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Shrubby Samphire seed germination responses: Plant growth studies to inform the recovery plan

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Executive summary

A recovery plan for *Tecticornia arbuscula*, commonly known as Shrubby Samphire, was developed by Delta Environmental Consulting (2024a) for Green Adelaide, to provide information to guide restoration efforts, and recommend further studies and recovery actions. Shrubby samphire is a key structural plant species in the nationally vulnerable ecological community *Subtropical and Temperate Coastal Saltmarsh* (TSSC 2015), which provides habitat for threatened species such as the vulnerable Samphire Thornbill *Epthianura albifrons* (Coleman 2017), and the critically-endangered Orange-bellied Parrot *Neophema chrysogaster* (White et al. 2016). The recovery plan reviews available literature and studies, and highlights the various values and threats facing this community. This includes the current and future impacts of altered tidal inundation due to sea level rise and other anthropogenic influences, and indicates shrubby samphire is sensitive to inundation (Mount et al. 2010; Coleman and Coleman, 2024b), aridity (Prahalad, 2019) and salinity stress (Boon et al. 2016). Populations have declined and the absence of shrubby samphire seedling recruitment highlights the importance of filling knowledge gaps relating to seed germination. Plant growth studies were recommended, which included investigating germination and longevity of shrubby samphire seeds by Federation University.

This study aims to improve understanding of the opportunities and barriers to successful shrubby samphire recruitment, by examining seed responses to environmental factors such as light, temperature and salinity. This knowledge will be used by Delta Environmental Consulting to develop a nursery and revegetation protocol to assist community groups and natural resource managers in revegetation efforts. Seed longevity trials are also currently underway at Federation University.

Our studies indicate that shrubby samphire seeds have a strong preference for fluctuating light and dark conditions, suggesting that germination will be more successful if seeds are sown on or just below the soil surface, to meet light requirements. The window of opportunity for germination is fairly broad (7 °C to 30 °C), taking around three weeks to reach 50% germination of seeds sown in warmer conditions. Hot conditions (35 °C) were a barrier to germination and only low numbers germinated in our trials.

Salinity both delayed germination and reduced germination percentages as concentrations increased, and no seeds germinated at seawater or hypersaline concentrations. However, seeds germinated rapidly following exposure to freshwater conditions at the end of salinity trials. This indicates that shrubby samphire seeds can withstand the osmotic stress of high salinity for prolonged periods, and may germinate in larger numbers following rainfall in cool to warm conditions. Delays to start germination were significant, and seeds in brackish conditions (6 g/L) took two months to reach 50% germination, while at higher concentrations 50% was not achieved during the trial. In seawater concentrations (36 g/L), it took four weeks to reach just 10% germination.

The barriers to successful germination of shrubby samphire are evident, with germination significantly reducing or ceasing during periods of high salinity or temperature, or if seeds are buried in the soil without light. There is a clear preference for lower salinity levels during cool to warm conditions, suggesting rainfall events are important to reduce salinity and provide a germination window sufficiently long enough for seeds to germinate and seedlings to establish. Salts are more likely to be flushed out in the free-draining sandy substrates in the supratidal

zone (Coleman and Coleman 2024a). These opportunities may decrease with climate change, and a range of strategies should be implemented to safeguard this species against future impacts. Seed longevity studies, currently underway, will provide data to inform seed banking opportunities.

It is recommended that nursery trials are conducted on priming seeds with seawater prior to sowing in cool-warm conditions, to maximise propagation success. The low seed-fill rate should also be further explored by conducting tests on a range of collections, to see if this typical for shrubby samphire. Ample seed should be collected to account for low seed fill, for both nursery propagation and direct seeding techniques. Experiments on drought stress would also be highly informative, as some *Tecticornia* species (e.g. *Tecticornia lylei*) have been found to be more sensitive to drought stress than salinity stress (Monie et al. 2025; Monie et al., unpublished), and mature shrubby samphires have also been found to be sensitive to aridity (Prahalad, 2019). Growth rates of young seedlings should also be determined, as well as the conditions needed for successful seedling establishment, as this is one of the most vulnerable life cycle stages (Zhang et al. 2021). Monitoring is essential to further inform and improve management, particularly for a species that provides a structural element to a vulnerable ecological community, and habitat for threatened species. As Coleman and Coleman (2024a) point out, there may be a relatively small window available for retreat opportunities for the shrubby samphire. Strategies that reduce impacts to shrubby samphire communities and create habitats suitable for mature stands into the future are critical, as the germination stage is even more sensitive to environmental stressors. Field trials are recommended on revegetation methods introducing seed into the environment, to determine responses under natural (fluctuating) conditions.

