Northern Territory Environment Protection Authority

ENVIRONMENTAL QUALITY REPORT

BIODIVERSITY OF THE HOWARD SAND PLAINS SITE OF CONSERVATION SIGNIFICANCE

August 2015
Version 0.3

Northern Territory Environment Protection Authority
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Darwin
Northern Territory 0801

Important Disclaimer

Acknowledgement

The NT EPA acknowledges the assistance provided by Northern Territory Government departments of Land Resource Management and Mines and Energy in developing this Environmental Quality ReporT.

Figures

Tables

Abbreviations

CCNT	Conservation Commission of the Northern Territory
DLPE	Department of Lands, Planning and Environment
DLRM	Department of Land Resource Management
DME	Department of Mines and Energy
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999* (Cth)
Endangered	Species listed as in danger of extinction under the TPWC Act and/or the EPBC Act
FFD	Flora and Fauna Division of DLRM
ML/yr	Megalitres per year
NRETAS	Department of Natural Resources, Environment, the Arts and Sport
NT EPA	Northern Territory Environment Protection Authority
NT EPA Act	*Northern Territory Environment Protection Authority Act*
NTG	Northern Territory Government
SOC	Site of Conservation Significance
Sand sheet heaths	Defined by Liddle and Fisher (2014) as plant communities 3 and 4, and here, unless otherwise mentioned, it is extended to include similar plant communities 6, 9, 10 and 13. Similarities include vegetation structure, overlaps in species composition and soils, as well as high numbers of species of bladderworts (*Utricularia*)
Threatened species	A species listed under the TPWC Act or EPBC Act as vulnerable or endangered
TPWC Act	*Territory Parks and Wildlife Conservation Act*
Vulnerable	Species listed under the TPWC Act or the EPBC Act as vulnerable to extinction

Units

cm	Centimetre
ha	Hectare
km	Kilometre
km^2	Square kilometre
m	Metre
mm	Millimetre
tpa	Tonnes per annum

Executive summary

The Northern Territory Environment Protection Authority (NT EPA) is of the opinion that unless something is done to prevent it, rapidly increasing threats to the biodiversity of the Howard sand plains Site of Conservation Significance (SOC) (Figure 1) will result in the extinction of what seems likely to be the most significant area of biodiversity in the Darwin region. The threats are primarily caused by long term extraction of sand and gravel, and adjacent expansion of urban and rural developments. The information and assessments that led the NT EPA to this conclusion are documented in this report.

The report is an environmental quality report under section 28 of the *Northern Territory Environment Protection Authority Act* (NT EPA Act) and will provide a basis for advice to the Minister for the Environment (the Minister) under section 25 of the NT EPA AcT.

The objectives of this report are to document:

- the significance of the biodiversity of the Howard sand plains SOC
- the vulnerabilities of the threatened biodiversity to potential disturbance
- threatening processes impacting on the biodiversity of the Howard sand plains
- the absence of, and improbability of finding, techniques to effectively rehabilitate the sand plains' biodiversity
- options for securing the preservation of areas that may be sufficient to provide security for the threatened biodiversity, and possibly 10 species of near threatened plant, 13 species of plant for which there too few data to be able to determine conservation status, and two species of threatened animal.

Findings

1. The Howard sand plains SOC contains a community of carnivorous plants, bladderworts of the genus *Utricularia* that is of national and likely international significance.
2. The vulnerable carnivorous bladderwort, *Utricularia dunstaniae,* is found in the Howard sand plains and is of Northern Territory significance.
3. The endangered plant, *Typhonium taylori,* is found only on the Howard sand plains, and is of national and Northern Territory significance.
4. The endangered Darwin palm, *Ptychosperma macarthurii,* is found in the Howard sand plains and lower Adelaide River floodplain, and is of Northern Territory significance.
5. The vulnerable Howard toadlet, *Uperoleia daviesae*, is primarily found on the Howard sand plains and small areas along the Elizabeth River and adjacent floodplains, and is of Northern Territory and likely national significance.
6. The area has the only known Northern Territory record and location of an endangered orchid species (*Habenaria rumphii*).

7. Of lesser significance is the presence of an additional plant species vulnerable to extinction, ten species of near threatened plant, 13 species of plant for which there are too few data to be able to determine their conservation status, and two additional species of threatened animal (the northern quoll, the yellow-spotted monitor).

8. The Howard sand plains is classifiable as threatened with extinction according to criteria for the assessment of ecological communities under the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (EPBC Act); although this act cannot be applied to the Howard sand plains (i.e. not all northern Australian sand plains' biodiversity may be threatened).

9. The bladderwort community, *U. dunstaniea, T. taylori* and the Howard toadlet are found in habitats provided by sand sheet heath vegetation occupying approximately 2 259 ha of the seasonally inundated/saturated flood plains.

10. The Darwin palm is dependent on habitat provided by spring-fed monsoon rainforests.

11. The biodiversity of the sand plains is vulnerable to:

    - alteration of the distribution and abundance of sand sheet heaths and monsoon rainforests across the north-south and east-west extents of the flood plains (land clearing)

    - spatial and temporal alteration of ground water tables, and surface water flows across the entire wetland system in relation to ground water seepage, spring flows, patterns of Wet season inundation/saturation and Dry season water availability

    - alteration of topographic and micro-topographic features relevant to maintaining existing patterns of surface water flows, inundation and water logging.

12. Approximately 31.8% of the SOC is occupied by existing urban and rural development on lands around the low plateau margins of the plains. Urban/rural development over much of the remaining land is constrained by seasonal saturation and inundation.

13. Abstraction of ground water from over 3 000 domestic bores in the adjacent rural residential area, and bores for the supply of water to the Darwin area have lowered the late Dry season water table by up to 15 m and possibly more in some areas, with a less extreme lowering spread into the sand plains.

14. Approximately 3.5% of the SOC is subject to farming/forestry, with 4.1% having been subject to disturbance from extractive mining, the vast majority of which is in the seasonally wet areas of the floodplain (this does not include upland areas subject to gravel extraction).

15. Seventy-five percent of the area's extractive industry on the floodplains occurs within the area's sand sheet heaths, with 502 ha (21%) of it subjected to extractive mining as of 2013.

16. There are no known techniques capable of rehabilitating sand sheet heaths to a state that would allow for the preservation of the threatened species or community. Nor are there likely to be such techniques.

17. Knowledge of the biology of the threatened biodiversity, other than the Darwin palm, is rudimentary, largely limited to distributional records obtained from low intensity quadrat sampling or informal searches.

18. Land clearing and extractive mining have had a significant impact on the spatial distribution and abundance of sand sheet heath habitat across the Howard sand plains.

19. Knowledge of the hydrology of the sand plain is essentially non-existent at a scale relevant to the habitat requirements of the threatened biodiversity, being limited to casual observations during natural history studies and informal searches.

20. There has been no hydrological investigation of the impacts of extractive mining on the area's hydrology, the threatened biodiversity and its habitats, or the interaction between the impacts of mining and abstraction of ground water.

21. The limited state of knowledge of the sand plains and its biodiversity necessitate a risk averse, precautionary approach to ensuring the future of the threatened biodiversity.

22. The lowest risk option for protection of the threatened biodiversity is to establish a protected area over much of the seasonally inundated and water logged area of the sand plains (Option 1).

23. This option would allow for maximum possible protection of the biodiversity from threats, although full transition of land use would take some time. It would provide for the closest possible achievement of the outcomes required of a risk averse protected area. It would provide:

    - protection of the majority of the sand plains and bladderwort habitats across sufficient of the north-south habitat variation to protect all 11 of the broad niched bladderwort species, all 14 of the narrow niched species evaluated, and have potential to protect another species
    - protection of all the known populations of *U. dunstaniae*, with additional habitat that may contain additional populations
    - protection for six of the 11 populations of *T. taylori,* including the three largest populations, with additional habitat that may contain additional populations
    - protect for both populations of the Darwin palm
    - extensive areas of habitat for the Howard toadlet
    - extensive protection from mining for the range of sand plains' micro-habitats that are the basis of habitat specialisation of the bladderwort species and *T. taylori*

- extensive areas of habitats that provide or are likely to provide for life history stages of the threatened biodiversity
- protection for the metapopulation dynamics of the threatened species over the majority of the sand plains, and minimisation of future deterioration
- protection, to the greatest extent possible, of the hydrological conditions across the wetland system, as well as providing the best opportunity for remediation of hydrological conditions
- the Howard sand plains with a protected area design that facilitates future management of external threats and the protected area
- a possible future recreation site in an area of mine disturbed sand plains just north of Gunn Point Road.

It would also provide the potential for some level of protection for possibly 10 species of near threatened plant, 13 species of plant with too few data to be able to determine their conservation status, and two species of threatened animal.

24. Protection of some of the upper Howard River catchment (Option 2) has the capacity to provide the threatened biodiversity with some level of security. It would have potential risks (higher than Option 1) associated with maintenance of the hydrology and the absence of linkage between the east and west of the sand plains.

25. Approaches based on definition and protection of core habitats and surrounding buffers with or without linkage areas are risk prone (Options 3, 4, and 5), and cause potential uncertainty in the extractive mining industry. These involve potential for future adjustment and expansion of the protected area should they prove inadequate. These options should not be implemented.

26. All five options involve a potentially significant economic cost. All involve reduction in the abstraction of ground water from the sand plains. All involve some level of transition of the extractive mining industry away from the sand plains. The costs of the latter would vary depending on the possible future extent of mining in the sand plains, and the duration of the required transition. The greater the extent and duration of mining activity, the greater the threat to the threatened biodiversity.

27. Implementation of an effective protected area is a good first step to insuring the future of the threatened sand plains' biodiversity.

1 Introduction

The Northern Territory Environment Protection Authority (NT EPA) is of the opinion that unless something is done to prevent it, rapidly increasing threats to the biodiversity of the Howard sand plains will result in the extinction of what seems likely to be the most significant area of biodiversity in the Darwin region. The threats are caused by long term extraction of sand and gravel, and adjacent expansion of urban and rural developments. The information and assessments that led the NT EPA to this conclusion are documented in this report.

The Howard sand plains Site of Conservation Significance (SOC) (Figure 1) has been designated as one of 67 Northern Territory SOCs (Harrison *et al*. 2009). The designation is based on the presence of:

- bladderwort communities (carnivorous plants of genus *Utricularia*) of global significance
- a species of bladderwort (*Utricularia dunstaniae*) listed as vulnerable to extinction in the Northern Territory
- a herb (*Typhonium taylori*) listed as endangered under Australian and Northern Territory legislation and found nowhere else in the world
- the only Northern Territory populations of the endangered Darwin palm (*Ptychosperma macarthurii*), found on the Howard sand plains and adjacent western floodplain of the Adelaide River (8 populations in total, 2 of which are in the SOC)
- the vulnerable Howard toadlet (*Uperoleia daviesae*), a frog found primarily in the Howard sand plains and small areas of sand plain along the adjacent Elizabeth River and nearby drainages.

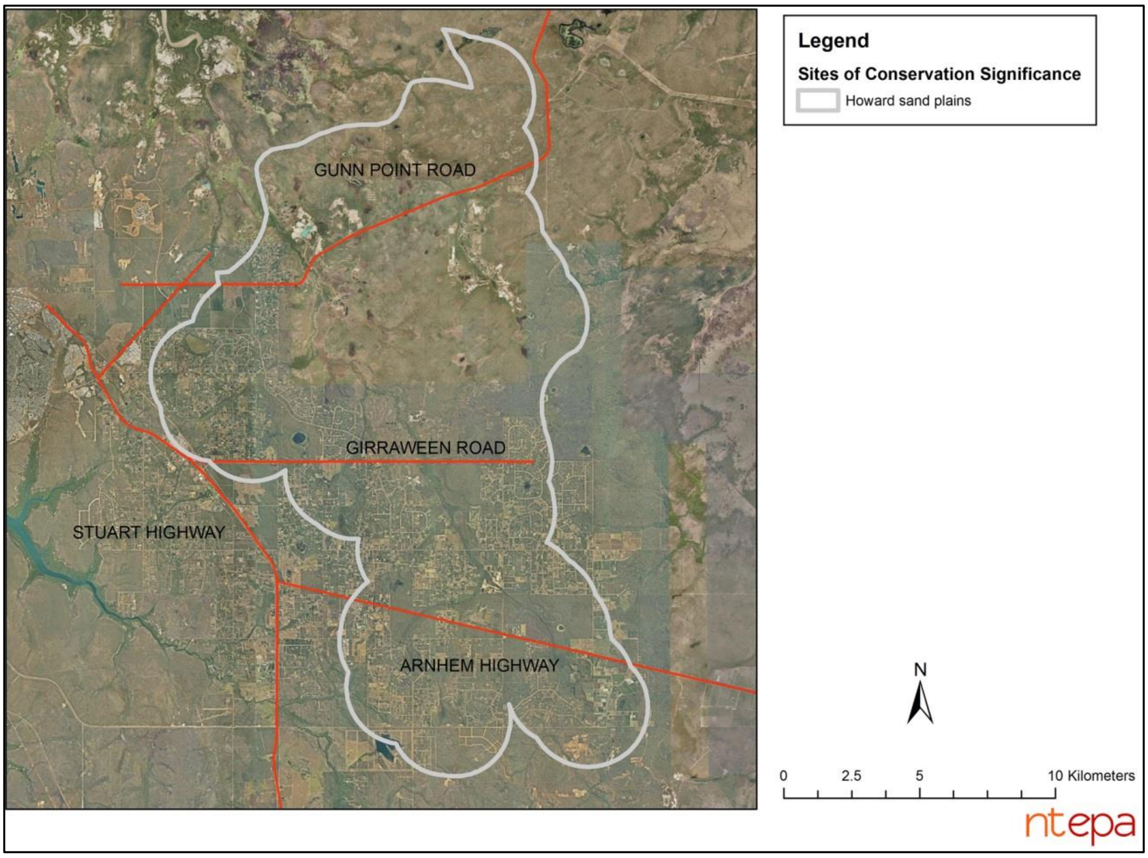

Figure 1: The Howard sand plains Site of Conservation Significance (mapping of SOC NTG, DLRM)

The area is the only known Northern Territory record and location of an additional endangered plant species (*Habenaria rumphii*), 10 species of near threatened plant, 13 species of plant for which there are too few data to be able to determine their conservation status, and two additional species of threatened animal (the northern quoll and the yellow-spotted monitor).

This report is an environmental quality report under section 28 of the *Northern Territory Environment Protection Authority Act* (NT EPA Act) and will provide a basis for separate advice to the Minister for the Environment (the Minister) under section 25 of the NT EPA Act.

1.1 Objectives

The objectives of this report are to document:

- the significance of the biodiversity of the Howard sand plains SOC
- the vulnerabilities of the threatened biodiversity to potential disturbance
- threatening processes impacting on the biodiversity of the Howard sand plains
- the absence of, and improbability of finding techniques to effectively rehabilitate the sand plains' biodiversity
- options for securing the preservation of areas that may be sufficient to provide security for the threatened biodiversity, and possibly 10 species of

near threatened plant, 13 species of plant for which there are too few data to be able to determine their conservation status, and two species of threatened animal.

To meet the above objectives, the NT EPA has:

- reviewed available literature on the biodiversity of the Howard sand plains
- made particular use of research conducted over many years by the Flora and Fauna Division (FFD) of the Department of Land Resource Management (DLRM)
- examined the adequacy of available information for understanding the nature and extent of threatening processes on the Howard sand plains
- examined options and determined a least risky design for preservation and future management of the sand plains' threatened biodiversity.

The objectives of the report are compatible with the environmental objectives of the Northern Territory Government's Framework for the Future policy. The preferred protected area would be in keeping with the Northern Territory Government being signatory to the National Strategy for Ecologically Sustainable Development, Australia's Biodiversity Conservation Strategy, and signing the National Strategy for Ecologically Sustainable Development in 1992. It is in accord with the Strategy's guiding principles, including 'where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation'.

2 The Howard sand plains environment

2.1 Site location

The Howard sand plains SOC is located within 30 km to the east of Darwin. It occupies an area of approximately 264 km^2, approximately 27 km north to south and 16 km east to west. The area consists of areas of fine sand along river flood plains surrounded by gravelly rises. It is the plains of fine sand, referred to in this document as the Howard sand plains, that are the particular focus of this report.

The landscape is underlain by Proteozoic (2 500 to 542 million years ago) alluvium and gravels, overlain by lower Cretaceous (146 to 66 million years ago) alluvium and gravels, later overlain by a thinner layer of recent late Tertiary (16 to 2.58 million years ago) sediments (Wells and Harrison 1978). These strata have eroded to form low plateaus with low foothills surrounding floodplains and incised stream lines. The floodplains contain seasonally saturated/inundated white sand plains with a basal lithology (gross character of a geological formation) of brown clay with quartz clasts (small rocks/grains resulting from breakdown of larger rocks), or in some cases ferricrete (sediments cemented together by iron oxides) (Doyle 2011). Clayey sands predominate along the streamlines. The sand plains are the largest in the Northern Territory (Harrison *at al.* 2009). Shallow depressions have formed on the surface of some more elevated areas.

The sand plains are distributed along an approximately 2 km wide strip either side of the Howard River. The sand may reach the surface close to the river. The thickness of the sand body varies irregularly according to presence and absence of sink holes and other local variation in geology, but exhibits a pattern of decreasing thickness to the west, and to the north east (Doyle 2001). Depths to the west of the Howard River reach up to 13 m, and 15 m have been recorded on to the east of the river. The general pattern of change is associated with rises in altitude and changing geology to the west, north east, and east of the floodplain.

The area is underlain by a seasonally recharged aquifer hosted in Koolpinyah dolomite. The Power and Water Corporation managed Howard East Borefield accesses the ground water to provide water for Darwin. Numerous springs and seepages emerge from the edges of the floodplain during the Wet season (Cook *et al*. 1998; Vanden Broek 1980) and may continue flowing well into the Dry season.

The seepages and soaks providing flows from the periphery of the floodplain derive from Yin Foo's (2004) Layer 1; the highly permeable surface lateritic stratum and the immediately underlying gradation of claystone, sandy claystone and clayey sandstone to the sandstone stratum. Wet season flows to the sand plains include those from direct input from rainfall, the seepages, soaks and springs on the periphery, surface flows from the periphery and flows from the Howard River and associated minor tributaries. The sandy areas are likely to contain areas of potential or preferential recharge (Yin Foo 2004). Variation in depths to the sand layer, depths of the sand layer, location of sink holes, north-south and east-west variation in location of the sand plains in relation to gravely rises at the edge of the sand plains, proximity to and location along the Howard River and its minor tributaries provide a diversity of depositional and hydrological environments that have not been examined in any detail.

Vegetation mapping (Liddle *et al*. 2013) indicates a total of 21 vegetation types occupying the seasonally inundated and saturated areas of the SOC. A list of the names of the vegetation types and the numbers used to describe them is provided in Appendix A. The names are lengthy and the numbering system is used throughout the report.

The vegetation types vary in area occupied from 0.25 to 6.47 km^2 and occur in patches varying in number from two, to a high of approximately 92 of one vegetation type. A majority of vegetation types occur as highly dispersed patches. Estimates of numbers of patches per species are taken from Liddle *et al.'s* (2013) maps and are approximate only. The intention is to draw attention to the dispersed nature of many of the vegetation types. Five vegetation types occur in fewer than 10 patches each and represent a total of approximately 2% of the area of the mapped sand plains' vegetation. An additional five species occur in 10 to 20 patches each (31% of the sand plains' area). The majority of the vegetation types (11) and the total area of those vegetation types (66% of the area) occur in greater than 20 patches each.

The vegetation is best viewed as a mosaic of patches of vegetation types across the sand plains, with each type generally occurring in a number of locations as prescribed by the hydrographic and soil requirements of each type.

Vegetation types vary in distribution across the east-west hydrological and soil gradients of the sand plains. For example, some communities (e.g. 9, 15) are riparian communities located along the Howard River and other drainage lines. Others are located towards the periphery of the sand plains (e.g. communities 2a, 2b, 14), and others distributed along the margins of the Howard River and other drainage lines (e.g. 3a, 3b, 4a, 4d, 6, 9, 10 and 13).

