Freshwater Macrophyte Communities of the Macleay River

2015-2016

Final Report to Kempsey Shire Council

May 2016

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University of New England
Aquatic Ecology and Restoration Research Group

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Cover Photo:
Macleay River at Turners Flat Bridge and accompanying macrophyte bed made up of predominantly native species including: *Vallisneria nana*, *Myriophyllum verrucosum, Potamogeton octandrus, Potomogeton perfoliatus, Hydrilla verticillata, Najas tenuifolia* and *Elodea canadensis* (B. Vincent, 2015).

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A monospecifc, canopy forming stand of Egeria densa *in flower and covered in a filamentous alga in the Macleay River (B. Vincent, 2015).*

Contents

PART 1 A Literature Review of *Egeria densa* (Planch.)

1.1. Introduction

Egeria densa, commonly referred to as Leafy or Brazilian Elodea, Dense Waterweed or simply Egeria, is a herbaceous waterplant (macrophyte) and is native to the eastern South American countries of, Uruguay, Argentina and Brazil (Parsons & Cuthbertson, 1992). Egeria is recognised as one of the world's worst aquatic weeds, causing many direct impacts including ecological and economic losses.

Egeria is a member of the aquatic plant family *Hydrocharitaceae*. In Australian waterways, Egeria is easily confused with two other members of the same family: *Hydrilla verticillata* (Hydrilla) a native species, and *Elodea Canadensis* (Elodea) an exotic species (Figure 1) (Parsons & Cuthbertson, 1992). The sale and distribution of Egeria is banned in several Australian states and territories (Johnson, undated), including NSW, where it is classed state-wide as a type 4 noxious weed (NSW DPI, 2014). Here we review the current literature on *Egeria densa*, focusing on its dispersal, invasiveness, ecological and economic impacts on freshwater ecosystems and management techniques. We also summarise the existing information on the extent of *Egeria densa* in the Macleay River.

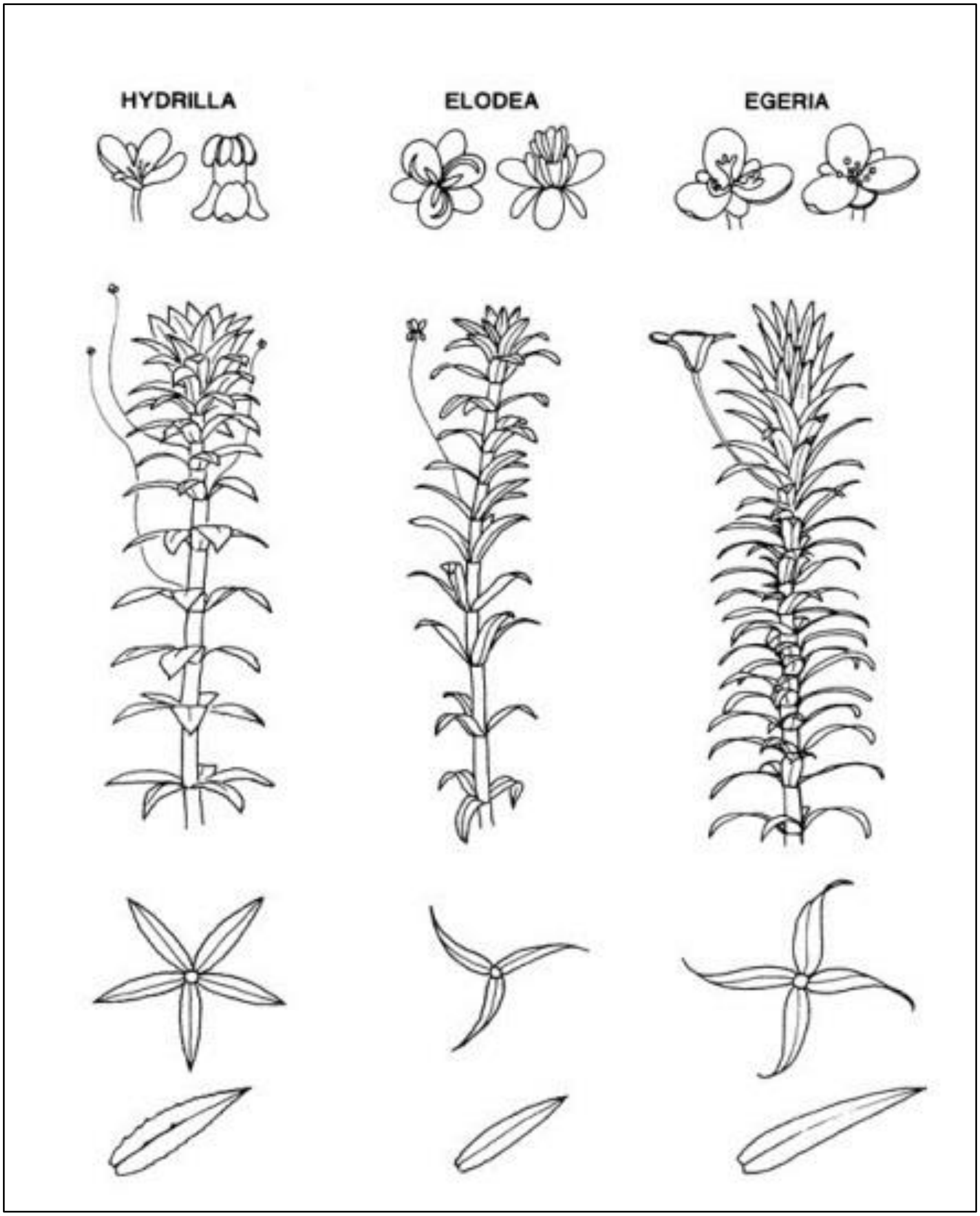

Figure 1. *Three of the most dominant freshwater macrophyte species in the Macleay River between Halls Peak and Kempsey. Note the similarity between all three members of the Hydrocharitaceae family. The native macrophyte* Hydrilla verticillata *is on the left.* Elodea canadensis*, the most prolific exotic weed in the Macleay River, is in the centre.* Egeria densa*, the exotic weed of interest, is pictured on the right (Image courtesy of UF/IFAS University of Florida, 2015).*

1.2. Description

Egeria densa is a submerged perennial freshwater macrophyte, with densely foliated 'leafy' and much branched buoyant stems (Parsons & Cuthbertson, 1992). Linear leaves are 1-3cm long, approximately 5mm broad, and bright green with minutely serrate margins (Parsons & Cuthbertson, 1992; Walsh et al; 2013). Egeria has short internodes and leaves are generally present in whorls of 3-7 (Parsons & Cuthbertson, 1992). Both male and female flowering plants occur in their natural habitat. However, only male plants exist in Australia. White showy male flowers, approximately 1-2cm in diameter, are presented just above the water surface on long perianth tubes (Figure 2) (Parsons & Cuthbertson, 1992; Walsh et al., 2013), with flowering taking place throughout summer and into early autumn (Sainty & Jacobs, 1994). The plant can be found as floating beds or rooted to the substrate at depths of up to 7m (Parsons & Cuthbertson, 1992). Outside its natural range, Egeria can form dense monospecifc, canopy-forming stands and is capable of tremendous primary productivity, achieving a large standing biomass (Yarrow et al., 2009).

Figure 2. *A close-up image of the flower produced by the male plant of Egeria, Macleay River (Ben Vincent, 2015).*

1.3. Distribution

Originally promoted as a good "oxygenator" of fresh water, Egeria has been widely naturalised outside its range as a result of the aquarium trade. Subsequently, Egeria is now found on all continents except Antarctica (Yarrow et al. 2009), most notably throughout the waterways of the Americas, Europe, New Zealand and Australia (Sainty & Jacobs, 1981, Parsons & Cuthbertson, 1992). Egeria was first reported growing in Australia's waterways, in the suburbs of Melbourne in the early 1950s (Parsons & Cuthbertson, 1992). By the early 1980s, Egeria had migrated north into NSW coastal water systems (Sainty & Jacobs, 1981), and was recorded in low abundance in the Hawkesbury-Nepean River in 1986 (Roberts et al. 1999). *Egeria densa* was first reported in the Macleay River near Kempsey, NSW, in 1998 (MHL, 1998), and has been described in the reaches both upstream and downstream of Fredrickton (MHL, 1998; West et al., 2004; Telfer, 2005; WMA Water, 2009).

Egeria prefers nutrient-rich, still, or slow flowing waters (Sainty & Jacobs, 1994). Optimal growth occurs in shallow, low-light, turbid conditions, in water temperatures of 25°C. However, the plant can tolerate a range of temperatures and grows between 10°C and 35°C (Johnstone et al., 2006). Growth is accelerated in spring by the plant's ability to store energy overwinter in its basal stems and root crown (Walsh et al., 2012).

1.4. Dispersal

Despite its ability to sexually reproduce, only male plants of *Egeria densa* have been naturalised in Australia, where dispersal is by asexual (vegetative) means (Parsons & Cuthbertson, 1992). Vegetative spread and propagation occurs when stem fragments greater than two nodes in length are broken-off from the parent colony and transported downstream by dispersal vectors (Parsons & Cuthbertson, 2001; Sainty & Jacobs, 2003). Adventitious roots and new shoots form from buds along the stem fragments. Once established, plants put on new growth in spring, with growth continuing rapidly throughout summer until early autumn. This allows the plant to establish thick beds of intertwined stems just below the water surface (Parsons & Cuthbertson, 2001). Growth rates may vary depending on a range of factors; however, under optimal conditions in Lake Rotoroa in New Zealand, Egeria populations were observed to double in density in the space of one year (Tanner et al., 1990), while in the U.S., Egeria increased 10-fold within two years (Washington State Department of Ecology, 2003).

Once established in an aquatic system, the main means of dispersal is by stem fragments being rapidly transported downstream stream during both baseflow and flood events (Roberts et al., 1999). The species can also be translocated through boating (Thomaz et al. 2015) and fishing activities (NSW DPI, 2016), and can also be spread as a result of mechanical control techniques, as the large numbers of small fragments are usually broken-off during the removal process (Yarrow et al., 2009). Despite its recognition as an illegal water plant in Australia, Egeria occasionally is still deliberately planted and harvested for the aquarium trade (NSW DPI, 2016; Johnson, undated).

1.5. Egeria Invasiveness

Egeria densa has been recognised as one of the most invasive macrophyte species in the world (Thomaz et al., 2015). The susceptibility of ecosystems to exotic macrophyte invasion is controlled by abiotic and biotic conditions within those ecosystems (Thomaz et al. 2015). Disturbance rates, resource availability, severe drought, low nutrient concentrations, and extreme acidity and salinity are some of the abiotic filters that influence 'invasibility' (Fridley, 2011), while the diversity of native species (Capers et al., 2007; Michelan et al., 2013) and native herbivores and pathogens are examples of biotic filters that can reduce invasibility (Keane & Crawley, 2002; Blossey, 2011) . The invasiveness of a plant species are controlled by the particular traits that it possesses, such as the ability to produce tubers or rhizomes, reproduce asexually from fragments, a high phenotypic plasticity, a combination of short life cycles and rapid growth rates, and efficient dispersal mechanisms (Sculthorpe, 1967; Santamarı´a, 2002; Bianchini Junior et al., 2010; Thie´baut, 2011; Schultz & Dibble, 201). All of these are traits of *Egeria densa*. Additionally, the metabolism of Egeria further increases its adaptability and invasiveness, as Egeria has the physiological ability to switch photosynthetic pathways under very low CO_2 levels to a C_4-like pathway, offering a flexible carbon incorporation strategy; this is a useful tool in lentic freshwater systems (Yarrow et al., 2009).

Exotic macrophyte species regularly perform better than native species in anthropogenically eutrophic aquatic systems (Daehler, 2003). Eutrophication, either naturally occurring or human-induced, refers to the process of nutrient enrichment in waterbodies (mainly compounds of Nitrogen and Phosphorus), promoting excessive plant growth, resulting in an accumulation of organic matter (Boulton et al., 2014). Despite the belief that rooted macrophytes obtain most of their nutrients from the sediment even in eutrophic systems (Carignan & Kallf, 1980; Barko & Smart, 2006), Quinn et al., (2011) reported that in Australian rivers, there was an association between exotic species and eutrophic conditions that was not observed in native species. Invasive macrophytes such as *Egeria densa* are not limited by nutrient availability in the sediment (Quinn et al., 2011), because they can take up nutrients suspended in the water column. Thus, nutrients in the water column and the sediments both influence macrophyte invasiveness. Hence, eutrophic systems have an increased risk of invasion (Engelhardt, 2011). This agrees with the "fluctuation of resource availability" hypothesis that states 'invasibility increases whenever and wherever the quantity of resources not used by natives species increases' (Davis et al., 2000).

In addition to eutrophication, climate change is also expected to increase the success of invasive macrophyte species, not least through increased temperatures (Thomaz et al. 2015) and the potential acidification of freshwater ecosystems (Trenberth et al., 2007). Species of the family *Hydrocharitaceae* including *Egeria densa*, can use dissolved organic and inorganic compounds as additional resources for growth, the availability of which may increase in acidified freshwaters (Vestergaard & Sand- Jensen, 2000). This will give these species a competitive advantage over other (native) macrophyte species (James et al., 1999, & Mormul et al., 2012).

Egeria has a high potential to rapidly colonise disturbed areas (Pistori at al., 2004; Mony et al., 2007). For example, since its establishment in the Hawkesbury River, floods have rapidly increased the range and spread of Egeria (Roberts et al., 1999). Although the degree of invasion susceptibility in the Macleay is unknown, it has been suggested by some that macrophytes in the lower Macleay River have increased in recent years to levels of weediness, with macrophyte beds now dominated by the exotic species *Egeria densa* and *Elodea canadensis* (Telfer, 2005; WMA Water, 2009; GeoLINK, 2010). Egeria has reportedly rapidly spread through the Macleay (GeoLINK, 2010), with a combination of nutrient enrichment, floods, acidified waters, anthropogenic disturbance and physiological traits the suggested causes of its range expansion.

1.6. Egeria Impact

Macrophyte weeds are among the world's worst weeds in terms of their direct economic and ecological losses (Charudattan, 2001; Bunce et al., 2002). In Californian lakes and reservoirs, Egeria reportedly spreads at the rate of 100 acres per year, given the right environmental conditions, with removal costs estimated at several million dollars per annum (Californian State Parks, 2014). In Australian waterways, *Egeria densa* is a pest species (Bowmer et al., 1984) and can cause economic damage (Roberts et al., 1999; Walsh et al., 2013) by increasing siltation, slowing water velocity, choking irrigation channels, clogging equipment, and impeding hydroelectricity activity, navigation in waterways, commercial and recreational fishing, boating, swimming and other recreational activities (Parsons & Cuthbertson, 2001); it may even depreciate the monetary and aesthetic value of waterfront property (Roberts et al., 1999).

Egeria is able to rapidly produce under ideal conditions (Pistori et al., 2004) negatively affecting ecosystem functions and services (Yarrow et al., 2009). Thick, monospecific stands beds of *Egeria densa* are known to cause environmental impacts by crowding-out, reducing or replacing native aquatic flora, altering habitat conditions, reducing light density, depleting dissolved oxygen, and causing fluctuations in water quality (Cronk & Fennessy, 2001; Weber, 2003; Yarrow et al., 2009; Walsh et al., 2013; Johnson, undated). Roberts et al. (1999) suggest that in the Hawkesbury system, dense beds of *Egeria densa* are negatively impacting water chemistry, changing the distribution and abundance of both native macrophytes and invertebrates, and inhibiting fish migration. Ecological impacts from exotic macrophyte invasions may be cascading, resulting in the change of whole communities or even entire ecosystem changes (Bunn et al., 1998; Midgley et al., 2006; Yarrow et al., 2009; Coetzee et al., 2014). The invasion of exotic macrophytes has in some cases been the direct cause of decreases and local elimination of native macrophytes (Parsons et al., 2009; Thomaz et al., 2015). For example, in the Hawkesbury River in NSW, Vallisneria Americana (now *V.australis* or *V.nana*) abundance is in significant decline since the invasion of *Egeria densa* (Roberts et al., 1999). Nonetheless, there is no record of an extinction caused by an invasive macrophyte species (Thomaz et al., 2015), and cases where Egeria represents a real threat to native species diversity and ecosystem function are low in number (Roberts et al., 1999).

