# Instream Woody Habitat Mapping of the Curdies Estuary

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Unpublished Client Report for Fisheries Victoria

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**Front cover**

Curdies Estuary downstream of Curdievale (Renae Ayres); Estuary Perch (Tarmo A. Raadik); Black Bream (Jeremy Hindell).

# Instream woody habitat mapping of the Curdies Estuary

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**May 2015**

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# Acknowledgements

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# Summary

The sustainability of fisheries resources is dependent on the diversity, complexity, availability and connectivity of habitats to support the survival, growth and reproduction of fish populations. The Curdies Estuary, in south-west Victoria, is a popular fishing destination containing key recreational fisheries, despite its environmental condition being very poor and a history of habitat loss and degradation. In the early to mid-1900s, instream woody habitat (IWH) was removed from the Curdies Inlet upstream towards Timboon to facilitate boat navigation and support water carriage of farming resources and passengers. Removal of IWH and damage to native riparian vegetation are now listed as potentially threatening processes in the Victorian *Flora and Fauna Guarantee Act 1988*. Waterway management activities, including installation of IWH and replanting riverbanks, are now actively carried out to improve waterway health and habitats that support production of fish resources.

In this study, we mapped and assessed current IWH distribution and density in the Curdies Estuary to inform reinstatement of IWH. The spatial location of IWH masses and their size and complexity, water depth, boat ramps and jetties were surveyed along 19.3 km from the Curdies Estuary mouth to upstream of Curdievale. This data was used to produce an IWH density map and an interpolated water depth map for the study reach.

IWH were generally small and isolated in volume and distribution in the Curdies Estuary. The Curdies Inlet, the reach between the Curdies Inlet and Curdievale, and the reach upstream of Curdievale had no IWH to low densities of IWH. The most upstream 3 km of the study reach had relatively higher densities of IWH. Riparian vegetation was intact in this section and likely contributed to the IWH inputs observed. Seagrass and rocky outcrops were observed in the Curdies Estuary and these also provide important instream habitats for fish. Water depth varied across the study reach, but was relatively deeper in the reach above Curdies Inlet and just upstream of Curdievale. Curdies Inlet was consistently shallow. The Curdies Estuary had lower average IWH density compared to average densities recorded in other Victorian estuaries that have also been desnagged.

Identifying the locations for IWH installation can be informed by combining the IWH density and water depth data. Deeper areas with low IWH densities could be targeted to provide refuge areas for fish during low tide or low water flows. Installing IWH in sections upstream and downstream of Curdievale would increase IWH available for fish populations in the Curdies Estuary, as well as improve ecological connectivity between the upper estuary and Curdies Inlet. Rather than installing IWH in the Curdies Inlet, restoring and expanding seagrass beds could be considered.

Rehabilitating IWH in the Curdies Estuary will improve the availability and connectivity of habitat for fish species that occupy or utilise the estuary, including key recreational fish, such as Estuary Perch and Black Bream. We predict that increasing IWH densities will benefit fish communities and the fishery, and provide overarching ecosystem advantages; however our knowledge of how fish populations utilise and respond to IWH installation is limited. Therefore, monitoring is recommended to inform future actions in an adaptive management framework.

Other factors, such as permits and approvals, water flows, riparian vegetation condition, land tenure, infrastructure (such as boat ramps and jetties), and waterway use and user groups, should also be taken into account when making decisions on IWH installation.

# 1. Introduction

Waterways and riparian zones provide habitats essential for the survival, growth and reproduction of water dependent fauna, such as fish, frogs, aquatic invertebrates and waterbirds. The diversity, complexity, availability and connectivity of these habitats influences waterway condition and ecosystem function. Furthermore, the sustainability of fisheries resources is dependent on the integrity of instream and riparian habitats to support healthy fish populations.

Instream woody habitat (IWH), otherwise known as instream woody debris, large woody debris or 'snags', consists of trees, branches and logs that fall in or are washed into waterways. IWH is important habitat for fish and other water dependent fauna. For fish in particular, it provides shelter and refuge areas to avoid predators and fast water flow, feeding sites and food resources, spawning sites and nursery areas, and markers for territorial or migratory species (Crook and Robertson 1999; Nicol *et al.* 2002). Additionally, IWH provides other structural and chemical functions by protecting the stream bed and banks, helping develop scour pools, and contributing to organic enrichment through their decay and trapping of other organic debris (Nicol *et al.* 2002).

However, there is a long history of IWH removal from many waterways in Victoria and elsewhere throughout south-eastern Australia. Snagging operations were undertaken from the late 1800s in many waterways, including the Murray, Goulburn, Curdies, Gellibrand, Tarwin, Tambo and Snowy Rivers (The Argus 1891). During the early to mid-1900s, IWH was removed from the Curdies Inlet upstream towards the Timboon railway river crossing (Camperdown Chronicle 1911; Camperdown Chronicle 1950). Clearing of the river of obstructions was expected to facilitate easy and cheap water carriage of farming produce and passengers to the railway at Timboon, as well as downstream shipment of agricultural lime from the Curdies River Lime Company (Camperdown Chronicle 1911). IWH removal and other threats have contributed to the current very poor environmental condition rating of the Curdies Estuary (DEPI 2013).

Despite the perceived benefits of historical snagging operations, the detrimental impacts of removing IWH on waterway health are now recognised. Removal of instream woody debris increases water flow velocity, degrades streambeds, increases channel width, causes a loss of habitat, and reduces the productivity and diversity of aquatic ecosystems (Gippel *et al.* 1996; Maddock 1999; Erskine and Webb 2003; Brooks *et al.* 2004). Removal of wood debris from Victoria streams and Degradation of native riparian vegetation along Victorian rivers and streams are listed as potentially threatening processes in the Victorian *Flora and Fauna Guarantee Act 1988*. Reinstating IWH is accepted as an integral component of rehabilitating waterways and this is achieved by manually installing individual logs, root-balls or complex log structures into the waterway channel and/or replanting native riparian vegetation to encourage longer term, natural inputs of IWH (Rutherfurd *et al.* 2000; Saddlier 2008).

To help target IWH rehabilitation efforts more effectively, Kitchingman *et al.* (2013) developed a method to map IWH density. This information can inform IWH installation locations. This approach has since been applied to map densities of IWH in many Victorian waterways (Ayres *et al.* 2013; Kitchingman *et al.* 2013b; Ayres *et al.* 2014; Kitchingman *et al.* submitted; Tonkin *et al.* submitted).