Introduction

Tecticornia arbuscula, commonly known as Shrubby Samphire, is a large, long-lived, stem-succulent halophytic (salt-tolerant) shrub endemic to coastal saltmarshes in southern Australia. It is a key species in *Subtropical and Temperate Coastal Saltmarsh,* which is vulnerable nationally under the Commonwealth Environment Protection and Biodiversity Conservation Act (EPBC Act)(TSSC 2015), and provides critical habitat for many threatened species including the vulnerable Samphire Thornbill *(Acanthiza iredalei rosinae*)(Coleman et al. 2017), critically-endangered Orange-bellied Parrot (*Neophema chrysogaster*), as well as the White-fronted Chat (*Epthianura albifrons*). Coleman and Coleman (2024a) outline that threats to shrubby samphire include sea-level rise and borer infestation, resulting in the dieback of important Samphire Thornbill breeding habitat, potentially increasing risk of predation. A local recovery plan has been developed by Delta Environmental Consulting (Coleman and Coleman 2024) to support the restoration of breeding habitats and nesting success, recommending further studies to guide local recovery actions. In areas with previous shrubby samphire dieback in 2017, Coleman and Coleman noted a lack of any new seedling recruitment, with many areas now unvegetated or encroached upon by the inundation-tolerant Bearded Glasswort, *Salicornia quinqueflora.* Many shrubby samphire plants were no longer evident or had been impacted by road widening and inundation in floodways. Other reports noted that shrubby samphire was sensitive to both hypersalinity and inundation (Boon et al. 2016). Predictions by Sinclair et al. (2022) show that Shrubby Samphire likely tolerates inundation for longer periods in seawater or brackish conditions, compared to freshwater conditions which had higher percentages of predicted deaths. The absence of new recruits

highlights knowledge gaps relating to shrubby samphire seed ecology. Coleman and Coleman (2024a) recommend germination and longevity studies, to inform the development of a nursery and revegetation protocol to assist community groups and natural resource managers.

This project aims to understand the seed germination responses of shrubby samphire *Tecticornia arbsuscula* to light, temperature and salinity: (i) what are the windows of opportunity for seed germination under different light and temperature regimes? (ii) what are the temperature thresholds where germination ceases?, and (iii) what effect does salinity have on the germination windows for shrubby samphire?

Known habitats of shrubby samphire

Shrubby samphire is a key species in tidally inundated, floristically diverse subtropical and temperate coastal saltmarshes in southern Australia (TSSC 2015). Pressure from sea level rise and anthropogenic disturbances has resulted in hydrological changes affecting a range of factors including soil moisture, salinity and pH, in conjunction with climatic variation and freshwater sources such as rainfall and rivers (Coleman and Coleman 2024a). Shrubby samphire commonly grows upslope of encroaching mangroves on the elevated margins of saltmarshes. Studies have shown that soils in shrubby samphire habitat are typically sands, loamy sands and sandy loams, with higher soil moisture and hypersalinity that seems to be detrimental to shrubby samphire health and survival (Coleman and Coleman 2024b). Areas further upslope that are considered potential habitat for shrubby samphires have lower soil moisture and salinity levels, both of which are likely to increase with sea level rise (Coleman and Coleman 2024b). Coleman and Coleman (2024a) state shrubby samphire may be the first of *several* species to reach tolerance limits for inundation, suggesting the ecological community should be reassessed for higher level of threat.

Samphire seed germination

Seed germination and seedling establishment are known as the most vulnerable life cycle stages for plants (Zhang et al. 2021), however there is a lack of knowledge about the majority of samphire species, including the shrubby samphire. Shrubby samphire seeds mature mainly over summer (Understorey Network 2025), with plants retaining some fruits at all times of the year (Coleman 2014), however there is no published literature on seed germination ecology.

All species have germination cues from environmental factors such as light, temperature and salinity, and determine the conditions under which germination will be optimal, reduce, or stop altogether (Baskin and Baskin 2014). Halophytes (salt-tolerant plants) are defined as plants that can reproduce in salinities over 200 mM NaCl, or 11.69 g/L (Flowers and Colmer 2015). While samphires are salt-tolerant, species have varying sensitivities to salinity during germination, and seeds need to withstand harsh environments that may be highly variable throughout the year. Seeds may be exposed to periods of inundation, hypersalinity, aridity and extreme temperatures, all of which can affect extend windows of opportunity needed for germination, and ultimately the population dynamics within a community. Seeds are also exposed to salinity levels vastly higher on the soil surface, compared to the rootzone conditions of mature plants (Ungar 1978).

Seed germination has not been studied for the majority of samphires in Australia, and the few that have were mostly tested only in fluctuating light and dark conditions, and under one temperature regime (e.g. English et al. 2011, 2013; Malcom 1964; Purvis 2002). There is a general trend for seed germination of salt-tolerant plants to reduce with increasing salinity levels, and responding with rapid germination following exposure to fresh water (Cochrane 2018; Gairola et al. 2020). This maximises chances of seedling survival by waiting until salinity levels are reduced. This is also true for samphires (Purvis et al. 2009). Increasing temperatures are also known to exacerbate the effects of salinity and water stress.

Seed germination methods

Seed collection and storage

Shrubby samphire seeds were provided by Hindmarsh Island Landcare Nursery, which were collected from the Mundoo Channel Provenance at Hindmarsh Island, South Australia, in early May 2022. Seeds were received by Federation University in August 2024 and stored in the seed ecology lab in a dark cabinet at approximately 22 °C until use in experiments. Light and temperature experiments were conducted between September and November 2024, followed by salinity experiments in early 2025.

Seed germination protocol

Shrubby samphire seeds were retained within the fruits for the experiments, as attempting to extract them caused damage, even after soaking for 24 hours. Fruits that appeared plump were selected with tweezers under a microscope. Seeds were surface-sterilised in 1% w/v sodium hypochlorite (NaOCl) solution for three minutes, then rinsed three times with sterilised distilled water. Each treatment consisted of four replicates of 25 seeds (100 seeds per treatment combination). Seeds were placed into 9 cm Petri dishes on Whatmans® filter paper moistened with treatment solution (sterilised distilled water for light and temperature, and sodium chloride (NaCl) for salinity). Petri dishes were sealed with Parafilm and clingfilm to prevent evaporation, and incubated in temperature and light controlled incubators (Thermoline Scientific Temperature and Humidity Cabinet, TRISLH-495-1-SD, Volume 240, Wetherill Park, NSW, Australia) fitted with white fluorescent lamps with a photosynthetic photon flux of 40 µmol m^{-2} s^{-1} (Fig. 1). Both trials ran for 60 days and germination was recorded every two to three days. At the end of the salinity trial, ungerminated seeds were exposed to fresh water for 14 days to establish responses following salinity stress.

