Baseline Ecological Monitoring of Lake Hawdon North, 2021

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NGT Consulting

Report to the South Australian Government Department for Environment and Water

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Cover photos: Clockwise from top left: Vicki Natt (FoSSE) counting shorebirds; a quadrat within aquatic vegetation; sharp-tailed sandpipers foraging; *Euphrasia collina* ssp. *collina*; Australian mudfish. All photos taken at Lake Hawdon North, October to November 2021.

Respect and Reconciliation

Aboriginal people are the First Peoples and Nations of South Australia. The Coorong, connected waters and surrounding lands have sustained unique First Nations cultures since time immemorial.

The *Healthy Coorong, Healthy Basin* program acknowledges the range of First Nations' rights, interests and obligations for the Coorong and connected waterways and the cultural connections that exist between Ngarrindjeri Nations and First Nations of the South East peoples across the region and seeks to support their equitable engagement.

Aboriginal peoples' spiritual, social, cultural and economic practices come from their lands and waters, and they continue to maintain their cultural heritage, economies, languages and laws which are of ongoing importance.

The Department for Environment and Water (DEW) works across the State with Aboriginal South Australians to conserve and sustain Country. Through this work we seek to improve the relationship between Aboriginal and non-Aboriginal Australians and build respect based on mutual understanding and acceptance of each other.

Acknowledgements

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Fieldwork for the fish component was conducted by Aquasave-NGT ecologists Ruan Gannon and Corey Young.

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Australian Government

Government of South Australia

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Executive Summary

The purpose of this study was to establish the methodology and obtain the baseline (pre-restoration) ecological data that will enable the measurement of ecological outcomes should the restoration of Lake Hawdon North (LHN) proceed. The ecological objectives of the restoration of LHN are:

Objective A. improve the availability and quality of foraging habitat (salt marsh/open mud flats) for the seven *Healthy Coorong, Healthy Basin* (HCHB) Regional Bird Refugia (RBR) target shorebird species, which are at risk from deteriorating conditions in the southern Coorong;

Objective B. increase the area of open mudflat/open water aquatic habitat, maintain the area of Baumea arthrophylla and Gahnia filum sedgelands and reduce the area of Melaleuca halmaturorum shrublands;

Objective C. do no harm, i.e. at the very least maintain identified existing ecological values, in particular the highly significant native fish community of the Lake Hawdon system, which includes diadromous species and covers both Lake Hawdon North and adjoining Lake Hawdon South Conservation Park.

In relation to each objective, this study has determined:

Objective A:

- Four of the seven target shorebird species of the HCHB RBR (sharp-tailed sandpiper, red-necked stint, red-capped plover and common greenshank) were present in LHN in November 2021 (Section 2) in abundances within the range anticipated based on past surveys of adjoining Lake Hawdon South (see Taylor 2020). Of the remaining target species, curlew sandpiper has been recorded previously in LHN and banded stilt have been recorded in adjacent Lake Hawdon South and may utilise LHN at times. This confirms that LHN provides suitable habitat for at least five of the target shorebird species in its current, unrestored state. The predicted increase to the carrying capacity of LHN for target shorebirds resulting from restoration (Taylor 2020) appears to be reasonable based upon the abundances observed in November 2021.
- An area of inundated open mudflat habitat in LHN had a lower abundance and lower diversity of macroinvertebrates than an area of similar habitat in Lake Hawdon South that is known to support high densities of target shorebirds when water levels are suitable (Section 3). Sediments in Lake Hawdon South were less compact and had organisms present at greater depths than sediments in LHN. Encouragingly, despite the less favourable status of the LHN sediments as a food resource, target shorebirds were recorded in the same area that sediment sampling occurred. This suggests that hydrological restoration alone will increase the carrying capacity of LHN, even without improvement to sediment food resources, as shorebird habitat is already provided when water levels are suitable. However, given a key difference between the two sediment monitoring locations is water regime, it is hypothesised that hydrological restoration will also improve the status of LHN sediments as a food resource for target shorebirds due to increased duration of inundation. Baseline data collected for this study will enable that hypothesis to be tested.

Objective B:

- Seven vegetation transects established within LHN (Section 4) include areas of all the vegetation types listed in Objective B, including areas of *M. halmaturorum* shrubland proposed for clearance under restoration. Resurvey of these transects following restoration will provide a direct measure of how well Objective B has been achieved. In particular, monitoring following the clearance of *M. halmaturorum* shrubland will

measure the success of this activity and can provide an early warning if further action is required to permanently eliminate this invasive native species from open mudflat habitat.

- *Melaleuca halmaturorum* recruitment monitoring in Lakes Hawdon North and South (Section 5), established in 2008, provides a measure of how effectively current management of LHN (sheep grazing and current hydrology) is preventing the recruitment of *M. halmaturorum* in areas where it currently exists in low density. The most recent data suggest slightly increased *M. halmaturorum* recruitment. Thus, without hydrological restoration, the expansion of *M. halmaturorum* shrubland within LHN (see Taylor et al. 2014) may continue. Ongoing *M. halmaturorum* recruitment monitoring will enable this issue to be examined and the effectiveness of hydrological restoration, if it occurs, to be assessed.

Objective C:

- The threatened Australian mudfish (*Neochanna cleaveri*) was detected in LHN for the first time (Section 6). The size distribution of mudfish caught in LHN suggests the species may be migrating seasonally into LHN from source populations elsewhere, likely from adjoining Lake Hawdon South, however its persistence in the sediments of LHN during the dry phase cannot be ruled out. The threatened little Galaxias (*Galaxiella toourtkoourt*) was also detected in LHN for the first time. This is also a species believed to survive the dry phase by burrowing into wetland sediments. These species, and the fish community of LHN in general, are anticipated to benefit from hydrological restoration, which will align the water regime of LHN more closely with that of Lake Hawdon South, where both species have well established populations with broad size class distribution.
- The proposed clearance of *M. halmaturorum* shrubland from the bed of LHN poses temporary risks for the fish community related to poor water quality caused by dead vegetation decomposing while submerged. With the significance of the fish community highlighted by this study it is important this risk be carefully managed should restoration proceed.
- The areas of dense *Melaleuca halmaturorum* shrubland that has established on the formerly open bed of LHN in recent decades support a relatively low diversity and low abundance community of bush birds, consisting mostly of common, generalist species (Section 7). Its clearance and restoration as open mudflat for shorebirds and other waterbirds is unlikely to cause harm to local bush bird populations.

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Abbreviations

DEM	Digital Elevation Model
HCHB	*Healthy Coorong, Healthy Basin* program
LHN	Lake Hawdon North
mAHD	meters Australia Height Datum (elevation relative to mean sea level)
OGW	On-Ground Works project (of the HCHB)
RBR	Regional Bird Refugia component (of the HCHB OGW)
WSEL	Water Surface Elevation

1. Introduction

1.1. *Healthy Coorong, Healthy Basin*

The Coorong, and Lakes Alexandrina and Albert Wetland is located at the terminus of the Murray-Darling Basin (MDB) System in South Australia. It is a system of shallow lakes, lagoons and wetlands covering over 140,000 hectares that is extremely diverse and is an important refuge for migratory and non-migratory waterbirds in the Murray Darling Basin. In 1985 the Coorong, and Lakes Alexandrina and Albert Wetland was declared a Ramsar Wetland of International Importance, largely due to its role in supporting a diverse and abundant waterbird community. The site is also subject to a number of international migratory bird agreements including the Japan Australia Migratory Bird Agreement, the China Australia Migratory Bird Agreement and the Republic of Korea Migratory Bird Agreement and is an Icon Site of the Murray-Darling Basin Living Murray Initiative.

It is well documented (e.g. Brookes et al. 2018) that the Coorong and Lower Lakes has undergone ecological decline, which has been exacerbated by unsustainable water extractions in the MDB and the Millennium Drought. The *Healthy Coorong, Healthy Basin* (HCHB) program proposes to implement works to support the long-term health of the Coorong, with a focus on the Coorong South Lagoon (CSL). The program is being delivered by the South Australian Government Department for Environment and Water (DEW) and is jointly funded by the Australian and South Australian Governments.

The HCHB program will be achieved through six projects, including the On-Ground Works (OGW) project. The OGW project is proposing to implement on-ground works to support the mitigation of threats to key Coorong biota. The OGW project includes the Regional Bird Refugia (RBR) component, which aims to improve the availability and quality of habitat for seven target migratory and non-migratory shorebirds at priority wetlands in the Lower Lakes and South East of South Australia to provide regional refugia. The seven target shorebird species are:

- sharp-tailed sandpiper;
- curlew sandpiper;
- red-necked stint;
- common greenshank;
- banded stilt;
- red-necked avocet; and
- red-capped plover.

A multi criteria decision analysis (MCDA) was undertaken to evaluate the potential of 23 wetlands in the South East region to provide habitat for key species of waterbirds disadvantaged by deteriorating conditions in the southern Coorong (Hunt et al. 2019). Lake Hawdon North was one of two South East (SE) wetlands receiving the highest MCDA score. A feasibility assessment completed in July 2020 (Taylor 2020) indicated the availability of habitat for the target species could be greatly increased by restoring hydrology and removing shrubland vegetation that has invaded in recent decades. This shrubland is unsuitable habitat for the target species and has established on former open mudflats (Taylor 2014) that would have provided ideal shorebird habitat. Assuming habitat for the target species consists of open mudflats inundated from 0 (damp) to 10 cm depth, Taylor (2020) found that restoration (shrubland removal combined with restored hydrology) could increase the carrying capacity of LHN for target species by 531%.

Following the 2020 feasibility assessment, further investigations have been undertaken examining various aspects of the proposed restoration including:

- detailed design of infrastructure;
- the ideal method to remove shrubland vegetation;
- approvals;
- Traditional Owner perspectives;
- stakeholder and broader community engagement; and
- downstream environmental water requirements.

This Baseline Ecological Monitoring Report forms part of the above suite of investigations. Its purpose is to provide baseline (pre-restoration) ecological data that will enable the measurement of ecological outcomes should the restoration of LHN proceed.

1.2. The Proposed Restoration of Lake Hawdon North

Lake Hawdon North is one of several large, seasonal to permanent wetlands within the Coorong region of the East-Asian Australasian Flyway. Located in relative proximity (65 km) to the Coorong and Lakes Alexandrina and Albert Ramsar site, Lake Hawdon North supports species that are subject to international migratory bird agreements. The wetland is part of a network of coastal wetlands that extends from the southern end of the Coorong South Lagoon to Lake Bonney SE.

Lake Hawdon North is a seasonally inundated wetland of 2,475 hectares (based on DEW regional wetland mapping) located approximately 15 km east of the coastal town of Robe in the South East of South Australia, in country that is the southern limit of the Meintangk and northern limit of the Boandik nations. Taking into account adjoining Lake Hawdon South (3,298 ha), the Hawdon complex has a total area of 5,773 ha, making it one of the largest wetland systems in the region. Lake Hawdon North receives surface water inflows from Drain L, the Lake Hawdon Connecting Drain (via Lake Hawdon South) and a network of smaller local drains from adjoining properties to the east and north. It is also recognised as a groundwater dependent ecosystem (Cranswick and Herpich 2018), receiving seasonal groundwater discharge from the regional unconfined aquifer (Harding 2018). Lake Hawdon North is grazed by sheep under licence while Lake Hawdon South is a Conservation Park from which sheep grazing was excluded in May 2009 (Taylor and Brown 2019). A lease for the mining of dolomitic limestone extends over 237 ha of the southern part of Lake Hawdon North.

The Lake Hawdon system is known to support internationally significant abundances of migratory shorebirds (Christie and Jessop 2007, Ferenczi et al. 2020), although surveys have focused on Lake Hawdon South. The relatively brief period of seasonal inundation that occurs within LHN in late winter/early spring is poorly aligned within the presence of migratory shorebirds (October to March), meaning this wetland has lower habitat value to these species than the adjoining Lake Hawdon South.

The hydrological changes, i.e. reduced duration of inundation, and associated changes to vegetation that have occurred at LHN due to the construction of Drain L have been described in previous reports (Ecological Associates 2009, Taylor 2020). A restoration feasibility assessment (Taylor 2020) described the actions required to enhance LHN as habitat for the seven target shorebirds of the HCHB RBR component. In summary, these actions are:

- the construction of a regulator on Drain L, where it exits LHN, and the implementation of a target hydrograph over the wetland that would extend the duration of shallow inundation through spring and summer; and
- the removal of approximately 650 ha of *Melaleuca halmaturorum* shrubland, which has invaded the bed of the wetland in recent decades, to restore open mudflat habitat.

The ecological objectives of the restoration project are:

- specifically within LHN, to:

  Objective A. improve the availability and quality of foraging habitat (salt marsh/open mud flats) for the seven HCHB RBR target shorebird species, which are at risk from deteriorating conditions in the southern Coorong;

  Objective B. increase the area of open mudflat/open water aquatic habitat, maintain the area of *Baumea arthrophylla* and *Gahnia filum* sedgelands and reduce the area of *Melaleuca halmaturorum* shrublands;

  Objective C. do no harm, i.e. at the very least maintain identified existing ecological values, in particular the highly significant native fish community of the Lake Hawdon system, which includes diadromous species and covers both LHN and adjoining Lake Hawdon South Conservation Park;

- More broadly, to:
  - not adversely impact the health of the downstream Robe Lakes; and
  - provide additional complementary foraging habitat to act as a 'buffer' against worsening conditions in the CSL, particularly during drier periods when waterbirds rely heavily on coastal wetlands.

Nature Glenelg Trust, in collaboration with the Department for Environment and Water, have developed this baseline ecological monitoring program to enable the ecological outcomes of restoration to be measured and assessed against those project objectives specific to LHN. The elements of the monitoring program and their relationship to the ecological objectives of the restoration project are as follows:

Objective A

- Shorebirds and other waterbirds: quantify the abundance of the seven HCHB RBR target shorebird species and other waterbirds across LHN to establish a pre-restoration baseline and to guide future surveys.
- Shorebird food resources: quantify the diversity and abundance of macroinvertebrate food resources for shorebirds in the sediments of both Lake Hawdon North and Lake Hawdon South to establish a pre-restoration baseline and a comparison between the two sites.

Objective B

- Vegetation transects: establish transects that describe the pre-restoration vegetation of LHN and enable future changes arising through restoration to be observed and monitored.
- *Melaleuca halmaturorum* recruitment: continue previously established monitoring of the abundance and size distribution of this invasive native species to provide an indication of the effectiveness of management, primarily grazing and hydrology, at preventing its proliferation.

Objective C

- Fish: undertake fish monitoring of existing and new monitoring locations throughout the Lake Hawdon system and compare results to previous data to provide a detailed understanding of the diversity, abundance and distribution of fish species and the demography of key threatened species.
- Bush Birds: improve understanding of the diversity and abundance of bush birds in the areas of *Melaleuca halmaturorum* shrubland proposed for clearance to provide a basis for the restoration project to minimise impacts to fauna.

This report is divided into sections specific to each of the above elements of the monitoring program. Future monitoring of each element could be undertaken independently of other elements.

2. Shorebirds and Other Waterbirds

2.1. Background

The use of Lake Hawdon North by shorebirds and other waterbirds has received limited previous attention. Stewart et al. (2001) undertook a comprehensive biological survey of the entire Lake Hawdon system that included targeted waterbird counts over portions of both Lake Hawdon North and Lake Hawdon South. In reporting, data for both lakes were combined, making it impossible to determine which they apply to. Six of the seven HCHB RBR target shorebird species were recorded across the Lake Hawdon system by these surveys, the exception being red-necked avocet.

Christie and Jessop (2007) provided data for five shorebird surveys of LHN that occurred annually between 2002 and 2006. These surveys were conducted in winter and were limited to the mining tenement at the southern end of LHN (Maureen Christie, FoSSE, pers. com., 22/11/21). Thus, these surveys were not spatially comprehensive, covering approximately 10% of the total area of the wetland, and were not timed appropriately to detect peak abundances of migratory shorebirds, particularly the seven target species of the HCHB RBR. However, these surveys did confirm LHN as an internationally significant site for double-banded plover, with 600 recorded on one occasion (Christie and Jessop 2007). Double-banded plover is a winter migrant to eastern and southern Australia from the South Island of New Zealand (Geering et al. 2007). Red-necked stint, curlew sandpiper and red-capped plover were also recorded at LHN during these winter surveys.

NatureMaps (DEW 2021a) indicates that three of the seven target species have been recorded at LHN; common greenshank, red-capped plover and sharp-tailed sandpiper.

In summary, existing records indicate that five of the seven HCHB RBR target shorebird species occur at LHN:

- sharp-tailed sandpiper;
- curlew sandpiper;
- red-necked stint;
- common greenshank; and
- red-capped plover.

However, the abundance and spatial distribution of these species across the site has not previously been investigated and is unknown. Banded stilt have previously been recorded in the Lake Hawdon complex but is unclear if the species has been observed in LHN. Red-necked avocet have not previously been recorded in either Lake Hawdon North or South.

An objective of the proposed restoration of LHN under the HCHB RBR component is to improve the availability and quality of foraging habitat for the seven target shorebird species, therefore information on the pre-restoration abundance of these species is required to enable the outcomes of restoration to be measured. Given the large size of LHN, ideally a representative area of suitable habitat of manageable size could be surveyed in one day or less to provide the baseline. This would ensure that the baseline methodology did not place onerous obligations upon future repeat surveys. However, in the case of LHN, a complicating factor is that areas of the wetland currently unsuitable for shorebirds, due to the presence of dense shrubland and short-duration inundation, are likely to become favourable habitat under restoration.

Given the uncertainty relating to current versus restored habitat availability, a census approach was used to obtain a more comprehensive understanding of current shorebird and general waterbird use of LHN.

2.2. Methods

The census was conducted over two days on 9th and 10th November 2021. Teams consisted of two to three members, with at least one experienced shorebird and waterbird surveyor to lead each team. Teams included representatives from NGT, Friends of Shorebirds SE (FoSSE) and the University of Adelaide (UoA). Team members were:

- Maureen Christie (FoSSE) – team leader
- Vicki Natt (FoSSE) – team leader
- Cath Bell (FoSSE) – team leader
- Micha Jackson (UoA) – team leader
- Bryan Haywood (NGT) – team leader
- Josie Doyle (FoSSE)
- Graham Doyle (FoSSE)
- Holly Prest (FoSSE)
- Ben Taylor (NGT)

The survey area was assessed on foot, with vehicle access around the margins of the wetland arranged prior with adjoining landholders. Teams were equipped with binoculars and spotting scopes. Call identification was also used to detect some species.

The survey area consisted of the mapped extents (DEW "LANDSCAPE_Wetlands" layer) of LHN, comprising wetland polygons S0109028 and S0108576, as well as an adjacent wetland to the immediate north, wetland S0108587 (Figure 1). This adjacent wetland was included in the survey area because it is hydraulically connected to LHN when WSEL exceeds approximately 4.15 mAHD, which is within the regulated WSEL range under the proposed restoration of LHN (3.60 – 4.30 mAHD).

The survey area was overlaid with a grid of 220 square cells, each 400 × 400 m (16 ha) in size. Cells were aligned with Drain L to avoid the difficulties of cells straddling both sides of the drain. Cell boundaries were identifiable to surveyors on the ground using the AvenzaMaps® application on mobile phones, enabling bird counts per cell to be made. Areas within cells but outside of the target wetland polygons (i.e. adjoining paddocks) were considered as outside the survey area and were not counted. Drain L itself was counted as part of cells in the row D-15 to P-15.

Mudflat and open water habitats in each cell were assessed and all birds within these habitats counted. This included both inundated and dry mudflats. Other habitat types were not systematically counted, however birds observed within these habitats (shrublands, grasslands (mostly dominated by introduced pasture grasses), *Gahnia filum* sedgelands, *Baumea arthrophylla* sedgelands) were opportunistically counted.

For each cell an estimate of the percent inundation by area was made by surveyors on the ground. These data were used in combination with the DEM to estimate the overall extent of surface water within LHN at the time of the survey.

Weather conditions in Robe (15 km to the west of LHN) on 9th November were overcast with a maximum temperature of 18.5°C and 20 km/hr south-west winds at 3.00 pm. On 10th November conditions were sunny, maximum temperature 15.8°C with 19 km/hr southerly winds at 3.00 pm.

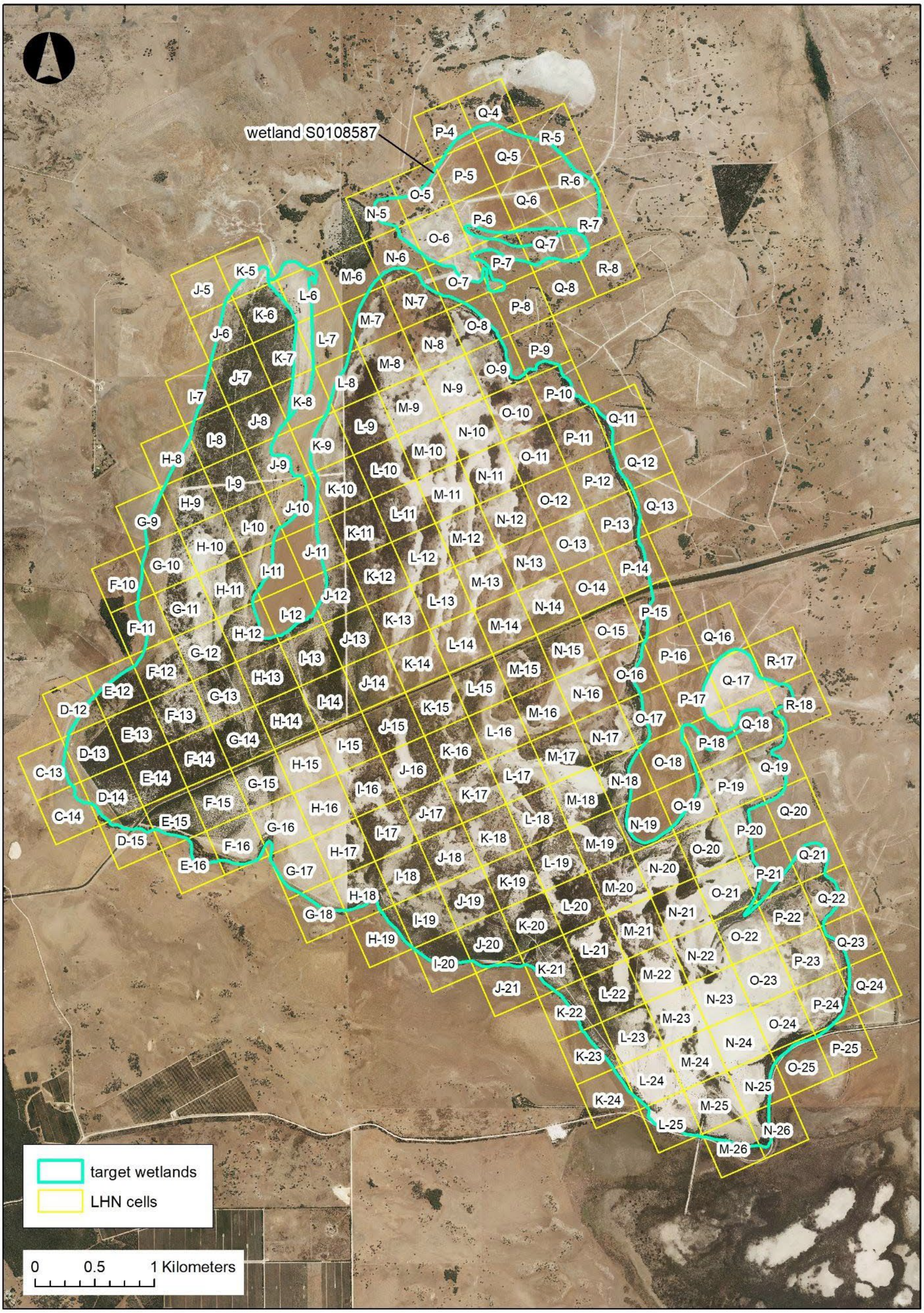


Figure 1. Survey area (target wetlands) and overlying grid of 220 cells.

2.3. Results

Water Levels

The estimates of percent inundation per cell obtained in the field have been combined with the 2m regional DEM to map the extent of inundation at the time of survey. Notably, the WSEL was not consistent across LHN. To map the extent of inundation it was necessary to split the DEM within LHN and adjust the WSEL within sub-units, consisting of clusters of cells, to align with field observations. The WSEL assumed in relevant cells to map the extent of inundation is shown in Figure 2. Achieving a neat alignment between field observations and the DEM remained challenging and explains the straight edges of the inundated extent observable in some locations (Figure 3).

There was a marked difference in WSEL, and thus area inundated, north and south of Drain L. Surface water was present within only four of the 115 cells north of Drain L and was <5% in each of those four cells. A WSEL of 3.85 mAHD was estimated for three cells immediately north of Drain L towards the eastern side of LHN (L-14 to N-14). A WSEL of 4.01 mAHD was estimated for wetland S0108587 (in cell O-6), which was hydraulically isolated.

South of Drain L, the highest WSEL in LHN was in the south-east (within the mining tenement, near the Old Naracoorte Rd) and east, where a WSEL of 4.15 mAHD was estimated. Water levels declined towards the north-west, with a WSEL of 3.75 estimated for cell H-15 at the north-western edge of the inundated area. With the generally higher WSEL south of Drain L, 75 of the 105 cells in this area featured surface water.

Our estimates of WSEL indicate a 40 cm difference in WSEL within LHN on the dates of the census.

Drain L itself was inundated but had a relatively low flow rate, gauged at c.40 ML/day (DEW 2021b) and a WSEL lower than the adjacent bed of LHN. It was also noted that the Lake Hawdon Connecting Drain was delivering low flows into the southern end of LHN during the survey. The Connecting Drain regulator was closed and flows were confined to the fishway at a rate of c.5 ML/day (visual estimate).

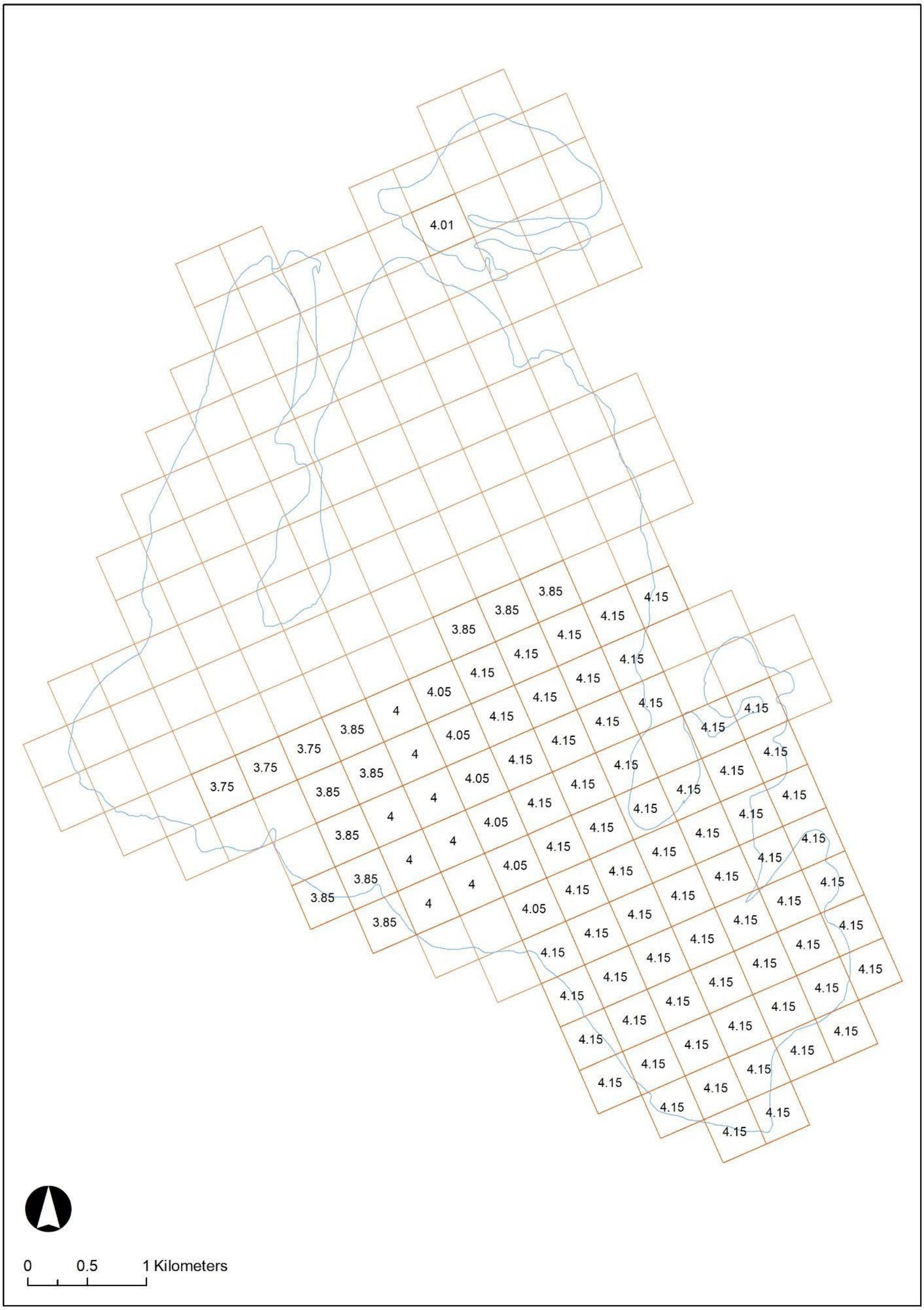


Figure 2. Estimated WSEL (mAHD) within each cell on the census dates.
Unlabelled cells were dry based on field observations.

