Northern Territory guidelines for targeted surveys of threatened and significant plant species

Supplement 1: Typhonium field surveys

Department of Environment, Parks and Water Security

Flora and Fauna Division

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Acronyms	Full form
DEPWS	Department of Environment, Parks and Water Security
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
NT	Northern Territory
TPWC Act	*Territory Parks and Wildlife Conservation Act 1976*

Contents

1. Introduction

These Guidelines provide a best-practice protocol for targeted survey and data collection of *Typhonium* species in the Top End of the Northern Territory (NT). The document is a supplement of the Northern Territory guidelines for targeted surveys of threatened and significant plant species (Cuff *et al.* 2020), one of the Flora and Vegetation Guidelines Series. This Series is a set of guidelines for sampling and describing flora and vegetation in the NT, and covers the following topics:

- Targeted surveys of threatened and significant plant species (Cuff *et al*. 2020);
- Field methodology for vegetation mapping and flora survey (Lewis *et al*. in prep.); and
- Guidelines for the collection of plant specimens (Jobson *et al*. in prep.), and Policy for accessioning specimens to the NT Herbarium collection (DEPWS in prep.).

The Flora and Vegetation Guidelines and Supplements are intended to become referenced documents under relevant Northern Territory legislation (e.g. Northern Territory Environment Protection Act 2019) and should be adhered to for the consistent collection and classification of flora and vegetation information.

1.1. Purpose

The purpose of this document is to provide conservation managers, environmental consultants and development proponents in the NT with a set of guiding principles and methods for surveying for *Typhonium* species in the field. **The reader is advised to use this supplement in tandem with the Northern Territory guideline for targeted surveys of threatened and significant plant species 46/2020 (Cuff *et al.* 2020) (see above)**.

Due to the cryptic nature of many *Typhonium* species, methods have been designed to improve the detection probability of targeted surveys, with reduced risk of false-negative results. The recommendations provided herein are designed to:

1. Facilitate targeted surveys that provide reliable information on the presence or absence of *Typhonium* species at a site[1]; and
2. Ensure that data collection provides accurate estimates of the number and distribution of individuals, demographics or the area of habitat.

1.2. Background

The genus *Typhonium* is comprised of geophytic perennial forbs in the Family ARACEAE. It is known from southern and eastern Asia, Papua New Guinea and Australia. *Typhonium* species in Australia are mostly found in the higher rainfall areas to the north, extending down the east coast to the subtropics; although at least two species (*T*. sp. Sandover and *T*. sp. Tobermorey) are known from the arid southern NT.

Nineteen species of *Typhonium* have been recorded in the NT (Table 1); five have been assessed as threatened[2], five are data deficient, fourteen are considered endemic to the NT and nine have restricted distributions. Note that in some circumstances, the data-deficient species and the range-restricted species are considered Significant Species and require consideration under the provisions of the NT Planning Scheme for the purposes of some types of development.

[1] Defined as the area targeted for the proposed development or action.

[2] Assessed as either Vulnerable, Endangered or Critically Endangered under either the NT *Territory Parks and Wildlife Conservation Act 1976* or the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*

Table 1: The conservation status of *Typhonium* species native to the NT (as at December 2020). It is recommended that users consult the most up to date regulations of the relevant legislation for current conservation listings.

TPWC = *NT Territory Parks and Wildlife Conservation Act 1976*

EPBC = Commonwealth *Environmental Protection and Biodiversity Conservation Act 1999*.

Scientific name	TPWC	EPBC	Restricted Range	NT Endemic
Typhonium cochleare				Y
Typhonium flagelliforme				
Typhonium johnsonianum	Data Deficient		Y	Y
Typhonium jonesii	Endangered	Endangered	Y	Y
Typhonium liliifolium	Data Deficient			
Typhonium mirabile	Endangered	Endangered	Y	Y
Typhonium praetermissum	Vulnerable		Y	Y
Typhonium roxburghii				
Typhonium russell-smithii	Data Deficient			Y
Typhonium sp. Charles Darwin			Y	Y
Typhonium sp. Cobourg	Data Deficient		Y	Y
Typhonium sp. Cox Peninsula			Y	Y
Typhonium sp. Kununurra				
Typhonium sp. Murgenella				Y
Typhonium sp. Oenpelli				Y
Typhonium sp. Sandover	Vulnerable		Y	Y
Typhonium sp. Tobermorey		Data Deficient		
Typhonium sp. Wollogorang				Y
Typhonium taylori	Endangered	Endangered	Y	Y

