900	09/06/2022	22.7
10	26-50	Melaleuca cajuputi	76,800	10/06/2022	11.1
Total			**141,900**		

Labor

task	work output	unit	worker days	
soil mixing	4	m³	20	
tube S filling	30,000	tubes	52	
tube M filling	15,000	tubes	40	
polybag filling	50,000	polybags		
transplanting	10,000	seedlings	6	
sorting seedlings	640	seedlings	3	

Expenditures

cost item	#	unit	total (VND)	category
Salary workers	80	days	32,000,000	salary
Coco peat	6	m³	10,000,000	material
Concrete mixer	1	unit	7,000,000	equipment
Construction soil dump	1	unit	300,000,000	construction
First aid kit	1	unit	150,000	other
Fungicide	2	liter	500,000	material
Total			**349,650,000**	

MONTHLY NURSERY OVERVIEW TEMPLATE

unique land use

				Month	Year
Weather					
Precipitation		mm			
Temperature a		°C			
Humidity avg		%			
Germination bed					
bed no.	**area (m²)**	**species**	**# seed**	**germination date**	**size (cm)**
1					
2					
3					
Total					

Net house					
batch	**table no.**	**species**	**# seedlings**	**transplanting date**	**size avg. (cm)**
1					
2					
3					
Total					

Labor				
task	**work outpu**	**unit**	**orker days**	
soil mixing		m³		
tube S filling		tubes		
tube M filling		tubes		
polybag filling		polybags		
transplanting		seedlings		
sorting seedlings		seedlings		

Expenditures				
cost item	**#**	**unit**	**otal (VND**	**category**
Salary workers		days		salary
Coco peat		m³		material
Concrete mixer		unit		equipment
Construction soil		unit		constructio
First aid kit		unit		other
Fungicide		liter		material
Total				

Pest & disease
description

Maintenace work
description

Injury
description

Comments

Plant Development Record

General Information:				#	Ø Height (cm)	root-collar diameter (mm)	Comment on root development
Species			Month 1				
Batch No.			Month 2				
Tabel			Month 3				
Germination:			Month 4				
Seed Source			Month 5				
Sowing Treatment			Month 6				
# Seeds			Month 7				
Date of Sowing			Month 8				
1st Germination			Month 9				
% Germination			Month 10				
Comment			Month 11				
			Month 12				