There is also north-south variation in the distribution and level of dominance (relative area occupied by a vegetation type) of vegetation types. The subdivision of the SOC by Gunn Point Road, Girraween Road and the Arnhem Highway (Figure 1) provides a simple basis for demonstrating patterns of vegetation community distribution and dominance along the north-south axis.

Table 1 documents the number of vegetation types in each of these areas and the four dominant vegetation types in each area. The numbers clearly indicate that the number of vegetation types in each area is high relative to the total number of vegetation types (21), and the absence of some vegetation types (one to four types per area) from each area. It also demonstrates significant north-south variation in the dominance of vegetation types among the four areas.

Table 1: Number of vegetation types and vegetation dominance across the sand plains

Vegetation criterion	North of Gunn Point Road	Gunn Point Road to Girraween Road	Girraween Road to Arnhem Highway	South of Arnhem Highway
Number of vegetation types	16	20	18	17
Dominant vegetation types	2a, 2b 6, 10	3a, 3b, 9, 12 and/or 15	4a, 4c, 8, 15	2a, 4c, 4d, 5

2.1.1 Bladderwort communities of global significance

Bladderworts

The carnivorous bladderworts (genus *Utricularia*) are small herbaceous plants found in aquatic, semi-aquatic and moist terrestrial habitats in most countries of the world; especially in tropical and sub-tropical areas. Some species are epiphytes growing on other plants. ‘Bladder’ refers to the plants’ trap for capturing prey, while ‘wort’ means a herb; often used in relation to plants used as food or for medicinal purposes (Oxford English Dictionary). The bladderwort’s structure is unusual among flowering plants in that there are no clearly defined roots, stems or leaves. Stems (stolons) usually remain below the water or soil surface. The flowers are often the only parts of a bladderwort visible above the surface of soil or water. All bladderworts have the bladders or traps attached to the stolons below the surface. The bladders trap small organisms such as protozoans (single celled organisms) and rotifers among terrestrial species, or water fleas, nematodes, and insect larvae among aquatic species. Some bladderworts produce leaf-like photosynthetic shoots at the surface of the soil or water.

Flowers are asymmetrical and can be colourful. Flowers may be either self-pollinating or pollinated by insects. Little is known of pollination biology of bladderworts. Wasps, flies and butterflies have been observed visiting flowers (Taylor 1989). The timing and duration of flowering of the sand plains' bladderwort species varies according to species, and the availability of water in micro-habitats used (Cowie 2002). Seeds are small (less than 1 mm) and may be dispersed by water, adherence to water birds or other animals, or in the case of epiphytic species, by wind.

Significance of the Howard sand plains bladderworts

Taylor (1989) first drew attention to the exceptional species richness of the Howard sand plains' communities of bladderworts in a taxonomic assessment of the world's bladderworts (genus *Utricularia*). He reported up to 14 species of bladderwort in an area of no more than 0.1 ha. He noted that more species may have been present as an additional five were found within a few kilometres. This compares to Taylor's (1989) report that the island of Trinidad has exceptionally high species richness i.e. 16 species in 276 ha, or 19 species on the entire island. More recent work by the FFD and the Northern Territory Herbarium has found up to 12 bladderwort species in a single 20 m by 20 m plot, 16 species in a single vegetation type and a total of 26 species identified from the Howard sand plains SOC (DLRM 2015). One species, *U. mulleri*, is recorded from woodland in the SOC, with 25 occurring on the sand plains. There may be additional species present. For example, Wakabayashi (2010) recently described a Howard sand plains' species of bladderwort not previously known to science.

The likely global and national significance of the Howard sand plains' bladderwort community is reinforced by information gathered to determine centres of bladderwort species richness in the Northern Territory. Liddle *et al*. (2013) analysed species richness of bladderwort communities in 253, 20 m by 20 m plots across regions in the Northern Territory, and at a broad geographic scale (25 km by 25 km quadrats).

Results indicated that the centre of bladderwort species richness in the Northern Territory is in the Darwin area incorporating the Howard sand plains. Species richness was highest in the Howard sand plains. Only 2% of samples contained greater than seven species; all were in the Howard sand plains.

Distribution of bladderworts on the Howard sand plain

The simplest approach to understanding the distribution of bladderwort species across the sand plains is to examine species occurrence in relation to the vegetation mapping provided by Liddle *et al*. (2013). Data on bladderwort distributions come from the DLRM Flora Atlas. At 2 July 2015, there were 495 records from the Flora Atlas with an additional three records yet to be included in the Atlas at that time. The records of the 25 species provide the most complete account of bladderworts on the Howard sand plains.

The number of species of bladderwort in each plant community (Liddle *et al*. 2014) was determined and the number of vegetation communities with particular numbers of bladderwort species is provided in Figure 2.

Two of the vegetation communities had no record of a bladderwort species. The remainder of the vegetation communities had between one and 16 species. The number of vegetation communities fall into two groups, one with relatively few bladderwort species (one to six), and the remaining 10 communities with between 11 and 16 species.

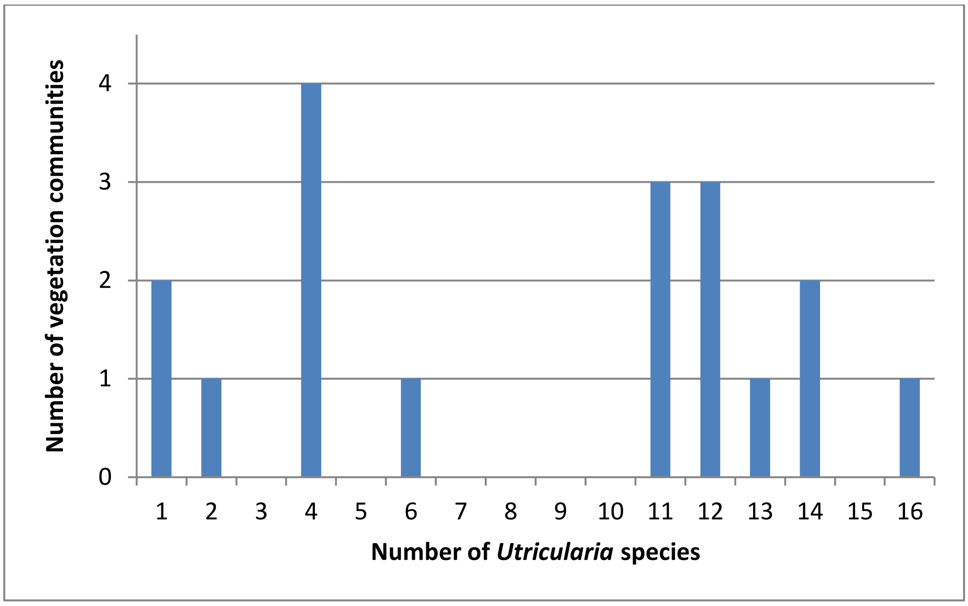

Figure 2: Number of vegetation types in relation to number of species of bladderwort

The pattern in Figure 2 is based on species presence and absence data, taking no account of the relative abundance of each species' records among the vegetation communities. A species that occupies ten communities and has ten records in each (100 records) has a significantly different distribution from another species with 100 records from the same ten communities, but with one record from each of nine communities, and 91 records from one community. A more complete understanding of the species' distributions would account for the distributions of each bladderwort species' individual records among all the vegetation communities.

Taking account of the distribution of individual records among vegetation communities allows for determination of whether records of several species distributions are independent of each other in relation to the vegetation types (test the null hypothesis that the pattern of distribution is random).

A non-random clumping of records and species within a few vegetation types would indicate that some vegetation communities are more likely than others to have large numbers of species and records, while an over-dispersed distribution would indicate that species numbers and abundances were more equitably abundant i.e. no particular vegetation community was more or less important than any other.

A measure of niche breadth (Levins 1968) of each species, and an assessment of niche overlap (Pianka 1973) among species are used to, respectively, describe the distribution of each species' records among the vegetation communities, and assess the null hypothesis of randomness of species distributions with respect to each other. Computation of the indices made use of EcoSimR (Gotelli *et al.* 2015). Results of the niche overlap analysis are provided in Appendix C. The distribution of niche breadths among the bladderwort species is provided in Figure 3. Most bladderwort species records have relatively narrow niche breadths of 4 or less (e.g. the threatened *U. dunstaniae* at 2.91), and relatively few have niche breadths equal to or greater than 7 (e.g. *U. leptoplectra,* at 10.8, the broadest of the recorded niche breadths).

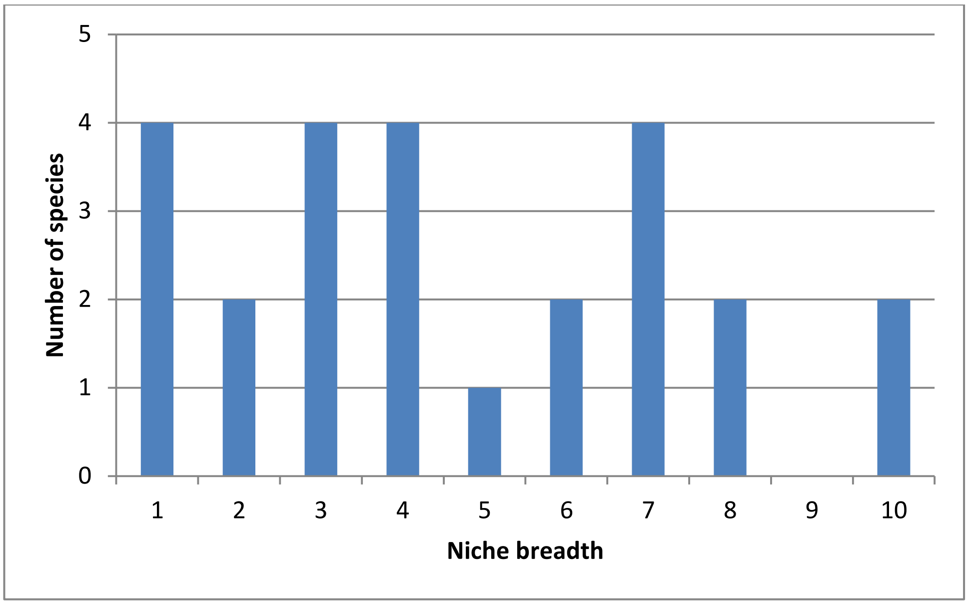

Figure 3: Number of bladderwort species in relation to niche breadth

The probability of the observed level of niche overlap being greater than the upper 95% confidence interval of the simulated mean overlap is greater than 99%. The observed level of niche overlap is not random, with there being a much higher level of niche overlap than would be expected from chance alone.

The observed, and a simulated example of a randomly generated niche overlap indicate significant clumping of individual records and species in 10 of the vegetation communities: 3a, 3b, 4a, 4b, 4c, 4d, 6, 9, 10 and 13 (Appendix C). These ten vegetation communities are the same communities found to have records of eleven or more bladderwort species, and are located relatively close to drainage lines.

Mean niche breadth of bladderwort species in the communities with relatively few species (1, 2a, 2b, 5, 11, 12 and 14) (14 species, B = 5.51) is not significantly different for the mean niche breadth of species recorded from the species rich vegetation communities (24 species mean B = 4.87) (Mann-Whitney U-test, U=133, z= -0,9078> -1.96). $p > 0.05$).

The similarity of the mean niche breadths of species in the two groups is a product of the majority species in the low species communities being shared with the high species community group. The proportions of narrow niche species in the two community groups ($B \leq 4$), is likewise similar (4 of 14 species compared to 8 of 24 species). Narrow niched species are usually species found having combinations of records from few vegetation communities and few records in total. The lower species richness communities have no records of 9 species that occur in the high species richness communities.

Only one bladderwort species (*U. linearis*) is recorded exclusively from the low species richness communities. It is recorded from community 2a which is often distributed towards the edges of the sand plains. This is compared to nine species that are only recorded from the species rich vegetation communities.

There are relatively few records of bladderworts from the low species richness communities (35), compared to those from the high species richness communities (421).

High species richness in 20 x 20 m plots

Liddle *et al.* (2013) counted the number of bladderwort species in 69 20 x 20 m plots spread across the 21 vegetation communities. The number of plots was positively correlated with the total area of each vegetation type ($r_s = 0.56$, $p < 0.01$). One vegetation type received a number of sample plots disproportionate to its total area. Five plots were counted in community 4b even though it has a total area of only 0.93 km^2. This community is distributed in approximately 12 patches of an average size of 0.08 km^2, often located adjacent to slightly elevated areas of eucalypt woodland.

Results were reported as the maximum number of bladderwort species found in each community, and the mean number of species from all plots in each vegetation community. Maximum numbers of species varied between 0 and 12, with mean numbers between 0 and 8. Community 4b had the highest maximum number of species (12), followed by 4a (8). Community 4b again had the highest mean number species (8), followed by community 12 (5) and communities 2a, 4a, 4c, 11, and 13 with 4 species each. The single record of 12 species from community 12 is aberrant, as it came from a small patch of community 4 vegetation enclosed in the community 12 type. Maximum and mean numbers from the vegetation communities are not correlated ($r_s = 0.22$, $p > 0.05$). The number of plots per vegetation type tended to be low (e.g. 7 communities had only one plot). This limits the potential for detecting a relationship between maximum and mean numbers of species, and an accurate understanding of the maximum numbers of species in plots in each vegetation community.

This limitation on the data can be partially overcome by comparing the mean maximum numbers per plot from vegetation communities with few bladderwort species (communities 1, 2a, 2b, 5, 8. 11, 12 and 14) with those from communities with high richness (communities 3a, 3b, 4a, 4b, 4c, 4d, 6, 9, 10 and 13). The species poor communities averaged maximum species numbers of 1.75, compared to the species rich communities mean of 5.9. It can be assumed that vegetation communities with high numbers of bladderwort species may in general be more likely to maintain higher number of species in small plots than communities with fewer species. This general assumption would be subject to modification according with as yet unknown habitat factors.

Distribution of vegetation communities along the north-south axis of the sand plains

The distribution of bladderworts across the north-south axis of the sand plains is assessed on the basis of frequency of records across the vegetation types, and assessing likely possible distributions using patterns of relative dominance of vegetation communities in the four areas defined by Gunn Point Road, Girraween Road and the Arnhem Highway (Figure 1 and Table 1). Records of occurrence of the bladderworts species are too few to examine individual distributions across the north-south axis of the sand plains.

Table 2 provides information on the relative dominance of the more abundant vegetation communities in each of the four areas. Areas of vegetation communities having high species richness of bladderworts were classified by inspection as dominant (as per Table 1), extensive, little, very little or zero. The latter two categories are not included in the table.

Community 4d is the only community present in appreciable areas across all four areas of the sand plains, and in all areas it provides little habitat. Communities 13 and 4b provide small areas of habitat in the Gunn Point Road to Girraween Road areas. Areas classed as 'little' are not included in the following discussion. The area north of Gunn Point Road has relatively large areas of four communities, Gunn Point Road to Girraween five communities. Girraween Road to the Arnhem Highway three communities, with one located south of the Arnhem Highway.

Table 2: Patterns of vegetation community abundance across the north-south axis of the sand plains

Vegetation	Area (km^2)	North of Gunn Pt Rd	Gunn Pt to Girraween Rd	Girraween Rd to Arnhem Highway	South of Arnhem Highway
3a	5.18	Extensive	Dominant1		
3b	2.72	3	Dominant	Little	
4a	2.38			Dominant	
4b	0.93		Little	Little	
4c	2.34			Dominant	Dominant
4d	2.88	Little	Little	Little	Little
6	5.31	Dominant	Extensive		
9	3.93		Dominant	Extensive	
10	2.66	Dominant	Extensive		
13	1.69		Little	Little	

The north-south variation in vegetation dominance (Table 2) is also reflected in changing availabilities of vegetation communities that have records of high numbers of bladderwort species. Eleven of the bladderwort species have relatively broad niches and occur across all or a majority of vegetation communities that maintain high species numbers. The occurrence of these species may be little influenced by the north-south gradient. Fourteen species have relatively narrow niches (index less than or equal to four) and may have distributions strongly influenced by the north-south gradients.

The potential effects of the north-south variation in vegetation communities on the distribution on each of the 56% of bladderwort species that have narrow niches were inferred from the Flora Atlas records in relation to the more dominant vegetation types in each sector (Table 3).

The results imply that the northern sector has potentially relatively large areas of habitat for seven narrow niched species, the Gunn Point Road to Girraween Road sector 10 species, the Girraween Road to Arnhem Highway sector eight species and the southernmost sector seven species. No single sector provides extensive habitat for more than 10 of the narrow niched species (Table 3). The northern three sectors or the southern three sectors as single protected areas would provide extensive habitat for all the species.

Table 3: Availability of significant areas of potential habitat for the narrow niched species of bladderwort

Species	Niche breadth	North of Gunn Pt Rd	Gunn Pt Rd to Girraween Rd	Girraween Rd to Arnhem Highway	South of Arnhem Highway
U.aurea	1.8	X	X		X
U.caerulea	2.7	X	X		
U.circumvoluta	2.0	X	X	X	
U.dunlopii	1.0		X	X	
U.dunstaniae	2.9			X	X
U.gibba	3.6			X	X
U.involvens	2.7		X		X
U.kimberleyensis	4.0	X	X	X	X
U.leptorhyncha	4.0		X	X	X
U. linearis	1.0	X			X
U.minutissima	3.5	X	X		
U.simmonsii	1.5		X	X	
U.subulata	2.7			X	
U.triflora	1.0	X	X		

Figure 4: Sand sheet heath community 3b (NTG, Photographer D. Liddle)

2.1.2 The vulnerable Utricularia dunstaniae

U. dunstaniae is listed under the *Territory Parks and Wildlife Conservation Act* (TPWC Act) as being vulnerable to extinction (Kerrigan and Cowie 2007a) (Figure 5). The species is endemic to Australia and is found in the Mitchell Plateau in Western Australia, and in the Northern Territory. The species is recorded from the Howard sand plains, Jabiru (Taylor 1989), once from the McMinns Lagoon area, once from the Adelaide River floodplain and more recently the Cobourg Peninsula, near Murgenella and near the Finniss River.

The species is an annual, terrestrial bladderwort that produces a solitary yellowish flower at the end of the Wet season or early Dry season (April to May) (Cowie 2002). The lower petals form two erect spikes with filamentous like appendages up to 4 cm long. *U. dunstaniae* is one of four northern Australian bladderwort species to produce flowers with insect-like appearances. The others are *U. dunlopii, U. capilliflora* (both found in the Northern Territory) and *U. antennifera* (which is only found in Western Australia).

All four species may mimic a female insect, attracting males to 'mate' with the flower and so transferring pollen from one mimic plant to the next. The possible pollinator remains unknown and could be some other form of insect pollination. The uncommon nature of the species records and presence in three different vegetation communities are suggestive of pollination requiring an insect capable moving over reasonably long distances.

U. dunstaniae grows in microhabitats that are wetter than those used by some other bladderworts species in the area. Its small and isolated populations are often found where water percolates from the ground (Cowie 2002).

Figure 5: ***Utricularia dunstaniae*** **(NTG, Photographer D. Liddle)**

Liddle *et al*. (2013) found *U. dunstaniae* in sand plain heath vegetation communities 4a, 4b, and 4d. It was also found to occur in an isolated area of sand sheet heath within vegetation community 12. The Flora Atlas records indicate presence in communities 4b, 4c and 6. The former records indicate that the Gunn Point to Girraween sector may provide extensive habitat for this species, along with the Girraween to Arnhem Highway sector.

The total population of the species is estimated to be less than 1 000 individuals scattered across seven sites (Kerrigan and Cowie 2007a), with only eight records from the sand plains.

2.1.3 The endangered Typhonium taylori

The small, seasonal herb *T. taylori* was discovered in 1996 and scientifically described in 1997 (Figure 6). *T. taylori* is found in several places scattered over an area of approximately 43 km^2 of the Howard sand plains area. The total habitat occupied is only 0.28 km^2 (Liddle and Trikojus 2010). It occurs nowhere else in the world (Kerrigan and Cowie 2007b).

The species is listed as endangered under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and the Northern Territory TPWC Act.