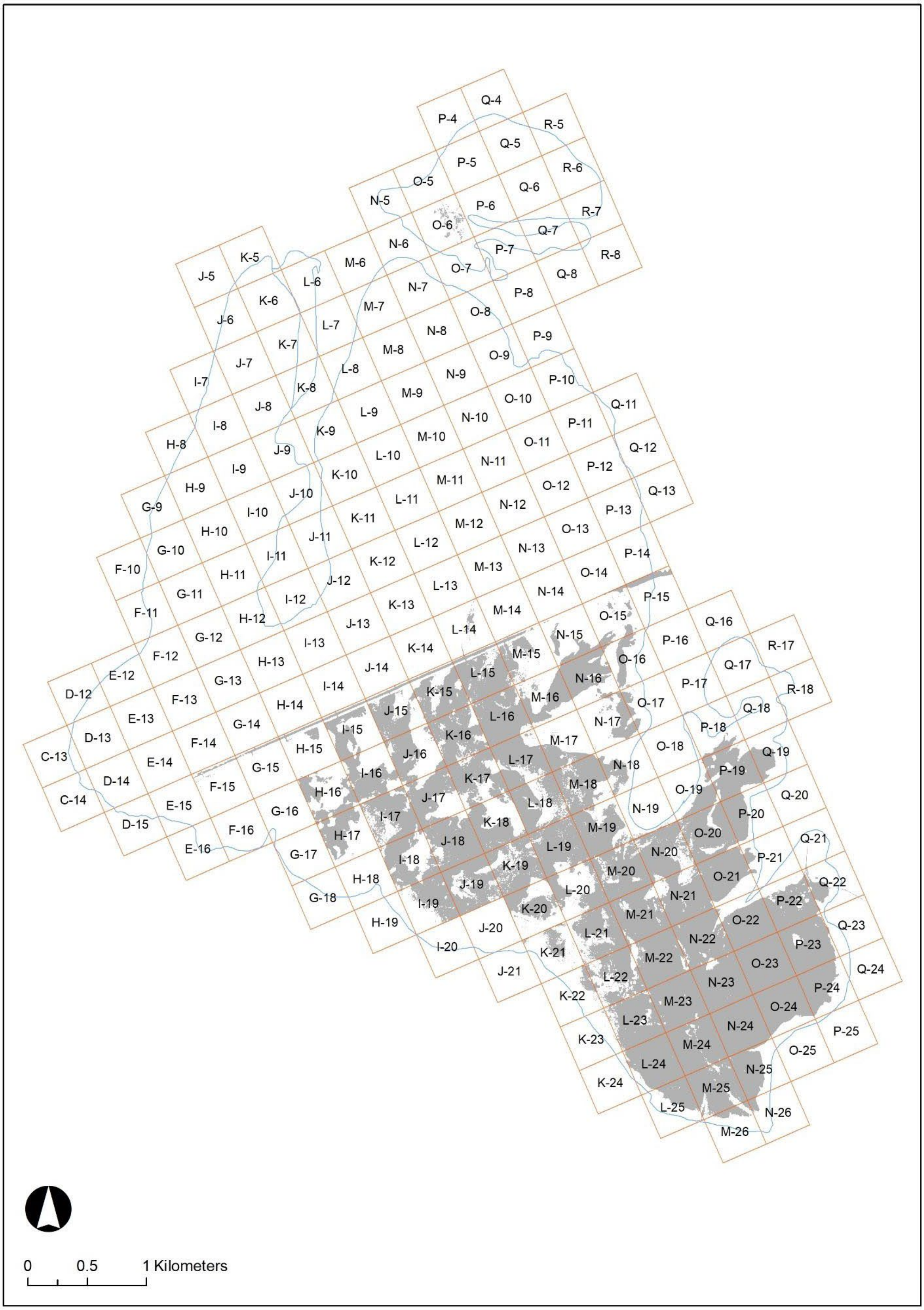


Figure 3. Estimated extent of inundation of the survey area on the census dates.

Bird Abundance

The census recorded 69 bird species in two categories:

- Confident counts for the entire survey area were obtained for 28 species of open water and mudflat habitat. Total counts for these species are presented in Table 1 and counts for each cell are presented in Appendix A.
- The remaining 41 species were recorded opportunistically. While these species were counted when observed, total numbers counted are not representative of the entire survey area because these species favour dense shrubland and *Gahnia* vegetation that was not systematically surveyed for the census (but see Section 7). For these species, counts for each cell are presented in Appendix A and total counts are presented in Appendix B.

Waterfowl were most abundant in the south-east of the survey area, where water depths were greatest due to a combination of a high WSEL (compared to other areas) and excavations within the mining tenement. The most abundant species was Australian shelduck (2786), which was present in 16 cells and formed some large flocks of up to 800 individuals. Grey teal were also an abundant waterfowl (1394) in the same area but also on Drain L. Black-winged stilt were relatively abundant (1313), mostly in the south-east of the survey area. Black swan with young were observed and a number of recently abandoned swan nests were encountered.

Whiskered tern was the second most abundant species (1834), observed mostly in flight foraging over open water over most of the survey area, but occasionally roosting on the ground in larger flocks of up to 260. It was the most widespread species, present within 49 cells. White-faced heron was the next most widespread species, present within 28 cells, but in much lower abundance (123).

Of the species recorded opportunistically, several large flocks (up to 75 individuals) of black-tailed native hen were observed. A number of cryptic birds of dense wetland habitats were observed including golden-headed cisticola, little grassbird, striated fieldwren and white-fronted chat (in 18 cells). A number of bush birds were observed in a range of habitats from tall, dense *M. halmaturorum* shrubland to open grassland (see also Section 7). These included the state rare beautiful firetail.

Table 1. Total counts for bird species systematically counted the Lake Hawdon North census.

Common Name	Total
Australasian shoveler	22
Australian shelduck	2786
Australian white ibis	11
banded lapwing	5
black swan	159
black-winged stilt	1313
Caspian tern	1
cattle egret	2
chestnut teal	116
common greenshank	**47**
great cormorant	2
great egret	2
grey teal	1394
hardhead	6
hoary-headed grebe	11
little egret	27
masked lapwing	153
musk duck	5
Pacific black duck	330

Common Name	Total
pink-eared duck	2
red-capped plover	**140**
red-necked stint	**331**
royal spoonbill	1
sharp-tailed sandpiper	**674**
silver gull	702
straw-necked ibis	1
whiskered tern	1834
white-faced heron	123

Target Shorebird Distribution

Of the seven HCHB RBR target species, only sharp-tailed sandpiper, red-necked stint, common greenshank and red-capped plover were recorded in the census. Curlew sandpiper, red-necked avocet and banded stilt were not recorded. The combined total abundance of target species was 1192 and they were located within 22 of the 220 cells. As expected, target shorebirds were mostly located in cells with shallow (0 – 10 cm) inundation, however there were exceptions, with low numbers (2 – 10, 18 in total) of red-capped plover observed in three dry (possibly damp) cells. Of the 79 cells within the survey area that were partially or completely inundated, a total of 1174 target shorebirds were present in 19 cells.

The combined abundance and distribution of the target shorebird species is shown in Figure 4. Single species abundance and distribution maps for each of the four species recorded are provided in Figure 5, Figure 6, Figure 7 and Figure 8.

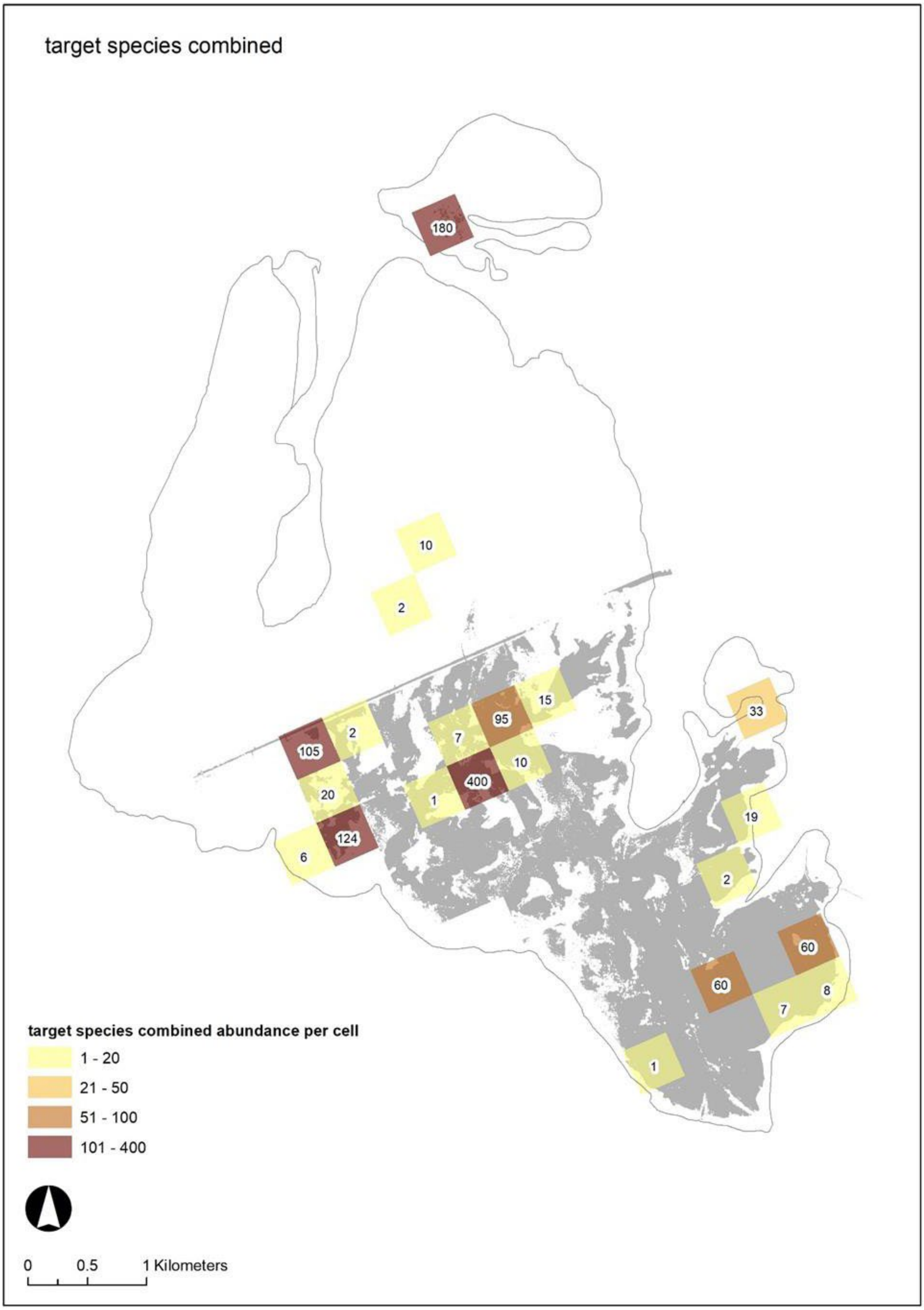


Figure 4. Distribution and abundance of HCHB RBR target shorebirds (combined) at LHN, 9-10 November 2021. Extent of inundation is also indicated.

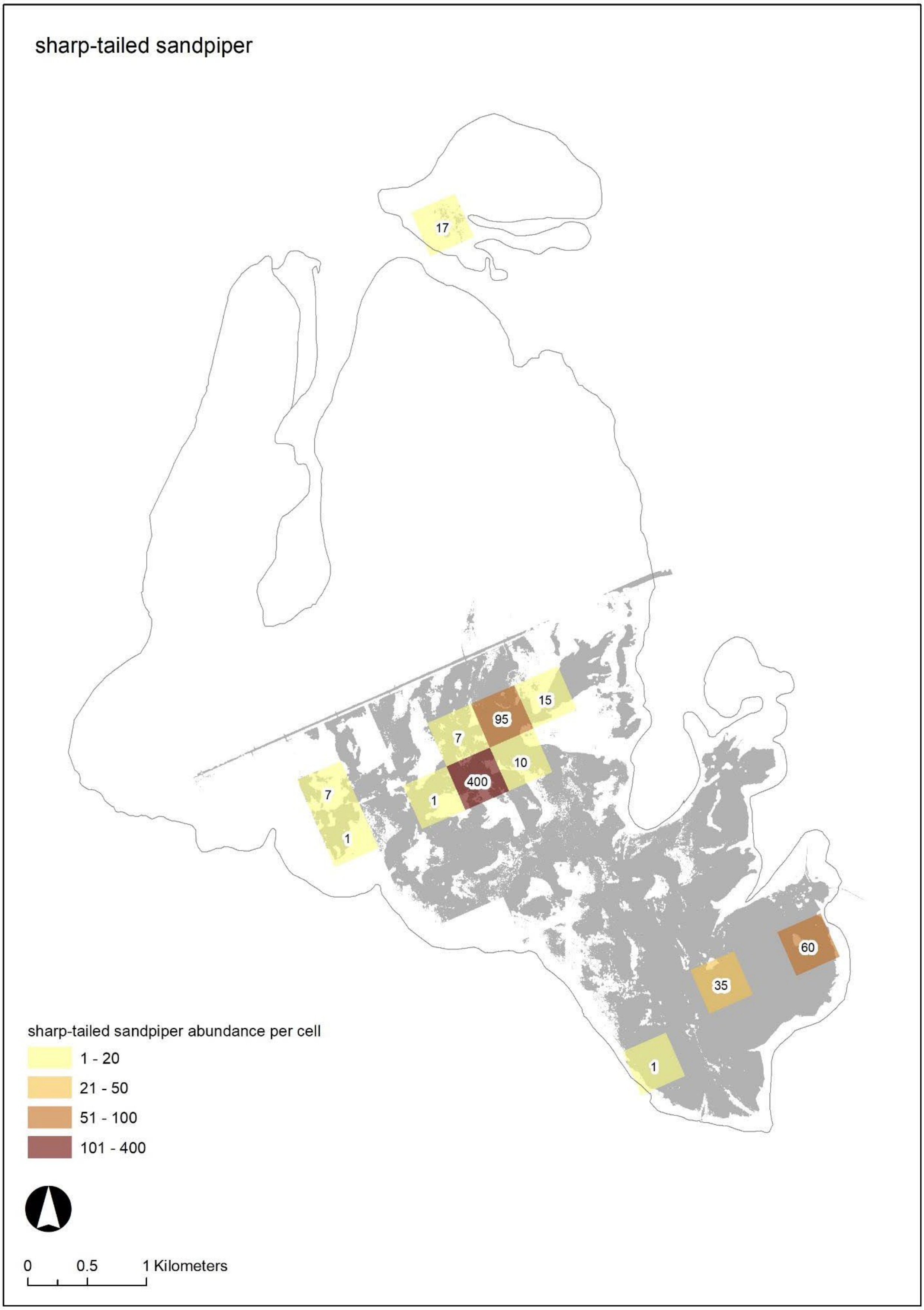


Figure 5. Distribution and abundance of sharp-tailed sandpiper at LHN, 9-10 November 2021. Extent of inundation is also indicated.

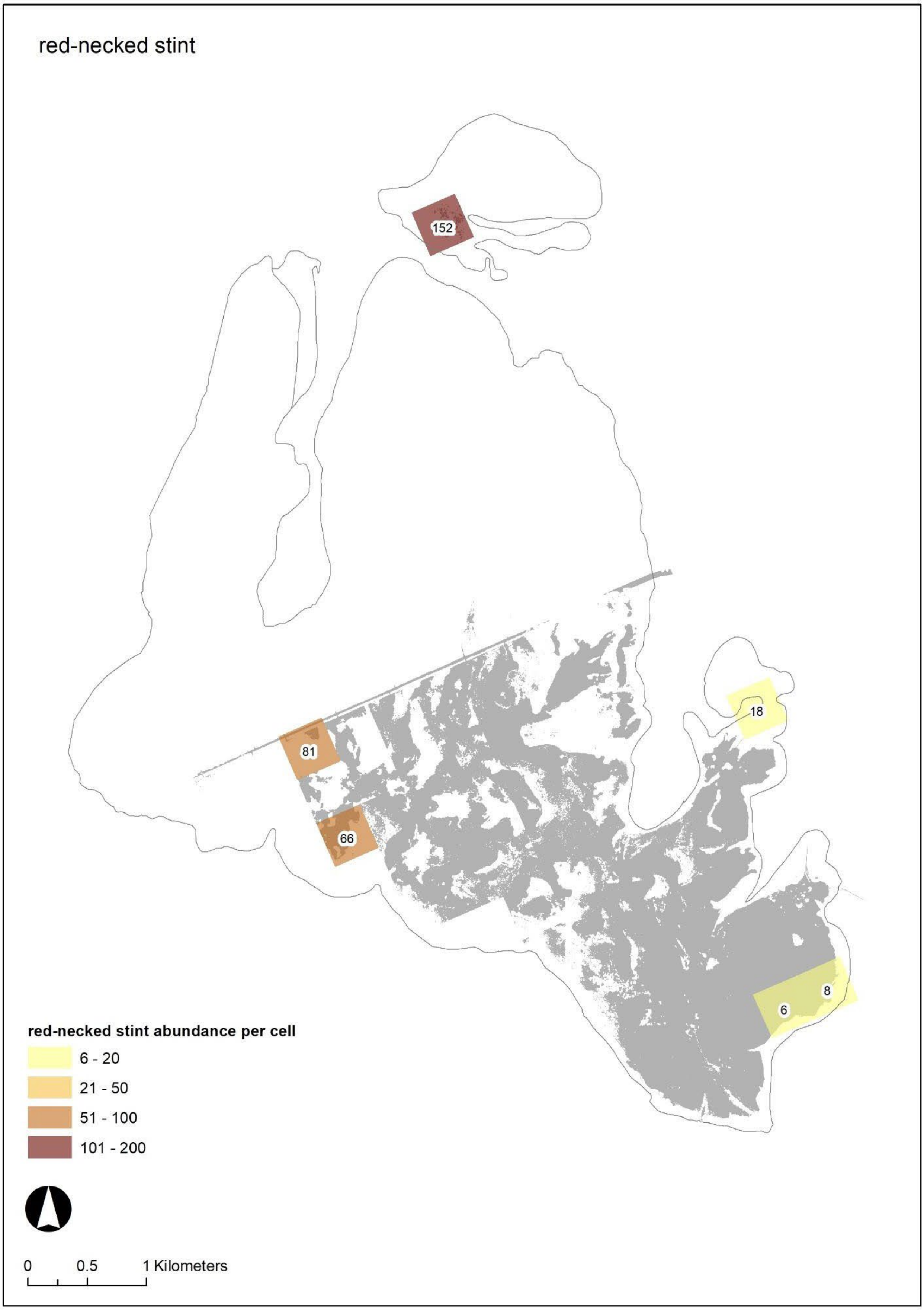


Figure 6. Distribution and abundance of red-necked stint at LHN, 9-10 November 2021.
Extent of inundation is also indicated.

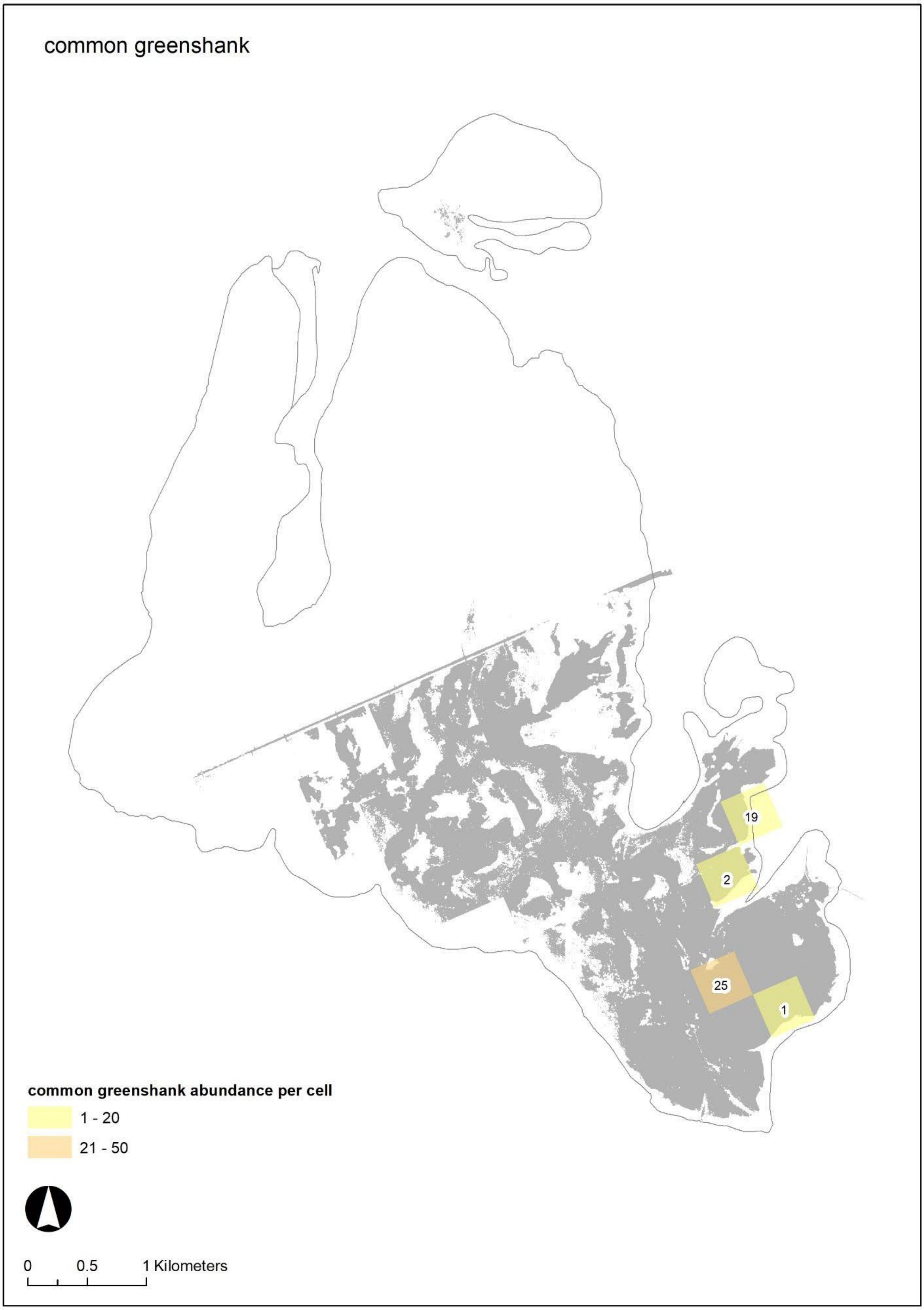


Figure 7. Distribution and abundance of common greenshank at LHN, 9-10 November 2021.
Extent of inundation is also indicated.

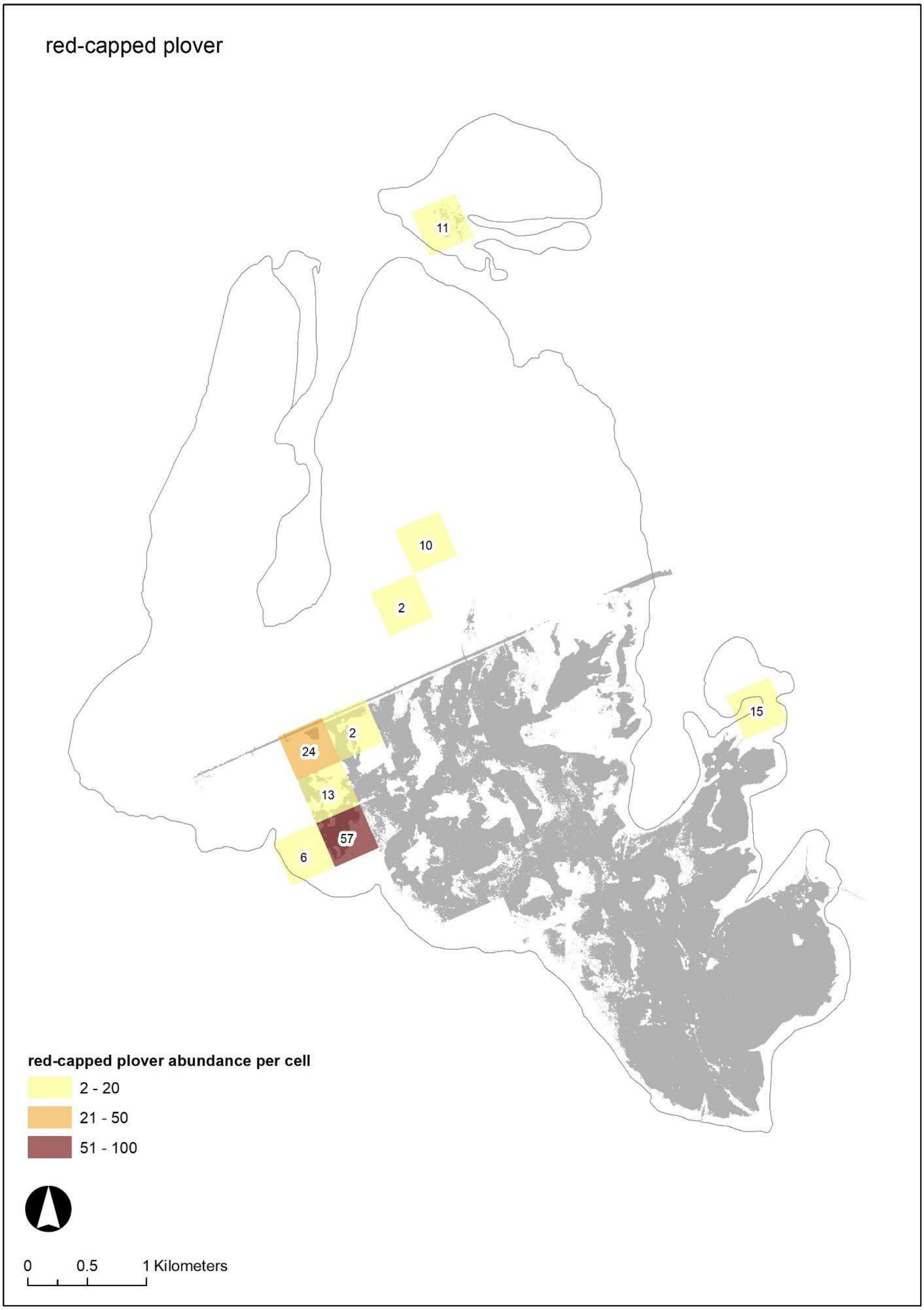


Figure 8. Distribution and abundance of red-capped plover at LHN, 9-10 November 2021. Extent of inundation is also indicated.

2.4. Discussion

The census confirmed that Lake Hawdon North supports four of the seven target shorebird species in abundances within the range anticipated based on past surveys of adjoining Lake Hawdon South (see Taylor 2020). The results therefore support the prediction (Taylor 2020) that restoration (shrubland removal combined with restored hydrology) is likely to increase the carrying capacity of LHN for shorebirds.

The cell occupancy of target shorebirds at LHN in early November (present in 19 of 79 partially or completely inundated cells) raises questions. The 60 unoccupied but inundated cells may comprise unsuitable habitat due to other factors, potentially the presence of unfavourable (dense, tall) vegetation. However, based on our observations, only a small proportion of the inundated area was dense *Gahnia filum* sedgeland and/or *Melaleuca halmaturorum* shrubland (contemporary vegetation mapping is not yet available to confirm this). The majority was open water within a patchwork of emergent *Baumea arthrophylla* sedgeland and low herbland, i.e. suitable habitat if water depth is suitable.

Excessively high water level is a more likely explanation for the absence of target shorebirds from much of the inundated area. A WSEL of 4.15 mAHD was estimated for 50 of the 79 inundated cells. Through much of this area the bed of LHN is 3.90 – 4.00 mAHD. Therefore depth was 15 – 25 cm over a large portion of the inundated area of LHN on the census dates, which is outside the ideal range of 0 (damp) – 10 cm for the target shorebird species (O'Connor et al. 2013, Paton 2010).

The timing of the census is also a factor likely to influence the results. The census was undertaken in early November to coincide with the presence of surface water in LHN, which is known to drain and dry quickly, typically by early summer. With migratory shorebirds typically arriving in the region from October and departing in March (Ferenczi et al. 2020), the census occurred quite early in the season. At this time, regional habitat availability is typically relatively high, and particularly so in 2021 given the high rainfall and low temperature conditions experienced in the South East region, and southern Australia broadly, over the preceding winter/spring. This underscores a key issue identified previously (Taylor 2020); the minimal overlap between habitat availability at LHN under current management and the habitat requirements of migratory shorebirds in the region. LHN clearly supports shorebirds under current management, however, when LHN habitat is available (inundated), regional habitat is not in short supply. If restoration proceeds, the extent of inundation observed on the baseline census dates would typically occur later in the season, when regional habitat availability would be lower due to the drying and shrinking of inundated areas over spring and summer.

The baseline census provides several indicators of target shorebird abundance and distribution at LHN that can be compared to post-restoration survey data to assess restoration outcomes. These indicators include:

- Total abundance (combined or per species);
- Proportion of inundated cells occupied;
- Density within suitable habitat (depth 0 cm (damp) – 10 cm);
- Number of target shorebird (and other wader) species present.

The census data confirm that future surveys should target inundated areas (depth 0 cm (damp) – 10 cm), with only low numbers of one species, red-capped plover, present in areas without surface water. These observations inform the best available baseline and all future interpretations of response will be relative to the findings present herein.

3. Shorebird Food Resources

3.1. Methods

The focus of this component was to conduct baseline monitoring of macroinvertebrate abundance and diversity in the wet, muddy sediment (i.e. potential foraging habitat for shorebirds) of LHN and Lake Hawdon South, prior to the drying of LHN and during the migratory shorebird non-breeding season (i.e. September to April). This sampling can be considered the 'before' component of a Before-After Control-Impact statistical design (should additional invertebrate surveys follow the construction of a regulator at LHN) to assess the effectiveness of the action with regard to sediment fauna.

Macroinvertebrate sampling at Lake Hawdon followed a modified version of the protocol currently used to study shorebird food resources in the Coorong as part of the *Healthy Coorong, Healthy Basin* Trials and Investigations Component 4 (waterbirds) project.

Macroinvertebrate surveys were conducted within one sub-region of each lake (hereafter 'survey site'). Surveys were conducted on September 22nd and 23rd, 2021 and November 9th and 9th, 2021. Survey sites were located along the south-western and north-eastern edges of Lake Hawdon North and South, respectively (Figure 9). These sites were easily accessible, had similar substratum and vegetation characteristics, and are expected to provide some inundated shorebird feeding habitat (i.e. wet, muddy sediment) to allow macroinvertebrate sampling on both occasions under current biophysical conditions and management practices.

At each site, five transects were established, approximately 50 m apart running perpendicular to the waterline with three sampling points on each transect, for a total of 15 sampling points per trip, per site. Two sampling points were located at fixed points approximately 150 m apart, one near the shoreline (hereafter "Fixed Point 2"), and one towards the centre of the lake (hereafter "Fixed Point 1"). A third sampling point was located wherever the waterline occurred along the transect on the survey date (hereafter "Waterline") (Figure 10). The water depth at each sampling point was recorded.

A sediment core of 9 cm diameter (0.0064 m^2 surface area) was taken at each of the three locations along each transect. At LHN, the cores reached a depth of 10 cm. At Lake Hawdon South, the deeper substrate of the lakebed prevented the sinking of cores to 10 cm depth in most instances, so a core was taken to the maximum depth possible at each sampling point, and this depth was recorded.

Sediment cores were sieved *in situ* using a 500 µm mesh sieve. All material retained by the sieve was placed in a plastic zipped storage bag. Within 48 hours, samples were transferred to a white invertebrate sorting tray along with some water and all macroinvertebrates were removed using tweezers and stored in ethanol. Later, all macroinvertebrates were sorted under a dissecting microscope into the lowest possible taxonomic group and enumerated.

To visualise the composition of the benthic assemblages of the two lakes, a Non-metric Multi-dimensional Scaling (NMDS) analysis was plotted using the Vegan package (Oksanen et al. 2007) in the R software environment for statistical and graphical computing (R Core Team 2020) version 4.0.2. Analysis was performed using the relative abundance of each organism category (refer to Table 2) using a Hellinger transformation, which is appropriate for data that have some abundant species and some rare species; cores in which we did not find any invertebrates were excluded from the NMDS analysis.

