

Evaluation of Aquatic Rehabilitation in the Bourke to Brewarrina Demonstration Reach, Barwon-Darling River, Australia

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NON-TECHNICAL SUMMARY

Evaluation of Aquatic Rehabilitation in the Bourke to Brewarrina Demonstration Reach, Barwon-Darling River, Australia

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NON-TECHNICAL SUMMARY:

Monitoring is most effective when it feeds back directly into management, making it responsive and adaptive. Without adaptive management and the acknowledgment of both successes and failures, rehabilitation science will fail to progress. Fundamental to this process is comprehensive and regular review of rehabilitation findings, not only to fine-tune monitoring and rehabilitation programs, but also to avoid perpetuating costly and ineffective rehabilitation practices that are based on untested assumptions, rather than being informed by an evidence-based approach.

Consistent with the adaptive approach to river rehabilitation, several ‘demonstration reaches’ have been established throughout the Murray-Darling Basin to showcase to the community the cumulative benefits of addressing multiple threats to native fish simultaneously through multi-faceted intervention programs. This may involve activities such as the provision for fish passage, riparian fencing and revegetation, re-snagging and alien species management. The Bourke to Brewarrina Demonstration Reach was established in 2006 as a partnership between the NSW Department of Primary Industries, the Western Catchment Management Authority and the Murray-Darling Basin Authority. Specific interventions undertaken in the reach include:

- Reintroduction of instream wood (re-snagging)
- Partial construction of a partial width rock ramp at Brewarrina Weir
- Carp musters
- Fencing of riparian areas to exclude stock and provision of off-channel water points
- Gully erosion works

This report marks a significant milestone for the implementation and evaluation of demonstration reaches in the Murray-Darling Basin. Being the most progressed monitoring program of all the Basin’s demonstration reaches, it is the first opportunity to scientifically evaluate ecological outcomes arising from the program. This evaluation is based on sound experimental design (incorporating controls, references and repeated sampling) and the explicit testing of hypotheses (Boys et al. 2009). Because of funding constraints, monitoring in the Bourke to Brewarrina Demonstration Reach focused on one of the multiple interventions (re-snagging) in combination with reach-scale condition monitoring. The explicit hypotheses surrounding this monitoring are outlined in Table 1 with a brief summary of the experimental design and methods used.

Table 1. Hypotheses explicitly tested in the Bourke to Brewarrina Demonstration Reach.

Hypothesised Response of Indicator	Methods	Chapter
Sub-reach re-snagging		
H1a: The abundance of Murray cod changed in re-snagging sites following re-snagging, suggesting a response to rehabilitation relative to the control and reference reaches.	Multiple-Before-After-Control-Impact (MBACI) design with additional reference reaches. Electrofishing surveys at ten re-snagging, control and reference reaches, two years prior to and two years after re-snagging.	4 & 8
H1b: The abundance of golden perch changed in re-snagging sites following re-snagging, suggesting a response to rehabilitation relative to the control and reference reaches.	As H1a.	4 & 8
H1c: 'Nativeness' (proportion of total native fish to alien fish) changed in re-snagging sites following re-snagging, suggesting a response to rehabilitation relative to the control and reference reaches.	As H1a.	4 & 8
H2a: Re-snagging resulted in a change in mean depth relative to reference and control sites, suggesting scour effects from large wood placement.	MBACI design with additional reference reaches. Bathymetric surveys at ten re-snagging, control and reference reaches, once prior to and once after re-snagging.	5 & 8
H2b: Re-snagging resulted in a change in the hydraulic character relative to reference and control sites, suggesting response to large wood placement.	MBACI design with additional reference reaches. Hydraulic surveys at ten re-snagging, control and reference reaches, once prior to and once after re-snagging.	5 & 8
General reach-scale condition monitoring		
H3a: Total species richness measured across the demonstration reach changed during rehabilitation activities, suggesting a response in the demonstration reach relative to the control reaches.	Two-Factor repeated measures analysis of variance (ANOVA), comparing annual change in the demonstration reach (30 replicate sites) across five years to changes occurring in two control reaches: Namoi River (7 replicate sites) and Gwydir River (7 replicate sites).	6 & 8
H3b: Native species richness measured across the demonstration reach changed during rehabilitation activities, suggesting a response in the demonstration reach relative to the control reaches.	As H3a.	6 & 8

H3c: Alien species richness measured across the demonstration reach changed during rehabilitation activities, suggesting a response in the demonstration reach relative to the control reaches.	As H3a.	6 & 8
H3d: Native fish abundance measured across the demonstration reach changed during rehabilitation activities, suggesting a response in the demonstration reach relative to the control reaches.	As H3a.	6 & 8
H3e: Alien fish abundance measured across the demonstration reach changed during rehabilitation activities, suggesting a response in the demonstration reach relative to the control reaches.	As H3a.	6 & 8
H3f: ‘Nativeness’ measured across the demonstration reach changed during rehabilitation activities, suggesting a response in the demonstration reach relative to the control reaches.	As H3a.	6 & 8

1.1. Effectiveness of re-snagging

Native fish such as golden perch and Murray cod are most frequently found in close proximity to large wood. Detailed mapping of large wood throughout the demonstration reach (Chapter 3) showed that in many parts of the reach (particularly at either end), this type of habitat is below the levels seen in upstream reference reaches. Based on these observations, it was predicted that by increasing large wood loading to reference (closer to natural) levels through re-snagging, subsequent improvements in the abundance of native fish such as golden perch and Murray cod would occur, potentially improving the proportion of native fish to alien fish (nativeness). Consequently, re-snagging was undertaken at multiple sites, with the level and location of re-snagging informed by the mapping activities. Hypotheses relating to the response of key native fish indicators were monitored using a modified MBACI design (Table 1).

Contrary to our predictions, there was no evidence that the abundance of golden perch or Murray cod, or ‘nativeness’ responded to re-snagging (Chapter 4). Although at times both golden perch and Murray cod were captured on snags within 12 months of their placement, across a suite of replicated re-snagging sites, there was not a consistent measurable response relative to natural background and inter-annual variability. There are a number of alternative explanations discussed in this report as to why a response was lacking (Chapter 8). It may be that re-snagging did not create the predicted changes in turbulence, scour and fill that are thought to increase habitat complexity and attract fish, a finding supported by geomorphic and hydraulic monitoring (Chapter 5). This may change with time and further hydraulic and bathymetric surveys are underway subsequent to two high-flow events that occurred in the reach after the re-snagging experiment ended. It may also be that site-based re-snagging (in this case in 300-m ‘pockets’) is insufficient in scale to impact native fish that can often be highly mobile.

Given that golden perch did not differ in abundance between reference, control and re-snagging reaches, and given that they are highly mobile (Chapter 7), it is not surprising that they did not

respond to re-snagging. Murray cod, in comparison, where at times recaptured within the same area as they were previously tagged (Chapter 7) and were found in significantly higher abundances in reference sites with larger loading of large wood. Despite this, re-snagging failed to produce a measurable response in the abundance of this species.

Results of the current study, when viewed alongside the largely variable reports of success in the literature, demonstrate that at the very least, the success of re-snagging can be context specific. Therefore, projects need to be evaluated where possible to identify successes and failures and better understand when and where alternative solutions to instream rehabilitation may be more appropriate.

1.2. Whole-of-demonstration reach responses

Demonstration reach-scale condition monitoring failed to detect a response in key fish assemblage indicators, which could be attributed to rehabilitation interventions (Table 1, Chapter 6 and 8). This is hardly surprising given the small scale of re-snagging (approximately 3 km treated in a 210 km reach) and lack of response to re-snagging, the sparse nature with which riparian and gully erosion measures were applied across the reach, a lack of interventions targeting carp, delays experienced in the construction of a fishway at Brewarrina Weir (an upstream barrier to fish passage) and the fact that there were insufficient resources to remediate fish passage at Bourke Weir, a significant barrier to upstream migration into the reach.

Changes in key fish indicators that did occur in the demonstration reach between years were clearly related to inter-annual differences in environmental disturbances rather than rehabilitation interventions (Chapter 6 and 8). For example, two successive floods in the summer of 2009/10 and 2010/11 resulted in the significant recruitment of juvenile carp into the demonstration reach in the latter years of monitoring. The 2010/11 flood was also followed by a blackwater event and significant native fish kill. This, combined with fish kills in previous years, is possibly related to repeated and severe epizootics of epizootic ulcerative syndrome (EUS) (Appendix 5), which undoubtedly contributed to lower native fish abundances in recent years.

Rehabilitation programs can fail to create or detect a biotic response when faced with large-scale disturbances such as drought or floods. Although it is highly unlikely that floods in the current study constrained rehabilitation responses in the Bourke to Brewarrina Demonstration Reach, the inter-annual variation created by large-scale environmental disturbances such as this can make it more difficult to test for significant treatment time interactions. This makes it difficult to discern rehabilitation responses from background environmental 'noise' within an MBACI design.

1.3. Implications for this and other demonstration reaches

In conclusion, after five years of monitoring (incorporating multiple years of pre-intervention monitoring) within a scientifically robust design, there was no evidence of eco-hydraulic response in relation to re-snagging or the general suite of interventions applied at the reach scale. A fundamental premise of demonstration reaches is being able to engage the community and demonstrate that systematically addressing multiple key threats to river health can have a positive impact on native fish. Critical to this is that improvements need to be measurable and monitored. Whether a failure to detect a response to activities in the Bourke to Brewarrina Demonstration Reach was related to an inability to apply interventions at a sufficient scale to induce a response or due to difficulties associated with detecting responses in a highly variable system, the findings highlight a critical need to take stock and revisit the demonstration reach concept. The findings contained within this report should not be viewed in isolation, but rather need to be critically examined alongside those of other demonstration reaches in the Basin as they emerge.

Applying the findings of this monitoring may be a challenge, since it was not explicitly stated from the outset what actions would be triggered by different outcomes. Do practitioners continue to monitor in expectation of lag effects? Do they intensify investment in an attempt to induce a larger measurable response? Or do they reconsider the feasibility of undertaking such a diverse rehabilitation program over such an ambitious spatial scale? Some recommendations are proposed for consideration. One of these is that monitoring be ceased, or temporally scaled back in the Bourke to Brewarrina Demonstration Reach, until such time that sufficient funding is obtained to undertake major works, with a likelihood of inducing a measurable response to native fish in the reach (for example, the Bourke Fishway). This report will be critical in ensuring that monitoring can be restarted at a later date without a loss of ‘institutional memory’.

It is recommended that researchers and managers involved in the Native Fish Strategy critically examine the findings presented in this report alongside the results from other demonstration reaches as they emerge. In light of these results and given that being able to ‘demonstrate’ a response is a critical part of the “demonstration reach”, it is necessary to objectively and critically debate whether the demonstration reach model is, in fact, the ‘best’ way to engage the community about native fish habitat rehabilitation. It is also recommended that as the results of monitoring programs from different demonstration reaches become available, scientists revisit the monitoring of Boys et al. (2009) so that monitoring approaches can be refined and improved.

Regardless of the future of the demonstration reach concept or individual demonstration reaches, one should not doubt the valuable contribution that they will make in stimulating debate and challenging some untested assumptions of rehabilitation practice within the Murray-Darling Basin. By doing so, they will undoubtedly inform the sound investment of natural resource managers in ongoing aquatic rehabilitation and improve how rehabilitation projects are monitored. Critical to this is ensuring that methods and findings are documented in reports such as this and made publically available.

KEYWORDS:

Native Fish Strategy, Murray cod, EUS, fish migration, river rehabilitation, re-snagging, large wood, habitat mapping

2. GENERAL INTRODUCTION

2.1. Background and need

The ecological ramifications of human activity in the dryland rivers of the Murray-Darling Basin are already evident. An extensive cyanobacteria bloom that affected over 1000 km of the Barwon-Darling River in 1991 (the world's largest blue-green algal bloom on record) was a likely consequence of water resource development and a clear sign of the deteriorating state of this river system (Bowling and Baker 1996). Within the Murray-Darling Basin, native fish populations are estimated to be approximately ten percent of pre-European settlement levels (MDBC 2003). This raises concerns over the current state and long-term survival of the fish assemblage. Sixteen of the 35 native fish species in the Basin are officially listed as threatened in either state or national legislation (Morris *et al.* 2001, MDBC 2003). In addition, a recent comprehensive survey of the fish fauna of this river failed to collect 33 per cent of the native fish species reported from the area, with many iconic species such as Murray cod (*Maccullochella peelii*), freshwater catfish (*Tandanus tandanus*) and silver perch showing evidence of declining abundance and distribution (Schiller *et al.* 1997, Gehrke and Harris 2004). Whilst native fish species have undergone reductions in both distribution and abundance, introduced species such as carp (*Cyprinus carpio*) and gambusia (*Gambusia holbrooki*) have become widespread, not only in the Barwon-Darling River, but also throughout much of the Murray-Darling Basin. Carp now contribute more than 90 per cent of the total fish biomass in many rivers in the Murray-Darling Basin (Faragher and Lintermans 1997) and are considered a major threat to the future of the Basin's native fish stocks (Koehn 2004).

The Barwon-Darling River is officially recognised as an endangered ecological community (NSWF 2003), and it has been acknowledged that under the current levels of development, fish populations cannot return to pre-European-settlement levels (Gehrke and Harris 2004). NSW DPI and the CRC for Freshwater Ecology, after a three-year study, published a report in 2005 titled 'Fish Habitat Assessment and Protection in the Barwon-Darling and Paroo Rivers' (Boys *et al.* 2005). The study established a set of principles for the rehabilitation of aquatic habitat and the protection of fish assemblages within these dryland rivers. The report highlighted the following areas of concern in the Barwon-Darling River:

- Low abundance of suitable instream habitat in some reaches
- Presence of numerous weirs that impede fish passage
- Prevalence of bank slumping
- Lower densities of riparian vegetation in some areas
- Dominance of alien species (especially carp)

A key recommendation of Boys *et al.* (2005) was that the stretch of river between the townships of Bourke and Brewarrina be used as a 'demonstration reach' to showcase to the community the cumulative benefits of undertaking a number of interventions (e.g. provision for fish passage, re-snagging, alien species management) for the rehabilitation of native fish habitat and populations. Along with other demonstration reaches being implemented throughout the Murray-Darling Basin, this semi-arid region demonstration reach gives a basin-wide context to restoring fish communities in inland NSW.