Figure 6: Typhonium *taylori* (NTG, Photographer D. Liddle)

*T. taylori i*s a tuberous plant that lies dormant during the Dry season. During the Wet season (late December to February in particular) plants push up leaves as long as 45 mm and grow to an average height around 22 mm. The above ground growth of the plant survives into the early Dry season, with no significant growth from the time of first emergence to the time of senescence (dying of above ground parts). An average of only 2.2 leaves is produced by each plant (Liddle and Trikojus 2010). Insect damage to leaves increases gradually through the growth season with some leaves lost entirely (Liddle and Trikojus, 2010). Leaves lost to insects are not replaced during the growth season in which the leaves are lost.

Flowering occurs in association with production of the first leaf during the early Wet season. Flowers are brownish purple and last one or two days and are rarely observed. A solitary inflorescence (a complex of flowers) emerges to about 7.5 cm, with an entirely underground stalk. An approximately 6.5 cm long spathe (a modified sheath-like leaf) partially encloses the inflorescence. It is closed at the bottom and open at the top with a maximum width of 5.5 mm. The spathe is two chambered with the lower 1.5 cm underground. The spathe semi-encloses a spadex (a spike like structure) about 5.5 cm long, 1 cm wide at its base and extending beyond the top of the semi-enclosing spathe. The top pointed portion of the spadex has no flowers. Below this portion is a zone of male flowers (3.5 mm long), followed by a naked zone (1 mm), then a zone of modified sterile flowers (6 mm) and finally a zone of female flowers (1 mm).

The female flowers are likely to be pollinated by beetles, as with other species of *Typhonium* (Broderbauer *et al*. 2012).

Rove beetles (Staphylinidae), dung beetles (Scararabaeidae), and other beetle groups that favour carrion, dung or decaying vegetation pollinate *Typhonium* species. The beetles are attracted to the *Typhonium* by odours emitted from the zone of modified sterile flowers. On entering, the beetles slip down into the bottom chamber of the inflorescence (because of specialised slippery cells lining the inner surface of the spathe). The entering beetles are trapped by the spathe twisting and closing the entrance to the bottom chamber. This separates the upper male flowers (inactive at this stage) from the lower female flowers (active at this stage) in the lower chamber. Entry of the beetles is facilitated by the spadex tilting forward, and then becoming erect at closure of the bottom chamber. Pollen on the beetles is transferred to the female flowers, which then cease to be receptive to pollen. The slippery cells on the spathe surface cease to be slippery and the male flowers produce pollen. The spathe twists and opens, releasing the beetles carrying a newly acquired load of pollen. Exit is facilitated by the spadex tipping forward for a second time. The spathe then closes again and the spadex resumes an erect posture. The colour of the spathe gradually changes from reddish to brown during the process.

There is no reported observation of the fruit of *T. taylori.* It might be expected to be a small berry as with other species of *Typhonium*. There is no knowledge of the mechanism of fruit dispersal; although an animal agent is likely to be involved.

Liddle *et al*. (2013) found *T. taylori* in sand sheet heath vegetation communities 4a, 4b, 3a and 3b along with a presence in five other communities, i.e. nine vegetation types. The two largest know populations occur in community 3a, with the third largest located in community 3b.

Liddle and Trikojus (2010) conducted a survey of the Howard sand plains SOC and located a total of 10 populations out of 12 sites examined. The three largest populations had recorded observations of 574, 508 and 58 individuals. An additional population had been recorded by the Northern Territory Herbarium during earlier work.

T. taylori is small and difficult to see making population estimates difficult. The three largest populations were additionally sampled using distance methods along straight line transects; to obtain more quantitative estimates of population size. The estimates were 28 222, 35 577, and 2 638 individuals in each population respectively. The numbers of plants seen in each of the populations during sampling were 139, 355 and 33 respectively. The difficulty with the quantitative estimates is that, as is often the case with estimates of population abundance of wild populations, the level of confidence in the estimates is low. The lack of precision is reflected in Liddle and Trikojus' (2010) estimate of the total known population as being somewhere between 34 000 and 131 000 individuals. These broad confidence intervals make effective monitoring of the populations impossible.

Numbers of *T. taylori* seen in the remaining seven populations of the 10 population studied by Liddle and Trikojus (2010) were 30, 29, 11, three populations with two individuals and one population with one individual.

2.1.4 The endangered Darwin palm (*Ptychosperma macarthurii*)

The Darwin palm (Figure 7) was formerly known as *P. blesserii.* It is a slender palm with 'feather-like' fronds with 30 to 40 leaflets either side of a midrib. It has a clumping growth form. Flowering occurs between May and December, with fruits between August and December. The pendulous inflorescences contain separate male and female flowers, with males ceasing to produce pollen before female flowers become active (Essig 1973). Pollinators are likely to be bees and flies. Fruits are red and dispersed by birds.

Figure 7: The Darwin palm (*Ptychosperma macarthurii*) (NTG, Photographer D. Liddle)

The species is known in the Northern Territory from eight populations on the Howard sand plains and adjacent western floodplain of the Adelaide River. The species is found in monsoon rainforests forests associated with springs. The species in total occupies less than one square kilometre of habitat and has a known population of 1037 plants. Over 70% of individuals occur in a single population at Crocodile Creek (Liddle *et al*. 2006).

The TPWC Act lists the Darwin palm as endangered with extinction.

The Darwin palm occurs as two populations in the Howard sand plains. Both populations occur in the same vegetation type; spring fed monsoon rainforest (Figure 8) (Liddle *et al*. 2013; community 16).

The Darwin palm is found in northern Queensland where it is not threatened by extinction (Kerrigan *et al*. 2007).

Figure 8: Spring fed monsoon forest (Community 16) (NTG, Photographer D. Liddle)

2.1.5 The vulnerable Howard toadlet (*Uperoleia* daviesae)

Discovered in 2000, the Howard toadlet is listed under the TPWC Act as vulnerable to extinction (Figure 9). Its distribution is largely confined to the Howard sand plains and areas of habitat in drainages of the Elizabeth River, (including areas near Noonamah and adjacent areas and the proposed city of Weddell). There is a record from near Berry Springs and a population in the Sunday Creek area extends just south of the SOC (Reynolds and Gattidge 2013).

The toadlet is small (less than 23 mm long) and has an orange-red groin with a narrow yellow to pale red mid-vertebral stripe. The dorsal surface is black with numerous pale brown tubercles (bumps). The ventral side is cream. Toes are not fringed and have little webbing.

Little is known of the species' natural history. Individuals emerge, call, mate, lay eggs and grow from tadpoles to adult form during the Wet season. Habitats used are largely inundated sand sheet heaths or areas adjacent to *Melaleuca* (paperbark) woodlands. These sites are shallowly inundated situations receiving flows from more elevated areas. Males call in small numbers. The call has 22 pulses and is raspy (Young *et al*. 2005; Fisher *et al*. 2005). Males often call from small mounds created by earthworms around *Diptapsilanthus spathaceus,* other sedges and perennial grasses. Males may call from a small cavity dug from the side of the mound (Reynolds and Grattidge 2013). Call sites are adjacent to water usually less than 3 cm depth (Reynolds and Grattidge 2013). The inhospitable conditions of the Dry season likely force the Howard toadlet into inactivity; similar to what occurs for most individuals of other Northern Territory species of this genus. The locations and habitats used to survive the Dry season are not known.

Figure 9: The Howard toadlet (*Uperoleia daviesae*) (NTG, Photographer S. Young)

The majority of records from the Howard sand plains are from the community 3 grouping (Liddle *et al*. 2013) (64%, N=25). The additional 36% of records include 12% from eucalypt woodland; 8% from community 7, and 1% from each of community 2a, community 6, community 9, and community 13. Records from eucalypt woodland are of interest given the absence of information on habitats the Howard toadlet uses to pass the Dry season.

Additional records from disturbed habitats included two from residential areas and 20 from disturbed sites. Records from disturbed sites were associated with past extractive mining.

Assessment of the species habitat preference is made difficult by the somewhat haphazard nature of sampling efforts. This contrasts with the clearly defined sampling programs used in assessing bladderwort species and *T. taylori* (Liddle and Trikojus 2010; Liddle *et al*. 2013). Biased sampling seems to have been inevitably caused by sampling being restricted to tracks allowing access during the Wet season when the toadlet is active. Although this deficiency prevents the conduct of a rigorous assessment of the Howard toadlet's habitat preference, it is clear that it has a preference for sand sheet heath vegetation with the sedge *D. spathaceus* in the ground layer vegetation and for habitats with an open canopy.

2.2 Land use in the Howard sand plains

2.2.1 Rural and urban development and expansion

Lands subject to rural residential development, and farming and forestry cover approximately 32% of the seasonally inundated or water logged lands of the Howard sand plain SOC (Liddle *et al*. 2013). These data are current as of the date of the imagery used to conduct the mapping (2010). The developments are largely restricted to the more upland surrounds of the flood plain, with the seasonally water logged/inundated sand plains constraining development. Rural and urban 'infill' and/or 'densification' are likely to continue into the future. These developments may impact the sand plains by causing loss of habitat, alteration in stormwater quality, quantity and flow rates, abstraction of water and recreational activities of residents.

Rural development around the western rim of the sand plain is not expected to have caused significantly enhanced levels of nutrients and toxicants in, or enhanced flows of storm water to and through the flood plain. Rural land use would not be expected to cause the levels of enhanced run-off and elevated nutrients and toxicants associated with urban development (Skinner *et al*. 2009).

Further expansion of rural residential and urban development south into the proposed Hughes-Noonamah and Noonamah Ridge urban development areas, and the proposed city of Weddell will inevitably alter the quality and quantity of stormwater flows through these areas. These changes to stormwater are important because these sand plains are the only other areas where the Howard toadlet is found. These sand sheets may also provide habitat for the threatened *U. dunstaniae.* Significantly increased volumes and rates of flow during storm events will impact negatively on the sand sheets and any threatened species present. The impacts would include erosion, scouring and sedimentation detrimental to the topographic and micro-topographic features essential to maintenance of existing biodiversity. Enhanced nutrient and toxicant inputs from urban and road run off would further degrade the nutrient poor status of the sand sheets; causing potential alteration of habitat and damage to plants dependent on nutrient poor habitats. The degradation of Mitchell Creek, Palmerston, following urban expansion provides an example of the impacts of improperly managed stormwater. It would be inappropriate to depend on these relatively small areas of sand sheet for the long term preservation of the sand plain biodiversity.

Flora Atlas records of bladderworts from sites impacted by rural development include relatively few species (6) and these species have a broader mean niche breadth (7.62) than the mean niche breadth of the species of bladderwort as a whole (4.44). The species in residentially disturbed areas do not include any of the narrow niched species i.e. the species present are commonly recorded from a variety of vegetation communities.

Rural and urban development on the sand plain has been associated with a significant lowering of the late Dry season water table in some areas; especially following Wet seasons with low rainfall. Haig and Townsend (2003) demonstrated that water abstraction from rural domestic, agricultural and municipal bores in the McMinns and Girraween Lagoon area following low rainfall Wet seasons caused a lowering of the late Dry season water table. This was 8 to 10 m greater than the average 10 m reduction in areas of the Howard River catchment not affected by abstraction. Wet season rainfall replenishes the aquifers and brings the water table to or close to the surface.

Yin Foo (2004) modelled the McMinns/Howard East groundwater system in response to increasing demand for abstraction from the aquifer. Modelling compared the outcomes of scenarios of the natural condition, the situation as it existed in 2004, and what might occur with implementation of the first two stages of a five stage development plan for additional municipal abstraction. He found that the 2004 scenario resulted in a doubling of recharge to the Layer 2 aquifer (Layer 1 is near the surface, Layer 2 is deeper and is used for abstraction). The 2004 scenario was associated with significant lowering of discharge to streams, springs, swamps and wetlands from Layer 1 compared to the natural scenario. There was a late Dry season draw down of 10 m under the rural residential area. The first two stages of the development were predicted to cause no increase in the depth of the draw down, but would expand the area of the draw down into the area of the sand plains. The projected future development would increase drawn down in the rural residential area to 15 to 21 m with further expansion of the drawdown area. Evapotranspiration would be reduced by 43% (the estimates of evapotranspiration and recharge did not include the effects of extractive mining (section 5.3.3)). Flows to the Howard River would be 40% of that received under natural conditions. The NT EPA does not possess monitoring data that may confirm these results.

The Power and Water Corporation is in the process of equipping four of the Howard East Bore Field's bores to provide additional emergency water supplies for Darwin (PowerWater undated). The McMinns-Howard East Bore Field is theoretically capable of supplying Darwin with 20% of its water needs. Limitations to infrastructure limit this potential supply to 15%. Current Power and Water Corporation abstraction is less than 20% of the abstraction from the bore field, most being accounted for by domestic bores. The Power and Water Corporation is licenced to abstract up to 8 420 ML/yr from the six bores in the area. Equipping the bores is designed to allow the Power and Water Corporation to provide emergency supplies should there be infrastructure or water quality failures at Darwin River Dam. It will also allow the Corporation to access its total licenced abstraction to meet a current shortfall in supply of 2 420 ML/yr. The shift is proposed to reduce the risk associated with ground water contamination from rural and mining activities (PowerWater undated).

The move to increase abstraction from the eastern portion of Howard East Bore Field, and increase abstraction from the entire bore field, seem likely to cause a larger Dry season lowering of the water table, and expand the zone of influence to the east of its current significant extent. More recent modelling of the aquifer by the DLRM is not available to the public.

2.2.2 Land use planning under the Northern Territory Planning Scheme

The recent Darwin Regional Land Use Plan 2015 (the Plan) provides a map of the location of the Howard sand plains SOC, and describes it as part of a natural area. It also provides maps of the locations of threatened vegetation communities. The Plan describes the Howard sand plains as follows:

> *Howard Sand Plains – extensive seasonally inundated wetlands with shallow lagoons and swamps and sandy substrates that provides habitat for communities of carnivorous plants (bladderworts) that are internationally*

> *significant because of their species richness, a nationally threatened plant species (*Typhonium taylori*) found nowhere else in the world, a threatened palm found nowhere else in the Northern Territory (*Ptychosperma macarthurii*), a threatened species of bladderwort (*Utricularia dunstaniae*), and a threatened species of frog (the Howard toadlet (*Uperoleia daviesae*) found nowhere else in the world. The future survival of this centre of unique biodiversity is dependent on the identification and establishment of areas capable of ensuring their long term protection.*

The Plan notes that:

> *Darwin Harbour, Shoal Bay, the Howard Springs Sand Plains, Finniss River and Adelaide River Coastal Floodplains and Fogg Bay are all recognised as being of national and international significance. Key Environment and Heritage Objectives in the Regional Context and Policy section of this plan establish a framework to ensure more detailed planning and assessment of development occurs in the context of appropriate identification and protection of areas of conservation significance.*

A key Objective of the Plan is to:

> *Protect and maintain the significant biodiversity and habitats (natural landscapes) of the region, including the threatened plants and animals under the Territory Parks and Wildlife Conservation Act 2013 (NT) and the Environment Protection and Biodiversity Conservation Act 1999 (Cth).*

The Howard sand plains SOC received a similar designation in the immediately past land use plan.

2.2.3 Mining of extractive minerals in the Howard sand plains

Demand and uses of extractive minerals

The Howard sand plains are a major source for the supply of fine sand, coarse sand and gravel to the construction industry in the Darwin Region (Doyle 2001). Total Darwin region extraction of these extractives plus crushed rock for the four years to 2001 was 1.3 million tonnes, which was approximately 50% of the Northern Territory usage (Doyle 2001). Northern Territory production of sand in 2000-01 was 328 725 tonnes (Department of Mines and Energy (DME)), with sand production in 2013-14 reported by the DME to be 753 663 tonnes. This is greatly in excess of Doyle’s (2001) predicted 500,000 tonnes of sand likely to be produced in 2020. The rapid increase in mining of extractives is associated with recent demand from urban expansion and development along with the INPEX gas plant and other developments on Darwin Harbour.

Fine sand is used for land fill in new land developments, housing pads, piping bedding sand, sanitary land fill and mortar and plaster (Doyle 2001). In these applications the sand needs to be free of vegeTable matter but is neither screened nor washed. Washed fine sand is used in manufacture of pavers and as an additive for concrete in paving slabs, pipes, and bridge beams. Washing to reduce silt and clay content is required for these latter purposes.

Coarse sand is used as concrete aggregate and in the manufacture of concrete blocks. Natural gravel is primarily used as road base, fill material and as decorative stone. High quality gravel is used for road base-course, with lower quality gravel used as shoulder and sub-base material. Natural gravel does not have the strength of manufactured crushed rock. Crushed rock must be used in urban areas, greatly reducing demand for the natural equivalent (Doyle 2001).

Extraction of superficial deposits of fine sand

Superficial fine sand deposits occur across the Howard sand plains. These are located at the surface on top of a superficial lateritic layer, or may have accumulated in stream channels where the laterite has leached away. On average the sand is 1 m in thickness and contains generally less than 10% clay and silt (Doyle 2001).

Extraction is a relatively simple process involving no more than removal of the native vegetation, stripping away the upper 100 mm to remove the organic content, followed by stripping of the sand to a depth, on average, of 50 cm (but up to 2 m), and stockpiling, screening and washing depending on clay and silt content and projected end uses. Stripping depths are usually defined by a need to cease stripping above underlying laterite in order to avoid contamination with clays, an underlying layer of ferricrete, or as defined by the depth of the water table during the Dry season (Figure 10). The pits cover areas of land limited by the boundaries of extractive licences and permits, and the area covered by economically viable deposits of sand.

Figure 10: Sand mining in the Howard sand sheet (NT EPA, Photographer C.Smith)

Extraction of coarse sand deposits

Coarse sand deposits have been identified and are being exploited in areas adjacent to and/or on the Howard sand plains. 'Sand deposits are generally located within a 2 km wide corridor either side of the river and are 0-15 m below the current topographic surface' (Doyle 2001). Depths are generally shallower at lower topographies to the west and east of the Howard River. Exploitable deposits in the Howard River area are on average about 12 m thick. Extraction of coarse sand involves (Doyle 2001) removal of sand sheet vegetation, removal of an average 2 m of lateritic gravel and clay/claystone, excavation of overburden and coarse sand to the depth of the Dry season water table (about 10 m below the surface) and dredging of coarse sand below the Dry season water table to depths of up to at least 20-25 m. The extractives are screened, washed and products stock piled (gravel, coarse sand and fine sand).

Bucket excavation has been used although this limits the depth of extraction to about 6 m compared to 20-25 m or possibly more using dredging. Dredging has not been used for approximately 10 years (Boral *pers. comm.)*.

Extraction of gravel

Natural gravel is sourced from erosional remnants of lateritic, hard mineral crust near or at the top of the soils in the Darwin region, which are extensive. Most gravel sources close to Darwin are largely exhausted. For example areas near Girraween Road west and east of the Howard River and near Gunn Point Road were largely depleted by 2001 (Doyle 2001).

Lateritic gravel is stripped from shallow pits, screened to remove oversize material and stockpiled (Doyle 2001).

2.2.4 Extent of mining extractive minerals on the Howard sand plains

Lands subject to mining disturbance cover 4.1% of area of seasonally saturated or inundated soils of the Howard sand plain SOC (Liddle *et al*. 2013). These data are current as of the date of the imagery used to conduct the mapping (2010). Areas disturbed by upland gravel extraction have not been mapped.

Mining of extractive minerals in the Howard sand plains has altered and continues to alter the extent and distribution of sand sheet heaths across the north-south and east-west extents of the flood plains. Sand sheet habitats occupied approximately 8% (2 160 ha) of the SOCS. As of 2013, 21% (461 ha) of the sand sheet heaths had been subject to mining. The sand sheet heaths accommodate approximately 75% of the extractive industry activities within the seasonally saturated floodplains of the SOC. Permit and licence areas are distributed across the north-south and east-west axes of the sand plains, other than where there are reservations from mining associated with water abstraction bores, or where there are areas that may be difficult to access or do not contain viable sand resources (Figure 11).