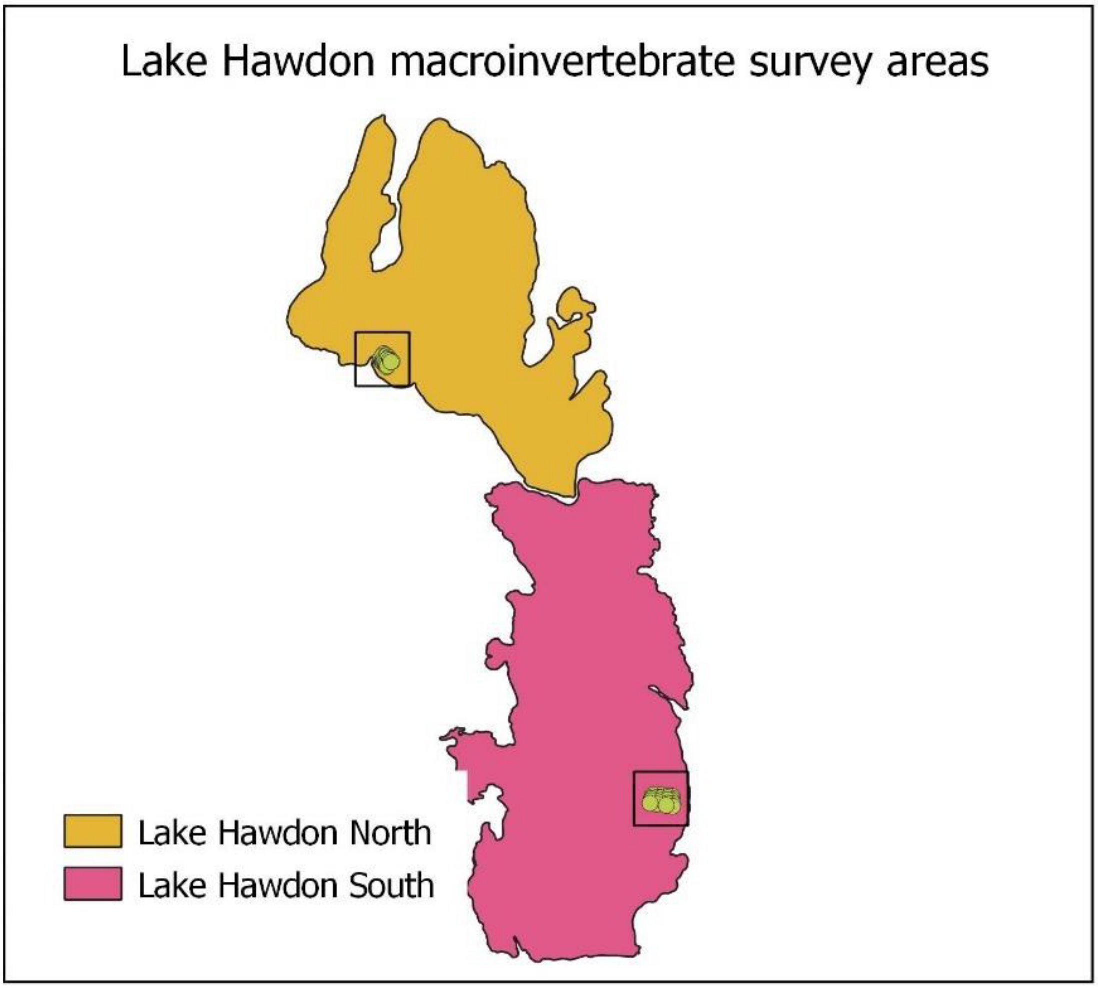


Figure 9. Lake Hawdon macroinvertebrate survey sites.

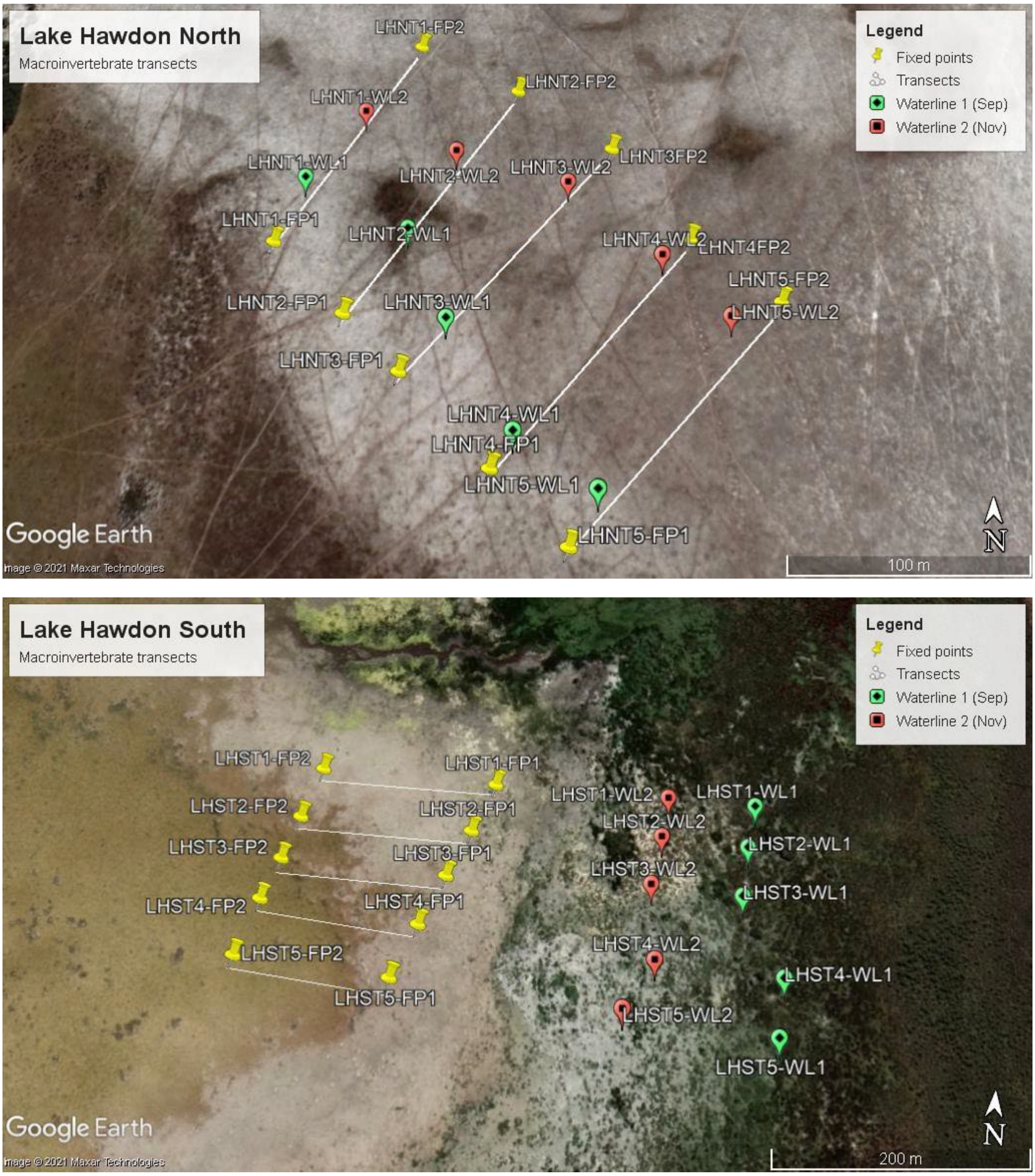


Figure 10. Lake Hawdon macroinvertebrate transects, showing two fixed points (yellow; “FP1” = Fixed Point 1” and “FP2” = Fixed Point 2) and two waterline points (one in September; green, “WL1” = Waterline 1 and one in November; red, “WL2” = Waterline 2).

3.2. Results

A total of 1,363 individual macroinvertebrates were collected across both trips and sites (30 total samples), including 245 at Lake Hawdon North (217 in September and 28 in November; Table 2) and 1,118 at Lake Hawdon South (767 in September and 351 in November; Table 2).

At Lake Hawdon North, a total of 107, 50 and 88 organisms were collected from Fixed Point 1, Fixed Point 2 and the Waterline, respectively (Table 2; Figure 11). At Lake Hawdon South, a total of 283, 782 and 53 organisms were collected from Fixed Point 1, Fixed Point 2 and the Waterline, respectively (Table 2; Figure 11).

At Lake Hawdon North, where core samples were divided into two core depths, a total of 227 organisms were collected at 0-3cm depth (89% of the total) and just 18 organisms were collected at 3-10cm depth. In general, the sediment was compact and difficult to sieve at Lake Hawdon North. Vegetation and vegetation roots were also regularly encountered in the sediment.

Ten invertebrate taxa were identified at Lake Hawdon North and 16 taxa at Lake Hawdon South, as well as two unidentified organisms at Lake Hawdon North (Table 3; Figure 11; Figure 12).

At Lake Hawdon North the vast majority of organisms collected (almost 90% of 245 total individuals) were Oligochaetes (Table 3). These were subdivided according to size, with megadrile Oligochaetes (i.e. Oligochaetes with body thickness > 10mm) most abundant (Table 3). At Lake Hawdon South the make-up of invertebrates was more diverse with more than 20 individuals of microdrile Oligochaetes (52% of 1,118 total individuals), *Capitella* sp. (24%), Chironomidae larvae (10%), Ostracoda spp. (5%), Amphipoda spp. (4%), and Physidae sp. (2%) recorded (Table 3). Interestingly, megadrile Oligochaetes were absent from Lake Hawdon South sediments.

The dissimilarity in the types of invertebrates inhabiting wet muds at the two lakes is illustrated in the NMDS plot (Figure 13).

At Lake Hawdon North, the average water depth across the five transects was 3.9 ± 1.56 cm (September) and <1cm (November) at Fixed Point 1, and 16.9 ± 1.64 cm (September) and 19.9 ± 14.57 cm (November) at Fixed Point 2. At Lake Hawdon South, the average water depth across the five transects was 48.3 ± 3.23 cm (September) and 31 ± 5.83 cm (November) at Fixed Point 1, and 44.1 ± 2.13 cm (September) and 25.4 ± 3.58 (November) at Fixed Point 2. The average core depth across the five transects at Lake Hawdon South was 7.2 ± 2.78 cm (September) and 6.3 ± 0.45 cm (November) at Fixed Point 1, and 7.9 ± 2.53 cm (September) and 9.2 ± 1.92 cm (November) at Fixed Point 2.

Table 2. Total invertebrate count from all samples for September and November, 2021.

LAKE HAWDON NORTH												
	Transect 1		**Transect 2**		**Transect 3**		**Transect 4**		**Transect 5**		**TOTAL**	
	Sep	*Nov*	*Sep*	*Nov*	*Sep*	*Nov*	*Sep*	*Nov*	*Sep*	*Nov*	*Sep*	*Nov*
Fixed Point 1	1	1	51	17	3	0	11	3	20	0	86	21
Fixed Point 2	12	0	4	0	1	1	8	4	20	0	45	6
Waterline	2	0	33	0	0	1	43	0	8	1	86	6
Total	15	1	88	17	4	2	62	7	48	1	217	28
LAKE HAWDON SOUTH												
	Transect 1		**Transect 2**		**Transect 3**		**Transect 4**		**Transect 5**		**TOTAL**	
	Sep	*Nov*	*Sep*	*Nov*	*Sep*	*Nov*	*Sep*	*Nov*	*Sep*	*Nov*	*Sep*	*Nov*
Fixed Point 1	38	10	55	11	49	45	15	35	6	19	163	120
Fixed Point 2	69	10	66	27	116	33	123	67	199	72	573	209
Waterline	14	9	5	2	2	4	7	3	3	4	31	22
Total	121	29	126	40	167	82	145	105	208	95	767	351

Table 3. Types of macroinvertebrates collected at Lake Hawdon

ORGANISM	LAKE HAWDON NORTH	LAKE HAWDON SOUTH
Oligochaeta sp. - megadrile	207 (84.5%)	0
Oligochaeta sp. - microdrile	12 (4.9%)	584 (52.2%)
Polychaeta – Capitella sp.	2 (0.8%)	266 (23.8%)
Diptera larvae - Chironomidae	1 (0.4%)	115 (10.3%)
Diptera larvae - Ceratopogonidae	0	2 (0.2%)
Diptera larvae - Stratiomyidae	0	5 (0.5%)
Diptera adult spp.	2 (0.8%)	1 (0.1%)
Hydrophilidae larvae - Berosus sp.	1 (0.4%)	2 (0.2%)
Hydrophilidae adult - Berosus sp.	0	3 (0.3%)
Dytiscidae larvae - Necterosoma sp.	0	2 (0.2%)
Corixidae nymph - Micronecta sp.	0	2 (0.2%)
Amphipoda spp.	15 (6.1%)	41 (3.7%)
Ostracoda spp.	0	59 (5.2%)
Gastropoda Physidae sp.	1 (0.4%)	25 (2.2%)
Gastropod Coxiella sp.	0	7 (0.6%)
Trichoptera sp.	0	1 (0.001%)
Elyaidae Eylais sp.	2 (0.8%)	3 (0.3%)
Unknown	2 (0.8%)	0
Total	**245**	**1118**

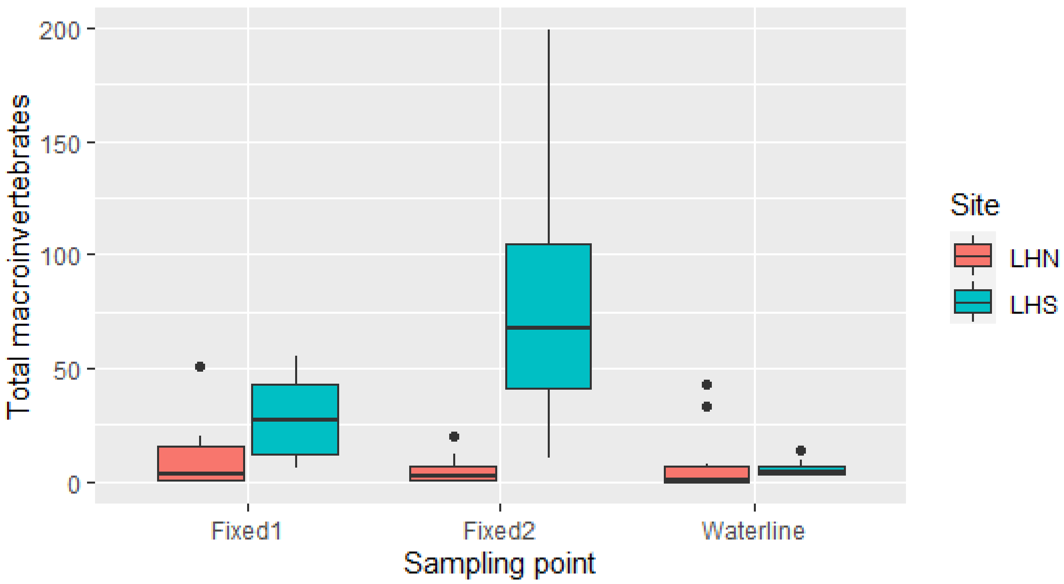


Figure 11. Number of macroinvertebrates collected at each site at Fixed Point 1, Fixed Point 2 and the Waterline (on the day of the survey).

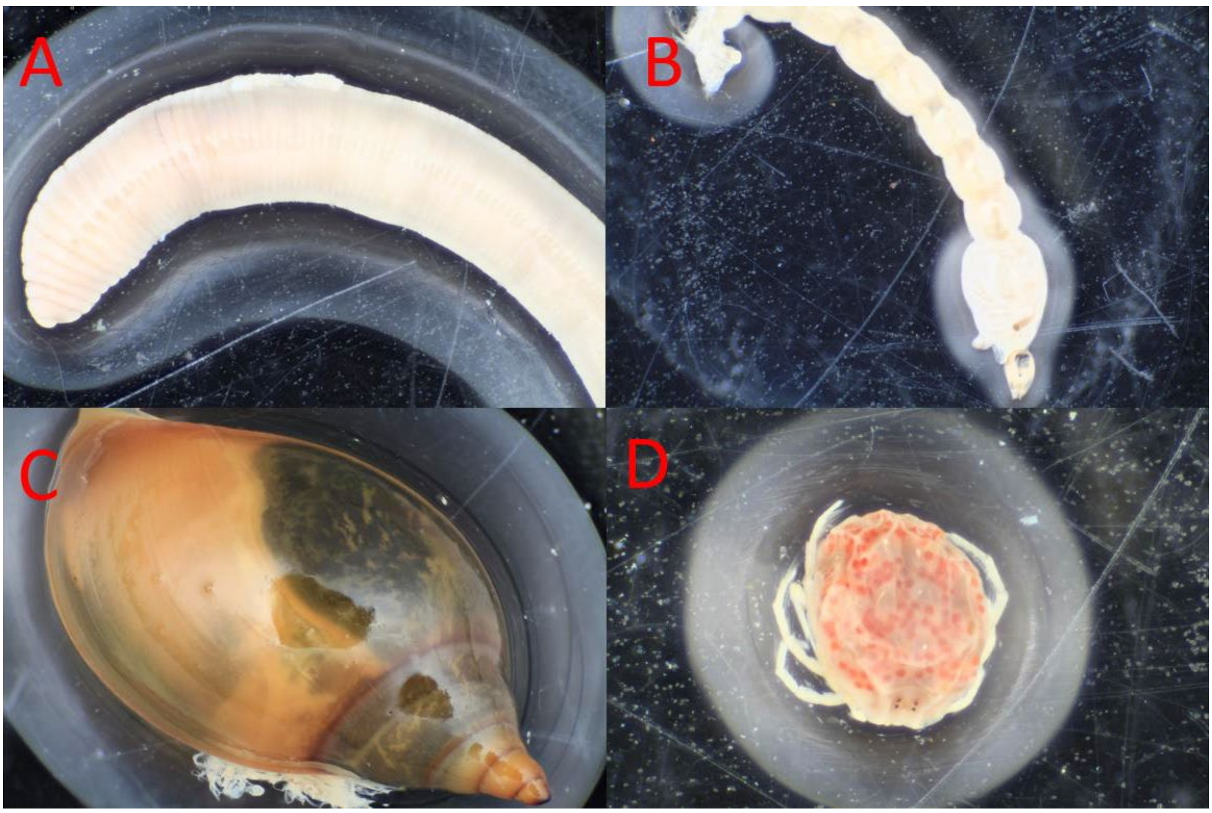


Figure 12. Examples of invertebrates found at Lake Hawdon North and Lake Hawdon South. A. Megadrile oligochaete ; B. Chironomid larvae; C. Physidae sp. D. Eylais sp.

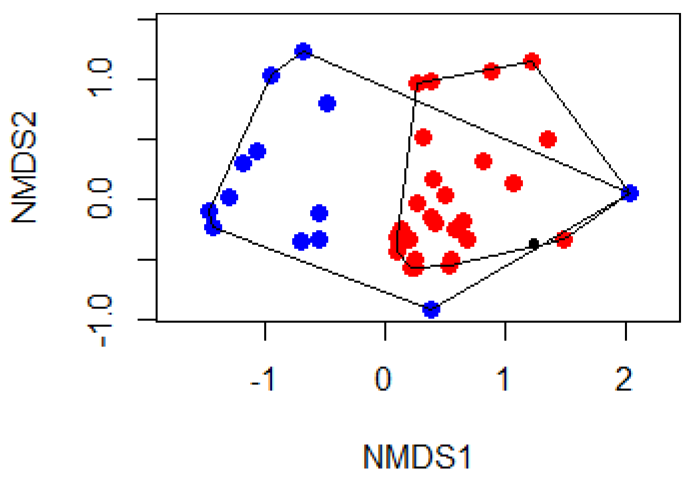


Figure 13. Non-metric Multi-dimensional Scaling plot (NMDS) of macroinvertebrates at the two sites (Lake Hawdon North; blue, Lake Hawdon South; red).

3.3. Discussion

More than 80% of the total macroinvertebrates collected came from Lake Hawdon South (1,118 of 1,363) and macroinvertebrates were more diverse at Lake Hawdon South than Lake Hawdon North (Table 3). This result is unsurprising because the sediment was much more compact and difficult to sieve (and therefore presumably more difficult for invertebrates to colonise) at Lake Hawdon North. This was further reflected in the lack of organisms in the deeper parts of the Lake Hawdon North cores and the dominance of megadrile Oligochaetes in the samples. Freshwater invertebrates have adapted a variety of life history strategies for surviving desiccation in wetlands subject to wetting and drying, however altered water regimes may alter the phenology of desiccation responses, and cause increased local extinctions (Strachan et al. 2015). It may be that the highly altered water regime at Lake Hawdon North prevents most aquatic invertebrates from persisting there under present conditions.

Far fewer organisms were found in November than in September (85% less in Lake Hawdon North and 59% less in Lake Hawdon South). This is unsurprising at Lake Hawdon North where the waterline and water depths had receded significantly between the two periods (Figure 10), causing the sediment to harden further. It is more surprising at Lake Hawdon South, where conditions seemed broadly similar (though the waterline had receded somewhat (Figure 10) and water depth was somewhat shallower). A contributing influence could be that recession rate is significantly greater than the invertebrate colonisation rate.

At Lake Hawdon South, fewer organisms were found at the waterline than at either of the fixed points on both sampling trips, but there was no clear pattern at Lake Hawdon North (Table 2; Figure 11). This result from Lake Hawdon South is unsurprising because the waterline was very high during both trips, almost to the tall fringing vegetation (Figure 10). However, it is expected that the area that included the waterline on both trips will dry out later in the season. Given its proximity to fringe vegetation and its longer time spent dry, it seems likely that this section would be difficult for invertebrates to colonise. Consistent with this result, the fixed point closer to the centre of the lake, which had deeper water and is likely to remain wet longer into the summer, held more invertebrates than the fixed point further from the centre of the lake (Figure 11).

At both sites, some invertebrates detected in low numbers in our samples were more frequently observed by the team swimming in the water column, including Eylais mites and Berosus beetles. These invertebrates have a mostly epi-benthic lifestyle, so additional sampling using a different technique (e.g. seine netting) would be needed to quantify the abundance and diversity of these invertebrates that are more free-moving.

Based on the results of this study, it seems unlikely that either site surveyed provided significant food resources for short-billed shorebirds (e.g. red-necked stint, red-capped plover) in the sediment in September or November. At Lake Hawdon North, megadrile Oligochaetes dominated the benthic fauna, and we did not observe any individuals on the surface. Moreover, the sediment was quite hard and included short grassy vegetation, which is likely to make prey in the sediment largely inaccessible. Short-billed shorebirds may however find additional food resources from flying insects landing on the ground or benthic organisms swimming in the water column, and we did observe 42 Red-capped Plovers (of which 38 were observed foraging) and 14 Red-necked Stint (of which 12 were observed foraging) during a 20 minute count in November. At Lake Hawdon South, water levels were mostly too high (Figure 10) for short-statured shorebirds to be present, though we observed 170 Black-winged Stilts (of which six were observed foraging) during a 20 minute count in November.

A cautionary note about interpretation of these results is that the survey areas covered in this project (Figure 33) were chosen because they seemed to represent the best available shorebird habitat in each lake at present, however they are unlikely to represent the full spatial variation between Lake Hawdon North and Lake Hawdon South, or within each lake. Additional surveys distributed throughout the lakes would be needed to fully document the invertebrate fauna in each lake. Nonetheless, we feel that this initial comparison between a region of Lake Hawdon North and Lake Hawdon South that each seem suitable as potential shorebird habitat is instructive and indicates some important considerations for future management interventions at Lake Hawdon North.

An additional survey of macroinvertebrates is planned by the Component 4 (waterbirds) team of the *Healthy Coorong, Health Basin* Trials and Investigations project to obtain a reasonable baseline under current management conditions across a migratory shorebird non-breeding season. It is of particular interest to survey Lake Hawdon South when water levels have receded sufficiently to provide extensive foraging habitat for shorebirds, and to confirm whether any moisture remains in the sediment of the sampling points in Lake Hawdon North in summer (i.e. the core non-breeding season for migratory shorebirds).

4. Vegetation Transects

4.1. Methods

The location of vegetation transects was chosen in order to best:

- document the vegetation of the lowest elevations of Lake Hawdon North where, if hydrological restoration occurs, the duration of inundation will be longest and therefore shorebirds are most likely to be concentrated post-restoration;
- document the vegetation in locations where changes to the vegetation are anticipated to be most pronounced post-restoration, e.g. due to mechanical clearance of shrubland and or highly altered hydrology; and
- align spatially with other parameters to enable deeper exploration of associations between these parameters and ecosystem response through future monitoring.

Transects were positioned to be indicative of vegetation zonation across the elevation gradient in the general area of the wetland in which they were located. Transect start locations were on elevated ground (typically within terrestrial (non-wetland) vegetation), and end locations at a low point on the wetland bed. The endpoint was located where a consistency of vegetation was apparent and elevation had also become consistent (i.e. the wetland bed is flat). The length of each transect was determined by these factors.

Both ends of each transect were permanently marked in the field using low survey pegs (not star droppers) to reduce the risk of vehicle collision (including vegetation clearance machinery during restoration), harm to animals and disturbance by livestock.

GPS coordinates (AMG, GDA 1994, Zone 54) were recorded at both ends of each transect and a compass bearing taken from the start point. A photograph was taken at each end, looking along the transect. A general site description was recorded noting forms of disturbance (e.g. stock impacts, native herbivores, fire, fences and tracks), along with measurements of weediness, vegetation health and evidence of change.

The vegetation composition and density was recorded along each transect. Where possible a tape measure was placed along the transect beginning at the terrestrial end. For transects longer than 200 m a handheld GPS was used to record the locations of changes to vegetation. For longer transects, particularly across structurally diverse landscapes, GPS approximation is considered to have a similar margin of error to tape measurement.

The three most dominant species were recorded for each of six defined strata in a six-metre envelope along each transect, made up of three metres each side of the line between the start and end posts. The defined strata were:

- 1st Tree: Trees
- 2nd Tree: Mallee or shrubs
- 1st Shrub: >2 metres
- 2nd Shrub: 1 – 2 metres
- 1st Ground: 0.3 – 1 metre, generally tall sedges and grasses or small shrubs
- 2nd Ground: <0.3 metre, generally forbs and small grasses or sedges

Previous workers using this methodology (e.g. Dickson et al. 2013) have found that where only the 2nd ground stratum is present over extended distances (several hundred metres) recording only three dominant species was insufficient to describe the vegetation. Therefore, in areas of wetland where only the 2nd ground stratum was present, a maximum of five co-dominant species was recorded. This included the open mudflat habitat that restoration of Lake Hawdon North is intending to increase in extent.

The projected cover of each of the species was recorded using the following categories:

- Dense (70 - 100%)
- Mid-dense (30 - 70%)
- Sparse (10 - 30%)
- Very Sparse (1 - <10%)
- Clumped (<1%) or
- Scattered (<1%)

At each location along the transect, where the projected cover of one or more dominant species changed in any strata, the location was recorded.

A management focus on *Melaleuca halmaturorum* required this species to be treated differently to other wetland plant species at Lake Hawdon North. The projected cover of this species was recorded wherever it was present, even if non-dominant, noting that this had the potential to make the number of species recorded in each strata greater than three. Additionally, *M. halmaturorum* was divided into size classes as follows:

- Seedling/sapling: <0.3 m height
- Juvenile: 0.3 – 1.0 m height
- Established: >1.0 m height

At the end (lowest elevation) of each transect, and within an area of consistent water depth and floristic composition, three permanent 2 x 2 m quadrats were established and the aquatic vegetation recorded. The quadrats were located at positions 2, 6 and 10 m along the 10 m extension of the transect (Figure 14), on the left side when looking into the wetland. The quadrats had similar species composition and were located at the same depth (to within 2 cm).

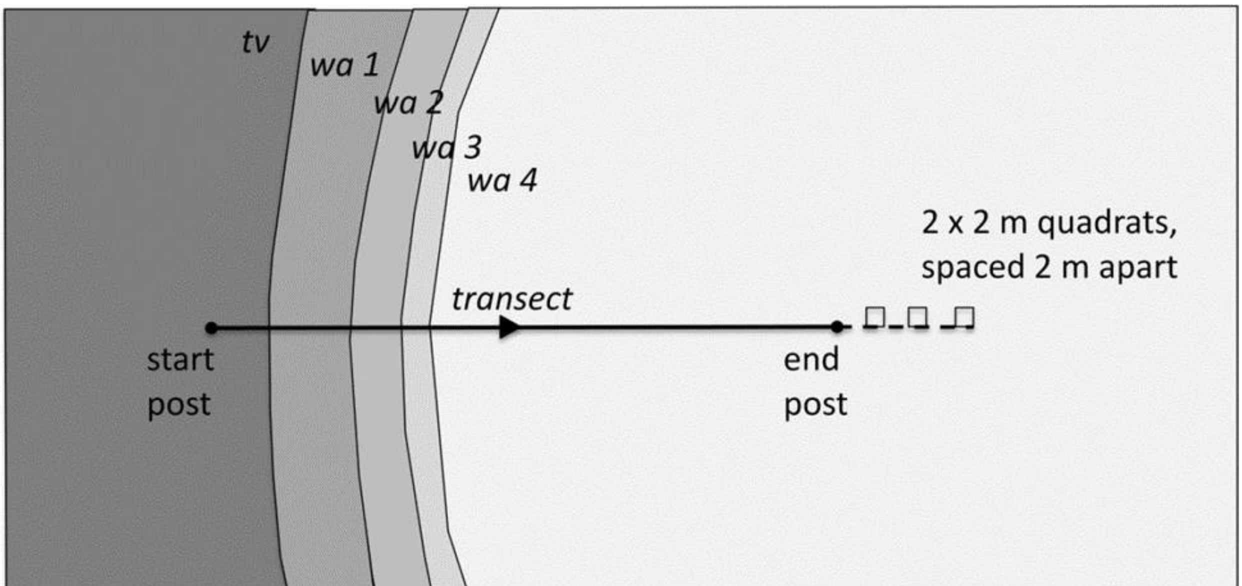


Figure 14. Arrangement of transects and quadrats.

The electrical conductivity, temperature, pH and dissolved oxygen concentration of surface water (where present) was recorded at the first quadrat and a depth measurement and photograph taken for all quadrats. Every plant species present within each quadrat was recorded and given a projected cover score using the Braun-Blanquet scale as follows:

- 5: 75 to 100%
- 4: 50 to 75%
- 3: 25-50%
- 2: 5 to 25%
- 1: numerous or scattered but less than 5% cover
- +: few, with small cover
- r: rare or solitary, with small cover.

Quadrats provide more detailed data on plant species present at the lowest lying elevation of the transect as all species are recorded, not simply the dominant species.

Seven transects were established within Lake Hawdon North (Figure 15), with a combined length of 2,105 m. Transects were surveyed between 10th and 12th October 2021.

Figure 15. Vegetation transect locations (yellow lines) in Lake Hawdon North.

4.2. Results

The following section provides specific details about transect location, length and initial start and end photopoint photos. Vegetation data for each transect is summarised using a kite chart, illustrating transect position and density of each of the dominant species recorded. Location details are also provided for each of the quadrats, along with species recorded and their cover core and a representative photo from one of the quadrats.