The aim of this study was to map and identify IWH density and distribution in the Curdies Estuary to inform decisions about reinstating IWH to support healthy waterways and fisheries and enhance fishing opportunities. The Curdies Estuary is a popular recreational fishing, boating and tourism destination. The environmental values of the Curdies Estuary are a drawcard underpinning its social and economic values. The Curdies Estuary supports various large and small bodied fish species, including several key recreational fish species, such as Estuary Perch (*Macquaria colonorum*) and Black Bream (*Acanthopagrus butcheri*) (Nicholson *et al.* 2009; Warry and Reich 2010; Kent 2011). An output of the study will be a high resolution IWH density map of the Curdies Estuary to understand current IWH densities and distribution and assist identification of potential installation locations for IWH. The output will complement seagrass and riparian vegetation mapping data recently collected for the Curdies Estuary by Monash University and Corangamite Catchment Management Authority, respectively.

This project informs priorities in the Corangamite Waterway Strategy 2014-2022 (Corangamite CMA 2014), which identifies the Curdies Estuary as a priority waterway and notes that improving its riparian and instream habitat and bank stability is a fishery management priority. The project also has synergies with the Curdies Estuary management plan (Water Technology 2008) and past fish habitat assessments by Fisheries Victoria's Fish Habitat Assessment Group (Nicholson *et al.* 2009; Kent 2011).

# 2. Methods

## 2.1 Study location

The Curdies River is located in the Otway Coast Basin in coastal, south-west Victoria (Figure 1). The Curdies River begins near Lake Purrumbete in the north and flows in a south westerly direction, passing the township of Peterborough before discharging into the Southern Ocean. Its main tributaries are Scotts, Black Glen and Cooriemungle Creeks. The Curdies Estuary extends for ~17 km from the estuary mouth near Peterborough to above Boggy Creek Road, Curdievale (Figure 2). The Curdies Inlet forms part of the Peterborough Coastal Reserve and borders Port Campbell National Park and the Bay of Island Coastal Park.

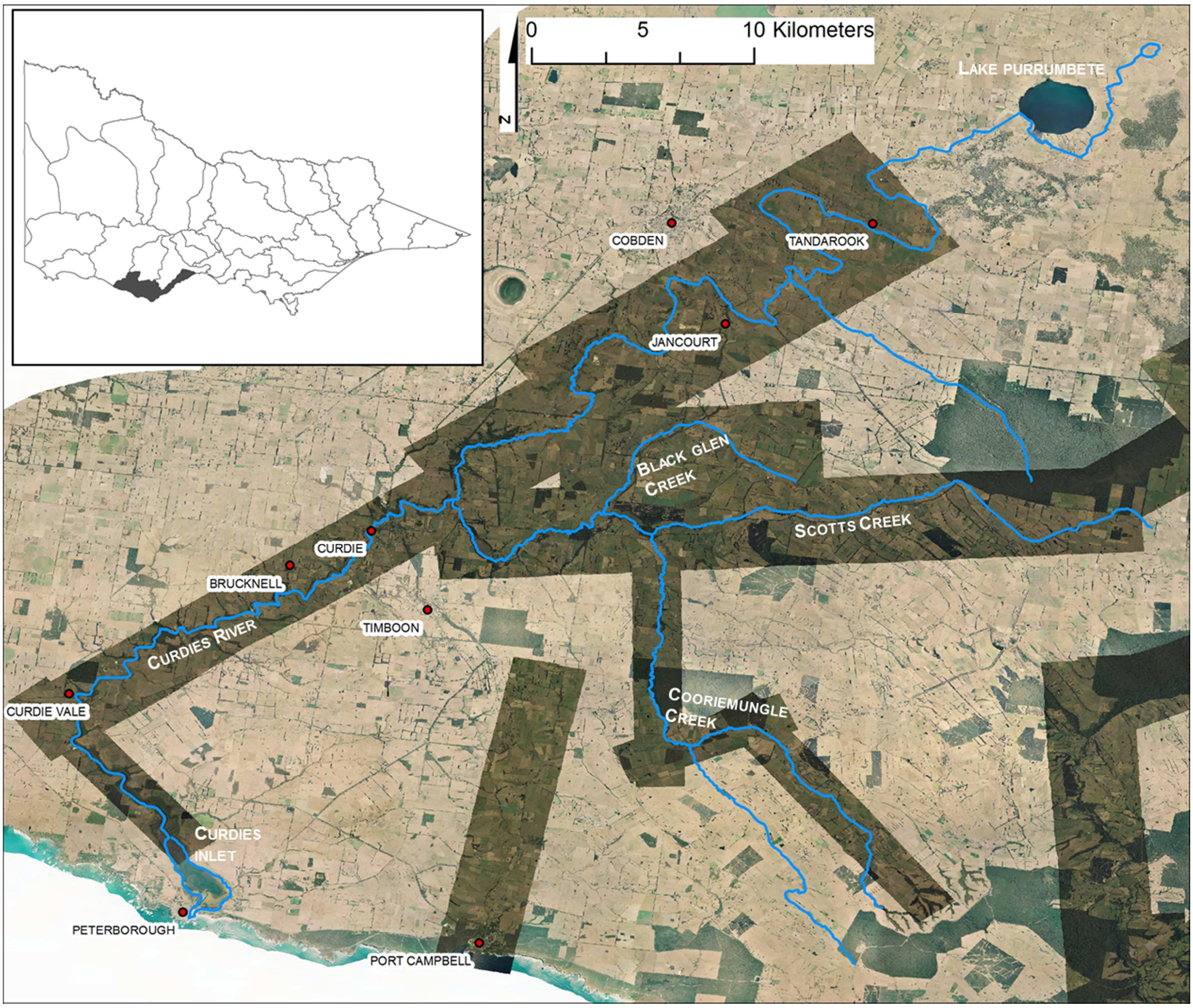


**Figure 1. The Curdies River catchment within the Otway Coast Basin (insert: shaded grey), Victoria**

**Figure 2. The Curdies Estuary within the Otway Coast Basin (insert: shaded grey), Victoria**

## 2.2 Instream woody habitat mapping and analysis

IWH was mapped along 19.3 km of the Curdies Estuary from the estuary mouth upstream towards Timboon (Figure 2). Mapping occurred between May 18th to 21st, 2015 via boat and followed methods described in Kitchingman *et al.* (2013). During the sampling period the estuary mouth remained closed. IWH was defined as individual or aggregations of dead wood greater than 1 m in length and 10 cm diameter, and located below the high bank level (excluding the floodplain). IWH was geo-located using a Trimble® GeoExplorer® 6000 series handheld Global Navigation Satellite System (GNSS) coupled with a laser rangefinder. A geo-referenced side imaging system (Hummingbird® 998c SI side imaging sonar) was used to identify completely submerged IWH.

Individual IWH masses were assigned a size (relative area of structural coverage: < 5 $m^2$, < 10 $m^2$, < 20 $m^2$ or > 20 $m^2$) and complexity (1 trunk, 2 trunks, 3 trunks or complex) category. Each IWH mass was assigned a volume based on conversion of categories to wood volumes (Kitchingman *et al.* 2013).