Typhonium species are seasonally dormant when conditions are dry, and emerge from underground corms or tubers following favourable rainfall. Species found in the Top End emerge during the wet season, producing foliage first and flowers soon after. Fruiting also happens during the wet season. Some species can be difficult to locate in the field or to identify to species level. As such, they are considered cryptic species for the following reasons:

- Plants can be scattered and sparsely distributed across a population, or instead highly clustered;
- Most Top End species are small, and often hidden amongst tall grasses or other vegetation;
- Many species have polymorphic leaves (i.e. ranging considerably in shape and size), which can make it difficult to identify them without reproductive material;
- Flowering events are often very short, perhaps only a few days, and the flower can decay very quickly afterwards;
- Flowering is usually during the wet season for Top End species, when access to sites can be impractical and infeasible; and

- For the arid land species, emergence and flowering is dependent on rainfall events that can be infrequent and unpredictable.

Due to these cryptic features, detection rates of *Typhonium* during surveys can be low, therefore surveys must be conducted in a manner that will optimise the probability of detecting target species if present.

2. Survey Guidelines

Please note that this Supplement provides advice specifically for *Typhonium* **field surveys**. For general information on survey planning and design, refer to Cuff *et al*. (2020, Section 2.). For guidance on the assessment of survey data, refer to Bickerton *et al*. (in prep.).

2.1. Optimal timing for field surveys

Ideally the field survey should be conducted at a time when detection and field identification of the target species is optimal. For example, survey times may need to be adjusted to account for:

- The species being visible (*Typhonium* species will only emerge after sufficient rainfall; also detectability may decline as the surrounding ground layer vegetation becomes more dense);
- Flowering or fruiting times;
- Adequate leaf tissue being available (when genetic sampling and analysis are required for identification); and
- Year to year variation in seasonal conditions which affect emergence, flowering and fruiting.

Recommended survey times for threatened and significant *Typhonium* species are provided in Table 2. Surveyors are advised to consult available resources (see Cuff *et al*. 2020, Appendix 1) for additional information on the life history and biology of the target species, or contact Flora and Fauna Division, Department of Environment, Parks and Water Security (DEPWS) at Biodiversity.DEPWS@nt.gov.au for further advice. Any variation from these recommendations should be justified in the survey report with appropriate evidence.

For *Typhonium* species, the use of morphological traits for identification can be difficult and unreliable without reproductive material, as the leaves are commonly polymorphic (Kerrigan & Cowie 2006, Kerrigan *et al* 2007). Additionally the window of availability for field identification of appropriate material is narrow and highly unpredictable, as plant detectability during the flowering growth phase is also extremely low. To compound these issues, many *Typhonium* species are geographically sympatric (see Table 3). For these reasons, molecular methods are recommended for identification at the species or subspecies level (see Section 2.1.1.).

On this basis, timing of the survey should aim to achieve maximum detectability. For *Typhonium* species in the Top End, the time following the first monsoonal burst until approximately the end of February is when the plants are at maximum vegetative growth and detection is considered satisfactory. Vegetative growth is typically triggered before the onset of this first monsoonal burst and is consolidated by the monsoonal conditions. This typically results in strong leaf initiation and growth during and in the weeks immediately following these rains that may continue for a period of months depending on prevailing climatic conditions.

It is worth noting that the earlier surveys are conducted within this window the better, as the effective transect width is larger (see Section 2.2.2.) and the incidence of 'false negative' records is reduced when the height and density of tall annual grass cover (e.g. *Sorghum* spp.) is minimised within the survey area. Material suitable for molecular identification/confirmation can be readily obtained during this period.

