A bright light on the dark forest floor: observations on fairy lanterns Thismia rodwayi F.Muell. (Burmanniaceae) in Tasmanian forests

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Introduction

Thismia rodwayi is one of Tasmania's most cryptic flowering plants. It is our only virtually subterranean species (Curtis and Morris, 1994) and until 2002 had seldom been recorded since European settlement.

The common name ascribed to *T. rodwayi* is 'fairy lanterns'. This name aptly describes the appearance of the small orange and red fleshy flowers that barely emerge from the soil surface and are typically covered by leaf-litter. These brightly coloured flowers are about 10-22 mm in length and have an obovate longitudinally striped floral tube (the 'lantern'), surmounted by six perianth lobes - the inner three arching inward and cohering at the top, and the outer lobes spreading (Figure 1, Figure 2). The vegetative part of the plant is white and entirely subterranean. The roots are about 1-1.5 mm thick and spread 4-15 cm. They give rise to erect flower stems (0.5-3 cm), which bear about six colourless bracts (these are the 'leaves'), which increase in size toward the terminal flower. The plant lacks chlorophyll and is therefore incapable of photosynthesis. It is considered a saprophyte, although this term is slightly misleading as it derives its energy from a fungus, the fungus being the true saprophyte.

T. rodwayi was first recorded in Tasmania (near Hobart) in 1890 and at that time caused quite a stir amongst botanists around the world (von Mueller, 1890a,b) because it was one of the first species in the family to be found in temperate climates (most species are tropical and subtropical). Since that first collection, the species had until recently only been found on five other occasions: from the Mt Field area, the Little Denison River area, somewhere in the northeast and a further site on the lower slopes of Mt Wellington.

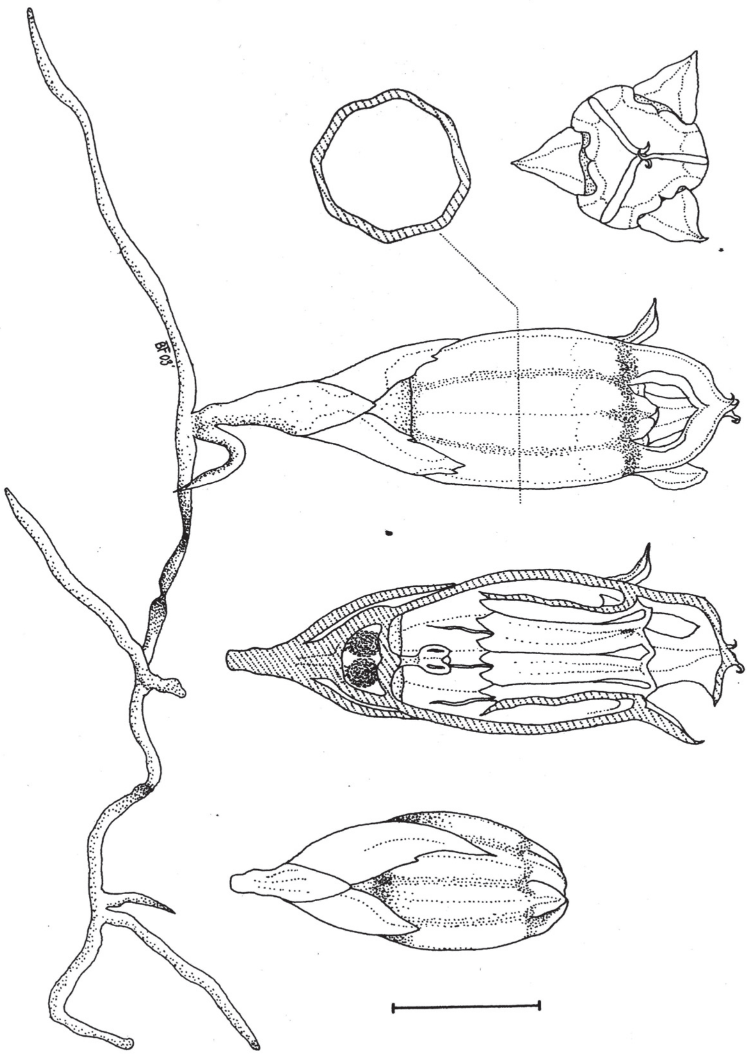

Figure 1. Line drawing of *Thismia rodwayi* drawn from dissected fresh specimens. Drawing by Brian French. Scale bar indicates 1 cm.