Similarly to the native macrophyte *Hydrilla verticillata*, *Egeria densa* can form large, dense surface covers (Haller and Sutton 1975, Sainty and Jacobs 1994) that effectively limit the amount of light penetration into the water column, allowing the species to intercept a greater amount of light and potentially outcompete the native *Vallisneria* sp. (Roberts et al., 1999).

While *Egeria densa* has not caused the severity of problems in Australia as it has to date in other countries, e.g. Japan, New Zealand, and the United States (Roberts et al. 1999), the authors of an Australian study into the impact of Egeria expressed concern at the speed at which Egeria was dispersing and increasing in abundance, and its potential to quickly displace native macrophyte species (Roberts et al., 1999). In the Hawkesbury-Nepean River, NSW, *Egeria densa* had significantly increased in biomass during a two year period, and appeared to be outcompeting and displacing the native *Vallisneria* a*mericana* (now *Vallisneria australis*), impeding river flow, restricting fish migration and modifying native fish and invertebrate ecology (Roberts et al. 1999). To our knowledge, the full extent of the impacts of Egeria on the Hawkesbury/Nepean River system are unknown for the sixteen years since Egeria establishment.

While the negative effects of Egeria have been well documented (Roberts et al., 1999; Cronk & Fennessy, 2001; Parsons & Cuthbertson, 2001; Weber, 2003; Yarrow et al., 2009; Walsh et al., 2013; Johnson, undated; Californian State Parks, 2014; Thomaz et al., 2015), potential positive effects also need to be considered. Waterbirds have been observed actively feeding amongst Egeria beds in countries where it has been naturalised (Bartodziej & Weymouth, 1995; Corti & Schlatter, 2002), including Australia. During their field studies on the Macleay River, GeoLINK (2010) observed water birds such as pelicans, black swans, and great and little black commorants feeding among Egeria, in addition to observing eels, mullet, glass fish, gudgeons and gobbies swimming amongst the exotic macrophyte species. West et al. (2004) noted that in the Macleay River, Egeria may also provide habitat for the freshwater Australian Bass. However, Egeria may also support pest species, such as Mosquito Fish (*Gambusia holbrooki*), as was observed in this study (Figure 3). In its native range, Egeria supports relatively diverse communities of epiphytic algae, zooplankton and fish species (Pelicice & Agostinho, 2006), and may also increase macroinvertebrate biomass (Diehl & Kornijów). While determining which species utilise Egeria may present practical difficulties due to its weedy dense growth (Birch/GeoLINK, 2010), the ecological role of Egeria in the Macleay River is a question worth pursuing.

Egeria has recently been recognized as an 'ecosystem engineer' due to the species' increased capacity to stabilise sediment, reduce turbidity, and sequester excess nutrients (Yarrow et al., 2009). Studies comparing nutrient uptake in both native and exotic macrophytes in nutrient enriched aquatic systems, found exotic species increased in productivity by shifting allocation patterns to take advantage of increased nutrients, while native species were often unaffected or negatively affected (Woo & Zedler, 2002; Houlahan et al., 2006; Quinn et al., 2007; Hastwell et al., 2008). It is therefore plausible that along with other macrophyte species in the Macleay River, Egeria may act as a nutrient sink in that it takes up excess nutrients from the sediment and water column that would otherwise promote algal blooms (WMA Water, 2009).

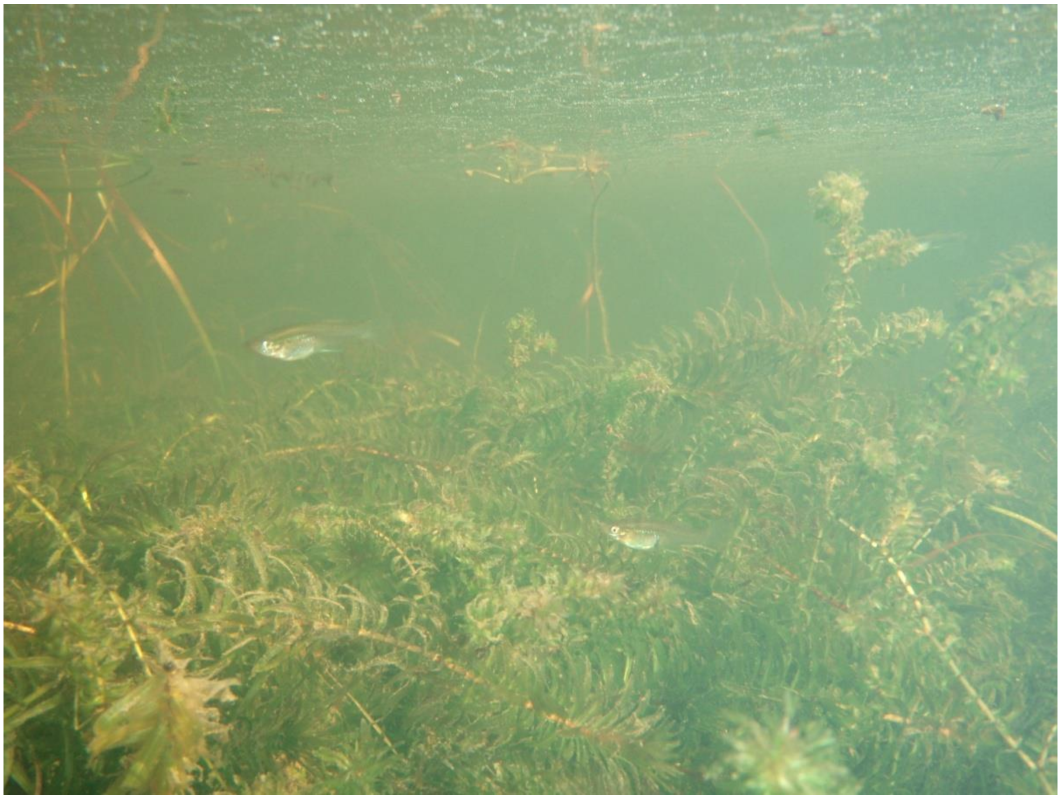

Figure 3 *Egeria may provide habitat for both native and exotic fish species, such as the Mosquito Fish* (Gambusia holbrooki) *pictured above in the Macleay River (Ben Vincent, 2015).*

1.7. Egeria Control

Once *Egeria densa* is established in an aquatic system, removal is extremely difficult at best, and likely impossible (Csurhes et al., 2008). The difficulty with Egeria removal is that all control and removal methods need to thoroughly kill or completely remove the plant in order to prevent regrowth from stem fragments (Jordan, 2007). However, manipulation of any or all of the abiotic requirements needed to support macrophyte growth (that is, sufficient water, light, nutrients, a suitable temperature range, and an appropriate substrate) can result in some level of control of a macrophyte species (Roberts et al., 2001). Trialled removal techniques include physical removal, flow regimes and natural disturbance, chemical control, biological control, and reduced nutrient input and riparian management and are discussed next.

1.7.1. Physical removal

Small-scale hand-pulling or large-scale mechanical control can temporarily reduce *Egeria densa* biomass. However, such methods have also proven counterproductive in that they also promote the rate of spread of Egeria by producing large numbers of small broken stem fragments, each capable of forming a new plant (Parsons & Cuthbertson, 2001). Following removal, plants are then destroyed by burning, drying, burying or can even be used as fertiliser (Sainty & Jacobs, 2003). Physical and mechanical removal methods are only effective as 'short-term solutions' (Oliveira et al., 2005;Yarrow et al., 2009; Curt et al., 2010), and harvesting and mowing techniques should only be employed as last resort control measures (Washington State Department of Ecology, 2003; Curt et al., 2010).

1.7.2. Flow regimes and natural disturbance

Flow attributes such as flood timing, time since last flood, magnitude, rate of drawdown, duration, and frequency all affect macrophyte community composition and structure; the response of specific species depend on specific attributes and interactions with flooding and drying regimes (Capon et al. 2009). Given its preference for slower moving waters (GeoLINK, 2010), anecdotal evidence suggests that large flood events may remove the majority of built-up biomass of Egeria (Rod McDonagh *pers comm*. cited in GeoLINK, 2010). However, Roberts et al. (1999) reported that in the Hawkesbury-Nepean River, flooding has actively promoted the downstream spread of Egeria.

A combination of low temperatures and desiccation could potentially remove Egeria from a system (Yarrow et al., 2009). As *Egeria densa* is intolerant of dessication, it requires a permanent water source for growth and propagation (Capon et al. 2009). Water level fluctuations, such as flushing and draining under manual flow regimes, have proved successful in managing Egeria in certain situations, such as lakes and reservoirs (Sainty & Jacobs, 2003). For instance, in Lake Mulawa, a dam on the Murray River on the NSW/VIC border, several lake drawdowns were employed, with the second significantly reducing Egeria biomass and distribution from 60% volume of the lake in 2008, to 1% the following year (MDBA, 2015).

Natural disturbances may also reduce invasiveness. An Australian study found that during a prolonged drought period when water levels dropped low enough to expose plants to air and desiccation, stem viability in *Egeria densa* was compromised (Dugdale et al., 2012). Given that the Macleay River is susceptible to drought (West et al., 2004), naturally occurring seasonal fluctuations may result in drying phases where Egeria biomass is reduced. This would promote native species (for example, *Myriophyllum verrucosum*) that have adaptations to such events.

Additionally, as salinity increases, *Egeria densa* growth rates and root formation are reduced, with growth completely stopping at concentrations greater than five parts per thousand (<5ppt, Johnstone *et al*. 2006). Therefore, thick macrophyte beds dominated by Egeria in the Kempsey/Christmas Creek vicinity, observed by previous authors (MHL, 1998; West et al., 2004; Telfer, 2005; GeoLINK, 2010), may be the species' downstream limit in the Macleay River.

1.7.3. Chemical control

Chemical control of Egeria has been partially achieved through the combined use of copper and herbicides, but can have detrimental effects to the surrounding aquatic environment (Westerdahl & Getsinger, 1988; Curt et al., 2010). In the U.S., Diquat, Endothall (aquatic herbicides) and complexed copper combinations are used to suppress the growth and spread of Egeria, with excellent results (Westerdahl & Getsinger, 1988). However, a recent study in New Zealand on the effectiveness of these two aquatic herbicides produced mixed results. Not only was Endothall found to be ineffective in killing *Egeria densa*, it was effective in killing native *Potamogeton* and *Myriophyllum* species, while Diquat was found to be ineffective in turbid waters (Hofstra & Clayton., 2001). Two further products, 'triclopyr', and 'dichlobenil', produced temporary epinastic shoot growth and reduced vigour, respectively, in all study species (Hofstra & Clayton., 2001). The authors of this study concluded these products had limited success in killing targeted weed species and had negative impacts on native macrophyte species (Hofstra & Clayton., 2001). Nonetheless, small infestations of *Egeria densa* in Tasmanian waterways are currently treated with both Diquat and a product called Hydrogel (DPIPWE, 2014).

The use of Fluridone (Sonar®) for the control of Egeria in a lake in the U.S. reduced the waterweed by 95%, with subsequent regrowth still suppressed 5 years later at 11% of the initial population (Washington State Department of Ecology, 2003). For the first two years following Fluridone treatment, native macrophyte frequency was also reduced. However, there was an increase in species richness three years after treatment, and despite lower densities during the reestablishment phase, there appears to be limited long-term negative effects on native macrophyte species (Parsons et al., 2009). In Australia, Fluridone has been trialled for suppression of weedy native macrophyte growth, particularly *Vallisneria* sp. in artificial lakes used for Olympic training and competition and recreational purposes (Roberts et al., 2001). Although there was a six-month delayed response following Fluridone treatment, significant declines were detected in species richness and biomass of native macrophyte species including *Vallisneria australis*, *Hydrilla verticillata*, *Myriophyllum verrucosum*, and four *Potamogeton* spp., (Roberts et al., 2001), all of which are present in the Macleay River.

Chemical applications for the control of *Egeria densa* in rivers are limited by environmental constraints (Cronk & Fennessy, 2001; Parsons & Cuthbertson, 2001; Washington State Department of Ecology, 2003; Weber, 2003). While in some situations chemical control is deemed a suitable management mechanism, herbicide treatments need to be first approved. In NSW, Reglone® (Diquat) is currently the only herbicide registered for use in controlling Egeria (DPI, 2015). Up to date chemical information should be sought before use from both the Australian Pesticides and Veterinary Medicines Authority website (APVMA, 2016) and the Department of Primary Industries 'NSW WeedWise' website (DPI, 2015).

1.7.4. Biological control

Where chemical herbicides are deemed too expensive, ineffective, or damaging to the environment, a biological control might provide the only suitable control solution (EDCP, 2006). The 'enemy release hypothesis' supposes that in their new ranges, invasive species have escaped their natural enemies: herbivores and pathogens in the case of macrophytes (Blossey, 2011). Thus, a biological control agent is often missing from the species' new found range.

In Argentina, a native leafminer fly, *Hydrellia* sp. has been found feeding on Egeria, making it the only currently known specialist herbivore of *Egeria densa* (Walsh et al., 2013). Early results indicate that this Dipteran species may be a suitable candidate for biological control (Walsh et al., 2013). In Brazil, a fungus species (*Fusarium* sp.) which reportedly damages *Egeria densa*, is a subject of ongoing research for its potential as a biological control agent (Washington State Department of Ecology, 2003; Curt et al., 2010).

In addition to pathogens and invertebrates, fish and bird species may also reduce Egeria biomass. As an unwelcomed noxious species with invasive risks of its own, the Grass Carp (*Ctenopharyngodon idella*), has been introduced into some lakes in the U.S and feeds on Egeria (Washington State Department of Ecology, 2003; Curt et al., 2010). However, the carp is also capable of removing entire macrophyte communities, native species included, and should only be introduced into water bodies where inlets and outlets can be screened (Washington State Department of Ecology, 2003). During an Egeria eradication study in small reservoirs in Spain, the authors of a three year study concluded that while complete removal of the macrophyte was not possible, domestic Peking ducks (*Anas platyrhynchos*) proved to be an effective control of the waterweed (Curt et al., 2010). Although the ducks reportedly broke of stem fragments while eating the plants leaves and tips as a protein and fibre source, they reportedly stripped them of leaves, rendering them unable to spread and making them susceptible to decay (Curt et al., 2010). Other studies have also highlighted the potential for *Egeria densa* control by waterbirds (Lopetegui et al., 2007). In two southern Chilean wetlands, Corti & Schlatter (2002) found that the Black-necked Swan (*Cygnus melanocoryphus*) was dependent on Egeria for up to 92% of its dietary requirements, and may therefore play an important role as a regulator of Egeria.

Interestingly, no studies of invasive macrophytes to date have looked at the genetic diversity of *Egeria densa* in Australia. A study in Brazil on populations of *Hydrilla verticillata*, a native Australian macrophyte, has shown that invasion of the species throughout the Parana River Basin are all clones of the first successful invasive population (Thomaz et al., 2015). While genetic diversity of Egeria has not been extensively examined, early studies between North and South American populations indicate "remarkably similar genotypes", suggesting that the species may be susceptible to pathogen attacks (Yarrow et al., 2009), and that control methods targeting particular genetic strains might offer potential future control options.

1.7.5. Reduced nutrient input and improved riparian management

Anthropogenic disturbance and intensive land use promotes species richness and abundance in exotic macrophytes (Catford & Downes, 2010; Sass et al., 2010; Quinn et al., 2011). Furthermore, a meta-analysis concluded that exotic aquatic species also generally outperform native aquatic species in eutrophic conditions (Gonzalez et al., 2010; Quinn et al., 2011). This may be because exotic macrophytes generally have a greater phenotypic plasticity than native species, making them fitter, hardier plants capable of adapting to a greater range of conditions (Hastwell at al., 2008). For instance, while phosphorus (P) appears to be the commonly limiting nutrient, Egeria readily and rapidly absorbs both nitrogen (N) and P from the water column, and can continually take up nutrients without increasing biomass (Feijoó et al., 2002). Long-term management of evasive macrophytes in nutrient rich systems is therefore likely to require reduced nutrient loading (Johnson, undated), through the use of slow release fertilisers (Boulton et al., 2014), reduced anthropogenic disturbance and improved land management practices (Boulton et al., 2014; Thomaz et al., 2015).