Table 2: Recommended survey timing for the detection and collection of genetic material for threatened and significant *Typhonium* species. Sources: Flora NT; NT Threatened Plant Factsheets (See Cuff *et al*. 2020, Appendix 1). N.B. Flowering and fruiting times given here are from recorded observations; seasonal conditions may cause variation in the actual timing.

Habitat	*Typhonium* species	Flowering time	Fruiting time	Optimal survey time	Considerations	Notes
Eucalypt woodland or forest	*T. jonesii*	Dec – Feb	Jan – Mar	Jan - Feb	Magnitude and duration of wet season Timing of first monsoonal burst Proposed survey method	Optimal timing recommendation reflects preference for molecular confirmation of identity
	T. liliifolium	Dec – Feb	Jan – Mar			
	T. mirabile	Oct – Nov	Dec			
	T. praetermissum	Nov – Jan	Jan – Feb			
	T. russell-smithii	Oct – Feb	Mar			
	T. sp. Cobourg	Nov - Dec				
	T. sp. Cox Peninsula	Nov – Jan	Jan – Feb			
Seasonally inundated	*T.* sp. Charles Darwin	Nov		Jan – Feb, before the site becomes inaccessible		
	T. johnsonianum	Nov – Feb	Dec – Jan			
	T. taylori	Jan				
Arid Zone	*T.* sp. Sandover	Apr (following good rains)		Immediately following sufficient summer rains	Magnitude, frequency and timing of rainfall Proposed survey method	Molecular confirmation is preferred but not essential, as the species is not sympatric with other *Typhonium* spp.
	T. sp. Tobermorey	Mar – May (following good rains)				

Table 3: Threatened and significant *Typhonium* species that are geographically sympatric with other *Typhonium* species (but not necessarily in similar habitat).

T = *Typhonium*; Y = yes. Sources: Flora NT; NR Maps (See Cuff *et al.* 2020, Appendix 1); Ian Cowie *pers. comm*; Nick Cuff *pers. comm*.

Sympatric *Typhonium* species	Threatened and Significant *Typhonium* species									
	T. johnsonianum	*T. jonesii*	*T. liliifolium*	*T. mirabile*	*T. praetermissum*	*T. russell-smithii*	*T.* sp. Charles Darwin	*T.* sp. Cobourg	*T.* sp. Cox Peninsula	*T. taylori*
T. cochleare		?		?		Y	?	?		
T. flagelliforme	Y	Y		Y	Y	Y	Y	Y	Y	
T. johnsonianum					Y	Y	Y		Y	
T. jonesii				Y						
T. mirabile		Y								
T. praetermissum	Y					Y	Y		Y	Y
T. russell-smithii	Y				Y		Y		Y	?
T. sp. Charles Darwin	Y				Y	Y		Y	Y	Y
T. sp. Cobourg						Y	Y		Y	
T. sp. Cox Peninsula	Y				Y	Y	Y	Y		?
T. sp. Kununurra			Y							
T. taylori	Y				Y	?	Y		?	

2.1.1. Using molecular methods to identify *Typhonium* species

DEPWS recommends the use of molecular methods for taxonomic identification, particularly of woodland and floodplain *Typhonium* species, as:

1. Morphological identification of flowers and fruits is often hampered by a brief flowering season or inability to access the site at an appropriate time;
2. A reliable method to obtain sequences from tissue samples is readily available;
3. Molecular sequences of a known species identity are readily available to compare against the sample material;
4. The methods and analyses are relatively affordable; and
5. Appropriate expertise is available in the NT to analyse and interpret the molecular data.

Using molecular methods for taxonomic identification can allow greater flexibility in the timing of presence/absence surveys and improved confidence in the delineation of species.

Proponents or conservation managers wishing to apply molecular methods to identify species or population differentiation in *Typhonium* spp. should firstly consult with the Flora and Fauna Division of DEPWS at Biodiversity.DEPWS@nt.gov.au for specific information on sample collection, storage and analysis procedures. General sample collection recommendations are provided in Cuff *et al.* (2020).

