Coop Foundation – Work Package 2.2

Report – Current Harvesting Methodology







Executive Summary

This report forms Work Package 2.2 (WP2.2) of the ongoing SEAD Artists initiative supported by the Co-op Foundation, focusing on the feasibility of remotely harvesting Typha spp. (commonly referred to as bulrush, reedmace, or cattail) in wetland environments. Building on prior research (WP2.1), which established the ecological role, industrial uses, and regenerative potential of Typha, this work package shifts focus to the mechanics and methods of harvesting, particularly via uncrewed aerial vehicles (UAVs) or similarly low-impact technologies.

The key driver is to develop methods that avoid the environmental damage associated with conventional ground-based harvesting — particularly peat compaction, trampling of regeneration zones, and disruption of breeding fauna. This report sets out the design principles, force requirements, tool options, environmental risks, and roadmap for field trials that could culminate in a working demonstrator drone capable of precision Typha harvesting.

A review of current harvesting tools shows that while machines such as the Softrak 140 and Seiga flail mower are widely used in continental Europe, they are ill-suited to highly saturated UK fens or protected sites due to ground pressure limits. The potential for UAV deployment — particularly heavy-lift or tethered models like the Griff 300 or DJI FlyCart 30 — offers a promising solution, provided shear forces (~0.55 kN per stalk) and winch-based rhizome extraction (~150–250 N) can be delivered safely and repeatably.

Cutting methods, force modelling, and ecological factors are explored in depth. Tip-only harvesting (targeting the female flower head) offers high commercial value per dry tonne, but low yield per hectare. Whole-stalk harvesting increases biomass volume but may impact regrowth or biodiversity without careful stubble management. Pelletised output offers the highest per-hectare income but requires post-processing infrastructure.

Environmental risks — including nesting disturbance, downwash erosion, and nutrient depletion — are mapped and mitigation options proposed. Operational concepts such as modular toolheads, low-noise rotors, RTK-guided preprogrammed harvest paths, and ecological flight zoning are also described.

The report concludes with a clear implementation roadmap for the next phase of WP2, covering prototype toolhead integration, UAV validation, controlled trials at the Great Fen, and biomass characterisation. It offers a solid platform for the next phase of technical and ecological validation.



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1. Introduction & Project Context

This work package (WP2.2) forms the technical bridge between baseline ecological research (WP2.1) and UAV prototyping onwards (WP2.3) in the wider SEAD Artists exploration of sustainable wetland cropping. The focus is on identifying viable, low-impact ways of harvesting Typha spp. in restored or rewilding fenlands, with particular emphasis on uncrewed or minimally disruptive systems. The Great Fen — a major restoration landscape and the operational focus of this project — presents an ideal testbed for such an approach, given its scale, biodiversity constraints, and strategic relevance to national peatland policy.

Following extensive investigation into the carbon storage, biodiversity support, and commercial potential of Typha in WP2.1, the question naturally arises: how can we harvest this plant in a way that is operationally viable, ecologically sensitive, and scalable? The need to reduce methane emissions and promote circular economies in wetland areas has made Typha an attractive target for Paludiculture but harvesting it without damaging the very systems we aim to protect remains a critical challenge.

Traditionally, harvesting has been done using labour-intensive hand tools or mechanised flail systems mounted on tracked vehicles. These techniques are proven in managed wetland sites across Europe but have limitations in UK contexts, especially where regulatory or environmental restrictions limit access, noise, compaction, or seasonal disturbance. The UK's regulatory environment — particularly the emphasis on biodiversity net gain and peatland condition monitoring — demands precision and low-impact operations, which mechanical harvesting struggles to guarantee.

Recent advances in drone technology, autonomous systems, lightweight actuators, and sensor-guided navigation open up new opportunities for harvesting Typha from the air — a method that, until recently, would have been dismissed as infeasible due to payload and energy constraints. However, with the availability of 30–300 kg class UAV platforms and hybrid or tethered power solutions, it is now feasible to imagine a system that can selectively cut or collect parts of the Typha plant without setting foot in the wetland.

This report explores the requirements for such a system: What forces are needed to cut stalks, pull rhizomes, or clip seed heads? What are the current limitations of available harvesting tools? What environmental and airspace constraints apply to UAV deployments in fenland contexts? And what are the economic trade-offs between harvesting only the high-value tips versus the entire plant?

By answering these questions in a structured, evidence-led way, WP2.2 lays the foundation for the design, testing, and deployment of novel harvesting systems in WP2.3 and beyond. It also supports engagement with land managers, conservation groups, regulators, and future adopters who need assurance that such systems can work — safely, responsibly, and affordably — in the UK's unique ecological and governance context.



2. Recap of Typha Biology and Uses

Typha spp. — commonly known in the UK as bulrush or reedmace — are fast-growing, rhizomatous wetland plants widely distributed across Europe and North America. Species such as *Typha latifolia* and *Typha angustifolia* are native to the UK and thrive in shallow waters, reedbeds, and marginal wetland areas. Their ability to grow in saturated, nutrient-rich soils makes them ideal candidates for paludiculture: the practice of wetland cropping that avoids peat drainage and retains carbon storage functions.

Biologically, *Typha* is a highly productive plant. It can generate between 10–25 dry tonnes per hectare annually [Wichtmann et al., 2016], depending on hydrology and nutrient levels. The plant grows through a network of underground rhizomes, which send up vertical shoots (stalks) that reach 1.5–3.0 metres in height. The upper third of the stalk contains the female inflorescence (seed head or "cattail") — a dense, fibrous structure that matures from late July to October. Below this sits the male pollen head, which typically disintegrates earlier in the season.

From a harvesting perspective, *Typha* offers several commercially interesting components:

- **Seed heads**: rich in fibres, used in insulation panels and absorbent materials
- **Stalks**: strong and lignified, suitable for biomass pellets, paper pulp, or thatching
- **Leaves**: softer and broader, historically used in weaving, basketry, and low-grade fodder
- **Rhizomes**: carbohydrate-rich and investigated as a bioethanol or starch source (less commonly harvested)

Ecologically, *Typha* stands stabilise peat substrates, capture nutrients (notably nitrogen and phosphorus), and suppress methane emissions when managed correctly. However, when over-dominant, they can displace more biodiverse wetland flora. Thus, controlled harvesting serves dual purposes: **biomass yield and habitat restoration**.