Figure 2. *Thismia rodwayi* in situ, showing growth habit (note: leaf litter has been removed). Photo: H & A Wapstra

But in 2002, the profile of this diminutive species changed: it was discovered on the lower slopes of Mount Wellington by Sapphire McMullen-Fisher (as part of fungus surveys) and in the same year in the Meander area by Sandy Tiffen and Nick Fitzgerald (in a proposed forestry coupe). These discoveries, combined with the conservation status of the species (listed as rare on the Tasmanian *Threatened Species Protection Act, 1995*) and the imminent forestry activities near the new site at Archers Sugarloaf, prompted research and further surveys by the Forest Practices Authority (then Board), the results of which were presented in Roberts *et al.* (2003a,b) and Wapstra *et al.* (2004).

This work indicated that the species occurs in wet and damp sclerophyll forest in seven disjunct areas of Tasmania (1. Ben Lomond region: 1 site, exact location unknown, 1980s; 2. Mt Wellington area: 3 sites, 1890, 1980s, 2002; 3. Mt Field area: 1 site, 1923; 4. Little Denison River area: 1 site, 1968; 5. Meander area: 18 sites from 5 locations separated by c. 5 km, 2002-2004; 6. Cluan Tier: 1 site, 2004; 7. Black Sugarloaf: 1 site, 2004).

The specific aims of this paper are to present:

1. Information on new sites for *Thismia rodwayi* in northern Tasmania, including the results of annual monitoring of populations of the species since 2002.
2. A systematic surveying and sampling method.
3. Information on the biology and morphology of the species.
4. Results of a preliminary analysis of the volatile chemical compounds associated with flowers of the species (during the course of sampling, a distinct pungent odour was noticed from flowers wrapped in moist paper stored in plastic containers for storage prior to curation, indicating a potential connection to pollination and/or dispersal vectors).
5. Results of bioclimatic modelling based on known sites for the species in Tasmania.

The broader objective of this paper is to improve the profile of *Thismia rodwayi* in the scientific and naturalist community with the intention of heightening interest in the species, hopefully leading to the discovery of further sites. The paper concludes with some suggested research priorities for the species with the intention of attracting post-graduate student interest.

Methods

Survey sites

Many of the known sites recorded in December 2002 and reported in Roberts *et al.* (2003b) were resurveyed in 2003 and 2004, using the sampling method described above. Most previously recorded flowers have been pegged using a metal stake with a label indicating the date of the survey, how many flowers were present, the stage of anthesis (e.g. bud, mature flower, decaying flower) and whether specimens were taken (usually only taken if flowers broke off during sampling). The pegged site was used as the centre point for the plot.

Additional surveys were conducted in the vicinity of previously recorded sites in apparently suitable habitat (i.e. wet sclerophyll forest dominated by *Eucalyptus obliqua*, *E. delegatensis*, *E. viminalis*, *E. globulus* or *E. regnans* with an understorey with one or more of *Bedfordia salicina*, *Pomaderris apetala* and *Olearia argophylla*). Three new sites have been reported (all in 2004) from the Black Sugarloaf area (S. Lloyd, pers. comm.), the Meander area near Sales Rivulet (M. Wapstra and A. Chuter, pers. obs.) and the Cluan Tiers (R. Barnes, pers. comm.).

Sampling method

Since 2002, a standard survey method has been used for both long-term monitoring of known sites and surveying of potential habitat. At each site, several 1 m^2 quadrats (a metre ruler or other metre measure is used to define the search area) are searched by hand. Coarse debris such as logs and rocks are first carefully lifted from the leaf litter. The top layer of leaf litter is then manually shifted to expose the lower leaf litter / soil surface interface. At this point, careful manual shifting of the remaining leaf litter and loosening of the top few centimetres of soil is undertaken. When at full anthesis, flowers of *T. rodwayi* are obvious because of their colour but do break easily from the underground stem, so care is needed (gloves or digging implements have been found to be too coarse in most cases). Buds and decaying flowers are less obvious but, with experience, are rarely missed. If specimens are found, leaf litter is carefully replaced over the sample site to prevent desiccation. Approximately 5 minutes is needed to search each quadrat and usually about 30 minutes is spent at each site (depending on the number of observers). This method allows a crude comparison of relative density among sites to be made. If specimens are located, it is often prudent to search carefully the immediately surrounding leaf litter because flowers are often clustered within less than 2 metres of each other. Following a "line" such as a decayed log can also prove fruitful.

Description

Specimens were dissected under a binocular microscope to produce transverse and longitudinal sections of the flower. Digital images of each part of the plant including roots, corolla and reproductive organs were taken. A line drawing representing the plant was produced.