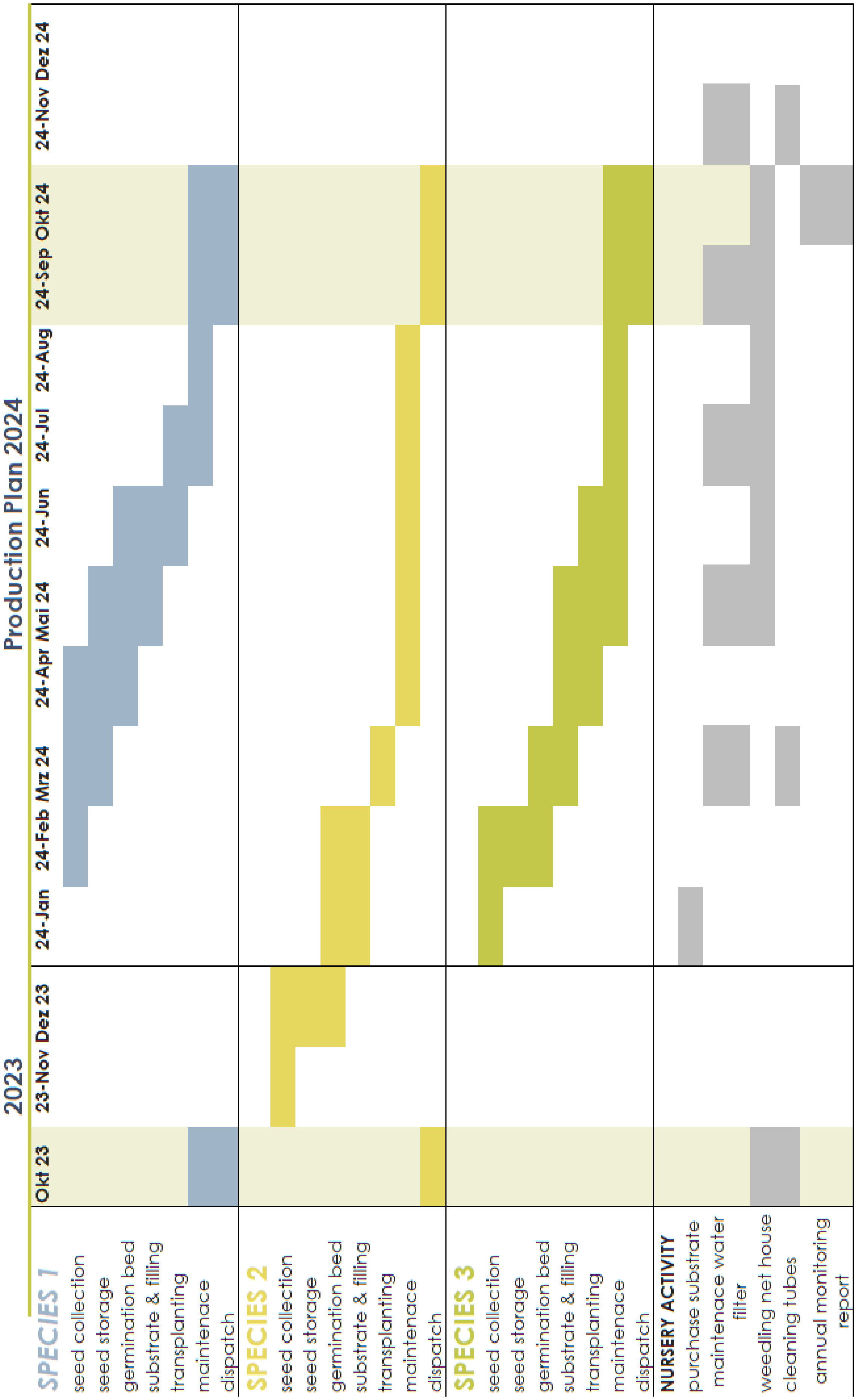
Substrate:			Dispatch	Date	#	Location	Ø Height (cm)	root-collar diameter (mm)
Substrate Mix			Dispatch 1					
Nurserys Care:			Dispatch 2					
Date of Transplanting			Dispatch 3					
# Transplanted								
Container Type								

Schedule	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12
# seedlings sorted												
Fertilizer application (g/m²)												
Spacing (%)												

Peast & Disease	Species	Month	Intensity	Measurment
Insect				
Fungi				
Bad quality				

General comments on species development and future recommendations

SPECIES PRODUCTION CYCLE MANAGEMENT EXAMPLE



unique land use

Experimenting and Testing

ANNEX 2

EXPERIMENTING WITH SUBSTRATE

The composition of seedling substrate directly impacts the growth and health of plants. Different species have varied requirements regarding soil texture, pH levels, nutrient content, and water retention capacity. By testing various substrate combinations, nurseries can identify the optimal mix that promotes vigorous growth and minimizes the risk of diseases or nutrient deficiencies.

Moreover, economic factors come into play. Substrates represent a significant expense for nurseries, and finding cost-effective yet efficient materials is essential for profitability. By testing different combinations, nurseries can identify substrates that offer the best balance between cost, performance, and sustainability.

The choice of substrate materials can also contribute to eco-friendly cultivation methods. Testing alternative substrates allows nurseries to explore options that reduce dependence on non-renewable resources, minimize waste, and decrease environmental impact.

Different substrate ingredients, sales and measuring beaker for creating different substrate mixes

The different substrate mixtures tested and approved for use should then be recorded (see example table in following pages) as a reference for nursery staff.