2.2. Bourke to Brewarrina Demonstration Reach activities

The Bourke to Brewarrina Demonstration Reach began in 2006 from an agreement between the Western CMA and NSW DPI. In subsequent years, the Murray-Darling Basin Authority became

involved in funding ongoing works. In the 210km of river between the townships of Bourke and Brewarrina, a number of on-ground rehabilitation works have been carried out under the scope of a multi-faceted demonstration reach approach (Barrett 2004). Such works involved:

- Reintroduction of instream wood (re-snagging) (complete)
- Construction of a partial width rock ramp at Brewarrina Weir (underway at time of publishing)
- Carp musters (complete)
- Fencing-off of riparian areas to stock and provide off-channel water points (complete)
- Gully erosion works (complete)

2.3. Interventions monitored

Rehabilitation scientists and practitioners mostly agree that some form of evaluation is essential to progressing rehabilitation practice (Bradshaw 1996, Hobbs and Norton 1996, Lake 2001, Giller 2005, Jansson *et al.* 2005, Palmer *et al.* 2005, Brooks and Lake 2007). Unfortunately, however, to date such monitoring and evaluation has been inconsistently applied (Downs and Kondolf 2002, Brooks and Lake 2007). As demonstration reaches become established in the Murray-Darling Basin, it is crucial that interventions are appraised in a sound manner, preferably within an adaptive rehabilitation framework. Without the proper appraisal of ecological outcomes, there is the risk of reducing the scientific credibility of and public support for aquatic rehabilitation as a way of facilitating the recovery of native fish populations in riverine systems. Hence, a framework was developed to guide the assessment of ecological response to multiple interventions (Boys *et al.* 2009).

In designing a monitoring program at the Bourke to Brewarrina Demonstration Reach, the key principals of the Boys *et al.* (2009) framework were adopted. Central to this was monitoring the condition of the reach as a whole (condition-based monitoring), as well as monitoring intervention-specific responses (intervention-based monitoring). To achieve this with sufficient scale, rigour and replication, it was acknowledged that not all interventions were suitable to monitor, and the limited available resources would have precluded this anyway. Therefore, the monitoring undertaken to date focused on:

1. The collective response to works via reach-scale **condition monitoring** of the fish assemblage
2. Providing the scientific basis to design a **re-snagging** program and monitoring eco-hydraulic responses to this intervention

2.4. Scope and structure of this report

Specific objectives of this report are:

1. Documenting the monitoring activities, sites and specific methodologies carried out within the demonstration reach (throughout document)
2. Providing a background review of the fish community and fish habitat of the reach (Chapter 2)
3. Mapping pre-existing in-channel large wood loading throughout the demonstration reach and developing reference benchmarks for large wood loading to guide the selection of priority sites and the level of re-snagging to be undertaken (Chapter 3)
4. Reporting on fish assemblage responses to re-snagging works (Chapter 4)
5. Reporting on hydraulic and geomorphological changes that have resulted from re-snagging activities (Chapter 5)
6. Reporting on the reach-scale condition monitoring of the fish assemblage carried out over five years (Chapter 6)
7. Outlining the demonstration reach tagging program and presenting preliminary findings (Chapter 7)
8. Synthesising the key results to date and making recommendations for future monitoring and evaluation activities within the context of this and other demonstration reaches (Chapter 8)
9. Reporting on other notable findings obtained during monitoring, including two internationally significant outbreaks of red spot disease (Appendix 5)

3. BACKGROUND INFORMATION ON FISH AND HABITAT

3.1. Geomorphology and hydrology

The Barwon-Darling River is one of Australia's larger dryland rivers, draining an area of 650,000 km² within the Murray-Darling Basin (Figure 1). The total length of the Barwon-Darling River from Mungindi to its confluence with the Murray River at Wentworth is 2740 km. Major tributaries of the Barwon-Darling River draining from the north include the Culgoa, Warrego and Paroo, and from the east, the Gwydir, Namoi and Macquarie Rivers.

The Barwon-Darling River is a 'wash-load' system with low gradient, high sinuosity, low stream power, highly cohesive river bank materials and an extensive floodplain (Thoms et al. 2004). Like many dryland rivers, the Barwon-Darling River is highly turbid and has high suspended sediment loads supplied from a sparsely vegetated semi-arid catchment (Olley and Caitcheon 2000). The river has a deeply-incised channel (Figure 2) and a relatively simple low-flow channel structure. Increased structural diversity occurs at higher stages within the channel, with the presence of in-channel benches, bars, flood runners and anabranches (Sheldon and Thoms 2004, Thoms *et al.* 2004, Thoms *et al.* 2005).

The main channel between Mungindi and Tilpa can be divided into four functional process zones, separated by the townships of Collarenebri, Brewarrina and Bourke (Figure 3). Identified from an extensive multivariate analyses of 800 river channel cross-sections, each zone has a distinct bankfull cross-section size, complexity, shape and downstream behaviour, thus producing characteristic stream powers and sediment yields for each zone (Thoms et al. 2004). For example, between Presbury Weir and Collarenebri, the bankfull cross-sectional area increases downstream. This is in contrast to the reach between Collarenebri and Brewarrina, where cross-section areas decrease downstream. Between Brewarrina and Bourke, and Bourke and Tilpa, the bankfull area remains relatively constant; however, the latter is 50 per cent larger than the former (Thoms et al. 2004).

The Barwon-Darling typifies a dryland river system, flowing through areas where semi-arid to arid conditions predominate (Thoms and Sheldon 2000). Being an allogenic river, it derives most of its tributary input from beyond the semi-arid zone in the relatively well-watered upper catchment. Given that there is a downstream reduction in tributary input and high rates of evaporative loss, there is a general downstream reduction of channel size (Thoms et al. 2004). Whilst the Barwon-Darling river is an unregulated upstream of the Menindee Lakes, there are a number of low-level weirs along its length to supply town water. The most notable of these weirs are located at the towns of Brewarrina, Bourke and Louth.

The Barwon-Darling river is hydrologically one of the most variable in the world (Puckridge et al. 1998) and although low flows predominate, these are punctuated by occasional floods that inundate anabranch channels, billabongs and extensive areas of the semi-arid floodplain. Discharge in the Barwon-Darling River has been reported to vary from 0 to 911 per cent of the long-term average (Walker 1986). Figure 4 shows the extreme hydrological variability of flows in the Barwon-Darling River, highlighting the predominance of low flows and rarity of floodplain inundation.

The regulation of rivers since European settlement has fundamentally changed the nature of flows within the Murray Darling Basin. This hydrological change has resulted from the construction of dams and weirs (river regulation), the extraction of water (water resource development) and the construction of flood mitigation structures on the floodplain (e.g. levees and dykes). These actions have affected both flow and flood pulses in the Barwon-Darling River System, resulting in a

change in the frequency, duration and size of flows, including: median daily flow reductions of up to 73 per cent; increases in the occurrence of low flows by 210 per cent; and decreases in the occurrence of high flows by 60 per cent (Thoms and Sheldon 2000).

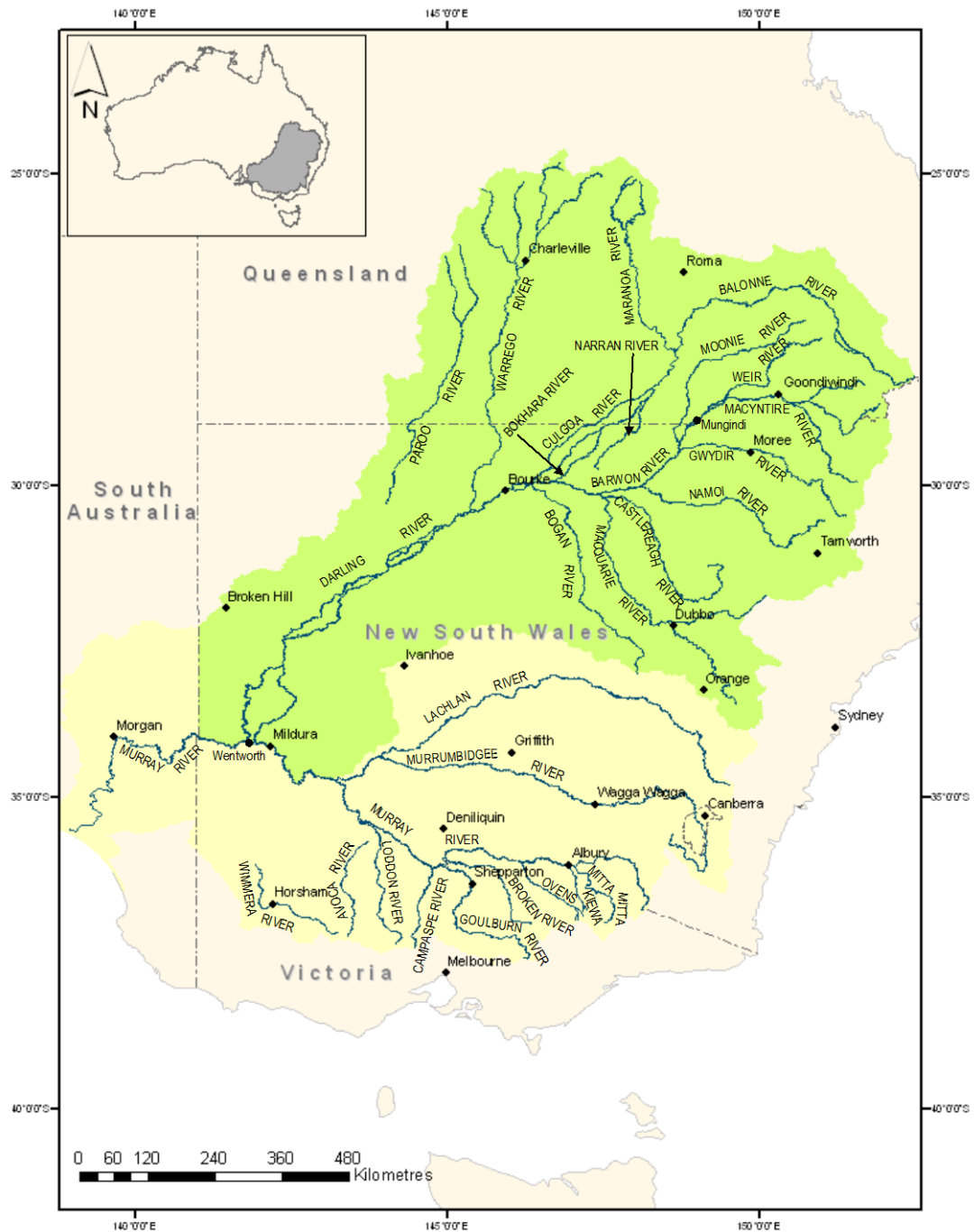


Figure 1. Murray-Darling Basin showing the Barwon-Darling River system (green) and the Murray River system (yellow).



Figure 2. The Barwon-Darling River between Bourke and Brewarrina. This photo shows the river corridor restricted to the lower stages of a deeply-incised channel.

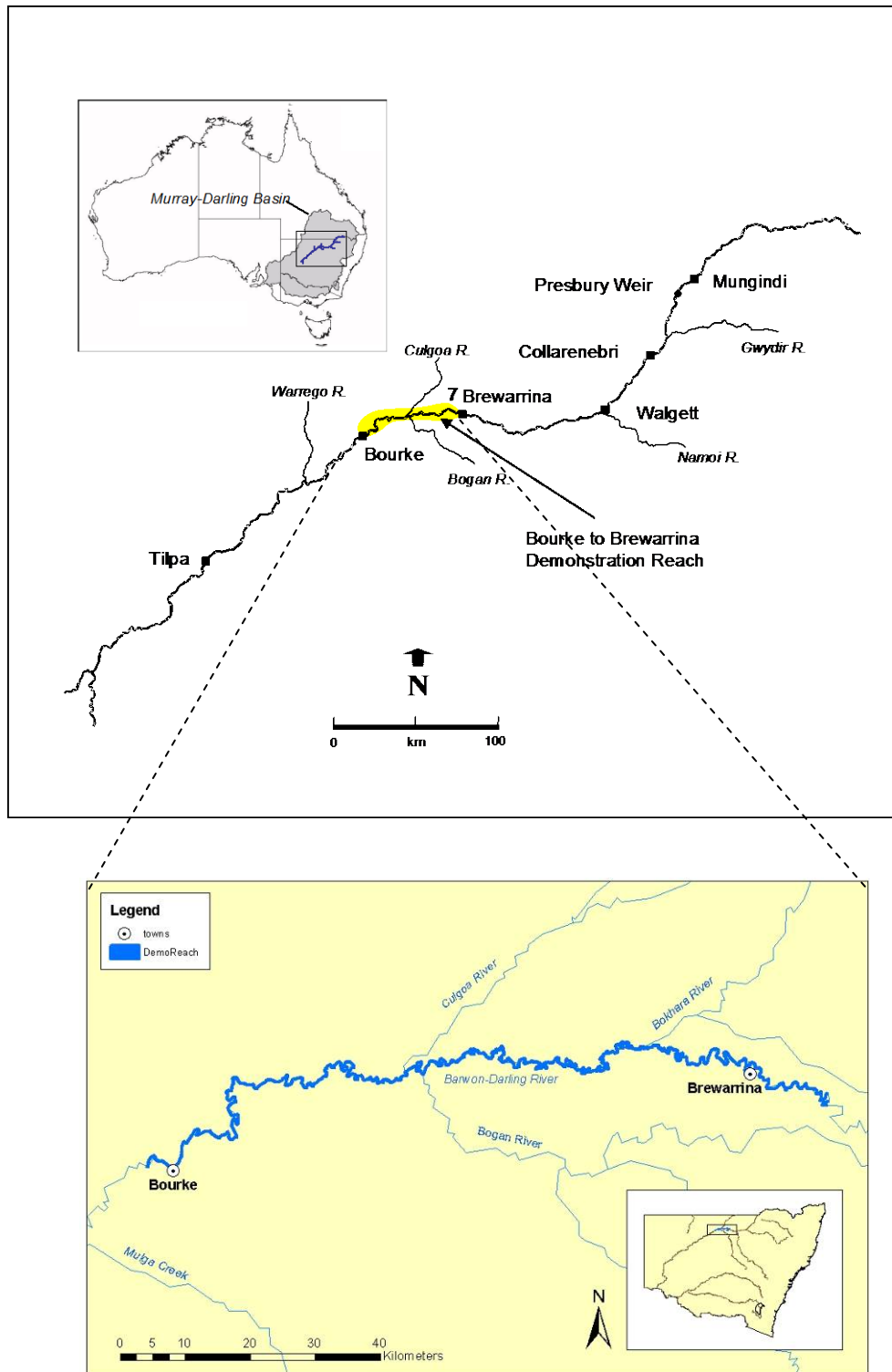


Figure 3. Barwon-Darling River showing major towns and tributaries and the location of the demonstration reach.