Additionally, the main biotic filters required to deter invasive macrophytes - competition, herbivory and pathogen activity - are achieved through the maintainance of natural macrophyte cover and species assemblages that support accompanying natural pathogens and herbivores (Roberts et al., 1999; Quinn et al., 2011). It has also been proposed that aquatic systems may be less susceptible to macrophyte invasion through maintenance of a healthy functioning riparian zone, due partly to a shading effect (Boulton et al., 2014; Thomaz et al., 2015), and partly through nutrient buffering.

1.8. Summary

Egeria is recognised as one of the world's worst aquatic weeds. Outside of its natural range in South America, Egeria has naturalised throughout many countries on all continents except Antarctica, mainly as a result of the aquarium trade and anthropogenic disturbance. With the ability to reproduce asexually, Egeria is able to rapidly expand its range in aquatic systems once established. Egeria growth is promoted by favourable biotic and abiotic factors such as high nutrient inputs, high disturbance rates, high plasticity, reduced or removed natural herbivores and pathogens and efficient dispersal mechanisms. The impacts caused by Egeria are many, and include direct ecological loses such as reducing or replacing native aquatic flora, reducing light density and altering habitat conditions, and also economic losses by increasing siltation, reducing water flow, choking irrigation channels, reducing navigation in waterways and impeding commercial and recreational fishing activities. Control options are currently limited to chemical and physical control and these have their own negative environmental impacts. Ongoing research into biological controls is producing promising results. Long-term management of *Egeria densa* is likely to involve a combination of the control options discussed, in addition to a reduction in nutrient loading and anthropogenic disturbance, improved land management practices and restoration of riparian vegetation.

PART 2 Mapping macrophytes in the freshwater Macleay River with a focus on the exotic weed species *Egeria densa* (Planch.)

2.1. Introduction

The Macleay River Catchment (11,450km^2) (GHD, 2015), is located on the Mid North Coast of New South Wales, 340kms north of Sydney. Major town centres in the catchment include Armidale, Guyra, Uralla and Walcha on the Tablelands, Kempsey on the floodplains and South West Rocks at the river mouth. The Macleay River Catchment is typified by five distinct landform units, that from west to east are the Tablelands, Escarpment and Ranges, Hills (low elevation), Coastal Floodplains, and Coastal Sandplains (Alluvium, 2012). Significant tributaries of the mid-to-upper Macleay include Salisbury Waters and the Gara, Tia, Apsley, Wollomombi, Chandler and Styx Rivers, Kunderang and Warbro Brooks, and Georges, Fiveday, Nulla Nulla, Toorumbee and Dungay Creeks (Figure 4).

Prior to European settlement in the 1830s, the Macleay River Catchment was inhabited by the Aboriginal Dunghutti nation (WMA Water, 2009). Early land use by European settlers was primarily for timber gathering and ship building on the floodplains, followed by clearing on the tablelands for agriculture, cropping and the grazing of livestock, with accessible parts of the escarpment and gorge country logged for timber and small areas of mining in the gorge country (WMA Water, 2009). Today, landuse in the Macleay catchment is diverse and includes cattle and sheep grazing, horticulture and cropping, dairying, mining and quarrying, forestry and agro-forestry, light and commercial industry, urban and tourist development, National Parks, and fishing and oyster farming (WMA Water, 2009). Further information detailing catchment characteristics, historic and current landuses, and ecological condition can be found in previous Macleay Catchment based studies (West et al., 2004; Telfer, 2005; WMA Water, 2009; GeoLINK, 2010; GHD, 2015).

Past and present land tenure, vegetation clearing and historic mining practices in the Macleay Catchment have contributed to heavy metal contamination, in the form of arsenic and antimony (WMA Water, 2009; GHD, 2015), and resulted in highly degraded, weedy riparian zones where pasture species outcompete native fringing vegetation (GeoLINK, 2010; Ryder et al., 2016). Nutrient enrichment of the Macleay River is a product of both urban and rural runoff as a result of anthropogenic disturbances, including agricultural practices and sewerage treatment plant discharges (WMA Water, 2009), and is the suspected cause contributing to an increase in the presence of in-stream exotic macrophytes, notably Egeria densa and Elodea canadensis (MHL, 1998; West et al., 2004; Telfer, 2005; WMA Water, 2009; GeoLINK, 2010). Other than an earlier study mapping fish habitats in the Macleay (West et al., 2004) little is known of the extent of exotic or native macrophyte species in the main trunk of the Macleay.

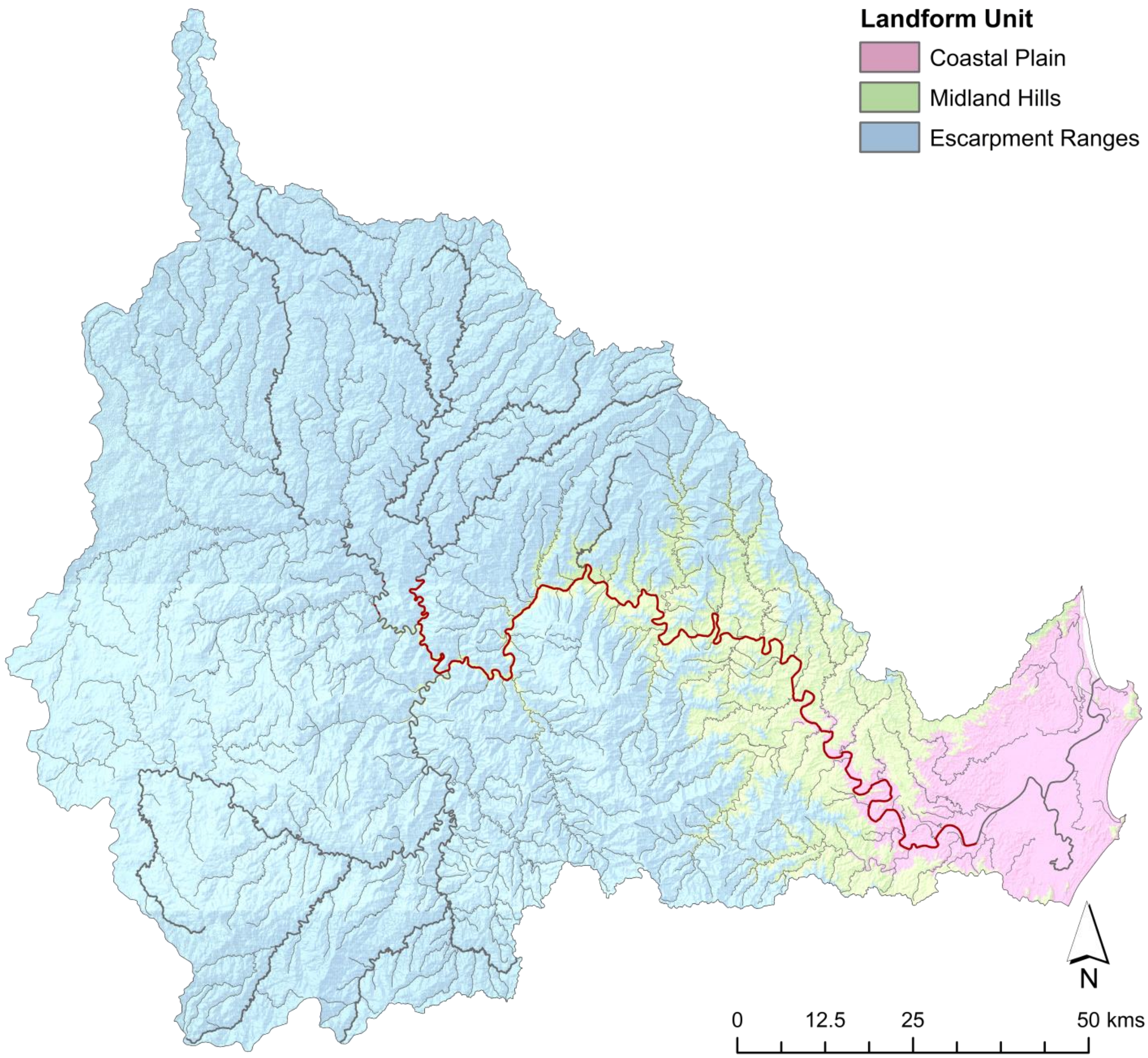

Figure 4 *The Macleay River catchment showing the study reach (red streamline) and the escarpment ranges, midland hills and coastal plain landform units (blue, green and pink, respectively).*

2.2. Freshwater macrophytes

Macrophyte is the term given to aquatic plants that are visible to the naked eye, are floating, emergent or submergent, and include flowering plants, ferns and large algal species (Boulton et al. 2015). Macrophytes are found worldwide in most aquatic systems such as lakes, rivers, wetlands reservoirs and estuaries (Thomaz et al. 2015). Macrophytes perform vital biological roles in aquatic ecosystems (Westlake, 1975), providing food and habitat to a variety of organisms including invertebrates, fish and birds (Dibble et al., 1996). They also perform important ecological roles reducing riverbank erosion (Carpenter & Lodge, 1986), and influencing water and nutrient cycling by removing excessive nutrients (Carignan & Kallf, 1980; Carpenter & Lodge, 1986; Barko et al. 1991, Hart et al. 1993; Bronmark & Hansson, 2005;). Their ability to remove and effectively control excess nutrients is an increasingly valuable ecosystem service for anthropogenically disturbed aquatic ecosystems (Roberts et al. 1999).

Native macrophytes are an important natural biological feature in rivers because they enhance water quality by: (all taken from Sainty & Jacobs, 1994).

- Removing sediments and nutrients from the water column and competing with algae, thereby reducing the occurrence of problematic blooms.
- Reducing river bank and river bed erosion by slowing river flow and trapping suspended sediment.
- Providing food, habitat and breeding sites for a variety of aquatic and terrestrial organisms including invertebrates, crustaceans, turtles, fish and birds.
- Producing dissolved oxygen, an essential requirement for aquatic fauna and important to the regulation of nutrient release by sediments into the water column.
- Reducing turbidity by slowing river flow.
- Controlling both light penetration and water temperature, thereby restricting algal growth and providing aquatic habitat.
- Maintaining in-stream habitat and species diversity and aesthetic appeal.

2.3. Previous Macleay macrophyte studies

Egeria densa is now naturalised throughout coastal NSW (Sainty and Jacobs 1981), including in the Macleay River (MHL, 1998; West et al., 2004; Telfer, 2005; WMA Water, 2009; GeoLINK, 2010). Several previous Macleay River studies have documented the presence of *Egeria densa* and attempted to quantify its density, spread and impact in sections of the main trunk of the river (MHL, 1998; West et al., 2004; Telfer, 2005; WMA Water, 2009; GeoLINK, 2010). These are summarised below.

MHL, 1998 –

Manly Hydraulics Lab first described the presence of *Egeria densa* in the Macleay River in the vicinity of Christmas Creek during an environmental baseline study (MHL, 1998). As part of their assessment of macrophyte bed width and species composition, they introduced a method of sampling macrophytes using transect survey lines at four locations crossing the Macleay River (MHL, 1998). Using visual assessments MHL reported extensive and continuous macrophyte beds (10-25m wide) along both the right and left banks of the Macleay River, adjacent to the floodplain between Kempsey and Bellimbopinni (1998). Native macrophyte species (*Vallisneria sp., Potamogeton spp.*, *Najas tenuifolia* and the higher order algal species *Chara* sp.), and exotic macrophyte species (*Egeria densa*, and *Elodea canadensis*) were present (MHL, 1998). The authors reported that the mid-section of the river, approximately 150-200m in width (what we have referred to in our report as Channel Vegetation), was 3-4metres deep and void of macrophyte beds (MHL, 1998). MHL (1998) suggested that the large, lush and very dense macrophyte beds on the left and right banks could be a result of nutrient loading, but they could not be sure for how long the beds had been present. Egeria was recorded from only one side of the river on just one of the four transect lines (MHL, 1998).

West et al., 2004 –

West et al. conducted a large scale study as part of their Bass Habitat Mapping Project in the Hawkesbury, Shoalhaven and Macleay Rivers (2004). In the Macleay, 80% of the river habitat from Georges Junction to the mouth of the River was mapped (West et al., 2004). Field surveys were conducted using a series of thirty-one ortho-rectified, digitally mapped aerial photographs. In addition, a continual 500m buffer zone was produced that assessed the adjacent landuse to the river, and river features including pools, rapids, riffles and runs were mapped. Macrophytes were visually assessed and logged where water was clear, while a depth sounder in combination with a bathyscope and underwater video were used to assess areas of less clarity. Following 144 km's of sampling on the Macleay River, 87% of the bottom of the freshwater section of the Macleay River was found to be devoid of macrophytes (West et al., 2004). In addition, the authors reported that the majority of the Macleay River macrophyte beds mapped were of 'undesirable' plant species, dominated by *Elodea Canadensis* (30% of total macrophytes). Native macrophytes species included *Myriophyllum spp*., *Vallisneria spp*., and *Potamogeton spp*. (20, 15, and <1% of the total macrophytes, respectively), with neither *Hydrilla verticillata*, nor *Najas tenuifolia* observed in the Macleay River during this study (West et al., 2004). *Egeria densa* was recorded at very low levels (<0.05% of total macrophytes), while a further 30% of macrophyte cover was reported as unknown (West et al., 2004). Similarly to MHL (1998), West et al. (2004) suggested that eutrophication may be promoting undesirable species, listing *Elodea canadensis* as the 'problem plant' in the Macleay River. Based on a study conducted by Harris (1988), West et al. (2004) considered the in-stream presence of both Elodea and Egeria representative of poor water quality, while good water quality was indicated by the presence of *Vallisneria* spp. Despite *Vallisneria* spp. totaling 15% of all macrophytes recorded, West et al. (2004) reported little evidence of Vallisneria in the Macleay River.

Telfer, 2005 –

In their review of existing research, Telfer (2005) highlighted the potential link between weedy macrophytes and elevated nutrient levels in the Macleay River, and the need to address this knowledge gap, as well as the range extent and impact on native macrophyte species of the weedy, exotic macrophytes *Egeria densa* and *Elodea canadensis*. The recommendations of this study were to study the response of exotic species to different natural flow regimes, including drought, baseflow and flood events, different levels of nutrient increase, and the impact that both Elodea and Egeria had on native macrophyte species in the Macleay River (Gerrand, 2005; Telfer, 2005).

WMA Water, 2009 –

The authors of this report note the difficulty in ascertaining the impact of exotic species and the need for extensive macrophyte surveys in the Macleay River (WMA Water, 2009). They suggest that the exotic macrophytes species *Egeria densa* and *Elodea canadensis* may have outcompeted native macrophyte species in parts of the Macleay River Upper Estuary. However, the authors also highlight the uncertainty surrounding species determination and make educated assumptions based on the previous work of MHL (1998). Despite the potential weediness of these large macrophyte beds, the authors found that they remove excess nutrients from the water column without which there would likely be an increase in algal blooms (WMA Water, 2009). Finally, they recommended further research into the importance of habitat structure and biogeochemical cycling of the macrophyte beds in the Macleay River.

GeoLINK, 2010 –

Using MHL (1998) and West et al., (2004) as a basis for their study, a report to Kempsey Shire Council by GeoLINK (2010), aimed to investigate the dynamics of Egeria and map its distribution a) semi-quantitatively, by replicating the MHL (1998) survey, and b) generate an accurate spatial layer of the downstream extent of Egeria from Kempsey. Using orthorectified aerial photography, the authors estimated the extent of spread of Egeria by direct comparison to the data collected by West et al., 2004. The report found that since its first detection in 1998, *Egeria densa* had rapidly spread and was now the dominant macrophyte species in the brackish estuary waters upstream of its downstream limit, at the Gladstone/Smithtown Bridge (2010). Large beds of macrophytes observed during field surveys were dominated by *Egeria densa*, but to a lesser extent did contain the native macrophytes *Vallisneria* and *Potamogeton* spp., as previously reported (MHL, 1998; West et al., 2004). Anecdotally, Egeria appeared to be capable of spreading almost the entire river width in dry times, was outcompeting native macrophyte species, and was creating a navigational obstacle (GeoLINK, 2010). The GeoLINK (2004) report acknowledged that while weedy exotic macrophyte species dominated intertidal mudflats, providing important connectivity with upstream habitats, the ecological importance of Egeria and Elodea species remained uncertain, despite recording waterbird sightings and eel and mullet activity amongst the weed-dominated beds during the study period. GeoLINK (2010) highlighted the consequences of eutrophication, such as an increase in Egeria and Elodea dominated macrophyte beds, and suggested that parts of the Macleay River are nutrient enriched-due to a combination of factors including sewage inputs, runoff from agricultural lands, coastal upwelling and stormwater runoff. The authors concluded that the logistical complications in controlling Egeria, and the species' potential role as both a nutrient sink and habitat, warranted the need for further study into the ecological role of exotic weed species in the Macleay River, but also highlighted the importance of limiting the spread of such species into neighbouring catchments/waterways (GeoLINK, 2010).