Figure 1. Seed incubators in our seed ecology laboratory

Light and temperature was assessed by exposing seeds to two light regimes (12 hours light, 12 hours dark; and constant darkness). Constant darkness was achieved by wrapping Petri dishes in aluminium foil and only opening them under green light conditions to prevent photoreactions. Temperature was assessed at four different day/night temperatures (17/7 °C, 25/15 °C, 30/20 °C, 35/25 °C) under each light regime. The light and temperature combination that resulted in highest germination was subsequently used for assessing salinity.

Salinity effects on germination were determined for six different concentrations of NaCl, as shown in Table 1. Every 10 days, each replicate of seeds was transferred to a new Petri dish with the relevant treatment solution, to reduce impacts from mould or evaporation and to maintain consistent treatment concentrations.

Table 1. Salinity concentrations and osmotic potentials tested for Shrubby Samphire seed germination responses

Salinity	Osmotic Potential (MPa)	NaCl (g/L) at 20 °C (fluctuating 25/15 °C)	Equivalent NaCl (mM)
Freshwater	0.00	0	0
Brackish	-0.5	6	105.5
Brackish	-1.5	18	316.50
Brackish	-2.5	29.99	527.49
Seawater	-3.0	35.98	632.99
Hypersaline	-4.5	53.97	949.49

At the end of the trials, the remaining seeds that had not germinated were assessed for seed fill and viability. Any unfilled seeds without a mature embryo were excluded from the total seeds. Seeds with intact embryos were categorised as viable after testing with tetrazolium (1% solution of 2,3,5-triphenyltetrazolium chloride), if they stained evenly red or dark pink. Those partially stained or unstained were not viable (Fig. 2).

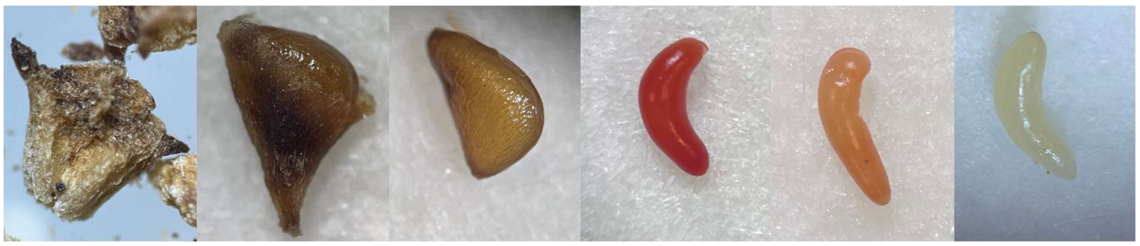

Figure 2. Shrubby samphire seeds and viability testing (from left to right): fruit, seed in pericarp, imbibed seed removed completely from fruitlet, viable embryo (stained red), weakly viable embryo (pale stain), dead embryo (no stain)

Data analysis

To understand the responses of shrubby samphire seeds to temperature, light and salinity over time, data were analysed using the R statistical environment, version 4.3.2 (R Core Team 2023). We fitted a three-parameter log-logistic function using a curvilinear log-logistic model (*drmte* function in the *drcte* package, version 1.0.30 Onofri et al. 2023). This determined the maximum germinated proportion (P_{MAX}) of seeds for each treatment, and time in days (t_{50}) to reach 50% of P_{MAX} for each treatment. We then established which treatments were significantly different (*compParm* function in *drc* package v3.0-1 Ritz et al. 2015). To understand the time (in days) needed to reach 1, 10, 25, 55 and 99% germination of the total

seed lot (i.e. all seeds sown in each treatment), we calculated *quantiles*. This method was chosen as it describes the germination behaviour of seeds over the whole germination period, and can be used to predict proportions of seeds at any given time. It is helpful for understanding the germination window, how long is needed under a particular set of conditions for seeds to germinate to a particular quantity.

Shrubby samphire seed germination responses

Seed characteristics, fill and viability

Shrubby samphire seeds are pale golden brown, approximately 1.5 mm long, with a slightly curved embryo. Seeds Hindmarsh Island Population had a fill rate of 68%. Due to low seed numbers and to avoid seed wastage, population viability was calculated based on post-trial results (germinated seeds plus viable seeds), therefore some seeds may have died from treatment effects during the experiment. Seeds also provided by Coleman from April 2024, had very few filled seeds, and were therefore not used in the experiments.

Light and temperature effects on seed germination

Shrubby samphire seeds germinated most successfully under fluctuating light/dark conditions, at temperatures ranging between 7 °C and 30 °C (Fig. 3; model output in Appendix 1). Optimal germination occurred at 25/15 °C (light/dark), reaching maximum germination (P_{MAX}) of 0.63 (63%) (Appendix 1). In contrast, germination was generally poorer in constant darkness, except at the coolest temperature of 17/7 °C. Few seeds germinated in hot conditions of 35/25 °C under either light regime (P_{MAX} 0.10-11, or 10-11%). Differences in P_{MAX} were mostly significant for the cooler three temperatures (in light/dark), and the majority of other treatments.