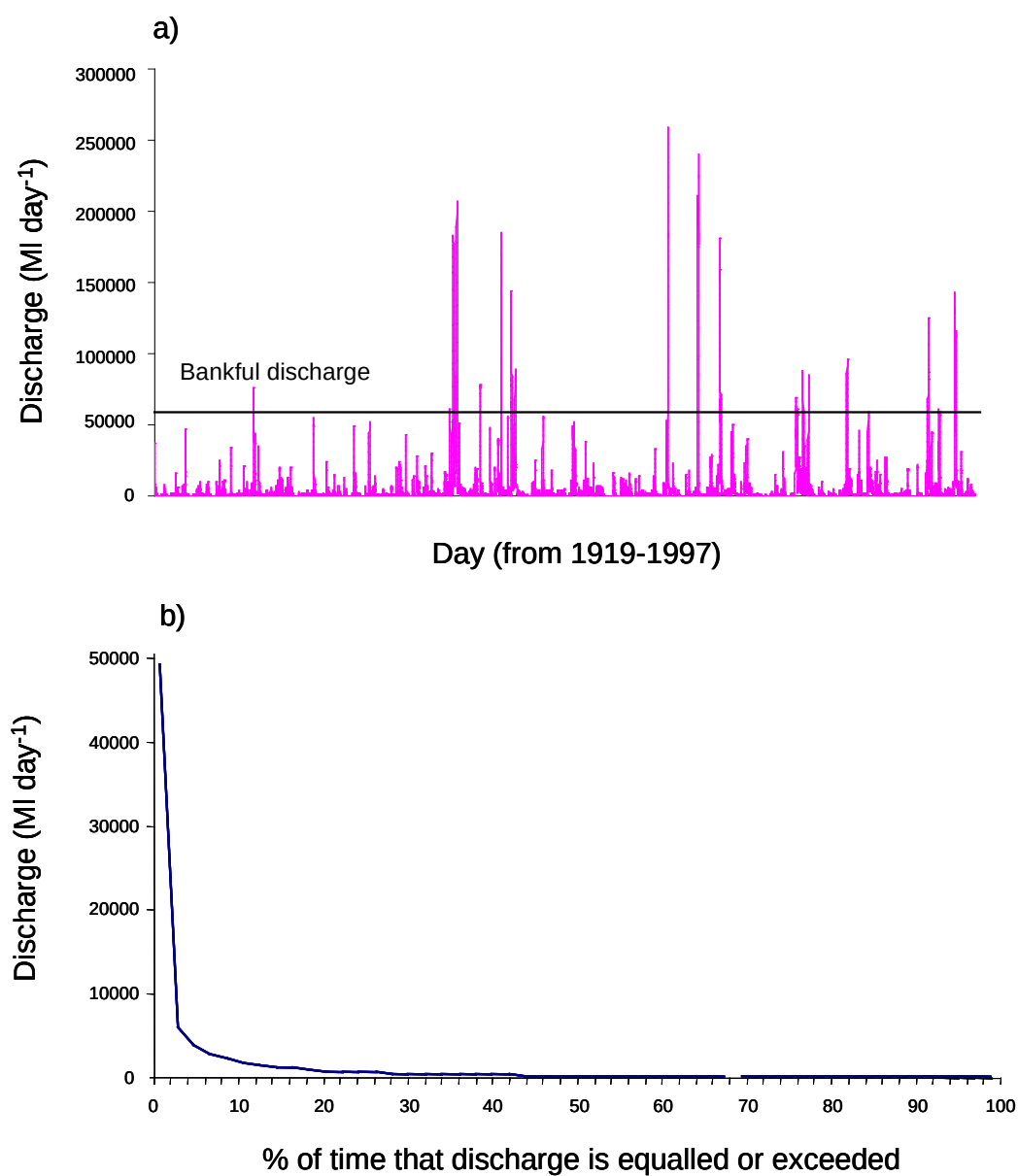


Figure 4A. Hydrograph of the Barwon-Darling River at Walgett (Dangar Bridge Gauging Station – No. 422001) for the period of 1919-1997. Note: data are modelled under current water resource development conditions. Data source: QLD DNR IQQM.

Figure 4B. Flow duration curve based on daily discharge at the Dangar Bridge Gauging Station. Data source: NSW OFFICE OF WATER.

3.2. Fish assemblage

Thirty species of fish inhabit the Barwon-Darling River system (Gehrke and Harris 2004). Of these, only 12 native and three introduced species can be expected to occur between Bourke and Brewarrina (Table 2). This list was compiled at the start of the demonstration reach project by reviewing current species distributions using historic and current fisheries data. The records were collected between 1993 and 2005 from the New South Wales Department of Primary Industries Freshwater Fish Database (NSW DPI 2012) as well as Australian Museum records (cited in Morris et al. 2001).

Table 2. Fish species expected to occur in the Bourke to Brewarrina demonstration reach, including notes on their likely occurrence and distribution (Source: Boys 2007)

Common Name	Scientific Name	Likely Occurrence and Distribution
Native		
Australian smelt	<i>Retropinna semoni</i>	Common; widespread
Bony herring	<i>Nematalosa erebi</i>	Common; widespread
Murray-Darling rainbowfish	<i>Melanotaenia fluviatilis</i>	Common; more likely in upper reaches
Un-specked hardyhead	<i>Craterocephalus stercusmuscarum</i>	Rare; isolated and patchy distribution upstream of Bourke
Freshwater catfish	<i>Tandanus tandanus</i>	Likely; patchy distribution
Golden perch	<i>Macquaria ambigua</i>	Common; widespread
Lakes carp gudgeon Midgley's carp gudgeon Western carp gudgeon	<i>Hypseleotris</i> spp.	Likely; widespread
Murray cod	<i>Maccullochella peelii</i>	Common; widespread
Silver perch	<i>Bidyanus bidyanus</i>	Rare; isolated and patchy distribution
Spangled perch	<i>Leiopotherapon unicolor</i>	Common; more likely in upper reaches
Introduced		
Carp	<i>Cyprinus carpio</i>	Common; widespread
Gambusia	<i>Gambusia holbrooki</i>	Common; widespread
Goldfish	<i>Carassius auratus</i>	Common; widespread

3.3. In-channel fish habitat

During low flow conditions, a small variety of habitats are available to fish. A recent assessment of fish-habitat associations in the Barwon-Darling River identified a total of six discrete low flow, mesohabitat types nested within reaches (Boys *et al.* 2005, Boys and Thoms 2006) (Table 3): large wood; three edgewater features: smooth bank, irregular bank and matted bank; and two open water features: mid-channel and deep pools. Riffle sections are absent from most of the Barwon-Darling River and Bourke to Brewarrina Demonstration Reach, although the depth does fluctuate between deeper pools on the outside of meanders and long constant depth sections of open water.

Table 3. Description of meso-scale fish habitats in the demonstration reach during low flow conditions

In-channel Features	Description
Large wood	Whole trees, branches and root masses (Stevens 1997), no longer rooted to the ground but may still be living (Gurnell <i>et al.</i> 2000), minimum dimensions of 1m in length and 0.1m in diameter (Gippel <i>et al.</i> 1996a, Marsh <i>et al.</i> 1999). Traditionally referred to in the literature as coarse or large woody debris.
Mid-channel	Middle of channel; slow-moderate velocities; moderate depth (1-3m); no hydraulic refuge or structural complexity.
Deep pool	Discrete portion of the mid-channel with increased depth (3-6m) relative to remainder of the channel; slow velocities; typically associated with channel scour on meander bends.
Matted bank	Bank with exposed roots of riparian trees; typically associated with irregular/erosional banks; instream cover provided by roots; undercut banks may also be present due to uneven erosion; shallow (<1m); slow velocity.
Irregular bank	Bank with a roughed bank-water interface due to irregular erosion of bank or underlying bed rock; shallow (<1m); some cover provided by uneven surface.
Smooth bank	Smooth bank-water interface; low relief; shallow (<1m); slow velocity; primarily fines or sand substrate; often associated with bars.

During the low flows, which predominate for the majority of time in the demonstration reach, fish typically display non-random use of habitat (Boys *et al.* 2005, Boys and Thoms 2006, Boys 2007). Golden perch and Murray cod are strongly associated with large wood, whereas there is only a weak association between bony herring and large wood. Whilst golden perch and Murray cod are large wood specialists, rarely found associated with other habitats, carp are more general in their use of habitats. Bony herring are strongly associated with smooth and irregular banks but are also ubiquitous in most habitats. Open water (mid-channel and deep pool) habitats are characterised by relatively low abundances of all species and a particularly weak association with golden perch, Murray cod and carp.

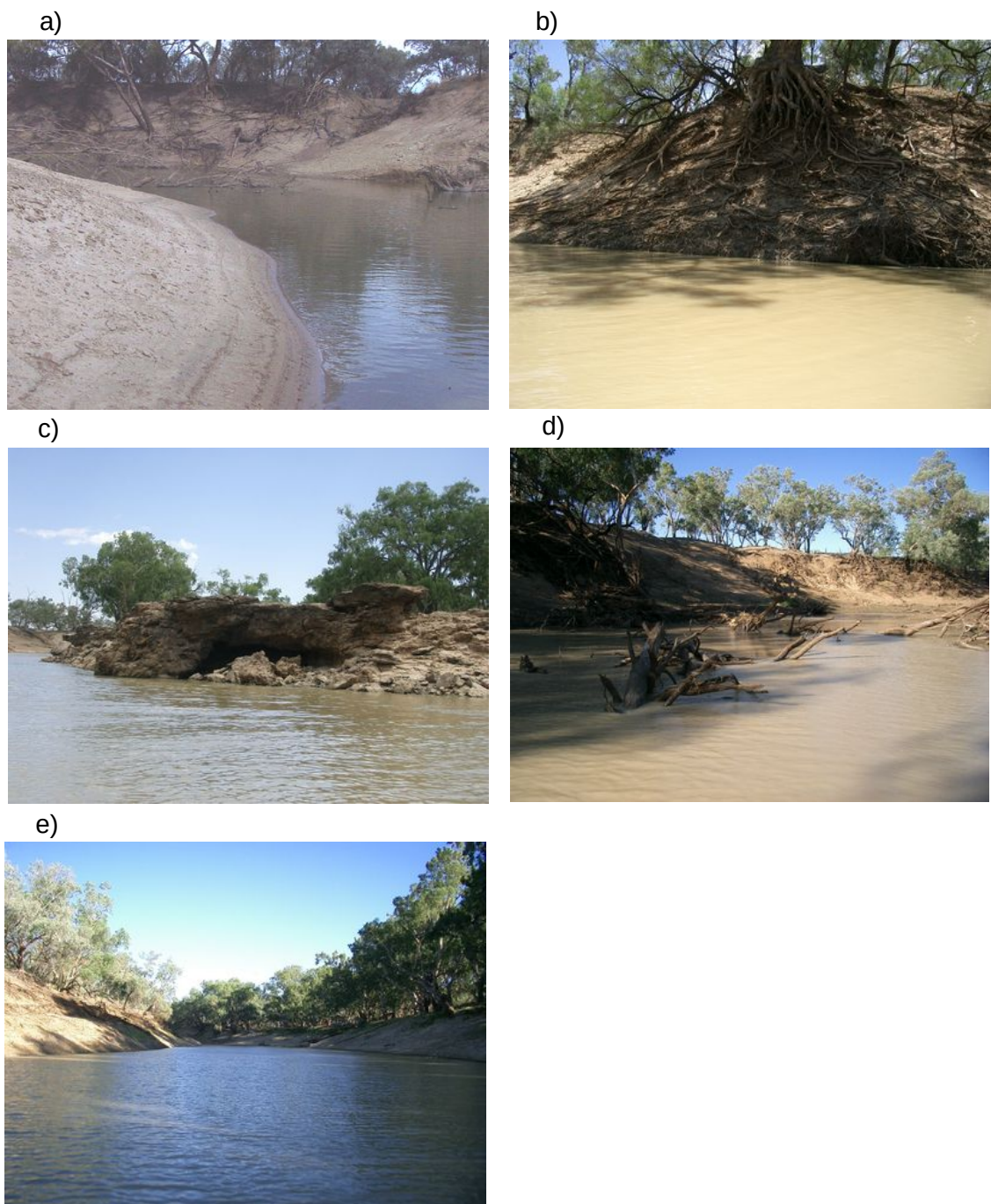


Figure 5. In-channel mesohabitat units available to fish in the Bourke to Brewarrina demonstration reach during predominating low flow conditions: a) smooth bank b) matted bank c) irregular bank d) large wood e) open water habitat, either mid-channel or deep pool.

4. LARGE WOOD MAPPING TO INFORM RE-SNAGGING

4.1. Objectives

1. To precisely map in-channel large wood within the demonstration reach
2. To use hydrological modelling to obtain an accurate indication of the availability of large wood under different flows and therefore through time
3. To determine appropriate re-snagging targets based on river-scale benchmarks
4. To use re-snagging targets to identify potential re-snagging, control and reference sites to the re-snagging experiment (Chapter 4 and 5)

4.2. Methods

4.2.1. Large wood surveys

The location of pieces and piles of large wood, along with a number of attributes relating to their size and structural complexity, were recorded by two technicians by boat or by foot when the river level was too low to navigate by boat. Preliminary results from the Murray River suggest that larger fish counts are associated with large wood, which is more structurally complex (Hughes *et al.* 2007). In the Barwon-Darling River, it has been found that larger numbers of golden perch and carp were associated with large wood with the largest size/complexity scores (Thiem 2002). Based on these observations, there is an ecological basis for differentiating large wood based on size and complexity. Therefore, size and complexity attributes were measured, although these attributes are not considered further in this report. The size and complexity classes used were the same ones used by Hughes (2001) on the Murray River and Thiem (2002) and Boys (2007) on the Barwon-Darling River. The length and breadth of large wood pieces or piles were estimated by sight and placed into one of four classes: 0-10m, 10-20m, 20-30m and 30-40m. The product of length and breadth gave the planform area of the large wood piece or pile. Large wood was also assigned to one of four structural complexity classes (Table 4). All large wood spatial and attribute data was recorded on a Toughbook® laptop computer using the ArcPad software package linked to a GPS. Surveys were completed between October 2006 and July and September 2008.