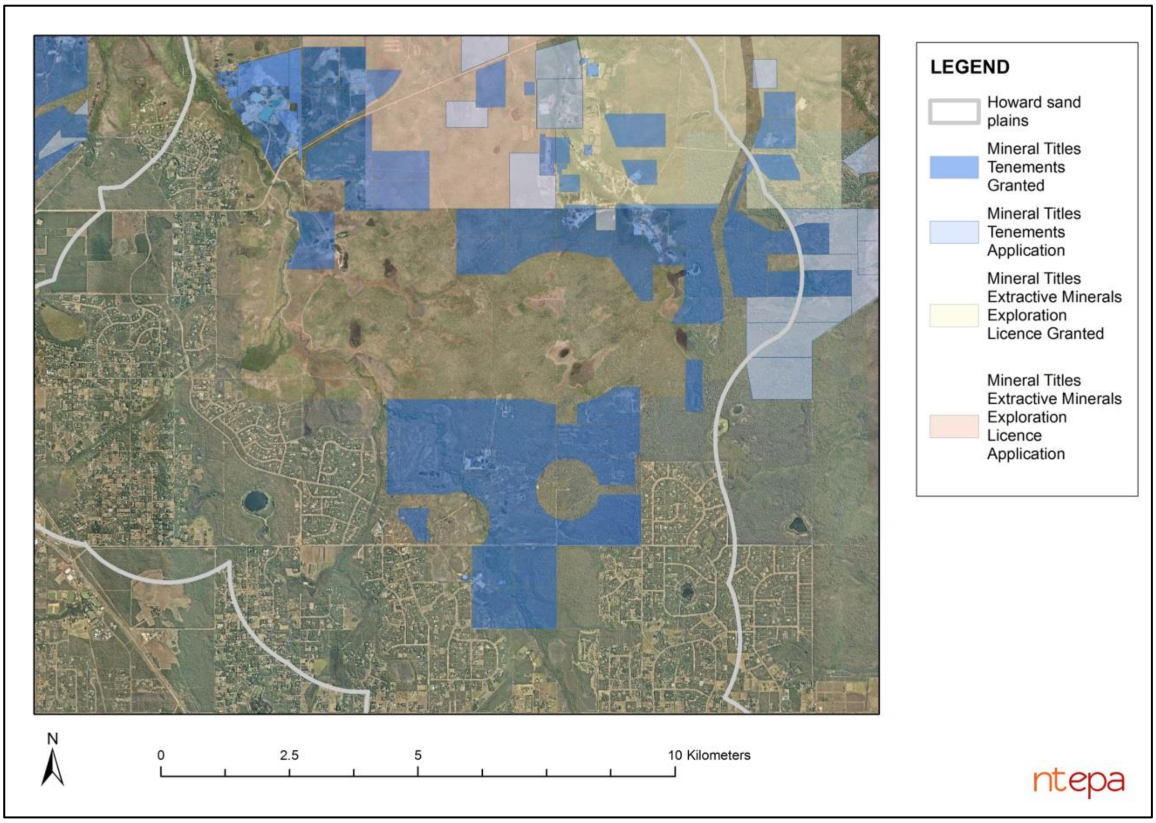

Figure 11: Mineral titles across the Howard sand plain (NTG, DME)

2.2.5 Rehabilitation of the Howard sand plains following disturbance

Two studies of rehabilitation of extractive sites have been completed. Additional work is being undertaken by Charles Darwin University in collaboration with the Extractive Industry Association, Greening Australia, Power and Water Corporation and the FFD (www.greening/australia.org.au/project/howard-sand-plains).

Tayler (2004) undertook a review of the extractive industry's rehabilitation performance in relation to Australian best practice in mined land rehabilitation. He found that the rehabilitation of extractive sites had historically been poor in the Northern Territory.

Rehabilitation of extractive sites was first addressed in the 1970s by the then Commonwealth Department of Northern Australia. The agency recommended even re-spreading of top soil with the pit floor ripped along the contour. Direct application of seed prior to the Wet season was recommended with use of fertiliser as appropriate.

The Conservation Commission of the Northern Territory provided guidance on the rehabilitation of borrow pits in 1983 (Applegate 1983). These recommendations included deep ripping of pit floors, stockpiling of top soil, recommended pit sizes and buffers between pits and from drainage lines, and a maximum pit depth of 1.5 m. These recommendations and those of the Commonwealth were used by DME in developing guidelines for the extractive industry in 1985. These guidelines did not differ greatly from those of the previous recommendations. None of the recommendations dealt with the consequences of differing vegetation or soils, or a need for monitoring success of the rehabilitation.

Current DME recommendations for rehabilitation for the extractive industry are generic and relate to all mining operations. It consists of a Commonwealth 2006 publication by the Department of Industry, Tourism and Resources titled: *Leading practice sustainable development for the mining industry: mine rehabilitation*. This provides high level generic advice for the entire mining industry, together with case studies. None of the case studies relates to the extractive industry. DME provides an advisory note: *Mining Management Plan (MMP) structure for the extractive operations.* This includes recommendations for rehabilitation, largely limited to advising the inclusion in the MMP of information on ‘infilling, replacement of top soil, revegetation techniques and ripping/scarification etc’.

The paucity of advice on rehabilitation of extractive sites, particularly sand extraction sites, seems likely to reflect the absence of consensus on the goals of such rehabilitation, and the absence of techniques likely to provide for rehabilitation of sites to allow protection of the sand plains’ biodiversity.

Price *et al.* (2005) conducted an intensive study of the effectiveness of rehabilitation of extractive sites for fine sand and gravel in the sand plains and other areas adjacent to Darwin. They assessed recovery of woody vegetation and found that:

- mined sites recovered about 50% of the stem count and canopy
- mined sites recovered about 10% of the basal area and mature tree count
- time since mining had no influence on recovery, even after 27 years
- deeper mines had poorer recovery
- gravel mines did not recover as well as sand mines
- only 35% of expected woody species were present on sand mined sites
- only 41% of expected woody species were present at gravel mined sites.

No attempt was made to assess the effectiveness of rehabilitation in terms of bladderwort or other herbaceous species.

The authors concluded that there was a need to improve the standard of rehabilitation, and that the capacity to rehabilitate to a level that could support the area’s threatened species was problematic.

These conclusions were endorsed by Grattidge (2013) when developing guidance for rehabilitation following sand mining in the Howard sand plains. The detailed guidance largely reflected procedures and processes widely used in rehabilitation of shallow mining sites. These remain largely untested and of necessity include procedures and processes that remain hypothetical. Grattidge (2013) did not claim that the proposed processes would or necessarily could result in rehabilitation of the sand plains’ biodiversity.

Flora Atlas records of species of bladderwort from old mining sites (14) have a mean niche breadth (6.13), significantly broader than that of the community of bladderworts as a whole (4.44)($U = 107.5$, $z = -2.12 < -1.96$, $p < 0.05$). These disturbed site records lack all but one of the recorded narrow niched species i.e. *U. simmonsii* which occupies shallow water and is able to make use of old mining sites. In general species recorded from old mining sites are those for which there are a large number of records from a variety of vegetation communities.

Recent work involving Charles Darwin University, the Extractive Industry Association, Greening Australia and the FFD has focused more specifically on rehabilitation for effective re-colonisation by species of bladderwort. While these studies are ongoing, there has been little success in providing for colonisation by the rarer and often microhabitat specific species (Herath 2014). The nature of *Typhonium’*s and the bladderwort species’ microhabitat specialisations (e.g. location of *U. dunstaniae* in areas of water percolating from the ground and the importance of worm mounds to this and other species), may well preclude appropriate rehabilitation at the bottom of a pit (often under water), or on an artificially sloped rehabilitation.

There is no known way in which to rehabilitate the Howard sand plains biodiversity. The nature of the sand plains and the biology of its biodiversity are likely to preclude effective rehabilitation in the long term.

3 Threats to the biodiversity of the Howard sand plains

Potential threats to the sand plains’ biodiversity are associated primarily with urban and rural development, and the activities of the extractive mining industry. The impact of a development/threatening process on any species or ecological community is a function of the vulnerability of that species/community to the disturbance (as determined by its habitat requirements and life history), the extent and severity of the disturbance, and the adequacy of any mitigation or rehabilitation applied during and following the disturbance.

This section describes the potential vulnerabilities of the threatened community and threatened species to potential sources of threat, and assesses the extent and nature of the threats.

3.1 Vulnerability of the Howard sand plains' biodiversity to threats

The vulnerabilities of the species rich bladderwort community, the vulnerable *U. dunstaniae*, the endangered *T. taylori*, the endangered Darwin palm and the vulnerable Howard toadlet to habitat disturbance are assessed using an analysis of known habitat requirements, and where appropriate, knowledge of other vulnerabilities (e.g. fire and weeds). The vulnerabilities of the Howard sand plains biodiversity are expressed in terms of the habitat or other features that are critical to its continued existence.

3.1.1 Vulnerabilities of the bladderwort communities of global significance

The patterns of distribution of bladderwort species vary across the Howard sand plain vegetation types and across the flood plain (Cowie 2002). Some species are found predominantly in the west and north of the floodplains, some in the north eastern area, and another group of species is more likely to occur in the southern parts of the area. These differences are likely to be influenced by the micro-habitat requirements of the various species (section 2.1.1).

Taylor (1989) was the first to report significant differences among the micro-habitat requirements of bladderwort species on the sand plains. He found that *U. gibba* occurred in deeper pools, anchored to the bottom or margins, while *U. leptoplectra* was found on the pool margins, but extended away from the pools into wetter areas among hillocks/hummocks. In contrast *U. circumvoluta, U. capilliflora, U. dunstaniae, U. holtzie, U. hamiltonii, U. kamienskii, U. lasiocaulis* and *U. quinquedentata* occurred in shallower water (a few millimetres to a few centimetres deep) between hillocks. *U. caerulea, U. chrysantha, U. odorata and U. subulata* (cliestogamous form only, i.e. bears closed flower buds that self-pollinate) occurred towards the edge of surrounding woodlands among taller grasses and sedges.

Hillocks play a significant role in providing a diverse habitat capable of maintaining many species of bladderwort (Cowie 2002). Earth worms (likely to be species of *Diplotrema*, G. Dyne *pers. comm.*) build low hummocks of soil a few centimetres or more in height around the bases of the sedge *D. spathaceus* or grass tussocks. It is thought the mounds allow worms to remain above water level during the Wet season. The mounds provide the hillocks and depressions noted by Taylor (1988). Cowie (2002) noted that *U. capilliflora, U. dunstaniae, U. holtzie, U. hamiltonii,* and *U. lasiocaulis* occupied the shallow water in depressions while *U. caerulea, U. chrysantha, U. kamienskii, U. odorata* and *U. quinquedentata* inhabit the dryer mounds (or moist sand in areas that started to dry out). The proportion of mound dwelling species increased as these habitats dried out.

Other habitat requirements noted by Cowie (2002) included:

- *U. limosa* – tolerant of stagnant water
- *U. caerulea* (small white form) – ephemerally moist areas in *Eucalyptus* woodland
- *U. kimberleyensis* – seasonally water logged *E. alba* woodland
- *U. caerulea* (large form) and *U. odorata* – seepage areas that remain waterlogged for most of the year

- *U. chrysantha* and *U. odorata* – tend to peak after water has receded, with *U. odorata* found on sites with more grass
- *U. leptoplectra* – found in finer textured soils down slope, with prevalent grasses, deeper surface water and no ground water seepage.

These examples are likely to be only some of the intricacies of habitat partitioning among species of *Utriculia* on the sand plains. Maintenance of these micro-habitat features and the capacity for partitioning of micro-habitats through time, in association with changing hydrological conditions, are likely to be critical in maintaining the species rich communities.

The ecology of the species rich bladderwort communities suggests vulnerability to:

- alteration of the distribution and abundance of sand sheet heaths across the north-south and east-west extents of the flood plains (i.e. habitat removal)
- spatial and temporal alteration of ground water tables, and surface water flows across the entire wetland system in relation to ground water seepage, spring flows, patterns of Wet season inundation/saturation, and Dry season water availability
- alteration of topographic and micro-topographic features relevant to maintaining existing patterns of surface water flows, inundation and water logging.

There is no available information concerning the vulnerability of the bladderwort community to fire, weeds or feral animals. The introduced pasture grass *B. humidicola* can form dense monocultures on the sand plains and should be regarded as a significant threat (Liddle and Trikojus 2010).

3.1.2 Vulnerabilities of the vulnerable *Utricularia dunstaniae*

The habitat requirements of *U. dunstaniae* are not documented beyond the species having requirements for sand plain heath vegetation and wetter environments than some associated bladderwort species. It is often associated with water percolating from the ground. There is no detailed information on the species growth period, or the nature and duration of hydrological conditions necessary for growth and reproduction. The species is distributed in very small populations over what may include areas distributed over much of the north-south extent of the sand plain (Kerrigan and Cowie 2007a; Liddle *et al*. 2013). The habitat requirements for maintaining effective pollination over the small and widely dispersed populations remain unknown.

The habitat requirements and the little that can be surmised indicate vulnerability to:

- alteration of the distribution of sand sheet heaths across the north-south and east-west extents of the flood plains (i.e. land clearing)
- spatial and temporal alteration of ground water tables, and surface water flows across the entire wetland system in relation to ground water seepage, spring flows, patterns of Wet season inundation/saturation, and Dry season water availability (particularly reduction in duration of active Dry season discharges for slightly elevated areas)

- alteration of topographic and micro-topographic features relevant to maintaining existing patterns of surface water flows, inundation and water logging.

Nothing is known about the potential impacts of fire, weeds and feral animals on *U. dunstaniae.* The introduced pasture grass *B. humidicola* can form dense monocultures on the sand plains and should be regarded as a significant threat (Liddle and Trikojus 2010).

3.1.3 Vulnerabilities of the endangered *Typhonium taylori*

Known *T. taylori* populations are restricted to sand sheet heath vegetation located in the western, north to south portion of the Howard sand plain. In this habitat it is restricted to areas of water logged soils and inundation in areas of flowing water such as adjacent to springs arising from neighbouring gravelly rises. Plants may become submerged. Timing of plant emergence in the Wet season varies among sub-populations according to timing of increasing water availability. Additional plants may initiate growth as late as May if water availability lasts. This may occur when the above ground parts of plants in other subpopulations are in senescence (Liddle and Trikojus 2010).

The critical nature of water availability is well demonstrated by the growth patterns of plants in three populations studied by Liddle and Trikojus (2010). The differences in growth pattern were attributed to the differing effects of different human infrastructure on surface water hydrology.

One population studied had a bitumen road 100 m upstream of the site, a bitumen road along one edge of the site and was adjacent to a water production bore. This was the driest site studied. It exhibited a relatively rapid increase in plant senescence and hence apparent population decline from March to May (Liddle and Trikojis 2010). By May there was little water left on the site even though it was present across the floodplain upstream of the nearby road.

A second site had less infrastructure intrusion (a series of vehicle tracks that did not impede water flow) and the plants exhibited an in general longer survival of the above ground parts, and limited apparent population decline between March and May.

A third population was in the vicinity of roads, tracks and old mining areas; with the site upstream of impediments to the flow of water. It seemed the wettest site. This site exhibited continued appearance of new plants throughout the period January to May.

These limited observations are likely to be indicative of the sensitivity of *T. taylori* to changes in hydrology and potential impacts from development on the sand sheet. The observations do not provide detailed information on particular plant responses to particular infrastructure or changes in hydrology. Nor do they provide critical information on the likely effects of infrastructure on the plants’ growth, survival or reproductive output; all critical to population growth and survival.

The habitat requirements for enabling effective pollination by rove, scarab or other beetles over the small and widely dispersed populations remain unknown.

T. taylori is vulnerable to:

- alteration of the distribution of sand sheet heaths across the north-south and east-west extents of the flood plains (land clearing)
- spatial and temporal alteration of ground water tables, and surface water flows across the entire wetland system in relation to ground water seepage, spring flows, patterns of Wet season inundation/saturation, and Dry season water availability
- alteration of topographic and micro-topographic features relevant to maintaining existing patterns of surface water flows, inundation and water logging.

Little is known of the potential impacts of fire, weeds and feral animals on *T. taylori.* The introduced pasture grass *B. humidicola* can form dense monocultures on the sand plains and should be regarded as a significant threat (Liddle and Trikojus 2010).

3.1.4 Vulnerabilities of the endangered Darwin palm

The Darwin palm, along with the monsoon rainforests in which it is found, is dependent on the presence of a spring fed-water supply. Elimination or reduction in the water supply, ground water or surface water, could be expected to impact negatively on the palm. Reduction in water supply to the monsoon rainforest could potentially result from lowering of the water table as a result of abstraction, topographic disturbance to recharge zones in adjacent upland eucalypt forests/ woodlands or topographic disturbance adjacent to the monsoon rainforest. Liddle *et al*. (2006) found that apparently localised lowering of the water table late in the Dry season was associated with increased risk of fire. Fires were instrumental in lowering the abundance of adult Darwin palms in the Whitewood Jungle (located in the west of the Howard sand plain) by 60% over the years 1990 to 2000.

The Darwin palm is known to be vulnerable to:

- potential clearing of monsoon forest habitat
- spatial and temporal alteration of ground water tables, and surface water flows across the entire wetland system in relation to ground water seepage, spring flows, patterns of Wet season inundation/saturation, and Dry season water availability
- alteration of topographic and micro-topographic features relevant to maintaining existing patterns of surface water flows, inundation and water logging.

Fire, possibly exacerbated by the invasion of introduced grasses, is known to negatively impact on the Darwin palm. Feral animals have significant negative impacts on Darwin palms (Liddle *et al*. 2006; Barrow *et al*. 1993).

3.1.5 Vulnerabilities of the vulnerable Howard toadlet

Little is known about the vulnerabilities of the Howard toadlet to various forms of potential impact. In particular there are no data in relation to critical life history staging habitats such as where eggs are laid, where tadpoles grow to maturity, or where the juvenile and adult toadlets spend the Dry season.

The available information is that the Howard toadlet is found primarily in the Howard and Elizabeth River and associated catchments, and has a preference for sand sheet heath vegetation. It has been found in other open habitats, and rarely in eucalypt forest adjacent to sand sheet heaths.

Reynolds and Grattidge (2013) recorded an instance where a Howard toadlet population was transected by the development of a road and a drain. The drain intercepted flows across area, making part of it no longer suitable for the Howard toadlet.

The howard toadlet is potentially vulnerable to:

- alteration of the distribution and abundance of sand sheet heaths across the north-south and east-west extents of the flood plains (land clearing)
- spatial and temporal alteration of ground water tables, and surface water flows across the entire wetland system in relation to ground water seepage, spring flows, patterns of Wet season inundation/saturation, and Dry season water availability
- alteration of topographic and micro-topographic features relevant to maintaining existing patterns of surface water flows, inundation and water logging.

3.1.6 Summary vulnerabilities of the threatened sand plain biodiversity

The threatened community of bladderworts, the threatened plant species and threatened Howard toadlet are all subject to largely the same vulnerabilities to threats. These involve the known effects of clearing and mining in removing habitat, changes to surface and ground water hydrology, and aspects of topography and micro-topography that are either related to maintenance of the spatial and temporal characteristics of the hydrology, or to specific aspects of the biology of particular organisms.

Known and potential vulnerabilities to fire, weeds and feral animals cannot be effectively assessed from available information; other than for the Darwin palm. It is recognised that the other threatened sand plain biodiversity are or could be vulnerable to these threats, that the impacts of these threats may be increased by various developments, and that the threats are likely to require management as part of any proposal for preserving the sand plain biodiversity. For example, the introduced pasture grass *B. humidicola* can form dense monocultures on the sand plains and should be regarded as a significant threat (Liddle and Trikojus 2010).

In summary, the biodiversity of the threatened Howard sand plains is vulnerable to:

- alteration of the distribution and abundance of sand sheet heaths and monsoon rainforests across the north-south and east-west extents of the flood plains (land clearing)
- spatial and temporal alteration of ground water tables, and surface water flows across the entire wetland system in relation to ground water seepage, spring flows, patterns of Wet season inundation/saturation and Dry season water availability

- alteration of topographic and micro-topographic features relevant to maintaining existing patterns of surface water flows, inundation and water logging.

3.2 Threats to the sand plain biodiversity

The major, immediate sources of threat to the sand plain biodiversity are rural and urban development and expansion, and the extractive mining industry.

3.2.1 Threats to sand sheet heath distribution and abundance

The major current threat to the distribution and abundance of sand sheet heaths is the clearing of land associated with extractive mining, including clearing to establish pits, stock piles, sand washing and screening, office and facilities, roads and tracks.