Germination was also significantly faster in light/dark conditions, reaching 50% of P_{MAX} most rapidly at temperatures of 30/20 °C (11 days), 25/15 °C (12 days). Germination was slightly slower at 17/7 °C (19 days in light/dark, 21 days in constant darkness).

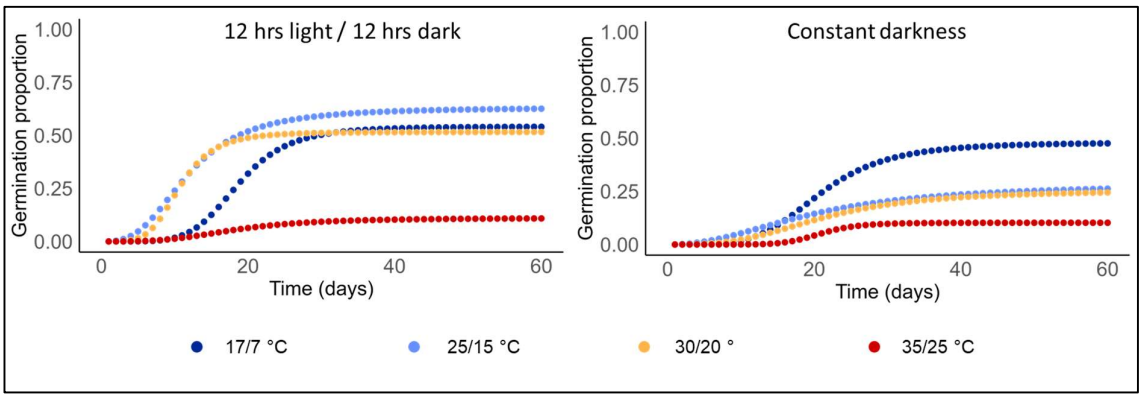

Figure 3. Cumulative germination of shrubby samphire seeds at four different temperatures (17/7 °C, 25/15 °C, 30/20 °C, 35/25 °C) under two light regimes (12 hrs light / 12 hrs dark; constant darkness)

Shrubby samphire seeds were also faster to reach 1, 10, 25 and 50% germination of the total seeds sown in the light/dark treatment, particularly under 25/15 °C (3, 7, 10 and 19 days) and 30/20 °C (5, 8, 11 and 23 days), compared to most other treatments (Fig. 4). In constant darkness, these two temperatures were much slower to reach 10 and 25%, and no

treatments reached 50% of the total seeds sown. These results were achieved in freshwater conditions, with no influence from salinity.

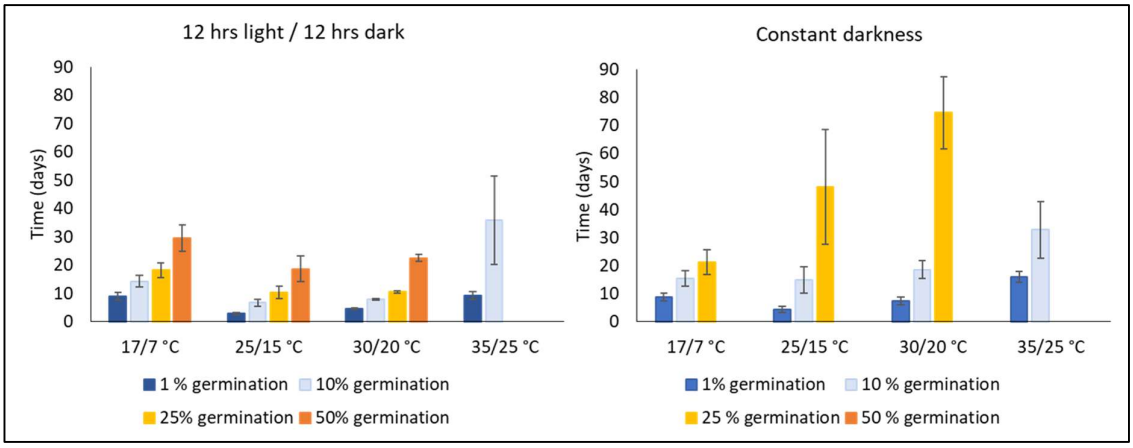

Figure 4. Time (days) to reach 1, 10, 25 and 50% germination of the total shrubby samphire seeds under different light and temperature treatments

Salinity effects on seed germination

Salinity significantly reduced maximum germination of shrubby samphire seeds as salinity increased under an optimal light and temperature regime of 25/15 °C, fluctuating light/dark (Fig. 5; model output in Appendix 2). Over 50% of the total seeds sown germinated in both freshwater conditions and salinity of 6 g/L (-0.5 MPa). However, germination reduced to a maximum of 15% at salinity levels equivalent to seawater (36 g/L), and no germination occurred in hypersaline conditions (54 g/L).

After exposing seeds to freshwater, however, germination rates rapidly increased in all treatments 18 g/L and higher, reaching levels similar or greater than the freshwater treatment. Highest overall germination following freshwater exposure was achieved in salinity treatments 30 g/L or higher, which reached 81-85% of the germinable seeds.