For quality control, field collected IWH data were visually checked prior to analysis. Data were then used to calculate the average IWH density for the study reach and generate a map of IWH density (volume per metre squared ($m^3m^{-2}$) for each map pixel). IWH density was calculated using a Kernel Density Estimate (KDE) function on the geo-located IWH masses (O'Sullivan and Unwin 2010). The KDE was performed with a 100 m radius and weighted by an average IWH volume attributed to the various size and complexity combinations. The IWH density map of the study reach can be used as a baseline measure for any subsequent additions of IWH.

## 2.3 Water depth mapping and analysis

Water depths were recorded using the geo-referenced side imaging system (Hummingbird® 998c SI side imaging sonar) at 3 second intervals. Longitudinal and latitudinal water depths were recorded by boating in a broad, zig-zag fashion across the navigable channel at a speed maintained at about 5 km/hour.

Field collected water depth recordings were checked for erroneous readings prior to analysis. Any erroneous readings identified were filtered out. Using GIS software, water depth points were interpolated (Inverse Distance Weighting) across the channel width to give a relative indication of water depth changes along the study reach.

The distance between left and right banks (channel width) was measured at random points throughout the survey reach using the laser rangefinder.

## 2.4 Mapping of other infrastructure

Geo-locations of fishing platforms, public boat ramps and private jetties were also collected using the Trimble® GeoExplorer® 6000 series handheld Global Navigation Satellite System (GNSS) and laser rangefinder.

## 2.5 Water quality

Water quality was measured primarily to characterise the salinity profile of the Curdies Estuary and to identify the uppermost extent of the estuary. Water quality data were collected at approximately 1 m depth intervals from the surface to the bottom at seven sites within the estuary, including two Estuarywatch water quality monitoring locations at Peterborough and Curdievale (Figure 3). Temperature (°C), dissolved oxygen (mg/L), electrical conductivity (mS), pH and turbidity (NTU), measurements were collected using a calibrated field-laboratory analyser (TPS 90-FLT: TPS, Brisbane, Australia).

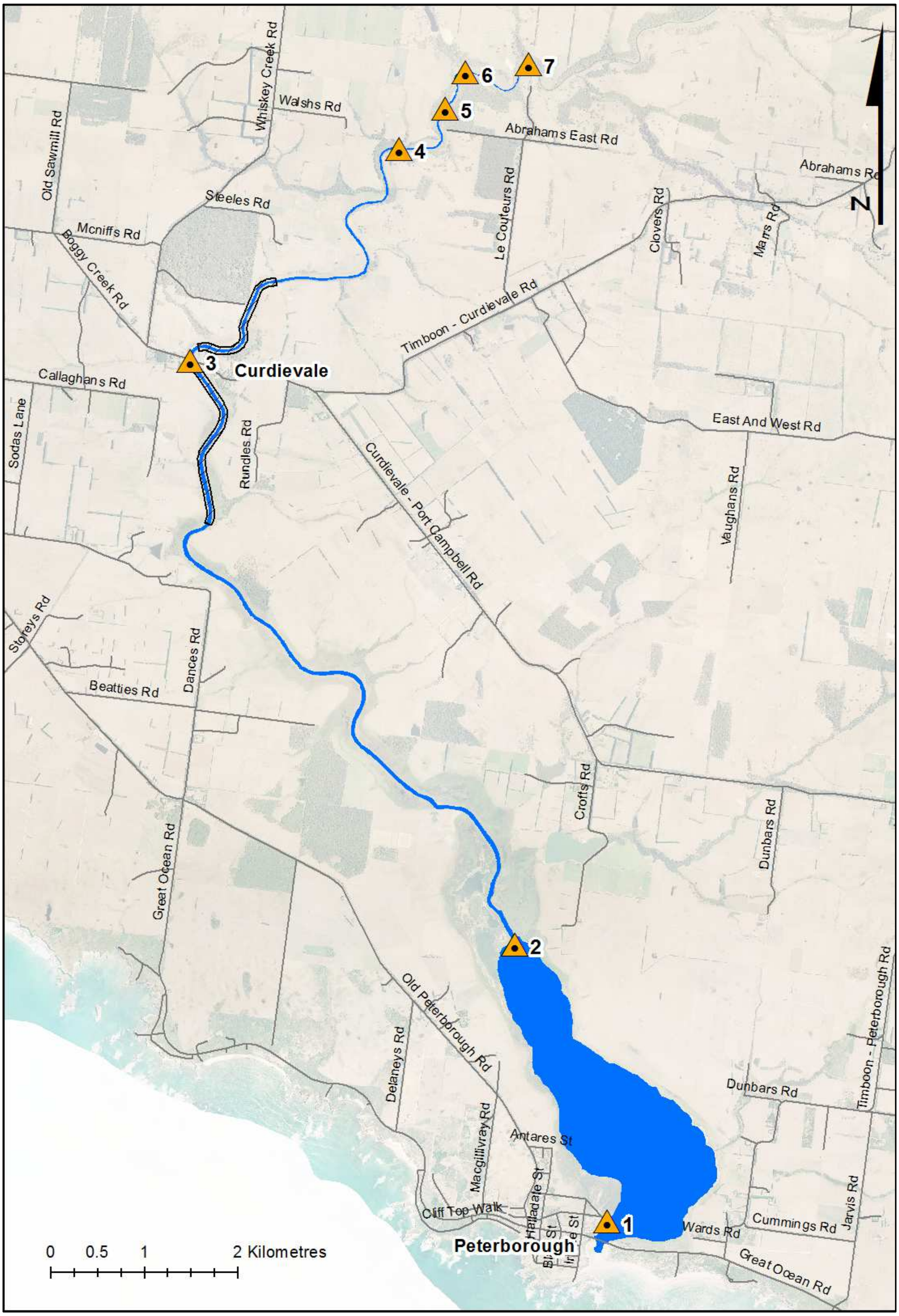


**Figure 3. Locations in the Curdies Estuary where water quality was measured (numbered yellow triangles). Locations 1 and 3 correspond to EstuaryWatch monitoring sites. The ski zone is denoted by diagonal black lines.**

# 3. Results

## 3.1 IWH density

IWH density ranged from 0 to 0.01 $m^3m^{-2}$ along the study reach (Figures 4 and 5), with an average IWH density of 0.00004806 $m^3m^{-2}$. IWH densities were relatively higher in the most upstream 3 km of the study reach. An isolated occurrence of high IWH density occurred upstream of Curdievale in the ski zone. Elsewhere in the study reach, IWH densities were low.

## 3.2 Water depth and channel width

Water depth varied across the study reach up to 8 m (Figures 6 and 7). The Curdies Inlet was consistently shallow, with maximum water depths between 0.5 to 0.9 m. Channel width varied between approximately 0.5 to 1.5 km. Upstream of the Curdies Inlet to Curdievale, water depths were relatively deeper, often between 5 to 8 m and channel width varied between 35 to 45 m. Above Curdievale, water depth decreased and was frequently between 4 – 6 m; channel width gradually narrowed as moving upstream from 20 m to 10 m.