As noted in section 2.3.4, 21% of the sand sheet heath has been subject to mining and extractive mineral approvals that are widely scattered across the sand plain. None of the areas subject to extractive mining has been or can be effectively rehabilitated to allow subsequent recovery of the threatened biodiversity.

In addition there are lesser levels of clearing associated with roads and sites for urban development, and ground water abstraction and delivery.

On this basis it is reasonable to conclude that land clearing has had and will continue to have increasingly significant impacts on sand sheet distribution and abundance. All elements of the threatened sand sheet biodiversity are similarly likely to have experienced significant alteration in habitat distribution and abundance, fragmentation and lowered interconnection among populations. This is likely to increase with ongoing land clearing, especially from extractive mining which is largely focused on this habitat.

Doyle (2001) estimated that available superficial sand would be exhausted by 2035 at an estimated extraction rate of 300,000 tonnes per annum. The rate of extraction over the past 15 years approximates this rate of extraction (DME).

The spring fed monsoon rainforest habitats have not suffered any known impact from land clearing although there is potential for the rainforests and the Darwin palm to have suffered indirect consequences in relation to water availability. Any future clearing of these habitats would result in a significant impact on the two Darwin palm populations in the sand plains, and on the species in the Northern Territory as a whole. Enhanced abstraction of water seems likely to impact negatively on the rainforest, particularly following a series of low rainfall Wet seasons.

3.2.2 Threats to seasonal patterns of water tables, inundation & saturation

Threats to hydrology are known to be related to impacts of rural and urban development and extractive mining.

Threats related to rural and urban development are ground water abstraction leading to documented significant lowering of Dry season water tables (section 2.3.1) and unquantified, but known to be extensive, impacts of human recreational activities. Human recreational activity causing development of tracks, hollows and compaction of the ground from machinery have unassessed impacts on patterns of surface water flows through the sand plain habitats. They are also likely to alter topographic and micro-topographic features, including those manufactured by earthworms, which provide a hydrological basis for microhabitat selection among wetland plants.

Potential threats from mining involve:

- pits and excavations reducing ground water flows to areas of percolation and springs causing altered patterns of surface water flows and availability
- pits and excavations enhancing drainage from areas of ground water percolation and springs
- impoundment of surface water flows in pits and other mining activity caused depressions intercepting, reducing and altering surface flow volumes and patterns
- impoundments in pits and excavations enhancing Dry season evaporation of ground water and earlier lowering of the water table (especially in areas with high hydraulic capacity)
- impoundment in pits and excavations enhancing infiltration to ground water, causing earlier raising of the water table to its maximum
- abstraction of water for use or pit de-watering causing enhanced rates of lowering of water tables in the Dry season.

The potential threats from mining are not independent of each other. For example there are interactions between the water table lowering effects of enhanced evaporation from a pit and the raising of a water table by early Wet season rains. These are difficult to measure and assess (e.g. Arnold *et al*. 2002). The outcomes however are likely to vary according to timing and quantities of early rains, and the late Dry season weather. Whatever the outcomes of interactions in any particular year, the pattern of outcomes across years seems unlikely to conform to those prior to mineral extraction.

Increasing areas for shallow and deep pits intersecting the water table, increasing numbers of stockpiles and other infrastructure, increasing lengths of roads and tracks and pit dewatering will inevitably cause significant change in the spatial and temporal patterns of surface water flows and availability of ground water. The impact of these changes with expansion of the extractive industry cannot be predicted with precision. It is reasonable to conclude that change to surface and ground water is likely to have a negative influence on the quality of habitat for the threatened species and community.

3.2.3 Impacts on the threatened biodiversity

The bladderwort species (including *U. dunstaniae*), *T. taylori* and the Darwin palm have high levels of known habitat or microhabitat specialisation. These are largely defined by seasonal and spatial patterns of water flow, depth and duration of inundation and waterlogging, and substrate types. Change to the seasonal and spatial patterns caused by interactions between abstraction and the hydrological impacts of mining would inevitably impact on the availability of micro-habitats, and in consequence the threatened biodiversity.

Mining and other infrastructure is known to impact *T. taylori* by altering temporal and spatial patterns of surface water flow (Liddle and Trikojus 2010) as well as impacting all the sand heath vegetation by removal.

Low rainfall wet seasons and associated lowering of water tables may alter the temporal pattern and availability of surface flows, ground water percolation and spring flows critical to growth and longer term survival of the species rich bladderwort communities and *U. dunstaniae.* As observed for *T. taylori,* these seem vulnerable to disruption of water flows by mining excavations, roads, etc., (e.g. reducing the period of discharge of water from slightly elevated areas after the Wet season), with consequent reduction in micro-habitat diversity, and negative impacts on the species. Negative impacts on the hummock building earthworms would exacerbate microhabitat loss.

Liddle *et al*. (2006) documented a dramatic 65% reduction in the number of adult Darwin palms in Whitewood jungle (on the western edge of the sand plain). This was attributed to fire associated with drying of the monsoon rainforest during a period of low rainfall Wet seasons, exacerbated by significant lowering of the water table caused by abstraction. The level of abstraction of water from the sand plains has increased since that time (Yin Foo 2004; Yin Foo (as quoted in Woodward *et al*. 2008)), and is likely to increase in the near future.

It is reasonable to assume that altered patterns of ground and surface water hydrology would also impact the Howard toadlet. Impacts would particularly relate to altered temporal and spatial availability of habitats that provide it with opportunities for Wet season breeding and feeding activities.

Lowering of water tables caused by abstraction interacting with the effects of disturbance from mining have impacted on ground water and surface water hydrology across the entire Howard sand plain wetland system, and has had recorded impacts on the threatened biodiversity.

3.2.4 The Howard sand plains as a threatened ecological community

The significance of the sand plains' bladderwort community is based on the two parameters investigated by Liddle et al. (2013). Both these parameters, a high number of bladderwort species in the Howard sand plains (26) and high numbers of bladderwort species in small areas, e.g. 20 by 20 m (up to 16), are the features that help define the national and global significance of the sand plains' bladderwort community. This significance is augmented by the presence of the vulnerable *U. dunstaniae,* the endangered *T. taylorii,* the endangered Darwin palm, the vulnerable Howard toadlet and the other threatened and near threatened and data deficient species (and in one case a threatened species that may be present) (section 1). It is all of these parameters that define the significance of the sand plains.

The EPBC Act provides the only legislation that could be used to list a Northern Territory ecological community as threatened with extinction. Nominations for listing are submitted according to a required format. Adherence of one or more criteria determines whether a particular submission leads to listing of a community.

The first step is to determine an accurate description of the community in question, and determine its distribution across Australia. Liddle *et al*. (2014) demonstrate that sand plains habitats (with bladderworts) occur in scattered patches across the

Top End of the Northern Territory. Similar communities occur in other parts of northern Australia. To be eligible for listing as a threatened ecological community under the EPBC Act the Howard sand plains would need to be classifiable as uniquely different from the other sand plains communities. The distinctiveness of the Howard sand plains is based on it occurring in the largest area of sand plains in the Northern Territory, and it containing a uniquely large number of bladderwort species, a large number of these species occurring in small areas of habitat, and the presence of the threatened species.

Based on current information these unique features do not qualify the Howard sand plains community for nomination as a threatened community. Any nomination would require nomination of sand plains in general, and most of these are unlikely to be threatened with extinction. The EPBC Act process is based on broad criteria not suitable for listing of communities, which although of national and likely global significance in terms of species richness and threatened species, are part of a broader array of communities that are not threatened.

The EBPC Act nomination form and criteria none the less provide a basis for determining whether this uniquely biodiverse community is threatened with extinction. A completed nomination form is provided in Appendix B.

The nomination form indicates that the Howard sand plains' heaths should be regarded as, at a minimum, endangered with extinction. Criteria 4 and 6 (reduction in community integrity and probability of extinction) indicate the community should be regarded as critically endangered, while criteria 2 and 5 (size of geographic distribution and decline in the coming 10 years) indicate a listing of endangered. Criteria 1 and 3 (decline in geographic distribution in the past 50 years, and decline in a population playing a major role in the community) suggest a listing of vulnerable to extinction. A critically endangered assessment could easily be supported.

4 Conservation of the Howard sand plains' biodiversity

Urban and rural development and the extractive mining industry in the Howard sand plains area are impacting negatively on the areas' biodiversity. The impacts relate to documented vulnerabilities of the sand plains' threatened community and species. The impacts cannot be rehabilitated.

The objective of this section is to provide a lowest risk option for preservation of an area/s of the Howard sand plains that will allow for the long term persistence of the Howard sand plains' threatened biodiversity, and that can be implemented in the near term. Effective protection would include protection of the bladderworts species, protection of areas of the highest species richness of bladderworts and protection of the threatened species

This section documents the strengths and weaknesses of our knowledge of the Howard sand plains, identifies objectives in order to meet the needs of effective protected areas, and the specific requirements to meet these objectives, discusses options for a risk averse approach to the design of a protected area/s that takes account of the strengths and weaknesses of existing knowledge of the sand plains, and outlines a risk averse final lowest risk option for the protected area. Appropriate design parameters are determined, and evaluated in relation to the positive and negative consequences of changes to those parameters.

4.1 Limitations to knowledge of the sand plains

4.1.1 Limitations to knowledge of biodiversity

Knowledge of the Howard sand plains biodiversity is limited to sampling of the sand plains to determine:

- the species richness of bladderworts in various plant communities on the sand plains, and the distributions of individual bladderwort species (including *U. dunstaniae*) (formal quadrat survey and less structured searches; 495 records in the Flora Atlas)
- the distribution of *T. taylori* in relation to the sand plains and vegetation types (formal survey of 11 quadrats in likely environments and less structured searches)
- extensive searches and evaluation of Darwin palm populations (many years of information)
- records of the Howard toadlet from informal sampling
- casual nature observations.

The Flora Atlas data on the species rich bladderwort communities are limited. These data are accepted as the most complete, accurate dataset available and have been used in preparation of this report. The patterns of distribution determined are those present in the data. These do not necessarily provide a 100% accurate depiction of bladderwort distributions. Data on *U. dunstaniae* are similarly constrained.

The limited number of sample plots were too few (69) to adequately determine which vegetation communities have the highest number of bladderwort species in small areas. Some plots were found to have high numbers of bladderwort species, and these are confined to 10 vegetation communities; the same communities with the records as high numbers of species from all sampling methods.

Sampling of *T. taylori* may have been similarly deficient. Eleven plots is a very small number of plots. Plots were located in areas thought to provide appropriate habitat. No indication was provided as to the presence or extent of similar habitats in other parts of the sand plains.

Documented knowledge of the life histories, natural histories and ecology of the species rich bladderwort communities*, U. dunstaniae,* and *T. taylori* are limited to the distributional and habitat data listed above, and a brief natural history account of *T. taylori's* seasonal growth cycle. Data on population sizes are limited to estimates (with extremely large confidence intervals) for three *T. taylori* populations. There are no data on pollination or fruit dispersal of these species.

The Darwin palm has been relatively well studied producing useful data of species distribution, population sizes, habitat requirements, pollination, fruit dispersal and population genetics. There is also a good understanding of the effects of changing water tables, fire, and feral animals on populations of Darwin palms.

The Howard toadlet data are biased by sampling having been constrained by the difficulty of accessing the wetlands during the Wet season. Sampling is largely limited to access via roads and tracks, leaving large areas of the sand plains not sampled, few records to assess (N=47), and providing a limited capacity to assess habitat preferences. There is little known of the species' biology or level of population fragmentation on the sand plains.

Limitations to the understanding of the Howard sand plains biodiversity are summarised in Table 4.

Table 4: Understanding of Howard sand plains biodiversity

	***Utricularia* community**	***U. dunstaniae***	***T. taylori***	***P. macarthurii***	***U. daviesae***
Distribution	North-south & east-west species distributions can only be inferred from vegetation community distributions	Few identified	Few populations identified	Adequate	Inadequate data, biased sampling
Habitats	Existing data provide clear patterns of species richness among vegetation communities	Known vegetation types described	Vegetation types described	Adequate data, possibly dated	Inadequate data, biased sampling
Population size / abundance	No population data	No population data	Broad confidence intervals on population data	Adequate data, possibly dated	No population data
Population fragmentation	No data	Few, dispersed small population	Few, dispersed	Dispersed, adequate data	No population fragmentation data
Seasonal growth, reproductive cycle	Little known	Little known	Basic description	Adequate data	Basic description
Pollination / fruit dispersal / dispersal / population genetics	Unknown	Unknown	Unknown but likely to as for other *Typhonium*	Adequate data	Unknown

4.1.2 Limitations to knowledge of hydrology

Knowledge of the hydrology of the Howard sand plains is biased by the imperative of providing Territorians with a water supply. There has been no investigation of the intricacies of the surface water-ground water interaction at a scale appropriate to understanding the needs of the threatened biodiversity. There has been no investigation of the local hydrological impacts of extractive mining on surface and ground water flows across the Howard sand plain wetland system. There is no understanding of the cumulative impacts of abstraction and mining on the hydrology at any scale, and there is no appropriately detailed understanding of the hydrological requirements of the threatened species. Nor are there any detailed records of how, or in what ways, abstraction and mining have impacted the hydrological environments of the threatened biodiversity, other than for the historical impacts of abstraction on the Darwin palm.

4.1.3 Limitations of data and design of a protected area

Three classes of data limitation pose significant risk in the design for a protected area. These limitations require a risk approach to the design using the available information and generally accepted and proven ecological understanding.

Fifty-six percent (14 species) of the sand plains' bladderwort species have narrow niches. This is a product of these species being recorded from few of the vegetation communities, often compounded by there being few records of each species. In these cases there are too few records to allow for selection of particular areas or parts of vegetation communities that can be guaranteed to provide for protection of large populations of the species, or even guaranteed protection of known numbers of different populations. These requirements can only be met by using inferences made from the habitat preferences of the various species, and the distribution and abundance of those habitats across the sand plains.

Knowledge and understanding of the surface hydrology and its interaction with ground water is negligible. This knowledge is critical to being able to provide protected area boundaries that ensure maintenance of the spatial and temporal distribution of surface water flows. Under these circumstances any boundary will inevitably have to be a risk averse 'best bet'.

Knowledge of the biology and fragmentation of species is negligible other than for the Darwin palm. An appropriate protected area design will necessarily have to involve recourse to accepted and proven ecological understanding.

4.2 Required outcomes of a protected area on the Howard sand plains

The key outcomes of a risk averse protected area design are to:

- preserve the apparent north-south and east-west variation in the occurrence of habitat for bladderwort species, and in consequence preservation of most if not all of the species

- preserve the range of micro-habitats that are the basis of habitat specialisation among the bladderwort species and the broad distribution of species rich bladderwort communities across the majority of vegetation types

- preserve the known populations of *U. dunstaniae*, and if possible habitat that may contain additional populations
- preserve at least the vast majority of the few known populations of *T. taylori,* and habitat that may contain additional populations
- preserve the two populations of Darwin palms
- preserve the majority of known Howard toadlet locations in the sand plains
- preserve areas of habitats that greatly improve the probability of protecting viable populations of the numerous narrow niched species
- preserve habitats that provide or are likely to provide for life history stages of the threatened biodiversity
- preserve the metapopulation dynamics of the threatened species
- protect hydrological conditions across the wetland system
- provide a design that facilitates future management of threats and the protected area.

4.3 Risk averse protection of wetland biodiversity

The approach to development of the lowest risk option for a protected area is based on recognition that the Howard sand plains is a wetland system, and that the sand sheet heaths are wetlands often bordered by other wetland types. There are a number of definitions of wetland. The simplest is that provided by the Macquarie Dictionary (Yallop 2005 (ed.)): 'an area in which the soil is frequently or permanently saturated with or under water'. There are many other definitions, such as that provided in Article 1 of the Ramsar Convention on wetlands (UNESCO 1994). The Macquarie Dictionary definition is sufficiently encompassing to accommodate the higher level of detail included in this and other definitions.

Design of wetland preservation areas can be based on:

(a) identification of habitat areas of primary significance (core habitat) that are sufficient to sustain the wetland areas that are to be preserved

(b) designation of surrounding areas (buffers) to provide a risk averse approach to protecting the species and populations by ensuring their adequate inclusion in the protected area, inclusion of habitat for all life history stages and population and community processes of the species of concern, and protection of the area and its species and communities from external threats

(e.g. Water and Rivers Commission 2000; Semlitsch and Bodie 2003; DERM 2011).

All such guidelines require detailed evaluation of the wetland to be preserved (e.g. DERM 2011). This can only be undertaken with certainty if there is substantial knowledge and understanding the systems to be preserved, and the threats to the systems. The fundamental requirement is that each situation be examined according to its characteristics, conservation needs and current understanding; with guidelines tailored to suit the individual circumstance (DERM 2011).

Preservation of the metapopulation dynamics of species is a key consideration in the design of wetland protected areas. The ecology of metapopulation dynamics is well understood and potentially applies to any organism. All populations have a finite probability of going extinct. The probability of extinction is influenced by population size (the smaller the population the higher the probability of extinction), and the rate at which the population is colonised by individuals from adjacent populations (the higher the rate of colonisation, the lower the probability of extinction). Some species populations may naturally occur as multiple entities whose survival depends on colonisation (i.e. dispersal among populations). Other species' populations may become fragmented by development activities, with the survival of the fragments then depending on dispersal among populations. Fragmentation can also cause disruption of gene flow (genes in dispersing animals, seeds in dispersed fruit, or pollen) between subpopulations and have significant impacts on genetic diversity. The threatened biodiversity of the sand plains exists with many species having naturally small, widely dispersed subpopulations (e.g. many of the bladderwort species, *T. taylori*), and most are vulnerable to fragmentation from mining and infrastructure.

Size of a protected area has a direct bearing on the vulnerability of an area to outside threats, and the capacity to manage the area. A small, fractured area has a larger perimeter to area ratio than a larger area. This increases the level of exposure of small protected areas to outside impacts (e.g. hydrological impacts caused by mining, unpredictable pollution events), exacerbates the future difficulty of managing the preserved area/s (e.g. fire management), and increases the cost of fencing a number of small areas relative to fencing a single area of equivalent total area.

4.3.1 Core habitats for the sand plains threatened biodiversity

Core habitat is easily defined in many wetland systems as being the high water mark, the edge of a swamp, or a river bank with its riparian vegetation. Using this definition of core habitat would require the entire area of seasonally inundated and saturated wetlands of the Howard sand plain to be defined as core habitat (i.e. the entire area mapped by Liddle *et al*. (2013)).

Liddle and Fisher (2014) chose to define core habitats, focusing on habitats containing larger numbers of records of the threatened community and species. This entailed defining one or more wetlands types as core habitats from among other contiguous wetland types in a single wetland system. There are no available guidelines that address this approach. They used the vegetation mapping and quadrat data of Liddle *et al*. (2013) to identify habitat types that could be viewed as core habitats. The determinations were made for bladderwort communities and for each of the threatened species as follows.

Determination of core habitats for species rich bladderwort communities, and *U. dunstaniae* were conducted together. Priorities were based on the presence of *U. dunstaniae*, levels of maximum species richness of bladderworts in quadrats, and levels of average bladderwort species richness for vegetation types. The core habitats for bladderworts were vegetation communities 4a, 4b, 4c and 4d. These communities maintain many of the richest areas of bladderwort species, and the recorded presence of *U. dunstaniae.* All core habitats are sand sheet heaths.

Core habitats of *T. taylori* were determined as the vegetation type with the greatest abundance of *T. taylori* in the three largest populations, the vegetation type with the second greatest abundance of *T. taylori* in the three largest populations, and vegetation types with other occurrences. The core habitats were the vegetation community groups 3a and 3b. Both core habitats are sand sheet heaths.

Core habitats determined for the Darwin palm were the only two areas of the vegetation type where the species occurs, i.e. spring-fed monsoon forest, vegetation type 16.

Core habitats determined for the Howard toadlet were the primary natural vegetation type occupied by the species: vegetation community group 3a and 3b. Both core habitats are sand sheet heaths.

DLRM (2014c) subsequently made minor refinements to the mapping of the core communities, and applied a slightly modified process for selecting habitats type. The results are essentially the same (DLRM 2015). The core habitats remained communities 3a, 3b, 4a, 4b, 4c, 4d, and 16.