Box 1: Designing Substrate Tests

1. Identify Goals: The nursery should define specific goals for the testing, such as adjusting water retention (see drainage test in following page), ph level, or nutrient mixture.
2. Select Substrates: Choose a range of substrate materials to test, including traditional options like topsoil and compost, as well as alternative materials such as peanut husks. Pre identify the ratio of different substrate materials into a set of distinct substrate mixes to be tested. Mixes should be informed by the characteristics of the materials and the goals the nursery is seeking to achieve (e.g., drainage rate, PH level, nutrient mix, etc.)
3. Design Experiment: Some tests may require specific tools or even the use of a lab, while others will be based on monitoring the growth rate and performance of seedlings growing in different substrates. In all instances, clearly set the indicators that will be monitored, ensure that the sample groups (e.g. different substrate mixtures, different seedling species in a substrate mix, etc.) are large enough to yield statistically significant results, and control variables to ensure consistency across all groups.
4. Monitor Indicators and collect data: Record data on the key indicators in a uniform manner for all of the substrate mixtures over the duration of the experiment. This data can be complimented by any additional observations that emerge from the experiment.
5. Evaluate Results: Analyze the data to identify which substrate combinations perform best according to the identified goals. Combine this data with the results from other experiments on different substrate aspects to determine the best option for weach species
6. Iterate and Refine: Based on the results, adjust the substrate combinations and repeat the testing if necessary to further optimize plant growth and performance.

SUBSTRATE DRAINAGE TEST

unique land use

The rate at which a substrate drains is a vital consideration when choosing mixtures for different species. Species have different water requirements, with some requiring more water and others at higher risk from fungi and disease. Equally, the different growth rates and germination periods of species mean some may be grown during the rainy season, others during the dry season, and others experiencing both. These factors make the drainage capacity of substrate mixtures an important aspect of decision making when nursery managers choose the compositions for different species.

Fortunately, drainage tests are simple and require minimal technology, making them feasible for nurseries to undertake on site. To test the drainage capacity of soil, the following steps should be followed:

1. **Prepare Substrates**: Choose several substrate mixtures to test, representing different combinations of materials such as peat moss, perlite, vermiculite, sand, composted bark, or coconut coir. Measure and thoroughly mix each substrate blend to ensure consistency.

2. **Select Pots**: Use identical pots for each substrate mixture to ensure uniformity in testing conditions. Ensure that the pots have drainage holes at the bottom to allow excess water to escape.

3. **Weigh Dry Substrates**: Weigh each empty pot and record the weight. Then, fill each pot with a different substrate mixture, ensuring they are filled to the same level. Weigh each pot with the dry substrate and record the weight.

4. **Saturate Substrates**: Thoroughly saturate each substrate mixture by slowly pouring water into each pot until water begins to drain from the bottom. Allow the water to fully saturate the substrate, ensuring it is evenly distributed throughout.

5. **Weigh Saturated Substrates**: Weigh each pot immediately after saturating the substrate to determine its weight at full water capacity. Record these weights.

6. **Monitor Drainage**: Place all pots in a dry area where no additional moisture is added. This ensures consistent testing conditions for all substrate mixtures.

Weigh at Intervals: At predetermined intervals (e.g., 10 minutes, 1 hour, 3 hours, 6 hours, 24 hours, and 3 days), weigh each pot again to track the change over time.

Record Observations: Record the weights of each pot at each time interval. Note any visible differences in drainage rates or water retention among the substrate mixtures.

9. **Evaluate Results**: Analyze the data collected to determine the drainage characteristics of each substrate mixture. Compare the weights of the pots over time to assess how quickly each substrate drains excess water. This information can then be used to identify the best substrate mixtures for each species and to inform further experimentation.

Substrate Recipe Table

Ingredient	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5
ingredient 1					
ingredient 2			×		
ingredient 3	✓				
ingredient 4	✓	✓			
ingredient 5	×			✓	
ingredient 6			×		
ingredient 7	×	×			
....	×	×	×	✓	✓
characteristics	....	....	....	....	....

unique land use

EXPERIMENTING WITH MICORHYZA

A plant nursery can experiment with introducing mycorrhizal fungi to seedlings to increase their capacity for nutrient absorption and prepare them for planting on the restoration site. There are three core techniques for introducing mycorrhizal fungi that nurseries could experiment with depending upon their capacities: The mycelial inoculant technique, he soil inoculant technique, and the spore inoculant technique.