The surveyor will need to ensure that sequence information and associated metadata are generated to be compatible with data standards for the International Nucleotide Sequence Collaboration. Submit all resultant molecular analyses, sequence data and metadata to Flora and Fauna Division at Biodiversity.DEPWS@nt.gov.au for future use, as per permit conditions.

2.2. Site survey methods

As detailed in Cuff *et al*. (2020, Section 2.3.), three methods are recommended for targeted plant surveys, with variations of these approaches used for sites or habitats (Cropper 1993, Keith 2000, McCaffrey *et al*. 2014):

- Parallel field traverses or transects (Cropper 1993), for relatively smaller areas, usually ≤ 100 hectares (ha) or high intensity land uses (e.g. residential development, mineral extraction or mining). This is the recommended approach for all proposed surveys with a total footprint under 20 hectares (ha) in size;
- Targeted meander-traverses, either for medium-sized survey areas, usually 100 – 500 ha, or where the potential habitat of the target species occupies a linear or narrow ecotone; and
- Quadrat-based methods, for large (> 500 ha) and/or predominantly inaccessible areas (e.g. where broad-scale land clearing is proposed). The quadrat method is also used in preliminary surveys to characterise habitat where little or no habitat data exist.

Recommendations for using these three methods to survey for *Typhonium* species are provided below (Section 2.2.3.). Searching for *Typhonium* species is more reliable on clear days with little or no wind. Factors that may increase searching time include low light levels, bad weather, wet grass and steep slopes (Moore *et al*. 2011). Details of the survey conditions and the traverse length should also be included in any reporting.

When and where such methods are to be adopted will largely need to be assessed by the proponent on a case by case basis and balanced against factors such as:

- Cost/logistic constraints – the cost, access or workplace health and safety constraints of employing high intensity methods over a large site may not be practical; and
- Target detectability – Most *Typhonium* species are inherently less detectable and require more survey effort per unit area than trees, shrubs and cycads.

Proponents are strongly advised to seek the input of suitably qualified professionals to determine the best survey methods and intensity, based on the potential risk associated with any proposed action. Further advice on methodological approaches can be obtained from the Flora and Fauna Division (Biodiversity.DEPWS@nt.gov.au), DEPWS.

2.2.1. Two-step survey approach

DEPWS recommends that all targeted *Typhonium* surveys be conducted in two stages, regardless of the survey method chosen by the surveyor. With the two-step approach, an initial survey is conducted to determine the presence or absence of the target species. If presence is confirmed, a second survey focuses on the distribution and abundance of the species. It is also recommended that multiple surveyors are utilised, surveying independently.

The presence/absence survey utilises a wider traverse width than for a density/abundance survey (Section 2.2.2.), and allows for a reduced survey intensity. As a consequence, the detection probability per traverse is likely to be lower, so care must be taken to ensure a sufficient number of traverses are made to provide confidence in the survey results.

2.2.2. Width, length and area of field traverses

The width of the survey traverse will be determined by the size of the target species and the density of the habitat. For example, the arid-land *T.* sp. Sandover and *T.* sp. Tobermorey are relatively large plants, growing in open low vegetation where their glabrous leaves are easy to spot, so traverses can be much wider. In contrast, *T. taylori* is a small plant with leaves < 5 cm in length, growing in dense woodland, making it difficult to detect, which means traverses will be much narrower. Presence/absence surveys can be conducted at a reduced intensity, thus allowing for wider field traverses (see Table 4).

Table 4: Recommended field traverse widths for field surveys of *Typhonium* species.