4.2.2. Hydrological modelling of large wood availability

Due to the Barwon-Darling River's deeply incised channel and variable flows, it was essential to determine the availability of large wood under the full range of flow scenarios. Availability at different flows was determined using the commence-to-inundate (CTI) height of all large wood within the reach, which is defined as the channel height (measured to the nearest 0.1m) at which approximately 50 per cent of the large wood structure becomes inundated by river flows. CTI height was measured for each large wood structure using a Haglof Vertex Laser® VL400 hypsometer. It uses ultrasonic signals to obtain the range of the large wood from the instrument and combines this with the angle of measurement obtained from a tilt sensor to trigonometrically calculate the height of the structure above the instrument eye level. Simple conversions are then applied to calculate the CTI height, with the methods slightly differing depending on whether the height was measured from the water level in a boat, from the bottom of the channel or from the top of the bank (Figure 6 and Figure 7). All surveys were conducted when a large proportion of the reach was dry, therefore maximising the potential to map all large wood.

The conversion of CTI heights collected in the field into a measure of availability was a multiple-stage process. Firstly, the CTI height for each large wood piece was converted to a CTI discharge

(Ml day^{-1}) using rating tables that depicted the nearest gauging station within the reach. It was assumed that the flow data obtained from the nearest gauging station was representative of flows in the mapped section because both locations are within a functional process zone with very similar bankfull cross-section and bed slopes (Thoms in press). CTI discharge was then converted into a measure of inundation using flow duration curves, giving a value of the percentage of time that the CTI discharge was equalled or exceeded. Each large wood piece or pile was then assigned to one of two availability groups based on the duration of its inundation. Those pieces that inundate at low flows, which persist for 90 per cent of the time, were classified as 'low-flow available', since they are available to fish under low-flow conditions that predominate for 90 per cent of the time. Those pieces that inundate at higher flows, which persist for less than 10 per cent of the time, were classified as 'high-flow recruitable', since they are only available to fish during rarer events of elevated flow. Large wood in this region also has the potential to recruit into the low-flow channel when realigned by large flow pulses.

Table 4. Structural complexity classes used to describe large wood (Hughes 2001)

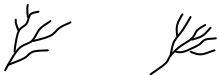
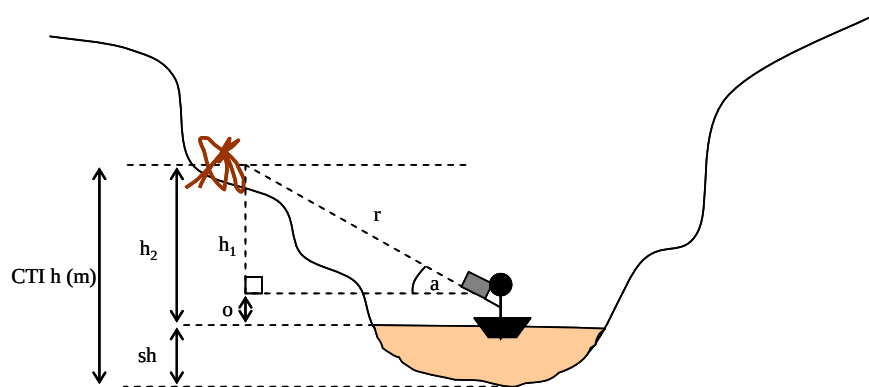
Description	Examples	Class
A single trunk or branch: a root mass or small part of a branch may be present.		1
Double trunk or branch or single trunk with one level of branching for most of the length.		2
Trunk with multiple branches for most of length, with 2 nd level of branching present.		3
Complete tree with extensive branching or an accumulation of large wood in which individual pieces cannot be resolved.		4



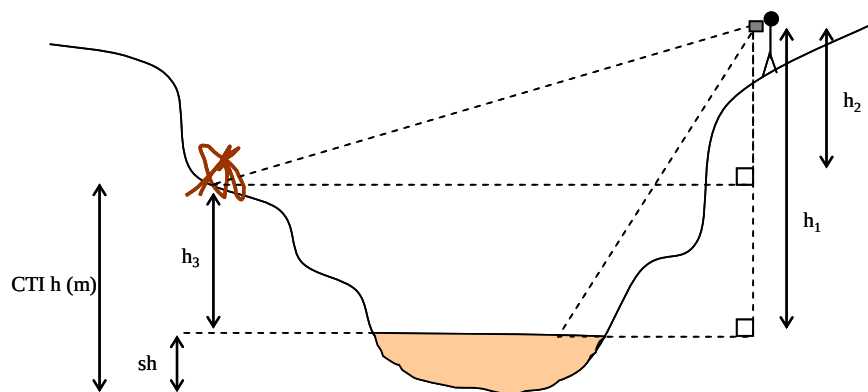
Figure 6. Mapping large wood in the Bourke to Brewarrina demonstration reach during extreme low flow conditions.

4.2.3. Reporting on large wood loading and establishing benchmarks for rehabilitation

The demonstration reach was divided into 207 one-kilometre segments (Figures 8-10) and large wood loading was analysed at this scale. An essential step to effective rehabilitation is to develop clear targets. Often these targets are based on returning a system to a pre-development state or reference condition. If detailed historical records of a perturbation have been kept, these reference benchmarks can be easily identified. For example, solid data exists on the number of large wood structures removed from the Murray River over the last century. However, no such records exist for the Darling, although one can assume that most of the historical de-snagging only extended as far upstream as the paddle steamers serviced. Based on this, it was assumed that sections of the river upstream of Brewarrina will reflect conditions close to the natural or reference state for the Barwon-Darling River. Therefore, to establish benchmarks on which to base rehabilitation targets, large wood loading was averaged (per kilometre) for 60 km of randomly selected river channel between Brewarrina and Mungindi (using data from Boys 2007). Reference benchmarks were established for ‘low-flow available’ loading as well as total within-channel loading, with 95 per cent confidence intervals associated with these means also calculated.



A Haglof Vertex Laser VL400 hypsometer was used to determine the commence to inundate height (CTI h) of each large wood structure, measured from a boat. The hypsometer uses ultrasonic signals to obtain the range of the large wood from the instrument (r) and combines this with the angle of measurement obtained from a tilt sensor (a) to trigonometrically calculate the height of the structure above the instrument eye level (h_1). A preset offset of the height of the instrument above water level (o) is automatically added to h_1 to obtain the height of large wood above the water level (h_2). Accuracy of ± 0.1 vertical metres is obtainable for objects less than 100 metres away. The stage height (sh) of the river on the survey day was obtained from the nearest gauging station and added to h_2 to obtain the final inundation height of the large wood.



Measuring commence to inundate height (CTI h) of each large wood structure by foot from the top of the bank was a three step process. Firstly the hypsometer was used to determine the height of the instrument above the water level (h_1). Secondly the vertical height of the large wood structure below the instrument level was measured (h_2), with $h_3 = h_1 - h_2$. The stage height (sh) of the river on the survey day was obtained from the nearest gauging station and added to h_3 to obtain the final inundation height (CTI h) of the large wood.

Figure 7. Methods used to survey commence to inundation heights of large wood structures from a boat and from the top of the bank.

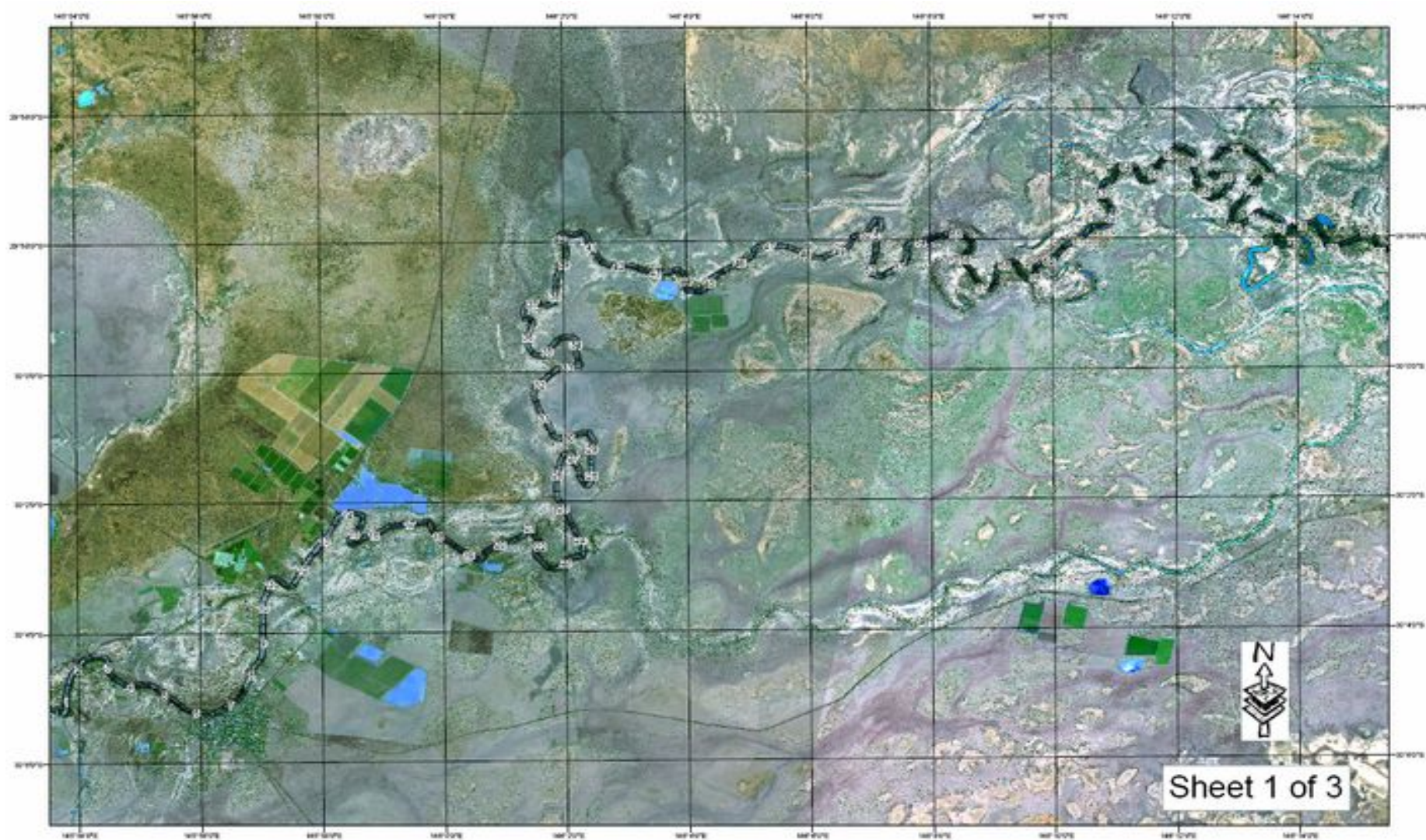


Figure 8. One-kilometre river segments at which large wood loading was analysed (Map 1 of 3). Segment 1 starts at Bourke Weir.

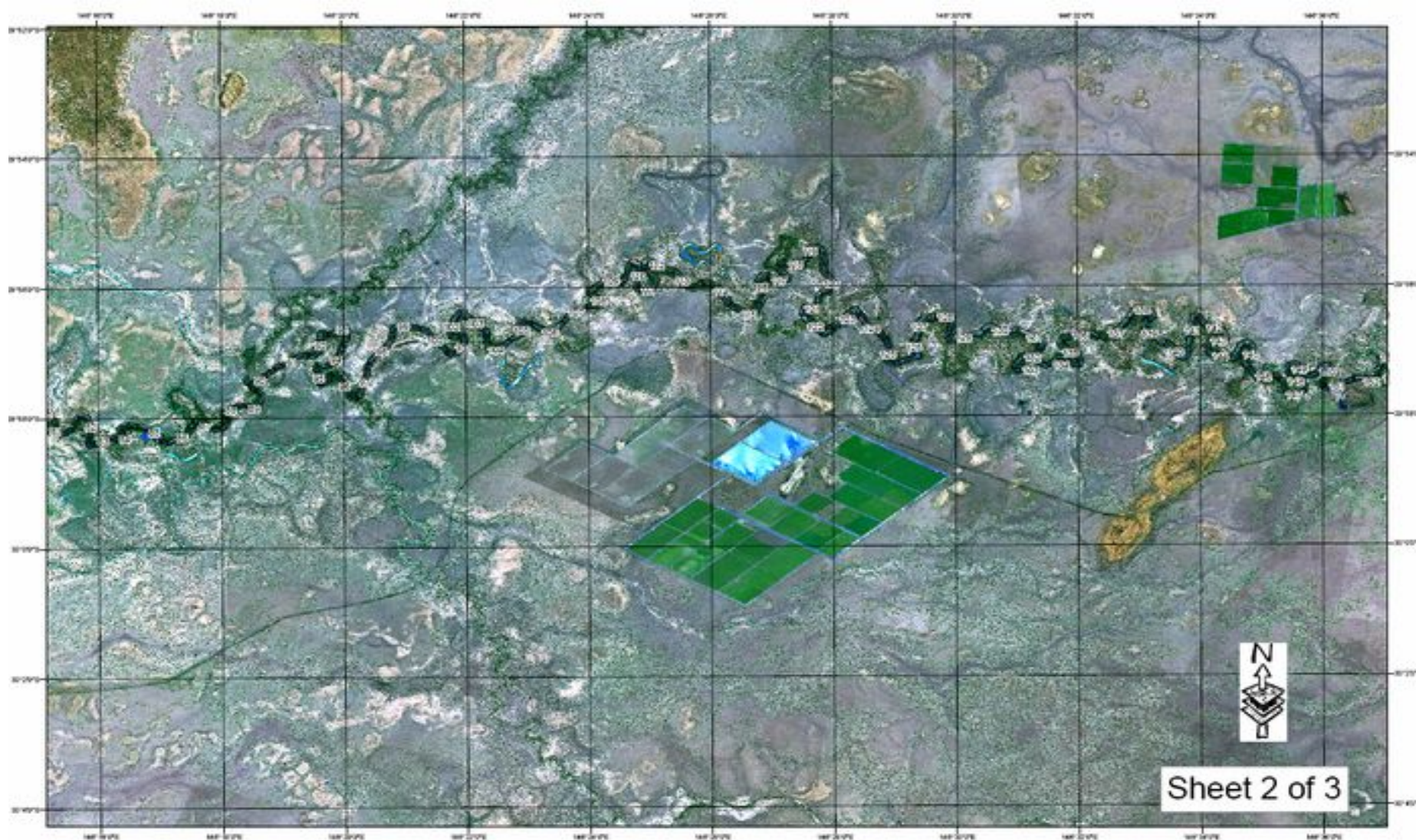


Figure 9. One-kilometre river segments at which large wood loading was analysed (Map 2 of 3).