## 3.3 Location of other infrastructure

Public boat ramps and fishing platforms are displayed in Figures 4 to 7. A public boat ramp, fishing platform, seal the loop bin and fish cleaning table are located on the west bank of Curdies Inlet upstream of the Great Ocean Road, Peterborough. At Boggy Creek Road, Curdievale, there is a public boat ramp, 4 fishing platforms, 2 fish cleaning tables and a seal the loop bin, as well as a water skiing zone downstream and upstream of this location. A private jetty occurs on the east bank further upstream at Emu District Scout Camp.

## 3.4 Water quality

Water quality results are listed in Table 1. Water clarity was high throughout the study reach. Salinity stratification was present in the upper estuary (Sites 4 - 7), whereas in the lower estuary (Sites 1 – 3) there was more even vertical distribution of electrical conductivity. Oxygen depletion occurred with increasing water depth at sites 4 to 7. The salinity data indicates that the extent of the upper estuary limit was further upstream of the study reach.

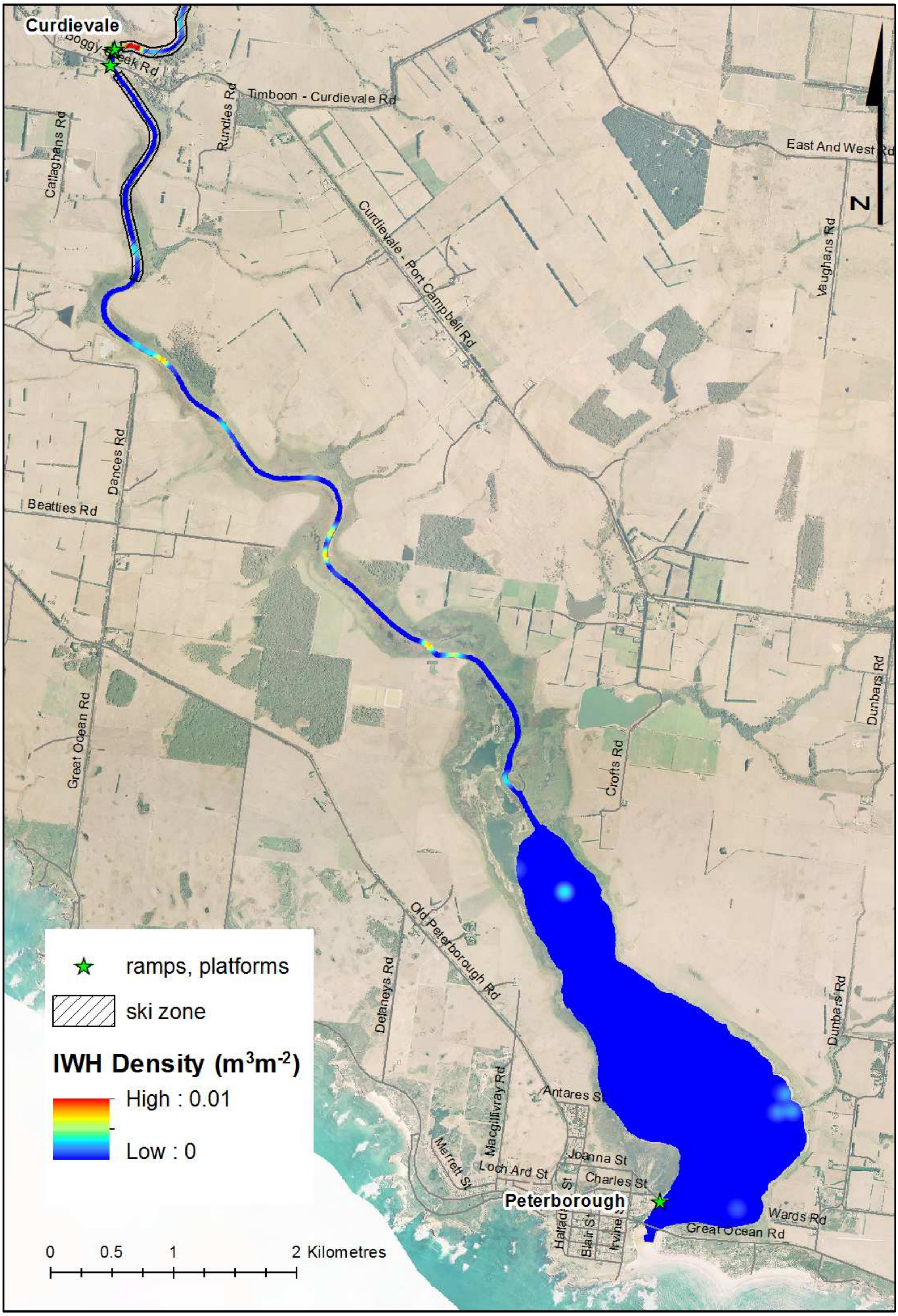


**Figure 4. Instream woody habitat (IWH) density ($m^3m^{-2}$) map of the Curdies Estuary between Peterborough and Curdievale. Locations of boat ramps and platforms are denoted by green stars. The ski zone is denoted by diagonal black lines.**