Species	Leaf length (cm)	Habitat characteristics	Traverse width (m)	
			Presence/ Absence	**Abundance/ Density**
T. taylori	<5	Melaleuca woodland/Sandsheet Heath	5	1 - 5
T. jonesii	4 – 8		15-20 (or 6/100m interval)	5-10
T. mirabile		Eucalypt open forest		
T. russell-smithii	~ 10 (narrow)			
T. sp. Cobourg				
T. sp. Charles Darwin				
T. sp. Cox Peninsula	5 - 9	Eucalypt woodland		
T. praetermissum				
T. johnsonianum	narrow	Mixed woodland		

<table>
<tr><th rowspan="2">Species</th><th rowspan="2">Leaf length (cm)</th><th rowspan="2">Habitat characteristics</th><th colspan="2">Traverse width (m)</th></tr>
<tr><th>Presence/ Absence</th><th>Abundance/ Density</th></tr>
<tr><td>T. liliifolium</td><td>20 - 40</td><td>Grassland, shrubland, low open woodland</td><td></td><td></td></tr>
<tr><td>T. sp. Sandover</td><td rowspan="3">Large</td><td>Sandy creeklines with Eucalypt woodland over a dense grassland understorey</td><td rowspan="3">20</td><td rowspan="3">20</td></tr>
<tr><td>T. sp. Tobermorey</td><td>Open woodlands and grasslands, margins of creek flats</td></tr>
<tr><td>T. sp. Kununurra</td><td>Alluvial grasslands</td></tr>
</table>

If the presence/absence survey has detected threatened or significant *Typhonium* species, a survey will be required to determine density and/or abundance. For these surveys, DEPWS recommends that the maximum distance between traverses for *Typhonium* species should be no more than 10 m in open forest or woodland, and 1 – 5 m in closed vegetation. These recommendations account for the fact that *Typhonium* species are often obscured by other vegetation and are very difficult to observe from a distance.

Importantly, DEPWS also recommends that multiple independent observers be employed to undertake the traverses, as the detection rate varies across observers. For example, if it has been calculated that 48 traverses are required at a site, then 4 observers could be employed do undertake 12 traverses each.

The total length of field traverses will depend on the area and shape of the potential habitat to be surveyed. Cuff *et al*. (2020, Table 4) provides an estimate of potential lengths of field traverses based on recommended separation widths if a parallel field traverse method is employed, assuming 100% coverage of potential habitat is required.

Full coverage is not always achievable, especially for areas of 50 ha or more (refer to Cuff et al. 2020, Section 2.3 for alternative methods), and may not be required, to determine presence/absence of the target species. To justify any decision to vary the transect width, separation distances and/or total length traversed the proponent must demonstrate high confidence of detectability of the target species with the proposed changes.

Effective transect width and thus area sampled on any one traverse is also likely to vary across a season. The detectability of small forbs decreases significantly with the increasing density of tall grasses over the growing season. For this reason, effective transect width may decrease by 1 – 5 m as the season progresses.

2.2.3. Recommended survey effort

For the three survey methods recommended by DEPWS, the minimum effort required to ensure confidence in the results of a presence/absence survey is provided below. N.B. For all three methods, multiple surveyors should be utilised, surveying independently and preferably concurrently.

2.2.3.1. Parallel field traverse (≤ 100 ha)

Consult Table 4 to determine the recommended traverse width for a presence/absence survey of the target species. Each hectare (100 m x 100 m) is divided into 100 m traverses (e.g. for a 16 m traverse width, there will be 6 x 100 m traverses). Although the total area of the site is covered in this way, the effective area observed will be approximately 12 - 40% of total area, depending upon the height and density of the vegetation. NB For the arid zone *Typhonium* species, the effective area surveyed will be close to 100%.

2.2.3.2. Targeted meander traverse (100 – 500 ha)

Traverses are surveyed at the minimum required distance apart (Table 4); however the traverses are spaced non-systematically depending on understorey density and aiming to maximise coverage of the highest likelihood potential habitat of the target species. This method relies on the operator's understanding of the habitat requirements of the target species. The aim is to sample a minimum of 10% of the potential habitat at the site.

2.2.3.3. Quadrat-based survey (> 500 ha)

Stratify the potential habitat at the site into high likelihood and lower likelihood zones of potentially suitable habitat (see Cuff *et al*. 2020, Section 2.3.5.1.). Randomly place 100m x 100m survey grid cells within the two stratified zones, at a predetermined ratio. Survey six x 100 m traverses within each grid cell.