Transect 1

Start Easting: 400495	End Easting: 400616
Start Northing: 5887535	End Northing: 5887693
Bearing: 38°	
Length: 199 m	
Start photo	End photo
	

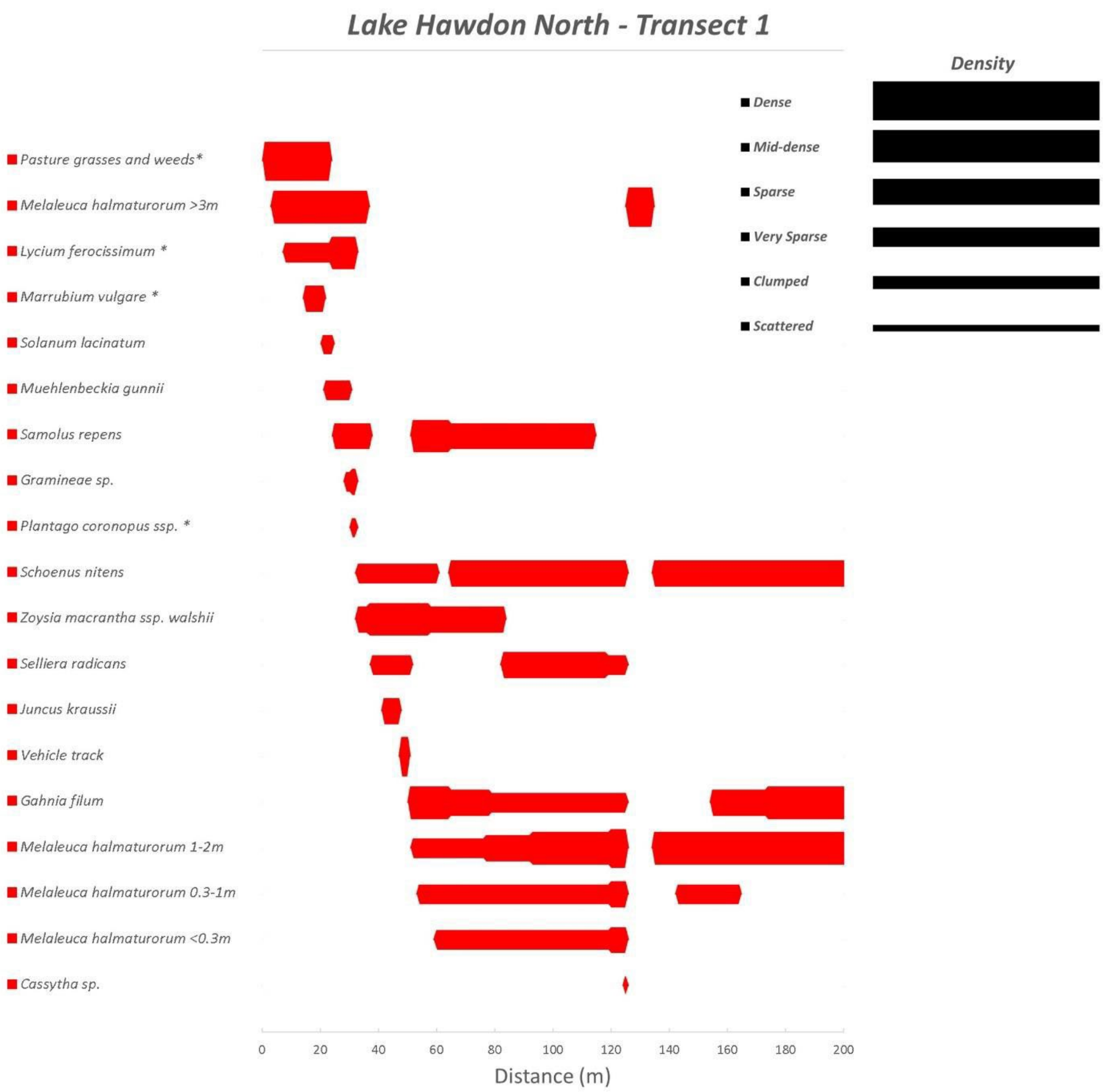


Figure 16. Kite chart for vegetation transect 1.

Transect 1 Quadrats

Survey date	11/10/2021		
Transect End Stake Easting	400616		
Transect End Stake Northing	5887693		
Quadrat number	1	2	3
Water quality and quantity	No water		
Species			
Gahnia filum	2	3	3
Schoenus nitens	1	1	1
Drosera pygmaea	R		R
Gramineae sp.	R		
Melaleuca halmaturorum 0 - 0.3m	R		
Melaleuca halmaturorum 1 -2m	1	3	3

Figure 17. Transect 1, Quadrat 1.

Transect 2

Start Easting: 401902	End Easting: 402033
Start Northing: 5887354	End Northing: 5887505
Bearing: 25°	
Length: 199.9 m	
Start photo	End photo
	

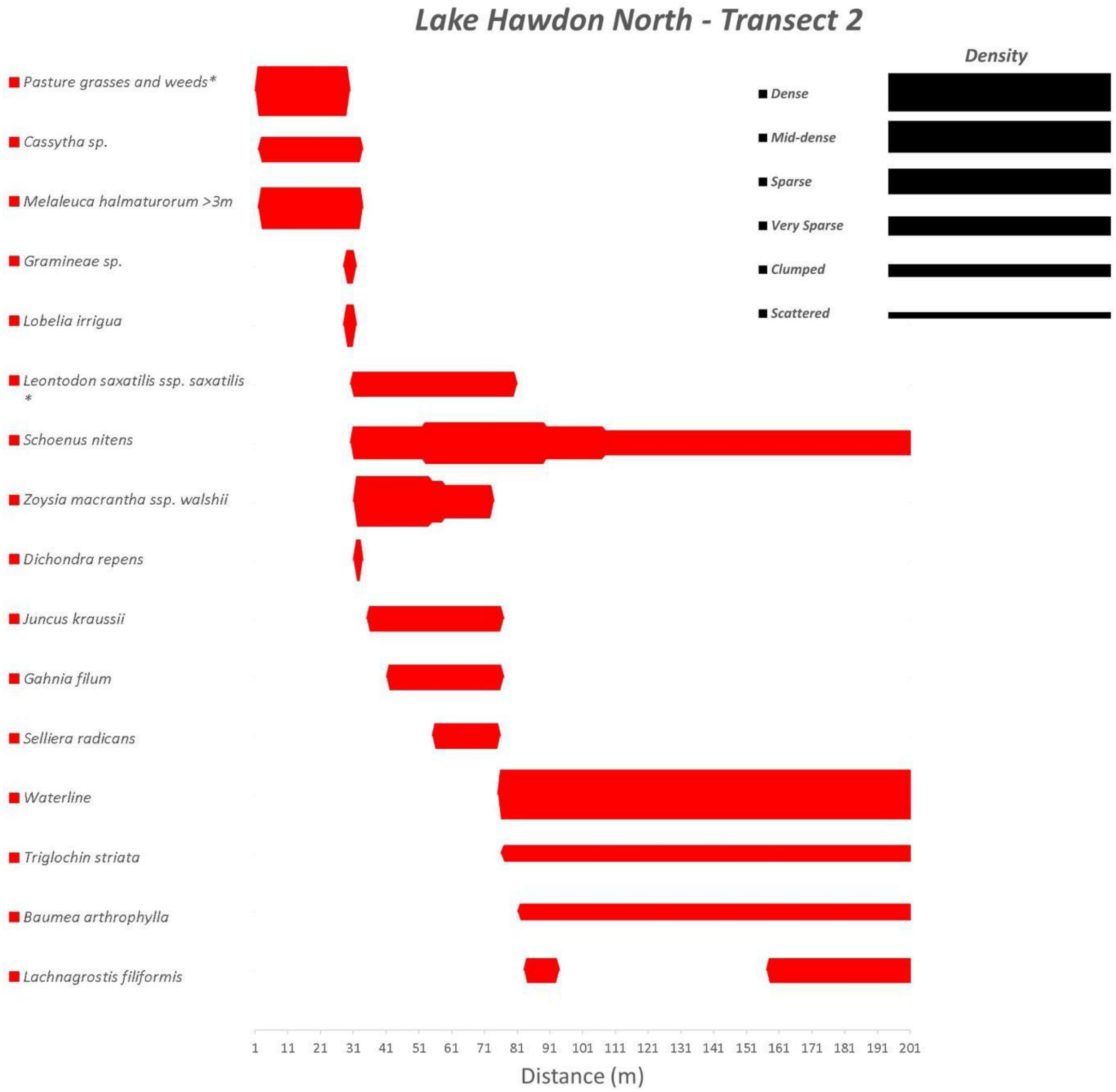


Figure 18. Kite chart for vegetation transect 2.

Transcect 2 Quadrats

Survey date	11/10/2021		
Stake Easting	402033		
Stake Northing	5887506		
Quadrat number	1	2	3
Water quality and quantity			
EC (µS/cm)	4486		
Temperature (°C)	15.5		
pH	8.85		
DO (mg/L)	17.97		
depth (cm)	17.5	17	17.5
Species			
Schoenus nitens	1	1	1
Isolepis fluitans	+	+	
Triglochin striata		+	+

Figure 19. Transect 2, Quadrat 1.

Transect 3

Start Easting: 402807	End Easting: 403012
Start Northing: 5886822	End Northing: 5886970
Bearing: 56°	
Length: 252.8 m	
Start photo	End photo
	

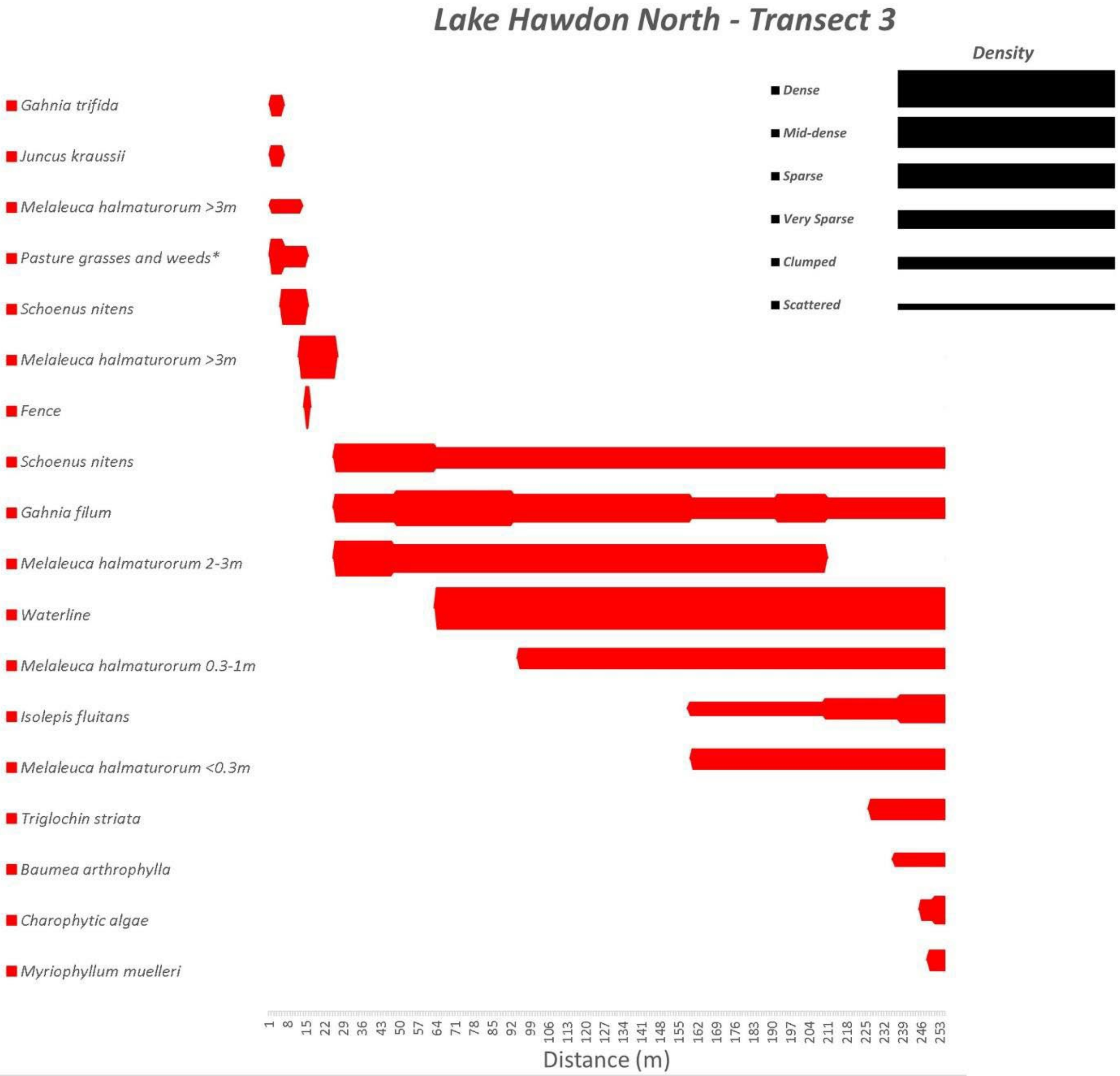


Figure 20. Kite chart for vegetation transect 3.

Transect 3 Quadrats

Survey Date	11/10/2021		
Transect End Stake Easting	403012		
Transect End Stake Northing	5886971		
Quadrat number	1	2	3
Water quality and quantity			
EC (µS/cm)	4022		
Temperature (°C)	17.5		
pH	8.37		
DO (mg/L)	22.58		
depth (cm)	16.5	16.5	18
Species			
Schoenus nitens	1	1	+
Melaleuca halmaturorum 0 - 0.3m	1	1	1
Melaleuca halmaturorum 0.3 -1m			2
Lachnagrostis filiformis	2	2	3
Isolepis fluitans	1	1	1
Charophytic algae	2	2	1
Myriophyllum muellerii	R	R	R
Triglochin striata	R		
Selliera radicans	R	1	+

Figure 21. Transect 3, Quadrat 1.

Transect 4

Start Easting: 404147	End Easting: 403997
Start Northing: 5889111	End Northing: 5889335
Bearing: 325°	
Length: 305.8 m	
Start photo	End photo
	

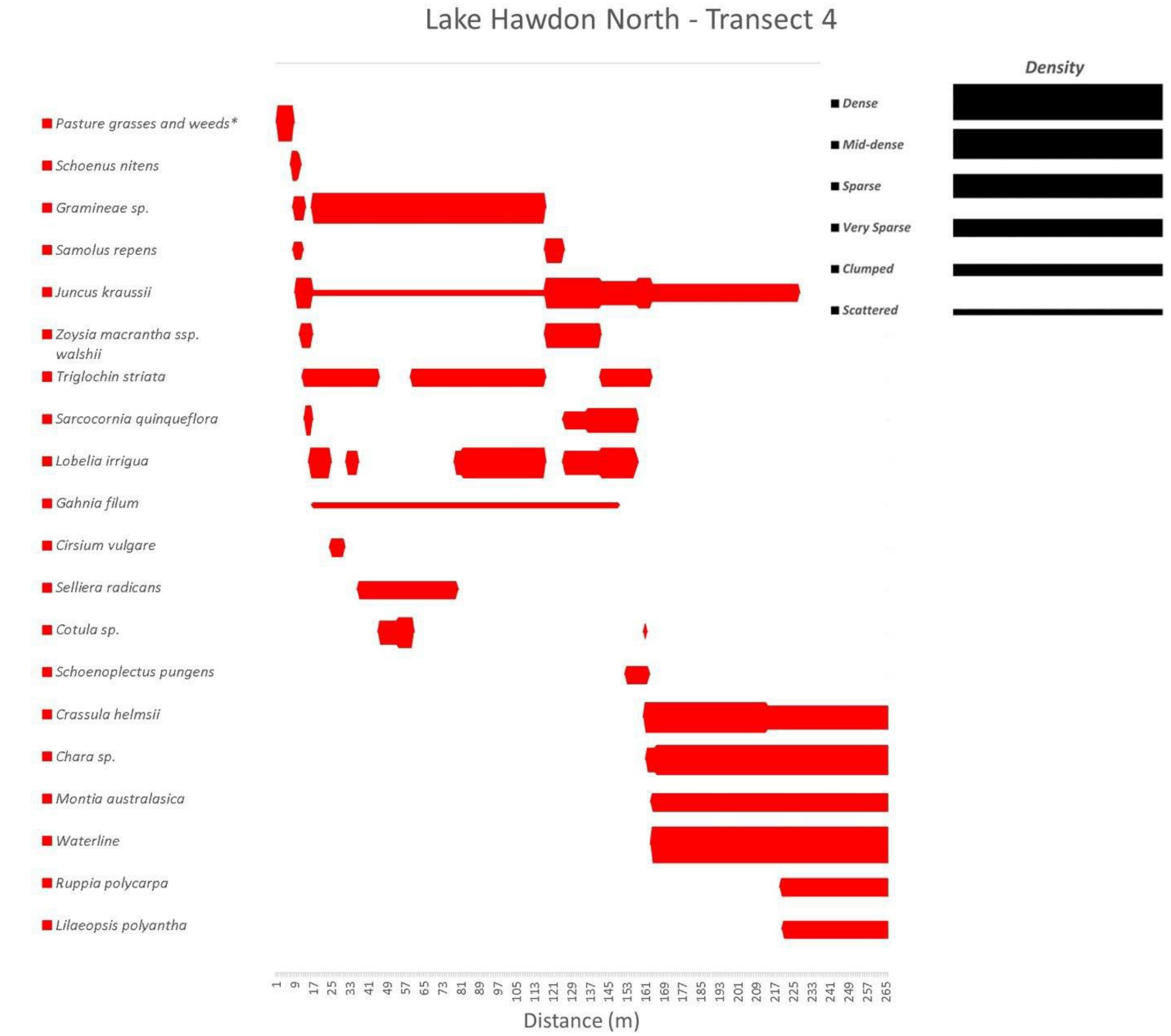


Figure 22. Kite chart for vegetation transect 4.

Transect 4 Quadrats

Survey date	12/10/2021		
Transect End Stake Easting	403997		
Transect End Stake Northing	5889335		
Quadrat number	1	2	3
Water quality and quantity			
EC (µS/cm)	5965		
Temperature (°C)	17.05		
pH	9.06		
DO (mg/L)	18.9		
depth (cm)	18	18	18
Species			
Myriophyllum muellerii	3	3	3
Lilaeopsis polyantha	2	2	2
Montia australasica	1	1	
Crassula helmsii	1	1	1

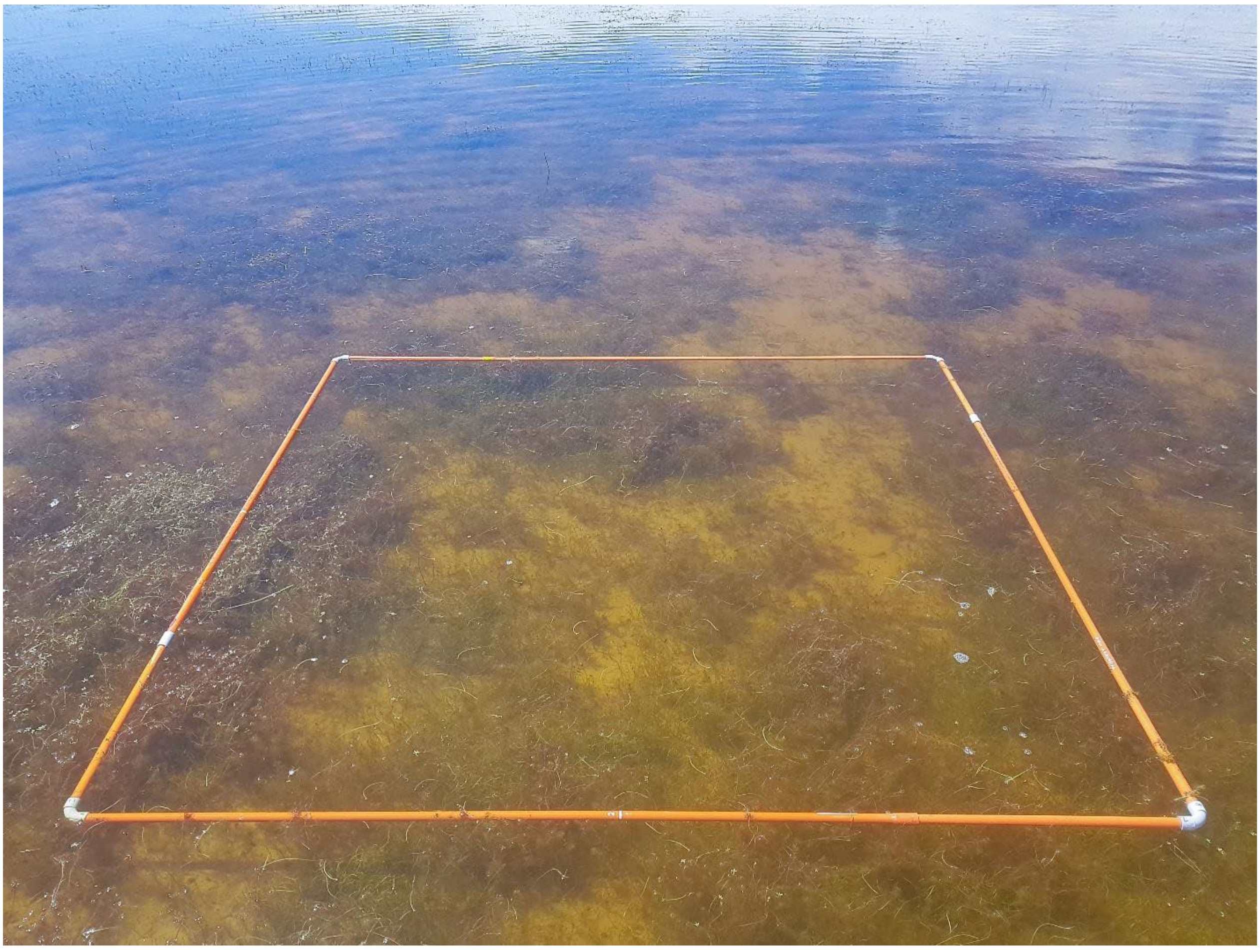


Figure 23. Transect 4, Quadrat 1.

Transect 5

Start Easting: 404932	End Easting: 404570
Start Northing: 5887854	End Northing: 5887849
Bearing: 270°	
Length: 362 m	
Start photo	End photo
	

Figure 24. Kite chart for vegetation transect 5.

Transect 5 Quadrats

Survey date	12/10/2021		
Transect End Stake Easting	404569		
Transect End Stake Northing	5887848		
Quadrat number	1	2	3
Water quality and quantity			
EC (µS/cm)	5024		
Temperature (°C)	15.3		
pH	8.44		
DO (mg/L)	17.21		
depth (cm)	44	44	45
Species			
Charophytic algae	2	2	2
Myriophyllum muellerii		R	

Figure 25. Transect 5, indicative view of quadrat location.

Transect 6

Start Easting: 401185	End Easting: 401250
Start Northing: 5887412	End Northing: 5887690
Bearing: 15°	
Length: 285.5 m	
Start photo	End photo
	

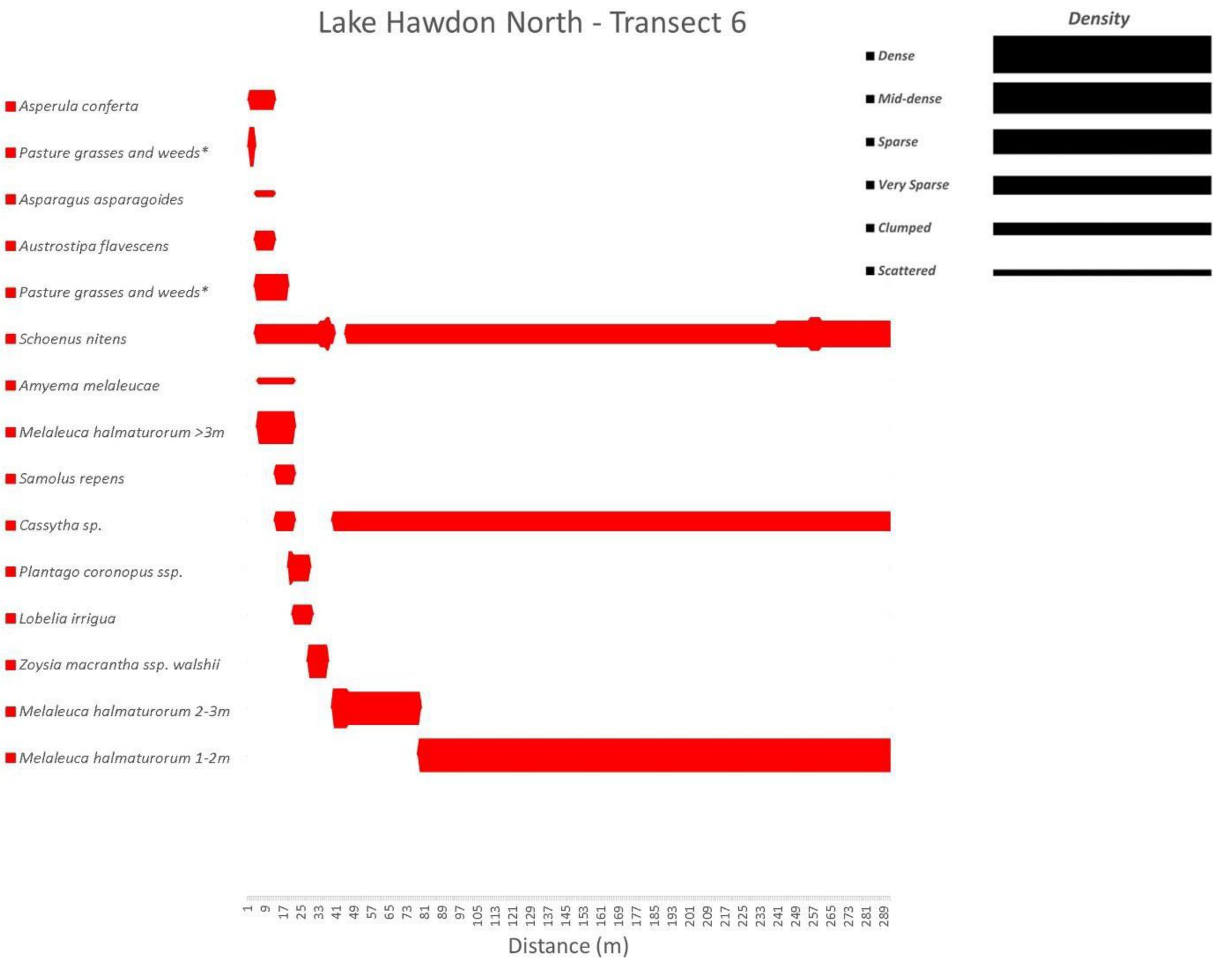


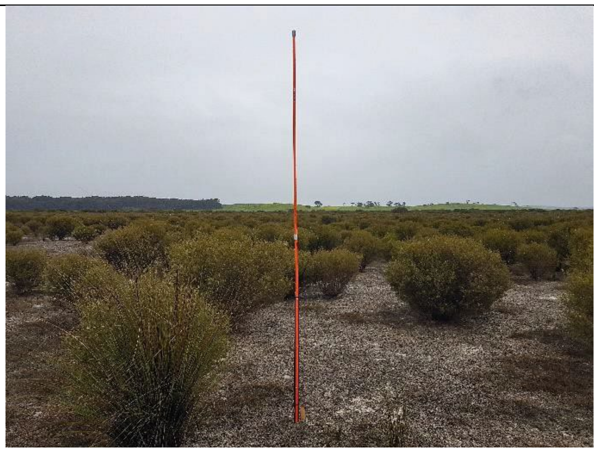
Figure 26. Kite chart for vegetation transect 6.

Transect 6 Quadrats

Survey date	12/10/2021		
Transect End Stake Easting	401250		
Transect End Stake Northing	5887690		
Quadrat number	1	2	3
Water quality and quantity	No water		
Species			
Gahnia filum	R		
Schoenus nitens	2	2	2
Drosera pygmaea	R	R	R
Melaleuca halmaturorum 0.3 -1m		R	
Melaleuca halmaturorum 1 -2m		2	3
Triglochin striata	+	R	
Melaleuca halmaturorum	2		
Samolus repens	+		R
Selliera radicans	+	+	R

Figure 27. Transect 6, Quadrat 1.

Transect 7

Start Easting: 400818	End Easting: 401316
Start Northing: 5889520	End Northing: 5889560
Bearing: 85°	
Length: 500.2 m	
Start photo	End photo
	

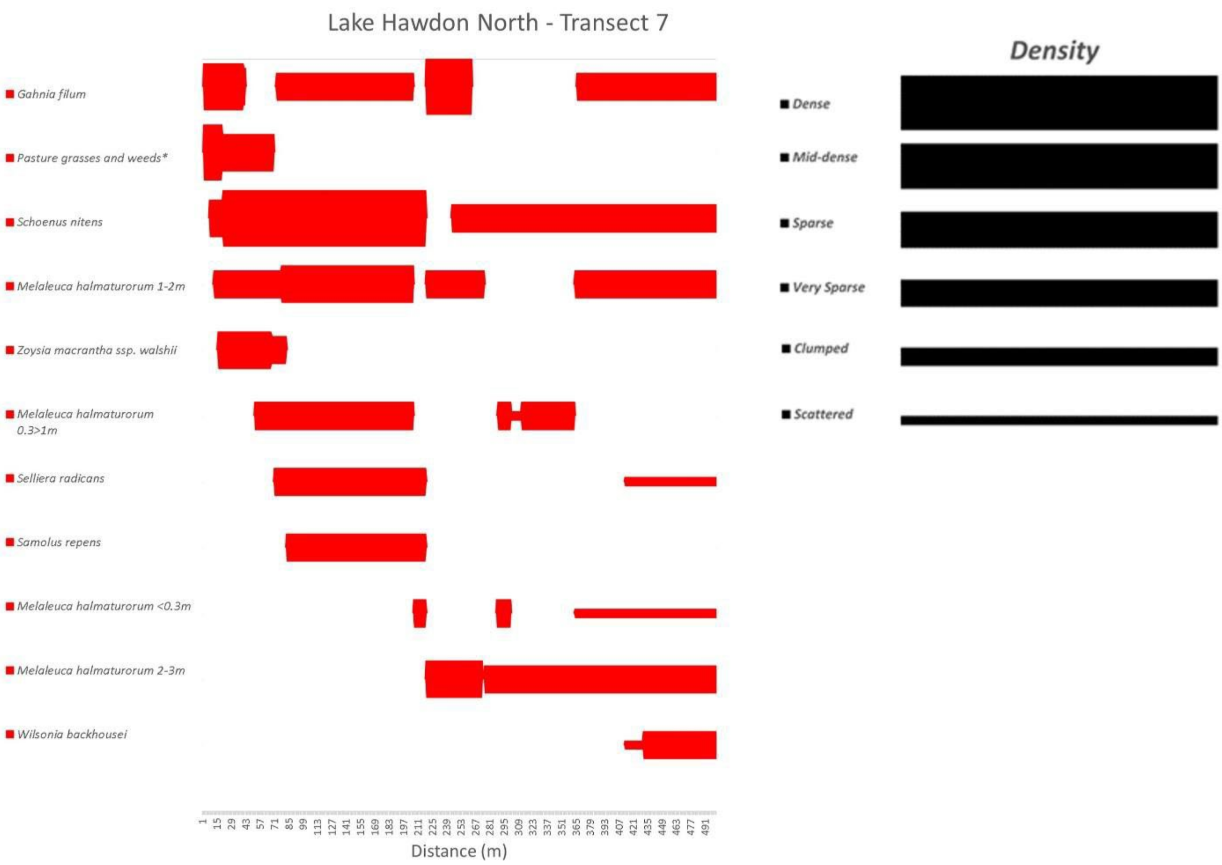


Figure 28. Kite chart for vegetation transect 7.