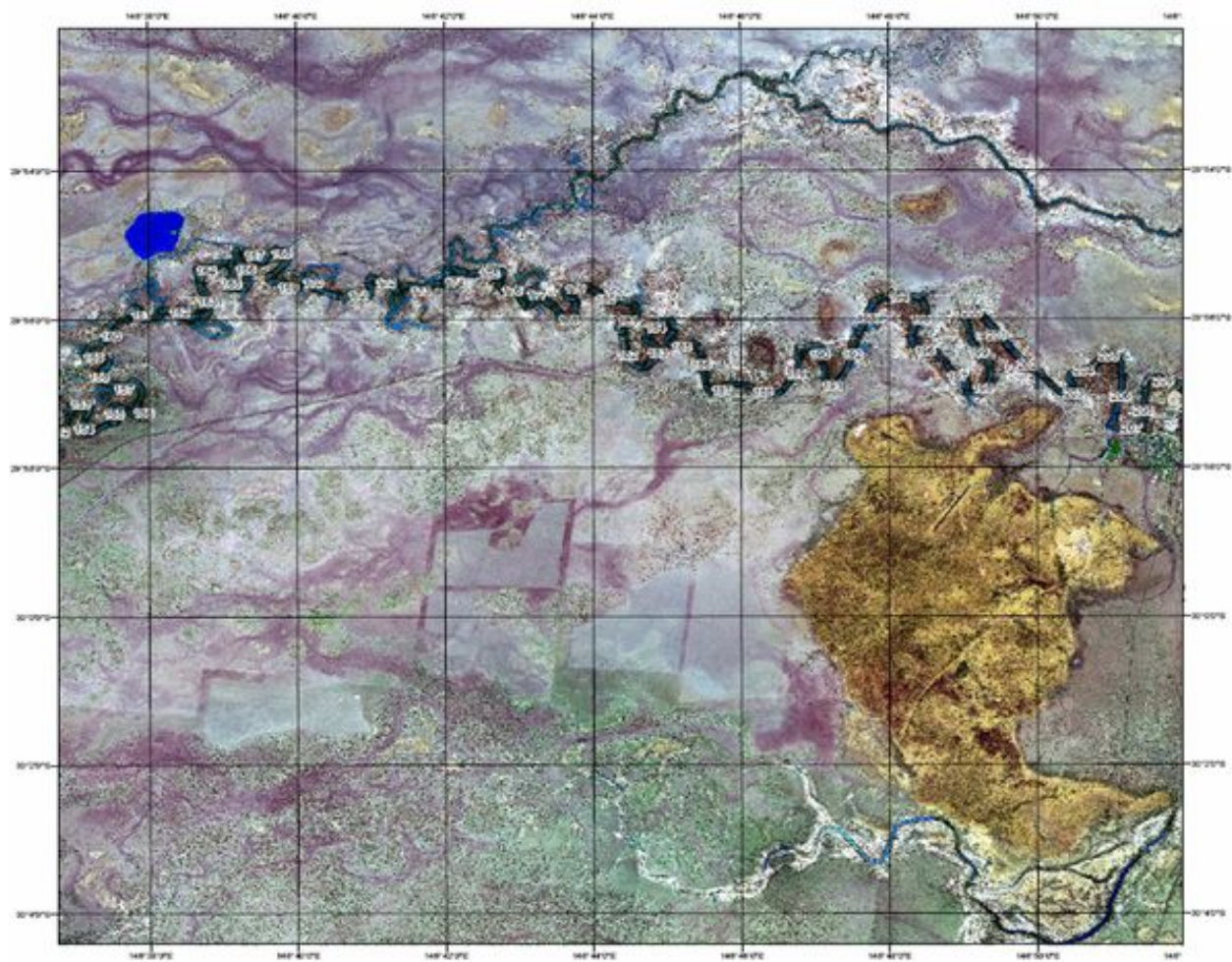


Figure 10. One-kilometre river segments at which large wood loading was analysed (Map 3 of 3). Reach 207 ends at Brewarrina Weir.

4.3. Results

4.3.1. Hydrological modelling of large wood availability

In the 207 km of river channel that were mapped, a total of 7295 individual large wood structures or piles were recorded. Hydrological modelling using CTI heights and flow duration data indicates that most of this large wood remains un-inundated and therefore unavailable as fish habitat for most of the time (Figure 11). For 90 per cent of the time, only 10 per cent of the large wood habitat is available to fish. The other 90 per cent of the structures serves as a temporary high flow habitat or a source for future recruitment into the low-flow channel. This inundation profile reflects both the predominance of large wood pieces at higher levels within the deeply incised channel, as well as a predominance of low-flow conditions.

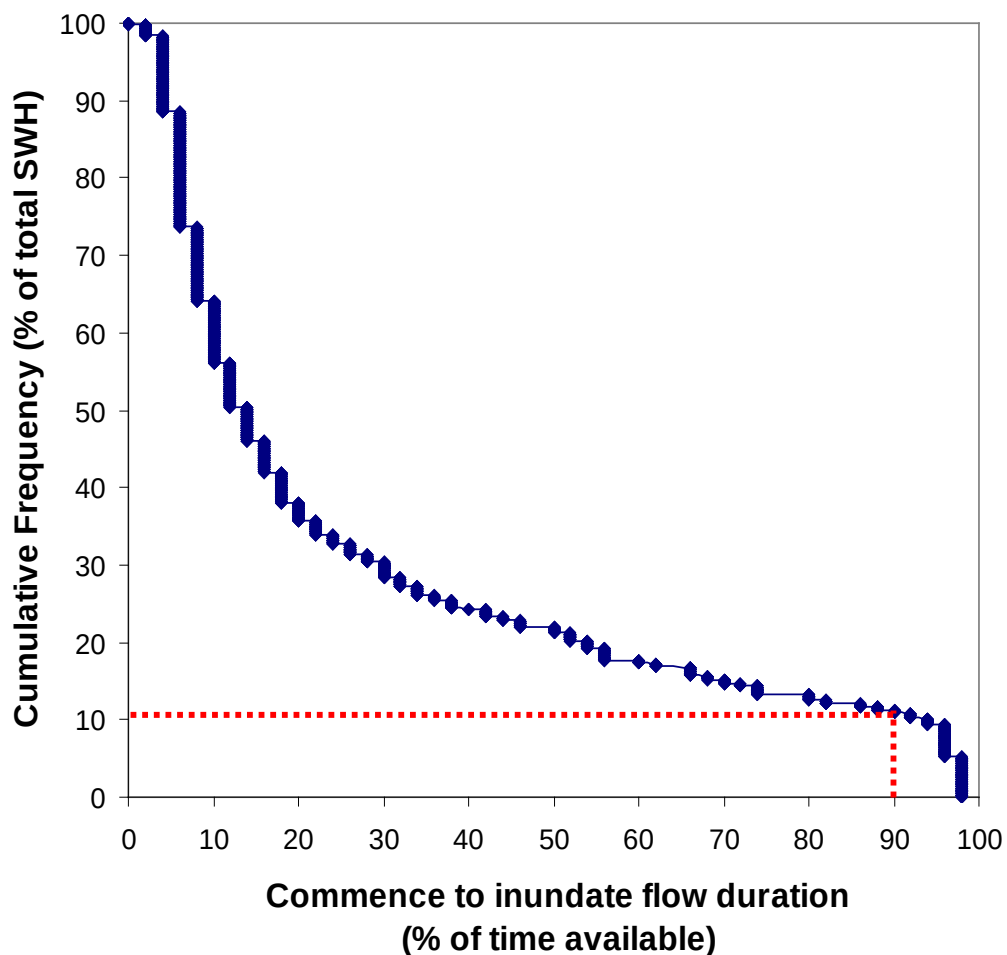


Figure 11. Cumulative frequency of all large wood structures in the demonstration. The dotted line indicates the availability (% of total in channel large wood) available during predominant low-flow conditions.

4.3.2. Spatial distribution of large wood and rehabilitation targets

Segments of river in the lower (Bourke Weir pool) and upper (the vicinity of Brewarrina) end of the demonstration reach typically included large wood loadings that fell short of the reference condition benchmarks (Table 5 and Figure 12). Therefore, they were candidates for in-channel habitat enhancement or re-snagging. In contrast, the middle sections of the demonstration reach (Warraweena and Beemery) generally included large wood loadings that exceeded the reference benchmarks, and were therefore candidates for in-channel habitat protection or selection as reference sites for the re-snagging experiment (Figure 12). Where the current large wood loading fell short of reference condition benchmarks, this deficit should be used to inform where re-snagging works are conducted, as well as provide a quantitative measure of how many structures are required per kilometre to bring the loading up to a 'reference-like' condition. Current large wood loadings, as well as the differential between current loadings and reference benchmarks, are summarised in Appendix 1.

Table 5. Reference benchmarks based on large wood loading (#/km) at six 10-km reaches between Brewarrina and Mungindi. Based on data from Boys 2007.

	Low flow available	Total within channel
Mean	7.7	45.83
Standard error	0.40	6.85
Standard deviation	0.99	16.79
Upper 95% confidence interval	9.07	59.26
Lower 95% confidence interval	6.33	32.40

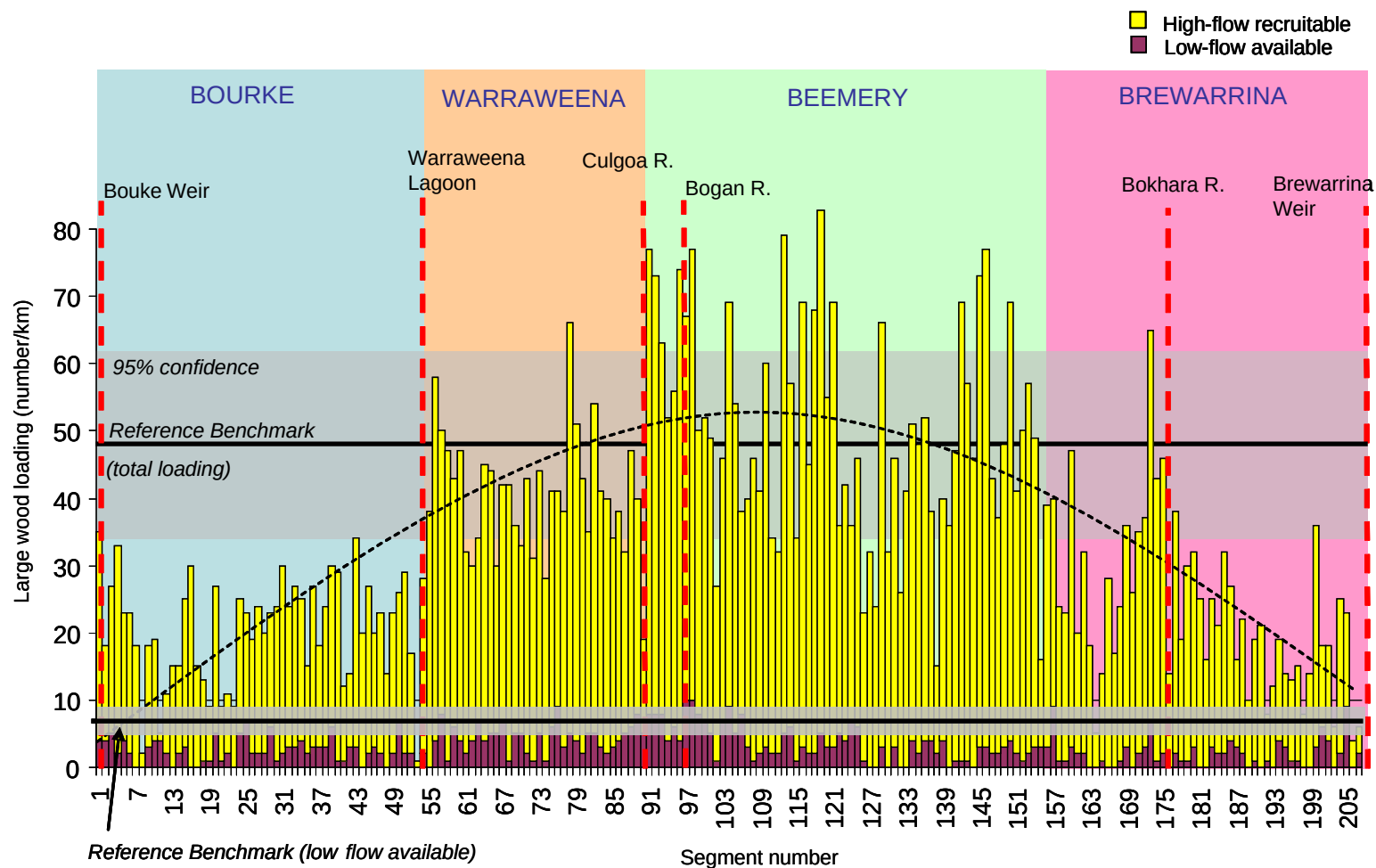


Figure 12. Large wood loading presented at the 1-km scale showing both ‘low-flow available’ and ‘high-flow recruitable’ structures as well as the relevant re-snagging benchmarks (benchmarks from Table 5). Four main river zones were identified based on the relation between large wood loading and the reference benchmarks. For the location of segment numbers, refer to Figures 8-10.