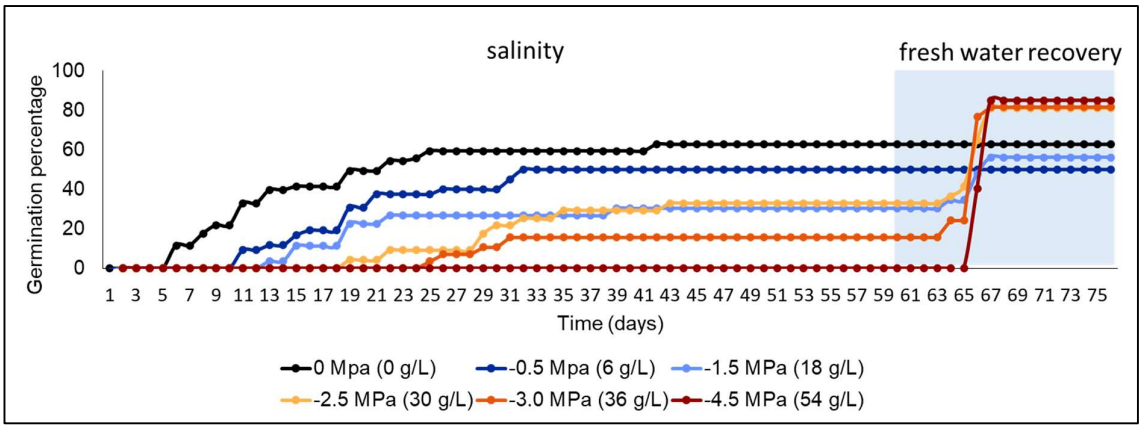

Figure 5. Salinity effects on shrubby samphire seed germination responses, followed by fresh water recovery period

Increasing salinity also significantly delayed germination time (Fig.6; Appendix 2). In brackish conditions, seeds reached 10% germination after 13, 16 and 25 days at salinities of 6, 18 and 30 g/L respectively, and seawater concentrations (36 g/L) after 28 days (Fig. 6). In

seawater concentrations, germination only commenced after 24 days. Even mild salinities (6 g/L) significantly delayed the time needed to reach 50% germination (two months).

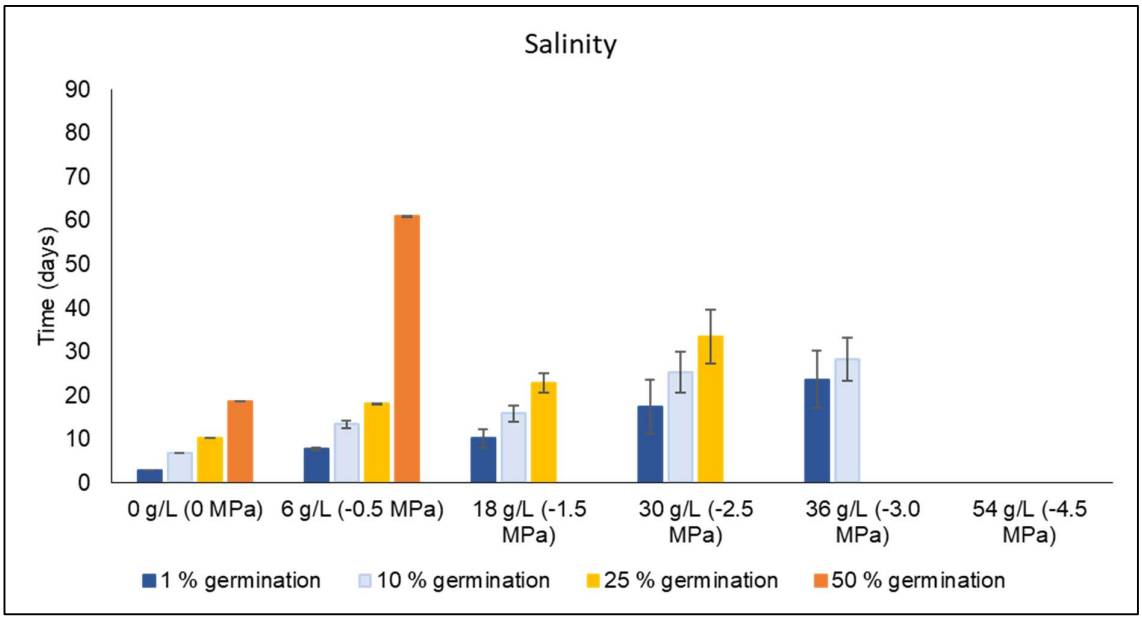

Figure 6. Time (days) to reach 1, 10, 25 and 50% germination of the total shrubby samphire seeds sown under different salinity treatments

Implications for natural recruitment, restoration and revegetation

Shrubby samphire seeds clearly germinated most successfully when exposed to both light and dark, indicating a light requirement and preference for seeds to be sown on or near the soil surface at most temperatures, rather than buried beneath the soil. The exception for shrubby samphire seems to be under cooler conditions, where seeds also germinated well with no light exposure. This is consistent with other salt-tolerant plants which germinated in higher quantities with light exposure, compared to dark conditions (Gairola et al 2020). However, comparisons with other samphires' responses to germination are lacking, as studies have only assessed germination in fluctuating light and dark conditions (e.g English and Colmer 2011, 2013; English et al. 2002; Purvis et al. 2009). The fragility of shrubby samphire seeds, even after soaking fruits in fresh water, suggests seeds not only disperse within the fruits (Coleman 2014), but germinate readily without needing to be removed from the fruit. Fruits may also give the seeds physical protection during the vulnerable germination stage.