2.4. Aims

Large scale longitudinal variation in macrophyte communities has received very little study (Pentecost et al., 2009), and the Macleay River is no exception. Despite their habitat complexity, entire river systems are rarely investigated (Pentecost et al., 2009). In undertaking a macrophyte survey for Kempsey Shire Council, to accurately characterise representative submerged vegetation and determine the precise distribution of the macrophyte species, we continuously surveyed 215 km's of the main trunk of the Macleay River. We aimed to:

- Review existing literature into the ecology and control of *Egeria densa*.
- Map all significant macrophyte beds, including the locations, extent, density and condition of all significant macrophyte communities from the confluence of the Chandler and Macleay Rivers to the downstream limit of the freshwater macrophyte communities.
- Map the extent of *Egeria densa.*
- Digitise the survey into ArcGIS shapefiles containing the mapped macrophyte communities.
- Provide management recommendations based on the review of existing control methods for Egeria and its current extent as mapped in this survey.

2.5. Methods

2.5.1. Study area

This study surveyed a total of 215 kms of the main trunk of the Macleay River, or just over half the total river length of 400 kms (Hill & Harris, 1991). Surveying started at Halls Peak on the edge of the gorge country in Oxley Wild Rivers National Park through until the floodplain flats of the township of Kempsey, NSW. Halls Peak was selected as a starting point for two reasons: (1) it was located on the Chandler River, approximately 14kms upstream of the Macleay/Chandler confluence, and offered the closest and best available access to the Macleay River, and (2) of the four major upstream tributaries, *Egeria densa* had recently been observed growing in the Styx River, an upstream tributary of the Chandler River (Ryder et al., 2016). Surveying encompassed three of the five land units in the Macleay catchment: Escarpment and Ranges, Hills (low elevation), and Coastal Floodplains (Figure 4).

2.5.2. Field surveys

Five surveys took place during summer 2015/2016 (Table 1). Sampling occurred over summer to incorporate flowering periods to assist species identification/observation, particularly for *Egeria densa*. The 201km freshwater section of river, from Halls Peak, through until the tidal limit at Belgrave Falls, was surveyed by kayaks. The remaining 14 kms of upper estuary, between Belgrave Falls and Kempsey, were surveyed using a small boat (courtesy of OEH). With much of the Macleay Catchment receiving below average summer rainfall, all sampling took place during very low flows.

Table1 *Sampling times, locations, distances and Macleay River height, as recorded at Georges Junction at the time of surveying.*

Sampling period	Date	River section	Distance paddled (km)	* River height – Georges Junction (m)
1	25th Nov – 27th Nov, 2015	Georges Junction - Bellbrook	63	0.65 – 0.59
2	30th Nov – 1st Dec, 2015	Halls Peak - West Kunderang	33.5	0.55 – 0.54
3	17th Feb, 2016 – 18th Feb, 2016	West Kunderang - Georges Junction	28.5	0.76 – 0.73
4	25th Feb, 2016	Belgrave Falls - Kempsey	14	0.69
5	8th Mar, 2016 – 11th Mar, 2016	Bellbrook - Belgrave Falls	76.5	0.54 – 0.51

* River height data source: DPIOW (2016).

2.5.3. Macrophyte identification and survey techniques

Macrophyte misidentification or the overlooking of a macrophyte species can far outweigh any potential error in cover (Pentecost et al., 2009). All macrophyte species sighted in our survey were collected, pressed and identified to species level using a variety of identification keys including field guides, herbarium entries and other online sources (Sainty & Jacobs, 1994; PlantNET, 1999 onwards; NCW Beadle Herbarium at UNE). A reference collection of macrophytes was produced from the survey and lodged with the (NCW Beadle Herbarium). Macrophytes were collected by hand in shallow waters. Where water depth was too deep to wade, collection was aided with a custom-made 'macrophyte grapnel', and observations made using a bathyscope (Figure 5). Macrophytes were classified as native or exotic.

Figure 5 *Macrophyte grapnel (wire brush attached to the end of a telescopic pole at stern of kayak) and bathyscope (orange cone at stern of kayak) used to assist macrophyte collection and identification in the field.*

Percentage cover is the most convenient primary metric used for quantifying aquatic vegetation (Kershaw & Looney, 1985; Pentecost et al., 2009). For this study, we visually assessed cover, a commonly accepted method in aquatic environments due to the difficult nature of sampling such systems (Pentecost et al., 2009). All macrophyte beds were classified into one of four habitat classes: edge vegetation (EV), channel vegetation (CV), riffle vegetation (RV), and backwater vegetation (BV). Macrophyte beds were assessed throughout each riverine habitat; pools, runs, riffles, rapids, estuaries and backwaters, and assigned a corresponding cover value (0-100%) based on mean cover observations throughout the location classes. For data visualisation and interpretation purposes, species cover values were assigned to one of five cover classes: very low (1-4%) < low (5-19%) < medium (20-39%) < high (40-59%) < very high (>60%). Species composition of macrophyte beds was also assessed, with relative cover value (0-100%) estimated for each species.

Similarly to West et al. (2004), we could not accurately assess macrophyte presence in deep river sections (>3.5 metres) due to poor light, turbidity and limitations with field equipment. These communities were extrapolated from adjacent macrophyte beds and published species distributions. These few areas have less accuracy and precision in cover and area than the directly surveyed majority, but are unlikely to impact our overall findings on species composition (presence/absence), and species cover, given their small proportion of the large sample size.

Typically, previous river macrophyte studies have excluded backwaters, full floristics, and biogeographical range, due to time and sampling limitations (Demars et al., 2012). In order to investigate all types of habitat and to avoid partial sampling, our sampling method in this survey involved kayaking downstream in a zig-zag pattern, along each reach, pool and backwater, with riffles and rapids haphazardly explored in kayak and more thoroughly on foot. To continually update changes in composition, density and cover, macrophyte beds were assessed several times throughout each of these river habitats by paddling over, alongside, and through beds.

2.5.4. Field mapping equipment

To ensure that macrophyte beds were mapped to scale, 1-km reaches of the baseflow channel were directly transcribed onto waterproof gridded A4 pages. The mapsheets were gridded into 50-m cells and included UTM WGS 1984 coordinates. A handheld Garmin GPS was used to locate position. A GoPro Hero4 video recorder and Olympus Tough waterproof camera were used to document locations, species growth forms and bed compositions.

2.5.5. GIS digitisation and spatial analysis

Once the field surveys were complete, each A4 mapsheet was scanned (colour, high resolution) and imported into ArcMap 9.3.1. Mapsheets were individually ortho-rectified using a minimum of six control points per river-km. Polygons were individually digitised as polygons with the total cover of the bed and relative cover for each species recorded as attributes for each polygon. After all polygons were digitised, the shapefile was manually checked for topological areas (that is, mismatches between the borders of adjacent polygons), and these were corrected. The area of each polygon was calculated using the Calculate Field Geometry algorithm in ArcMap 9.3.1.

The start and finish (in river-km) was recorded for each macrophyte species. All polygon records were exported to Microsoft Excel for data analysis of area and cover.

2.6. Results

2.6.1. Catchment scale summary

We observed twenty-one (21) different macrophyte species from twelve (12) different families throughout the study reach in the main trunk of the Macleay River (Table 2). Fifteen (15) of these species were native species while six (6) were exotic species. Of the six exotic species, four are recognised by the Local Control Authority (Kempsey Shire Council) as noxious weed species (Table 2). Of the 21 species, five were present throughout the entire 215-km reach. This included *Egeria densa*. *Hydrocharitaceae* was the most diverse macrophyte family in the Macleay (with six genera), followed by *Potamogetonaceae* with five genera.

***Table 2** Macrophyte species observed in the Macleay River including status, habitat, landform unit and species range throughout the study reach. Comparisons of species area % of the total area of the Midland Hills landform unit are given for 2004 (West et al.) and 2016 (this survey). Exotic species are listed in alphabetical order at the top of the table.*

No.	Family	Scientific Name	Common Name	Status	Habitat[1]	Landform Unit[2]	West et al., 2004. Area of spp. over Midland Hills	Vincent et al., 2016. Area of spp. over Midland Hills	Species Range Throughout Study Reach
1	*Hydrocharitaceae*	*Egeria densa*	Egeria	Exotic (Class 4)	All	All	0.1 %	15.9 %	Throughout study area.
2	*Pontederiaceae*	*Eichhornia crassipes*	Water Hyacinth	Exotic (Class 3)	B, E	MH	N/R	N/A	St. @ 168.5 Fin. @ 200.5
3	*Hydrocharitaceae*	*Elodea canadensis*	Elodea	Exotic	All	All	11.3 %	98.9 %	St. @ 0 Fin. @ 203.5
4	*Nymphaeaceae*	*Nymphaea* sp. *cultivar*	Giant Waterlily	Exotic	E	MH	N/R	N/A	St. @ 173 Fin. @ 198
5	*Alismataceae*	*Sagittaria platyphylla*	Sagittaria	Exotic (Class 4)	B, E	MH, CP	N/R	N/A	St. @ 197 Fin. @ 217
6	*Salviniaceae*	*Salvinia molesta*	Salvinia	Exotic (Class 3)	B, E, C	MH	N/R	N/A	St. @ 146.5 Fin. @ 180
7	*Azollaceae*	*Azola pinnata*	Ferny Azolla	Native	B, E, C	All	N/R	N/A	Throughout study area.
8	*Characeae* (Algae)	*Chara vulgaris*	Stonewort	Native	All	All	N/R	N/A	Throughout study area.
9	*Hydrocharitaceae*	*Hydrilla verticillata*	Hydrilla	Native	All	All	0	80.3 %	St. @ 51 >Kempsey
10	*Marsileaceae*	*Marsilea mutica*	Nardoo	Native	E	MH	N/R	N/A	St. @ 192 Fin. @ 192.5
11	*Haloragaceae*	*Myriophyllum verrucosum*	Red Watermilfoil	Native	All	All	7.6 %	81.2 %	Throughout study area.
12	*Najadaceae*	*Najas tenuifolia*	Waternymph	Native	All	MH, CP	0	45 %	St. @ 124 >Kempsey
13	*Menyanthaceae*	*Nymphoides indica*	Water Snowflake	Native	B, E, C	MH, CP	N/R	N/A	St. @ 120.5 >Kempsey
14	*Hydrocharitaceae*	*Ottelia ovalifolia*	Swamp Lily	Native	B, E	MH	N/R	N/A	St. @145.5 Fin. @ 159
15	*Potamogetonaceae*	*Potamogeton crispus*	Curly Pondweed	Native	All	ER, MH	N/R	N/A	St. @5 Fin. @ 193
16	*Potamogetonaceae*	*Potamogeton ochreatus*	Blunt Pondweed	Native	All	ER	N/A	N/A	St. @ 0 Fin. @38.5
17	*Potamogetonaceae*	*Potamogeton octandrus*	Pondweed	Native	All	MH, CP	N/A	N/A	St. @ 126.5 >Kempsey
18	*Potamogetonaceae*	*Potamogeton perfoliatus*	Clasped Pondweed	Native	All	All	* 0.3 %	99.5 %	St. @ 28.5 >Kempsey
19	*Potamogetonaceae*	*Potamogeton sulcatus*	Pondweed	Native	E	MH	N/R	N/A	St. @ 11 Fin. @ 38.5?
20	*Hydrocharitaceae*	*Vallisneria australis*	Eelweed	Native	All	ER, MH	N/R	N/A	St. @ 14 Fin. @ 147
21	*Hydrocharitaceae*	*Vallisneria nana*	Ribbonweed	Native	All	All	5.9 %	90.1 %	Throughout study area.

* Presumed *Potamogeton* species reported by West et al., (2004), given its dominance in 2016.

[1] Backwater, Edge and Channel habitats are represented by B, E and C, respectively.

[2] MH is Midland Hills, CP is Coastal Plain and ER is Escarpment Ranges.

2.6.2. Temporal comparison

Throughout the Midland Hills, West et al., (2004) reported total area on seven (7) of the macrophyte species documented in this survey (Table 2). Results indicate that all species significantly increased in area (e.g. *Elodea canadensis* increased from 11.3% of the Midland Hills area in 2004 to 98.9% of the same area in 2016). The remaining species common to the two reports(*Egeria densa*, *Myriophyllum verrucosum*, *Potamogeton perfoliatus* and *Vallisneria nana*) each followed a similar pattern, increasing in area in the 2016 survey by an order of magnitude. Furthermore, while this survey recorded the native macrophyte species *Hydrilla verticillata* and *Najas tenuifolia* as dominant species, they were not recorded as being present over the same 139.5 km reach in the 2004 survey.

2.6.3. Landform units

Of the three landform units surveyed, Midland Hills comprised the largest component of the study reach (7.53 km2 or 66%, Table 3). The Midland Hills also supported the highest number of macrophyte species, with 20 of the 21 species observed in the study reach. Additionally, the Midland Hills had a greater proportion of exotic species (30%) than the Coastal Plain (25%) or Escarpment Ranges (18%).

Table3 *Distribution of total species and total exotic species by Landform Unit. Total river length, area and total macrophyte area for the study reach are also presented.*

Landform Unit	Escarpment Ranges	Midland Hills	Coastal Plain	Total
Total Species	11	20	12	21
Exotic Species %	18% (2)	30% (6)	25% (3)	
River Length km	62 km	139.5 km	14 km	215.5 km
River Area km^2	1.94 km^2	7.53 km^2	1.92 km^2	11.39 km^2
Macrophyte Area	1.92 km^2	7.52 km^2	1.92 km^2	11.36 km^2

2.6.4. Habitat

All macrophyte species occurred in the Edge habitat (100%). Backwater habitats supported 86% of species, Channel habitats 67% and Riffle habitats supported 62% of all species found in the Macleay River. A similar pattern was observed for the occurrence of exotic species in habitats where Edge (100%) > Backwater (83%) > Channel (50%) > Riffle (33%).

Table 4 *Distribution of total species and total exotic species by Habitat.*

Habitat	Backwater	Edge	Channel	Riffle	Totals
Total Species %	86% (18)	100% (21)	67% (14)	62% (13)	21 Spp.
Exotic Species %	83% (5)	100% (6)	50% (3)	33% (2)	6 Spp.

2.6.5. Species range, distribution and potential sources

Of the 21 macrophyte species recorded in the main trunk of the Macleay, five were present throughout the entire 215kms surveyed: the exotic noxious weed species *Egeria densa*, and the native species *Azolla pinnata*, *Chara vulgaris*, *Myriophyllum verrucosum* and *Vallisneria nana* (Figure 6).

Exotic species

Elodea canadensis and the noxious weed species *Egeria densa* had the greatest range (>200 kms) of exotic species, with both species present at Halls Peak, the upstream extent of the study reach. Three of the four remaining exotic species were also noxious weed species but had much shorter ranges (<40 kms): *Salvinia molesta* (34 kms), *Eichhornia crassipes* (32 kms) and *Sagittaria platyphylla* (20kms). *Elodea canadensis* occurred throughout the main trunk of the Macleay River, with no obvious source. While the same was also true of *E. densa*, in recent Ecohealth surveys of the Macleay headwaters, Egeria was only observed in the Styx River, suggesting it to be the potential source. *S. molesta* first appeared in a flood runner backwater just below the Macleay River/Warbro Brook confluence, *E. crassipes* first appeared in the Edge Vegetation just below the Macleay River/Temagog Creek confluence and *S. platyphylla* was first recorded in a backwater at the Macleay River/Commong Creek confluence.