1) The mycelial inoculant technique:

This technique involves isolating and cultivating symbiotic fungi on artificial medium to create inoculants for infecting seedlings in nurseries. The first step of this approach is the isolation and cultivation of select species of symbiotic fungi (suitable species include Tylopilus felleus, Scleroderma spp., and certain species of Russula and Pisolithus spp.). The fungi are then cultured on a solid or liquid substrate, such as nutritional agar or a mixture of beer residue, lignohumate, vermiculite, and peat. After several weeks of cultivation, mycelial inoculants are produced by filtering and washing the mycelium, then grinding and mixing it with water to provide a "topsoil tea" that can be applied to the seedling substrate.

The advantage of this approach is the high level of control nurseries have over the mycorrhizal fungi being applied and the sanitary conditions in which they are grown, reducing the risk of introducing dangerous elements to the seedlings. The disadvantages are the high cost, technical knowledge, and resources required to isolate, identify, and cultivate the mycorrhiza.

2) The soil inoculant technique:

This technique utilizes soil and humus from natural forests or plantations containing established symbiotic relationships with fungi. Soil inoculants are produced by collecting, drying, and grinding soil or sporocarps from host trees, then mixing them with the substrate to be used for seedlings. This technique is best executed when the natural forest substrate materials are mixed into the substrate prior to or during seedling germination.

The benefit of this technique are that it is relatively simple and less demanding on a nurseries technological capacities. The drawbacks of this technique are that including raw materials from the wild poses the risk of introducing damaging elements, such as bacteria, harmful fungi, and diseases, to the seedlings. As such, it is particularly important, if implementing this approach, to systematically apply the mycorrhizal materials to small test batches and keep those seedlings isolated from the wider production cycle. The seedlings must be carefully monitored for any signs of disease and immediately removed with the area sanitized and the test stopped if signs of infection appear.

3) The spore inoculant technique:

This technique involves collecting sporocarps of symbiotic fungi from natural forests or plantations and processing them to produce dry or liquid spore inoculants. These inoculants are mixed with the substrate as a dry powder, or mixed with water to create a "topsoil tea" that is then applied to the seedlings either at the time of sowing or later in the seedlings development. It is recommended to apply the topsoil tea at the point of seed sowing of seedling germination as this allows an immediate assimilation between the seedling and beneficial microbiome.

This technique is less technologically demanding that the mycelial inoculant approach while also reducing the risk of introducing harmful elements as the selection of sporocarps is based on pre0identified fungi. However, the approach does still require sufficient expertise in identifying the relevant species of mycorrhizal fungi, timing the collection of sporocarps, and processing them for application. Additionally, the risk of contamination, though lower that with the soil inoculant technique, is not entirely removed.

The provided techniques offer avenues for cultivating mycorrhizal fungi beneficial for seedlings in nurseries. Depending on specific nursery conditions, appropriate measures should be chosen. While some fungal species exhibit symbiosis with numerous host plants, others have a narrower range, underscoring the importance of selecting symbiotic fungi suitable for fostering mycorrhizal associations with seedlings.

Optimal fungal candidates are those naturally found in symbiosis with mother trees, producing sporocarps at the base. Depending on the fungal species, production of either powder or liquid inoculants facilitates seedling inoculation or storage until sowing.

For best results, facilitating the introduction of mycorrhizal fungi to the seedlings at the point of germination is expected to produce the best results, regardless of which technique is used.

Experimenting with these techniques allows nurseries to enhance seedling growth and survival by establishing symbiotic relationships with beneficial fungi. This can lead to improved nutrient uptake, drought resistance, and overall plant health, ultimately contributing to successful plantation establishment and growth.

Experimenting with mycorrhizal fungi introduction should follow the same principles of experimentation outlined in the soil substrate experimentation.