An approximate 10 x 10 x 10 cm cube of soil, associated with two flowers growing close to each other that had almost perished, was excavated to determine the extent of the vermiform root system associated with each flower.

Chemical analysis of plant

Two mature flowers (that broke off during survey) were collected from the Meander area from a site supporting c. 25 flowers in a c. 3 x 3 m area. These were placed in separate 5 ml headspace glass vials, capped and stored on ice for transport to the laboratory. Flower volatiles were analysed by combined Gas Chromatography – Mass Spectrometry (GC-MS) on a Varian CP-3800 GC coupled to a Varian 1200 GC. In one protocol 0.5 mL of headspace air was injected in split mode onto a 30 m Varian VF–5 MS capillary column running an oven temperature program from 15°C to 170°C at 10 degrees per minute. In the second protocol a Solid Phase Micro Extraction (SPME) needle was used to collect flower volatiles for 10 minutes, before desorbing these in the GC-MS injection port.

Potential distribution

Based on the distribution of *T. rodwayi* records and its apparent preference for certain forest types, it is possible to estimate the extent of potential habitat in Tasmania. Using recognised vegetation mapping units known or likely to support the species, the area potentially occupied by the species was calculated. The mapping units used for this analysis were the RFA (Regional Forest Agreement) vegetation units: tall *E. obliqua* forest (OT), tall *E. delegatensis* forest (DT), *E. viminalis* wet forest (VW), *E. regnans* forest (R) and the damp sclerophyll complex DSC. In using these vegetation types, it should be noted that *T. rodwayi* tends to occur in the wet sclerophyll phase of the communities rather than the mixed forest (in the case of the first four communities) or the dry sclerophyll phase of the damp sclerophyll forest. However, more detailed mapping is not available and it is argued that the values used are indicative of the proportion of potential habitat in reserves.

CORTEX was used to map the potential range of *T. rodwayi*. This modelling tool is described in Peters and Thackway (1998). It is derived from BIOCLIM, a climate-based modelling approach inspired by Henry Nix of the Australian National University (Nix, 1986), and GARP, a rule-based genetic algorithm devised by David Stockwell (Stockwell and Peters, 1999).

The models are based on the concept of species-environmental envelopes (which are implemented as preconditions of rules). The model works at discovering the envelope that "contains" most (or all) of the observations in the smallest possible area. Environments are expressed as conjunctions of environmental variable ranges or categories (e.g. dolerite with slopes between 7% and 18% elevations between 100 and 900 m).

RESULTS AND DISCUSSION

Plant description (growth habit)

Figure 1 presents a detailed line drawing of dissected specimens of *T. rodwayi* and Figure 2 shows the growth habit of the species. In both graphics, the vermiform root system is clearly discernable. Approximately 75 cm of roots were extracted from a 10 x 10 x 10 cm clod of soil that supported two flowers of *T. rodwayi* (about 5 cm apart at the soil surface). There was no evidence that the flowers arose from the same root system. However, the 75 cm of root excavated was made up of numerous small sections (most c. 5 cm long) with tapered ends: whether this observation indicates the species is perennial arising from the same root stock each season or whether it simply indicates that the fragile roots are broken by soil perturbations (e.g. by worms) is not known.

Flowering habit and abundance

In Tasmania, mature (i.e. fully-formed) flowers of *T. rodwayi* have been recorded from as early as 12 October to as late as 19 December, indicating a flowering period of at least 3 months. Often, flowers are present in various stages of anthesis from early buds (appearing just above the soil surface) to fully mature flowers and often even "drying" flowers in a state of decay.

Long-term monitoring of known sites indicates that flowers are consistently present at most sites, although the abundance of flowers varies from year to year. This latter observation is more likely the result of incomplete sampling of all leaf litter at a site (which is near impossible) and the sampling of slightly different areas in each year. For example, at a site in the Meander area that supported 3 flowers in 2002 (from 12 m^2) and no flowers in 2003 (from 20 m^2), 25 flowers were observed in 2004 (from 5 m^2). In 2004, the original plot locations of 2002 were resampled (with flowers at one of three plots only) but additional searching only about 50 m downslope revealed a small densely clustered patch in an area of about 3 x 2 metres.

Chemical analysis

Using the first protocol (headspace air injected directly onto the column) two dominant volatiles were detected: 1-heptene and a-heptadiene (Figure 3). Protocol two (SPME) detected additional volatiles: 3-octanone, 3-octanol, myrtenal and myrtanol. Other volatiles were also detected by these two methods; however, they remain unidentified. It is unknown at this stage whether the identified volatiles contribute to the pungent odour of the flowers.