Native species

Azolla pinnata, *Chara vulgaris*, *Myriophyllum verrucosum* and *Vallisneria nana* had the greatest range (>215 kms) of the native species, with all four species present throughout the entire study reach (Figure 6). The three common species *Hydrilla verticillata* (165 kms), *Potamogeton perfoliatus* (187.5 kms) and *Potamogeton crispus* (188 kms) had slightly shorter ranges. *H. verticillata* was first recorded in the Escarpment Ranges 1km downstream of East Kunderang homestead. *P. perfoliatus* appeared to be sourced from the Apsley River, first observed at the Apsley River/Macleay River confluence. *P.crispus* first appeared shortly downstream of Halls Peak, but was locally extinct by the tidal limit at Belgrave Falls. *Vallisneria australis* (133 kms), *Nymphoides indica* (95.5 kms), *Potomogeton octandrus* (90 kms) and *Najas tenuifolia* (92 kms) all had significant ranges, circa. half the length of the main trunk of the Macleay River. *V. australis* first appeared at the Macleay River/Chandler River confluence, *N. indica* was first recorded downstream of Wilson's Creek, *N. tenuifolia* downstream of Gap Creek and *P. octandrus* first appeared downstream of Nulla Nulla Creek. *Potamogeton ochreatus* (38.5 kms), *Potamogeton sulcatus* (27.5 kms), *Ottelia ovalifolia* (13.5 kms) and *Marsilea mutica* (0.5 kms) were all present in the Macleay with comparatively small ranges. *P. ochreatus* and *P. sulcatus* were only present in the Escarpment Ranges, *O. ovalifolia* first appeared at the Warbro Brook/Macleay River confluence, and the two significant patches of *M. mutica* appeared in the Edge habitat of a small reach, 500m upstream of the Walshes Creek/Macleay River confluence.

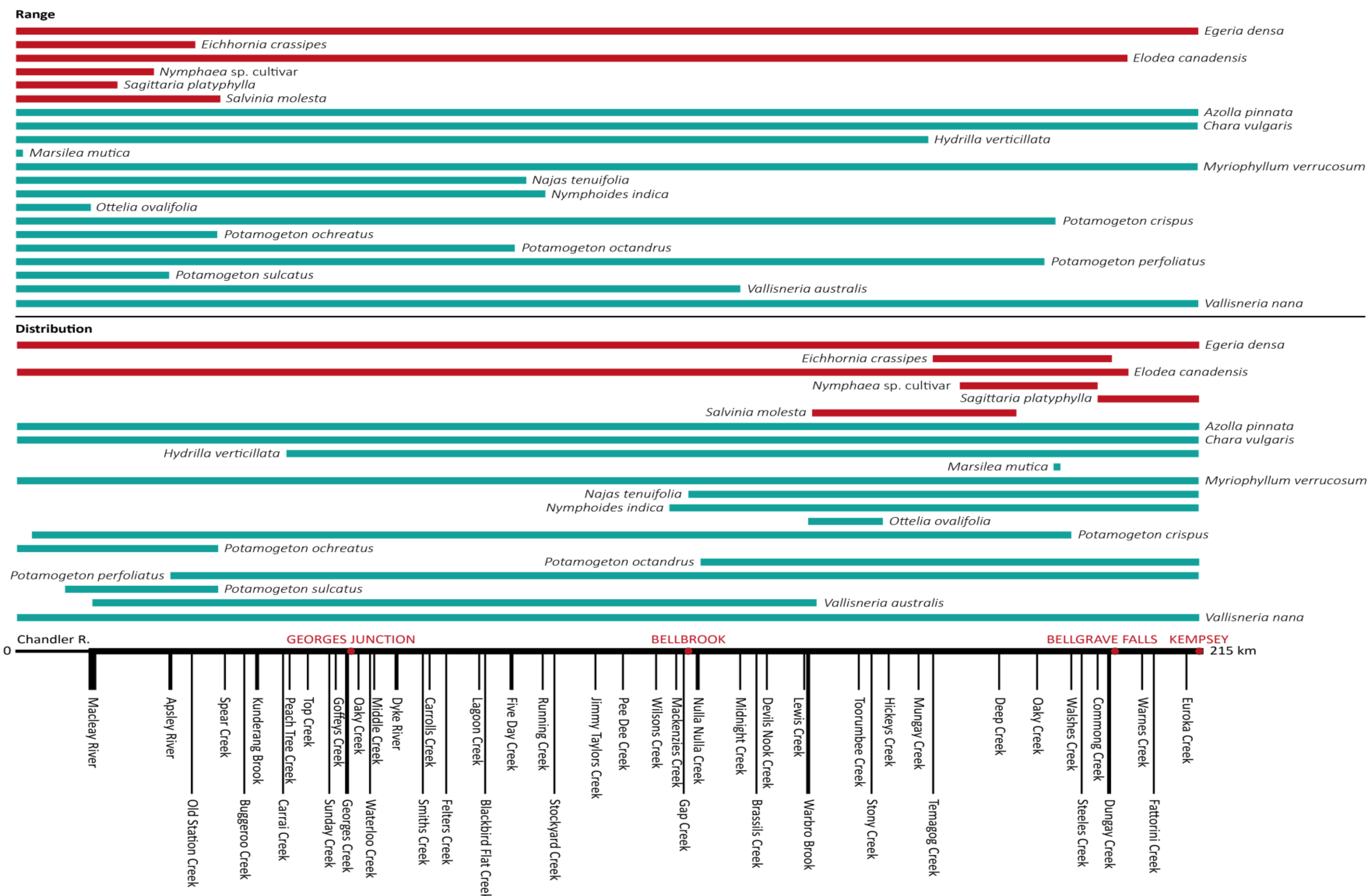

Figure 6 *Schematic diagram of Macleay macrophyte species distribution and range in relation to significant tributaries and the survey reach of the Macleay River (to scale where position on diagram represents longitudinal position in study reach).*

2.6.6. Exotic versus native species

Escarpment ranges

With respect to relative cover, both the Backwater (67%) and Channel (51%) habitats of the Escarpment Ranges were dominated by exotic species. In contrast, native species dominated Edge (54%) and Riffle (79%) habitats.

Midland hills

With respect to relative cover, all habitats in the Midland Hills were dominated by native species: Backwater (53%), Edge (68%), Channel (69%) and Riffle (86%).

Coastal plain

With respect to relative cover, the Backwater habitat in the Coastal Plain was almost entirely dominated by exotic species (95%). Conversely, native species almost entirely dominated the Channel (99%) and Riffle (98%) habitats, and were dominant in the Edge (63%) habitat.

Overall study reach

With respect to relative cover across the entire study reach, the Backwater habitat was dominated by exotic species (54%), while the remaining three habitats were dominated by native species: Edge (65%), Channel (72%) and Riffle (85%).

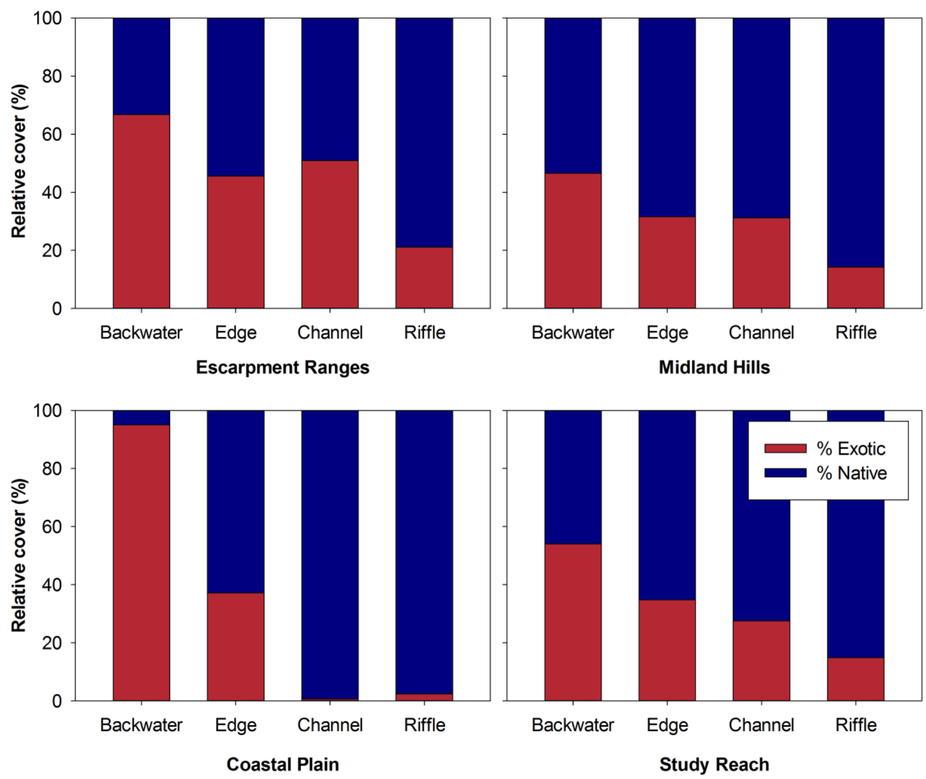

Figure 7 *Exotic versus native macrophyte species throughout the study reach of the main trunk of the Macleay River, using relative cover over habitats and landform units.*

2.6.7. Habitat components by mean relative cover

Escarpment ranges

In the Escarpment Ranges, mean relative cover of *Elodea canadensis* dominated Backwater (45%), Edge (39%) and Channel (55%) habitats and was second behind *Myriophyllum verrucosum* in Riffle habitat in terms of mean relative cover (22% and 29%, respectively, Figure 8). *Vallisneria nana* had the second greatest mean relative cover in both Channel (15%) and Edge (14%) habitats, while *Egeria densa* had the second greatest mean relative cover in the Backwater habitat (31%).

Midland hills

In the Midland Hills, *Elodea canadensis* had the highest mean relative cover in Backwater (22%), Edge (23%) and Channel (31%) habitats while *Vallisneria nana* was the dominant species in the Riffle habitat (32%, Figure 8).In terms of mean relative cover, *Egeria densa* was the second most dominant species in the Backwater habitat (18%), *Hydrilla verticillata* was the second most dominant species in both the Edge (17%) and Channel (24%) habitats and *Myriophyllum verrucosum* was the second most dominant species in the Riffle habitat (22%).

Coastal plain

In the Coastal Plain, *Hydrilla verticillata* had the highest mean relative cover in Edge (30%) and Channel (46%) habitats while the Riffle and Backwater habitats were dominated by *Vallisneria nana* (28%) and *Egeria densa* (80%), respectively (Figure 8). *Elodea canadensis* had the second highest mean relative cover in the Backwater habitat (15%), *Vallisneria nana* was the second most dominant species in both the Edge (12%) and Channel (22%) habitats and *Myriophyllum verrucosum* was the second most dominant species in the Riffle habitat (19%).

Overall study reach

Across the entire length of the study reach, *Egeria densa* had the highest mean relative cover in Backwater habitats (31%), *Elodea canadensis* dominated the Edge (23%) and Channel (31%) habitats, while Riffle habitats were dominated by *Vallisneria nana* (31%). The second most dominant species in terms of mean relative cover was *Elodea canadensis* in the Backwater habitats (25%), *Hydrilla verticillata* in both the Edge (17%) and Channel (24%) habitats and *Myriophyllum verrucosum* in the Riffle habitat (23%). *Myriophyllum verrucosum* and *Potamogeton perfoliatus* consistently occurred (±10%) in all habitats throughout the study reach, except for Myriophyllum in Backwater habitats, where it was rare (Figure 8).

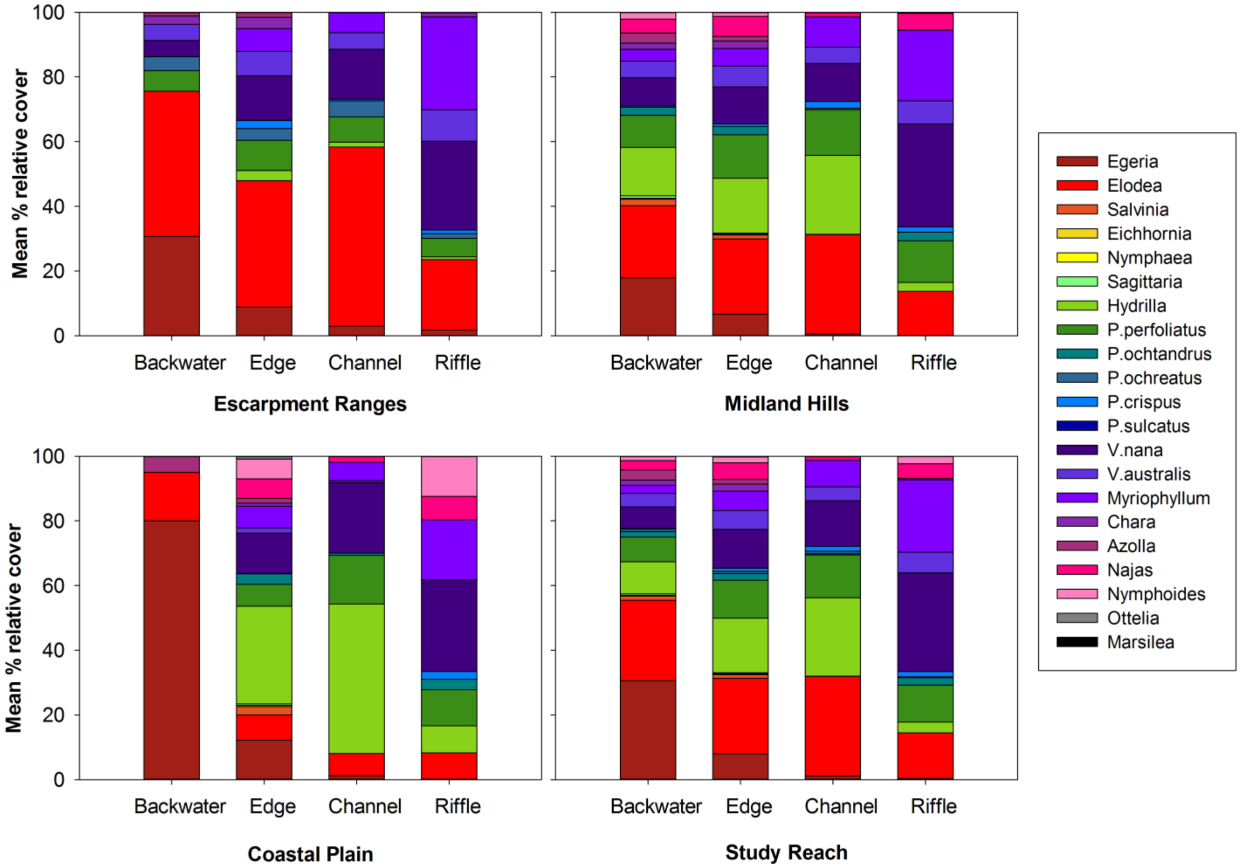

Figure 8 *Mean relative cover (%) of all species throughout the main trunk of the Macleay River, and within individual landform units and habitats.*

2.6.8. *The distribution and total area covered by dominant species*

Egeria densa

Egeria densa (Figure 9) occurred throughout all three landform units in the main trunk of the Macleay River: Escarpment Ranges (0.49km^2), Midland Hills (1.98km^2) and the Coastal Plain (0.78km^2). Among the habitats within landform units, Egeria frequency increased from upstream to downstream: Escarpment Ranges (25%) < Midland Hills (26%) < Coastal Plain (41%). Egeria was most dominant in the Edge habitat in all three landform units: Escarpment Ranges (64%, 0.3km^2), Midland Hills (83%, 1.6km^2) and the Coastal Plain (92%, 0.7km^2).

Egeria mostly occurred at low cover in the Escarpment Ranges (75%) and Midland Hills (79%), and at very high cover in the Coastal Plain (39%). This pattern was repeated in the Edge habitat where Egeria dominated (Figure 9). When totalled across the entire study reach, Egeria mostly occurred at low cover (68%, 2.2km^2), followed by medium cover (20%, 0.7km^2), only occurring at a very high cover in 10% of the Macleay River (0.3km^2), predominantly in the Coastal Plain.