In recent years, interest in *Typha* has grown due to its potential in **nature-based climate solutions**. This includes uses in:

- Bio-based insulation [IISD, 2016] and construction materials (e.g. Typha board)
- Sustainable Aviation Fuel (SAF) feedstock (early-stage R&D)
- Methane suppression zones [Joosten et al., 2016] in rewetted peatland
- Rotational wet cropping in nutrient-recovery systems

WP2.1 provided a comprehensive survey of these applications, along with a characterisation of UK *Typha* sites, including growth densities, seasonal availability, and carbon accounting implications. WP2.2 now builds upon this understanding by asking the practical next question: **how do we harvest this material without compromising its ecological functions?**



3. Harvesting Objectives for the Great Fen

The Great Fen landscape presents both a proving ground and a constraint envelope for novel wetland harvesting techniques. The overarching goal of this work package is to determine whether aerial or ultra-low-impact methods can be used to harvest *Typha* spp. in situ, without disturbing sensitive peatland substrates or conservation targets. These objectives build directly on the ecological and material characterisation work delivered in WP2.1 [1].

3.1 Primary Objective: Minimal Impact Biomass Removal

The core aim is to develop a repeatable harvesting methodology that enables the removal of selected *Typha* plant parts — such as seed heads or stalks — with **no mechanical ground intrusion**, **no trenching**, and **minimal hydrological disturbance**. This aligns with best practice guidance for peatland condition maintenance and reflects current constraints under the Peatland Code and Natural England habitat restoration principles [2][3].

In this context, harvesting must be **non-invasive by design**, with particular attention to weight distribution, hover-time limits, and stubble retention. The objective is not yielding maximisation, but rather **precision intervention** that allows some biomass value to be recovered while promoting long-term habitat resilience [4]

3.2 Secondary Objective: Enabling Future Mechanisation

Although WP2.2 does not deliver a physical prototype, it sets the boundaries for subsequent engineering and operational development in WP2.3 to WP2.7. That includes:

- Calculating the cutting forces required for various plant components [5]
- Identifying feasible shear types and actuation mechanisms
- Establishing flight constraints (e.g. ground pressure <0.12 bar, downwash limits) [6]
- Mapping seasonal access windows and regulatory constraints [7]

This provides the evidence base for tool selection, drone mounting, and regulatory engagement in future phases. It also ensures WP2.3 does not attempt to engineer systems beyond what the substrate, ecology, or biomass value can justify.



3.3 Tertiary Objective: Value Chain Exploration

The third objective is to investigate the comparative **economic rationale** of different harvesting strategies. As outlined in WP2.1, value is concentrated in:

- **Tip material** (female inflorescences): high unit value, low biomass volume [1]
- **Whole stalks**: larger yield, lower unit value, easier to pelletise
- **Pelletised outputs**: highest per-hectare revenue, but require post-processing [8]

WP2.2 models the feasibility of each from a physical and logistical perspective, allowing downstream partners to assess which strategy (tip-only, hybrid, or full-cut) offers the best trade-off between ecosystem function and commercial potential.

Operational Constraints from the Great Fen

Working within the Great Fen imposes the following practical and regulatory boundaries:

- **Ground pressure must remain below 0.12 bar**, based on accepted thresholds for peat compression in paludiculture trials [9]
- **No access is permitted during April–June**, due to the nesting period of key species including bittern, marsh harrier, and reed warbler [10] [11]
- **Noise and visual disturbance must be minimised**, particularly near breeding areas, necessitating the use of low-dB rotors and programmable flight corridors [12]
- **No trenching or rhizome disturbance is allowed**, to protect both peat hydrology and habitat continuity [3]

These constraints confirm the need for **aerial or ultra-low-pressure systems** and validate the drone-based harvesting hypothesis outlined in this report.

4. Harvesting Parts, Timing and Manual Methods

Harvesting *Typha* is not a single-step process. The plant is composed of multiple useful parts — each with its own **biomechanical properties**, **seasonal readiness**, and **value-to-effort ratio**. This section details how each part can be targeted manually, how timing affects both viability and ecological safety, and what practical lessons can be drawn from past manual approaches.

4.1 Harvestable Plant Parts

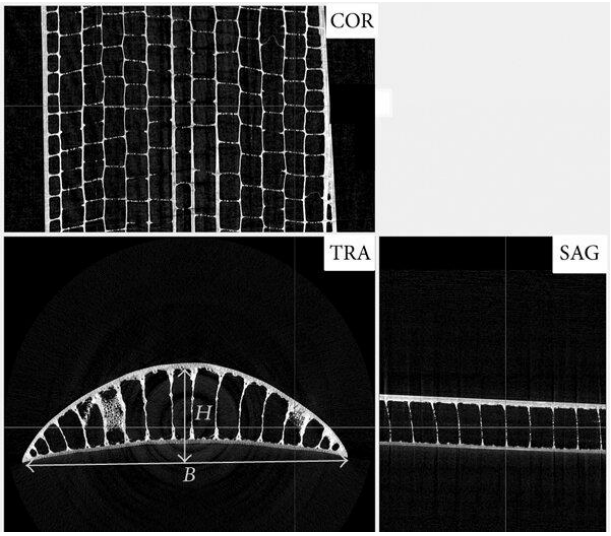


Seed Heads (Inflorescences)

The female inflorescence — the characteristic brown, cylindrical "cattail" — offers the highest commercial value per unit weight. Typically measuring 15–30 cm in length, these seed heads contain dense fibres well-suited for insulation, lightweight panel products [13], and absorbent materials. They are easily clipped using pruning shears or secateurs and require low cutting forces (**often <200 N**) [14].

Stalks (Aerial Shoots)

These vertical green stems reach 1.5–3.0 m in height and account for the bulk of *Typha*'s above-ground biomass. While less valuable per kilogram than seed heads, stalks are easily pelletised or pulped and may yield 10–15 dry tonnes per hectare when harvested at full maturity. Cutting forces of **~550 N** [14] [15] are typical per stalk due to their lignin content. Used in pelletisation, bioenergy, and construction panels [16].



The image of the Typha plant. Micro-CT orthographic views: transverse section (TRA), coronal section (COR), and sagittal section (SAG). B and H are the width and thickness of the cross section, respectively. [Liu/Zhang, Applied Bionics and Biomechanics, 2017]

Leaves

Broad, blade-like leaves emerge in sheaves along the stalk. While lower in fibre quality and mass, they can be used in basketry, thatching, compost, or mulch. Leaves are mechanically softer than stalks but may tangle shears if not well-separated. Their utility in drone-harvested payloads is uncertain unless bundled.