For a 95% confidence in the precision of a quadrat-based survey, DEPWS recommends that a minimum of 119 x 1 ha grid cells are to be surveyed, regardless of the size of the site. The Appendix (below) provides a summary of the statistical analysis used to reach this conclusion, and also provides examples where the confidence level, survey effort or detection probability may need to be varied.

Box 1 provides an example of the presence/absence component of a quadrat-based survey for *Typhonium mirabile*.

<u>Box 1:</u> *Typhonium mirabile* survey, Bathurst Island (Brennan *et al*. 2015).

Targeted presence/absence surveys (Joseph *et al*. 2006) were found to be an efficient means of detecting populations of the cryptic, ephemeral and widely dispersed *Typhonium mirabile* within > 9,000 ha of potential habitat on Bathurst Island. While this approach did not provide an estimate of total abundance, it did allow for a larger number of sample cells to be visited within the available survey period.

For the presence/absence component, potential habitat was identified, then divided into 1 ha (100 m x 100 m) grid cells. A total of 60 cells were randomly selected for field sampling, with a 60/40 bias across two strata (see Cuff *et al.* 2020 Section 2.3.5.1.).

Transects were replicated spatially across each sample grid cell as the repeat measure required to assess occupancy. Six parallel 100 m x 2 m (minimum) belt transects were sampled by three observers (2 transects per observer per cell), so that approximately 12 % of each cell was searched.

McArdle's (1990) formula was used to ascertain whether the number of transects surveyed was sufficient to determine absence of the target species at a confidence interval of > 0.90 (Figure 1, below). The detection rates of each observer, across all transects surveyed, ranged from 0.22 to 0.42, with the average detection probability of 0.35, and a confidence level of 0.92 (Table 5). This indicates the number of transects employed in the design was sufficient to confidently assess the presence/absence of the species.

<u>Table 5:</u> Summary detection probabilities (p) of three individuals surveying for *Typhonium mirabile* within 60 sample one hectare cells on Bathurst Island. α is a measure of averaged detection confidence level across observers for the survey.

Observer	Detection Probability (p)	Standard Error	95% Confidence Interval
A	0.42	0.08	0.27-0.58
B	0.40	0.08	0.26-0.56
C	0.22	0.07	0.12-0.38
Average	0.35		
α (Confidence Level)	0.92		