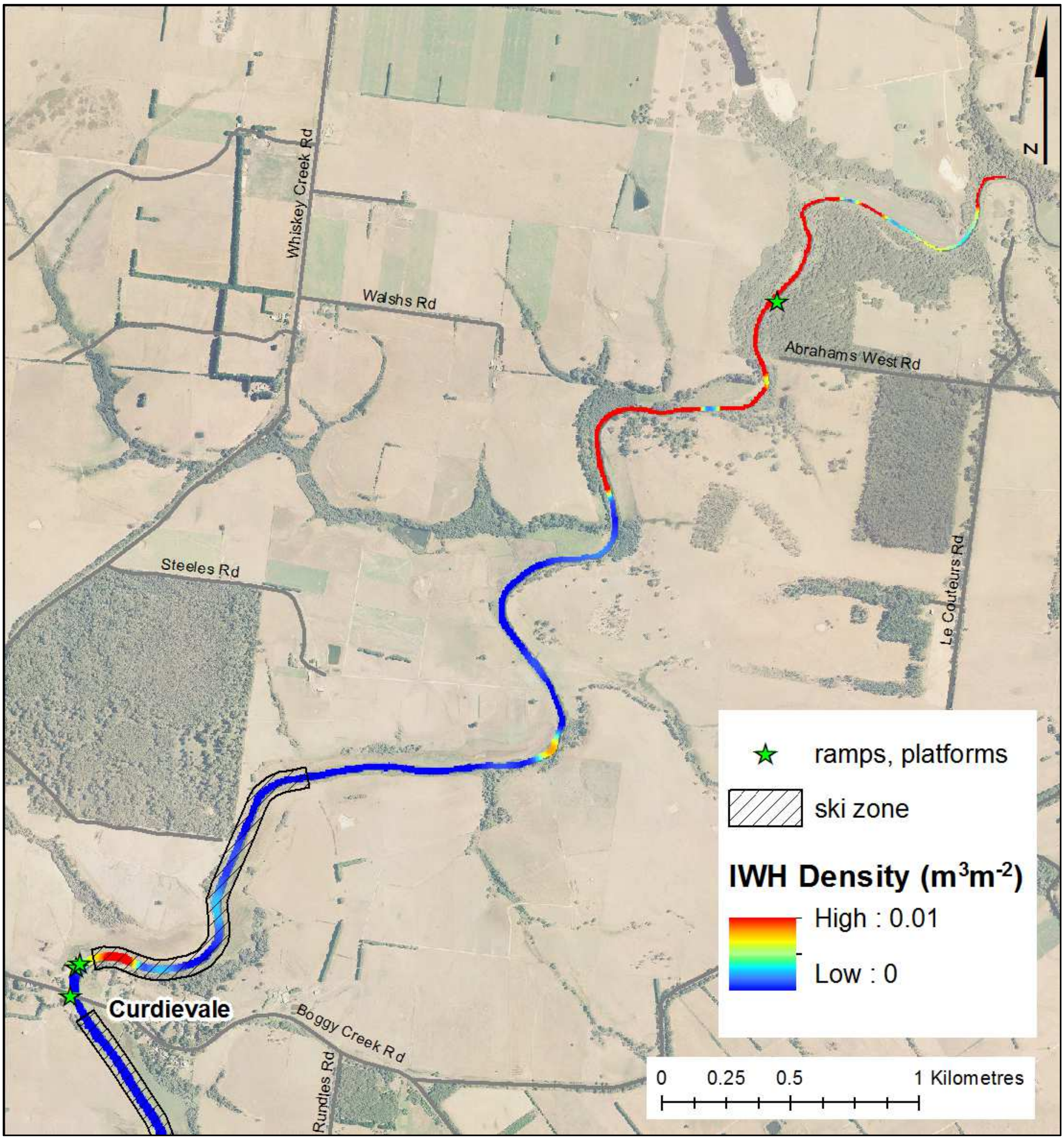


**Figure 5. Instream woody habitat (IWH) density ($m^3m^{-2}$) map of the Curdies Estuary upstream of Curdievale. Locations of boat ramps and platforms are denoted by green stars. The ski zone is denoted by diagonal black lines.**

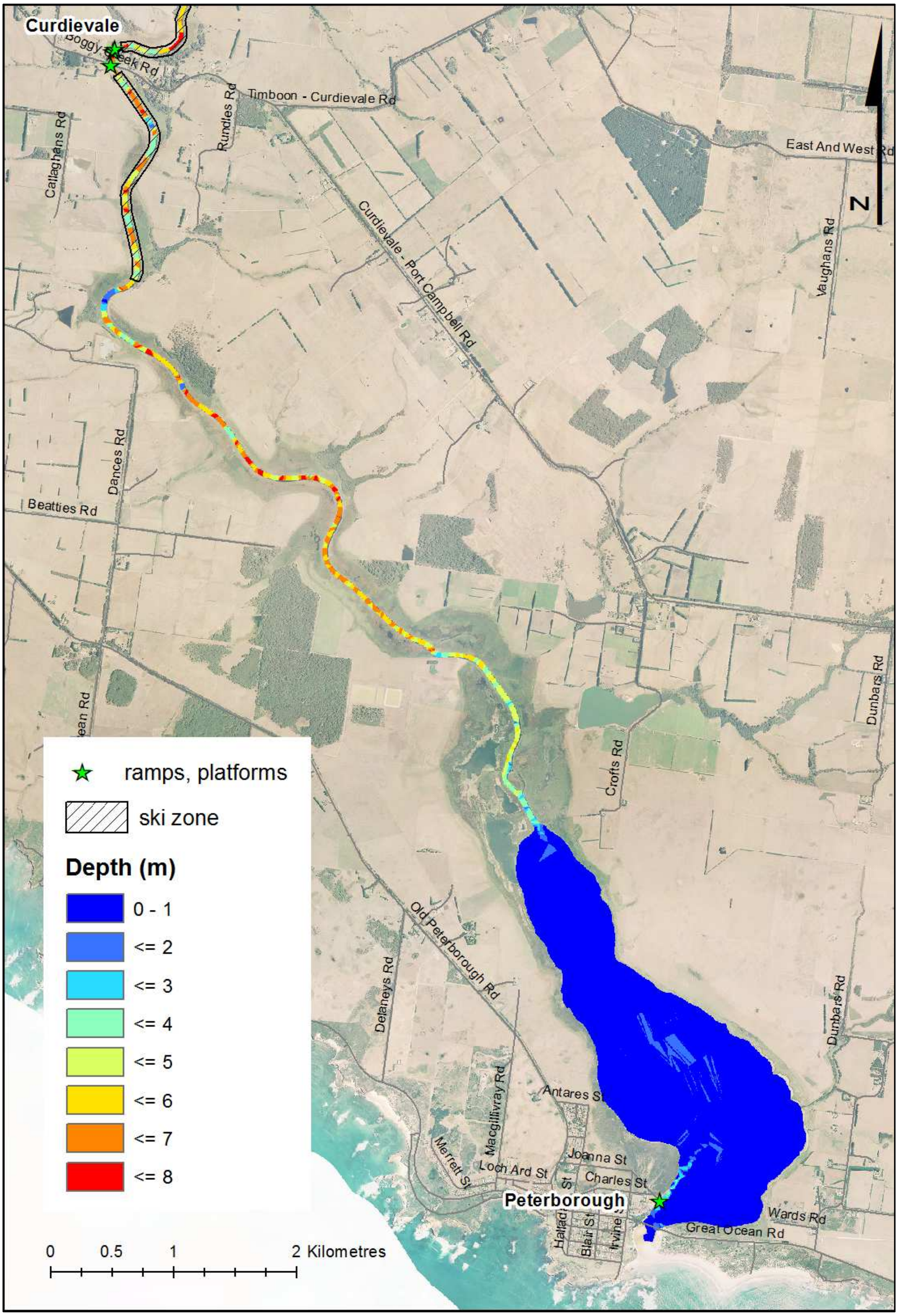


**Figure 6. Water depths (m) of the Curdies Estuary between Peterborough and Curdievale. Locations of boat ramps and platforms are denoted by green stars. The ski zone is denoted by diagonal black lines.**