Transect 7 Quadrats

Survey date	13/10/2021		
Transect End Stake Easting	401316		
Transect End Stake Northing	5889560		
Quadrat number	1	2	3
Water quality and quantity	No water		
Species			
Gahnia filum	R	1	1
Schoenus nitens	1	1	1
Melaleuca halmaturorum 0 - 0.3m			1
Melaleuca halmaturorum 0.3 -1m		1	2
Wilsonia backhousei	1	1	1
Samolus repens	R		1

Figure 29. Transect 7, Quadrat 1.

4.3. Discussion

The vegetation transects and quadrats provide a baseline that will enable, through repeat surveys over future years, an assessment of progress towards the vegetation related objectives of the restoration project, i.e. Objective B: increase the area of open mudflat/open water aquatic habitat, maintain the area of *Baumea arthrophylla* and *Gahnia filum* sedgelands and reduce the area of *Melaleuca halmaturorum* shrublands. The transects that extend into the *M. halmaturorum* shrubland proposed for clearance (Transects 1, 6, 7 and possibly 3) will be valuable in monitoring the effectiveness clearance combined with restored hydrology in terms of restoring invasive shrubland back to open mudflat habitat. Transects in other areas (Transects 2, 4 and 5) will provide information on how existing open mudflat habitat responds to restoration and ongoing management.

All transects have the potential to detect undesirable changes, such as *M. halmaturorum* recruitment, earlier than some remote methods, and can thereby serve as a valuable tool in ongoing management.

Further interpretation of the transect and quadrat data has not been undertaken at this point but will be used to inform emerging trends in response to management interventions, upon collection of follow up monitoring data.

5. *Melaleuca halmaturorum* Recruitment

5.1. Background

Concern that *Melaleuca halmaturorum* shrubland could proliferate and displace other vegetation in Lake Hawdon South following the cessation of livestock (sheep) grazing led to the establishment of a monitoring program in 2008 (Ecological Associates 2008). Initially, four *M. halmaturorum* recruitment monitoring sites were established in Lake Hawdon South only. In 2013 four sites were established in Lake Hawdon North, where sheep grazing was ongoing, to act as control sites to the Lake Hawdon South sites, from which sheep were excluded in May 2009 (Taylor and Brown 2019).

Analysis of data collected to 2019 (Taylor and Brown 2019) found that following grazing cessation, total seedlings increased dramatically at two of the four sites in Lake Hawdon South. The size distribution of seedlings also changed, with the proportion of seedlings in the tallest size classes increasing as the time since grazing cessation increased. No such changes occurred at control sites in Lake Hawdon North, where total seedling numbers and size distribution remained relatively constant, similar to levels observed in Lake Hawdon South prior to grazing cessation. Thus, ongoing sheep grazing appears to limit the recruitment of *M. halmaturorum* in Lake Hawdon North, although given that over 600 ha of the wetland features recently invaded *M.halmaturorum* (at various densities), grazing is not completely effective at preventing recruitment in all areas.

If the hydrological restoration of Lake Hawdon North proceeds, the water regime of the two wetlands will be more closely aligned than currently. Continued *Melaleuca halmaturorum* recruitment monitoring of both wetlands will serve the dual objectives of:

- Assessing the impact of grazing cessation upon *M. halmaturorum* recruitment in Lake Hawdon South;
- Assessing the status of *M. halmaturorum* recruitment in Lake Hawdon North under grazing and restored hydrology.

5.2. Methods

The four previously established monitoring sites in Lake Hawdon North were re-surveyed on 17 January 2022. An area contained by the outer edge (drip line) of the canopy of a parent *M. halmaturorum* shrub and a 5 m radius extending outwards from the drip line (Figure 30) was searched for seedlings. Seedlings were classified into six height classes: 0 – 10 cm, 10 – 20 cm, 20 – 40 cm, 40 – 70 cm, 70 – 100 cm and >100 cm.

The eight sites at which *M. halmaturorum* seedling density is monitored in the Lake Hawdon complex, four "treatment" sites in Lake Hawdon South (commencing 2008) and four "control" sites in Lake Hawdon North (commencing 2013) are shown in Figure 31. The most recent survey of the four treatment sites in Lake Hawdon South was completed in March 2021. Data for these sites are also presented in the results.

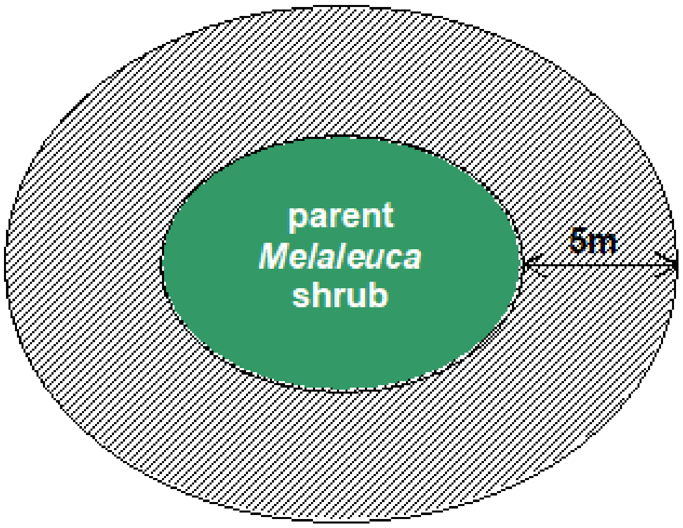


Figure 30. Diagrammatical representation (plan view) of area searched for *Melaleuca* seedlings (hatched area) adjacent to each parent *Melaleuca* shrub.

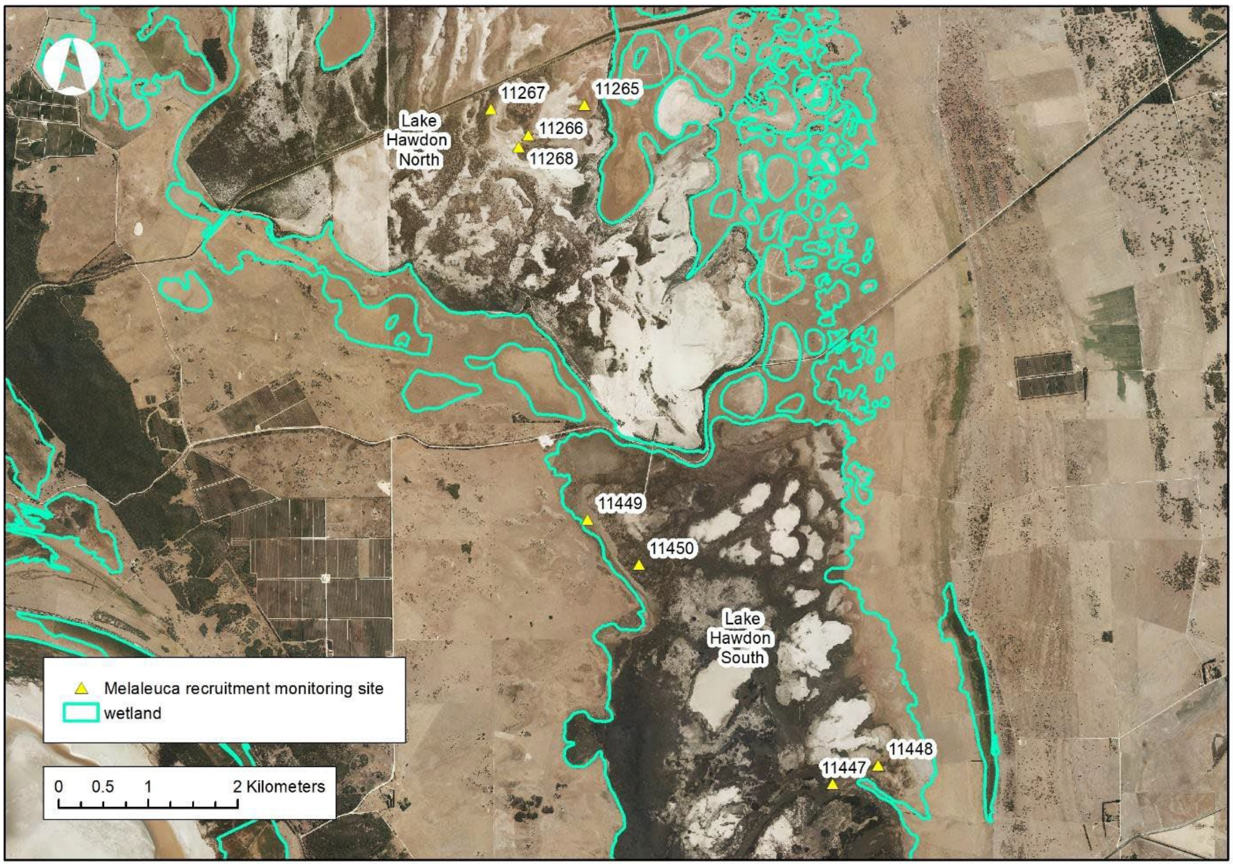


Figure 31. Locations of *M. halmaturorum* monitoring sites in Lake Hawdon North and South.

5.3. Results

In Lake Hawdon South in March 2021 total seedling abundance at sites 11447 and 11449 was lower than it had been in the preceding 4-6 monitoring years but markedly higher than at the commencement of monitoring in 2008. At sites 11448 and 11450 total seedling abundance has remained similar through all monitoring years and this pattern continued in 2021. In Lake Hawdon North in January 2022 total seedling abundance at the four monitoring sites was marginally to markedly lower than in the five previous monitoring years (Figure 32).

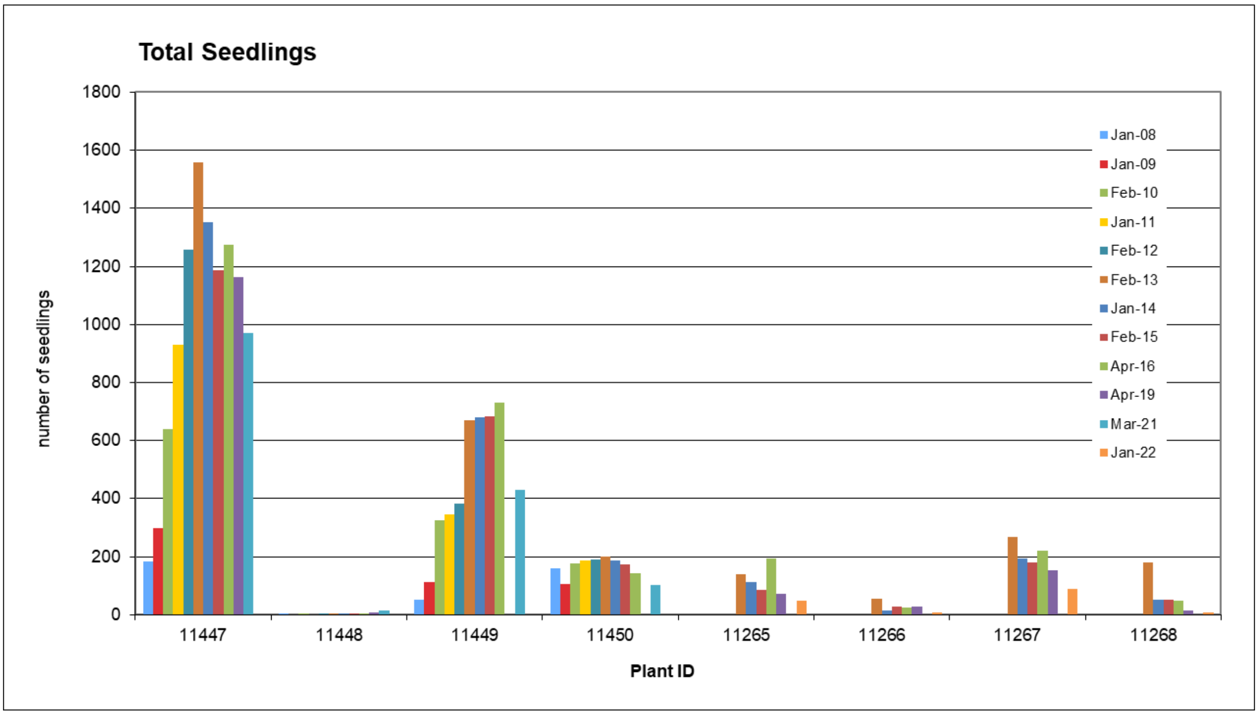
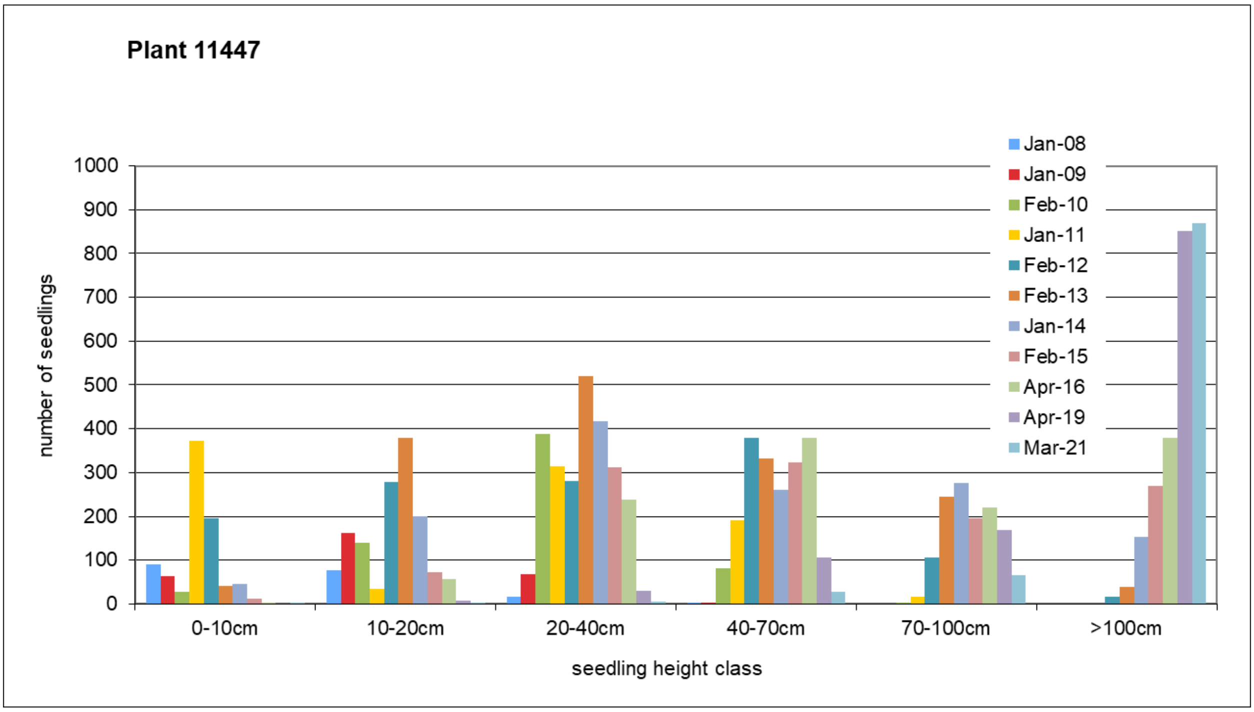


Figure 32. Total *M. halmaturorum* seedling abundance at monitoring sites in Lake Hawdon South (Plant ID 1147-50) to March 2021 and in Lake Hawdon North (Plant ID 11265-68) to January 2022.

In Lake Hawdon South in March 2021 at two sites (11447 and 11449) seedling size distribution was more skewed towards the tallest size class (>100cm) than for any previous monitoring year (Figure 33, Figure 34). The greatest number of seedlings occurred in the >100cm size class and numbers were approximately 10 times greater than the number in the next smallest size class (70-100cm) at these sites. Site 11448 has consistently had very low seedling abundance since 2008 and this continued in 2021, however there has been shift over time with increased seedling numbers in the two taller size classes. Site 11450 has shown no increase in total seedling abundance since 2008 but size class distribution has clearly shifted towards the taller size classes between 2008 and 2021.



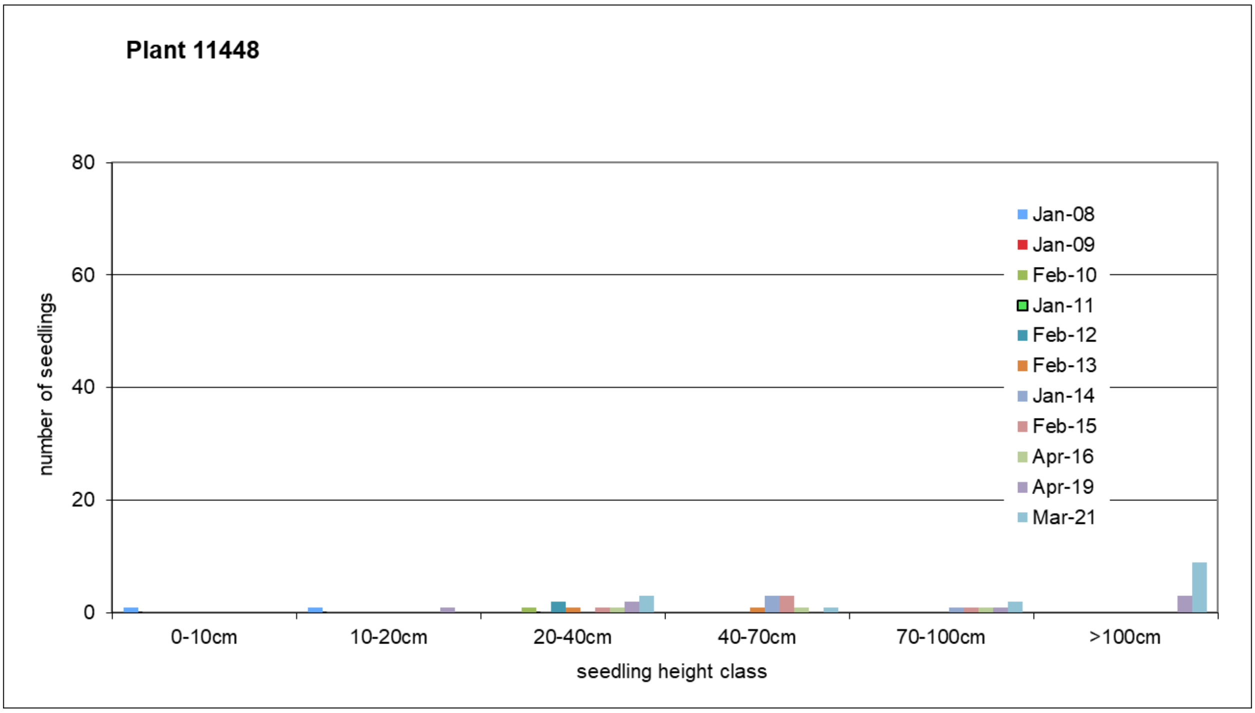


Figure 33. *M. halmaturorum* seedling size distribution at two monitoring sites in Lake Hawdon South (11447 and 11448), 2008 – 2021.

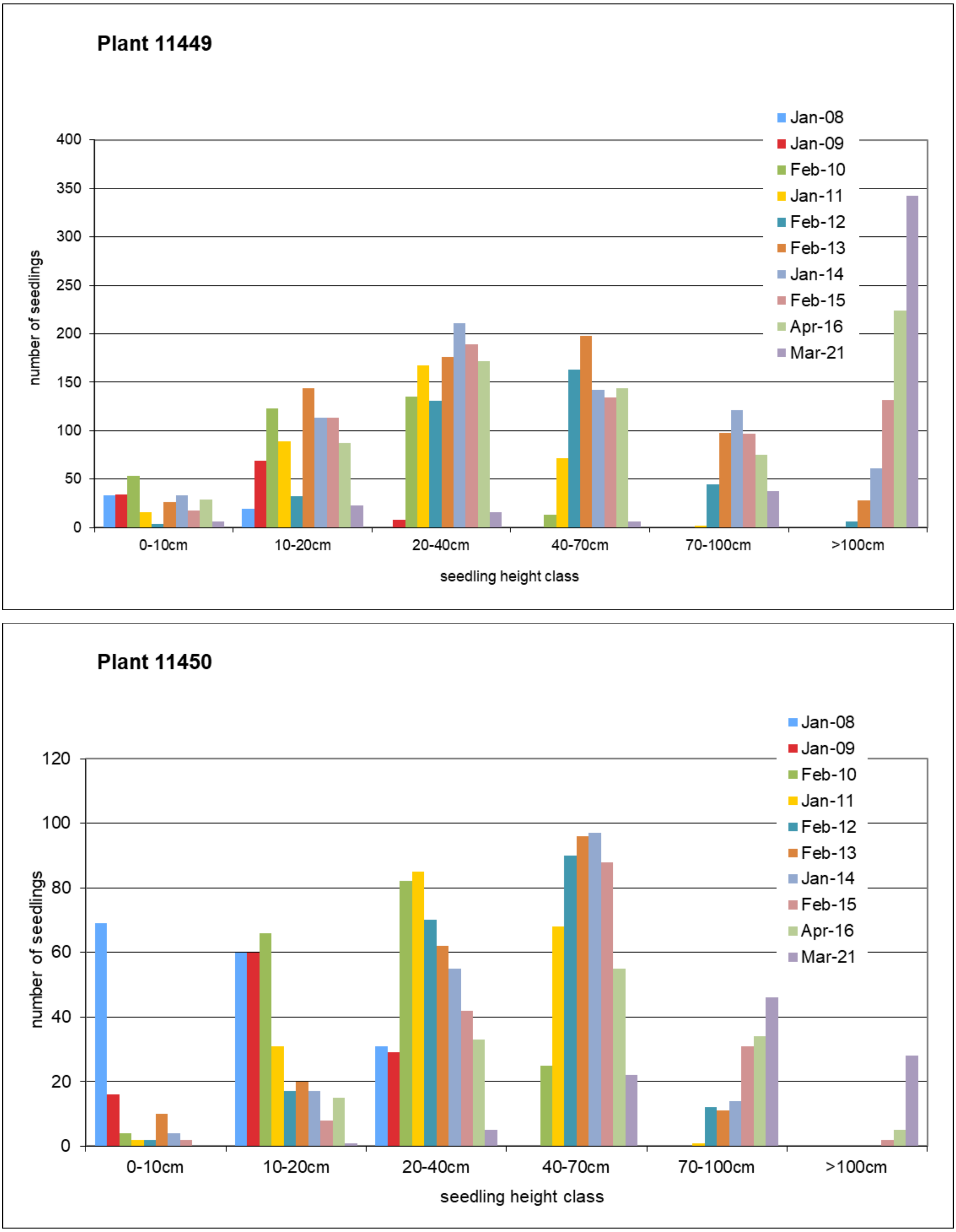
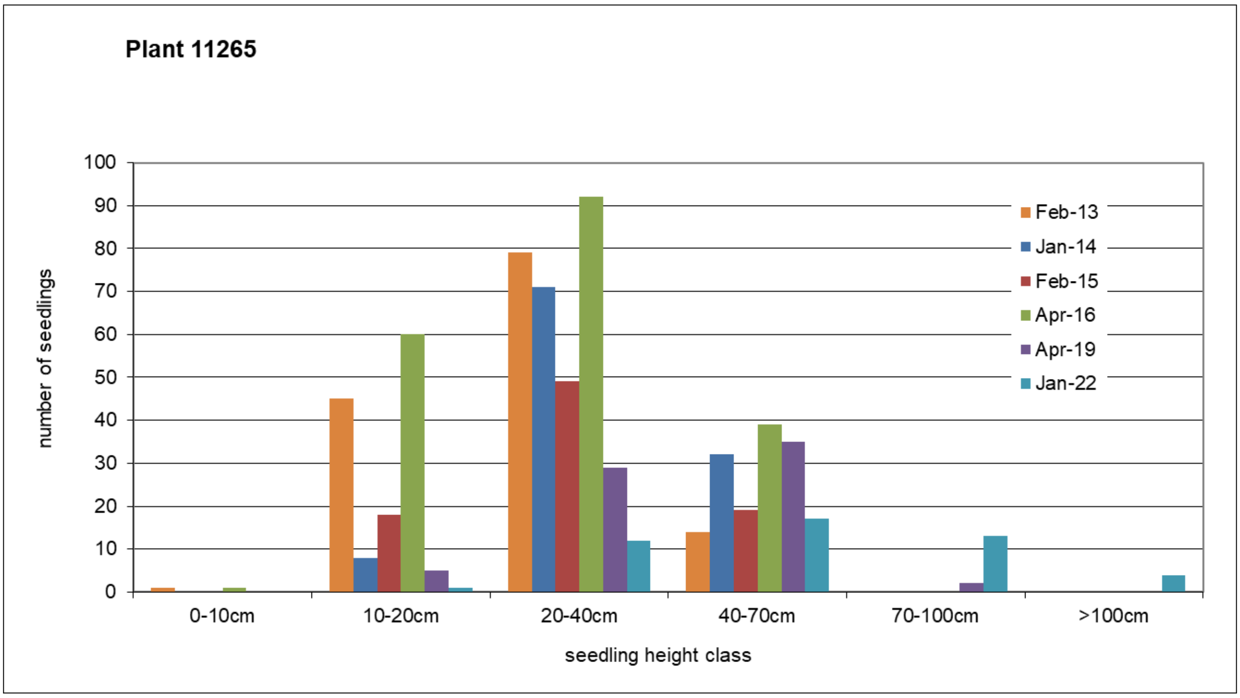


Figure 34. *M. halmaturorum* seedling size distribution at two monitoring sites in Lake Hawdon South (11449 and 11450), 2008 – 2021.

In Lake Hawdon North in January 2022 seedling size distribution had shifted slightly towards the taller size classes compared to previous years (Figure 35, Figure 36). At all sites, small numbers of seedlings were present in taller size classes from which they had previously been absent. Seedlings were largely absent from the smallest size classes. The shift in size class distribution at Lake Hawdon North over the monitoring period (2013 – 2022) was modest compared to the pronounced shift observed in Lake Hawdon South.



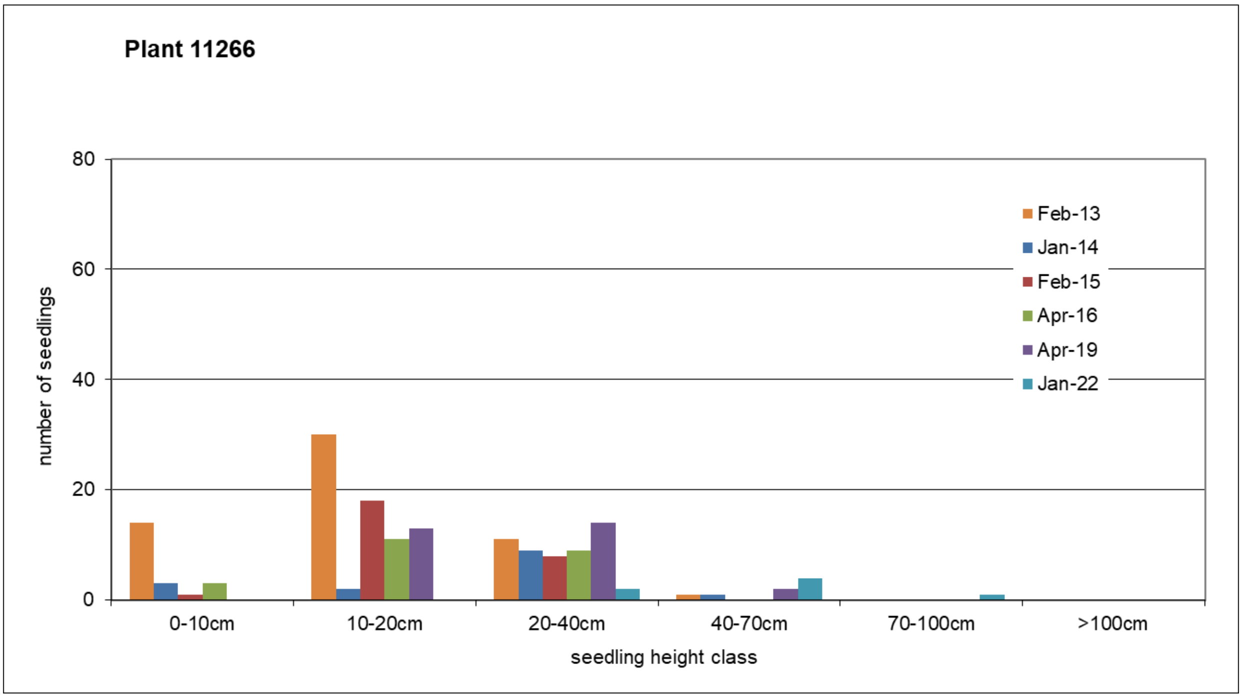
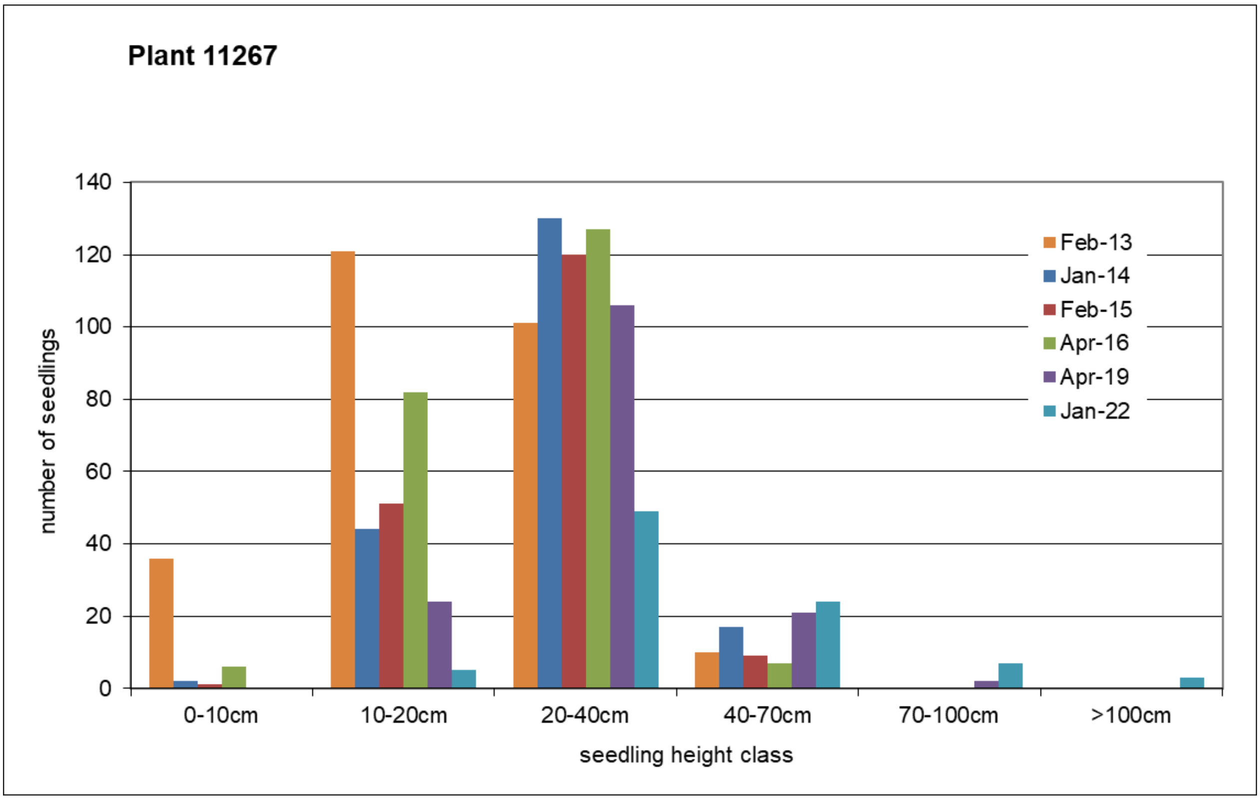


Figure 35. *M. halmaturorum* seedling size distribution at two monitoring sites in Lake Hawdon North (11265 and 11266), 2013 – 2022.