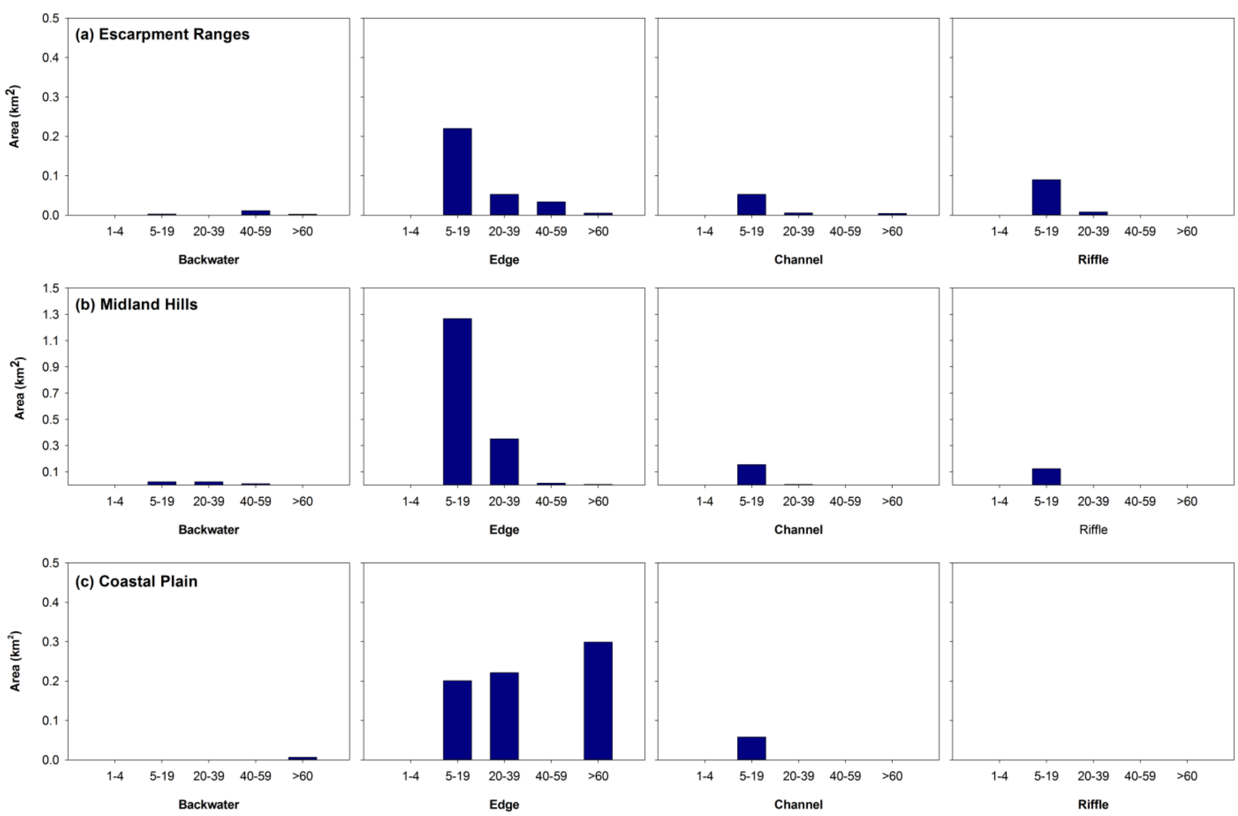

Figure 9 Egeria densa *distribution and total area within landform units and habitats.*

Elodea canadensis

Elodea canadensis was found across all three landform units in the main trunk of the Macleay River (Figure 10). Elodea occurred with the greatest frequency in the Midland Hills (99%, 7.5km^2), followed by Escarpment Ranges (80%, 1.6km^2) and, to a much lesser extent, in the Coastal Plain (11%, 0.22km^2). Elodea predominantly occurred in Channel habitat in the Escarpment Ranges (38%, 0.6km^2), Riffle habitat in the Midland Hills (41%, 3km^2) and Edge habitat in the Coastal Plain (36%, 0.7km^2). In Channel habitats in the Escarpment Ranges, Elodea predominantly occurred at medium (38%, 0.2 km^2) or very high cover (36%, 0.2 km^2). In Riffle habitats in the Midland Hills, Elodea predominantly occurred at low (66%, 2 km^2) or medium cover (34%, 1 km^2). In Edge habitats in the Coastal Plain, Elodea predominantly occurred at low cover (84%, 0.1km^2). When totalled across the entire study reach, Elodea mostly occurred at medium cover (54%, 5km^2), followed by low (35%, 3.1km^2) and high cover (6%, 0.6km^2).

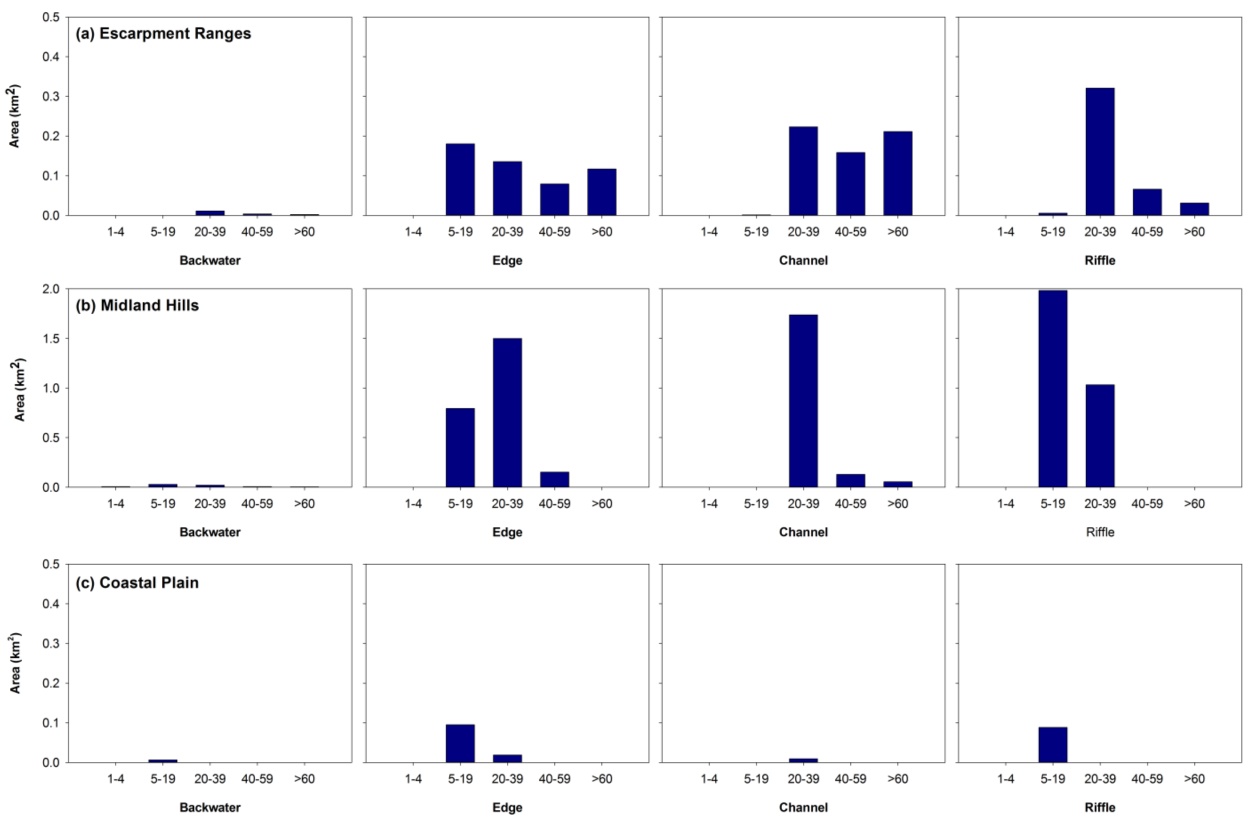

Figure 10 Elodea canadensis *distribution and total area within landform units and habitats.*

Hydrilla verticillata

Hydrilla verticillata occurred in all three landform units in the main trunk of the Macleay River: Escarpment Ranges (0.2km^2), Midland Hills (6.1km^2) and Coastal Plain (1.9km^2), where it predominantly occurred at medium (50% of area), low (56%) and very high cover (47%), respectively (Figure 11). Overall, Hydrilla frequency increased from upstream to downstream: Escarpment Ranges (10%) < Midland Hills (80%) < Coastal Plain (99%). Hydrilla predominantly occurred in Edge habitat in all three landform units: Escarpment Ranges (63%, 0.1km^2), Midland Hills (39%, 2.4km^2), and Coastal Plain (46%, 0.9 km2). Hydrilla also commonly occurred in Channel (33%, 2km^2) and Riffle (27%, 1.7km^2) habitats in the Midland Hills, and Channel habitat in the Coastal Plain (42%, 0.8km^2).

In Edge habitats, Hydrilla predominantly occurred at medium (50%, 1.2km^2) or low cover (49%, 1.2km^2) in the Midland Hills, and at low (48%, 0.4km^2) or very high cover (35%, 0.3km^2) in the Coastal Plain. When totalled across the entire study reach, Hydrilla mostly occurred at low cover (49%, 4km^2), followed by medium (37%, 3.1km^2) and very high cover (11%, 0.9km^2).

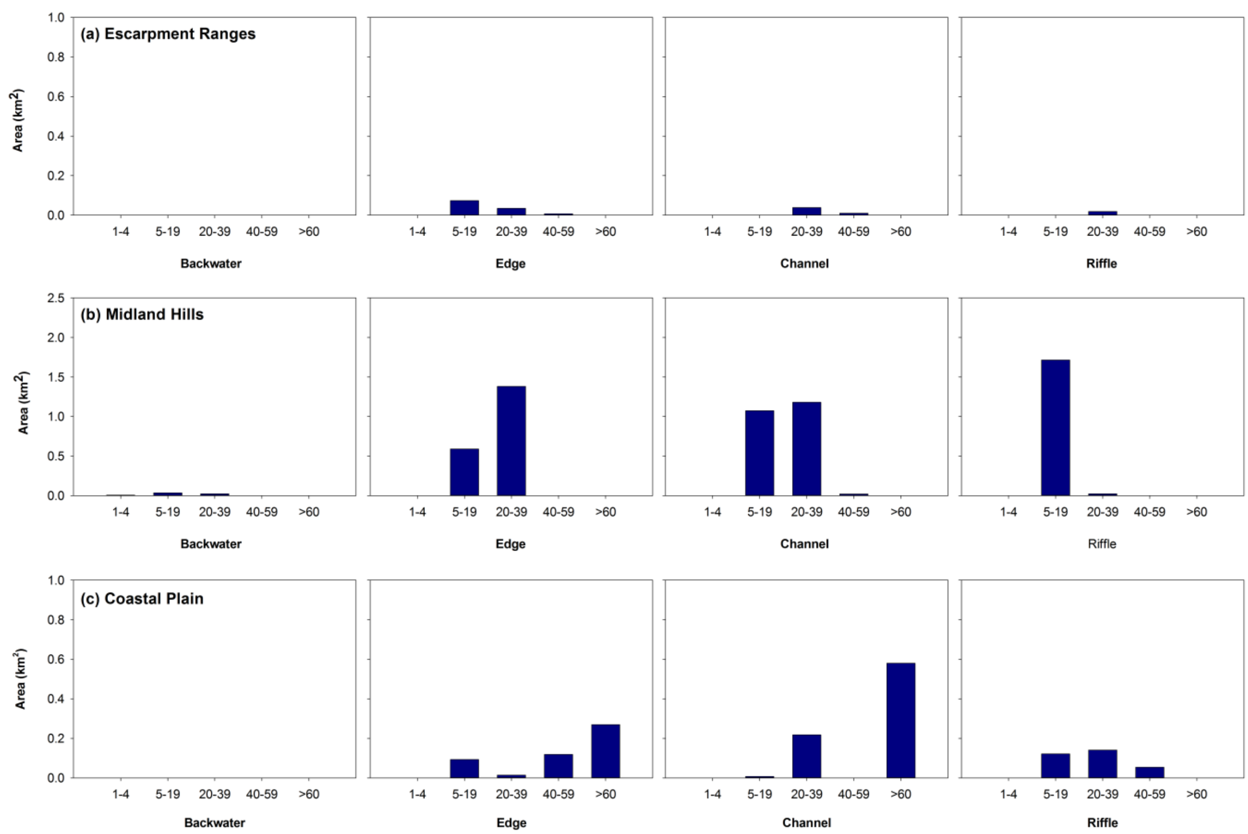

Figure 11 Hydrilla verticillata *distribution and total area within landform units and habitats.*

Vallisneria nana

Vallisneria nana occurred throughout all three of the landform units of the main trunk of the Macleay River (Figure 12). Greatest Vallisneria frequency occurred in the Midland Hills (90%, 6.8km^2), followed by Escarpment Ranges (86%, 1.7km^2), and the Coastal Plain (74%, 1.4km^2). Vallisneria predominantly occurred in Riffle habitats in Escarpment Ranges (45%, 0.8km^2) and Midland Hills (43%, 2.9km^2), and Channel habitats in the Coastal Plain (48%, 0.691km^2). However, Vallisneria also commonly occurred in Channel and Edge habitats in both the Escarpment Ranges (30%, 0.5km^2 and 25%, 0.4km^2, respectively) and Midland Hills (29%, 2km^2 and 27%, 1.8km^2, respectively), as well as in Edge habitats (36%, 0.7km^2) in the Coastal Plain.

In its most common habitat in Riffles, Vallisneria predominantly occurred at medium cover in the Escarpment Ranges (69%, 0.5km^2) and high cover in the Midland Hills (53%, 1.6km^2). Vallisneria mostly occurred at low cover in Channel habitats (61%, 0.4 km^2) in the Coastal Plain. Overall, Vallisneria predominantly occurred at medium cover in the Escarpment Ranges (57%), low cover in the Midland Hills (41%) and and high cover in the Coastal Plain (32%). When totalled across the entire study reach, Vallisneria mostly occurred at low cover (42%, 4.2km^2), followed by medium (34%, 3.4km^2) and high cover (23%, 2.3km^2).

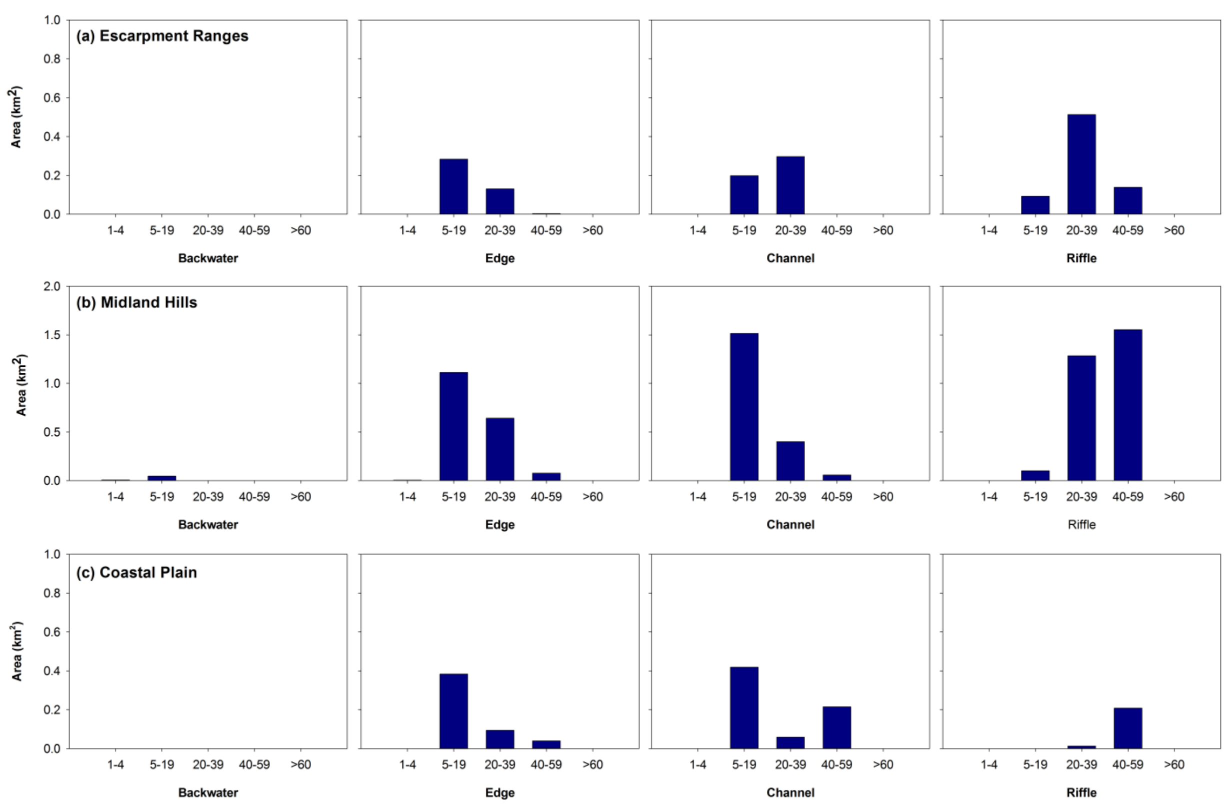

Figure 12 Vallisneria nana *distribution and total area within landform units and habitats.*

2.6.9. Comparative ability of GIS dataset

Figure 13 demonstrates a few of the visualisation capabilities of the spatial dataset. For example, at River-km 49 (located in the Escarpment Ranges at the confluence of Kunderang Brook and the Macleay River), the dataset reveals that the dominant habitat is Riffle (b), with total macrophyte cover of 20-39% (a) and a relative cover of 5-19% *Egeria densa* (c). However, the next riffle (b) upstream (River-km 48) also has a total macrophyte cover of 20-39% (a), but Egeria is absent (c).