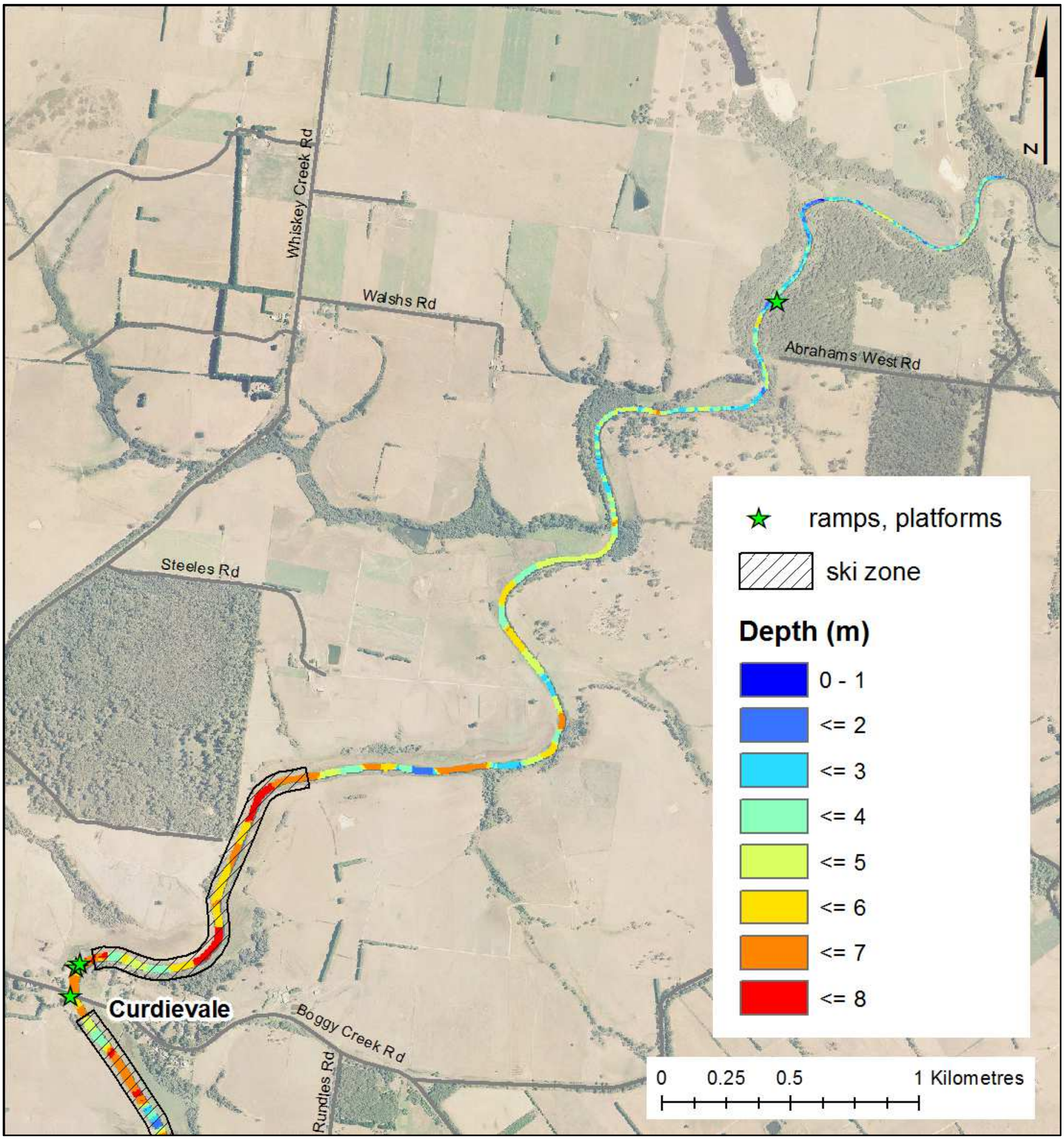


**Figure 7. Water depths (m) of the Curdies Estuary upstream of Curdievale. Locations of boat ramps and platforms are denoted by green stars. The ski zone is denoted by diagonal black lines.**

**Table 1. Summary of water quality measurements; Temp, temperature; EC, electrical conductivity; DO, dissolved oxygen. Locations correspond to Figure 3. Bold EC values indicate where surface water was relatively fresh.**

| Location | Water depth (m) | Temp (°C) | EC (mS/cm) | DO (mg/L) | pH | Turbidity (NTU) |
|---|---|---|---|---|---|---|
| 1 | 0.5 | 15.6 | 28.3 | 9.99 | 8.62 | 1.4 |
| | 1.0 | 15.4 | 28.0 | 10.24 | 8.63 | 1.5 |
| | 1.5 | 15.3 | 28.1 | 10.48 | 8.63 | 1.6 |
| | 2.0 | 15.2 | 28.5 | 10.22 | 8.63 | 2.7 |
| 2 | 0.5 | 14.6 | 22.1 | 9.61 | 8.27 | 2.2 |
| | 1.0 | 14.6 | 23.3 | 8.48 | 8.25 | - |
| 3 | 0.5 | 16.3 | 25.4 | 6.98 | 8.42 | 0.4 |
| | 1.0 | 15.6 | 27.0 | 6.45 | 8.41 | 0.3 |
| | 1.5 | 15.3 | 28.1 | 4.79 | 8.37 | 0.9 |
| 4 | 0.5 | 14.6 | **5.6** | 2.06 | 7.69 | 2.4 |
| | 1.0 | 15.6 | 27.5 | 7.30 | 8.13 | 0.4 |
| | 1.5 | 15.3 | 27.7 | 7.16 | 8.18 | 0.4 |
| | 2.0 | 15.6 | 28.1 | 3.42 | 7.99 | 0.7 |
| | 3.0 | 16.5 | 28.7 | 1.14 | 7.85 | 3.6 |
| | 4.0 | 16.8 | 29.0 | 1.00 | 7.84 | 4.3 |
| 5 | 0.5 | 14.9 | **3.3** | 11.84 | 7.91 | 5.1 |
| | 1.0 | 16.3 | 26.4 | 5.15 | 8.23 | 0.8 |
| | 1.5 | 16.2 | 27.7 | 5.09 | 8.23 | 0.6 |
| | 2.0 | 16.2 | 27.4 | 5.39 | 8.30 | 0.6 |
| | 3.0 | 16.2 | 27.9 | 4.40 | 8.24 | 1.0 |
| | 4.0 | 16.4 | 28.3 | 3.52 | 8.20 | 0.8 |
| 6 | 0.5 | 14.3 | **2.6** | 5.40 | 7.80 | 1.3 |
| | 1.0 | 15.5 | 25.8 | 7.71 | 7.73 | 1.8 |
| | 1.5 | 16.5 | 27.1 | 2.37 | 7.80 | 1.4 |
| | 2.0 | 16.8 | 27.7 | 2.69 | 7.89 | 1.2 |
| | 3.0 | 16.7 | 27.8 | 1.53 | 7.91 | 1.8 |
| 7 | 0.5 | 14.1 | **0.2** | 5.62 | 7.93 | 1.1 |
| | 1.0 | 14.7 | 21.9 | 0.61 | 7.71 | 6.8 |
| | 1.5 | 17.2 | 27.0 | 0.13 | 7.78 | 3.8 |
| | 2.0 | 17.6 | 27.0 | 0.07 | 7.77 | 4.3 |