Shrubby samphire seeds had low seed fill, and need to be sown in the fruits to avoid damage. This means a higher number of fruits are needed than might be expected, as it is difficult to tell which fruits contain mature seeds, even under a microscope (impractical in nursery situation). It will be important to understand if this is typical of this species (rather than simply a seasonal variation), as it determines how much seed should be collected and sown on a larger scale for revegetation.

Rainfall events are likely critical for shrubby samphire to germinate seed in more than low numbers. In the laboratory, salinity clearly reduces, delays or prevents germination in conditions where survival is risky. However, rapid germination following flushing seeds with fresh water gives us some insight into the rainfall effects of reducing salinity. This is a similar response to the majority of species in studies (Monie et al. 2025), including other species that

occur in coastal areas such as *Tecticornia pergranulata* which reduced by 50% at 23 g/L NaCl (English *et al.* 2002) and *Tecticornia halocnemoides* which showed a strong reduction above 20 g/L NaCl (Barrett 2000; Purvis et al. 2009). Higher overall germination for seeds previously exposed to seawater and hypersaline concentrations suggests there may be a salt priming effect. This means that while seeds are restricted from germinating until salinity reduces, some metabolic processes start within the seed (Debez et al., 2018). Barrett (2000) found that *Tecticornia indica* subsp. *bidens* germination increased from 3.3% to 50% after priming seeds in 40 g/L NaCl. There is value in conducting nursery trials to see if seeds that are initially exposed to seawater for a short period, germinate more rapidly and uniformly following subsequent watering with freshwater. This may improve overall propagation rates for a species that seems to have low seed fill, and streamline production of seedlings growing at a similar time, rather than sporadically over a longer period of time. Unless nurseries have climate-controlled glasshouses, seed priming should coincide with cooler weather to maximise germination and seedling growth. In field conditions, it is unlikely that much germination will occur in prolonged highly saline environments, particularly during the hotter weather.

The sensitivity to osmotic stress from salinity may indicate that seeds are also sensitive to water stress from drought. We have found from our own studies, that *Tecticornia lylei* seeds are more sensitive to drought stress than salinity stress, when comparing treatments of the same osmotic potential (MPa) (Monie et al., unpublished 2025). For many species, water stress can also prime seeds for faster germination after the stress is removed, as seeds can retain physiological changes after wet and dry cycles (Fenner and Thompson 2005). Reports that shrubby samphire is also sensitive to inundation, and recruitment is lacking in field conditions (Coleman and Coleman 2024a), suggests seeds may be sensitive to water stress at both ends of the scale. Therefore, care should be taken during propagation and field-based restoration that seeds have sufficient soil moisture, but are also protected from extended periods of flooding. Planning restoration activities around the cooler months will not only meet optimal light and temperature conditions for seed germination, but are also more likely to have sufficient soil moisture and reduced salinity levels to maximise chances of survival. Introducing seed into the landscape that involves burying beneath the soil may give seeds protection and increase soil moisture, but if seed is too deep, seeds may not have adequate light to germinate, or seedlings may not be able to emerge from the soil surface. Techniques that only lightly bury the seed may be most effective.

Coleman and Coleman (2024a) state there are three key strategies for shrubby samphire recovery: reducing anthropogenic impacts, creating new coastal retreat zones, and active revegetation. The sensitivity of shrubby samphire seeds to increasing temperature and salinity highlights the clear risks to successful germination, both currently and in the future. In areas where saltmarshes have been stranded with restrictions to tidal inundation causing hypersaline conditions, natural regeneration from shrubby samphire seeds is likely to be poor. Reconnecting these areas to natural tides and creating new areas for shrubby samphire is critical to provide suitable habitats for this species to retreat with climate change. Elevated areas with substrates that are free-draining to reduce salinity levels more rapidly after rainfall, may provide suitable habitats for revegetation. However, it is currently unknown how samphire seeds and seedlings respond to water stress from drought conditions, and how much moisture needs to be retained in the soil during this vulnerable stage. Given that seeds and seedlings are more sensitive to stress than established plants, creating or modifying habitats that address dieback in mature stands of shrubby samphire is an essential first step.

Recommendations

It is recommended when implementing strategies to assist recovery of the shrubby samphire that opportunities and barriers to seed germination success are considered. This includes the following actions:

- Develop a nursery protocol that maximises seedling production for revegetation, trialling strategies such as salt-priming prior to sowing in cool to warm conditions, seed burial depth (seed on surface or lightly buried), ensuring adequate moisture levels (protocol to be developed by Delta Environmental Consulting in 2025)
- Conduct water stress trials (inundation and drought) to establish effects on shrubby samphire seed germination and seedling establishment under increasing temperatures.
- Establish typical seed-fill and viability rates of different shrubby samphire populations across different seasons to understand seed quantities needed to be collected and sown to meet seedling requirements for revegetation, and understand expectations around natural regeneration.
- Establish shrubby samphire seed longevity to understand how long seeds can be stored, and potential impacts to nursery stock, revegetation efforts and natural regeneration (study currently underway at Federation University)
- Address negative impacts to existing mature shrubby samphire stands to ensure longevity and create opportunities for both natural regeneration and restoration (e.g. hypersalinity, water stress from inundation, drought).
- Create new habitats as retreat zones for active revegetation of shrubby samphire that meet requirements for successful germination of seeds.
- Conduct field trials with different revegetation methods to introduce seed and seedlings into both current and new habitats, taking into account seasonal requirements to maximise germination.