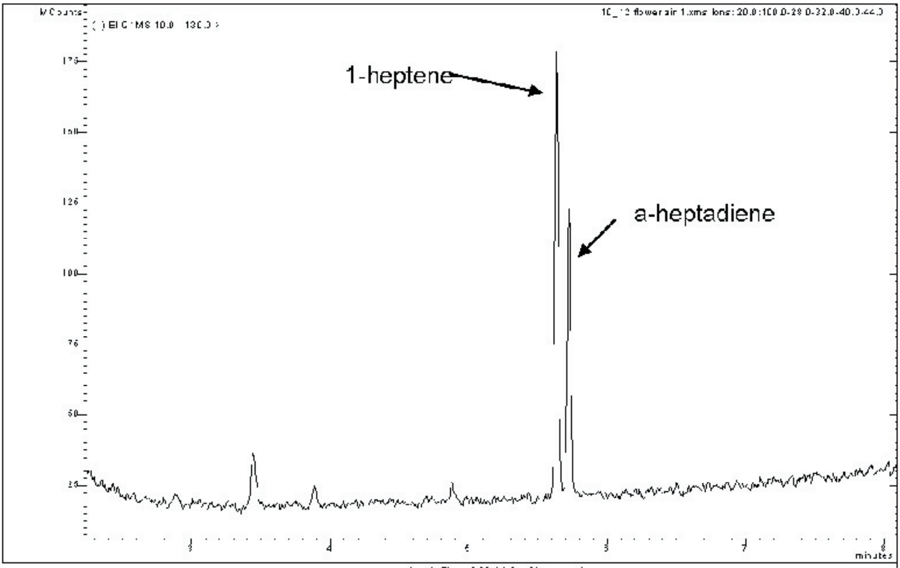

Figure 3. Chromatogram of GCMS analysis of flower volatiles. For the purposes of this paper, the small text can be ignored; the main point to note is the presence of two peaks in detection corresponding to the labelled volatiles 1-heptene and a-heptadiene.

Distribution

Thismia rodwayi is known from about 26 sites from 7 disparate locations around Tasmania. This widespread distribution appears to be reflective of the distribution of potentially suitable forest types (Figure 4) and probably indicates that with additional intensive survey the species might be discovered in other locations. Lending support to this postulation is that since the work of Roberts *et al.* (2003b), two additional sites have been located several kilometres from the previously recorded locations. The recent record from Cluan Tiers extended the range in the central north of Tasmania by 12 km to the northeast of the previously recorded sites in the Meander area.

The record from the Black Sugarloaf area north of Westbury extended the range by 34 km to the north-northeast of the Meander sites. Interestingly, both these sites, while in extensive areas of native forest, are separated from the previous sites by relatively large areas of cleared land. Having said that, several searches in apparently suitable habitat close to known sites proved fruitless (e.g. the species was not recorded from 80 1 m^2 plots over about 10 ha in the Jackeys Creek area about 1 km from several "reliable" sites). The environmental envelope suggested by the CORTEX model for *T. rodwayi* is defined by topography, rainfall and geology (Figure 5).