This report (section 2.1.1) sought to identify primary bladderwort habitats (vegetation communities) using niche overlap analysis to determine whether the assemblages of bladderwort species in plant communities were random or not. The patterns of distribution of species niches across vegetation types were not random; being highly clumped in 10 particular communities. These were 3a, 3b, 4a, 4b, 4c, 4d, 6, 9, 10 and 13. All these communities had records of 11 or more species of bladderwort and are here regarded as being the primary habitats of bladderwort species in the sand plains.

The species richness of small plots was examined separately and while one community had an unusually high species richness (4b), the number of sampling plots are low, and maximum species numbers recorded in each vegetation community did not bear a clear association with the number of bladderwort species in those communities. The average maximum number of species in plots from the primary habitats was found to greatly exceed that of the average from the low species richness plots. Given the restricted number of plots, it is appropriate to accept that maximum numbers in plots may be related to number of species in vegetation communities, and all 10 primary vegetation communities may potentially have large species numbers at an international level. The primary habitat of the Darwin palm is vegetation community 16, with communities 3a and 3b providing primary habitat for *T. taylorii* and the Howard toadlet.

The primary (core) habitats used in this report for assessing appropriate designs for protection of the sand plains' threatened biodiversity are 3a, 3b, 4a, 4b, 4c, 4d, 6, 9, 10, 13, and 16.

The distribution of primary habitats across the north-south axis of the sand plains is equally important in assessing the adequacy of design for protection of the biodiversity. Distribution and relative abundance of vegetation types vary across the north-south axis. In consequence the habitat potentially available for narrow niched species also varies across the area, impacting on the adequacy of a design for protection of the biodiversity.

4.3.2 The need for buffer zones

The conservation deficiencies of the core habitats need to be meet by buffer zones that provide some probability of including bladderwort species not enclosed in the primary habitats, an increased number of known *T. taylorii* populations, unknown populations of *U. dunstaniae*, other bladderwort species, *T. taylorii*, and a higher proportion of known locations of the Howard toadlet.

An additional need is to link as many of the core habitats as practical into a very few, larger manageable units that provide for metapopulation dynamics. Buffers need to provide a risk averse approach to mitigating the lack of knowledge of population sizes, distributions and life cycle requirements, as well as protection from outside threats. Buffer zones are necessarily multipurpose.

4.4 Buffer zone design

The design of a buffer zone guaranteed to overcome the inadequacies described in section 4.3.2 would require detailed biological and hydrological knowledge of the Howard sand plains, and the impacts of mining and urbanisation.

The review of the threats of mining to the sand plain biodiversity provides clear understanding of the way in which the sand plain hydrology is being or is likely to be impacted. It provides no understanding of the width of a buffer zone that would meet the requirement to protect the habitats from hydrological change. The issue is compounded by unknown interactions between the impacts of mining and those of abstraction.

A brief literature review of buffers and inferences that can be made from what is known of the distributions and biology of the threatened biodiversity are used to guide determination of appropriate buffers in the absence of detailed information. This relates particularly to determination of a risk averse width for buffer zones and provision of interconnectedness between populations that would allow for metapopulation dynamics.

There is a large number of buffer zone widths proposed for the protection of wetlands (e.g. Water and Rivers Commission 2000; DERM 2011; DLRM 2014a). These recommendations are highly varied, and often do not provide sound data based justifications for the recommendations. All relate primarily to providing protection from land clearing.

The buffer recommendations in the documents cited relate to a wetland surrounded by terrestrial habitat, often riparian vegetation. The wetland is the core habitat, and is protected by a buffer of terrestrial vegetation often viewed as also protecting core habitat for terrestrial biodiversity (i.e. vegetation types, species) that requires proximity to wetland, as well as protecting the core wetland habitat from external threats. The buffer's primary function is to stop land clearing close to wetlands. In some cases the recommendation includes a buffer to protect the buffer (e.g. DERM 2011).

These recommendations do not necessarily apply to the situation on the Howard sand plains. The Howard sand plains situation is one of a core wetland habitat often surrounded by additional wetland; both of which may have been exposed to land clearing, mining into the water table and the effects of abstraction. Areas outside a proposed buffer would likely continue to be cleared and mined, with the core habitat continuing to be affected by abstraction and possibly increasing hydrological impact from mining. The necessary buffer width required to avoid hydrological impacts on core habitat in the sand plains under these circumstances cannot be predicted. It is not simply a land clearing issue.

The approach taken in evaluating a possibly effective buffer width necessarily focuses on what can be gleaned from the literature. The NT EPA is unaware of any study on buffers appropriate to maintaining species rich communities of bladderworts, species of bladderwort or species of *Typhonium.*

There are data on recommended buffer widths for frogs. There are also data on the nature and importance of the metapopulation dynamics of frogs, and buffer widths that may be important to maintaining frog metapopulation dynamics. It is emphasised that as with the clearing guidelines discussed above, buffer widths proposed specifically for frogs relate to retention of terrestrial vegetation around a wetland; not land clearing and mining in, along with abstraction of water from, wetlands.

The literature on buffers appropriate to frogs, and the metapopulation dynamics of frogs are briefly reviewed to provide a basis for determining an option for a buffer width that might apply to a protected area in the Howard sand plains.

The result is reviewed in terms of what is known and can be inferred from the biology of *U. dunstaniae* and *T. taylori,* the general distributions of bladderwort species and the Howard toadlet, and Northern Territory recommendations on buffers to protect rainforests from the effects of land clearing (DLRM 2014b).

Frogs, metapopulations and buffers

Buffers around wetlands to protect frogs have been developed for two purposes, and have used data from a variety of different species. The purposes are to provide advice on buffers of terrestrial habitat around wetlands sufficient to provide for the every-day activities and life histories of frogs, and/or buffers that are sufficient to allow for juvenile dispersal and associated metapopulation dynamics.

Observations of frog movement during every-day activities provide a recommended buffer of 159 to 290 m (Semlitsch and Bodie 2003). A similar recommendation (100 to 400 m) was derived for seven frog species in the one region using frog species presence and absence data in wetlands (Ficetola *et al.* 2009). The wide range within the recommendations emphasises the significance of variation among frog species.

There are numerous studies documenting the nature and impacts (e.g. genetic) of disruption of dispersal on frogs (e.g. Vos *et al*. 2001; Ficetola *et al*. 2009; Heard and McCarthy 2012; Yu Wang *et al*. 2012). These studies generally demonstrate various human developments (e.g. roads, urban development, railways) that disrupt dispersal, often leading to genetic differentiation among populations in different wetlands. Ficetola *et al*. (2012) differed in that they used their results to encourage consideration of the landscape aspects of metapopulations in determining the scale at which connectedness (capacity of frogs to disperse) among populations is managed. As well as recognising that roads etc. caused significant blocks to dispersal, they recommended that a spatial scale of 300 to 1500 m be used in determining buffers.

Investigations into the metapopulation dynamics of the Australian endangered growling grass frog (*Litoria raniformis*) are used as an example where there has been detailed assessment of the metapopulation dynamics, along with provision of recommendations for appropriate buffer widths (Heard *et al*. 2012, Heard and McCarthy 2012; Heard *et al*. 2013). The growling grass frog is threatened by urbanisation on the fringes of Melbourne. Disruption of dispersal among the fragmented populations is considered to be a significant contributor to population extinction. Populations were recorded as going extinct and estimates made of the rates of dispersal. The probabilities of extinction and colonisation were modelled in relation to landscape features. Heard and McCarthy (2012) were able to determine that narrow buffers of riparian habitat (100 m or less both sides of the river) were associated with a relatively high probability of extinction over a 30 year period (53%). Increasing the buffer to 200 to 300 m both sides of the river reduced the probability of extinction over 30 years to 27%. The probability of extinction over a 30 year period was reduced further to 9% when a 400 to 750 m buffer was used each side of the river. They recommended the use of buffers greater than or equal to 400 m on both sides of a river.

The situations of the growling grass frog and the Howard toadlet are not directly comparable. The growling grass frog (80 mm) is larger than the Howard toadlet (<23 mm). The growling grass frog is likely to be able to move more quickly than the Howard toadlet, and travel longer distances during any given period of time. This does not necessarily imply that dispersal between fractured populations of the Howard toadlet would be any less significant than it is between fractured populations of the growling grass frog, and may in fact be the reverse, i.e. the effects of fracturing populations may become apparent with less habitat disturbance. It may be that the Howard toadlet populations are more vulnerable to fracturing than are those of the growling grass frog. The size difference may be significant in determining the size of buffers for every-day activities; but an every-day use function is dependent on the locations of habitats in which the Howard toadlet is able to pass the Dry season. This is unknown but likely to be eucalyptus woodlands which occur at variable distances from the identified core habitats.

The two situations also differ in that the growling grass frog is known to exhibit patchily distributed populations whose survival is directly associated with the connectedness of the populations. Too little is known of the distribution of the Howard toadlet to make a determination on the potential importance of metapopulation processes under natural circumstances, or the likelihood of mining, water abstraction and urban development having caused fragmentation. Continued mining of extractives, increased abstraction and urban development have the potential to cause fragmentation, or enhance any existing fragmentation of the species' populations.

An equally significant difference between the two situations is the differing roles of buffers in species preservation. The buffers for the growling grass frog are designed to ensure preservation of habitat suitable for dispersal; and this is related largely to avoiding infrastructure development and preventing land clearing. The role of buffers in the Howard sand plains is more complex, involving preservation of vegetation, and maintenance of appropriate hydrology in wetlands when adjacent wetlands are subject to impacts from abstraction of water, diversion of ground and surface water flows, mining and the development of mining and urban infrastructure, e.g. roads.

Buffers and the threatened biodiversity

The design of appropriate buffers for the sand plains is simplified by the core habitat of the Howard toadlet often coinciding with that of the threatened plant community and the threatened species other than the Darwin palm.

An appropriate design for the Howard toadlet may provide a similarly appropriate solution for bladderwort species and *T. taylori.* The effectiveness of a buffer for the toadlet in insuring the future security of the threated plant biodiversity is dependent on the core habitats and buffer providing a solution to any inadequacies of the core habitat in achieving the key outcomes of a risk averse protected area design specified in section 4.2.

The first seven concerns are partially accommodated by preservation of the core habitats for the plants and the toadlet. The adequacy of buffers designed on the basis of requirements for frogs and the biology of the Howard toadlet would depend on the capacity of the buffers to provide protection for threatened community and plant populations and species that may not be appropriately protected in the core habitat. The adequacy of such protection may be preliminarily determined using distributional data and previous studies. Any inadequacy of the distributional, population and life history information would necessitate a precautionary approach to determining an appropriate buffer on this basis.

The few known populations of *U. dunstaniae* and *T. taylori* are widely dispersed. Mining and other infrastructure has the potential to exacerbate the level of fracturing of the populations. The major issue associated with the existing population distributions and the effects of development on plants are those associated with maintaining gene transfer between populations via pollination and fruit dispersal.

U. dunstaniae has a specialised flower. This is likely to be related to the need to provide for pollination among widely dispersed populations of few individuals. The pollinator is unknown. The pollinator would likely need to be an insect capable of flying over considerable distances. Provision of buffers linking the widely dispersed populations may be essential to ensuring pollination of this annual plant. Nothing is known of the dispersal of *U. dunstaniae* seeds.

T. taylori likewise has a specialised pollination system that is likely to allow for long distance pollination. Rove and dung beetles are among the likely pollinators. These night-flying, unwitting pollinators are noted to be strong fliers able to cover long distances and rapidly locate new carrion or dung deposits (e.g. Bornenissza 1957; Roolin 2006). The relatively small size of the plant and its flowers indicate that the pollinator is likely to be relatively small (e.g. some rove beetles down to 1 mm or less long, and some dung beetles down to 2 mm long). Retention of buffers linking populations may be critical in maintaining gene flow in the long term. The fruit is unknown although it may be a small berry dispersed by some animal agent.

The core habitats of the Darwin palm are located immediately adjacent to core habitats of the other threatened biodiversity. The Darwin palm exhibits remarkably little genetic variation within and among populations (Shapcott 1998). Pollination is by generalised pollinators (Essig 1973). Given the wide separation between populations, pollination is likely to be localised and unlikely to benefit from provision of corridors linking populations.

Fruit dispersal is likewise generalised to cater for a number of bird species. Detailed studies have found that the frugivores can be sustained by retaining sufficient native vegetation within a 10 km radius of a rainforest to provide the birds with food during the Dry season (Bach and Price 1999; DLRM 2014(b)).

The core habitats of the Darwin palm would be included as core habitat in any design. The buffer provided for frogs should be extended to protect the monsoon rainforest; possibly using the DLRM (2014b) advice for rainforest buffers in upland areas. The DLRM advice is seemingly designed to avoid disruption of the supply of water to rainforest. The basis of this recommendation is not readily available.

4.5 Evaluation of options for a protected area in the Howard sand plains

4.5.1 Option 1 – The seasonally inundated and saturated area of the Howard sand plains north of Girraween Road plus a portion of the area between Girraween Road and the Arnhem Highway

This option (Figure 12) would necessarily include an additional 500 m buffer around the non-sand plains portion of the north eastern spring fed monsoon rainforest to protect its water supply.

Option 1 would provide:

- protection of the majority of the sand plains and primary bladderwort habitats across sufficient of the north-south habitat variation to protect all 11 of the broad niched bladderwort species, all 14 of the narrow niched species evaluated, and have potential to protect another species
- protection for all the known populations of *U. dunstaniae*, with additional habitat that may contain additional populations
- protection for six of the 11 populations of *T. taylori,* including the three largest populations, with additional habitat that may contain additional populations
- protection for both populations of the Darwin palm
- extensive areas of habitat for the Howard toadlet
- extensive protection from mining of the range of sand plains micro-habitats that are the basis of habitat specialisation of the bladderwort species and *T. taylori*
- extensive areas of habitats that provide or are likely to provide for life history stages of the threatened biodiversity
- protection for the metapopulation dynamics of the threatened species over the majority of the sand plains, and minimisation of future deterioration
- protection, to the greatest extent possible, of the hydrological conditions across the wetland system, as well as providing the best opportunity for remediation of hydrological conditions
- the Howard sand plains with a protected area design that facilitates future management of external threats and the protected area

- a possible future recreation site in an area of mine-disturbed sand plains just north of Gunn Point Road.

It would also provide the potential for some level of protection for possibly 10 species of near threatened plant, 13 species of plant with too few data to be able to determine their conservation status, and two species of threatened animal.

Exclusion of much of the area between Girraween Road and the Arnhem Highway and the sand plains south of the Arnhem Highway would exclude significant areas of vegetation communities 4a and 4c. These would have provided potential protection for four narrow niched bladderworts, including *U. dunstaniae.* It also fails to include relatively large areas of potential habitat (2a) for *U. linnearis,* another narrow niched species.

This lowest risk option would require cessation of sand mining throughout the protected area, and reduction in the abstraction of water as alternative supplies become available. These requirements would impose significant economic costs, and would require time. If implemented, the transition in land use should begin immediately. In the west the boundary of the managed protected area would be defined by the edge of the rural living and other development areas.

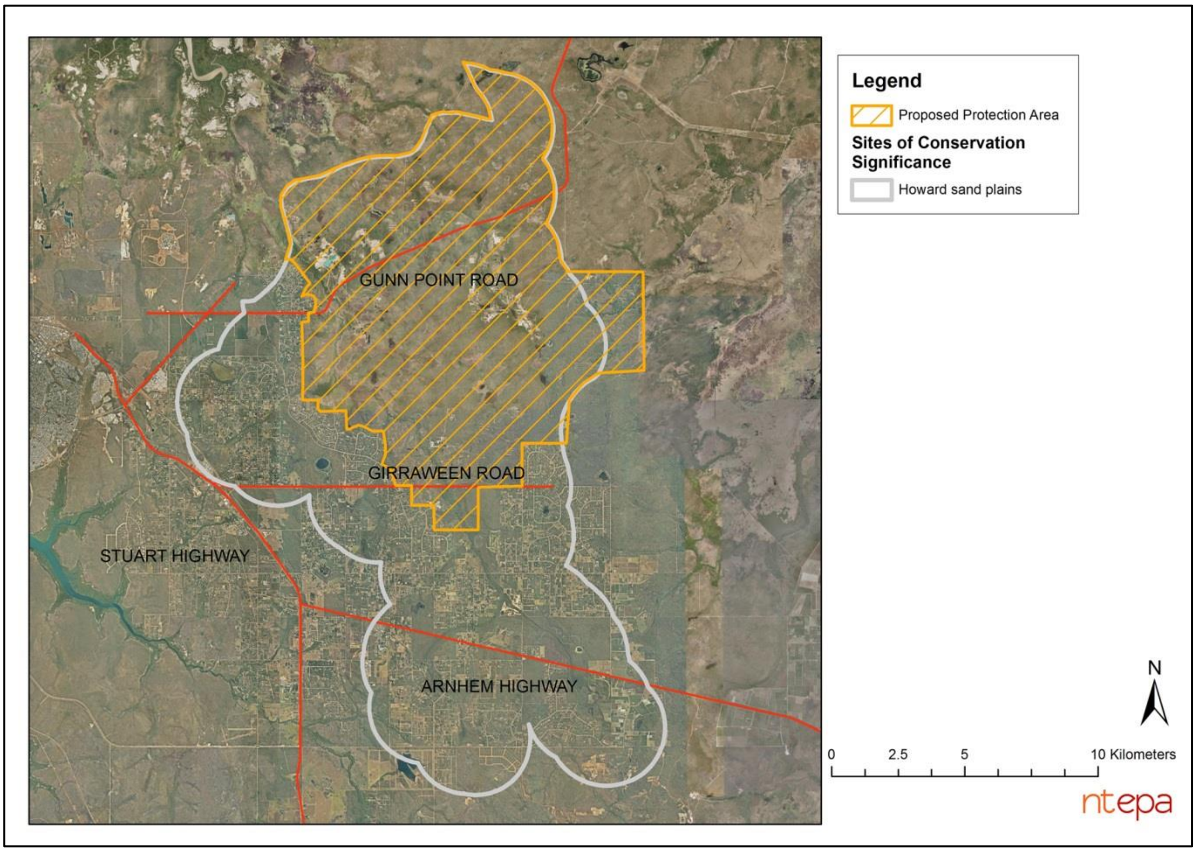

Figure 12: Option 1 – Protection of the entire, seasonally inundated and saturated area of the Howard sand plains north of Girraween Road plus a portion of the area between Girraween Road and the Arnhem Highway.

4.5.2 Option 2 – Protection of the upper Howard River catchment

This option provides for a clearly defined, manageable, single protected area in the western side of the sand plains south of the Gunn Point Road. The option is based on preservation of extensive areas of all 10 vegetation communities that contain a high species richness of bladderworts, as well as those of *U. dunstaniae, T. taylori,* the Darwin palm and the Howard toadlet. It would protect the course of the Howard River in the area and much of its immediate catchment. A separate, smaller protected area would be required in the north east to cater for the second population of the Darwin palm, associated sand plain areas and a portion of the catchment area (Figure 13). It is not possible in this option to provide an appropriate linkage between this area and the protected area in the west. The drainage system in the east drains north of Gunn Point Road. Option 2 would not include extensive areas of vegetation communities 3a, 3b and 6 located in the eastern portion of the sand plains. These communities have records of five narrow niched bladderwort species and *T. taylori* (but no known record of *T. taylori* from this eastern portion of the sand plains).

The draft boundaries proposed in Figure 13, especially the eastern boundary of the western area and the boundary around the eastern area, are largely arbitrary and will need to be refined on a risk averse basis according to available hydrological information. Once defined by the addition of hydrological understanding, that area would be the area to be subject to a reservation from mining. Finalising the boundaries of the protected area will require a review of the patterns of land tenure in the area.