Limitations and assumptions

As seeds are easily damaged during extraction from fruits, intact fruits were used for the experiment to avoid wastage of the small seed collection of seeds from the Mundoo Channel at Hindmarsh Island. It was difficult to determine which fruits contained mature seeds for the experiment, even under a microscope. Therefore, we needed to adjust the germination percentages to remove seeds that lacked a mature embryo, as seed fill was not high for the collection. This resulted in fewer seeds overall for the treatments, which was determined only at the ends of the experiments (destructive tests). Ideally, additional experiments would be conducted with other populations to gain further knowledge and confirm our results on germination responses to light, temperature and salinity.

Laboratory trials give insight into the germination of seeds under controlled conditions, however they do not replicate the fluctuating conditions in the field. This means that while we can make some assumptions about germination requirements and barriers, field trials are also needed that assess responses under natural climatic and soil conditions. We also only assessed the germination stage, therefore our trials do not provide evidence of the seedling establishment and survival, which are also vulnerable stages of reproduction. We elected to use sodium chloride (NaCl) for salinity trials, as this is commonly used to assess effects of

salinity stress and allows easy comparison with other species. It will also enable comparative analysis of water stress effects (osmotic potential) on seed germination, if this is conducted in the future. While seawater is dominated by sodium chloride, this does not reflect its true composition, and may have slightly different effects on germination, particularly in field conditions where concentrations fluctuate.

References

Barrett GJ (2000) Revegetation of salt-affected land after mining: germination and establishment of halophytes. (PhD), Curtin University of Technology

Baskin, C. C., & Baskin, J. M. (2014). Ecologically Meaningful Germination Studies. In Carol C. Baskin & J. M. Baskin (Eds.), *Seeds: Ecology, Biogeography, and Evolution of Dormancy and Germination* (pp. 5-35): Academic Press.

Boon P, Keith D and Raulings E (2016) 'Vegetation of coastal floodplains and wetlands in south-eastern Australia', in Capon S, James C and Reid M eds. (2016) Vegetation of Australian riverine landscapes: biology, ecology and management, CSIRO Publishing, Clayton, Victoria.

Cochrane, A., Yates, C. J., Hoyle, G. L., & Nicotra, A. B. (2015). Will among-population variation in seed traits improve the chance of species persistence under climate change? *Global Ecology and Biogeography, 24*(1), 12-24. doi:10.1111/geb.12234

Coleman P (2014) Samphires of the Adelaide and Mt Lofty Ranges regions, Natural Resources: Adelaide & Mt Lofty Ranges, Government of South Australia.

Coleman P and Coleman F (2024a) Shrubby samphire: A local recovery plan, Report prepared for Green Adelaide, Delta Environmental Consulting, DOI:10.13140/RG.2.2.11673.02402

Coleman P and Coleman F (2024b) Shrubby samphire: a soil study to inform restoration planning, Report prepared for Green Adelaide, Delta Environmental Consulting, Adela

Coleman P, Coleman F, Fotheringham D (2017) Thornbills, samphires & saltmarsh tipping points. Report prepared for Natural resources Adelaide & Mt Lofty ranges. Delta Environmental Consulting, Adelaide

Debez, A., Belghith, I., Pich, A., Taamalli, W., Abdelly, C., & Braun, H. P. (2018). High salinity impacts germination of the halophyte Cakile maritima but primes seeds for rapid germination upon stress release. *Physiol Plant, 164*(2), 134-144. doi:10.1111/ppl.12679

English, J. P., & Colmer, T. D. (2011). Salinity and waterlogging tolerances in three stem-succulent halophytes (Tecticornia species) from the margins of ephemeral salt lakes. *Plant and Soil, 348*(1-2), 379-396. doi:10.1007/s11104-011-0924-6

English, J. P., & Colmer, T. D. (2013). Tolerance of extreme salinity in two stem-succulent halophytes (Tecticornia species). *Functional Plant Biology, 40*(8-9), 897-912. doi:10.1071/fp12304

Fenner, M., & Thompson, K. (2005). Germination. In *The Ecology of Seeds* (pp. 110-135): Cambridge University Press.

Flowers, T. J., & Colmer, T. D. (2015). Plant salt tolerance: adaptations in halophytes. *Annals of Botany, 115*(3), 327-331. doi:10.1093/aob/mcu267

Gairola, S., Shabana, H. A., Al Ketbi, A., & Mahmoud, T. (2020). Seed Germination Behavior of Halophytes Distributed in Arid Arabian Deserts. In *Handbook of Halophytes* (pp. 1-17).

Monie, K., Turner, S.R., Palmer, G. (2025). A review of threatened and poorly known samphires in Australia: their distribution, observed environmental threats and ecological responses. *Biodivers Conserv* **34**, 1633–1669 (2025). https://doi.org/10.1007/s10531-025-03039-4

Monie, K., Turner, S.R., Palmer, G., Florentine, S.K. (unpublished, 2025). Effects of hydrothermal conditions and salinity stress on seed germination of threatened arid zone samphire *Tecticornia lylei*.

Mount RE, V Prahalad, C Sharples, J Tilden, B Morrison, M Lacey, J Ellison, Helman M and Newton J (2010) Circular Head coastal foreshore habitats: sea level rise vulnerability assessment: final project report to Cradle Coast NRM, University of Tasmania, Hobart.