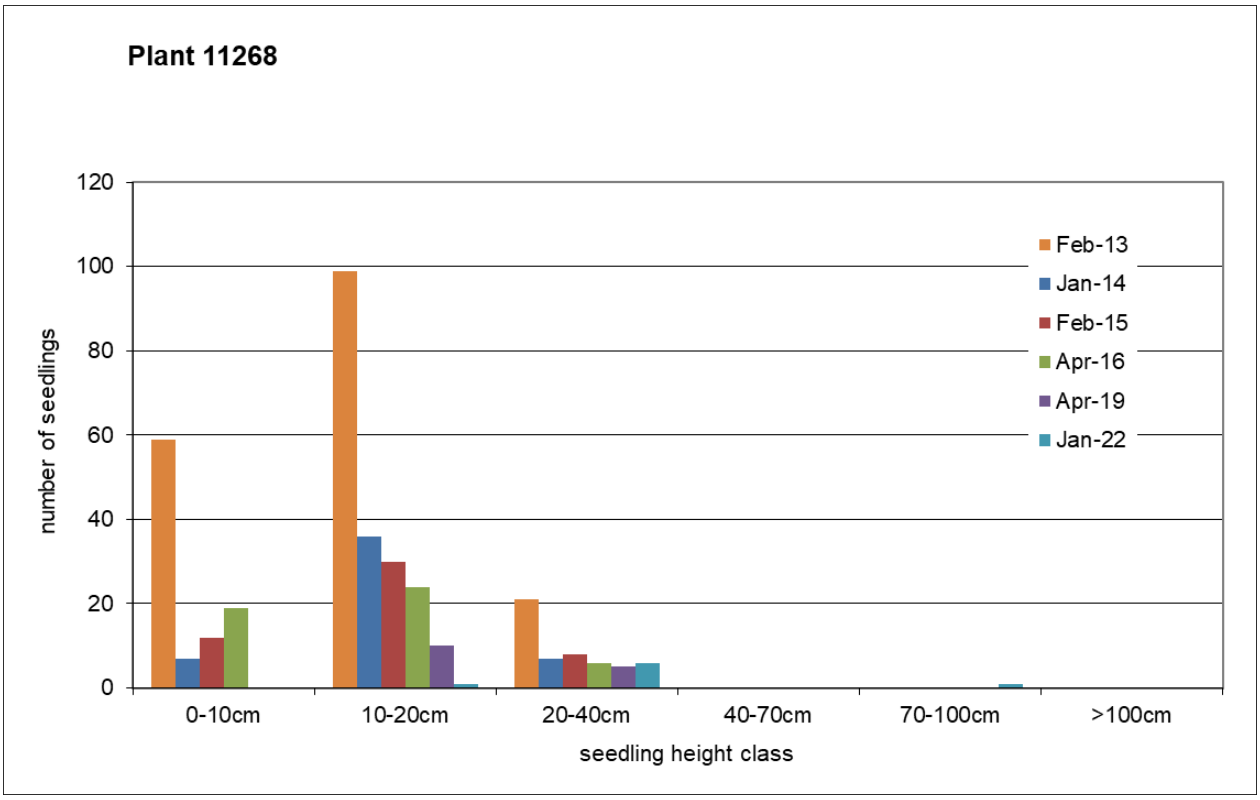


Figure 36. *M. halmaturorum* seedling size distribution at two monitoring sites in Lake Hawdon North (11267 and 11268), 2013 – 2022.

5.4. Discussion

Following the cessation of sheep grazing in Lake Hawdon South in May 2009, *M. halmaturorum* seedling abundance increased dramatically at two of the four monitoring sites. No such increase has been measured at monitoring sites in Lake Hawdon North, where sheep grazing is ongoing. These results suggest sheep grazing is limiting seedling abundance in Lake Hawdon North.

Site 11448 in Lake Hawdon South appears to be an infertile parent shrub, with very few seedlings observed since the commencement of monitoring in 2008. Site 11450 appears to be located at a lower elevation, within more inundation tolerant vegetation (*Baumea arthrophylla* sedgeland) compared to the other sites. The parent shrub at 11450 was recently identified as *Melaleuca brevifolia* (Bryan Haywood, pers. com.). These differences may explain the different results obtained at this site.

Seedling size distribution has changed dramatically at Lake Hawdon South since sheep grazing ended. The taller size classes, from which seedlings were absent in 2008, have become the dominant size classes. Large numbers of *M. halmaturorum* have successfully established at monitoring sites where previously only the parent shrub and low number of small seedlings were present. This is evident in the results and is also readily observable from comparative photographs (Figure 37)

Figure 37. Site 11447 in Lake Hawdon South in 2010 (left) and 2019 (right).

In contrast, ongoing sheep grazing appears to have prevented changes to the size distribution of seedlings in Lake Hawdon North over most of the monitoring period. However, in the most recent two monitoring events (2019 and 2022), a slight shift in size distribution is evident, with small numbers of species graduating into taller size classes that have previously been absent. This effect is not readily observable based on casual observations of the monitoring sites (Figure 38), but is discernible in the monitoring data. It suggests that sheep grazing may have become less effective at preventing *M. halmaturorum* graduating into taller size classes at Lake Hawdon North. This is consistent with aerial imagery and on-ground observations across Lake Hawdon North, which suggest *M. halmaturorum* shrublands have become taller, denser and more extensive during the last decade or so, consistent with a trend. It is clear that sheep grazing is only partially effective at preventing the proliferation of this species across the wetland.

Figure 38. Site 11268 in Lake Hawdon North in 2013 (left) and 2022 (right).

If hydrological restoration of Lake Hawdon North proceeds, the increased duration of inundation is anticipated to help suppress *M. halmaturorum* proliferation. Complete submersion for six weeks or more is known to kill *M. halmaturorum* seedlings (Denton and Ganf 1994). However, seedlings that are not completely submerged will likely survive extended inundation. The effectiveness of restored hydrology combined with ongoing grazing at preventing *M. halmaturorum* proliferation should continue to be monitored at Lake Hawdon North. Proliferation of *M. halmaturorum* shrubland is a potential threat to the ecological values of Lake Hawdon North, particularly the open mudflats that provide feeding habitat for migratory shorebirds and other waders.

6. Fish

6.1. Background

Against a backdrop of hydrological alteration, the southeast of South Australia (SE SA) continues to provide aquatic habitats that maintain important native freshwater fish fauna (Hammer 2002, Wedderburn and Hammer 2002). This includes freshwater wetlands, permanent flow to ephemeral drains, and an estuary with strong connectivity to upstream habitats within the Drain L Catchment. The Drain L Catchment supports regionally important native freshwater fish fauna, with 18 species, including six of state or national conservation concern recorded (Hammer et al. 2012). This includes the internationally vulnerable little Galaxias, *Galaxiella toourtkoourt*, and a westerly outlying population of the internationally endangered Australian mudfish, *Neochanna cleaveri*, with the latter remaining enigmatic despite targeted research (Hammer et al. 2012, Whiterod et al. 2020). Australian mudfish, along with several other species, are diadromous i.e. they require connectivity between marine and freshwater ecosystems to complete their lifecycle. Hence, hydrological connectivity across the catchment remains a primary consideration for these species (Hammer et al. 2012). Of particular note is the absence of introduced species, particularly Eastern Gambusia, across the catchment despite nearby source populations being present in adjacent catchments (Hammer et al. 2012, Whiterod and Gannon 2017). Within the catchment, Lake Hawdon South represents important habitat for strong populations of little Galaxias and Australian mudfish. Yet despite this proximity, both Australian mudfish and little Galaxias had not been recorded in the nearby Lake Hawdon North prior to this study, even after targeted survey effort (Hammer et al. 2012). This has been interpreted to reflect a prevalence of unsuitable habitat.

With respect to habitat being unsuitable for these species, the hydrological restoration of Lake Hawdon North offers excellent potential to enhance habitat for key native freshwater fish (Hammer et al. 2012). In relation to the investigation of options for hydrological restoration of Lake Hawdon North, it has been hypothesised (Taylor et al. 2021) that increased aquatic habitat extent and connectivity will lead to:

- increased diversity and abundance of freshwater fishes;
- colonisation by rarer threatened species, such as Australian mudfish and little Galaxias; and
- the continued absence of alien species in the catchment.

This section details surveys that add to baseline knowledge of fish communities to support a Before-After-Control-Impact (BACI) monitoring strategy to robustly assess spatial patterns and temporal trends of fish communities to evaluate these hypotheses. In this context, Lake Hawdon North was identified as the 'Impact' region whereas Lake Hawdon South (along with Drain L sites) was used as the 'Control' region. The surveys also provide for updated insight into the status of fish communities in the Drain L Catchment.

6.2. Methods

Sampling sites and protocol

During spring 2021, sampling occured at 14 sites across the study region of Lake Hawdon North (six sites), Lake Hawdon South and Bray Drain (six sites) and Drain L (two sites) (Figure 39, Table 1). The majority of sites had been sampled previously in 2010, 2011 and 2018 surveys, with five new sites (SE21-105, SE21-109, SE21-110, SE21-111, SE21-112) also sampled. All sites were sampled using four replicate single-wing fyke nets (3 m wing and 4 mm mesh size) set in the afternoon and left overnight before retrieving the following morning. All sampled fish were identified to species level, counted, and measured for total length (TL, mm) with general biological information (reproductive condition and external disease or parasites) also assessed. Records of other fauna opportunistically sampled were noted. At each site, environmental descriptors such as extent of underwater and edge vegetation cover as well as pool condition, flow and water quality were recorded to aid the interpretation of results and assist with broader condition assessment. An example of the diversity of habitat characteristics across sampling sites is provided in Figure 40. All monitoring was conducted in accordance with relevant permits (PIRSA Ministerial Exemption: ME9903118).

Table 4. Summary of fish sites sampled in Lake Hawdon and connected drains during spring 2021.

Site Code	Date	Waterway	Location	Easting	Northing
SE21-100	5/10/2021	Lake Hawdon North	Middle of wetland	403564	5889225
SE21-101	5/10/2021	Lake Hawdon North	NE of wetland	404010	5889393
SE21-102	5/10/2021	Drain L	Baxter Hill Rd	410778	5890320
SE21-103	5/10/2021	Lake Hawdon South	Lake Hawdon connector	405485	5884839
SE21-104	5/10/2021	Drain L	Just below Lake Hawdon North	399867	5886934
SE21-105	6/10/2021	Lake Hawdon South	Southern wetland	405581	5875850
SE21-106	6/10/2021	Lake Hawdon South	Southern end of wetland (Almanda)	404562	5876693
SE21-107	6/10/2021	Lake Hawdon North	SE of wetland	404549	5887438
SE21-108	6/10/2021	Lake Hawdon North	SW of wetland	403657	5887237
SE21-109	7/10/2021	Lake Hawdon North	Eastern wetland (south of drain)	401736	5888033
SE21-110	7/10/2021	Lake Hawdon North	Eastern wetland (north of drain)	402098	5887553
SE21-111	7/10/2021	Lake Hawdon South	Eastern wetland	408256	5879427
SE21-112	7/10/2021	Lake Hawdon South	SE of wetland	408238	5878222
SE21-113	7/10/2021	Bray Drain	Junction with Lake Hawdon	408858	5879547

Figure 39. Map of fish sites.

Figure 40. Selection of sites sampled during spring 2021.
Clockwise from top left: Lake Hawdon South – Lake Hawdon connector (SE21-103); Bray Drain - Junction with Lake Hawdon (SE21-113); Lake Hawdon North (SE21-109); Lake Hawdon North - Eastern wetland (north of drain) (SE21-110); Lake Hawdon South - Southern end of wetland (Almanda) (SE21-106); and Drain L - Eastern wetland (south of drain) (SE21-09).

6.3. Results

Catch summary

In spring 2021, a total of 920 fish were caught spanning seven native species, with no translocated native or alien species captured during the survey (Table 2). The most abundant species captured during the survey was the Australian mudfish, with a total 487 individuals (53% of the total catch) occurring across 13 of the 14 sampling sites. Australian mudfish were recorded from both wetland and drain habitats with most of the individuals captured in Lake Hawdon North and associated drains (297 fish, 61%), although respectable numbers of the species were still recorded at Lake Hawdon South and associated drains (190 fish, 39% of the total catch).

The diadromous common galaxias were the next most abundant species (178 fish). Despite being relatively abundant, this species was only recorded at five sites with most of the individuals being recorded within drain habitats. Other diadromous species recorded were Congolli *Pseudaphritis urvillii* (4 fish, <1% of the total catch) and shortfinned Eel *Anguilla australis*, (4 fish <1% of the total catch). Similar to Common Galaxias, these species were recorded primarily from drain habitats.

The third most abundant species recorded was the southern pygmy perch (*Nannoperca australis*), which was widespread across the catchment and was detected in both drain and wetland habitats at 11 of the 14 sites sampled. The threatened little Galaxias was also detected but did not occur in high abundance at any of the sites sampled. Nevertheless, the species was widespread and detected across 12 of the 14 sites sampled.

Photographic examples of species captured are provided in Figure 41.

Table 5. Summary of fish catch across the Lake Hawdon in spring 2021.

Site Code	Waterway	Location	Native species						
			Australian mudfish	Common Galaxias	Congolli	Shortfinned eel	Smallmouthed hardyhead	Southern pygmy perch	Little Galaxias
SE21-100	Lake Hawdon North	Middle of wetland	2				4	1	1
SE21-101	Lake Hawdon North	NE of wetland					3	7	2
SE21-102	Drain L	Baxter Hill Rd	1		2	2		3	
SE21-103	Lake Hawdon South	Lake Hawdon connector	105	27			23	15	6
SE21-104	Drain L	Just below Lake Hawdon North	3	140	1	2		5	1
SE21-105	Lake Hawdon South	Southern wetland	14						1
SE21-106	Lake Hawdon South	Southern end of wetland (Almanda)	17	8			2	14	4
SE21-107	Lake Hawdon North	SE of wetland	7						
SE21-108	Lake Hawdon North	SW of wetland	278	1			29	6	7
SE21-109	Lake Hawdon North	Eastern wetland (south of drain)	1	2			4	7	13
SE21-110	Lake Hawdon North	Eastern wetland (north of drain)	5					6	1
SE21-111	Lake Hawdon South	Eastern wetland	1						4
SE21-112	Lake Hawdon South	SE of wetland	39					37	10
SE21-113	Bray Drain	At junction with Lake Hawdon	14		1		2	28	1
		Total	487	178	4	4	67	129	51

In terms of opportunistic catch, tadpoles of various species, the common yabby *Cherax destructor* and swamp crayfish *Geocherax sp.* were frequently caught across Lake Hawdon sites, while Freshwater Crab *Amarinus lacustris*, Freshwater Shrimp *Paratya australiensis* and Long-necked Turtle *Chelodina longicollis* were caught in low abundances.

Figure 41. Examples of species caught during spring 2021.
Clockwise from top: Australian mudfish (mature), Australian mudfish (juvenile), little Galaxias, processing South Pygmy Perch and Australian mudfish, a large Shortfinned Eel, Southern Pygmy Perch.

Size distributions – southern pygmy perch and little Galaxias

Three of the fish species encountered are of conservation concern i.e. Australian mudfish and the two threatened native obligate freshwater (wetland) species, southern pygmy perch, and little Galaxias. Size distribution for Australian mudfish is presented in the temporal distribution section below. Southern pygmy perch were found at a range of sizes in both Lake Hawdon South (15–75 mm TL) and Lake Hawdon North (15–58 mm TL) in 2021, however larger individuals (>58 mm TL) were only found in Lake Hawdon South (Figure 42). Sizes ranges of little Galaxias were similar between Lake Hawdon South (15–40 mm TL) and Lake Hawdon North (24–37 mm TL) (Figure 43). No little Galaxias have been found in Lake Hawdon North prior to this study, however nine fish were found in 2021.

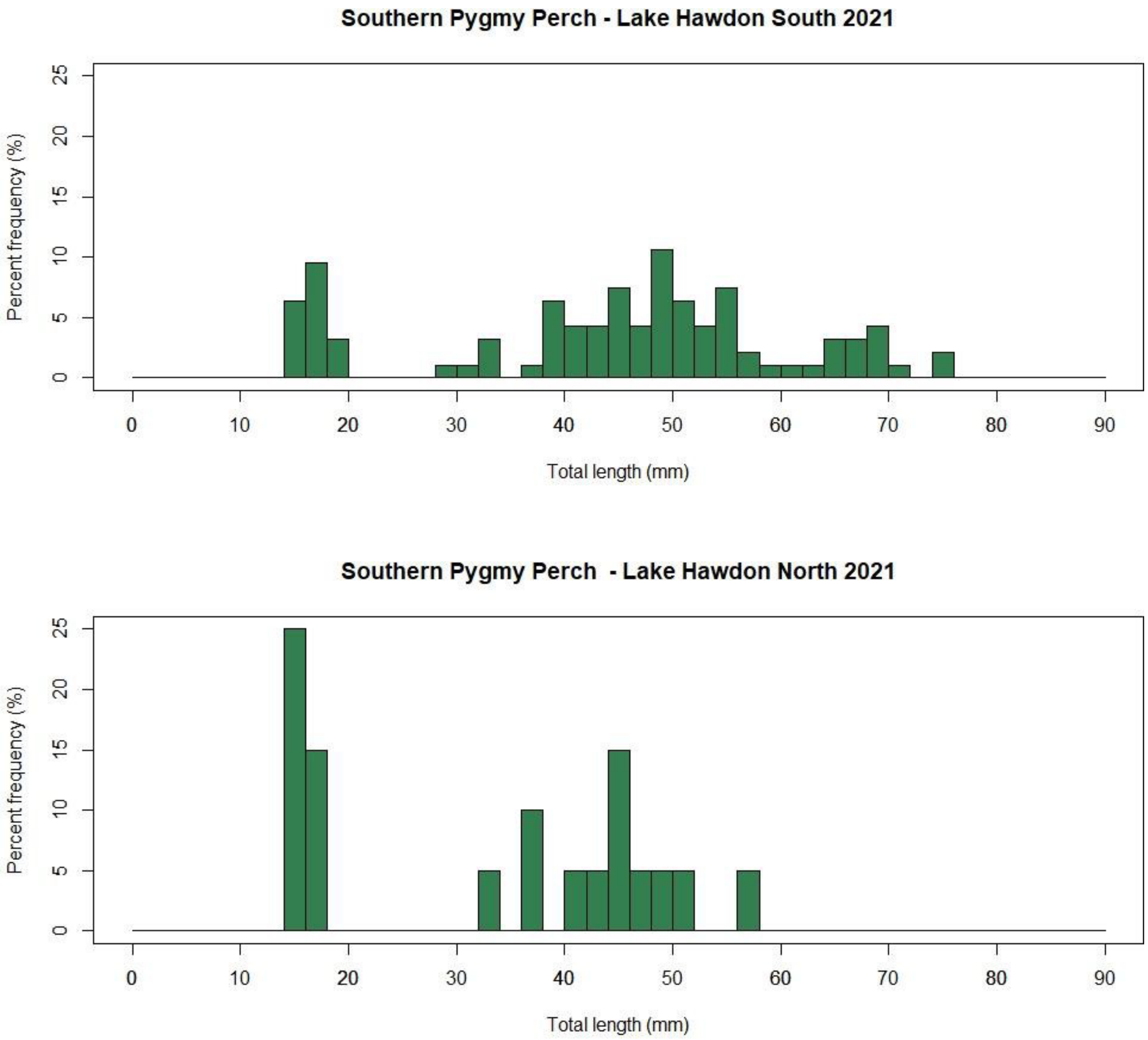


Figure 42. Length frequency distributions for Southern Pygmy Perch from Drain L catchment (i.e. Bray Drain and Lake Hawdon South) and Lake Hawdon North in spring 2021.

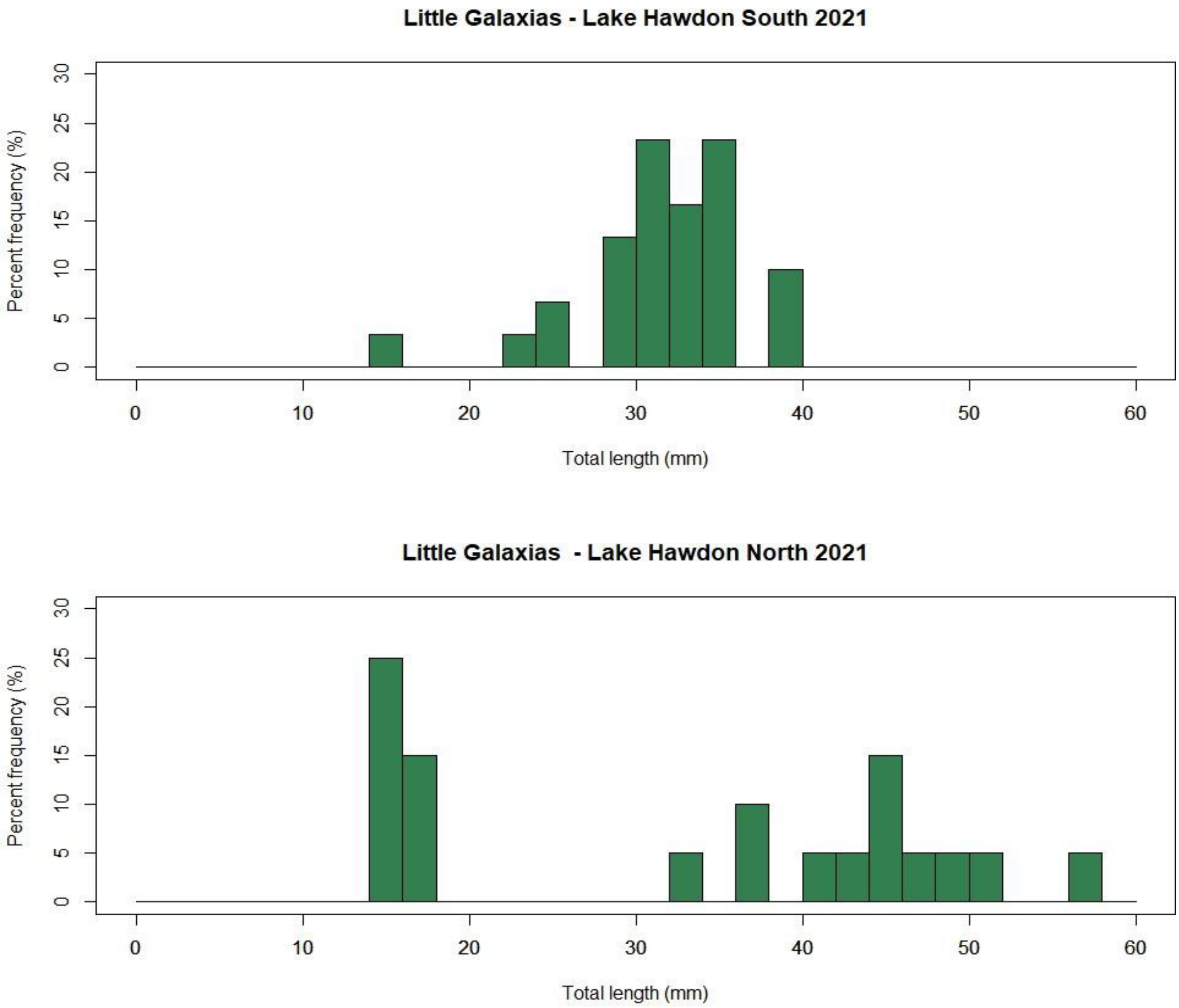


Figure 43. Length frequency distributions for little Galaxias from Drain L catchment (i.e. Bray Drain and Lake Hawdon South) and Lake Hawdon North in spring 2021.

Environmental descriptors

Sampled habitats consisted of two main categories, wetland and drain. The wetland sites were generally shallow and had relatively high levels of emergent and aquatic vegetation and no flow whereas drain sites showed lower amounts of emergent and aquatic vegetation, were deeper and exhibited medium to high flows. All sites sampled had low physical habitat, predominately rock and snags (ranging from 0 to 5% of water column), larger variation was observed in the amount of submerged aquatic vegetation (ranging from 0–70% of water column) and emergent vegetation (ranging from 0–80% of water column) across sites.

Water quality parameters (Table 6) were suitable for freshwater fish across all sites sampled with the exception of electrical conductivity which may be approaching upper tolerance levels for some species. Electrical conductivity ranged from 1409 $\mu S.cm^{-1}$ (SE21-105, Lake Hawdon South) to 6948 $\mu S.cm^{-1}$ (SE21-100, Lake Hawdon North). Dissolved oxygen concentration was at relatively high levels across all sites although was lower (4.4 $mg.L^{-1}$) at Almanda property (SE21-106) in Lake Hawdon South. The pH ranged between slightly alkaline to alkaline across all sites 7.46–9.25 while water temperature ranged from 10.7–19.6°C.

Table 6. Summary of fish catch across the Lake Hawdon in spring 2021.

Site Code	Waterway	Location	Subsurface physical %	Subsurface biological %	Emergent %	Edge vegetation %	Shade %	pH	Conductivity (uS/cm)	Temperature (°C)	Dissolved oxygen @0.2m (ppm)
SE21-100	Lake Hawdon North	Middle of wetland	0	60	0	40	0	9.03	6948	14.4	8.4
SE21-101	Lake Hawdon North	NE of wetland	1	70	10	90	0	8.15	6847	12.7	11.3
SE21-102	Drain L	Baxter Hill Rd	5	5	5	0	5	8.51	5364	13.4	8.3
SE21-103	Lake Hawdon South	Lake Hawdon connector	2	0	0	60	5	8.57	2352	13.3	9.8
SE21-104	Drain L	Just below Lake Hawdon North	2	5	5	0	0	8.53	4788	14.7	10.0
SE21-105	Lake Hawdon South	Southern wetland	0	5	80	85	0	8.53	1409	16.7	10.2
SE21-106	Lake Hawdon South	Southern end of wetland (Almanda)	2	5	80	80	0	7.46	2085	14.3	4.4
SE21-107	Lake Hawdon North	SE of wetland	1	20	15	60	0	8.40	3287	11.9	9.1
SE21-108	Lake Hawdon North	SW of wetland	2	0	5	80	0	8.65	3812	12.1	16.9
SE21-109	Lake Hawdon North	Eastern wetland (south of drain)	2	5	70	60	5	8.55	4990	15.2	10.9
SE21-110	Lake Hawdon North	Eastern wetland (north of drain)	0	10	2	20	0	9.25	3100	19.6	10.7
SE21-111	Lake Hawdon South	Eastern wetland	1	5	60	60	0	7.84	3960	10.7	7.0
SE21-112	Lake Hawdon South	SE of wetland	1	10	70	60	0	8.25	2420	13.5	10.8
SE21-113	Bray Drain	At junction with Lake Hawdon	5	2	0	0	0	8.52	2705	11.3	8.0

Temporal and spatial comparison of Catch per Unit Effort (CPUE) – Australian mudfish

Australian mudfish were sampled at five sites in 2010 and 2018, and six sites 2021 in Lake Hawdon South. Similar CPUE was recorded for Australian mudfish at the Lake Hawdon South wetland sites (i.e., southern wetland 'Almanda', northern end of wetland) in 2010 and 2018 but was slightly lower in 2021 (Figure 44). Differences were observed between 2010, 2018 and 2021 at Bray Drain-Gauge weir, where CPUE was highest in 2010 (6–10), lower in 2018 (1), and increased again in 2021 (2–5). Conversely, at Lake Hawdon South – Connector Drain, higher CPUE was recorded in 2018 (>10) than in 2010 (1) and CPUE increased again in 2021 (>10) (Figure 44).

No Australian mudfish were captured in Lake Hawdon North in past investigations; however, they were captured for the first time there in 2021. Australian mudfish were present in five of the six sites in Lake Hawdon North and in both the sites in Drain L. Highest CPUE (>10) was noted in the south-western part of Lake Hawdon North (Figure 44).

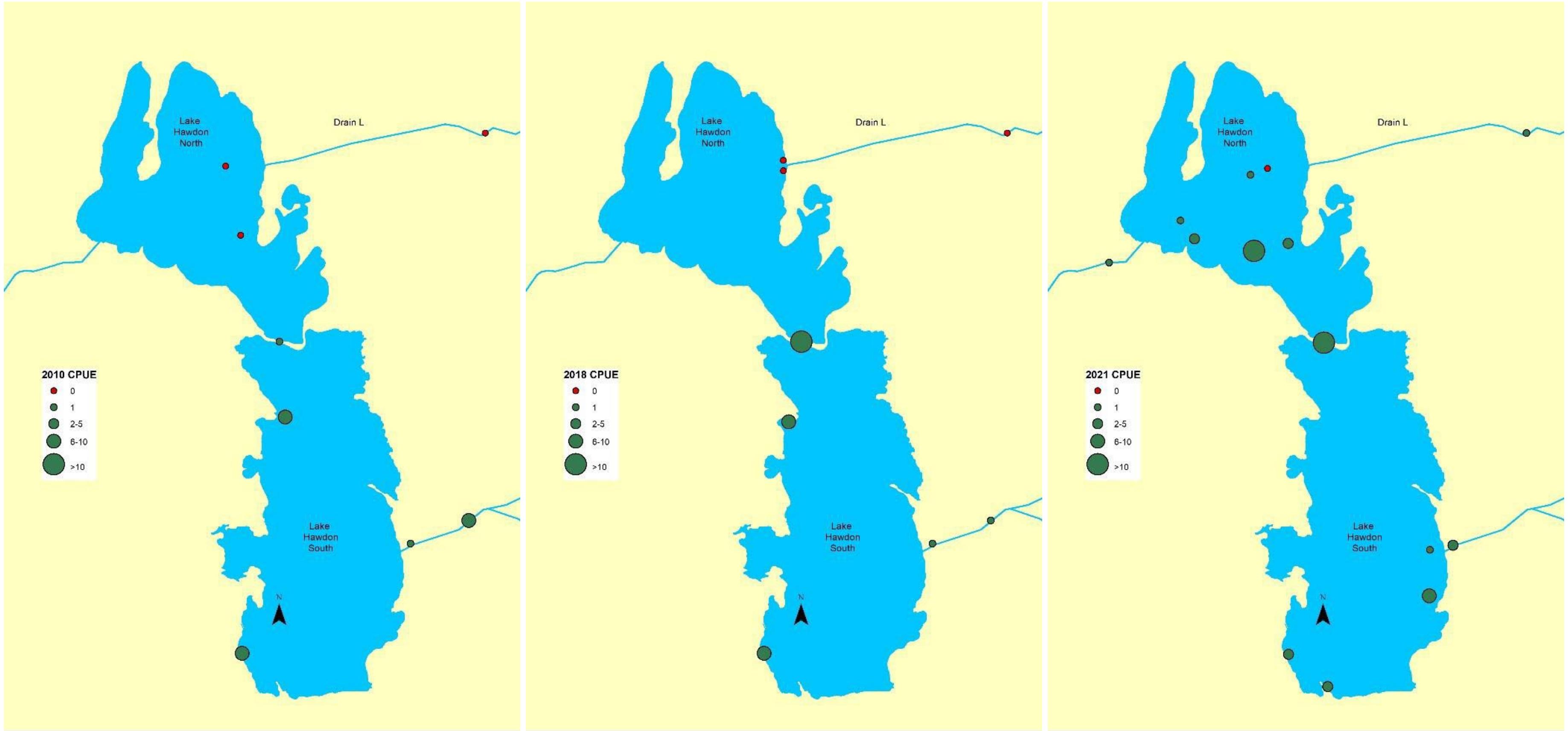


Figure 44. Comparison of Australian mudfish distribution and numbers in southeast South Australia between 2010 (left), 2018 (middle), and 2021 (right).