Option 2 would provide:

- protection of extensive areas of primary habitat for bladderwort species across sufficient of the north-south habitat variation to protect all 11 of the broad niched bladderwort species, all 14 of the narrow niched species evaluated, and have potential to protect another species
- protection of all the known populations of *U. dunstaniae*, with additional habitat that may contain additional populations
- protection for six of the 11 populations of *T. taylori,* including the three largest populations, with additional habitat that may contain additional populations
- protection of both populations of the Darwin palm
- extensive areas of habitat for the Howard toadlet
- extensive protection from mining of the range of sand plains micro-habitats that are the basis of habitat specialisation of the bladderwort species and *T. taylori*
- extensive areas of habitats that provide or are likely to provide for life history stages of the threatened biodiversity
- protection for the metapopulation dynamics of the threatened species over a significant portion of the western portion of the sand plains, and minimisation of future deterioration in that areas (less effective than Option 1 for the whole sand plains)
- protection, to lesser extent than Option 1, of the hydrological conditions of the wetland system, as well as providing the opportunity for remediation of hydrological conditions

- the Howard sand plains with a protected area design that facilitates future management of external threats and the protected area.

It would also provide the potential for some level of protection, less than Option 1, for possibly 10 species of near threatened plant, 13 species of plant with too few data to be able to determine their conservation status, and two species of threatened animal.

As with Option 1, exclusion from this option of much of the area between Girraween Road and the Arnhem Highway and the sand plains south of the Arnhem Highway would exclude significant areas of vegetation communities 4a and 4c, as for Option 1. These would have provided protection for four narrow niched bladderworts, including *U. dunstaniae.* It also excludes relatively large areas of potential habitat (2a) for *U. linnearis,* another narrow niched species. Relatively large areas of vegetation community 2a are also excluded by removal of areas north of Gunn Point Road from protection.

This option would not include extensive areas of vegetation communities 3a, 3b and 6 located in the eastern portion of the sand plains. These community types have records of five narrow niched bladderwort species and *T. taylori* (but no known record of *T. taylori* from this eastern portion of the sand plains).

This second lowest risk option would require cessation of sand mining throughout the protected area, and reduction in the abstraction of water as alternative supplies become available. These requirements would impose significant economic costs, although less than for Option 1, and would require time. If implemented, the transition in land use should begin immediately. In the west the managed protected area would be defined by the edge of the rural living and other development areas.

The major failings of Option 2 are the lack of linkage between the eastern and western areas of interest, and its having less capacity than Option 1 to protect the area’s hydrology and biodiversity other than the Darwin palm.

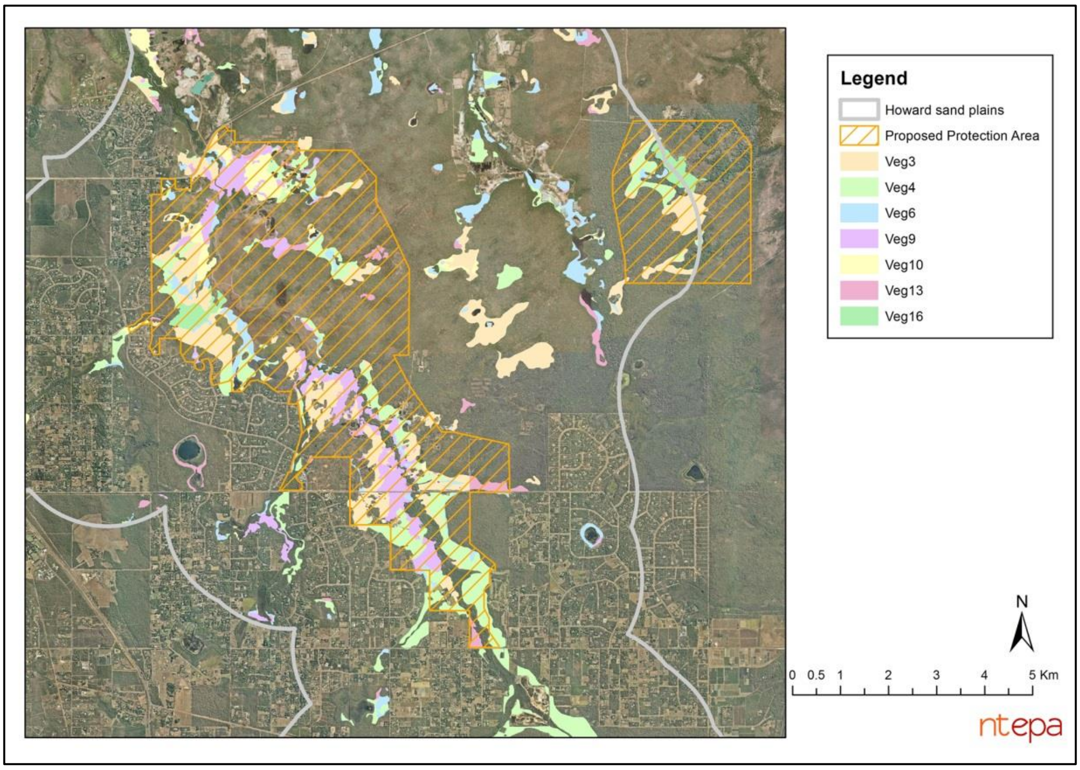

Figure 13: Option 2 – Protection of the upper Howard River catchment (core habitats NTG, Liddle and Fisher 2014)

4.5.3 Option 3 – Core habitats, 500 m buffers and linkage areas

Option 3 is based on the Liddle and Fisher's (2014) core habitats and 500 m buffers, as modified by adding an additional 500 m buffer around the entirety of the north eastern monsoon rainforest boundary, and providing for linkage areas between three of the four areas of core habitat and buffers (Figure 14). The core habitats used exclude vegetation communities 6, 9, 10 and 13. Each of these species rich communities has a bladderwort species richness similar to the Liddle and Fisher's (2014) core habitats. A protected area based on these core habitats may jeopardise some narrow niched bladderwort species. The linkage areas are in keeping with the recommendations of Heard and McCarthy (2012b) concerning frogs.

The linkage areas proposed are designed to link the three areas of core habitat and buffers in the west of the sand plains. The more northerly linkage is designed around the course of the Howard River, and contains areas of wetlands 3a, 6, 9, 10, 11 and 12. These wetland types are known to contain at least 11, 11, 10, 14, four and 10 species of bladderwort respectively (Liddle *et al*. 2013, all species records). The more southerly linkage also follows the course of the Howard River and contains areas of wetlands 2a, 3a, 3b, 4d, 8, 9, and 12. These wetland types maintain three, 11, 16, 12, four, and 10 species of bladderwort respectively (Liddle *et al*. 2013, all records). (Please note that subsequent minor adjustment to the mapping of vegetation community (DLRM 2014c) resulted in a reduction in the number of species from 10 to 6; this does not affect these statements.) Liddle *et al*.'s (2013) survey data recorded wetland type 6 as having three species recorded only once or twice in the survey (this in now one species, Flora Atlas), wetland type 9 having two such species, and wetland types 4d and 12 having one such species (Liddle *et al*. 2013) (there are now no such species known in these communities, Flora Atlas). The linkages provide a boost to the potential for protection of viable populations of bladderwort species as well as fostering metapopulation dynamics.

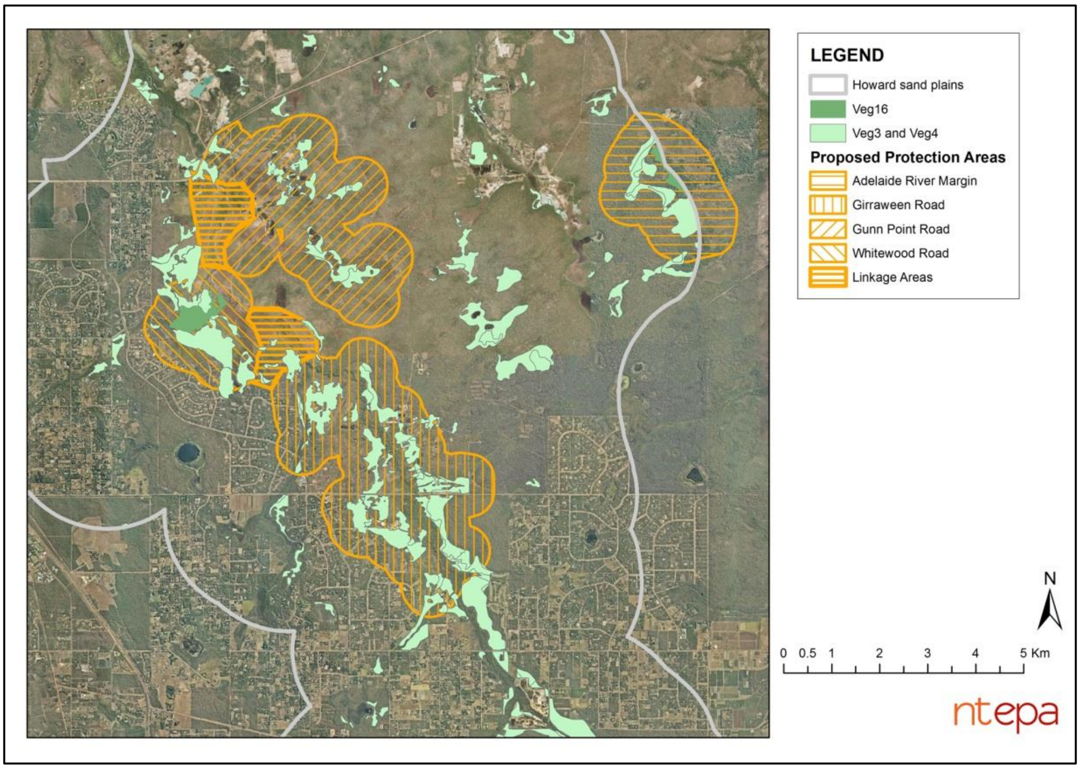

Figure 14: Option 3 – Core habitats, 500 m buffers and linkage areas (core habitats and 500 m buffers NTG, Liddle and Fisher (2014))

Inclusion of the two linkages would likely add to the number of bladderwort species protected, and overall preserved populations of bladderwort species. The more southerly linkage includes a known location of *T. taylori.* Choice of largely wetland areas for linkages of areas of wetland fauna and flora would provide appropriate habitat for dispersal and likely pollinators. This seems more appropriate than using linkages composed of more elevated eucalyptus woodland.

Option 3 would provide:

- protection of less extensive areas of primary habitat for bladderwort species than Option 2, less north-south habitat variation, less protection for all 11 of the broad niched bladderwort species, less protection for potentially all 14 of the narrow niched species evaluated, and have less potential to protect another species
- protection of all the known populations of *U. dunstaniae*, with potentially less additional habitat that may contain additional populations than Option 2

- protection of five of the 11 populations of *T. taylori,* including the three largest populations, with additional habitat that may contain additional populations
- protection of both populations of the Darwin palm
- extensive areas of habitat for the Howard toadlet
- less than Option 2's protection from mining of the range of sand plains micro-habitats that are the basis of habitat specialisation of the bladderwort species and *T. taylori*
- less than Option 2's areas of habitats that provide or are likely to provide for life history stages of the threatened biodiversity
- protection for the metapopulation dynamics of the threatened species over a significant portion of the western portion of the sand plains, and minimisation of future deterioration in that areas (possibly less effective than Option 2)
- protection, to lesser extent than Option 2, of the hydrological conditions of the wetland system, as well as providing the opportunity for remediation of hydrological conditions
- the Howard sand plains with a protected area design that does not facilitate future management of external threats and the protected area.

It would also provide the potential for some level of protection, less than Option 2, for possibly 10 species of near threatened plant, 13 species of plant with too few data to be able to determine their conservation status, and two species of threatened animal.

Exclusion of areas as proposed in Options1 and 2, plus those excluded in 3 would remove a larger amount of primary bladderwort habitat. Exclusion of much of the area between Girraween Road and the Arnhem Highway and the sand plains south of the Arnhem Highway would exclude significant areas of vegetation communities 4a and 4c, as for Options 1 and 2. These would have provided protection for four narrow niched bladderworts, including *U. dunstaniae.* It also excludes relatively large areas of potential habitat (2a) for *U. linnearis,* another narrow niched species. Relatively large areas of vegetation community 2a are also excluded by removal of areas north of Gunn Point Road from protection.

As with Options 2, Option 3 would not include extensive areas of vegetation communities 3a, 3b and 6 located in the eastern portion of the sand plains. These community types have records of five narrow niched bladderwort species and *T. taylori* (but no known record of *T. taylori* from this eastern portion of the sand plains).

This third lowest risk option would require cessation of sand mining throughout the protected area, and reduction in the abstraction of water as alternative supplies become available. These requirements would impose significant economic costs, less than for Option 1, and possibly 2, and would require time. If implemented, the transition in land use should begin immediately.

The major failings of Option 3 include the reduction in the area of habitat protected which increases the potential vulnerability to narrow niched bladderwort species by protecting only six vegetation communities as core habitats, rather than all ten communities with a high species richness of bladderworts. This option also lowers protection from hydrological and other impacts from mining, and provides for less effective maintenance of metapopulation dynamics than do Options 1 and 2.

4.5.4 Option 4 – Core habitats, 500 m buffers

A design for a protected area based on core habitats and 500 m buffers (Liddle and Fisher 2014) is provided in Figure 15.

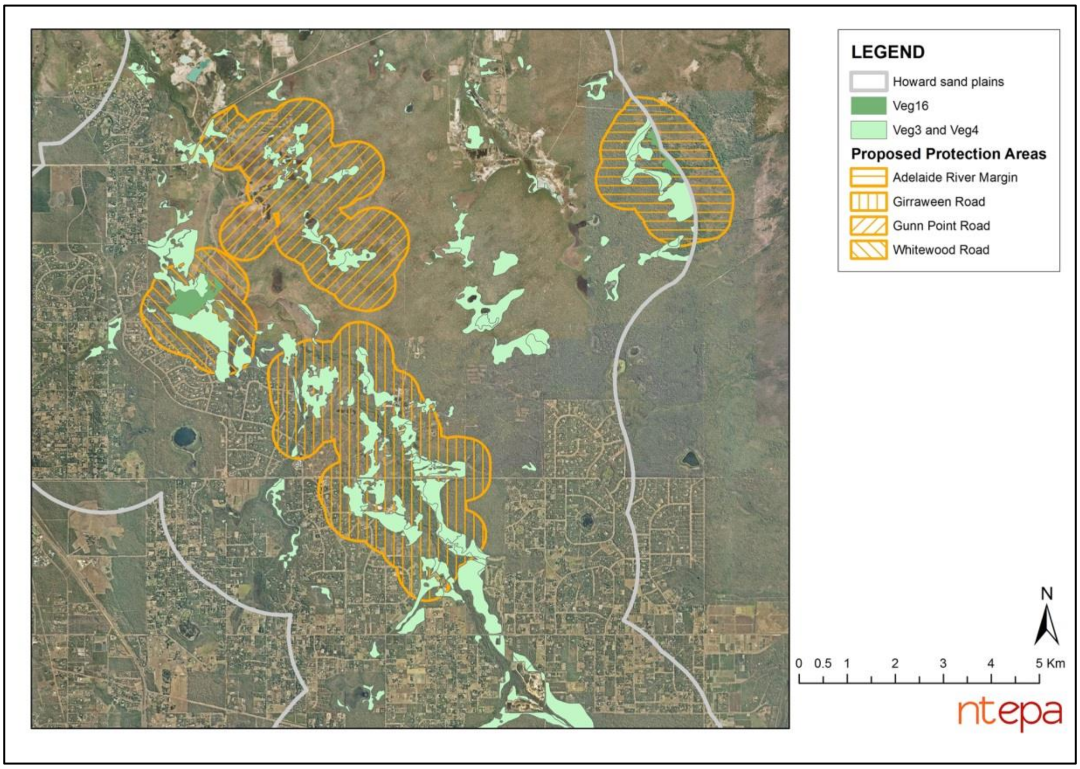

Figure 15: Option 4 – Core habitats and a 500 m buffer (NTG, Liddle and Fisher 2013)

Option 4 is the same as Option 3 minus the linkages. Loss of these areas would limit potential for maintenance of metapopulation dynamics and potentially reduce the number of protected populations, particularly narrowed niched bladderwort species.

Option 4 would provide:

- protection of less extensive areas of primary habitat for bladderwort species than Option 3, and although protecting less north-south habitat variation, it would likely provide less protection for all 11 of the broad niched bladderwort species, and lesser protection for possibly all 14 of the narrow niched species evaluated, and have less potential to protect another species
- protection all the known populations of *U. dunstaniae*, with less potential additional habitat that may contain additional populations than Option 3

- protection of five of the 11 populations of *T. taylori,* including the three largest populations, with less potential than Option 3 for additional habitat that may contain additional populations
- protection of both populations of the Darwin palm
- protection of extensive areas of habitat for the Howard toadlet
- less than Option 3’s protection from mining of the range of sand plains micro-habitats that are the basis of habitat specialisation of the bladderwort species and *T. taylori*
- less than Option 3’s areas of habitats that provide or are likely to provide for life history stages of the threatened biodiversity
- little protection for the metapopulation dynamics of the threatened species over a significant portion of the western portion of the sand plains, and less potential for minimisation of future deterioration in that areas (less effective than Option 3)
- protection, to lesser extent than Option 3, of the hydrological conditions of the wetland system, as well as providing less opportunity for remediation of hydrological conditions
- the Howard sand plains with a protected area design that does not facilitate future management of external threats and the protected area.

It would also provide the potential for some level of protection, less than Option 3, for possibly 10 species of near threatened plant, 13 species of plant with too few data to be able to determine their conservation status, and two species of threatened animal.

Exclusion of areas proposed in Options 1, 2, 3 and 4 would cumulatively remove a large amount of primary bladderwort habitat. Exclusion of the area between Girraween Road and the Arnhem Highway and the sand plains south of the Arnhem Highway would exclude significant areas of vegetation communities 4a and 4c, as for Options 1, 2 and 3. These would have provided protection for four narrow niched bladderworts, including *U. dunstaniae.* As with Options *2* and 3, Option 4 excludes relatively large areas of potential habitat (2a) for *U. linnearis,* another narrow niched species. Relatively large areas of vegetation community 2a are also excluded by removal of areas north of Gunn Point Road from protection.

As with Options 2 and 3, Option 4 would not include extensive areas of vegetation communities 3a, 3b and 6 located in the eastern portion of the sand plains. These communities have records of five narrow niched bladderwort species and *T. taylori* (but no known record of *T. taylori* from this eastern portion of the sand plains.

This second lowest risk option would require cessation of sand mining throughout the protected area, and reduction in the abstraction of water as alternative supplies become available. These requirements would impose significant economic costs, less than for Options 1, 2 and 3, and would require time. If implemented, the transition in land use should begin immediately.

The major failings of Option 4 are the reduction in the area of habitat protected, reliance on core habitat based on only six of the 10 vegetation communities with high species richness of bladderworts, a lowering of protection from hydrological and other impacts from mining, and a less effective maintenance of metapopulation dynamics than Options 1, 2 or 3.

4.5.5 Option 5 – Core habitats, 250 m buffers

The 250 m buffer option design is provided in Figure 16. This Option is essentially the same as Option 4 with a 250 m buffer around core habitats rather than a 500 m buffer (DLRM(c) 2014).

Option 5 would provide:

- protection of less extensive areas of primary habitat for bladderwort species than Option 4, less north-south habitat variation, less protection for all 11 of the broad niched bladderwort species, less protection for all 14 of the narrow niched species evaluated, and have possibly less potential to protect another species
- protection for all the known populations of *U. dunstaniae*, with potential less additional habitat that may contain additional populations than Option 4
- protection for five of the 11 populations of *T. taylori,* including the three largest populations, but less likely to contain additional habitat that may contain additional populations
- protection of both populations of the Darwin palm
- less extensive areas of habitat for the Howard toadlet
- less than Option 4's protection from mining of the range of sand plains micro-habitats that are the basis of habitat specialisation of the bladderwort species and *T. taylori*
- less than Option 4's protection of areas of habitats that provide or are likely to provide for the life history stages of the threatened biodiversity
- vulnerability to loss of metapopulation dynamics of the threatened species over a significant portion of the western portion of the sand plains, or for minimisation of future deterioration in that area (less effective than Option 4)
- protection, to lesser extent than Option 4, of the hydrological conditions of the wetland system, as well as providing less opportunity for remediation of hydrological conditions
- the Howard sand plains with a protected area design that does not facilitate future management of external threats and the protected area.

It would provide potential for some level of protection, less than Option 4, for possibly 10 species of near threatened plant, 13 species of plant with too few data to be able to determine their conservation status, and two species of threatened animal.