Onofri A (2023). drcte: *Statistical Approaches for Time-to-Event Data in Agriculture*. R package version 1.0.30, https://cran.r-project.org/web/packages/drcte

Prahalad V (2019). Tasmanian coastal saltmarsh ecology and conservation. University Of Tasmania.Thesis. https://doi.org/10.25959/100.00031416

Purvis, J. E., Datson, B., Meney, K., McComb, K., & Coleman, M. (2009). Effect of salt on germination of samphire species. *Natural Resources and Environmental Issues, 15*.

R Core Team (2023). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Ritz, C., Baty, F., Streibig, J. C., & Gerhard, D. (2015). Dose-response analysis using R. *PloS One*, *10*(12), e0146021.

Sinclair SJ, Batpurev K and Kohout M (2022) 'Considering vegetation flood tolerance in estuary opening decisions', Ocean and coastal management 220:106071, https://doi.org/10.1016/j.ocecoaman.2022.106071

Threatened Species Scientific Committee (TSSC) (2013) Commonwealth conservation advice for subtropical and temperate coastal saltmarsh, Department of Sustainability, Environment, Water, Population and Communities, Canberra

Understorey Network Incorporated (2025) Understorey Network: Communities, Tecticornia arbuscula. Accessed 14/4/25 from http://www.understorey-network.org.au/communities.html?species=Tecticornia%20arbuscula

Zhang H, Mingfang H, Hongyuan M, Li J , Zhenyong Z , Jinbiao M, Lei W (2021). Differential Responses of Dimorphic Seeds and Seedlings to Abiotic Stresses in the Halophyte Suaeda salsa, Frontiers in Plant Science, Volume 12 – 2021, https://www.frontiersin.org/journals/plant-science/articles/10.3389/fpls.2021.630338, DOI=10.3389/fpls.2021.630338, ISSN=1664-462X

Appendix 1. Light and temperature – germination model parameters

Table 2. Model estimates of maximum germination proportion (d = P_{MAX}) and median germination time (e = t50) of germinated seeds, and quantiles of time in days to 1, 10, 25 and 50% germination of total seed sample under different light and temperature conditions

Proportion of seed sample	Parameter	12 hrs light / 12 hrs dark				Constant darkness			
		17/7 °C	25/15 °C	30/20 °C	35/25 °C	17/7 °C	25/15 °C	30/20 °C	35/25 °C
Total germinated seeds	P_{MAX} (d)	0.54 ± 0.05	0.63 ±0.05	0.52 ± 0.05	0.11 ± 0.03	0.48 ± 0.05	0.29 ±0.05	0.26 ±0.05	0.10 ± 0.03
	t_{50} (e)	18.70 ± 0.83	11.83 ± 0.92	10.71 ± 0.55	18.29 ± 2.83	20.85 ± 1.19	19.80 ± 3.67	21.40 ± 2.73	20.88 ±1.29
Total seed sample	t_1	9.00 ± 1.43	2.873 ± 0.45	4.57 ± 0.35	9.19 ± 1.28	8.73 ± 1.31	4.31 ± 1.17	7.45 ± 1.38	15.94 ± 1.96
	t_{10}	14.23 ± 2.10	6.67 ± 1.31	7.86 ± 0.37	35.73 ± 15.66	15.42 ± 2.77	14.88 ± 4.66	18.49 ± 3.17	32.79 ± 10.16
	t_{25}	18.17 ± 2.67	10.24 ± 2.21	10.56 ± 0.39		21.24 ± 4.34	48.09 ± 20.41	74.58 ± 12.97	
	t_{50}	29.52 ± 4.61	18.69 ± 4.58	22.51 ± 1.13					

Likelihood ratio test (null: time-to-event curves are equal), LR value: 256.4417, df: 21, p-value: 2.083577e-42

Appendix 2. Salinity – germination model parameters

Table 3. Model estimates of maximum germination proportion (d = P_{MAX}) and median germination time (e = t50) of germinated seeds, and quantiles of time in days to 1, 10, 25 and 50% germination of total seed sample under different salinity concentrations at optimal conditions of 25/15 °C (12 hrs light, 12 hrs dark).

Proportion of seed sample	Parameter	0 g/L (0 MPa)	6 g/L (-0.5 MPa)	18 g/L (-1.5 MPa)	30 g/L (-2.5 MPa)	36 g/L (-3.0 MPa)	54 g/L (-4.5 MPa)
Total germinated seeds	P_{MAX} (d)	0.63 ± 0.05	0.50 ±0.05	0.30 ± 0.05	0.33 ± 0.05	0.16 ± 0.04	Removed from model (zero germination)
	t_{50} (e)	11.83 ± 0.92	18.11 ±1.00	17.78 ± 0.91	28.46 ± 1.23	27.46 ± 0.71	
Total seed sample	t_1	2.88 ± 0.00	7.66 ± 0.24	10.14 ± 2.02	17.38 ± 6.14	23.62 ± 6.53	
	t_{10}	6.67 ± 0.00	13.32 ± 0.75	15.8 ± 1.85	25.26 ± 4.63	28.34 ± 4.94	
	t_{25}	10.24 ± 0.00	18.07 ± 0.01	22.84 ± 2.23	33.39 ± 4.94		
	t_{50}	18.69 ± 0.00	61.02 ± 0.09				

Likelihood ratio test (null: time-to-event curves are equal), LR value: 209.389, df: 12, p-value: 3.743147e-38