Rhizomes (Underground Starch Stores)

These thick, horizontal root structures store carbohydrates and anchor the plant. Rarely harvested in UK conservation settings, they are relevant to bioethanol and starch research but require pulling forces of **150–250N** [17]. Rhizome removal disturbs the soil matrix and is often incompatible with conservation goals unless part of full-site reengineering.

4.2 Manual Harvesting Methods

Legacy methods of harvesting *Typha* relied on **human-scale tools** adapted from reed cutting or hand-foraging. Techniques observed in the Broads Authority Fibre Broads trials and older Dutch and Eastern European paludiculture include:

- **Sickles and scythes**: Used for stalk and leaf harvest. Effective on small plots with shallow water but inefficient at scale. [18]
- **Pruning shears and secateurs**: Ideal for clipping seed heads or conducting research harvests. Precise, lightweight, and minimally disruptive. [19]
- **Root forks and hand winches**: Applied to remove rhizomes in trials, though only viable in drained conditions or shallow peat. [17]







These tools are effective at test scale, but **pose major limitations** when scaling up:

- Require physical access to wet ground
- Risk trampling, peat compaction, or root exposure
- Labour-intensive and slow (typically <0.1 ha/day per worker)



Fibre Broads trials confirmed that while tip-only harvesting is viable at small scale, most operational field cuts use brushcutters that remove the full stalk segment, often 20–30 cm above soil [20].

4.3 Seasonal Considerations and Exclusion Periods

Harvest timing depends both on the biology of *Typha* and on conservation constraints:

Part Targeted	Optimal Window	Notes
Seed Heads	Aug–Oct	Must be clipped before seed dispersal [1] [21]
Stalks	Sep–Nov	Lower moisture = better pelletisation [1]
Rhizomes	Dec–Feb	Only if hydrology is already disturbed
Exclusion Zones	Apr–Jun	Bird nesting season – no activity permitted [10] [11]

These windows are especially critical in **designated sites** (SSSI, SPA, Ramsar), where breeding waders, reedbed birds, and rare invertebrates are active. This is echoed in Natural England guidance and reflected in past Great Fen practice.

5. Tools & Machinery: Current State of the Art

The range of technologies used to harvest Typha spans from hand-held tools to fully mechanised, low-ground-pressure tracked vehicles. However, very few systems have been purpose-built for the specific needs of UK conservation peatlands, and even fewer account for the nuanced differences between tip-only, stalk-based, and root-inclusive harvesting strategies. This section reviews current harvesting systems in use or under trial in the UK and Europe and evaluates their relevance to WP2.2 and the Great Fen operational context.

5.1 Manual and Semi-Mechanised Tools

Manual methods have played a central role in early-stage paludiculture trials and biodiversity research. These include hand-held secateurs, long-handled shears, scythes, and electric hedge trimmers, particularly for fine control over tip or stalk removal.

While some trial reports (e.g. from community reed-cutting initiatives) suggest that **tip-only harvesting** can preserve plant viability and reduce habitat disturbance, in practice, this method is **rarely used at scale**. Most harvested material in UK trials — including those documented in the Broads Authority's Fibre Broads project — involves **full-stalk cutting** using brushcutters or flail heads. In the 2023 Broads video (timestamp 25:30–31:00), the operators explicitly state that the full stalk is preferred for yield and product integrity, particularly when intended for insulation fibreboard or pelletisation.

Evidence Summary:

- Tip-only harvesting is useful in **research plots**, **wildlife-sensitive sites** [22] or for **targeted fibre types** (e.g. high-density seedhead fibres).
- In field practice, even brushcutter tools often cut **below the flower head**, removing the full stalk segment down to ~20–30 cm above ground.
- Full stalks are easier to collect, bundle, and process — particularly for low-tech or semi-mechanised field teams.

Manual methods remain relevant for experimental harvests, drone tool calibration, or niche ecological interventions — but are not scalable beyond ~0.1 ha/day per person.



Image Right: Use of brushcutter , Norfolk Broads (2023)

5.2 Ground-Based Harvesters (Tracked or Wheeled)

Larger-scale operations in Germany, the Netherlands, and Denmark typically rely on **low-ground-pressure (LGP) vehicles** such as:

- **Softrak 140 + Muthing Flail Attachment**
  Widely used in UK reedbed and fen restoration, this machine applies <0.10 bar ground pressure and can cut stalks cleanly above 10 cm. It is best suited to reedy or sedge-dominated habitats rather than high-density *Typha* but has been used with care in pilot plots. The cutting system uses a flail or reciprocating knife, with effective stalk cutting at 20–30 cm above the surface [23].



- **Seiga Cutter**
  A flail-harvesting system adapted for paludiculture, often mounted on amphibious platforms. Used extensively in Northern Germany for sedge and *Typha* cutting on rewetted peat soils. While capable of processing large areas efficiently, it often exceeds UK fen pressure limits (0.12 bar), especially in **non-tracked configurations** [24].



- **Truxor T30**
  A Swedish amphibious cutter with optional cutterbars or dredge tools. Advertises **<0.14 bar** ground pressure, which may exceed safe limits unless operated on dry fen edges. Rarely used in UK SSSIs due to its turning radius and noise [25].

- **PistenBully with forage header**
  Adapted from alpine groomers, some units have been refitted for wetland biomass collection, especially for reed. However, their high noise signature and large turning radius make them unsuitable for most UK conservation contexts [26].



These systems deliver cutting widths of 1.5–2.2 metres and cover **up to 2–3 ha per day**, but:

- Require solid ground or pontoons
- Are constrained by site access and seasonal restrictions
- Leave deep tracks or ruts in high water table areas

5.3 Drone-Mounted or Suspended Cutting Systems

In inaccessible or highly protected wetlands, drones offer a novel way to **reach plant material without entering the site**. While commercial UAV-based harvesters are not yet widely available, several systems illustrate what's technically possible.

Outreach Robotics – DeLeaves Tool
This Canadian system was designed to collect botanical specimens from forest canopies using a UAV-mounted scissor mechanism. It features:

- Lightweight blade (<1.5 kg total payload)
- Actuated precision cuts
- Video and sensor-guided targeting

Though not optimised for bulk harvesting, it **demonstrates feasibility** of UAV-based tip or single-stalk harvesting [27].