5. FISH RESPONSES TO RE-SNAGGING

5.1. Introduction

There has been a long history of large wood (or large woody debris) removal from rivers across the world, whether to source timber, reduce flood risk, remove obstacles to boat traffic, improve fish passage or “beautify” areas (Gregory *et al.* 2003, Brooks *et al.* 2004, Chin *et al.* 2008, Lester and Boulton 2008). In spite of this, it is generally recognised that large wood has an important influence on a river’s geomorphology, hydraulics and ecology in a way that is beneficial for aquatic biota (Harmon *et al.* 1986, Gippel 1995, Gregory *et al.* 2003, Schneider and Winemiller 2008). One of these benefits is the provision of habitat for fish (Harmon *et al.* 1986, Boys and Thoms 2006), with large wood increasing the structural complexity of river channels, providing velocity refuge, and foraging and spawning habitat (Angermeier and Karr 1984, Harmon *et al.* 1986, Lehtinen *et al.* 1997, Crook and Robertson 1999, Schneider and Winemiller 2008). Across most flows and times in the Barwon-Darling River, large wood is generally the only source of instream cover and structural complexity, and native fish such as golden perch and Murray cod are typically found in close proximity to large wood (Boys and Thoms 2006).

It is recognised that the removal of wood from river channels (de-snagging) can have negative eco-hydraulic impacts (Lester and Boulton 2008). Consequently, de-snagging is recognised as a key threatening process and illegal under various threatened species and fisheries management acts (e.g. NSW Fisheries Management Act 1994). Furthermore, the re-introduction of large wood (or re-snagging) has become a common part of river restoration programs (Reich *et al.* 2003, Kail and Hering 2005, Kail *et al.* 2007).

Although the ecological success of restoration works such as re-snagging is seldom evaluated (Palmer 2009), research that has been conducted provides little broad-scale consensus as to whether re-snagging produces measurable response in aquatic biota (Lester and Boulton 2008). Whilst some studies report enhanced fish and macroinvertebrate diversity (Hilderbrand *et al.* 1997, Brooks *et al.* 2001, Bond and Lake 2005, Nicol *et al.* 2005, Lester *et al.* 2007) and increased retention of organic matter or sediment (Wallace *et al.* 1995) following the reintroduction of wood, others at best report variable results (Larson *et al.* 2001, Brooks *et al.* 2006, Coleman 2006, Howell *et al.* 2010), or at worst report negative effects on geomorphology or biotic diversity (Spanhoff *et al.* 2006).

The less than definitive evidence regarding the success of re-snagging programs raises concerns that the significant investment being made by catchment management agencies on re-snagging may be based on unrealistic expectations of the responses it may induce. At the very least, it shows that the response may differ between areas and projects and that success should not be assumed. To better ascertain the generality of re-snagging success and its potential limitations in restoring rivers, a greater level of evaluation of more re-snagging projects across a larger range of river types is warranted, particularly outside of forested upland river systems where the research to date on this topic has focused (Lester and Boulton 2008).

This chapter reports on the response of native fish to re-snagging in the Bourke to Brewarrina Demonstration Reach. Previously, detailed snag mapping was undertaken of the entire 210km reach to determine areas where snag loading was below a pre-defined reference or ‘target’ condition and therefore warranted re-snagging (Chapter 3). Based on this assessment, a MBACI-designed experiment (Multiple-Before-After-Control-Impact) with references was used to compare native fish responses in sites that were re-snagged in comparison to control sites (untreated sites with below reference-state snag loading) and reference sites (untreated sites with adequate

reference-state loading), both before and after re-snagging. To test the prediction that re-snagging will result in positive responses to native fish, the following three hypotheses were tested:

H1a: The abundance of Murray cod changed in re-snagging sites following re-snagging, suggesting a response to rehabilitation relative to the control and reference reaches.

H1b: The abundance of golden perch changed in re-snagging sites following re-snagging, suggesting a response to rehabilitation relative to the control and reference reaches.

H1c: 'Nativeness' (proportion of total native fish to alien fish) changed in re-snagging sites following re-snagging, suggesting a response to rehabilitation relative to the control and reference reaches.



Figure 13. Large wood added to the river channel during re-snagging.

5.2. Methods

5.2.1. Experimental design and study sites

A modified MBACI design (Downes et al. 2002) was used in an attempt to discern responses that could be attributable to re-snagging from natural spatial and temporal variability. Re-snagged sites were compared to replicate control sites (requiring re-snagging but not re-snagged) and replicate reference sites (not requiring re-snagging and not re-snagged). These sites were sampled once a year (between summer and autumn) for two years prior to re-snagging and two years following re-snagging. Ten replicate sites were sampled in each treatment reach, as determined sufficient by power analysis (Appendix 3), resulting in the final design outlined in Figure 14.¹ Site locations are shown in Figure 15 to Figure 17.

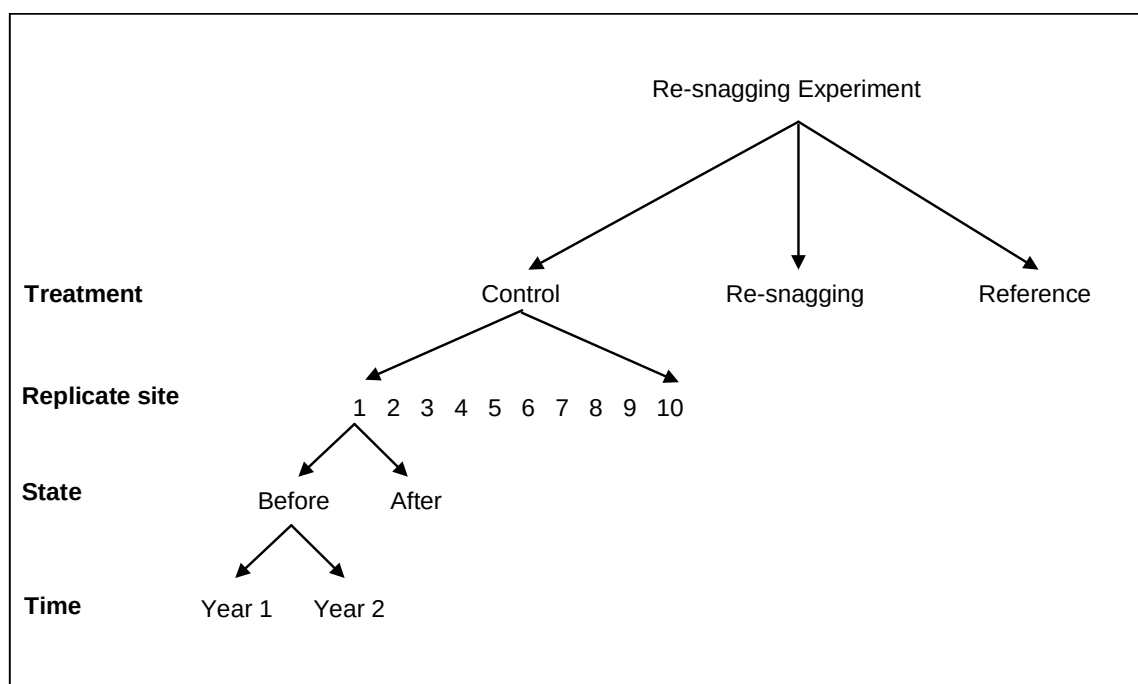


Figure 14. Re-snagging experimental design.

¹ An additional eleventh re-snagging site was sampled (B2B010) as a back-up site. To ensure symmetry in the experimental design, the data collected from this site was not analysed in this report.

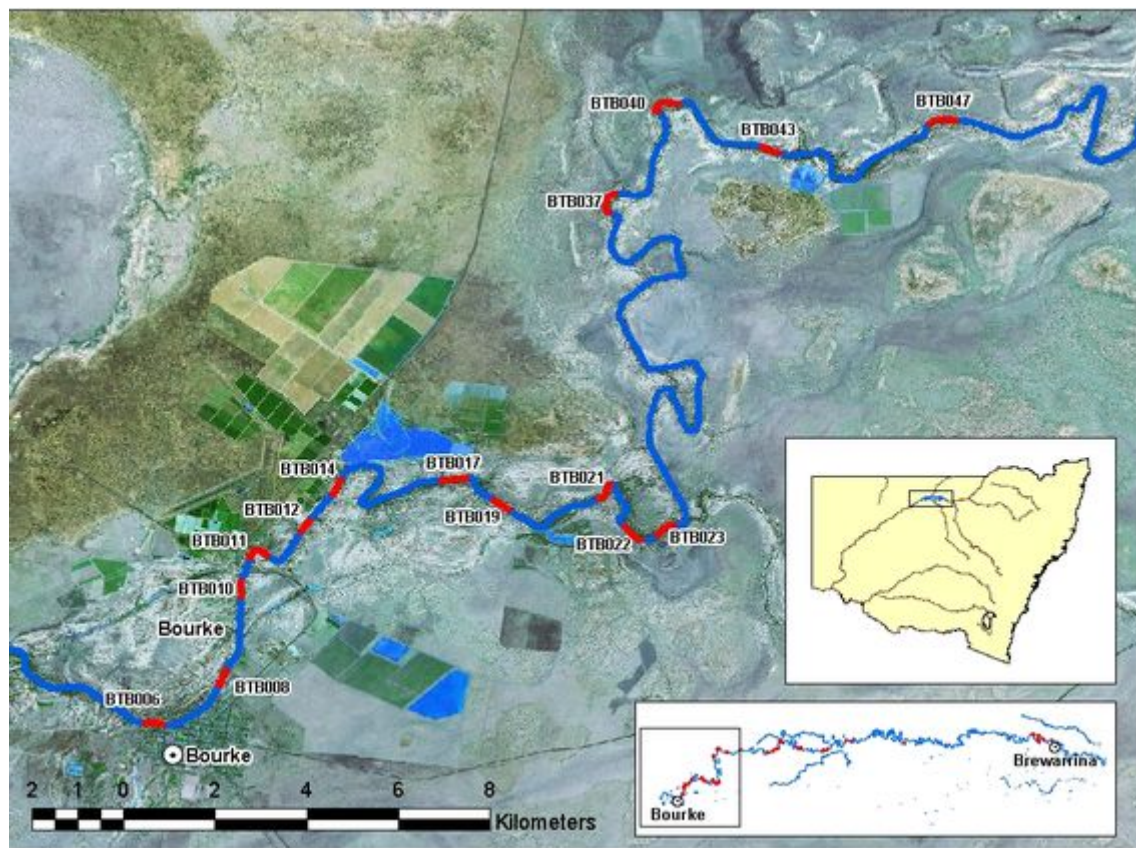


Figure 15. Re-snagging experiment site locations situated near Bourke. Refer to Table 6 and Appendix 1 and 2 for site details and allocation to each treatment.

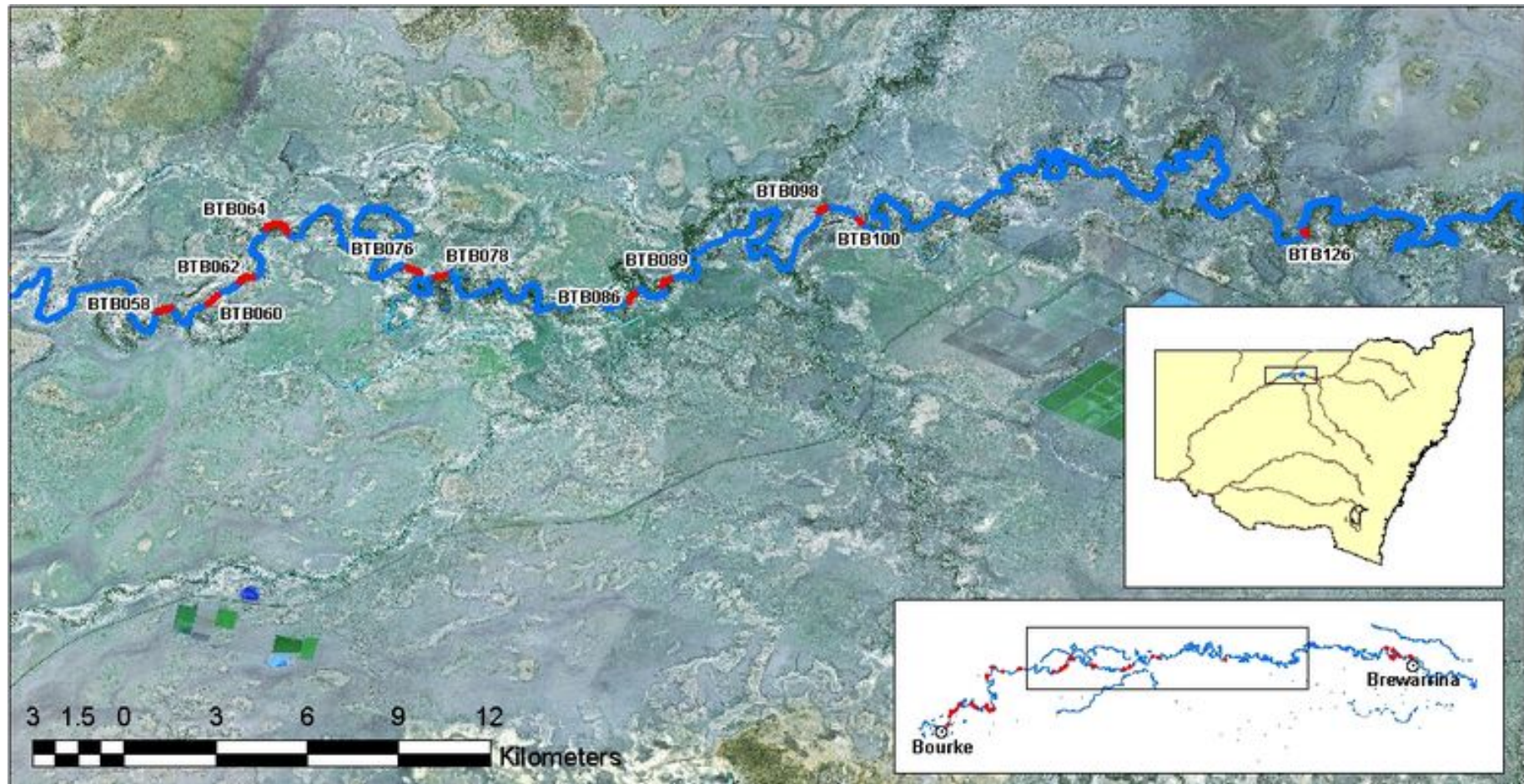


Figure 16. Re-snagging experiment site locations situated in the middle sections of the demonstration reach (Warraweena through Beemery). Refer to Table 6 and Appendix 1 and 2 for site details and allocation to each treatment.