# 4. Discussion

IWH removal has occurred historically in the Curdies River, including throughout the entire study reach (Camperdown Chronicle 1911). We found that IWH densities were variable in the Curdies Estuary. In general, relatively higher densities of IWH occurred in most upstream 3 km of the study reach. Figure 8 shows submerged instream woody habitat observed in this section of the study via the side scan sonar. Riparian vegetation in this reach included established woody trees and shrubs that likely contributed natural inputs of IWH (Figure 9). IWH densities were relatively low or absent from the estuary mouth to upstream of Curdievale. The Curdies Inlet is extremely wide (Figure 10) and thus, we expected to find IWH closer near the riparian zone rather than the middle of the inlet. The IWH located in Curdies Inlet appeared to be logs from an old platform extending from the east bank and also a snag near the top of Curdies Inlet which had possibly been transported from further upstream. These structures are not likely to provide significant shelter for fish. Upstream and downstream of Curdievale, there were isolated occurrences of low to medium IWH densities, including one instance where a large tree had recently fallen into the ski zone. The Curdies Inlet and the Curdies estuary to upstream of Curdievale are adjacent to farmland, lack woody trees and shrubs in riparian zones, and river banks are often impacted by stock access, thus the potential for natural IWH input is limited. Other instream habitat was observed in the Curdies Estuary that provide important habitat for fish, namely seagrass and rocky reef in the Curdies Inlet and rock substrates (Figure 11) in the reach upstream to Curdievale.

The range of IWH densities observed in the Curdies Estuary was low compared to data collected from other Victorian estuaries. Average IWH density in the Curdies Estuary was lower than that recorded in the Gellibrand Estuary (0.00007491 $m^3m^{-2}$; Ayres *et al.* 2014c), Anglesea Estuary (0.00024 $m^3m^{-2}$; Kitchingman *et al.* 2013b), Tarwin Estuary (0.000141 $m^3m^{-2}$; Ayres *et al.* 2014) and Merri Estuary (0.00022 $m^3m^{-2}$; Ayres *et al.* 2014b). The variation among estuaries may be attributed to differences in historical waterway management practices, catchment and landscape scale pressures, such as catchment clearing, flow extraction and impoundment (Lester and Boulton 2008), and characteristics of different bioregions (VRHS 2002). The Curdies, Gellibrand and Tarwin Estuaries were heavily desnagged in the late 1800s (The Argus 1891), while little information could be found about historical management practices in the Merri and Anglesea Estuaries. These estuarine IWH densities are much lower than IWH densities recorded in freshwater river reaches in Victoria (Kitchingman *et al.* submitted; Tonkin *et al.* submitted) where near-pristine IWH densities were on average 0.03 $m^3m^{-2}$ and current IWH densities were on average 0.01 $m^3m^{-2}$.

The availability and connectivity of IWH for fish in the Curdies Estuary could be improved by installing IWH in reaches where IWH densities were relatively low, particularly upstream and downstream of Curdievale in locations outside of the water ski zone. Water depths were relatively deeper in these sections, thus allowing opportunity for complex structures to be installed whilst maintaining a navigable river. These deeper sections of the Curdies Estuary are also likely to provide important refuge areas for fish during low water flows or low tide. Complex structures may consist of several logs, root balls or fish havens positioned collectively across multiple sites. The shallowness of Curdies Inlet means that it’s likely only suitable for single log installations, and even then, the process of installing structures may be too difficult. Rehabilitating and expanding the seagrass beds may be a more appropriate action to enhance instream habitat for fish in Curdies Inlet. Seagrass restoration projects have occurred elsewhere in Australia and overseas (Fonseca *et al.* 1988; Butler and Jernakoff 1999; Seddon 2004; BMT Oceanica 2013). Between Curdies Inlet and upstream of Curdievale, managing stock access and native replanting of riparian areas will also provide for longer term, natural inputs of IWH and help protect floodplain environments, which also are vital habitats for fish when inundated.

To enhance habitats to support sustainable fisheries resources, any installation or natural input of IWH would increase the availability of habitat for its fish community, as well as other water-dependent fauna, and is expected to provide other overarching ecosystem benefits. For example, instream habitat rehabilitation may also stabilise riverbanks and reduce flow intensity depending on the placement of such structures (Rutherfurd *et al.* 2000). Increases in IWH are expected to improve biofilm production which provides a food source for invertebrates that support fish populations (Rutherfurd *et al.* 2000). However, our knowledge of fish responses to IWH rehabilitation is limited. Monitoring is necessary to measure the response of fish communities to IWH additions and inform future actions following an adaptive management approach. Fish species and their life stages inhabiting the Curdies Estuary prefer and occupy different aquatic habitats (Drew 2008; Nicholson *et al.* 2009). IWH is a key habitat requirement for juvenile and adult Black Bream and Estuary Perch (Drew 2008; Nicholson *et al.* 2009; Douglas *et al.* 2010), which are popular recreational fish species in the Curdies Estuary. These estuarine species are expected to utilise IWH in estuaries for structural refuge and food resources, providing the IWH is accessible and partially or permanently submerged.

Other factors, in addition to current IWH densities and average water depth, that may need to be taken into account when installing IWH include:

- *Gaining permits and approval from appropriate government agencies.* Various management agencies have responsibilities for the Curdies Estuary and its surrounds (Nicholson *et al.* 2009). Whilst the Corangamite Catchment Management Authority manages the catchment and rivers, Parks Victoria, Moyne Shire and Transport Safety Victoria may have management responsibilities or interests relating to the Peterborough Coastal Reserve, local infrastructure and maritime safety. Government agencies need to agree with and approve the proposed activities before they can progress to the implementation phase.
- *Works access.* Heavy machinery is used to install IWH from the river bank or a barge. Areas with intact native riparian vegetation should be avoided to prevent damage. Barge access may also limit IWH placement.
- *Adjacent land tenure and land use.* Permission from landholders will be required if machinery access is via private property.
- *Local community input.* The community will have local knowledge of the area and their suggestions and support may influence the location of IWH installation. Nicholson *et al.* (2009) lists relevant stakeholder groups.
- *Waterway uses and user groups.* Waterways have a variety of values and are utilised for differing recreational and commercial activities. The Curdies Estuary is popular with recreational fishers, boaters, water-skiers, canoeists, kayakers, commercial fishers (eel fishery), local community members, beach-goers and tourists. The opinion and input from these groups is also important. For example, recreational fishers are increasingly aware that habitat is critical to support healthy, sustainable fisheries. Rather than installing habitat as fish attracting devices near popular angling locations, recreational fishers also support establishing quality habitat away from high fishing pressure to provide habitat for fish. Nicholson *et al.* (2009) lists relevant stakeholder groups.
- *Water flows.* Minimising movement of IWH installations by securing IWH installations to withstand extreme water velocity and positioning IWH in slow flow. Positioning of IWH within the channel width to ensure water coverage during low water flows or low and high tide.
- *Infrastructure.* Location of public and private infrastructure, such as bridges, jetties and boat ramps.