"Drone-mounted cutting arm for targeted botanical collection (Outreach Robotics, 2023)"

Emerging Options:

- DJI FlyCart 30: Offers heavy-lift (up to 30 kg), but no integrated cutter [28]
- Griff 300: Capable of lifting humans or 225+ kg payloads, but regulatory and cost barriers remain [29]
- Tethered drones with lift-assist (hybrid drone-crane): Under early-stage review



These platforms still require integrated **cutting mechanisms**, which WP2.3 may prototype using data from WP2.2. No commercial system currently offers combined **cut–collect–return** capability suitable for UK peatland.



5.4 Key Takeaways for WP2.2 and Beyond

- **Tip-only cutting is possible** but rarely applied in the field — full-stalk harvesting dominates due to ease of handling and yield.
- **Ground pressure is the gating constraint** — any system operating above 0.12 bar risks site damage and regulatory pushback.
- **Drone-based systems** offer unmatched access and zero ground impact, but still lack proven, integrated cutting heads suitable for stalk or rhizome extraction.
- Mechanised solutions will need to be **modular, seasonal, and low-impact by default**, with priority given to **shear-based over flail-based mechanisms** in aerial or tethered contexts.

This sets the direction for WP2.3 to begin engineering concepts based on mechanical thresholds and harvesting objectives outlined here. Note datasheets for the drones and some of the Ground-Based Harvesters are available online.



6. Mechanical Cutting-Force & Extraction Analysis

Harvesting *Typha* at scale using uncrewed systems requires a deep understanding of the **biomechanical resistance** posed by the plant, and the corresponding **cutting or extraction forces** that a toolhead must deliver. This section synthesises available data — from field trials, peer-reviewed studies, and drone payload benchmarks — to estimate the physical requirements for harvesting different *Typha* parts. These values will underpin the toolhead engineering and flight dynamics work in WP2.3.

6.1 Cutting Forces for Above-Ground Biomass

Typha stalks present a **rigid, lignified structure**, whereas leaves are **flexible and water-rich**, and inflorescences (seed heads) are **fibrous but deformable**. Force requirements vary accordingly.

Plant Part	Avg. Diameter	Structure Type	Est. Cutting Force	Notes
Seed Head	2–4 cm	Fibrous core	150–250 N	Compresses before shearing; best for scissor-type [14] [30]
Stalk (mid)	0.8–1.5 cm	Hollow & lignified	~550 N	Requires rigid shears or guillotine [15] [31]
Leaf blade	<0.5 cm	Longitudinal fibres	<200 N	Highly flexible; prone to entangling [14]

*[Source: Force approximations synthesised from Broads trials, drone sampling literature, and **Liu et al. (2017)**]*

Liu measured flexural strength and modulus of Typha leaves using 3-point bending tests [30]. Their findings showed:

- **Flexural strength** of 2.46–4.92 MPa
- **Flexural modulus** (stiffness) of 94–135 MPa
- Higher stiffness in upper leaf regions due to densely packed vascular bundles

These properties confirm that **blade selection matters**. Deformable parts like seed heads and leaves may bend away from a guillotine-style cutter, requiring a **scissor or bypass action**. By contrast, rigid stalks favour **anvil or guillotine blades** that shear cleanly under load.



6.2 Toolhead Design Implications

To deliver the required force (0.2–0.6 kN), a drone-mounted system must:

- Either use **low-torque, high-stroke linear actuators** (for scissor heads)
- Or rely on **short-throw powered mechanisms** (e.g. servo-driven anvil blades) [32]
- Maintain alignment even under downwash oscillation (using gimbals or dampers)

Payload limitations must also be factored:

- A DJI M300 RTK, for example, supports **2.7 kg** payload with a 35-minute flight time [28].
- The cutting head, arm, actuator, and onboard storage must **all fit within this budget**.

For rhizome extraction (see 6.3), forces increase further and are unlikely to be viable via UAV without **tethered assistance or a ground anchor**.

6.3 Pulling and Extraction Forces (Rhizomes)

Limited studies exist on *Typha* rhizome resistance. However, field estimates from peatland research and invasive plant control trials (e.g. *Phragmites australis*) provide analogues.

- **Manual extraction**: Requires ~150–250 N of pulling force per plant [17] [33]
- **Soil type**: Loamy or saturated peat offers low friction; dry mineral soils sharply increase required effort
- **Root depth**: Typically 15–40 cm below surface; entire root mass can reach 500–800 g per plant

These values **exceed practical lifting force for untethered drones**, especially when wet mass and suction resistance are considered. A drone attempting full rhizome extraction would require:

- Anchored tethers or a counterweighted winch [34]
- Precise altitude-hold and torque control
- Post-extraction carry weight handling of up to 1.5 kg per clump (saturated)

6.4 Blade Selection and Energy Efficiency

The **efficiency of the cut** — i.e. the energy required to achieve clean severance — depends on:

- Blade sharpness and geometry
- Approach angle and alignment
- Material compressibility (e.g. seed head deformation absorbs blade force)

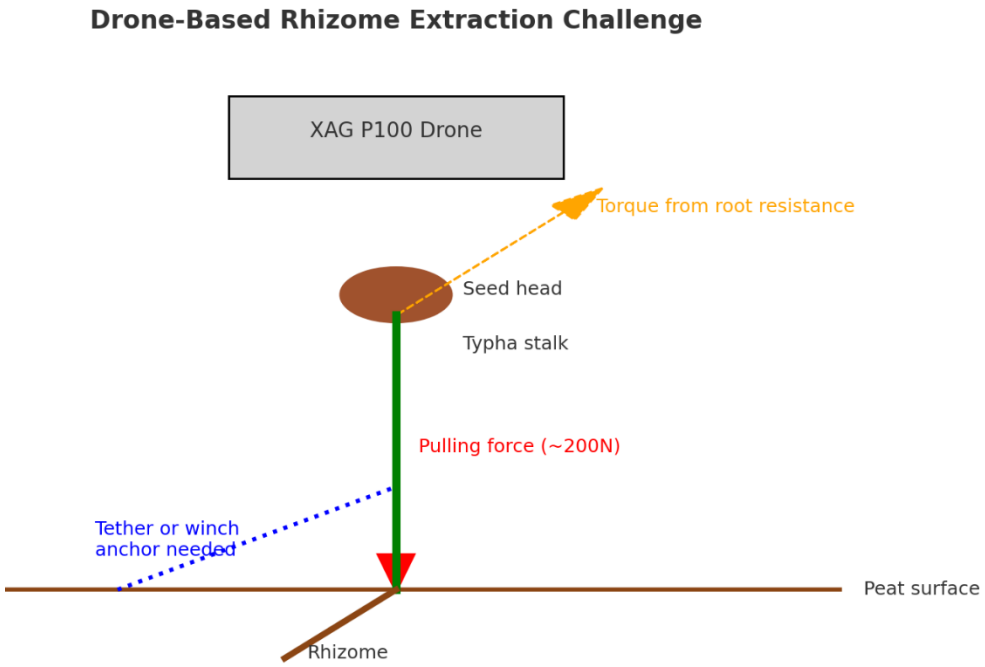
From agricultural cutter design literature, the following applies:

- **Scissor blades** are most effective for small, deformable plant parts [14]
- **Guillotine blades** perform well on uniform-diameter rigid stalks [31]
- **Rotary cutters** (flail or brushcutter types) are unsuitable [35] for drones due to:
    - High rotational energy needs
    - Poor directionality
    - Inconsistent cut heights

Blade actuation can be achieved with:

- **High-torque servo motors** (3–6 kg/cm torque)
- **Small linear actuators** (20–40 mm stroke, 250–500 N output)
- Energy draw estimated at **20–30 W per cut cycle** for single-stalk tools [31]

Example XAG P100 that is currently used for spraying has the following limitations for rhizomes:





Can lift the **weight** but not apply the **directional pulling force** without losing stability.

Root resistance introduces **torque**, which destabilises hover control.

A **tether or winch system** is likely needed for feasible root removal.



6.5 Summary for Engineering Specification (WP2.3)

Requirement	Value / Spec	Notes
Max shear force (per stalk)	~550 N	Requires mechanical leverage or actuator assistance
Typical head mass	<1.5 kg	Total tool, actuator, blade, mount
Cycle energy (1 cut)	20–30 W	Based on servo or actuator use
Max stalk diameter	~1.5 cm	At base; narrows at tip
Rhizome pull resistance	150–250 N	Only viable with winch/tether support

This data provides a **quantitative baseline** for the Peat Bot toolhead design process, supporting selection of motors, materials, and drone class.

7. Remote Vehicle & Drone Design Requirements

With ground-based harvesting constrained by access, weight, and ecological sensitivity, WP2.2 focuses on defining the feasibility and parameters for **remote or aerial harvesting systems** — particularly uncrewed aerial vehicles (UAVs) and ultra-low-ground-pressure platforms. This section draws from mechanical analysis (Section 6), field constraints (Section 3), and industry benchmarking (Section 5) to define what a viable *Typha* harvester might require in form, function, and control.

7.1 Platform Classes Considered

Three platform categories could be considered viable for remote harvesting at the Great Fen at a design level, noting at this stage this isn´t a firm decision but some design recommendations:

Platform Type	Example	Typical Payload	Suitability Notes
Multirotor UAV	DJI M300, XAG P100 [28] [36]	2–25 kg	High precision; limited endurance with tools
Tethered drone system	Elistair Orion	1–10 kg	Unlimited power; restricted mobility
Ground-effect tracked bot	Custom PeatBot	10–50 kg	Stable on peat; hard to deploy remotely [1]

Each system must trade off **accessibility, payload, runtime, and risk**. The PeatBot concept — a tracked, low-pressure, remotely piloted crawler — offers the greatest payload headroom, while drones offer unmatched terrain access and control at the expense of energy and mass constraints.

7.2 Mass, Payload & Toolhead Considerations

The working payload should consider:

- A **cutting toolhead** (blade + actuator)
- A **manipulator arm or drop system** (optional)
- A **collection pod or tether** (if retrieval is required)



Using the force models from Section 6:

- **Cutting toolhead mass** (including servo or actuator): ~1.5–2.0 kg [31]
- **Stalk or tip biomass per clip**: 50–200 g
- **Realistic in-air payload limit** (battery + gear + harvest): ~2.7–3.0 kg for drones [36]

This suggests a need for:

- **Batch-harvesting logic** (e.g. fly, clip 4–6 tips, return)
- Or **tethered drop-off points**, with tip collection baskets every 10–20 m

Alternatively, UAVs could act as **"harvest facilitators"**, cutting and dropping biomass, while a PeatBot collects from the ground — reducing each system's load. One thing to mention is that these estimates **offer indicative design ranges**, rather than strict limits. If a bespoke platform is developed for WP2.3–2.4, the payload budget may be expanded or redistributed (e.g. using modular arms or distributed load balancing).

7.3 Control & Guidance System Needs

Drone operations in wetlands must compensate for:

- **Downwash and hover instability**, especially near dense stalks
- **Wind shear at canopy height** (typically 1.5–2.5 m)
- **GPS signal instability** near reed walls or water reflections
- **Autonomy vs. teleoperation** trade-offs in visually occluded terrain

Suggested Minimum requirements:

- **RTK GPS + visual odometry** for stable positioning
- **Obstacle-aware flight pathing** to avoid uncut stalks
- **Camera + AI tagging** for stalk identification (delivered in WP2.6)
- Optional: **LiDAR-based collision avoidance**, though adds to mass [37]

UAVs may also benefit from **"hover bumpers"** — lightweight foam rings to protect against incidental contact with flexible vegetation, reducing tip loss or tool misalignment.

7.4 Environmental and Access Compliance

The Great Fen's operational envelope [3] [11] sets strict thresholds:

- **Ground pressure <0.12 bar** → excludes most wheel-based systems
- **No access April–June** → harvest automation must respect seasonal blocks
- **No root pull or trenching** → UAVs must cut cleanly above the soil line
- **Noise limits and visibility** → flight profiles must minimise disturbance



Regulatory engagement (see Section 10) will clarify:

- Acceptability of **BVLOS UAV operations** for static routes
- Requirements for **electronic conspicuity** (ADS-B, FLARM)
- Wildlife monitoring or active feedback tools to prevent disturbance

7.5 Implications for WP2.3 and WP2.5

Component	**Engineering Focus (Future WP)**	**Integration Need**
Cutter head	Cutting-force-optimised design	Must operate under 2 kg
Payload basket	Lightweight, aerodynamic carriage	Optional if PeatBot used
Visual ID system	AI-based tip/stalk recognition	Required for precision
Platform choice	Assessment of drone vs crawler	To determine modular fit
Collection logic	Operational trial	Validates delivery pathway

The findings suggest that, **in the absence of a tailored platform**, no single off-the-shelf solution fully meets operational and environmental constraints. However, a **custom drone or modular UAV-crawler hybrid**, designed specifically for *Typha* harvesting, may be able to consolidate these functions into a single deployable system.