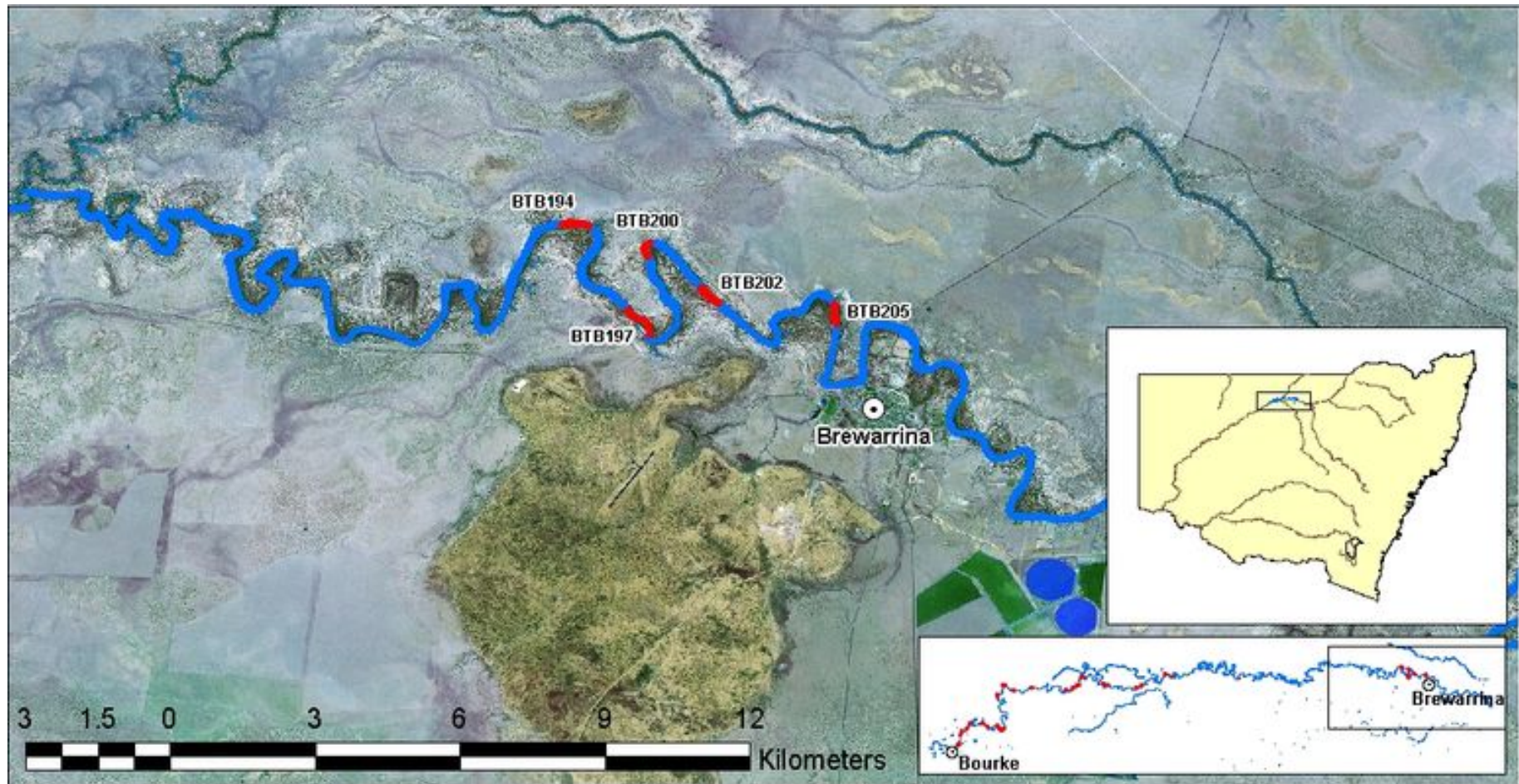


Figure 17. Re-snagging experiment site locations situated near Brewarrina. Refer to Table 6 and Appendix 1 and 2 for site details and allocation to each treatment.

Table 6. Site details for re-snagging, control and reference sites within the demonstration reach.

Site name	Latitude	Longitude	Treatment
BTB006	-30.0873	145.93537	Control
BTB011	-30.05433	145.95226	Control
BTB014	-30.03888	145.97023	Control
BTB017	-30.03911	145.98987	Control
BTB022	-30.05077	145.95168	Control
BTB043	-29.9732	146.05274	Control
BTB047	-29.96877	146.08578	Control
BTB062	-29.96511	146.17617	Control
BTB100	-29.94696	146.35577	Control
BTB194	-29.92843	146.80139	Control
BTB058	-29.97404	146.1519	Reference
BTB060	-29.97162	146.1668	Reference
BTB064	-29.95071	146.15573	Reference
BTB076	-29.96251	146.22954	Reference
BTB078	-29.96368	146.23328	Reference
BTB086	-29.96824	146.2925	Reference
BTB089	-29.96417	146.30294	Reference
BTB098	-29.94476	146.34674	Reference
BTB126	-29.95155	146.49022	Reference
BTB200	-29.93447	146.81749	Reference
BTB008	-30.07946	145.94612	Re-snagging
BTB012	-30.05535	145.95168	Re-snagging
BTB019	-30.04505	146.00342	Re-snagging
BTB021	-30.05535	145.95168	Re-snagging
BTB023	-30.05535	145.95168	Re-snagging
BTB037	-29.98254	146.02432	Re-snagging
BTB040	-29.96636	146.03298	Re-snagging
BTB197	-29.94912	146.81755	Re-snagging
BTB202	-29.94308	146.83052	Re-snagging
BTB205	-29.94317	146.85199	Re-snagging

5.2.2. Fish sampling

All sites were sampled between spring and autumn 2007 to 2010 using a five-metre, twin-hulled aluminium boat (research vessel *Electricus*) mounted with a Smith-Root 7.5 GPP electrofishing unit. Pulsed (120 pulses per second) direct electrical current (DC) was used due to the reduced tendency to produce strong and harmful muscular contractions in fish compared with alternating current (Snyder 2003). All other electrofishing settings were not standardised and were adjusted to achieve optimal catch efficiency for the given water conductivity. A total of 1080 electrofishing seconds (on time) was performed, at each site on each sampling occasion, with total fishing effort allocated across all samplable habitats by way of three passes (Figure 18). Fish were dip-netted from the water and placed in a live well to recover until measured and returned alive to the water after each shot. Any fish positively identified but not dip-netted were also recorded.



Figure 18. Electrofishing was conducted in 1080 continuous seconds of fishing effort at each site. The boat was moved along the left bank for 400 seconds, then down the right bank for 400 seconds, and finally up the middle of the channel for 280 seconds. Dots indicate low-flow available (red) and high-flow recruitable (yellow) large wood, as mapped in Chapter 3.

5.2.3. Statistical analyses

The response of Murray cod and golden perch abundance and nativeness (proportion of native individuals to alien individuals) to re-snagging was tested within the BACI design. This involved three factorial univariate permutational analyses of variance (PERMANOVA: Anderson 2001, McArdle and Anderson 2001) based on Euclidean distance and type III sum of squares. The factors analysed were Treatment (Tr, fixed, three levels: re-snagging, control and reference), Before versus After (BvA, fixed, two levels: before and after), Year (Yr, random nested within BvA, two levels: Yr 1 and Yr 2) and interactions between these terms. Univariate PERMANOVA creates a test statistic equivalent to the traditional F statistic of ANOVA, but generates probabilities using permutation of the data (999 times), therefore avoiding the usual normality assumptions of ANOVA. Given that a low number of permutations were possible for the BvA term, probability for this term was calculated using Monte Carlo randomisation (Anderson 2001). Transformations were used (golden perch $\ln(x+1)$ and nativeness $\ln(x)$) to homogenise variances before analysis. All analyses were carried out using the Primer v6 statistical package (Clarke and Gorley 2006).

5.3. Results and preliminary discussion

Fifteen species of fish ($n = 22,743$) were sampled across four years from all sites within the demonstration reach (Table 7). Bony herring ($n = 15,852$), carp ($n = 3,912$) and golden perch ($n = 1,285$) were the most abundantly caught species. Golden perch abundance increased significantly as the years progressed (Table 8: Yr(BvA) $F_{2,108} = 8.53$, $p = 0.001$) (Figure 19), but it did so at all treatments, and non-significant Tr*BvA and Tr*Yr terms indicate no detectable response to re-snagging (Table 8). Similarly, Murray cod showed a trend of increasing abundance with year (Figure 19), although the size of this increase was significantly larger at the reference sites compared to the control and re-snagging sites (Table 8: Tr $F_{2,4} = 10.65$, $p = 0.025$). Again, re-snagging sites did not increase relative to control sites in a way that would suggest a response to re-snagging. All treatments had significantly higher proportions of native fish (nativeness) in the two years prior to re-snagging than after (Table 8: BvA $F_{1,2} = 56.37$, $p = 0.024$), driven by a reduction in bony herring and gudgeon abundance, with a reciprocal increase in goldfish and carp numbers (Table 8). There was no indication of a differential change among treatments that would suggest a response to re-snagging (Figure 19). In conclusion, the results provide no evidence of a response in the three native fish indicators to re-snagging. The implications of this will be explored in detail and within the context of the results of other chapters in the general discussion (Chapter 9).

Table 7. Catch summary for electrofishing experiment.

Common name	Scientific name	Re-snagging reaches					Control reaches					Reference reaches					Grand Total
		Yr 1	Yr 2	Yr 3	Yr 4	Total	Yr 1	Yr 2	Yr 3	Yr 4	Total	Yr 1	Yr 2	Yr 3	Yr 4	Total	
Agassiz's glassperch	<i>Ambassis agassizii</i>	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1
Silver perch	<i>Bidyanus bidyanus</i>	3	0	1	0	4	2	0	1	0	3	3	0	1	0	4	11
Goldfish	<i>Carassius auratus</i>	24	13	22	184	243	6	14	8	99	127	1	39	9	59	108	478
Flyspecked hardyhead	<i>Craterocephalus stercusmuscarum</i>	4	1	0	0	5	0	4	0	0	4	2	0	0	0	2	11
Common carp	<i>Cyprinus carpio</i>	147	178	117	532	974	114	158	113	803	1188	78	131	143	1398	1750	3912
Gambusia	<i>Gambusia holbrooki</i>	43	10	24	15	92	116	2	1	5	124	152	1	1	5	159	375
Carp gudgeon	<i>Hypseleotris spp</i>	3	110	0	0	113	0	23	2	3	28	29	1	0	0	30	171
Lake's carp-gudgeon	<i>Hypseleotris sp5</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spangled perch	<i>Leiopotherapon unicolor</i>	4	22	2	116	144	3	13	3	103	122	5	11	2	103	121	387
Murray cod	<i>Maccullochella peelii</i>	7	4	9	20	40	6	6	11	23	46	11	33	43	42	129	215
Golden Perch	<i>Macquaria ambigua</i>	49	60	106	252	467	57	59	109	145	370	41	107	73	227	448	1285
Murray-Darling rainbowfish	<i>Melanotaenia fluviatilis</i>	0	4	1	4	9	3	2	0	7	12	1	1	0	5	7	28
Bony herring	<i>Nematalosa erebi</i>	2592	3028	127	1068	6815	1713	1481	121	1644	4959	1845	559	125	1549	4078	15852
Hyrtyl's tandan	<i>Neosilurus hyrtlii</i>	0	0	0	4	4	0	0	0	1	1	0	0	0	0	0	5
Australian smelt	<i>Retropinna semoni</i>	3	0	0	4	7	0	0	0	0	0	5	0	0	0	5	12
Total		2879	3430	409	2200	8918	2020	1762	369	2833	6984	2173	883	397	3388	6841	22743

Table 8. PERMANOVA results showing sources of variation within the BACI design for golden perch and Murray cod abundance and nativeness score. Significant sources of variation at the $p < 0.05$ are shown in bold.

Source	DF	MS	F	P (perm) [†]
Abundance of golden perch - $\ln(x+1)$ transformed				
Tr	2	0.7572	1.34	0.313
BvA	1	14.565	2.76	0.258
Yr (BvA)	2	5.2762	8.53	0.001
Tr * BvA	2	0.5122	0.91	0.563
Tr * Yr (BvA)	4	0.5651	0.91	0.411
Residual	108	0.6182		
Abundance of Murray cod - not transformed				
Tr	2	62.658	10.65	0.025
BvA	1	53.333	7.98	0.09
Yr (BvA)	2	6.6833	1.71	0.163
Tr * BvA	2	4.0083	0.68	0.55
Tr * Yr (BvA)	4	5.8833	1.50	0.179
Residual	108	3.9148		
Nativeness - $\ln(x)$ transformed				
Tr	2	1.5745	4.55	0.088
BvA	1	34.459	56.37	0.024
Yr (BvA)	2	0.6113	0.97	0.346
Tr * BvA	2	1.8588	5.37	0.062
Tr * Yr (BvA)	4	0.3461	0.55	0.740
Residual	108	0.6300		

Tr = Treatment

BvA = Before versus After

Yr (BvA) = Year nested within (BvA)

† Significant sources of variation at the $p < 0.05$ are shown in bold; P (perm) for term BvA obtained by Monte Carlo randomisation.