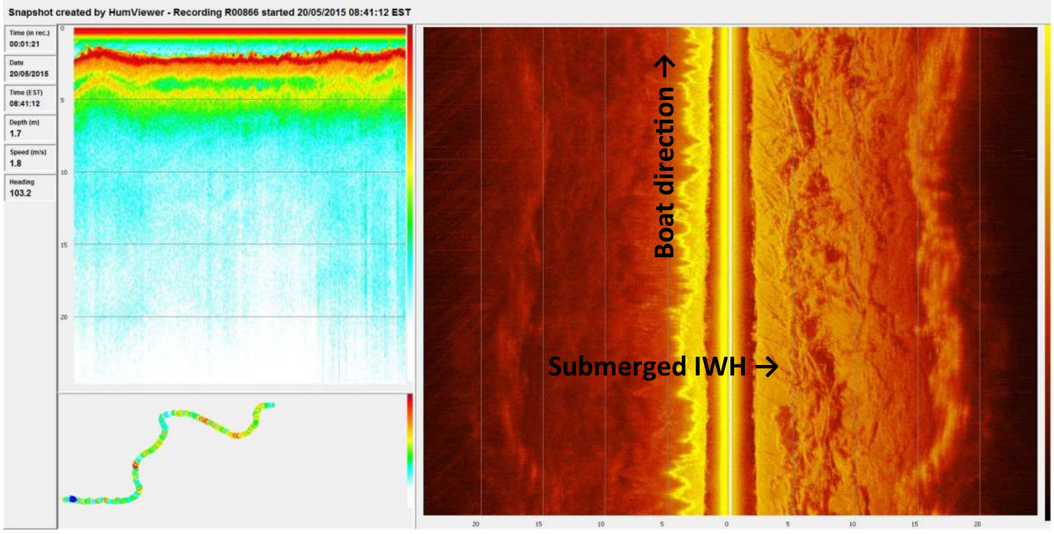


**Figure 8. Side scan sonar image of submerged instream woody habitat located upstream of Curdievale.**

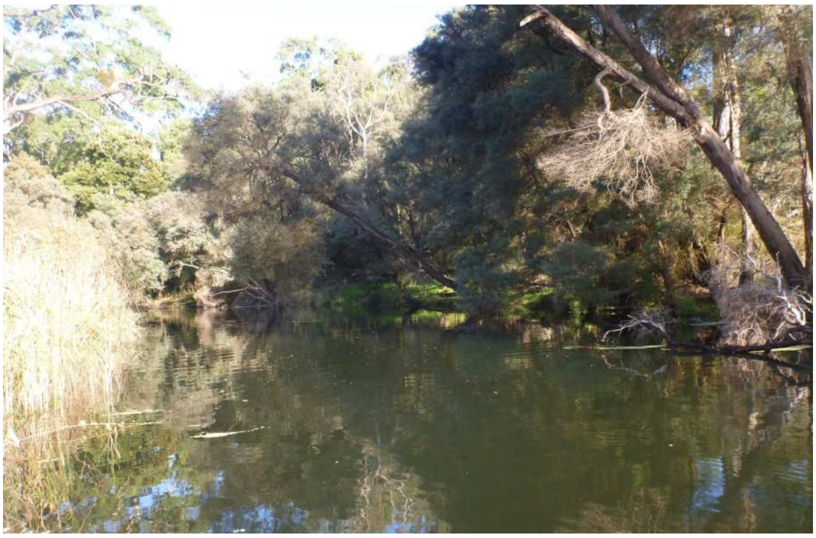

**Figure 9. Complex riparian vegetation in upper sections of the study reach.**

**Figure 10. The Curdies Inlet looking downstream towards the Great Ocean Road Bridge and Peterborough (Photograph: Renae Ayres).**

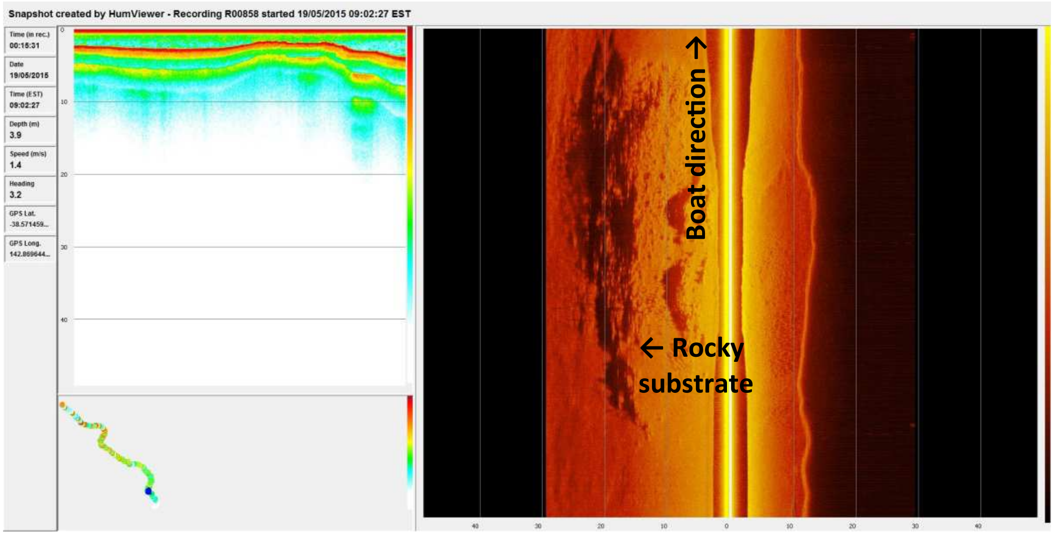


**Figure 11. Side scan sonar image of rock substrates located upstream of the top of Curdies Inlet.**

# 5. Recommendations

Our research of IWH in the Curdies Estuary indicated a lack of IWH, except for in the upper estuary. We recommend installation of IWH to improve fish habitat and increase fish abundances and the productivity of the Curdies Estuary fishery. These IWH installations may be best targeted in the reach upstream of Curdies Inlet to above Curdievale because this reach is likely a refuge area for fish in low water flows or low tides given its higher channel depth and width, and IWH installations here will help improve connectivity of instream habitats in the upper estuary to seagrass habitats in Curdies Inlet. This reach is also easily accessible to recreational fishers, with boat launching facilities available at Curdievale. Other factors should also be considered when selecting IWH installation locations, such infrastructure, machinery access, riparian vegetation condition, land tenure and community support. IWH installations would be best coupled with actions that improve riparian vegetation to encourage longer term, natural IWH inputs. We also recommend implementing a monitoring program to assess fish responses to IWH installations and inform an adaptive management approach.

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