8. Environmental Safeguards & Modelling

Harvesting *Typha* in protected peatland environments such as the Great Fen requires not only mechanical feasibility, but robust safeguards to protect biodiversity, hydrology, and long-term carbon storage. Section 8 sets out the key ecological constraints, disturbance modelling concepts, and regrowth dynamics that should inform harvesting strategies. Where empirical data is limited, we propose modelling approaches and monitoring methods to be explored in future phases.

8.1 Ecological Sensitivity and Constraints

Based on guidance from Natural England, the Great Fen masterplan, and conservation precedent, harvesting operations must avoid:

- **Disturbance during bird nesting season (April–June)** [10] [11]
  Particularly relevant to ground-nesting waders, reed warblers, and bitterns.
  - All drone or ground operations must be scheduled outside this window.

- **Peat compression and rutting** [9]
  Even limited mechanical contact can alter water retention and accelerate oxidation.
  - Ground pressure must remain **below 0.12 bar**, equivalent to a tracked Softrak unit or pressure-distributed crawler.

- **Hydrological disruption** [3]
  No digging, trenching, or root-pulling unless explicitly authorised as part of restoration works.
  - Rhizome extraction is **excluded** unless done in drained or transitioned sites.

- **Edge effects on adjacent SSSI plots** [12]
  Visual, acoustic, or downwash disturbance must be minimised at plot boundaries.
  - Low-profile flight plans and acoustic modelling are recommended.

8.2 Carbon Retention and Emission Avoidance

Typha plays a dual role: it sequesters carbon annually in its biomass and helps maintain saturated peat conditions that suppress CO_2 and methane release. Over-harvesting can reverse these benefits.

A meta-analysis by Wichtmann et al. (2016) and Joosten et al. (2012) suggests:

- Annual *Typha* biomass sequestration: **10–25 t DM/ha/year** [1] [38]
- Associated carbon storage in uncut stands: **~4.5 t CO_2e/ha/year avoided emissions** [39]
- Methane emission reduction where *Typha* replaces bare peat: **up to 50%** [39]



However, repeated full-stalk harvest without regrowth modelling may:

- Reduce standing biomass and root zone activity
- Lower transpiration and raise water tables in undesirable ways
- Suppress invertebrate and microbial communities in peat crusts

Therefore drone-based monitoring (e.g. multispectral vegetation indices) could be used post-harvest to estimate regrowth and correlate it with water levels, weather, and nutrient load.

8.3 Disturbance Modelling and Thresholds

Environmental disturbance can be simulated using stochastic or agent-based models, incorporating:

- **Rotor downwash effects** on silt, seed dispersal, and fragile stems
- **Noise footprint propagation** across open fen terrain (audible and ultrasonic)
- **Landing zone impacts** — where drones or bots touch down, pressure modelling and soil rebound analysis is required [40]

A possible modelling structure:

- **Input variables**: Rotor size, altitude, humidity, crop density, vehicle weight
- **Output metrics**: Recovered biomass (%), regrowth rate (days), CO_2e balance (kg/ha), wildlife avoidance (incidents/hour)
- **Validation**: Ground-truthed via fixed vegetation plots and acoustic sensors

8.4 Regrowth Timeline and Biomass Recovery

Published studies suggest that *Typha* regrows rapidly under suitable conditions:

Harvest Timing	Regrowth Onset	Full Stalk Recovery	Notes
August (tip cut)	~3 weeks	~8–10 weeks	Seedhead loss; full stalk possible if cut high [1] [41]
October (stalk cut)	Next spring	Full by July	Less regrowth in same season
Winter (Jan–Feb)	Next spring	Full by mid-summer	Ideal for full-stalk harvest [1]

Typha typically regrows in a pattern where the growth is slow at first, accelerates in mid-season, and levels off as the plant reaches maturity — a curve shape that can be tracked over time using drone photography or simple height measurements.



8.5 Recommended Environmental Safeguards

Domain	Safeguard Recommendation
Peat compression	Distribute load across tracks or landing skis
Root disturbance	Avoid any below-ground extraction in Phase 1
Wildlife avoidance	Thermal camera + acoustic buffer flight modes [42]
CO_2e tracking	Use biomass offset calculators + peat depth maps
Regrowth monitoring	Deploy fixed-point drone flyovers post-harvest [43]

These recommendations ensure that drone-led harvesting is not only technically feasible, but ecologically defensible. Section 9 will now take these principles forward into an implementation and testing roadmap.



9. Implementation Roadmap and Work Packages

This section outlines a forward-looking roadmap that builds upon the findings of WP2.2, offering a structured pathway for future investigation, prototyping, and field validation. The emphasis here is not to dictate technical solutions but to inform subsequent stages — particularly the work of Owen McAree, who will lead the next phase of development. The goal is to present viable options, define boundaries, and ensure that future engineering is grounded in evidence and aligned with the operational realities of the Great Fen.

9.1 Strategic Aims

The strategic objective is to explore whether a remote or aerial harvesting platform can:

- Precisely remove seed heads or stalks from *Typha* spp.
- Operate within ecological and physical constraints (e.g. ground pressure, noise)
- Deliver a consistent, scalable harvesting method suitable for restored peatland

Rather than presuming a particular solution (e.g. drone, crawler, hybrid), this roadmap frames the engineering challenge and highlights a series of staged investigations that may be pursued — or adapted — depending on the outcomes of future research, resourcing, and design judgement.