Temporal and spatial comparison of length – Australian mudfish

In September 2010, Australian mudfish ranged in length from 32–117 mm TL in Lake Hawdon South, with most being between 65–80 mm TL. Based on age-at-length determination of Whiterod et al. (2020), this dominant cohort was 1+ aged fish spawned in winter 2009. For Lake Hawdon South sampling in August 2018, most Australian mudfish were anticipated to be 1+ or 2+ aged fish (i.e., 80–95 mm TL) with little evidence of recent spawning. The significant rain and stream flows experienced during 2016–2017 likely contributed to the older fish being present. In October 2021, Australian mudfish ranged from 35–120 mm TL in Lake Hawdon South and Bray Drain and 32–81 mm TL in Lake Hawdon North (Figure 45, Figure 46). The Lake Hawdon North catch was dominated by fish 30–50 mm TL, which represent 0+ aged fish (or young-of-year) from spawning during early winter 2021 and the single 82 mm TL (likely 1+ aged fish) suggesting some localised spawning in 2020, or dispersal to the site. A similar 0+ aged fish cohort (35–55 mm TL) was detected in Lake Hawdon South, but a greater proportion of larger fish (73–120 mm TL), which likely represent 1+ (spawning in 2020) and 2+ aged fish (spawned in 2019), indicate spawning during previous years.

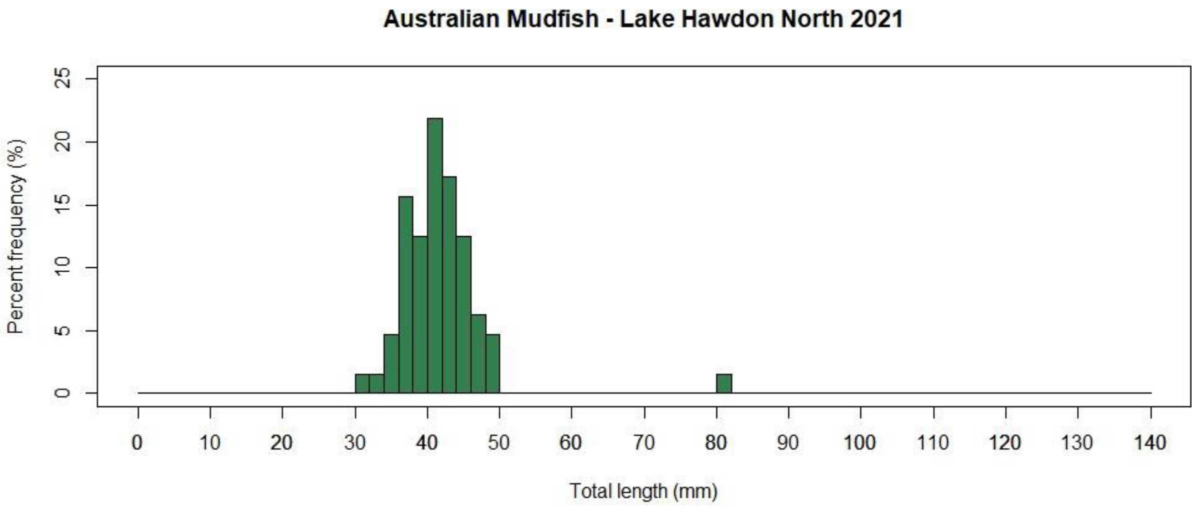


Figure 45. Length frequency distributions for Australian mudfish, collected from Lake Hawdon North in spring 2021.

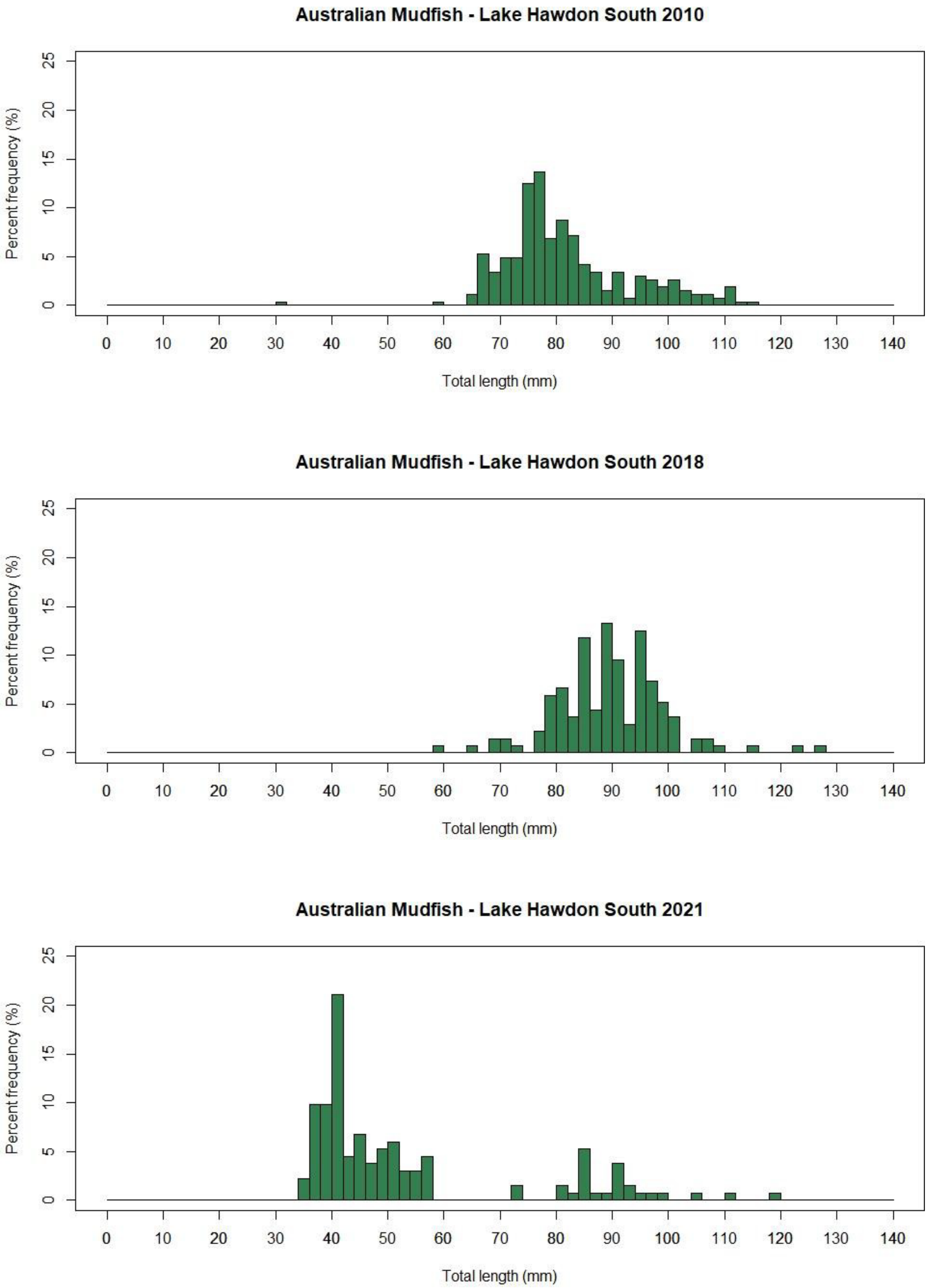


Figure 46. Length frequency distributions for Australian mudfish, collected from the Drain L catchment (i.e., Bray Drain and Lake Hawdon South) in winter 2010 (top), winter 2018 (bottom) and spring 2021.

Temporal comparison – other fish

A temporal comparison of native fish CPUE between 2010, 2018 and 2021 is presented in Table 7. Eight native fish species have been surveyed across this time. Smallmouthed hardyhead, a salt tolerant freshwater generalist, which require permanent surface water for survival, and generally occupy multiple habitats, was found at the highest CPUE in 2010 in Bray Drain and in moderately high CPUE in 2018 in Bray Drain.

As well as Australian mudfish, two other threatened native fish species, Southern pygmy perch and little Galaxias, which are obligate freshwater (wetland) species, have been observed in Lake Hawdon South and Lake Hawdon North. CPUE for southern pygmy perch in Lake Hawdon South and Bray Drain was highest in 2010, followed by 2018 and lowest in 2021. In Lake Hawdon North, CPUE of southern pygmy perch was similar amongst the three sample years but was overall lower than that found in Lake Hawdon South and Bray Drain.

CPUE for little Galaxias has been consistently high in Lake Hawdon South in 2010, 2018 and 2021, however highest CPUE was noted in 2018. Little Galaxias were observed for the first time in Lake Hawdon North in 2021 with CPUE comparable to that found in Lake Hawdon South in 2021.

Shortfinned eels were captured for the first time in 2018 near Baxter Hill Road and were recaptured there again in 2021. They were also sampled just below Lake Hawdon North in 2021 for the first time. Congolli *Pseudaphritis urvillii* have been found at low CPUEs on four occasions (0.25–0.5) in 2018 and 2021 in Lake Hawdon South, Drain L and Bray Drain and once at a higher CPUE of 2.25 in 2018 at the Lake Hawdon Connector site. Yelloweye mullet *Aldrichetta forsteri* was captured at one site, Drain L at Baxter Hill Road, in 2010 at a low CPUE (0.5) and no further captures have been noted.

Table 7. Summary of fish CPUE across Lake Hawdon in winter 2010, winter 2018 and spring 2021.

Site Code	Waterway	Location	Australian mudfish	Little Galaxias	Southern pygmy perch	Shortfinned eel	Common Galaxias	Congolli	Smallmouthed hardyhead	Yelloweye mullet
SE10-32	Lake Hawdon South	Lake Hawdon connector	0.5	5	16	0	0.5	0	1	0
SE10-33	Lake Hawdon South	Northern end of wetland	8.5	4.5	15	0	1	0	1	0
SE10-34	Drain L	Baxter Hill Road	0	4.5	6.5	0	0	0	3.5	0.5
SE10-35	Lake Hawdon South	Southern end of wetland (Almanda)	9	18.25	0.5	0	0	0	0	0
SE10-36	Bray Drain	At junction with Lake Hawdon	1	1.5	2.5	0	0	0	125	0
SE10-37	Bray Drain	Gauge weir	9	1	21	0	0	0	5550	0
SE11-20	Lake Hawdon North	Eastern side of wetland south 1	0	0	3	0	0	0	2	0
SE11-22	Lake Hawdon North	Middle of wetland north 3	0	0	1	0	0	0	7.5	0
SE18-14	Bray Drain	Gauge weir	1	0	16	0	0	0	0	0
SE18-13	Bray Drain	At junction with Lake Hawdon	0.25	0.5	9.5	0	0	0	59.25	0

Site Code	Waterway	Location	Australian mudfish	Little Galaxias	Southern pygmy perch	Shortfinned eel	Common Galaxias	Congolli	Smallmouthed hardyhead	Yelloweye mullet
SE18-15	Lake Hawdon South	Southern end of wetland (Almanda)	9.75	3.75	0	0	0	0	0.75	0
SE18-16	Lake Hawdon South	Lake Hawdon connector	14	37.25	9.75	0	1	2.25	2.5	0
SE18-17	Lake Hawdon South	Northern end of wetland	9	7.25	12	0	0	0.5	0	0
SE18-18	Drain L	Baxter Hill Road	0	0	12.5	0.25	0	0	0	0
SE18-19	Lake Hawdon North	North of drain	0	0	0.75	0	0	0	0	0
SE18-20	Lake Hawdon North	South of drain	0	0	4	0	0	0	0	0
SE21-100	Lake Hawdon North	Middle of wetland	0.5	0.25	0.25	0	0	0	1	0
SE21-101	Lake Hawdon North	NE of wetland	0	0.5	1.75	0	0	0	0.75	0
SE21-102	Drain L	Baxter Hill Road	0.25	0	0.75	0.5	0	0.5	0	0
SE21-103	Lake Hawdon South	Lake Hawdon connector	26.2	1.5	3.75	0	6.75	0	5.75	0
SE21-104	Drain L	Just below Lake Hawdon North	0.75	0.25	1.25	0.5	35	0.25	0	0
SE21-105	Lake Hawdon South	Southern wetland	3.5	0.25	0	0	0	0	0	0
SE21-106	Lake Hawdon South	Southern end of wetland (Almanda)	4.25	1	3.5	0	2	0	0.5	0
SE21-107	Lake Hawdon North	SE of wetland	1.75	0	0	0	0	0	0	0
SE21-108	Lake Hawdon North	SW of wetland	69.5	1.75	1.5	0	0.25	0	7.25	0
SE21-109	Lake Hawdon North	Eastern wetland (south of drain)	0.25	3.25	1.75	0	0.5	0	1	0
SE21-110	Lake Hawdon North	Eastern wetland (north of drain)	1.25	0.25	1.5	0	0	0	0	0
SE21-111	Lake Hawdon South	Eastern wetland	0.25	1	0	0	0	0	0	0
SE21-112	Lake Hawdon South	SE of wetland	9.75	2.5	9.25	0	0	0	0	0
SE21-113	Bray Drain	At junction with Lake Hawdon	3.5	0.25	7	0	0	0.25	0.5	0

6.4. Discussion

The current study builds on previous monitoring and research (Hammer and Tucker 2011, Hammer et al. 2012, Whiterod et al. 2020) to provide an updated insight into fish communities in the Drain L Catchment. This also allows for baseline information for comparison with future monitoring to assess the influence that the proposed hydrological restoration of Lake Hawdon North may have on fish populations. The spring 2021 survey revealed a fish community dominated by threatened native fish species, including Australian mudfish, Southern pygmy perch and little Galaxias, as well as diadromous species (common Galaxias, Congolli and Shortfinned eel). These findings are consistent with previous surveys (Hammer et al. 2012) but relevant to investigations of proposed hydrological restoration, Australian mudfish and little Galaxias were recorded, for the first time, in Lake Hawdon North. Interestingly, larger (>81 mm TL) Australian mudfish were only found in Lake Hawdon South and Bray Drain with smaller individuals found in Lake Hawdon North (<81 mm TL).

Consistent with previous studies, no alien or translocated fish species were detected throughout the 2021 investigations. Prevention of alien fish invasion, namely, *Gambusia holbrooki*, into the Drain L catchment is essential if the conservation values of Lake Hawdon South and Lake Hawdon North, including its Australian mudfish population, are to be conserved.

The outcomes of the survey emphasise that the present hydrological conditions in the study region currently provide suitable habitat for important native freshwater fish. Furthermore, the fact that Australian mudfish already persist in Lake Hawdon North present important considerations for the proposed hydrological restoration. However, the exact movements of Australian mudfish remain equivocal, and it still not confirmed whether the species is in fact diadromous. It is imperative that the proposed hydrological restoration and associated management actions (such as burning and removal of Swamp Paperbark (*Melaleuca halmaturorum*)) do not negatively impact the prevailing fish community. Rather, if implemented appropriately, this restoration will enhance habitat to build stronger populations of the native freshwater fish across the otherwise altered landscape of the region.

7. Bush Birds

7.1. Background

The proposed restoration of Lake Hawdon North involves the clearance of approximately 650 ha of recently invaded *Melaleuca halmaturorum* shrubland from the bed of Lake Hawdon North which, in combination with hydrological restoration, restores the former habitat of open mudflats / open water (Taylor 2020). While this is anticipated to restore foraging habitat for shorebirds and other waterbirds, it may represent a loss of habitat for fauna currently occupying these shrublands. To undertake a comprehensive fauna survey, covering a range of vertebrate and potentially invertebrate groups, would be a large and expensive undertaking. Given available time and resources, an assessment of the diversity and abundance of bush birds is likely to provide an achievable yet broadly representative indication of the habitat value of these *M. halmaturorum* shrublands for fauna generally.

BirdLife Australia have undertaken long term monitoring for birds and have developed guidelines to increase the collection of useful and scientifically valid information. Methods of bird surveys are categorised as:

- systematic bird surveys;
- unstandardised bird surveys; and
- species lists.

The value of the survey data depends upon the survey type as indicated in Figure 47.

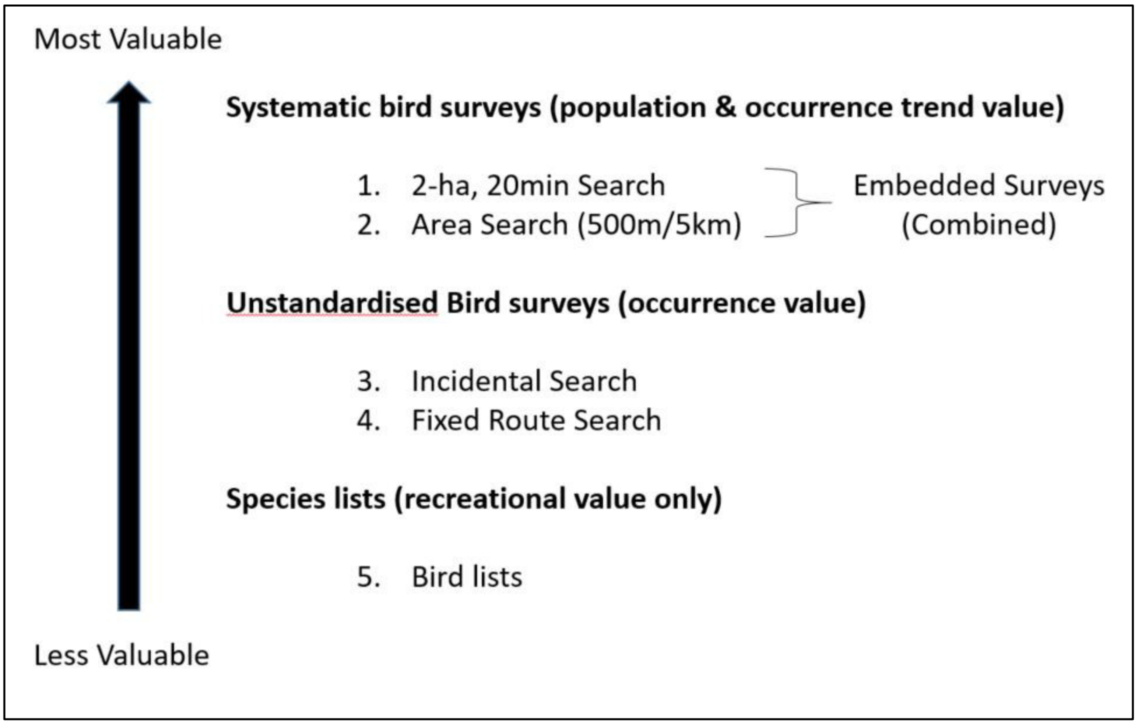


Figure 47. Birdlife Australia Bird Survey Techniques Guide
(adapted from https://birdata.birdlife.org.au/survey-techniques).

Data from systematic bird surveys (2 ha, 20 minute search, 500 m and 5 km area searches) provide the most beneficial bird occurrence and population change information in BirdLife Australia's toolkit.

7.2. Methods

For the *M. halmaturorum* shrublands proposed for clearance in Lake Hawdon North the method of bird survey chosen was the 2 ha, 20 minute search. The recommended shape for the 2 ha survey area is a 100 m x 200 m rectangle, however any variation which encompasses this physical area is acceptable. We used ArcGIS to predefine four circular survey sites, each with an 80 m radius (Figure 48). All sites were located north of Drain L and on the western side of the wetland, where *M. halmaturorum* invasion has been extensive in recent decades (Taylor et al. 2014). One survey site was located within each of four vegetation associations as mapped and defined by Ecological Associates (2009) that are proposed for clearance:

- Association B (site LHN-B): *Melaleuca halmaturorum* Tall open shrubland over *Gahnia filum* sedges over *Schoenus nitens*, +/- *Selliera radicans* sedges
- Association I (site LHN-I): *Melaleuca halmaturorum* Tall shrubland over *Gahnia filum* sedges over +/- *Schoenus nitens* sedges
- Association N (site LHN-N): *Melaleuca halmaturorum*, +/- *Gahnia filum* Mid open shrubland over *Schoenus nitens* sedges
- Association Q (site LHN-Q): *Melaleuca halmaturorum*, +/- *Gahnia filum* Low open shrubland over *Austrodanthonia setacea* tussock grasses over *Schoenus nitens, Selliera radicans* sedges

Three surveys were conducted in each of the sites over the three consecutive days 10th to 12th November 2021. Surveys were conducted once in the morning or afternoon of each day. Given that 13 years had passed since Ecological Associates (2009) completed this vegetation mapping, vegetation at the survey sites may have varied somewhat from the above descriptions. However, the survey sites are broadly representative of the vegetation proposed for clearance and are located within the proposed clearance footprint.

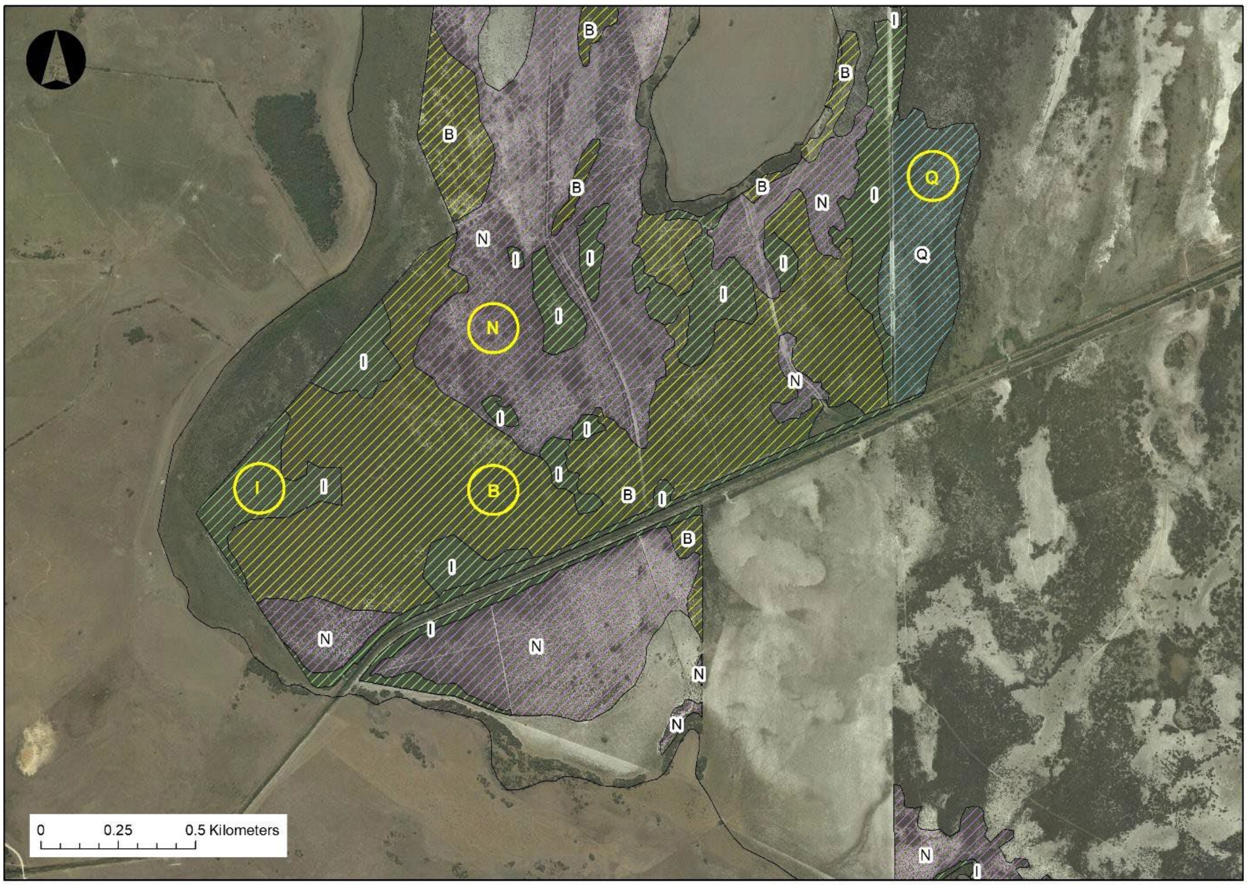


Figure 48. Bush bird survey sites (yellow circles) in the north-western part of Lake Hawdon North, with the vegetation mapping of Ecological Associates (2009) overlying a 2019 aerial image.

General habitat photographs were taken at each site (Figure 49 to Figure 52). Survey sites were located in the field using the Avenza Maps® application installed on a mobile phone. Birds seen or heard within the two-hectare area (including birds flying over) were recorded along with abundance and any evidence of breeding.

Incidental observations of any state or regionally significant birds were also recorded while on transit between sites. Any nests or evidence of breeding was noted.

The weather during surveys was consistently overcast (3/8 - 8/8 cloud cover), with moderate to strong winds and low temperatures (<20°C). Walking was the only means of accessing each survey site, which involved a round trip of 3.5 hours covering >10 km.

Figure 49. Bush bird survey site LHN-B.

Figure 50. Bush bird survey site LHN-I.

Figure 51. Bush bird survey site LHN-N.

Figure 52. Bush bird survey site LHN-Q.

7.3. Results

Nine species of birds were recorded across the four survey sites (Table 8). The most species rich sites were LHN-I and LHN-Q with six species. LHN-B and LHN-N each recorded three species. One beautiful firetail (*Stagonopleura bella*), which has a state and regional rating of rare (RA), was heard calling at LHN-N on the last morning.

Table 8. Bush bird survey site results.

			Count per site (total for all surveys)			
Atlas No.	**Common Name**	**Scientific Name**	**LHN-B**	**LHN - I**	**LHN-N**	**LHN-Q**
361	Grey fantail	*Rhipidura fuliginosa*		1		2
398	Golden whistler	*Pachycephala pectoralis*		1		
408	Grey shrike-thrush	*Colluricincla harmonica*		1	1	
448	White-fronted chat	*Epthianura albifrons*				15
475	Brown thornbill	*Acanthiza pusilla*	1			3
488	White-browed scrubwren	*Sericornis frontalis*	4	1	4	3
529	Superb fairy-wren	*Malurus cyaneus*	2	2		2
574	Silvereye	*Zosterops lateralis*		1		3
650	Beautiful firetail	*Stagonopleura bella*			1	
		Site-Species richness	**3**	**6**	**3**	**6**

Three other state and regionally significant species were observed outside of the 2 ha search areas, either flying over, calling nearby or flushed from nearby vegetation. These were blue-winged parrot (*Neophema chrysogaster*), striated fieldwren (*Calamanthus fuliginosus*), and Latham's snipe (*Gallinago hardwickii*).

No breeding birds were recorded within the survey sites, however white-fronted chats (*Epthianura albifrons*) were accidentally disturbed at their nests (in low *Melaleuca*) on two occasions while in transit.

On two consecutive days (an afternoon and morning) up to seven Latham's Snipe were flushed from two areas along tracks while walking between sites LHN-N and LHN-Q. Figure 53 shows the location where up to five Snipe were disturbed.

Figure 53. Latham's Snipe were flushed from both sides of this track.

7.4. Discussion

The bush bird surveys revealed a relatively low abundance and diversity of birds within the survey sites. All bird species recorded, with one exception (beautiful firetail), are common and widespread and typically occur in a diverse range of habitats including disturbed areas, farmland and residential areas. None are specific to the habitats of Lake Hawdon North. The vegetation was very dense and uniform, with low floristic diversity and little open ground for ground foraging species, which likely explains the low abundance and diversity recorded. Low numbers of state and/or regionally threatened species were recorded within the proposed clearance footprint, however several of these species were also recorded during the waterbird census within vegetation not proposed for clearance. The general conclusion from this targeted survey effort is that clearance of *M. halmaturorum* is unlikely to constitute a significant, negative impact on the overall biodiversity of the wetland, nor that of the wider region.

8. Other Notable Opportunistic Observations

During the waterbird census a small population (approximately 20 plants) of the emergent species *Euphrasia collina* ssp. *collina* (purple eyebright) was discovered within *Baumea arthrophylla/Gahnia filum* sedgeland in cell K-20 of Lake Hawdon North (easting: 404162, northing: 5886793). This species is listed as vulnerable in South Australia under the *National Parks and Wildlife Act 1972* (Version: 19.3.2021) and appears to be the first record of the species in Lake Hawdon North (DEW 2021a). The species has been recorded previously in adjoining Lake Hawdon South (Stewart et al. 2001), where several populations of many hundreds of plants occur within *Baumea arthrophylla* and/or *Baumea juncea sedgelands* (B. Taylor, pers. obs.). The proposed hydrological restoration of Lake Hawdon North may improve conditions for this species as it will align the water regime of Lake Hawdon North more closely with that of Lake Hawdon South where the species is more abundant. In fact, the species has been observed to respond favourably following hydrological restoration works at Long Swamp, in southwest Victoria (L. Farrington, pers. comm.).

Figure 54. *Euphrasia collina* ssp. *collina* in flower, Lake Hawdon North, 10/11/2021.