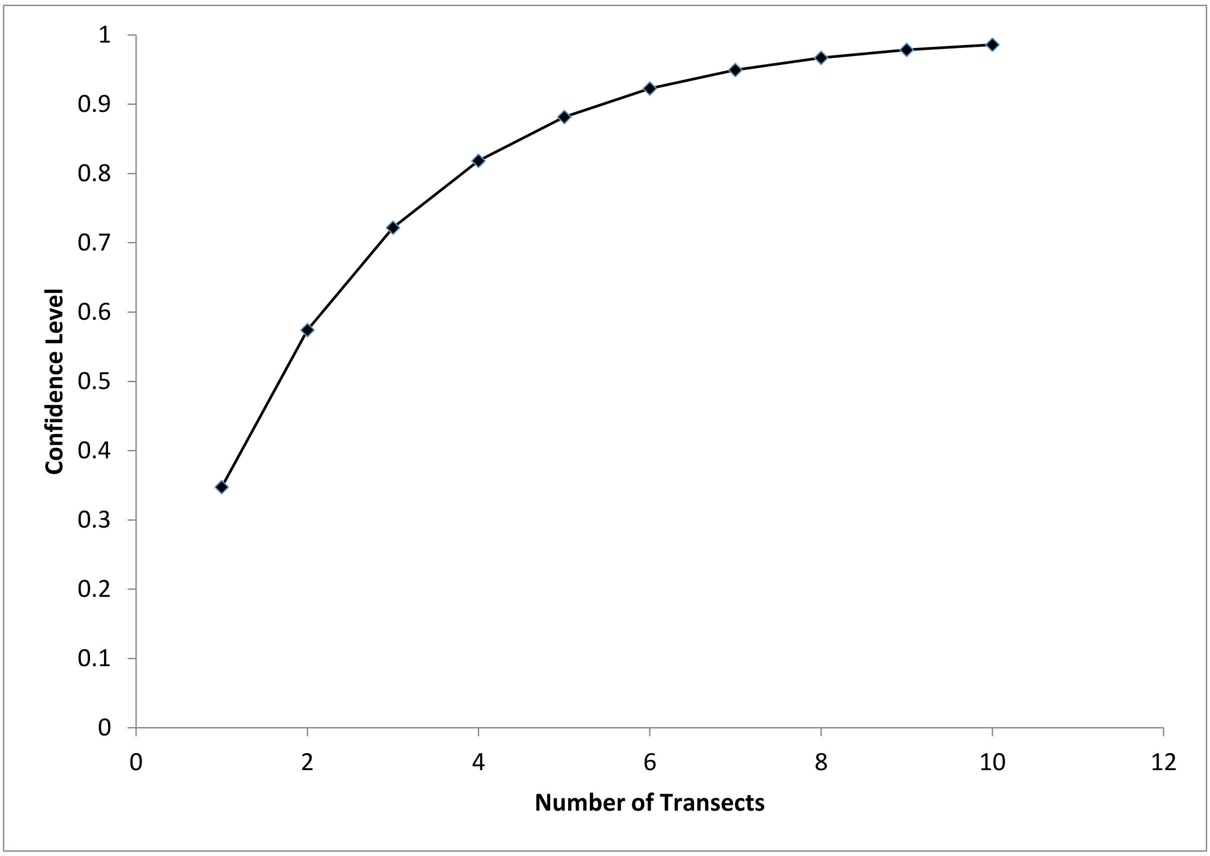

Figure 1: Detection confidence level of repeat transects for *Typhonium mirabile* in 1 hectare cells with average detection. Confidence levels (α) are a measure of the reliability of a given number of transects recording *T. mirabile* at a site with average detection based on the results from this study.

The boxed example shows that using the two-step method can reduce the rates of sampling and total distances/ha needed to adequately determine the presence/absence of *Typhonium* species at a large site. However, in many instances the survey intensity will need to be greater than the above to ensure adequate detection and the minimisation of false negative results in the data.

The initial presence/absence survey does not provide data on the distribution and abundance of the species across the site. The data from presence/absence surveys are used to inform the design of more targeted systematic surveys within areas where the species was detected. Any alteration of the recommended traverse spacings (Table 4) should be discussed with DEPWS prior to implementation in the field.

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Appendix: The quadrat-based survey method: an example

For large survey sites, DEPWS recommends the use of a quadrat-based method to determine presence/absence of target species (e.g. Brennan *et al*. 2015). This method uses grid cells as sample units and repeat transects with multiple observers. Here is an example of the use of a quadrat-based method to determine with a high degree of confidence the presence of a *Typhonium* species at a site.

Boxes 1 (Section 2.2.3.3.) and 2 (below) provide summaries of the initial study used to develop estimates of detection probability, occupancy probability and the number of traverses per grid cell required to estimate the level of error associated with survey detection. These estimates are indicative particularly for woodland and floodplain *Typhonium* species. They can be considered an informed starting point for providing recommendations on the level of effort required for a presence / absence survey, as well as estimate occupancy probability and detection probability across the area.

<u>Box 2:</u> Determining the number of survey grid cells required for a quadrat-based cryptic *Typhonium* survey (Brennan *et al*. 2015).

As detailed in Box 1, targeted presence/absence traverses were conducted in a survey for *Typhonium mirabile* subpopulations on north-east Bathurst Island (Brennan *et al*. 2015). The initial study area totalled approximately 10,000 ha, which was reduced to approximately 9,330 ha through the refinement of potential habitat mapping and stratification of the study area.

This study enabled estimates to be made of two key parameters, which were then used to investigate the range of statistical power a surveyor can expect when designing similar quadrat-based presence/absence surveys for *Typhonium* species. Occupancy probability and detection probability were found to be approximately 0.45 and 0.35 respectively, averaged across the highest ranking models (see Brennan *et al*. 2015).