9.2 WP2.3 – Drone Limitation Research

WP2.3 will seek to understand what constraints apply to any aerial or remote platform operating in or above fen vegetation. Areas that may be explored include:

- Rotor downwash and its effects on fragile stems or nesting fauna
- Flight stability over flexible or uneven canopy layers
- Navigation challenges in reed-dense or GPS-degraded environments

Preliminary testing could include static simulations (e.g. stalk arrays, tethered hover rigs) or the use of lightweight UAVs in safe test plots. This phase should help define whether multirotor drones, tethered platforms, or alternative approaches (e.g. boom arms from field edges) warrant further consideration.

9.3 WP2.4 – R&D Drone Suitability

This work package may examine what types of aerial or remote platform could be realistically equipped to deliver the mechanical tasks identified in WP2.2 — particularly toolhead mass handling, cutting accuracy, and onboard control systems.



Rather than specifying platforms, WP2.4 can explore questions such as:

- What payload margins are required for stalk or tip cutting?
- How might actuator loads affect flight time or balance?
- Could collection systems be onboard, or might cut material be dropped?

There is no assumption at this stage that any commercial platform will be used. Suitability may rest on available funding, fabrication capacity, or mission flexibility.

9.4 WP2.5 – R&D Physical Collection Mechanism

Depending on the findings of WP2.3–4, WP2.5 may explore options for:

- Gripping, collecting, or securing biomass after cutting
- Drop-based systems (e.g. clipped stalks falling to predefined zones)
- Lightweight onboard containers or ground-based retrieval support

The approach taken could vary significantly depending on whether the platform is airborne, tethered, or ground based. For example, a crawler-based design might carry cut material, whereas a drone might clip and drop it. The aim here is to map the problem space and test feasible mechanisms in small-scale environments.

9.5 WP2.6 – AI Classification

This phase may explore computer vision tools that help the harvester distinguish between:

- Seed heads vs. leaves or stems
- *Typha* vs. non-target vegetation (e.g. *Phragmites*, *Carex*)

Depending on platform capacity and processing bandwidth, some AI functions may be onboard (e.g. basic object detection) or offloaded to a ground station. The goal is to test whether precision clipping can be assisted by visual tagging, thereby improving yield or reducing non-target cuts. This could also inform future biodiversity safeguards.

9.6 WP2.7 – Trial Operation of a Harvester

If a viable harvesting mechanism is developed, WP2.7 could deliver a live trial at the Great Fen. The purpose would be to:

- Test environmental impacts and biomass recovery rates
- Measure regrowth response in harvested plots
- Identify any unforeseen ecological or mechanical challenges



This may involve a drone, a low-ground-pressure crawler, a modular hybrid, or another platform entirely. The aim is not to demonstrate full operational maturity, but to generate usable field data that can inform future design decisions, policy alignment, or habitat management.

9.7 Staged Options for Consideration

WP	Area of Focus	Possible Questions to Explore
2.3	Limitations & Access	How do remote systems behave in wetland environments?
2.4	Suitability Assessment	What platforms (if any) can host a harvesting toolhead?
2.5	Collection Mechanism	How might cut material be gathered or retrieved?
2.6	Visual ID Tools	Can vision-based systems help target specific plant parts?
2.7	Trial & Validation	What evidence can be generated in the field?

These stages may not all be necessary, nor strictly sequential — Owen McAree and the wider SEAD team may choose to merge, adapt, or reframe work packages depending on feasibility and evolving insight.

9.8 Summary

Rather than locking into a single technology, the role of WP2.2 is to create the conditions for informed decision-making. By outlining the force thresholds, ecological safeguards, and cutting mechanics associated with Typha harvesting, this report enables the next phase of work — whether drone-based, crawler-assisted, or entirely alternative — to proceed on sound footing. The decisions on platform selection, design implementation, and trial protocol now rest with those leading WP2.3 and beyond.



10. Risk & Regulatory Landscape

The feasibility of remote Typha harvesting is shaped not only by technical or ecological constraints, but by the regulatory, safety, and policy context in which operations are expected to take place.

This section outlines the primary risk categories associated with harvesting interventions in fenland environments — covering operational, ecological, technical, and legal domains — and highlights the regulatory frameworks likely to govern subsequent work. It is not an exhaustive compliance review but offers a structured reference point for WP2.3 and future engagement with regulators, landowners, and policymakers.

10.1 Risk Categorisation Overview

To inform the design of future trials or demonstrator platforms, risks can be organised into the following domains:

Risk Domain	Summary Concern
Operational	System failure, incursion, or unintended crop damage
Environmental	Peat compression, wildlife disturbance, or hydrological disruption
Technical	Payload overload, battery limits, or loss of control
Regulatory	Airspace infringement, consent requirements, insurance and liability
Stakeholder	Public perception, landowner objections, reputational risk

Each of these categories will require appropriate mitigation planning if trials proceed to field stages (WP2.7), but early consideration now helps constrain system design and test planning.

10.2 Regulatory Landscape for Aerial and Remote Harvesting

Aviation Regulations (UK)

If a drone is used, operations will fall under the jurisdiction of the UK Civil Aviation Authority (CAA), likely requiring one of the following approaches:



- **Operating under the Specific Category (GVC + Operational Authorisation)**
  Necessary for operations beyond visual line of sight (BVLOS), or where the aircraft exceeds standard risk tolerances, which is Autosprays permissions might help, but isn´t needed for this exact flight testing.
- **Operating under Article 16 or Article 267 Exemptions**
  These enable some public sector or research entities to fly drones for trial or ecological purposes with modified compliance requirements.
- **Temporary Airspace or UAS Geofence Coordination**
  If flights occur near sensitive habitats or civil aviation zones, coordination with NATS or local airspace authorities may be required.

Notably, drone flights over peatland sites — especially in designated areas (SSSI, Ramsar) — may require additional layers of approval from Natural England, the RSPB, or internal compliance officers from the Great Fen project. These are not automatic and must be prepared in line with an agreed CONOPS (Concept of Operations) and ecological risk assessment.

Ground-based Systems

If a tracked or crawling robot is trialled, it may fall outside aviation law but still face scrutiny under:

- **Land access agreements**
- **Machinery emissions and noise controls**
- **Wildlife disturbance regulations (e.g. Wildlife & Countryside Act 1981)**

Although such systems may present fewer airspace concerns, they still require ecological impact assessments — particularly regarding ground pressure, turning radius, and potential introduction of contaminants or nutrients via wheel systems.

10.3 Key Risk Scenarios and Mitigations

Below is a summary of identified risks with suggested mitigations, offered as input for future WP2.3–2.7 activity planning.