Another example, taken from the tidal limit (Figure 14), shows that the confluence of Dungay Creek and the Macleay River (River-km 198), forms a backwater at baseflow (b) with 60-100% total macrophyte cover (a) comprising 40-59% *Egeria densa* (c). Likewise, at the flood runner backwater immediately upstream of River-km 199 (b), total macrophyte cover is 60-100% across the entire backwater (a), but Egeria is restricted to the edges, where it dominates at 60-100% of relative cover (c).

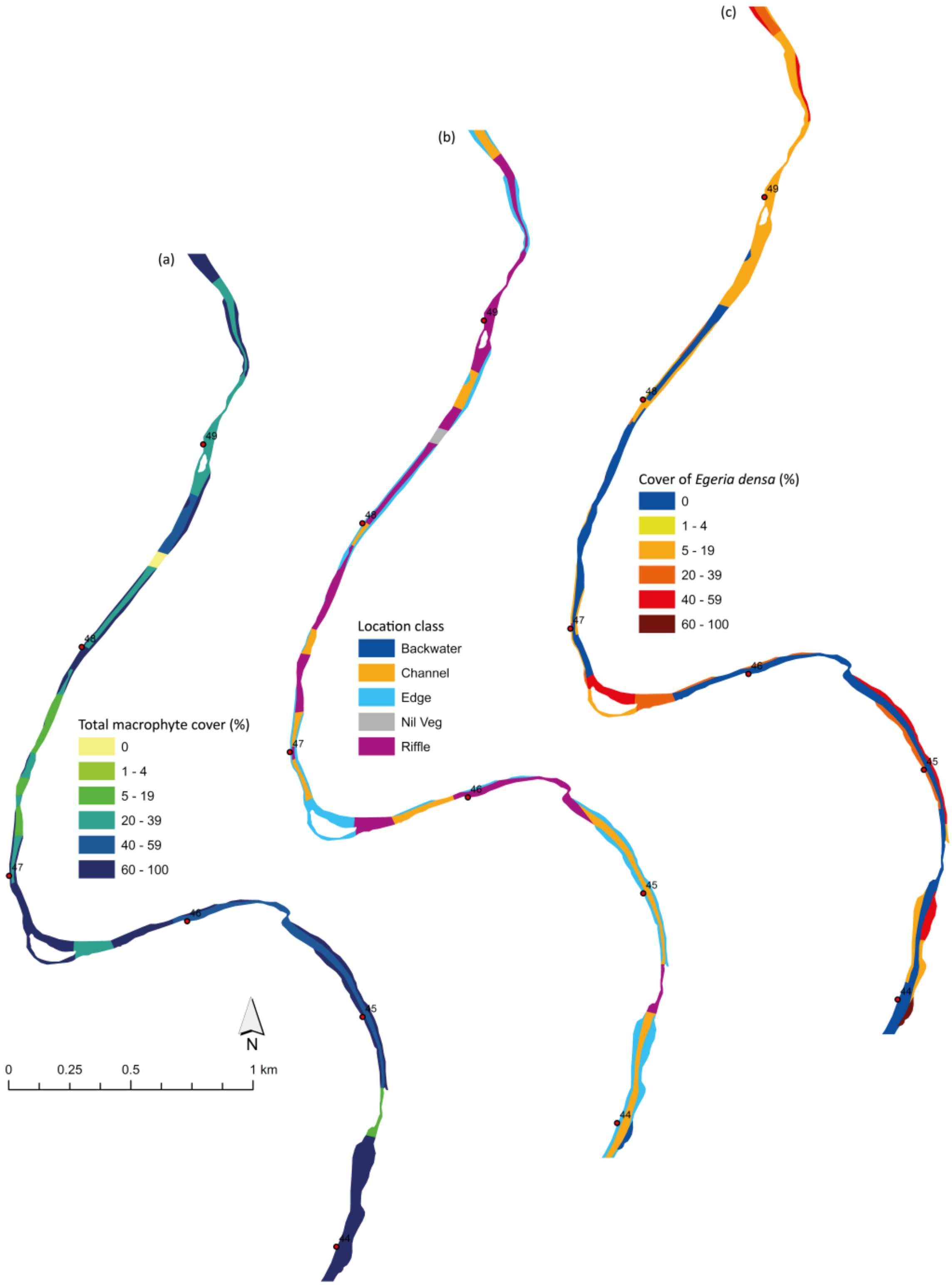

Figure 13 *Example excerpt of the GIS layers produced for the Macleay Macrophyte Report, where (a) is the total macrophyte cover, (b) is the location class, and (c) is* Egeria densa *cover a reach in the Escarpment Ranges of the main trunk of the Macleay River.*

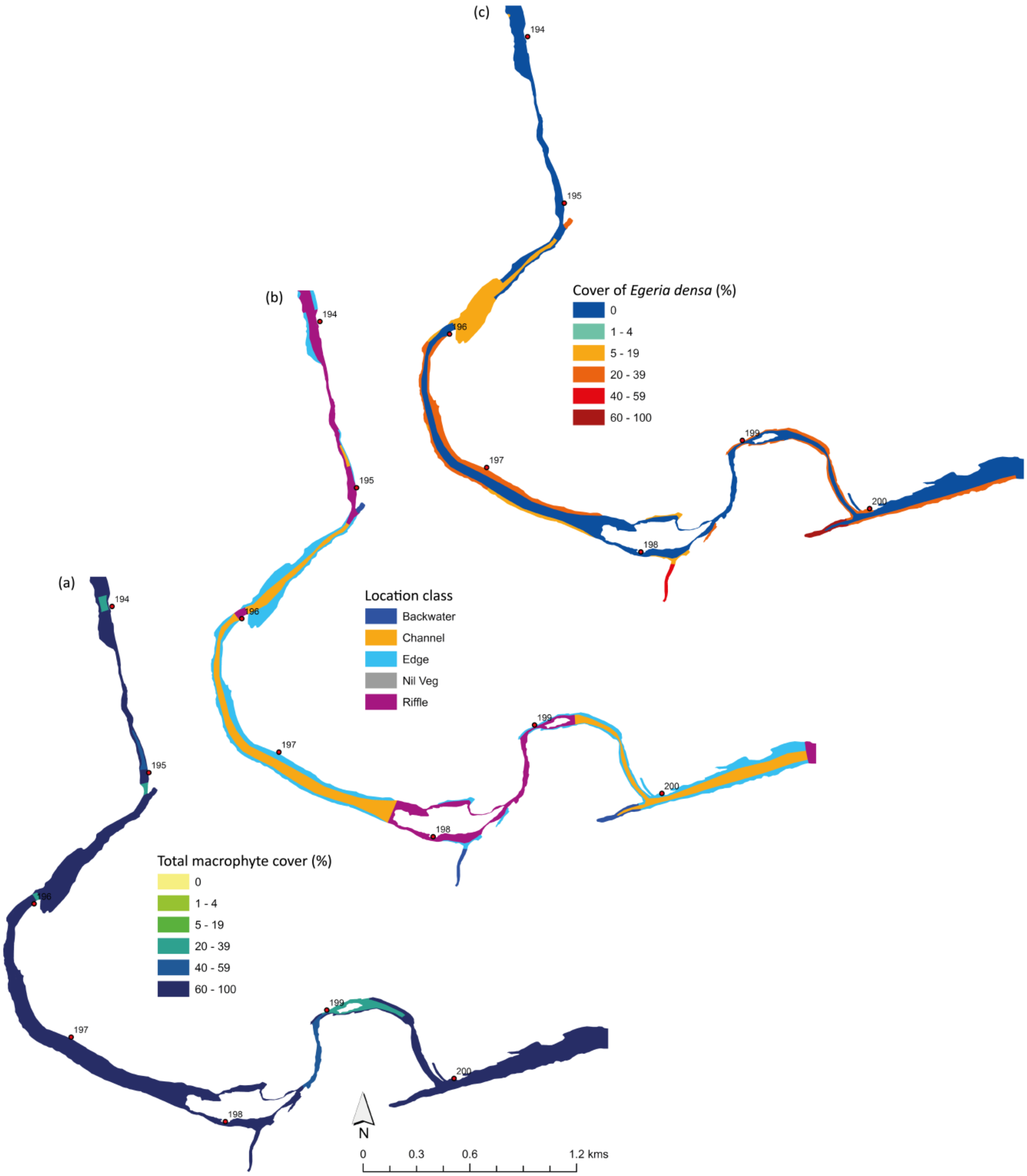

Figure 14 *Example excerpt of the GIS layers produced for the Macleay Macrophyte Report, where (a) is the total macrophyte cover, (b) is the location class, and (c) is Egeria densa cover for the tidal limit section (Midland Hills/Coastal Plain boundary) of the main trunk of the Macleay River.*

2.7. Discussion

This study was the first longitudinal field survey of most of the freshwater extent of the Macleay River and it documents the macrophyte communities including status (native/exotic), presence/absence, frequency, cover, area and habitat preferences. Macrophyte beds comprised a variety of native and exotic species and differed in size and cover, i.e. very sparse to very dense in cover. Few studies have mapped longitudinal patterns in macrophyte communities in Australian Rivers. However, these studies suggest that the Macleay River has relatively high species richness (Shiel & Williams, 1990; Mackay et al., 2003).

2.7.1. Distribution and cover of macrophyte species

Exotic species

Egeria (*Egeria densa*), and Elodea (*Elodea canadensis*), both have been reported previously in the Macleay River (MHL, 1998; West et al., 2004; Telfer, 2005; WMA Water, 2009; GeoLINK, 2010). In this study, *Egeria densa* occurred across all three landform units comprising the entire main trunk of the Macleay River. A recent Macleay Ecohealth survey in 2015 recorded *Egeria densa* in the Styx River, an upper catchment tributary of the Macleay River. Interestingly, the Ecohealth survey did not observe *Egeria densa* in any other of the upper Catchment tributaries (Chandler, Wollomombi, Gara, Salisbury, Apsley, Tia or Yarrowitch Rivers; (Ryder et al., 2016). This suggests that the Styx River could be the primary source of *Egeria densa* entering the Macleay River system. However, given the location of the Ecohealth site on the Styx River beside a road, the obvious human traffic at this site and the very low density of Egeria at this site, it is also possible that Egeria could have been transported here from a downstream source via human activity.

Elodea canadensis occurred in all three landform units comprising the study reach, but rapidly disappeared from the Coastal Plain just below the tidal limit at Belgrave Falls. While no *E.canadensis* was observed 500m downstream of the tidal limit, this species has previously been recorded in the Macleay River downstream of Kempsey (MHL, 1998). This suggests that Elodea has either, a) significantly contracted in range and distribution since 1998, or b) it could have been initially misidentified for a similar species of the same family, such as the native *Hydrilla verticillata*.

While the distribution, range and cover of the noxious weed *Egeria densa* was a focus of this survey, an additional three noxious macrophyte species were observed and documented by the survey. Water Hyacinth (*Eichhornia crassipes*) and Salvinia (*Salvinia molesta*) have been recorded previously in wetlands and dams on the Macleay Floodplain (Ruge/GeoLINK, 2010). However, this was the first survey to document Water Hyacinth, Salvinia and Sagittaria in the main trunk of the Macleay River. Given their potential for rapid colonisation of aquatic habitat, the presence and distribution of Salvinia and Water Hyacinth, both occurring in downstream reaches of the Midland Hills, and Sagittaria, occurring in the Midland Hills and Coastal Plain, are of equal or greater concern than Egeria to maintaining the aquatic health of the Macleay River. Management effort to limit the spread or completely remove Sagittaria, Water Hyacinth and to a greater degree, Salvinia, from the main trunk of the Macleay River may still now be feasible with this survey defining the localised extent of the distribution of each of these species.

Native species

The dominant native species observed during the study were Vallisneria nana, Hydrilla verticilata, Najas tenuifolia, Myriophyllum verrucosum, Potamogeton crispus, Potamogeton perfoliatus and Chara vulgaris and these species all have been recorded previously in the Macleay main trunk (MHL, 1998; West et al., 2004; Telfer, 2005; WMA Water, 2009; GeoLINK, 2010). A further eight native species were confirmed to occur in the Macleay River by this survey: Azola pinnata, Marsilea mutica, Nymphoides indica, Ottelia ovalifolia, Potamogeton ochreatus, Potamogeton octandrus, Potamogeton sulcatus and Vallisneria australis. The range and distribution data collected for all of the native species during this survey is important for management. For example, locating source tributaries can assist in identifying parent populations of a species which may be important conservation reserves for harbouring propagules. Additionally, baseline data on the range and distribution of native macrophytes can be used to assess change over time in response to ecological pressures, impacts of human activity such as contamination spills, eutrophication events and climate change, or management investment.

2.7.2. Species cover

Dominant species

Elodea canadensis occurred in all three landform units comprising the main trunk of the Macleay River, and was the most common macrophyte species in the Escarpment Ranges and Midland Hills. Elodea, recognised as a serious weed in many countries (Bowmer et al., 1995), was the dominant species throughout the Edge and Channel habitats and occurred as a co-dominant species in the Riffle habitat in both the Escarpment Ranges and Midland Hills. Our findings in the Escarpment Ranges and Midland Hills suggest that Elodea is a very adaptable, invasive species that is capable of inhabiting a variety of water depths and flow conditions. However, the sharp decline in the Coastal Plain suggests that Elodea has limitations to its invasiveness, likely driven by intolerance to salinity and warmer waters.

Egeria was the most common macrophyte species in Backwater habitats and increased in frequency and cover from upstream to downstream. As reported in previous studies, Egeria frequently occurred as an abundant or co-dominant species in the Coastal Plain (GeoLINK 2010), where it preferred both the low velocity, shallow waters of the Edge habitat and low velocity, deep waters of the Backwater habitat.

The native macrophyte *Hydrilla verticillata* occurred throughout all three landform units comprising the main trunk of the Macleay River. Similarly to Egeria, Hydrilla increased in frequency from upstream to downstream, suggesting that conditions required for Hydrilla growth in the main trunk of the Macleay River became more optimal at lower elevations along the longitudinal gradient. Edge and Channel habitats supported maximal Hydrilla growth, more so than either of the habitats of Riffles or

Backwaters. This suggests that Hydrilla has a preference for low-to-medium flow habitats in both deep and shallow waters at Midland and Coastal Plain landform units, that is, at lower elevations.

Another native species *Vallisneria nana* commonly occurred throughout all three landform units and across all four habitats. Despite the findings from West et al., (2004) that there was little evidence of *Vallisneria* sp. in the Macleay River, this study found *Vallisneria nana* to be the most frequently observed species throughout the survey, occurring throughout the entire study reach in 87% of all macrophyte beds.

2.7.3. Exotic species versus native species

Landform units

The highest overall proportion of relative cover attributed to exotic species in the main trunk of the Macleay River was found in the Backwater and Channel habitats of the Escarpment Ranges, not in the lower elevation, more populated (and nutrient-enriched) landform units as expected. However, these cover values were attributed to just two exotic species, *Elodea canadensis* and *Egeria densa*. Interestingly, while the number of exotic species supported in the Midland Hills increased threefold, the proportion of relative cover attributed to exotic species did not and all habitats in the Midland Hills were dominated by native species. Backwater was the only habitat that was dominated by exotic species in the Coastal Plain, even though this landform unit supported half of all the exotic species. This suggests that while exotic species are indeed thoroughly spread throughout the entire length of the Macleay River, as a whole they do not appear as yet to be out-competing native macrophyte species.