The results of this study allowed the surveyors to model detection confidence relative to the number of traverses in each grid cell (K), using the approach of MacKenzie & Royle (2005) for a standard design. The same approach can be used to ascertain the number of sample cells required to achieve a given level of precision, as shown in Table 6.

Table 6 The number of sample grid cells (s) required to achieve a given level of precision ($var(\psi)$), as well as the total survey effort (TS) this represents under acceptable survey intensity scenarios.

ψ = probability of occupancy;

$var(\psi)$ = level of precision;

s = number of sample grid cells;

K = number of traverses per sample grid cell;

TS = total number of traverses (TS = s x K); and

p* = probability of detecting the target species at least once during K traverses.

(N.B. for p* ≥ 0.8, K must be ≥ 4).

	$\boldsymbol{var(\psi)}$ =0.03		$\boldsymbol{var(\psi)}$ =0.05		$\boldsymbol{var(\psi)}$ =0.07		$\boldsymbol{var(\psi) = 0.1}$	
K	s	TS	s	TS	s	TS	s	TS
4	479	1916	173	692	88	352	43	172
5	376	1880	136	680	69	345	34	170
6	330	1980	119	714	61	366	30	180

The generally accepted level of precision of a study is ≤ 0.05, although this may vary according to the purpose of the study. However, given the number of cells required to achieve acceptable statistical power using the quadrat-based approach, it may not always be possible to fully implement such an approach.

By varying these parameters we see that for an equivalent total survey effort, cost and logistic savings may be gained through varying the balance between (s) and (K), and perhaps making compromises in the level of precision. These compromises may be acceptable on a case-by-case basis when considering the requirements for precision associated with a proposal. Justification of the sampling design and accordingly the level of precision of the survey will be integral to demonstrating the adequacy of the survey.

For example, reducing the number of traverses per grid cell will reduce the total number of hours per cell, thus allowing time for additional cells to be surveyed. In some situations, this may lead to a more complete sampling of the survey area, with an improvement in overall study reliability. This is particularly the case when considering species where occupancy is not uniform (e.g. species with clustered distributions within potential habitat).

Based on the Brennan *et al*. (2015) study, and the statistical analysis provided in Boxes 1 and 2, DEPWS recommends the following criteria for quadrat-based surveys of cryptic *Typhonium* species with low occupancy and detection probabilities (ca. 0.5):

1. Divide the potential habitat within a large study area into 100 m X 100 m grid cells. Randomly select approximately 119 grid cells (irrespective of total survey area[3]) for surveying, within stratification constraints (Cuff *et al*. 2020, Section 2.3.5.1.).
2. Conduct six parallel 100 m traverses, using three observers, in each grid cell ($p^* = 0.92$).
3. For species that exhibit clustered spatial patterns of abundance, an adaptive cluster sampling approach may be considered (see Christman 2004). Using this approach, sample grid cells are allocated randomly to begin with, but when the target species is encountered in one cell, adjacent grid cells are added to the sample to improve the potential detection rate of the target species.
4. In situations where the target species is suspected to have a highly clustered distribution, the surveyor may choose to conduct 4 traverses per grid cell, using two observers. While this will reduce the within-site detection probability ($p^* = 0.76$) it is deemed the minimum level acceptable to impart confidence to the results, and will allow for more sample cells to be surveyed for a similar total survey effort, as per Box 1 (Section 2.2.3.3.).

These criteria are general recommendations only and are likely to require further consideration by the surveyor before implementation from both logistic and statistical points of view. For example:

- It may be impractical to achieve this level of survey intensity within the access constraints of the study area;
- Detection or occupancy probabilities may vary significantly from the indicative figures used for these calculations, and thus recalculation of s and TS may be warranted; or
- It may unnecessary for a study to achieve the high levels of precision given in the example in Box 2.

The proponent and surveyor will need to determine the most appropriate level of survey intensity based on all these factors and provide suitable justification if an alternative design is used.

[3] For known occupancy and detectability, the power required to determine presence or absence with high confidence is not related to area. N.B. The survey design should always take in to account the size and spatial arrangement of the proposed survey area; however, it will not determine the number of cells required to confidently determine presence/absence.