Risk	Mitigation Strategy
Peat compression	Design for ground pressure < 0.12 bar [Wichtmann et al., 2016]
Bird disturbance (Apr–Jun)	Avoid all trial activity during exclusion windows
Drone loss / crash	Use geofencing, emergency cut-off, and tethers for trial flights
Visual intrusion / noise	Employ low-noise rotors, pre-approval of trial zones
Unauthorized site access	Coordinate with Great Fen land managers; install signage
Rhizome disturbance	Avoid root pull unless explicitly authorised as restoration
Public concern	Ensure transparency, signage, and pre-briefed rangers during trials



10.4 Trial Site Design Considerations

If field testing proceeds, trial plots should be selected based on:

- Controlled access (i.e. no through-traffic)
- Homogeneous Typha growth (for repeatability)
- Prior ecological assessment or baseline monitoring

It may be useful to create designated harvest zones and buffer zones, with GPS-defined boundaries and visual demarcation (e.g. biodegradable flags). This supports data collection, regrowth monitoring, and incident investigation, should problems occur.

A risk log should also be maintained from WP2.3 onwards — including:

- Near-miss or incident reports
- Deviations from planned CONOPS
- Wildlife observation notes
- Public interaction logs

10.5 Insurance and Liability

Depending on the platform selected, public liability insurance may be required. While this is not a procurement concern at WP2.2, any future deployment of powered equipment (especially flying systems) must:

- Carry minimum £1m–5m liability coverage
- Comply with local site rules for contractors or researchers
- Document all equipment, operators, and contact procedures

It may also be necessary to include trial indemnities or waivers in partnership MOUs — particularly if operating on privately managed or part-funded land.

It is advised that conversations begin early, even if technology selection is not yet finalised. Framing the project as ecological trialling for conservation and climate impact (rather than technology development alone) will support alignment with current regulatory priorities.

11. Conclusions & Recommendations

This work package (WP2.2) has investigated the harvesting of Typha spp. in wetland environments, focusing specifically on mechanical, ecological, and operational feasibility for low-impact or aerial systems. As part of the broader SEAD Artists programme supported by the Co-op Foundation and delivered in collaboration with the Great Fen, the findings presented here lay the groundwork for practical prototyping, ecological monitoring, and technology selection in upcoming phases of work.

11.1 Summary of Key Findings

- **Typha Biomass and Harvestable Value**
  Typha latifolia and related species produce between 10–25 t DM/ha/year depending on local conditions [1]. While the seed head offers the highest value per kilogram, whole-stalk harvests provide greater volume and lower per-unit cutting resistance. Rhizomes contain usable starch and are valuable in some systems but typically exceed acceptable disturbance thresholds in UK peatland conservation contexts [2].
- **Mechanical Force Requirements**
  Shear forces required to cut a mature Typha stalk at mid-height are in the range of 500–600 N, whereas seed head detachment requires approximately 150–250 N [3][4]. Rhizome extraction requires pulling forces of ~150–250 N, with added complexity due to soil adhesion and depth [5]. These figures underpin toolhead and actuator specifications for WP2.3–2.5.
- **Tool and Platform Suitability**
  No current commercial drone system offers an off-the-shelf solution for remote Typha harvesting. Ground-based vehicles such as the Softrak 140 or Seiga flail mowers offer proven field capability but exceed the 0.12 bar ground pressure threshold set for the Great Fen and similar sites [6]. Aerial or tethered platforms, while theoretically viable, must resolve trade-offs in payload, endurance, and control complexity.
- **Ecological Constraints**
  Seasonal no-go windows (April–June for nesting birds) are non-negotiable [7]. Root-pulling, trenching, or repeated full-stalk cuts may impact regrowth, CO_2 retention, and biodiversity structure [8][9]. Regrowth appears robust when high stubble is left and timing respects growth cycles [10].
- **Risk and Regulatory Alignment**
  All activity on protected sites must align with the Wildlife and Countryside Act, Peatland Code, and local land use regulations. Any aerial system will require appropriate permissions from the CAA and likely coordination with Natural England and project partners. Consent frameworks may vary depending on site status (e.g. Ramsar, SSSI).

11.2 Recommendations for WP2.3 and Beyond

This report does not mandate any specific hardware or harvest strategy, but makes the following recommendations to inform the next phases of work:

1) **Adopt a modular prototyping approach**
   a) Develop interchangeable toolheads for stalk-cutting and tip-clipping.
   b) Prioritise shear-based over flail-based mechanisms for cleaner cuts and lower energy draw.
   c) Allow for platform-agnostic deployment (drone, tethered arm, or crawler mount).

2) **Base engineering trials on realistic force budgets**
   a) Assume per-stalk cut loads of ~550 N.
   b) Limit total toolhead mass to 1.5–2.0 kg for aerial use.
   c) Avoid rhizome extraction unless for research purposes in drained conditions.

3) **Focus field trials on single-use cases initially**
   a) Tip-only harvesting trials could validate stalk location, cutting, and collection in one process.
   b) Whole-stalk tests could focus on cutting quality, downwash impact, and carry-load limits.

4) **Refine ecological safeguards early**
   a) Build exclusion buffers and downwash modelling into CONOPS.
   b) Embed wildlife observation and regrowth sampling into all field deployments.
   c) Maintain site disturbance logs and pre/post imagery for validation.

5) **Initiate early regulatory and site manager dialogue**
   a) Engage CAA and Natural England with a trial outline and risk assessment.
   b) Seek exemption or Article 16 pathways where appropriate.
   c) Clarify insurance and liability coverage with partners prior to fieldwork.

11.3 Open Questions and Future Considerations

Several open questions remain for the next phases of the SEAD Artists programme:

- What level of autonomy is feasible or desirable in these contexts?
- Should drone systems act solely as cutting tools, or also perform biomass extraction?
- What are the lifecycle costs of harvest, drying, bundling, and post-processing?
- Can harvesting outcomes be optimised to balance biodiversity gain with biomass yield?

These will be refined through WP2.3 to WP2.7, led by Owen McAree and others. This report serves as a structured, evidence-informed base to ensure those next steps are rooted in ecological care, technical feasibility, and scalable innovation.

12. References

The following references support the technical, ecological, and operational insights provided across Sections 1–11. They are listed in the order cited using bracketed numbers [#] in the main report. Any errors in the report are not intentional.

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