9. Summary and Recommendations

The ecological monitoring of the Lake Hawdon system undertaken in spring 2021 has improved scientific understanding of the ecology of this wetland complex of high conservation importance and provided baseline data against which future data can be compared to detect change. In relation to the three ecological objectives of the restoration project, the monitoring program revealed the following:

Objective A. improve the availability and quality of foraging habitat (salt marsh/open mud flats) for the seven HCHB RBR target shorebird species, which are at risk from deteriorating conditions in the southern Coorong;

- Four of the seven target shorebird species of the HCHB RBR (sharp-tailed sandpiper, red-necked stint, red-capped plover and common greenshank) were present in LHN in November 2021 (Section 2) in abundances within the range anticipated based on past surveys of adjoining Lake Hawdon South (see Taylor 2020). Of the remaining target species, curlew sandpiper has been recorded previously in LHN and banded stilt have been recorded in adjacent Lake Hawdon South and may utilise LHN at times. This confirms that LHN provides suitable habitat for at least five of the target shorebird species in its current, unrestored state. The predicted increase to the carrying capacity of LHN for target shorebirds resulting from restoration (Taylor 2020) appears to be reasonable based upon the abundances observed in November 2021.
- An area of inundated open mudflat habitat in Lake Hawdon North had a lower abundance and lower diversity of macroinvertebrates than an area of similar habitat in Lake Hawdon South that is known to support high densities of target shorebirds when water levels are suitable (Section 3). Sediments in Lake Hawdon South were less compact and had organisms present at greater depths than sediments in Lake Hawdon North. Encouragingly, despite the less favourable status of the Lake Hawdon North sediments as a food resource, target shorebirds were recorded in the same area that sediment sampling occurred. This suggests that hydrological restoration alone will increase the carrying capacity of Lake Hawdon North, even without improvement to sediment food resources, as shorebird habitat is already provided when water levels are suitable. However, given a key difference between the two sediment monitoring locations is water regime, it is hypothesised that hydrological restoration will also improve the status of Lake Hawdon North sediments as a food resource for target shorebirds due to increased duration of inundation. Baseline data collected for this study will enable that hypothesis to be tested.

Objective B. increase the area of open mudflat/open water aquatic habitat, maintain the area of *Baumea arthrophylla* and *Gahnia filum* sedgelands and reduce the area of *Melaleuca halmaturorum* shrublands;

- Seven vegetation transects established within Lake Hawdon North (Section 4) include areas of all the vegetation types listed in Objective B, including areas of *M. halmaturorum* shrubland proposed for clearance under restoration. Resurvey of these transects following restoration will provide a direct measure of how well Objective B has been achieved. In particular, monitoring following the clearance of *M. halmaturorum* shrubland will measure the success of this activity and can provide an early warning if further action is required to permanently eliminate this invasive native species from open mudflat habitat.
- *Melaleuca halmaturorum* recruitment monitoring in Lakes Hawdon North and South (Section 5), established in 2008, provides a measure of how effectively current management of Lake Hawdon North (sheep grazing and current hydrology) is preventing the recruitment of *M. halmaturorum* in areas where it currently exists in low density. The most recent data suggest slightly increased *M. halmaturorum* recruitment. Thus, without hydrological

restoration, the expansion of *M. halmaturorum* shrubland within Lake Hawdon North (see Taylor et al. 2014) may continue. Ongoing *M. halmaturorum* recruitment monitoring will enable this issue to be examined and the effectiveness of hydrological restoration, if it occurs, to be assessed.

- The complimentary monitoring of the extent of all vegetation types at Lake Hawdon North, using high resolution aerial imagery and machine learning (Muller 2022), also provides an important measure of achievement of Objective B and should be ongoing. This approach is less sensitive to subtle changes in the short term (e.g. an increase in *M. halmaturorum* seedlings) but has a more comprehensive, whole-of-wetland spatial coverage.

Objective C. do no harm, i.e. at the very least maintain identified existing ecological values, in particular the highly significant native fish community of the Lake Hawdon system, which includes diadromous species and covers both Lake Hawdon North and adjoining Lake Hawdon South Conservation Park;

- The threatened Australian mudfish (*Neochanna cleaveri*) was detected in Lake Hawdon North for the first time (Section 6). The size distribution of mudfish caught in LHN suggests the species may be migrating seasonally into LHN from source populations elsewhere, likely from adjoining Lake Hawdon South, however its persistence in the sediments of LHN during the dry phase cannot be ruled out. The threatened little Galaxias (*Galaxiella toourtkoourt*) was also detected in LHN for the first time. This is also a species believed to survive the dry phase by burrowing into wetland sediments. These species, and the fish community of Lake Hawdon North in general, are anticipated to benefit from hydrological restoration, which will align the water regime of Lake Hawdon North more closely with that of Lake Hawdon South, where both species have well established populations with broad size class distribution.
- The proposed clearance of *M. halmaturorum* shrubland from the bed of Lake Hawdon North poses temporary risks for the fish community related to poor water quality caused by dead vegetation decomposing while submerged. With the significance of the fish community highlighted by this study it is important this risk be carefully managed should restoration proceed.
- The areas of dense *Melaleuca halmaturorum* shrubland that has established on the formerly open bed of LHN in recent decades support a relatively low diversity and low abundance community of bush birds, consisting mostly of common, generalist species (Section 7). Its clearance and restoration as open mudflat for shorebirds and other waterbirds is unlikely to cause harm to local bush bird populations.

Baseline data becomes most relevant through comparison with subsequent data. To build upon the baseline obtained by this study, the following is recommended in relation to future monitoring:

- Vegetation transects and quadrats should be resurveyed two to three years after restoration and five yearly thereafter. Surveys should be timed such that water levels are similar to those of the baseline survey.
- *Melaleuca halmaturorum* recruitment monitoring should be undertaken every one to two years in January or February to align with previous surveys and, for practical reasons, when LHN is dry.
- The fish survey of the Lake Hawdon system should be repeated annually in the first two to three years following restoration. Timing should align approximately with the baseline, although a later survey should be more achievable under restored hydrology.
- An assessment of the fishway proposed for the Drain L regulator should be conducted over three periods (September, October/November and December) in its first year of operation.

- Shorebirds and other waterbirds of open water / mudflat habitats should be resurveyed in mid summer (e.g. early January) prior to restoration to improve confidence in abundance data and account for seasonal variation. This survey could be timed to coincide with the annual shorebird survey of Lake Hawdon South. Following restoration, shorebird counts should be undertaken in the first year of operation and annually thereafter. If a single annual survey, then it should be timed later in the summer so that the extent of inundation is manageable and birds are concentrated within available habitat.
- Ongoing waterbird survey effort should be informed by probabilities of detection, whereby the number of replicates may show a point at where additional replicates yield very little difference in terms of new species observed or variation to overall average estimates (e.g. Moore et al. 2011).

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APPENDIX A – Bird Abundance Counts for each survey cell

		Counts per cell																														
common name	Total	C-13	C-14	D-12	D-13	D-14	D-15	E-12	E-13	E-14	E-15	E-16	F-10	F-11	F-12	F-13	F-14	F-15	F-16	G-9	G-10	G-11	G-12	G-13	G-14	G-15	G-16	G-17	G-18	H-8	H-9	H-10
% water by area (approx.)		0	0	0	0	0	5	0	0	0	5	0	0	0	0	0	0	5	0	0	0	0	0	0	0	5	2	0	0	0	0	0
Species for which confident counts for entire survey area were obtained																																
Australasian shoveler	22																															
Australian shelduck	2786																															
Australian white ibis	11																															
banded lapwing	5																															
black swan	159																															
black-winged stilt	1313																															
Caspian tern	1																															
cattle egret	2																															
chestnut teal	116										9							19								2						
common greenshank	47																															
great cormorant	2																															
great egret	2																															
grey teal	1394																															
hardhead	6																															
hoary-headed grebe	11																															
little egret	27																															
masked lapwing	153																															
musk duck	5																															
Pacific black duck	330						4				1							16														
pink-eared duck	2																															
red-capped plover	140																											6				
red-necked stint	331																															
royal spoonbill	1																															
sharp-tailed sandpiper	674																															
silver gull	702																										25					
straw-necked ibis	1																															
whiskered tern	1834																															
white-faced heron	123						1																									

		Counts per cell																																	
common name	Total	H-11	H-12	H-13	H-14	H-15	H-16	H-17	H-18	H-19	I-7	I-8	I-9	I-10	I-11	I-12	I-13	I-14	I-15	I-16	I-17	I-18	I-19	I-20	J-5	J-6	J-7	J-8	J-9	J-10	J-11	J-12	J-13	J-14
% water by area (approx.)		0	0	0	0	7	60	50	0	0	0	0	0	0	0	0	0	0	20	50	70	90	80	0	0	0	0	0	0	0	0	0	0	0
Species for which confident counts for entire survey area were obtained																																		
Australasian shoveler	22																																	
Australian shelduck	2786						5																											
Australian white ibis	11					1													3															
banded lapwing	5																																	
black swan	159																																	
black-winged stilt	1313																																	
Caspian tern	1																																	
cattle egret	2																																	
chestnut teal	116																																	
common greenshank	47																																	
great cormorant	2																																	
great egret	2																																	
grey teal	1394																																	
hardhead	6																																	
hoary-headed grebe	11																																	
little egret	27						1												4															
masked lapwing	153					8	2		1												2													
musk duck	5																																	
Pacific black duck	330																																	
pink-eared duck	2																																	
red-capped plover	140					24	13	57											2															
red-necked stint	331					81		66																										
royal spoonbill	1																																	
sharp-tailed sandpiper	674						7	1																										
silver gull	702						84												73															
straw-necked ibis	1																																	
whiskered tern	1834						92													38	92	14	16											
white-faced heron	123						1	1											2	2		5												

		Counts per cell																																
common name	Total	J-15	J-16	J-17	J-18	J-19	J-20	J-21	K-5	K-6	K-7	K-8	K-9	K-10	K-11	K-12	K-13	K-14	K-15	K-16	K-17	K-18	K-19	K-20	K-21	K-22	K-23	K-24	L-6	L-7	L-8	L-9	L-10	L-11
% water by area (approx.)		60	?	70	70	90	0	0	0	0	0	0	0	0	0	?	?	?	80	65	80	50	90	50	10	0	0	0	0	0	?	?	?	?
Species for which confident counts for entire survey area were obtained																																		
Australasian shoveler	22																																	
Australian shelduck	2786																																	
Australian white ibis	11																			1														
banded lapwing	5								3				2																					
black swan	159																																	
black-winged stilt	1313																																	
Caspian tern	1																																	
cattle egret	2																																	
chestnut teal	116																																	
common greenshank	47																																	
great cormorant	2																																	
great egret	2																																	
grey teal	1394																																	
hardhead	6																																	
hoary-headed grebe	11																																	
little egret	27																																	2
masked lapwing	153	3																2	65															
musk duck	5																																	
Pacific black duck	330																																	
pink-eared duck	2																																	
red-capped plover	140																2																	
red-necked stint	331																																	
royal spoonbill	1																																	
sharp-tailed sandpiper	674			1																7	400													
silver gull	702	2							2										1										4					
straw-necked ibis	1																																	
whiskered tern	1834	6	17	44	50	13													12	31	264	19	24	11										
white-faced heron	123	8	2	1															8	2	1													

		Counts per cell																																		
common name	Total	L-12	L-13	L-14	L-15	L-16	L-17	L-18	L-19	L-20	L-21	L-22	L-23	L-24	L-25	M-6	M-7	M-8	M-9	M-10	M-11	M-12	M-13	M-14	M-15	M-16	M-17	M-18	M-19	M-20	M-21	M-22	M-23	M-24	M-25	M-26
		Counts per cell																																		
% water by area (approx.)		?	?	1	?	90	75	95	90	70	50	40	100	90	50	0	0	0	?	?	?	?	?	1	25	50	50	95	80	50	?	85	100	100	90	5
Species for which confident counts for entire survey area were obtained																																				
Australasian shoveler	22																																			
Australian shelduck	2786																														73				4	
Australian white ibis	11					1																												1		
banded lapwing	5																																			
black swan	159					3	1																							2		5				
black-winged stilt	1313																																			
Caspian tern	1																																			
cattle egret	2																																			
chestnut teal	116																																			
common greenshank	47																																			
great cormorant	2													2																						
great egret	2																													1						
grey teal	1394																																			
hardhead	6																																			
hoary-headed grebe	11																																			
little egret	27													8							2											1				
masked lapwing	153			3		2	6																35		2	2										
musk duck	5													3																						
Pacific black duck	330																													13						
pink-eared duck	2																																			
red-capped plover	140	10																																		
red-necked stint	331																																			
royal spoonbill	1																																			
sharp-tailed sandpiper	674					95	10							1												15										
silver gull	702			14										13	2							4		1								1				
straw-necked ibis	1														1																					
whiskered tern	1834					110	25	8	42	40	52	32	4	7	2										10			12	119	48	30	40	15	2	3	
white-faced heron	123			5		2	3				2	1		4											25		10			1	4	2				

		Counts per cell																																
common name	Total	N-5	N-6	N-7	N-8	N-9	N-10	N-11	N-12	N-13	N-14	N-15	N-16	N-17	N-18	N-19	N-20	N-21	N-22	N-23	N-24	N-25	N-26	O-5	O-6	O-7	O-8	O-9	O-10	O-11	O-12	O-13	O-14	O-15
% water by area (approx.)		0	?	?	?	?	?	?	?	?	2	5	75	?	25	0	60	70	85	100	100	60	10	?	5	?	0	0	?	?	?	?	0	5
Species for which confident counts for entire survey area were obtained																																		
Australasian shoveler	22																			4														
Australian shelduck	2786																			420	45													
Australian white ibis	11															3					1													
banded lapwing	5																																	
black swan	159																			75														
black-winged stilt	1313																			110	165				4									
Caspian tern	1																																	
cattle egret	2																																	2
chestnut teal	116																			40														
common greenshank	47																			25														
great cormorant	2																																	
great egret	2																1																	
grey teal	1394																			180	20													
hardhead	6																			6														
hoary-headed grebe	11																			3	8													
little egret	27																				1													1
masked lapwing	153										5		2												2									
musk duck	5																			2														
Pacific black duck	330												69			70				50														
pink-eared duck	2																			2														
red-capped plover	140																								11									
red-necked stint	331																								152									
royal spoonbill	1																			1														
sharp-tailed sandpiper	674																			35					17									
silver gull	702		300																1						6									
straw-necked ibis	1																																	
whiskered tern	1834										100	8	35				26	5	70	200	7													
white-faced heron	123										10	9					4								4									3

		Counts per cell																																	
common name	Total	O-16	O-17	O-18	O-19	O-20	O-21	O-22	O-23	O-24	O-25	P-4	P-5	P-6	P-7	P-8	P-9	P-10	P-11	P-12	P-13	P-14	P-15	P-16	P-17	P-18	P-19	P-20	P-21	P-22	P-23	P-24	P-25	Q-4	Q-5
% water by area (approx.)		?	?	?	25	70	80	80	100	85	?	?	?	?	?	?	?	?	?	?	?	0	5	?	?	?	80	40	10	15	100	60	0	?	?
Species for which confident counts for entire survey area were obtained																																			
Australasian shoveler	22								6	8																				4					
Australian shelduck	2786				76	28			750	10																	90	49		270	800	106			
Australian white ibis	11																																		
banded lapwing	5																																		
black swan	159								30																						40				
black-winged stilt	1313								6	435																		1		250	240	100			
Caspian tern	1						1																												
cattle egret	2																																		
chestnut teal	116								10	13																				17		6			
common greenshank	47						2			1																		19							
great cormorant	2																																		
great egret	2																																		
grey teal	1394								450	110																				5	500	125			
hardhead	6																																		
hoary-headed grebe	11																																		
little egret	27									5																	2								
masked lapwing	153							6																			2				2				
musk duck	5																																		
Pacific black duck	330					3				10																	2	4	2	74	10				
pink-eared duck	2																																		
red-capped plover	140																																		
red-necked stint	331									6																						8			
royal spoonbill	1																																		
sharp-tailed sandpiper	674									25																					60				
silver gull	702																										38			6	22	40			
straw-necked ibis	1																																		
whiskered tern	1834						3	10	10	5																			1		10				
white-faced heron	123																																		

		Counts per cell																				
common name	Total	Q-6	Q-7	Q-8	Q-11	Q-12	Q-13	Q-16	Q-17	Q-18	Q-19	Q-20	Q-21	Q-22	Q-23	Q-24	R-5	R-6	R-7	R-8	R-17	R-18
% water by area (approx.)		?	?	?	?	?	?	?	?	2	40	0	5	20	5	5	?	?	?	?	?	?
Species for which confident counts for entire survey area were obtained																						
Australasian shoveler	22																					
Australian shelduck	2786										50					10						
Australian white ibis	11																					
banded lapwing	5																					
black swan	159										3											
black-winged stilt	1313															2						
Caspian tern	1																					
cattle egret	2																					
chestnut teal	116																					
common greenshank	47																					
great cormorant	2																					
great egret	2																					
grey teal	1394															4						
hardhead	6																					
hoary-headed grebe	11																					
little egret	27																					
masked lapwing	153										1											
musk duck	5																					
Pacific black duck	330										2											
pink-eared duck	2																					
red-capped plover	140									15												
red-necked stint	331									18												
royal spoonbill	1																					
sharp-tailed sandpiper	674																					
silver gull	702									25	36					2						
straw-necked ibis	1																					
whiskered tern	1834																					
white-faced heron	123																					

		Counts per cell																														
common name	Total	C-13	C-14	D-12	D-13	D-14	D-15	E-12	E-13	E-14	E-15	E-16	F-10	F-11	F-12	F-13	F-14	F-15	F-16	G-9	G-10	G-11	G-12	G-13	G-14	G-15	G-16	G-17	G-18	H-8	H-9	H-10
% water by area (approx.)		0	0	0	0	0	5	0	0	0	5	0	0	0	0	0	0	5	0	0	0	0	0	0	0	5	2	0	0	0	0	0
Species counted opportunistically - counts not representative of entire survey area																																
Australasian pipit	16																													1	1	
Australian hobby	1																															
Australian magpie	25																									1		7	1	1		
Australian raven	5																															
beautiful firetail	3						1																									
black-tailed native-hen	221																															
brown falcon	2																															
brown songlark	6																															
brown thornbill	15																									4						
collared sparrowhawk	1						1																									
common blackbird	4																									2						
common bronzewing	2																	1														
common skylark	28																															
common starling	163																															
crested pigeon	3																															
emu	4																															
European goldfinch	11																	2								3						
galah	22																	4														
golden whistler	3																									1						
golden-headed cisticola	2																															
grey butcherbird	1																															
grey currawong	1																										1					
grey fantail	9										1							1								2						
grey shrike-thrush	17						1				1															2						
Horsefield's bronze-cuckoo	1																															
little grassbird	13																															
little raven	238																															
magpie-lark	25																											2				
Nankeen kestrel	2																															
raven sp.	22																															
silvereye	92																									2						
singing honeyeater	2																															
spiny-cheeked honeyeater	9										1																					
striated fieldwren	8																															
superb fairy-wren	20										2															1						
swamp harrier	8																															
wedge-tailed eagle	3																															
welcome swallow	22																				2					2						
white-browed scrubwren	4																	2														
white-fronted chat	75																										1					
willie wagtail	2						1																									

		Counts per cell																																
common name	Total	H-11	H-12	H-13	H-14	H-15	H-16	H-17	H-18	H-19	I-7	I-8	I-9	I-10	I-11	I-12	I-13	I-14	I-15	I-16	I-17	I-18	I-19	I-20	J-5	J-6	J-7	J-8	J-9	J-10	J-11	J-12	J-13	J-14
% water by area (approx.)		0	0	0	0	7	60	50	0	0	0	0	0	0	0	0	0	0	20	50	70	90	80	0	0	0	0	0	0	0	0	0	0	0
Species counted opportunistically - counts not representative of entire survey area																																		
Australasian pipit	16																																2	
Australian hobby	1																																	
Australian magpie	25		2									3														1			1	1				
Australian raven	5																																	
beautiful firetail	3																																	
black-tailed native-hen	221							24											7															
brown falcon	2																											1						
brown songlark	6									1																								
brown thornbill	15																																	
collared sparrowhawk	1																																	
common blackbird	4																																	
common bronzewing	2																												1					
common skylark	28																		1		2										2			
common starling	163																																	
crested pigeon	3																												2					
emu	4																																	
European goldfinch	11																									3								
galah	22										2																							
golden whistler	3																																	
golden-headed cisticola	2																																	
grey butcherbird	1		1																															
grey currawong	1																																	
grey fantail	9																																	
grey shrike-thrush	17										1																		1					
Horsefield's bronze-cuckoo	1																																	
little grassbird	13																				1	2	1											
little raven	238						1																											
magpie-lark	25	1				1	2												2															
Nankeen kestrel	2													1																	1			
raven sp.	22																									1								
silvereye	92							89																										
singing honeyeater	2																																	
spiny-cheeked honeyeater	9																																	
striated fieldwren	8																		1															
superb fairy-wren	20									3																								1
swamp harrier	8																					1												
wedge-tailed eagle	3																																	
welcome swallow	22					1																									2			
white-browed scrubwren	4																																	
white-fronted chat	75					2													20	5	1	3												2
willie wagtail	2																													1				

		Counts per cell																																
common name	Total	J-15	J-16	J-17	J-18	J-19	J-20	J-21	K-5	K-6	K-7	K-8	K-9	K-10	K-11	K-12	K-13	K-14	K-15	K-16	K-17	K-18	K-19	K-20	K-21	K-22	K-23	K-24	L-6	L-7	L-8	L-9	L-10	L-11
% water by area (approx.)		60	?	70	70	90	0	0	0	0	0	0	0	0	0	?	?	?	80	65	80	50	90	50	10	0	0	0	0	0	?	?	?	?
Species counted opportunistically - counts not representative of entire survey area																																		
Australasian pipit	16			1								4	2																					
Australian hobby	1																																	
Australian magpie	25										3																							
Australian raven	5																																	
beautiful firetail	3																																	
black-tailed native-hen	221																																	
brown falcon	2																																	
brown songlark	6								2					2																				
brown thornbill	15								3																									
collared sparrowhawk	1																																	
common blackbird	4																																	
common bronzewing	2																																	
common skylark	28		3		1							2							6	5	4	2												
common starling	163								5																				2					
crested pigeon	3																																	
emu	4	1																																
European goldfinch	11																																	
galah	22																																	
golden whistler	3																																	
golden-headed cisticola	2		2																															
grey butcherbird	1																																	
grey currawong	1																																	
grey fantail	9																																	
grey shrike-thrush	17										2													1										
Horsefield's bronze-cuckoo	1																																	
little grassbird	13					1													1	1	1	1		2										
little raven	238								5			2	2																					
magpie-lark	25	1																											2					
Nankeen kestrel	2																																	
raven sp.	22																																	
silvereye	92																																	
singing honeyeater	2																																	
spiny-cheeked honeyeater	9																												1					
striated fieldwren	8	1	2																1															
superb fairy-wren	20										3																							
swamp harrier	8												2																					
wedge-tailed eagle	3												1																					
welcome swallow	22		1																															
white-browed scrubwren	4																																	
white-fronted chat	75		1	3								6		4							1													
willie wagtail	2																																	

		Counts per cell																																		
common name	Total	L-12	L-13	L-14	L-15	L-16	L-17	L-18	L-19	L-20	L-21	L-22	L-23	L-24	L-25	M-6	M-7	M-8	M-9	M-10	M-11	M-12	M-13	M-14	M-15	M-16	M-17	M-18	M-19	M-20	M-21	M-22	M-23	M-24	M-25	M-26
		Counts per cell																																		
% water by area (approx.)		?	?	1	?	90	75	95	90	70	50	40	100	90	50	0	0	0	?	?	?	?	?	1	25	50	50	95	80	50	?	85	100	100	90	5
Species counted opportunistically - counts not representative of entire survey area																																				
Australasian pipit	16			3																																
Australian hobby	1																																			
Australian magpie	25																						2													
Australian raven	5									2	3																									
beautiful firetail	3														1																					
black-tailed native-hen	221							2						7																					27	
brown falcon	2																																			
brown songlark	6																					1														
brown thornbill	15														2																				1	
collared sparrowhawk	1																																			
common blackbird	4														1																					1
common bronzewing	2																																			
common skylark	28																																			
common starling	163																									2										
crested pigeon	3																																			
emu	4																																			
European goldfinch	11													1																					2	
galah	22									4		2																				2		2		
golden whistler	3													1	1																					
golden-headed cisticola	2																																			
grey butcherbird	1																																			
grey currawong	1																																			
grey fantail	9														3																					
grey shrike-thrush	17																																			
Horsefield's bronze-cuckoo	1																																			
little grassbird	13																																		1	
little raven	238																																			
magpie-lark	25																									2										
Nankeen kestrel	2																																			
raven sp.	22											2																			2	1				
silvereye	92														1																					
singing honeyeater	2													1																	1					
spiny-cheeked honeyeater	9														1																					
striated fieldwren	8														2																					
superb fairy-wren	20														2																	1		1		1
swamp harrier	8			1													1														1					
wedge-tailed eagle	3																												1							
welcome swallow	22														4																2				2	
white-browed scrubwren	4														2																					
white-fronted chat	75						2							1												10										
willie wagtail	2																																			

		Counts per cell																																
common name	Total	N-5	N-6	N-7	N-8	N-9	N-10	N-11	N-12	N-13	N-14	N-15	N-16	N-17	N-18	N-19	N-20	N-21	N-22	N-23	N-24	N-25	N-26	O-5	O-6	O-7	O-8	O-9	O-10	O-11	O-12	O-13	O-14	O-15
% water by area (approx.)		0	?	?	?	?	?	?	?	?	2	5	75	?	25	0	60	70	85	100	100	60	10	?	5	?	0	0	?	?	?	?	0	5
Species counted opportunistically - counts not representative of entire survey area																																		
Australasian pipit	16																											2						
Australian hobby	1																1																	
Australian magpie	25																																	
Australian raven	5																																	
beautiful firetail	3																				1													
black-tailed native-hen	221																					8												
brown falcon	2																										1							
brown songlark	6																																	
brown thornbill	15																					2												
collared sparrowhawk	1																																	
common blackbird	4																																	
common bronzewing	2																																	
common skylark	28																																	
common starling	163																				3							150						
crested pigeon	3																						1											
emu	4																																	
European goldfinch	11																																	
galah	22																	2																
golden whistler	3																																	
golden-headed cisticola	2																																	
grey butcherbird	1																																	
grey currawong	1																																	
grey fantail	9																																	
grey shrike-thrush	17																						1				4							2
Horsefield's bronze-cuckoo	1																		1															
little grassbird	13																																1	
little raven	238				50																													
magpie-lark	25																								3									
Nankeen kestrel	2																																	
raven sp.	22																																	
silvereye	92																																	
singing honeyeater	2																																	
spiny-cheeked honeyeater	9																					1	2											
striated fieldwren	8																		1															
superb fairy-wren	20																						2											
swamp harrier	8											1																						
wedge-tailed eagle	3			1																														
welcome swallow	22																																	
white-browed scrubwren	4																																	
white-fronted chat	75																				2							10						
willie wagtail	2																																	

		Counts per cell																																	
common name	Total	O-16	O-17	O-18	O-19	O-20	O-21	O-22	O-23	O-24	O-25	P-4	P-5	P-6	P-7	P-8	P-9	P-10	P-11	P-12	P-13	P-14	P-15	P-16	P-17	P-18	P-19	P-20	P-21	P-22	P-23	P-24	P-25	Q-4	Q-5
% water by area (approx.)		?	?	?	25	70	80	80	100	85	?	?	?	?	?	?	?	?	?	?	?	0	5	?	?	?	8	4	1	1	100	6	0	?	?
Species counted opportunistically - counts not representative of entire survey area																																			
Australasian pipit	16																																		
Australian hobby	1																																		
Australian magpie	25																													2					
Australian raven	5																																		
beautiful firetail	3																																		
black-tailed native-hen	221																									75				71					
brown falcon	2																																		
brown songlark	6																																		
brown thornbill	15							3																											
collared sparrowhawk	1																																		
common blackbird	4																																		
common bronzewing	2																																		
common skylark	28																																		
common starling	163				1																														
crested pigeon	3																																		
emu	4																				3														
European goldfinch	11																																		
galah	22					2		2																											
golden whistler	3																																		
golden-headed cisticola	2																																		
grey butcherbird	1																																		
grey currawong	1																																		
grey fantail	9						1	1																											
grey shrike-thrush	17																												1						
Horsefield's bronze-cuckoo	1																																		
little grassbird	13																																		
little raven	238							85																											
magpie-lark	25																									7									
Nankeen kestrel	2																																		
raven sp.	22																																		
silvereye	92																																		
singing honeyeater	2																																		
spiny-cheeked honeyeater	9							2																			1								
striated fieldwren	8																																		
superb fairy-wren	20																						2				1								
swamp harrier	8																											1							
wedge-tailed eagle	3																																		
welcome swallow	22																						6												
white-browed scrubwren	4																																		
white-fronted chat	75																											1							
willie wagtail	2																																		

		Counts per cell																				
common name	Total	Q-6	Q-7	Q-8	Q-11	Q-12	Q-13	Q-16	Q-17	Q-18	Q-19	Q-20	Q-21	Q-22	Q-23	Q-24	R-5	R-6	R-7	R-8	R-17	R-18
% water by area (approx.)		?	?	?	?	?	?	?	?	2	40	0	5	20	5	5	?	?	?	?	?	?
Species counted opportunistically - counts not representative of entire survey area																						
Australasian pipit	16																					
Australian hobby	1																					
Australian magpie	25																					
Australian raven	5																					
beautiful firetail	3																					
black-tailed native-hen	221																					
brown falcon	2																					
brown songlark	6																					
brown thornbill	15																					
collared sparrowhawk	1																					
common blackbird	4																					
common bronzewing	2																					
common skylark	28																					
common starling	163																					
crested pigeon	3																					
emu	4																					
European goldfinch	11																					
galah	22																					
golden whistler	3																					
golden-headed cisticola	2																					
grey butcherbird	1																					
grey currawong	1																					
grey faintail	9																					
grey shrike-thrush	17																					
Horsefield's bronze-cuckoo	1																					
little grassbird	13																					
little raven	238										90					3						
magpie-lark	25										2											
Nankeen kestrel	2																					
raven sp.	22									16												
silvereye	92																					
singing honeyeater	2																					
spiny-cheeked honeyeater	9																					
striated fieldwren	8																					
superb fairy-wren	20																					
swamp harrier	8																					
wedge-tailed eagle	3																					
welcome swallow	22																					
white-browed scrubwren	4																					
white-fronted chat	75																					
willie wagtail	2																					

APPENDIX B – Birds Counted Opportunistically

Counts are not representative of the entire survey area because these species favour dense shrubland and *Gahnia* vegetation that was not systematically surveyed.

Common Name	Total
Australasian pipit	16
Australian hobby	1
Australian magpie	25
Australian raven	5
beautiful firetail	3
black-tailed native-hen	221
brown falcon	2
brown songlark	6
brown thornbill	15
collared sparrowhawk	1
common blackbird	4
common bronzewing	2
common skylark	28
common starling	163
crested pigeon	3
emu	4
European goldfinch	11
galah	22
golden whistler	3
golden-headed cisticola	2
grey butcherbird	1
grey currawong	1
grey fantail	9
grey shrike-thrush	17
Horsefield's bronze-cuckoo	1
little grassbird	13
little raven	238
magpie-lark	25
Nankeen kestrel	2
raven sp.	22
silvereye	92
singing honeyeater	2
spiny-cheeked honeyeater	9
striated fieldwren	8
superb fairy-wren	20
swamp harrier	8
wedge-tailed eagle	3
welcome swallow	22
white-browed scrubwren	4
white-fronted chat	75
willie wagtail	2