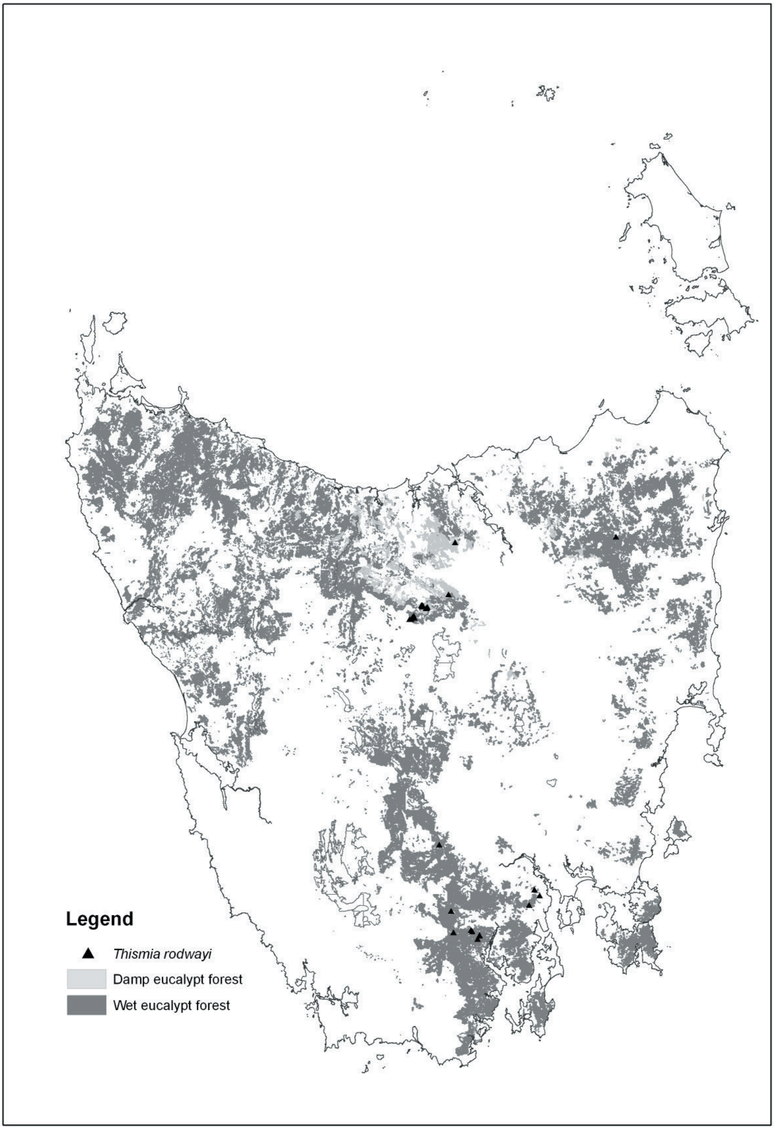

Figure 4. Map of Tasmania showing *Thismia rodwayi* records (black triangles) in relation to the distribution of wet and damp eucalypt forest (grey shading). Base data supplied by DPIWE; vegetation mapping based on TASVEG.

Figure 5. CORTEX model of predicted range of *Thismia rodwayi* in Tasmania.

Slopes are moderate to steep, curvature both down slope and across slope is concave and relief is moderate to high. Rainfall is low to moderate (approx. 320-820 mm/annum) and there is a marked preference for soils derived from Parmeneer sediments especially glacio-marine sediments. Note that these values refer in this case to those that characterise the 1000 m grid square.

The CORTEX model indicates that *T. rodwayi* may occur around much of the northern base of the Western Tiers, the Wellington Range extending west through to the Florentine Valley, parts of the Southern Forests and the wetter parts of the east coast including the Wielangta area and the hinterlands behind the Swansea-St Helens area. The fact that *T. rodwayi* has not been recorded from some of these areas probably indicates a lack of intensive survey (although some relatively intensive leaf-litter invertebrate surveys have been conducted in many parts of this predicted range).

A comparison of the broad vegetation map and the CORTEX model map indicates some overlap of areas potentially suitable for *T. rodwayi*. Of note, however, is that the CORTEX model does not predict extensive areas of potential habitat in the northeast, on the Tasman and Forestier Peninsulas, Maria Island, southern Bruny Island or the northwest wet eucalypt forests. These areas support very similar forest types at similar altitudes and on similar substrates to the known sites and so should not be discounted from further surveys. The CORTEX model excluded a record from northeast Tasmania because of a very low degree of precision: that a specimen has been found somewhere in the northeast is almost certain because it is apparently from this specimen that the line drawing in Curtis and Morris (1994) is based (A. Buchanan, pers. comm.), confirming the predictions of the model for this part of the State.

This bioclimatic model map may be useful for focussing further targeted searches for *T. rodwayi* in Tasmania, particularly when combined with the broad vegetation map. One note of caution is that although several of the records of *T. rodwayi* are in forests mapped as damp sclerophyll forest, all of these sites actually occur in the wet sclerophyll facies of this broad community: the site in Cluan Tiers is actually *Eucalyptus ovata* wet sclerophyll forest and the sites at Black Sugarloaf and Archers Sugarloaf are *E. obliqua* wet sclerophyll forest. Evidence from the Archers Sugarloaf area suggests that *T. rodwayi* is not present in the drier facies of damp sclerophyll forest (Roberts *et al.* 2003b).

Table 1 shows the extent and level of reservation at a Statewide level of five forest types associated with *T. rodwayi*. It is clear that while these vegetation types are targeted for clearing (for conversion to plantation) and other intensive forest management practices (such as clearfelling followed by high intensity regeneration burns), extensive areas of both the regrowth and oldgrowth phases of the communities are protected in formal reserves throughout the State. To date, *T. rodwayi* has been located in several formal reserves throughout its range and other known sites in wood production forests are being managed by prescription during harvesting operations (generally exclusion of the known site with a buffer of undisturbed native forest).