Habitat classes

The location and composition of a macrophyte community in a stream is strongly influenced by water velocity (Chambers et al., 1991; Riis & Biggs, 2003; Makkay et al., 2008), and water velocity appeared to be a driver of macrophyte distribution in the Macleay River. Overall, exotic species in the Macleay River showed strong preferences for very deep and/or shallow, slower velocity waters of the Backwater and Edge habitats. Native species dominated in both the deep and very shallow, faster velocity waters of the Riffle and Channel habitats. Such patterns may reflect the competitive strengths or requirements of exotic species, while simultaneously indicating niche habitat strongholds for native species.

Species

Elodea canadensis is the dominant macrophyte species in both the Escarpment Ranges and Midland Hills but rapidly decreased in cover once reaching the Coastal Plain. It is well documented that *Elodea canadensis* has relatively high light demands and is a temperate species that thrives in colder waters (Bowmer et al., 1995). It is therefore plausible that the dense, light-limiting macrophyte beds that occur in the Coastal Plain, in addition to the warmer, turbid, brackish waters that occur at the tidal limit of the Macleay River may be the limiting factors in terms of Elodea distribution, regardless of nutrient status.

However, the upstream-to-downstream increase in cover observed in *Egeria densa* may indicate increased nutrient availability in both the water column and in the sediments over the same longitudinal gradient. Throughout the Midland Hills and Coastal Plain, the native macrophyte species *Hydrilla verticillata* and *Najas tenuifolia* also increased in frequency and cover. However, existing literature is conflicted on the responses of native macrophytes to increased nutrient levels.

According to Quinn et al., (2011), native species are regularly outcompeted by invasive exotic species in eutrophic systems, while Lacoul & Freedman (2006) report that native macrophyte species are capable of responding to nutrient enriched systems. Furthermore, native species such as *Hydrilla verticillata* do have the capacity to become weedy and take advantage of nutrient-enriched conditions (Parsons & Cuthbertson, 1992, Bowmer et al., 1995). Hydrilla has even been found to outcompete *Egeria densa* under high nutrient conditions (Mony et al., 2007). An Australian study by Haller & Sutton (1975) demonstrated that due to its dense surface cover, the native macrophyte *Hydrilla verticillata* had the ability to out-compete another native ribbonweed species (*Vallisneria* sp.) by shading and limiting light penetration to the upper 0.3m of the water column.

In addition to the weedy encroachment in the lower Macleay River by *Egeria densa*, native species such as *Hydrilla verticillata* may also be responding to nutrient enrichment to the point of becoming weedy and outcompeting other native species unable to respond to such changes. While weedy growth of species such as Egeria, Hydrilla and Elodea may be undesirable in a natural system, management of nutrient-enriched systems may need to consider the underlying causes promoting such outbreaks, but also to the ecological services that such species provide for the impacted system, such as the removal of excess nutrients from the water column, and subsequent reduction in potential nuisance algal blooms (Sainty & Jacobs, 1994). Water chemistry, sediment type, underwater light, riparian vegetation shading, disturbances and hydrology are the main abiotic filters that can influence macrophyte invasions (Thomaz et al. 2015). More research is needed to determine the causes of and potential ecosystem services of weedy macrophytes in the Macleay River.

2.7.4. Temporal comparison

Study reach scale

While mapping Australian Bass habitats in the Macleay River, West et al., (2004) recorded area data for seven (7) macrophyte species. The freshwater section mapped over the two year period between 2002-2004 by West et al., (2004), was included in this survey as the Midland Hills landform unit. It was anticipated that these two spatially overlapping datasets (to within 0.2km^2 over the entire Midland Hills reach) could be used for a direct temporal comparison of macrophyte change. However, total species area calculations differed between the two datasets by an order of one-to-two magnitudes. The large discrepancies in macrophyte areas between the two surveys may be attributed to actual real increases and very large differences in macrophyte area, or more likely differences in field sampling techniques and the resolution of GIS mapping.

Coastal plain

Findings from the study undertaken by WMA Water (2009) suggested that the exotic macrophyte species *E.densa* and *E.canadensis* outcompeted native macrophyte species in the Coastal Plain of the Macleay River. While this study found nine native species present in the same landform unit (two of which were the dominant species *Hydrilla verticillata* and *Najas tenuifolia*), a direct temporal comparison could not be made due to the difference in spatial extent of the study reaches. Similarly the GeoLINK report (2010) reported an increase in *Egeria densa* and a decline in native species at the same Christmas Creek sites surveyed by MHL (1998) and West et al., (2004). Again, a direct temporal comparison was not made in this report due to the different study reaches surveyed. Therefore, it is recommended that future macrophyte surveys in the Macleay River should a) employ similar methods of data collection and analysis, and b) survey the same spatial extent as previous assessments in order to make any meaningful temporal comparisons (e.g. the site in the vicinity of Christmas Creek).

2.7.5. Noxious weed control

Egeria and Elodea

The first step in managing exotic species invasions is to document the range and distribution of the species to identify, catalogue and assess the ecological, economic and social threat posed by the species. This is essential before employing control measures to reduce the spread or remove the species. In the case of *Egeria densa* and *Elodea canadensis,* large scale removal of these species is extremely difficult once they become established in an aquatic system, with various chemical, physical, and biological control measures deemed impractical, environmentally detrimental, time consuming and expensive (Bowmer, 1995; Csurhes et al., 2008). Despite their long-term presence in Australia, Elodea and Egeria have not caused the widespread extended infestations here that have been widely observed in other parts of the world (Bowmer et al., 1995; Roberts et al., 1999). However, Roberts et al., (1999) warns of "the risk of complacency" of the potential threats of such invasive species as Egeria, arguing that water managers need to address the expansion of the species. While the immediate control of Egeria and Elodea in the Macleay River may prove to be extremely difficult, long-term management of evasive macrophytes in such systems is likely to require the reduction of nutrient inputs (Johnson, undated), through the use of slow release fertilisers (Boulton et al., 2014), reduced anthropogenic disturbance, improved land management practices and restoration of riparian vegetation (Boulton et al., 2014; Thomaz et al., 2015).

Sagittaria, Salvinia and Water Hyacinth

The limited distribution from source populations and relatively restricted ranges in the Macleay River suggests that the observed populations of the noxious species Sagittaria, and particularly Salvinia and Water Hyacinth have established recently. All three species have the capacity to spread rapidly and with 'daughter plants' of both Salvinia and Water Hyacinth widespread throughout their restricted ranges, control of these species should be a management priority. Identification of the nearest confluence or tributary to the most upstream population of a noxious macrophyte may indicate the primary source. Ecologically and economically efficient control programs should include adjacent water bodies and tributaries to reduce the spread of noxious weed species by focusing on the early control of sites that harbour source propagule material (Figure 15).

Figure 15 *A dense cover of Water Hyacinth found in an adjacent hillside dam above Belgrave Falls less than 400m from the tidal limit of the Macleay River, (B. Vincent 2016).*

2.8. Summary

Few studies have mapped macrophyte communities in Australian Rivers. This field survey of 215.5 kms of the main trunk of the Macleay River characterised macrophyte communities across three major landform units and four major habitats. We observed a diverse community of macrophyte species in the Macleay River, the majority of which were native species. While native macrophytes were more numerous overall, exotic macrophytes were almost as prevalent in terms of total macrophyte cover and area. Native and exotic macrophytes co-occurred throughout the entirety of the study reach but predominantly occupied different river habitats.

Weedy macrophyte beds are often a response to ecological imbalances in aquatic ecosystems and not necessarily the initial cause of the imbalance. The dense macrophyte beds of the lower Macleay River that comprise both exotic and native species may be a response to increased nutrient levels and turbidity, with the latter likely caused by long-term landuse change and anthropogenic inputs. While the removal of weedy species from an aquatic system may be considered due to environmental, economic and social impacts, consideration should also be given to the potential ecosystem services that these macrophytes provide such as removal of excess nutrients and habitat. Long-term management of weedy macrophyte growth will likely require managing nutrient inputs and anthropogenic impacts, improving land management practices and restoring riparian vegetation.

2.9. Recommendations

2.9.1. Management

- Immediate consideration should be given to control the distribution and spread of *Salvinia molesta*, *Eichhornia crassipes* and *Saggitaria platyphylla*. The first two species are highly invasive species. The localised extent of the current populations means that control is still possible within reasonable investment.
- If control of *Salvinia molesta*, *Eichhornia crassipes* and *Saggitaria platyphylla* are undertaken, it would be worthwhile to investigate source populations for these species in the tributaries above their first appearance in the main trunk of the Macleay River. This is Warbro Brook for *S. molesta*, Temagog Creek for *E. crassipes* and Commong Creek for *S. platyphylla*.
- The current distribution of *Egeria densa* and *Elodea canadensis* are too widespread through the Macleay River to be controlled by mechanical removal or herbicides without extensive and intensive investment, and without causing negative environmental impacts through large-scale physical disturbance or chemical side-effects.
- When the Macleay River experiences a large, bed-moving flood, a repeat survey would provide an updated assessment of the distribution of Egeria and Elodea.
- The population of *Egeria densa* in the Styx River downstream from the Armidale-Kempsey Road bridge may be the most upstream source of propagules in the Macleay catchment. If Council is interested in removing Egeria form the upstream tributaries of the Macleay, it would be worthwhile to determine the distribution of Egeria in the Styx River.
- If the population of Egeria in the Styx River covers a small range, direct removal by hand may be effective. If removal is attempted, it would be beneficial to monitor the site (ideally in summer when the macrophyte is flowering and easy to identify) to determine if the local population had been successfully eradicated. Ideally, the reach immediately downstream of this population would also be monitored to ensure the extent of the local population had been correctly identified and controlled.
- A repeat survey during the next flowering season would help answer research questions 7 and 8 below. It would also inform Council of the spread of *Salvinia molesta*, *Eichhornia crassipes* and *Saggitaria platyphylla*.

2.9.2. Further research

- Two previous Australian studies found there was a greater abundance of weedy macrophytes in areas adjacent to anthropogenic disturbance (King & Buckney, 2000; Catford & Downes, 2010). Further research could examine the association between adjacent landuse, riparian condition and weedy macrophyte infestations in the Macleay River using landuse GIS layers and ground-truthed riparian condition assessments. If established, this would help focus future riparian rehabilitation investment.

- Given the widespread distribution of *Egeria densa* in the Macleay, we recommend further research into the ecological roles it currently undertakes in the ecosystem. Specific areas of focus include:
    1. Does Egeria provide important habitat for aquatic macroinvertebrates and vertebrates such as exotic and native fish (e.g. Australian Bass), eels and turtles?
    2. Does Egeria provide an important food source for invertebrates and vertebrates including waterbirds?
    3. If Egeria does provide food for fauna, is it restricted to the freshwater foodweb, or does it contribute to the estuarine foodweb?
    4. What role do the macrophytes in the Macleay play in removing excess nutrients from the water column, and would removal of the macrophytes increase the frequency and magnitude of algal blooms in the river?
    5. If *Egeria densa* is removed, will other weedy macrophytes such as *Elodea canadensis* and *Hydrilla verticillata* expand their range?
    6. Do *Elodea canadensis* and *Hydrilla verticillata* facilitate the establishment and growth of *Egeria densa* by creating the optimal habitat for Egeria through reducing water velocity and increasing water temperature within macrophyte beds?
    7. What effects are the exotic weedy macrophyte species having on the native species, e.g. is Egeria outcompeting native species such as Vallisneria?
    8. This survey suggests that Egeria prefers habitat with slow-moving water such as the edges and backwaters. Once it has colonised its preferred habitat, will Egeria expand its habitat to competitively exclude native species in other habitats, i.e. will there eventual localised extinctions of native species?
    9. The backwaters adjacent to tributary confluences were commonly locations of dense weedy macrophyte beds. Is this due to localised inputs of nutrients bound to fine sediment inputs?

2.10. Other field observations

1. An epiphytic algae covered macrophytes typically in still, shallow waters of Edge or Channel habitat often downstream of riffles (Figure 16). The presence of this algae can indicate excessive nutrient enrichment of the water body. Both native and exotic species were affected including *Elodea canadensis*, *Egeria densa*, *Vallisneria nana*, *Potamogeton perfoliatus* and *Myriophyllum verrucosum*.

Figure 16 *Epiphytic algal growth on both native and exotic species throughout the study reach of the Macleay River was not uncommon.* Elodea canadensis *pictured was located downstream of a riffle in the Midland Hills (B. Vincent, 2015).*

2. Severe bank erosion was observed in some sections of the Macleay River, the worst of which occurred in the Midland Hills at River-km 174 (UTM grid reference 467500E, 656880S to 467475E, 6568475S, Figure 17).

Figure 17 *Severe bank erosion observed in the Midland Hills of the main trunk of the Macleay River (B. Vincent, 2015).*

3. Cattle were often seen grazing on macrophytes throughout the reach. This occurred mostly on the edge of the river (Figure 18), but occasionally cattle were seen deep in water eating macrophytes.

Figure 18 *Cows commonly were observed grazing the native macrophyte species Vallisneria nana (B. Vincent, 2015).*

4. Although *Vallisneria* species rarely flower in many river systems (River Science, 2001), widespread flowering of *V. nana* was observed in the Macleay River. Although *V. australis* flowering was far less common, it was often flowering where it appeared (Figure 19).

Figure 19. Vallisneria nana *and* V. australis *flowering in the Macleay River. The spiral flowering stems are very obvious at the surface of the macrophyte bed, but the flowers at the end of the stems are minute and difficult to see in the field.*

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Appendix

1. Other stream-side emergent 'semi'-macrophyte species that were sighted during the course of this study but considered outside the scope of this study due to their growth form (considered as submerged/emergent macrophytes for the purpose of this study), are given in Table A1.

Table A1 *Emergent macrophyte species observed in the freshwater Macleay River.*

No.	Family	Scientific Name	Common Name	Status
1	*Typhaceae*	*Typha orientalis*	Cumbungi	Native
2	*Cyperaceae*	*Schoenoplectus validus*	River Clubrush	Native
3	*Cyperaceae*	*Schoenoplectiella mucronatus*	Bog Bullrush	Native
4	*Poaceae*	*Phragmites australis*	Common Reed	Native
5	*Poaceae*	*Paspalum distichum*	Water Couch	Native
6	*Juncaceae*	*Juncus usitatus*	Common Rush	Native
7	*Cyperaceae*	*Eleocharis sphacelata*	Tall Spikerush	Native
8	*Cyperaceae*	*Eleocharis acuta*	Common Spikerush	Native
9	*Poaceae*	*Diplachne fusca*	Brown Beetle Grass	Native
10	*Cyperaceae*	*Cyperus eragrostis*	Umbrella Sedge	Exotic
11	*Cyperaceae*	*Bolboschoenus fluviatilis*	Marsh clubrush	Native
12	*Onagraceae*	*Ludwigia peploides ssp. montevidensis*	Water Primrose	Native
13	*Polygonaceae*	*Persicaria spp.*	Knotweeds	Native
14	*Poaceae*	*Paspalum spp.*	Paspalums	Exotic

2. The websites detailing control methods for the exotic freshwater Macrophyte species in the Macleay River are given in Table A2.

Table A2 *Links to Department of Primary Industries guide to control.*

Egeria (*Egeria densa*) - http://weeds.dpi.nsw.gov.au/Weeds/Details/182
Elodea (*Elodea canadensis*) - http://weeds.dpi.nsw.gov.au/Weeds/Details/240
Water Hyacinth (*Eichhornia crassipes*) - http://weeds.dpi.nsw.gov.au/Weeds/Details/145
Salvinia (*Salvinia molesta*) - http://weeds.dpi.nsw.gov.au/Weeds/Details/118
Water Lilies (Nymphaea sp. cultivar) - http://weeds.dpi.nsw.gov.au/Weeds/Details/259
Sagittaria (*Sagittaria platyphylla*) - http://weeds.dpi.nsw.gov.au/Weeds/Details/117