Exclusion of areas proposed in Options 1, 2, 3, 4, and 5 would cumulatively remove a large amount of primary bladderwort habitat. Exclusion of the area between Girraween Road and the Arnhem Highway and the sand plains south of the Arnhem Highway would exclude significant areas of vegetation communities

4a and 4c, as for Options 1, 2, 3 and 4. These would have provided protection for four narrow niched bladderworts, including *U.dunstaniae.* As with Options 2, 3 and 4, Option 5 excludes relatively large areas of potential habitat (2a) for *U. linnearis,* another narrow niched species. Relatively large areas of vegetation community 2a are also excluded by removal of areas north of Gunn Point Road from protection.

As with Options 2, 3 and 4, Option 5 would not include extensive areas of vegetation communities 3a, 3b and 6 located in the eastern portion of the sand plains. These communities have records of five narrow niched bladderwort species and *T. taylori* (but no known record of *T. taylori* from this eastern portion of the sand plains).

This least risk averse option would require cessation of sand mining throughout the protected area, and reduction in the abstraction of water as alternative supplies become available. These requirements would impose significant economic costs, less than for Options 1, 2, 3 and 4, and would require time. If implemented, the transition in land use should begin immediately.

The major failing of Option 5 is that it compounds all the failings of Option 4 by using a narrow 250 m buffer that lacks any known biological or hydrological justification. Option 5 does not meet many of the objectives of the protected area.

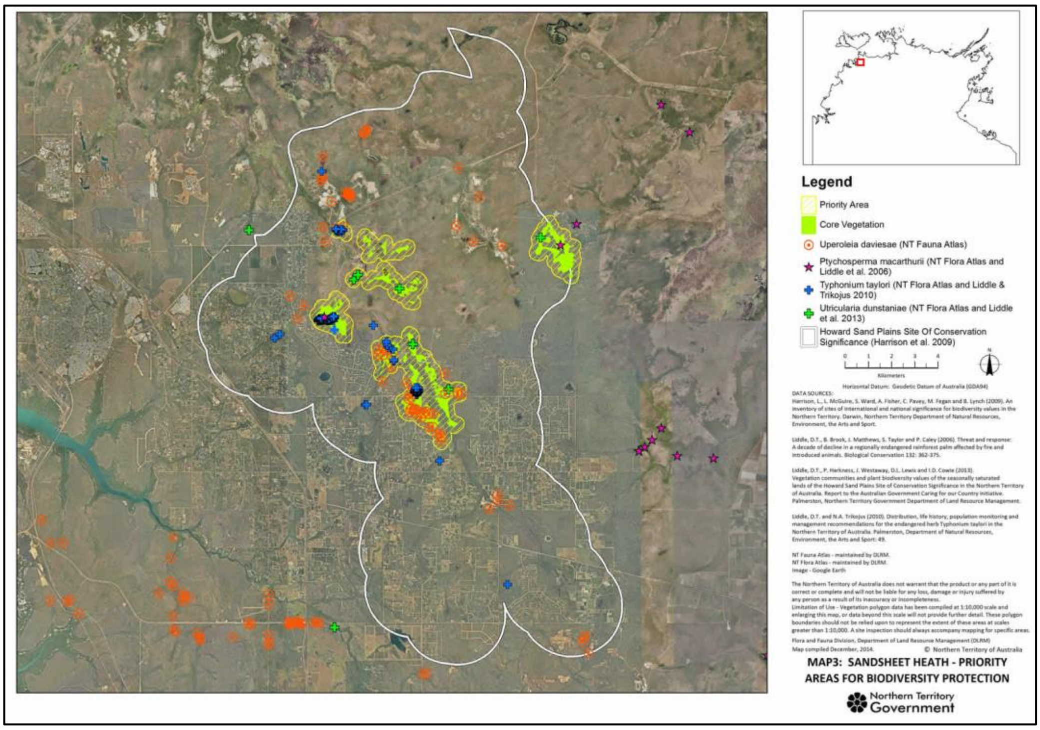

Figure 16: Option 5 – A protected area of core habitat with 250 m buffer zones (NTG, DLRM 2014c)

5 Conclusions

The Howard sand plains maintain a biodiversity that is of international, national and Northern Territory significance. Central to this significance are an internationally significant species rich community of carnivorous bladderworts, the nationally endangered perennial plant, *T. taylori*, the Northern Territory vulnerable annual carnivorous plant, *U. dunstaniae*, the Northern Territory endangered

Darwin palm, *P. macarthurii*, and the Northern Territory vulnerable Howard toadlet, *U. daviesae.* The threatened community and threatened species other than the Darwin palm occur primarily in sand sheet heath vegetation. The biology of the sand plains biodiversity is poorly known. The biodiversity of the Howard sand plains is threatened with extinction.

The threatened community and species are all vulnerable to negative, complex, interacting impacts imposed by urban expansion, abstraction of ground water, and the mining of extractive minerals. Habitat removal and hydrological impacts are of particular significance. The impacts of the threatening processes are incompletely understood, and little is known of the surface and ground water hydrology at a scale that is relevant to the threatened biodiversity. There is no known way of rehabilitating disturbed sand plains habitats to allow the biodiversity to re-establish.

There is too little known of the biodiversity and the hydrology of the area to effectively provide for preservation with a high level of certainty. The best that can be achieved is to use existing knowledge and information from the literature, and proven and accepted ecological understanding to implement an as risk averse as possible protected area design.

The lowest risk option is to protect the seasonally inundated and water logged area of the entire sand plains other than the areas south of the Arnhem Highway and the more southerly portion of the area between Girraween Road and the Arnhem Highway (Option 1). This option provides the best chance of meeting the outcomes required of the proposed protected area (section 4.2). Implementation of the option would necessarily involve significant economic cost in transition of the extractive industry to other areas, and in reducing the abstraction of ground water.

A design based on protecting the more significant part of the upper Howard River catchment (Option 2), including significant areas of the ten vegetation communities with the highest species richness of bladderworts, has the capacity to provide the threatened biodiversity with some level of security. It would have potential risks (higher than Option 1) associated with maintenance of the hydrology and the absence of linkage between the east and west of the sand plains. Option 2 is likely to have a slightly lower probability of achieving the outcomes required of the protected area. The economic cost of transitioning the extractive industry would be significant although less than for Option 1. The economic costs of reducing ground water abstraction would not be altered by adoption of this option.

Approaches (Options 3, 4, and 5) based on definition and protection of core habitats and surrounding buffers with or without linkage areas are found to be risk prone (compared to Options 1 and 2) and would likely fail to provide the objectives required of the protected area.

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Appendix A: Vegetation types mapped by Liddle *et al*. (2014) in the seasonally inundated and saturated areas of the SOC

Map Unit 1: *Lophostemon lactifluus* (red swamp mahogany), +/- *Erythrophleum chlorostachys* (ironwood) mid open forest with a mid open tussock grassland understorey

Map Unit 2a: *Melaleuca viridiflora* (broad-leaved paperbark) mid open woodland with a mid open tussock grassland understorey

Map Unit 2b: *Melaleuca viridiflora* low woodland with *Fimbristylis* mid open sedgeland understorey

Map Unit 3a: *Melaleuca nervosa* +/- *Pandanus spiralis* (screw palm) low open woodland with a *Sorghum intrans*, *Eriachne triseta* mid tussock grassland understorey

Map Unit 3b *Melaleuca nervosa*, *Grevillea pteridifolia* (fern-leaved grevillea) low open woodland with *Dapsilanthus spathaceus* low open sedgeland ground layer

Map Unit 4a: *Verticordia cunninghamii* (Cunningham's featherflower) and *Banksia dentata* mid open heathland with an emergent *Melaleuca nervosa* and *Grevillea pteridifolia* (fern-leaved grevillea) low open woodland and with *Dapsilanthus spathaceus* mid open sedgeland ground layer

Map Unit 4b: *Grevillea pteridifolia* (fern-leaved grevillea) +- *Melaleuca nervosa* low open woodland with or without a mid layer of *Pandanus spiralis* (screw palm) and *Verticordia cunninghamii* (Cunningham's featherflower) low isolated trees or heath shrubs and a *Dapsilanthus spathaceus* mid open sedgeland understorey

Map Unit 4c: *Grevillea pteridifolia* (fern-leaved grevillea) +- *Melaleuca viridiflora* (broad-leaved paperbark) +- *Melaleuca nervosa* low open woodland with a mid layer of *Banksia dentata* +- *Pandanus spiralis* (screw palm) +- *Verticordia cunninghamii* (Cunningham's featherflower) tall sparse heathland and a *Dapsilanthus spathaceus* mid sedgeland understorey

Map Unit 4d: *Grevillea pteridifolia* and/or *Lophostemon lactifluus* mid open woodland with or without a *Banksia dentata* low open woodland mid layer and mid tussock grassland/sedgeland ground layer

Map Unit 5 *Melaleuca dealbata* low open forest with a low sparse sedgeland understorey

Map Unit 6: *Lophostemon lactifluus +/- Melaleuca viridiflora* mid open woodland over a tall tussock grassland

Map Unit 7: *Acacia plectocarpa*, *Acacia latescens* low open woodland with a low open tussock grassland ground storey

Map Unit 8: *Melaleuca viridiflora*, *Acacia latescens*, *Pandanus spiralis* low open woodland with a low open tussock grassland or sedgeland ground storey

Map Unit 9: *Pandanus spiralis* (screw palm) +/- *Melaleuca viridiflora* low open woodland with a mid tussock grassland / sedgeland ground story

Map Unit 10: *Sorghum intrans*, *Alloteropsis semialata*, +-*Eriachne burkittii* tussock grassland with isolated *Acacia latescens* and *Grevillea pteridifolia* (fern-leaved grevillea)

Map Unit 11: *Hakea arborescens* and *Terminalia grandiflora* low open woodland with *Fimbristylis pauciflora* and *Eriachne burkittii* mixed low sedgeland or tussock grassland ground layer

Map Unit 12: *Lophostemon lactifluus* (Red Swamp Mahogany) +/- *Banksia dentata* and *Grevillea pteridifolia* (fern-leaved grevillea) low open woodland over *Dapsilanthus spathaceus* mid sedgeland understory with heath shrubs and tussock grasses

Map Unit 13: Tussock grassland with isolated *Melaleuca nervosa*

Map Unit 14: Aquatic bed with *Nymphoides* and *Eleocharis*

Map Unit 15: *Melaleuca cajuputi* mid open forest with *Pandanus spiralis* (screw palm) low open woodland mid stratum and sedgeland or grassland ground stratum

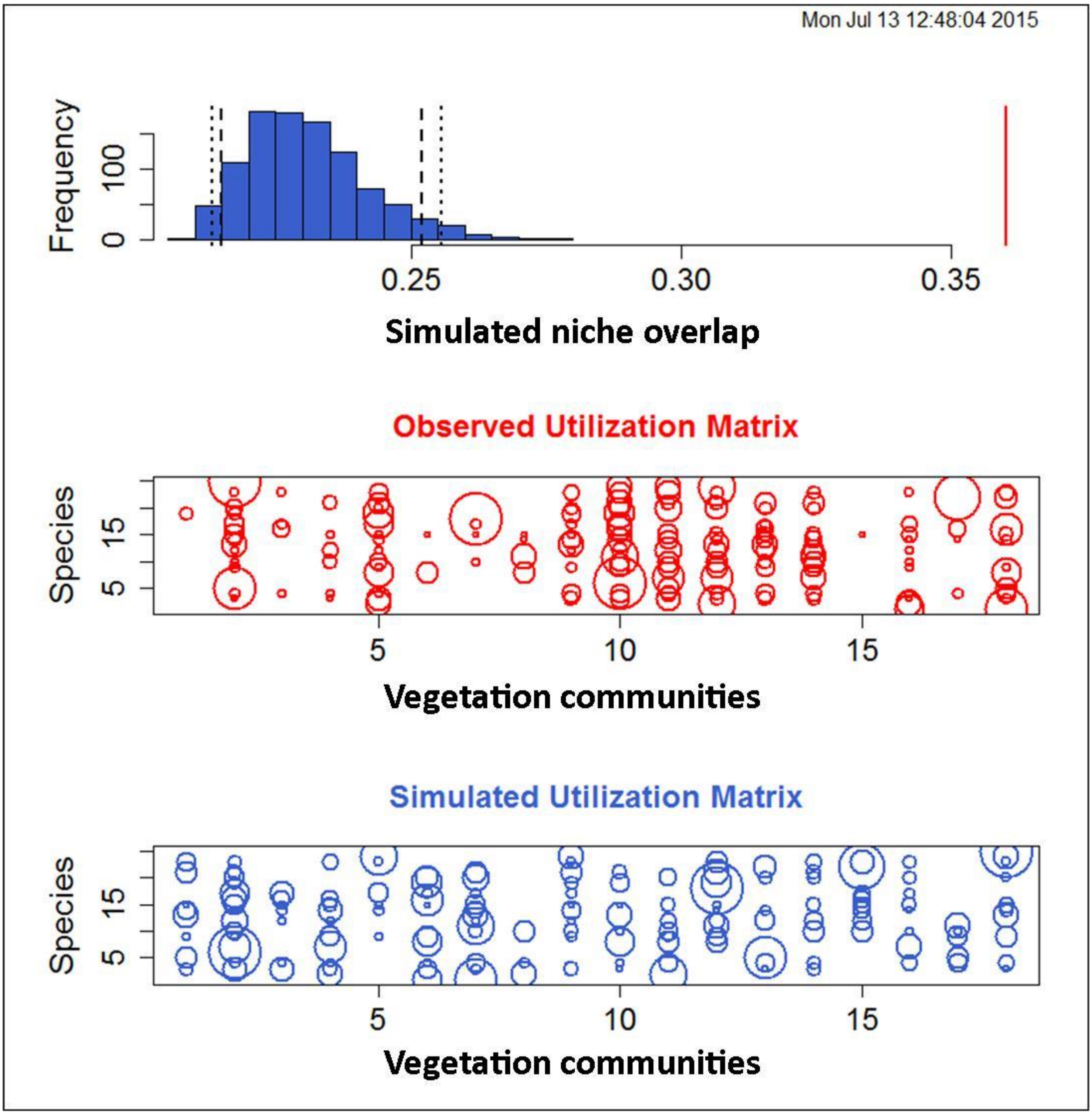
Map Unit 16: *Acacia auriculiformis* and *Carpentaria acuminata* closed forest

APPENDIX B: Species of *Utricularia* occurring on the Howard sand plains

Species	Status	Distribution
U. aurea	Least concern	
U. caerulea	Least concern	
U. capilliflora	Least concern	Endemic
U. chrysantha	Least concern	
U. circumvoluta	Least concern	
U. dunlopii	Least concern	
U. dunstaniae	Vulnerable	
U. gibba	Least concern	
U. hamiltonii	Near threatened	
U. holtzei	Near threatened	Endemic
U. involvens	Least concern	
U. kamienskii	Least concern	Endemic
U. kimberleyensis	Least concern	
U. lasiocaulis	Least concern	
U. leptoplectra .	Least concern	
U. leptorhyncha	Least concern	
U. limosa	Least concern	
U. linearis	Not evaluated	Endemic
U. minutissima	Least concern	
U. odorata .	Least concern	
U. quinquedentata r	Least concern	
U. simmonsii	Data deficient	
U. sP. small white	Least concern	
U. subulata	Near threatened	
U. triflora	Least concern	Endemic

APPENDIX C: Results of the niche overlap analysis

The mean of the distribution of the simulated niche overlaps (22.5) in the top Figure shows a clear difference from that of the mean level of overlap actually observed from the bladderwort records (vertical red line). The bottom two figures compare the observed utilisation matrix with one example of a simulated random utilisation matrix. The numbered vegetation types in the utilisation matrices correspond to (left to right): 1, 10, 11, 12, 13, 14, 2a, 2b, 3a, 3b, 4a, 4b, 4c, 4d, 5, 6, 8, 9).



Random Number Seed: 625

Number of Replications: 1000

Elapsed Time: 4.4 secs

Metric: Pianka

Algorithm: RA3

Observed Index: 0.36025

Mean Of Simulated Index: 0.23078

Variance Of Simulated Index: 0.00012267

Lower 95% (1-tail): 0.21499

Upper 95% (1-tail): 0.25205

Lower 95% (2-tail): 0.21319

Upper 95% (2-tail): 0.25572

P(Obs <= null) < 0.001

P(Obs >= null) > 0.999

P(Obs = null) = 0

Standardized Effect Size (SES): 11.689

Appendix D: Assessment of the threatened status of the sand plains heath of Howard sand plains

Item	Criterion	Critically endangered	Endangered	Vulnerable
1	**The decline in geographic distribution[1,2] is:**	Very severe *Occupancy decline greater than 80% in past 10 years*	Severe *Occupancy decline greater than 50% in past 50 years*	**Substantial** *Occupancy decline > 20%, in past 50 years* **21%[2,3]**
2	**The geographic distribution is:** and the nature of the distribution makes it likely that the action of a threatening process could cause it to be lost in:	Very severe *Very restricted* *Immediate*	**Severe** *Restricted* *Occupancy <100 km^2* **Occupancy[1,2] 59.45 km^2** *Near future (20 years)* **The next 16 years[3,4,5]**	Substantial *Limited* *Medium term*
3	For a population of a native species that is likely to play a major role in the community there is a:	Very severe *Decline > 70% over last 10 years*	Severe *Decline 40-69% in last ten years*	**Substantial** *Decline 10-39% in past 10 years* **Occupancy 19% decline, past 10 years[5]**

Item	Criterion	Critically endangered	Endangered	Vulnerable
	To the extent that restoration of the community is not likely to be possible in:	*Restoration unlikely in immediate future*	*Restoration unlikely in the near future*	*Restoration unlikely in mid-term* **Restoration is not possible[3]**
4	The reduction in its integrity across most of its geographic distribution is: As indicated by degradation of the community or its habitat, or disruption of important community processes, that is:	**Very severe** *Restoration is unlikely in the immediate future.* **There is no known method of restoring the community following habitat removal and disturbance of hydrology by sand mining[3]**	Severe *Restoration is unlikely in the near term*	Substantial *Restoration is unlikely in the medium term*
5	Its rate of continuing decline is: as indicated by: (a) Rate of continuing decline in its geographic distribution, or a population of a native species that is believed to play a major role[6] in the	Very severe *Projected rate of detrimental change > 80% in immediate future*	**Severe** *Projected rate of detrimental change >50% in immediate future* **Removal of habitat by sand mining leading to**	Substantial *Projected rate of detrimental change > 30% in immediate future*

Item	Criterion	Critically endangered	Endangered	Vulnerable
	community, that is: or (b) Intensification, across most of its geographic distribution, in degradation, or disruption of important community processes, that is:		**66.6% loss of habitat in the immediate term at rate observed over the past 15 years[4,5].**	
6	A quantitative analysis shows that its probability of extinction, or extreme degradation over all of its geographic range, is:	**Very severe** *At least 50% in the immediate future (10 years)* **Removal of habitat by sand mining leading to 66.6% loss of community in the immediate term at rate of mining observed over the past 15 years and from estimated future rates, a 100% probability of extinction by 2036[4,5]**	Severe *At least 20% in the immediate future*	Substantial *At least 10% in the immediate future*

1. Occupancy is taken to be the seasonally inundated sand plains of the Howard River.
2. Liddle, D. T., P. Harkness, D. L. Lewis, and I. D. Cowie. 2013. *Vegetation communities and plant diversity of the seasonally saturated lands of the Howard sand plains Site of Conservation Significance in the Northern Territory of Australia*. Report to the Australian Government Caring for our Country initiative.
3. NT EPA 2015. Biodiversity of the Howards sand plains. Environmental Quality Report, NT EPA, Darwin.
4. Doyle, N. 2001. *Extractive minerals within the outer Darwin area*. Northern Territory Geological Survey, Report 14.
5. Doyle (2001) estimated a total superficial sand resource for the Darwin area at 15,920 million tonnes. At this projected rate of 300,000 tonnes per annum this would be exhausted by 2054. The average annual rate of use to 2013 was approximately 300,000 tonnes. The Extractive Association estimates an average annual demand of 540,000 tonnes by 2021. The rate of use can be expected to increase beyond 2021. At an average rate of use of 540,000 tonnes per annum from 2014, the superficial sands of the Howard sand plains would be exhausted by 2036.