Table 1. Current Statewide extent and reservation levels of the five main forest types with which *Thismia rodwayi* is associated[1.] Bracketed values indicate extent and reservation levels of oldgrowth component of the community; data on new reserves to be created under the Supplementary Regional Forest Agreement of 13 May 2005 have not been included.

Community[2]	Current Extent (ha)	Reservation (ha)	% Reservation
E. viminalis wet forest[3]	6983	1326	19%
	(300)	(157)	(52%)
E. regnans forest	76587	18212	24%
	(12614)	(5960)	(47%)
Tall *E. obliqua* forest	450856	118018	26%
	(89791)	(51080)	(57%)
Tall *E. delegatensis* forest	294399	115335	39%
	(108389)	(67821)	(63%)
Damp sclerophyll complex[4]	43963	11264	26%
	(2198)	(1549)	(70%)

[1]Values are derived from TASVEG mapping and taken from those used by CARSAG (the scientific advisory group to the Private Forest Reserves Program, Department of Primary Industries, Water and Environment, used with permission.
[2]Community names as used in the Regional Forest Agreement
[3]Community is protected from further clearing on public and private land by State/ Commonwealth policy
[4]Oldgrowth areas of this community protected on public land under the Regional Forest Agreement

Postulations on pollination and seed dispersal

How *T. rodwayi* is pollinated is a mystery. Some members of the family Burmanniaceae are self-pollinating, which is facilitated by the close proximity of anthers and stigma (Maas-van de Kamer 1998). However, some observers have postulated that several species of *Thismia* may be pollinated by small flies (Diptera) attracted by scent and falling into the urceolate flowers (Stone 1980; Vogel 1962 cited in Maas-van de Kamer 1998). Vogel 1978 (cited in Maas-van de Kamer 1998) suggested that *Thismia fungiformis* may be pollinated by fungus gnats tricked into laying eggs in the fungus-mimicking flower. Fungus gnats are responsible for pollination is some Orchidaceae (e.g. the greenhoods, *Pterostylis* species), which has a superficially similar trap-like structure to the perianth. Comparison to other subterranean or near-subterranean flowering plants such as *Rhizanthella* (in the Orchidaceae) may provide some answers: ants are implicated in the pollination of this genus that has a superficially similar growth habit to species of *Thismia*.

What do our own observations suggest? Two observations made over the last 4 years of research on the species may provide a clue. The first is that specimens of *T. rodwayi* stored in moist conditions in a closed container (to prevent drying out during transport) begin to give off a detectable odour after only a few hours. This odour (to some people) is of rotten fish, which immediately brings to mind the fly-attracting tropical species of flowering plants such as the giant *Rafflesia* of southeast Asia. Blume (1849, cited in Coleman, 1936) also reported a smell of decaying fish about the root of *Sarcosiphon* (now *Thismia*) *clandestinus*. In species of *Rafflesia*, both olfactory and visual clues are important in attracting flies to flowers: pollination is by deception with the pollinators receiving no reward but an apparent offering of food and a possible brood place (Beaman *et al.* 1988) – a similar syndrome might occur in species of *Thismia*. Stone (1980) postulated that myophily (pollination by flys) occurred in species of *Thismia* because of the mitriform (cap-like) perianth apex of *T. clavigera*, although he noted no noticeable odour associated with this species. The second observation is that mature flowers of *T. rodwayi* are often "holed" in the wall of the flower and the flower itself often contains small particles of soil or faecal matter, presumably from small insects (M. Wapstra and B. French pers. obs.; A. Buchanan and Sarah Lloyd pers. obs.). Rübsamen (cited in Maas-van de Kamer 1998) twice found an egg or larva inside the nectaries of a *Gymnosiphon* flower (similar to *Thismia* in flower structure and growth habit).

The results of our preliminary chemical analysis did not indicate volatile chemical compounds usually associated with a fishy odour. Interestingly, the compounds 3-octanone, 3-octanol, 1-heptene, mrytenal and myrtanol were detected and these have been implicated in various behavioural responses in ants (Cammaerts and Mori, 1987), termites (Reinhard *et al.*, 2003), nematodes (Matsumori *et al.*, 1989), beetles (Pierce *et al.*, 1991), wasps (Rains *et al.* 2004), springtails (Bengtsson *et al.*, 1991) and flies (Birkett *et al.*, 2004). Clearly a more detailed chemical analysis of the volatile component of flowers of *T. rodwayi* would be needed to further elucidate the role of different chemicals in the life cycle of the plant.

We have not personally observed the seeds of *T. rodwayi*; however, the seeds of other species of *Thismia* are numerous, minute and well-adapted for dispersal by air or water (Maas-van de Kamer 1998). Wind dispersal of seeds of *T. rodwayi* seems unlikely because the flowers usually mature at the interface of the soil and dense layer of leaf litter, where air movement would be slight. A possible dispersal mechanism may be water, either flow over ground and through the layer of leaf litter and upper soil surface, or by rain splash out of the fruit cup. This latter mechanism was postulated by Stone (1980) for *T. clavigera* but both mechanisms are possible in the moderate rainfall habitat of *T. rodwayi* in Tasmania.

Flowers of *T. rodwayi* are also distinctively bright orange-red. While the flowers are rarely exposed above the leaf litter, digging by native animals such as potoroos and wombats would occasionally expose flowers, which might be attractive to birds or mammals, especially those that forage for fungi (such as potoroos). Whether the seeds of *T. rodwayi* can survive digestion by animals is not known. Beccari (1890 cited in Maas-van de Kamer 1998) supposed that the seeds of Burmanniaceae might also be dispersed by birds that have eaten earthworms that had ingested seeds.

It is interesting to note that flowers of *T. rodwayi* are usually found very close together, often clustered in small "colonies", which might support the notion of dispersal by raindrop splash or mechanical action of foraging animals. At one site, we observed flowers of *T. rodwayi* in a "line" perpendicular to the slope, which might support the notion of dispersal by over-ground water. Clustering of flowers has also been observed in *T. clavarioides* from Queensland (Thiele and Jordan, 2002): whether such clustering is related to the genetics of the plant (e.g. do the plants in a single patch comprise a single clone) or the method of pollination/dispersal is not known.

Research directions

For many of our rare plants, we know very little about their biology, ecology, distribution and habitat characteristics. With cryptic and ephemeral species such as *T. rodwayi*, we know even less because our ability to improve our knowledge is hampered by the logistics of finding enough material to work on. However, observations over the last 4 years have confirmed that several of the known populations of *T. rodwayi* in both the north and the south of the State "flower" consistently each year. Furthermore, several sites supporting 10+ flowers (with up to 25 flowers at one site) have been recorded, meaning that sampling need not "destroy" whole populations. The majority of the surveys reported in Roberts *et al.* (2003b) and this present paper are best regarded as cursory because at most sites only about 20 m^2 of leaf litter was excavated, indicating that perhaps the species is more widespread (but not necessarily abundant).

With this in mind, the following research directions are suggested with the intention of attracting post-graduate student interest in some or all of these aspects of the species:

- More detailed examination of the macro-habitat (e.g. forest type, geology, slope, aspect, altitude, etc.) and micro-habitat (e.g. leaf-litter depth and composition, soil type, moisture levels, associated vascular species, etc.) variables associated with the species through statistical modelling.
- Field-testing of the bioclimatic model presented in this current paper, examining the range of altitudes, geologies and forest types potentially supporting the species around Tasmania: suggested areas for focus include the Florentine Valley, further areas in the Southern Forests, parts of the east coast (including southern Bruny Island, northern Maria Island, the Wielangta forests and parts of the Eastern Tiers), the northeast forests and further sites around the northern base of the Western Tiers.
- Estimates of population numbers at each site with a more stratified random sampling method and assessment of the characteristics of the flowers (e.g. "life span" of individual flowers, how many buds mature, etc.).
- On-going long-term monitoring of known populations to examine how often the species flowers, whether it flowers in the same site every year and what factors might influence flowering (such as climate factors like rainfall, soil and air temperature, etc.).
- Examination of the pollination and dispersal mechanisms of the species through a combined field experiment assessing possible pollinating organisms (through insect trapping methods and possibly time-delay photography) and a more detailed analysis of the chemical compounds present in the flowers at different stages of maturity.
- Genetic relationships among populations within Tasmania and a comparison with specimens from Victoria and New Zealand (specimens of *T. rodwayi* from northern and southern Tasmania were provided in 2003 to Vincent Merckx and Peter Schols from the Laboratory of Systematics at the Institute of Botany and Microbiology (Belgium) to conduct DNA phylogenetic research on members of the Burmanniaceae family).

REFERENCES

Bengtsson, G., Hedlund, K. and Rundgren, S. (1991). Selective odor perception in the soil collembolan *Onychiurus armatus*. *Journal of Chemical Ecology* **17(11):** 2113-2125.

Beaman, R.S., Decker, P.J and Beaman, J.H. (1988). Pollination in *Rafflesia* (Rafflesiaceae). *American Journal of Botany* **75(8):** 1148-1162.

Birkett, M.A., Agelopoulos, N., Jensen, K.M.V., Jespersen, J.B., Pickett, J.A., Prijs, H.J., Thomas, G., Trapman, J.J., Wadhams, L.J. and Woodcock, C.M. (2004). The role of volatile semiochemicals in mediating host location and selection by nuisance and disease-transmitting cattle flies. *Medical and Veterinary Entomology* **18(4):** 313-322.

Cammaerts, M.C. and Mori, K. (1987). Behavioral activity of pure chiral 3-octanol for the ants *Myrmica scabrinodis* NYL and *Myrmica rubra* L. *Physiological Entomology* **12(4):** 381-385.

Coleman, D.G. (1936). *Sarcosiphon rodwayi* in Australia. *The Victorian Naturalist* **52:** 163-166.

Curtis, W.M. and Morris, D.I. (1994). *The Student's Flora of Tasmania Part 4b Angiospermae: Alismataceae to Burmanniaceae*. St. David's Park Publishing, Hobart.

Maas-van de Kamer, H. (1998). Burmanniaceae. In *The families and genera of vascular plants, monocotyledons. Lilianae (except Orchidaceae)*. Kubitzki, K. (ed.) Springer-Verlag, Berlin.

Matsumori, K., Izumi, S. and Watanabe, H. (1989). Hormone-like action of 3-octanol and 1-octen-3-ol from Botrytis cinerea on the pine wood nematode, *Bursaphelenchus xylophilus*. *Agricultural and Biological Chemistry* **53(7):** 1777-1781.

Nix, H.A. (1986). A biogeographic analysis of Australian elapid snakes. In *Atlas of Elapid Snakes of Australia* P. Longmore (ed.), Australian Flora and Fauna Series Number 7, Australian Government Publishing Service: Canberra). pp. 4-15.

Peters, D. and Thackway, R. (1998). *A new biogeographic regionalisation for Tasmania. Report prepared for the National Reserve System Program Component of the Natural Heritage Trust. Project NR 002: Undertake biophysical regionalisation for Tasmania*. http://www.gisparks.tas.gov.au/dp/newibra/home.html.

Pierce, A.M., Pierce,H.D., Borden, J.H. and Oehlschlager, A.C. (1991). Fungal volatiles – semiochemicals for stored-product beetles (Coleoptera, Cucujidae). *Journal of Chemical Ecology* **17(3):** 581-597.

Rains, G.C., Tomberlin, J.K., D'Alessandro, M. and Lewis, W.J. (2004). Limits of volatile chemical detection of a parasitoid wasp, *Microplitis croceipes*, and an electronic nose: a comparative study. *Transactions of the ASAE* **47(6):** 2145-2152.

Reinhard, J., Quintana, A., Sreng, L. and Clement, J.L. (2003). Chemical signals inducing attraction and alarm in European *Reticulitermes* termites (Isoptera, Rhinotermitidae). *Sociobiology* **42(3):** 675-691.

Roberts, N., Duncan, F., Wapstra, M. and Woolley, A. (2003a). *Distribution, habitat characteristics and conservation status of* Thismia rodwayi *F. Muell. in Tasmania.* A Report to Forestry Tasmania Conservation Planning Branch and the Forest Practices Board.

Roberts, N., Wapstra, M., Duncan, F., Woolley, A., Morley, J. and Fitzgerald, N. (2003b). Shedding some light on *Thismia rodwayi* F. Muell. (fairy lanterns) in Tasmania: distribution, habitat and conservation status. *Papers and Proceedings of the Royal Society of Tasmania* **137:** 55-66.

Stockwell, D.R.B. and Peters, D.P. (1999). The GARP modeling system: problems and solutions to automated spatial prediction. *International Journal of Geographic Information Systems* **13:** 143-158.

Stone, B.C. (1980). Rediscovery of *Thismia clavigera* (Becc.) F v. M. (Burmanniaceae). Blumea 26: 419-425.

von Mueller, F., (1890a). Notes on a new Tasmanian plant of the order Burmanniaceae. Proceedings of the Royal Society of Tasmania 1890-1891: 232-235.

von Mueller, F. (1890b). Descriptions of new Australian plants, with other annotations. The Victorian Naturalist 8: 114-116.

Wapstra, M., Woolley, A., Duncan, F. and Roberts, F. (2004). A bright light on our forest floor – *Thismia rodwayi* (fairy lanterns). Forest Practices News 5(4): 10-12.

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