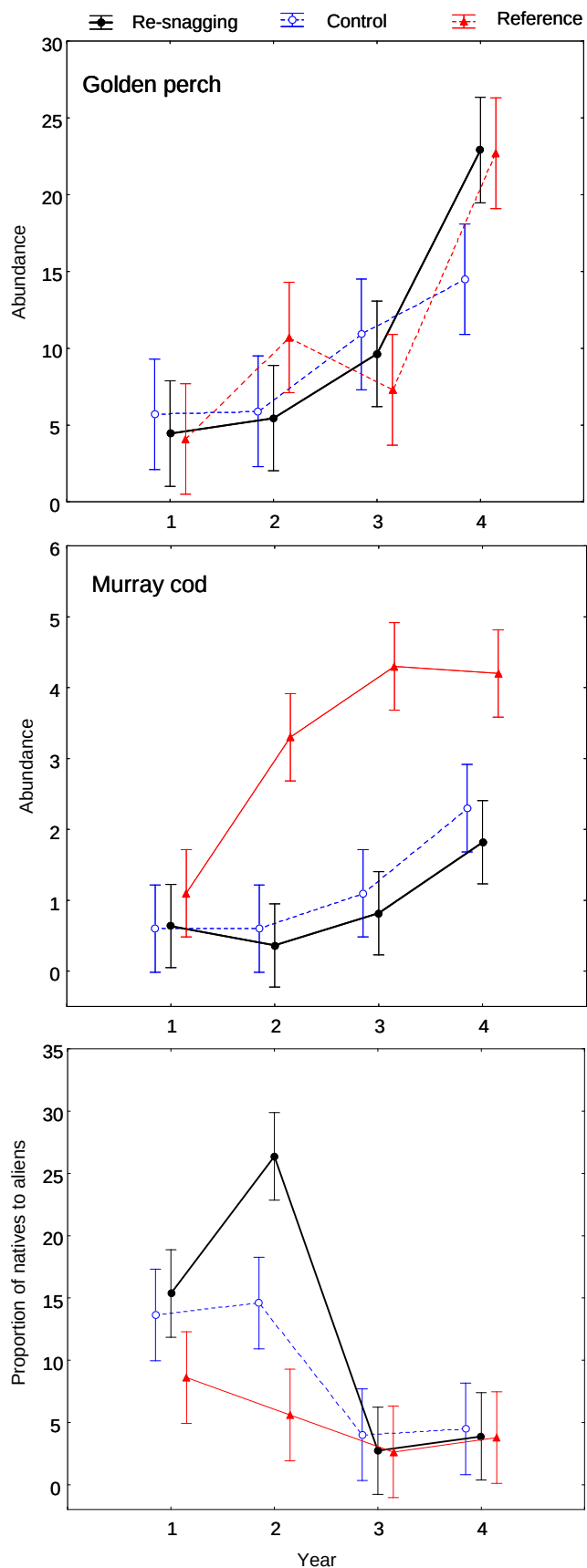


Figure 19. Means ($\pm$ S.E.) for abundance of golden perch (top), abundance of Murray cod (middle) and nativeness score (bottom) pre-re-snagging (Years 1-2) and post-re-snagging (Years 3-4) at re-snagging (black), control (blue dashes) and reference (red) reaches.

6. GEOMORPHOLOGICAL AND HYDRAULIC RESPONSES TO RE-SNAGGING

6.1. Introduction

Physical diversity enhances biodiversity in riverine systems (Poff *et al.* 1997, Thoms *et al.* 2006). At the reach scale, physical diversity can be defined by hydraulic characteristics such as water depth, flow velocity and turbulence, which create distinct hydraulic patches or areas of similar hydraulic character. The pattern or configuration of these hydraulic patches at the reach scale is influenced by the morphology of the river bed and banks as well as obstacles that may be present within the river channel (Dyer and Thoms 2006). In many inland rivers, large wood forms one of the major in-channel obstacles to flow. The particular influence large wood has on the hydraulic character of river reaches is dependent on its placement within the channel as well as the particular shape of each piece of large wood (Gippel *et al.* 1996b). In general, however, large wood has been shown to increase hydraulic diversity within river channels (Hughes *et al.* 2007). In addition, large wood can promote bed scour, causing deepening and pool formation on the downstream side of these structures, providing more complex fish habitat (Crook and Robertson 1999).

The Barwon-Darling River forms an important component of the larger Murray Darling Basin in south-eastern Australia. To date, little information exists on the hydraulic character of this river at scales appropriate to re-snagging activities. The introduction of large wood to a selection of sites within the Bourke to Brewarrina Demonstration Reach provides an opportunity to not only assess the association between large wood and geomorphological and hydraulic character, but also determine whether this is influenced by re-snagging activities. In relation to intervention monitoring of the re-snagging works, two hypotheses were tested:

H2a: Re-snagging resulted in a change in mean depth relative to reference and control sites, suggesting scour effects from large wood placement.

H2b: Re-snagging resulted in a change in the hydraulic character relative to reference and control sites, suggesting response to large wood placement.

6.2. Methods

6.2.1. Study sites

The same thirty sites surveyed for fish responses as part of the re-snagging experiment (Chapter 4 Figures 18-20) were surveyed for the purpose of this study. Sites were between 100 and 400 metres in length and were categorised as control, reference or re-snagging. Control sites were untreated sites considered to be representative of reaches with low abundance of large wood (see Chapter 3). Reference sites were considered to have near natural abundance of large wood, and re-snagging sites were those where the reintroductions of large wood occur. Ten individual sites were assigned to each treatment group.

6.2.2. Survey methods

Surveys were carried out along the thirty study sites between Bourke and Brewarrina on two occasions; once in May 2008, several weeks before re-snagging commenced, and again in November 2008 after re-snagging was completed. Low-flow conditions were present during both survey occasions. Flows of 40-63 ML/day at the Bourke Town Gauge station occurred during the May survey trip, whilst flows of 26-46 ML/day were present at the Bourke Town Gauge during the November survey trip. Flow velocities were recorded along each site using a boat-mounted acoustic Doppler profiler (ADP). Depth-velocity profiles and point depth measurements were recorded at five-second intervals as the boat was slowly driven in a zigzag pattern from bank to bank up each study reach (Figure 20). This equated to an average of 261 depth-velocity profiles per site. The X and Y co-ordinates were recorded using the ADP for each profile, allowing for the derivation of site scale depth-averaged velocity grids.



Figure 20. Surveys being undertaken with a boat-mounted ADP.

6.2.3. Data Analysis

Bathymetry

Point depth measurements were recorded using the ADP. Three individual depth measurements were taken at each five-second interval, one from each probe on the ADP, and these were averaged to give one depth measurement per recording. To analyse the point depth data, they were first grouped according to survey trip and treatment and analysed using a two-way factorial ANOVA. Second, individual sites were compared between the two survey trips using t-tests.

Hydraulic character

Individual velocity profiles were summarised as depth-averaged velocities in cm s^{-1} using the Sontek River Surveyor program. For each site and survey time, the depth-averaged velocities were interpolated to raster grids in ARCGIS 9.1 using an inverse distance weighted transformation (Figure 21). Grids were then reclassified into classes or hydraulic patches based on boundaries determined from the break points in the cumulative frequency curve of all depth-average velocity points. These grids, which represent velocity patches within the sites, were used to derive a number of metrics using the spatial analysis package FRAGSTATS Version 3.3 (McGarigal and Marks 1995). The nine metrics selected describe the abundance, shape, size, spatial arrangement and diversity of the hydraulic patches belonging to each of the a priori determined classes for each site.

The character of the sites was investigated using a range of multivariate statistical analyses. Firstly, association matrices were calculated using the Gower environmental difference measure, as suggested by Belbin (1993) for non-biological data. These were calculated for two datasets: one containing all patch variables and all sites (all site dataset), and a second containing only “re-snagged” sites (re-snagged only dataset). Analysis of similarity (ANOSIM) was then run on these association matrices to test for differences between time, treatment and time x treatment for the all site dataset and time for the re-snagged only dataset. Semi-strong hybrid multidimensional scaling (MDS; Belbin 1993) was then used to graphically represent these similarity matrices. Stress levels of less than 0.2 indicated that the ordination solutions were not random. Principle axis correlation (PCC; Belbin 1993) was then used to identify relationships between the patch variables and the location of each site in multidimensional space. Only those patch variables with an R^2 greater than 0.8 were considered. In addition, univariate t-tests were used to compare individual patch variables between the two survey times, when the data was separated by site type.

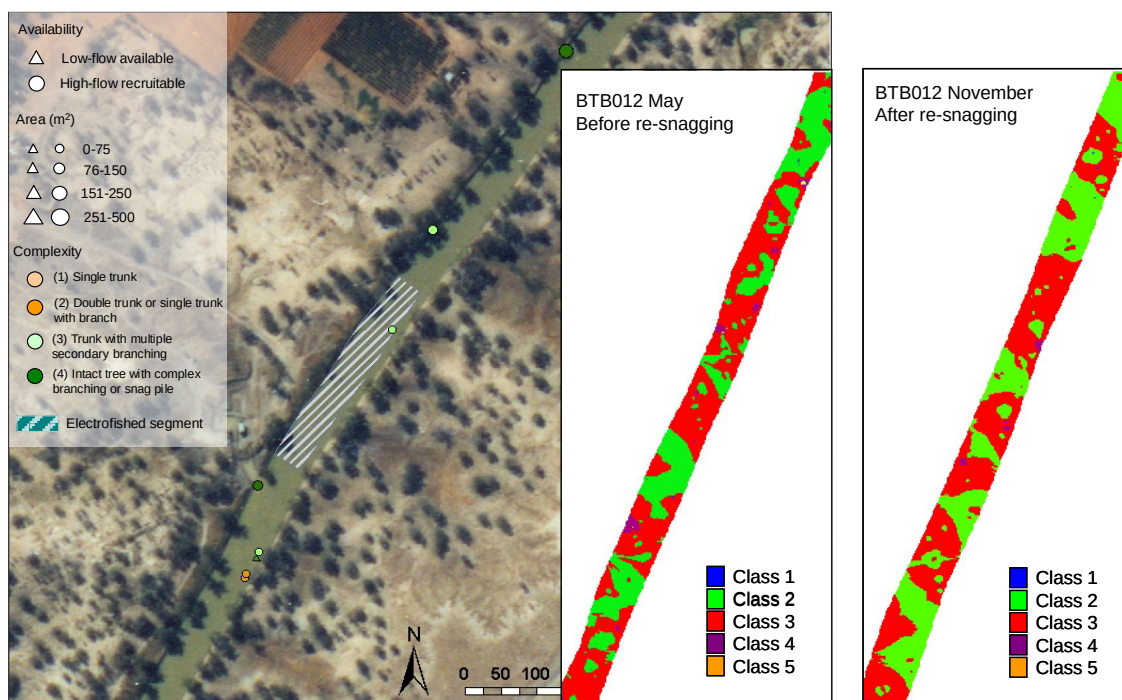


Figure 21. Aerial photo of site BTB012 prior to re-snagging, showing an example of a raster image generated of hydraulic classes obtained from ADP before and after re-snagging.

6.3. Results

The mean depth recorded across all sites during both survey trips was 2.5m and ranged from 0.82 to 6.93 metres. The two-way ANOVA revealed that depths significantly differed both between survey trips and between treatments. The mean depths were shallower in the first survey trip (2.41m, range 0.82 – 6.93m) than the second survey trip (2.56m, range 0.84 – 6.84). Reference sites had the lowest mean depth (1.95m, range 0.84 – 4.10), with re-snagging sites higher (mean 2.63m, range 0.82 – 6.70m), and control sites having the highest mean depth (2.79m, range 0.91 – 6.93). Post-hoc Bonferroni tests undertaken on the data when grouped by both trip and reach type showed that the reference sites were similar on both survey trips, the May control sites were similar to the November re-snagging sites, and both the May re-snagging sites and November control sites significantly differed from all other sites and times.

In terms of individual site comparisons between survey trips, of the thirty sites studied, sixteen showed significant differences in mean depths. Of these, twelve showed significant increases in mean depth, and four showed significant decreases in mean depth. Out of the sixteen sites to show significant differences, eight were re-snagging sites, five were reference sites and three were control sites.

Depth-averaged velocities (DAV) recorded over the two survey times ranged from 0 m s⁻¹ to 1.81 m s⁻¹. The median DAV was 0.13 m s⁻¹, whilst the 10th and 90th percentiles fell at 0.05 m s⁻¹ and 0.3 m s⁻¹ over the May and November survey times, respectively. A total of five DAV classes or hydraulic patches were determined from the cumulative frequency curve of all DAV points (Figure 22). The ranges of the DAV classes and the percentage of occurrences in each class are presented in Table 9, and an example of two of the resultant sites (site BTB012) are presented for both sampling times (Figure 21). The raster images derived from all sites in the study are presented in Appendix 4.

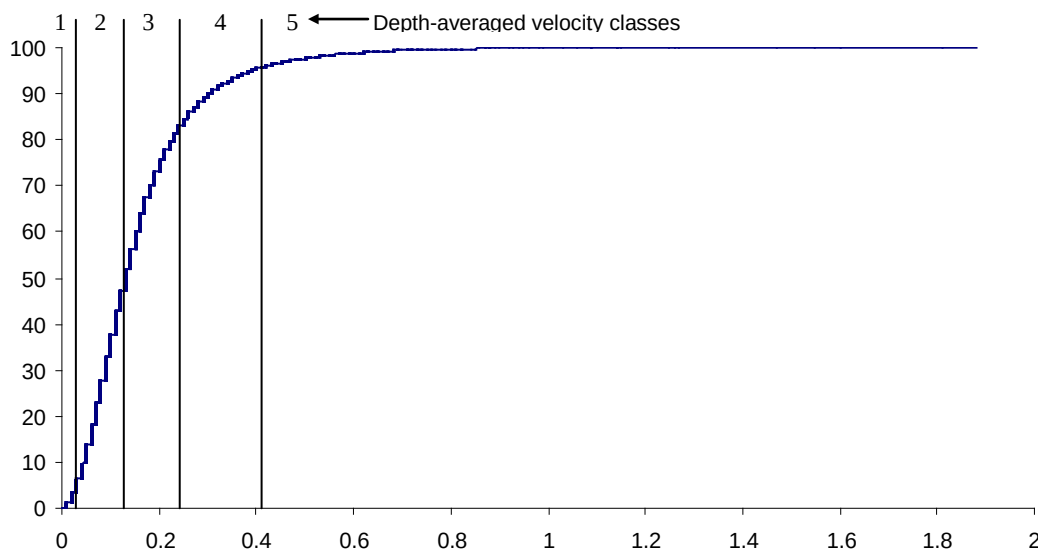


Figure 22. Cumulative frequency curve of depth-averaged velocities from all sites and sampling times. Vertical lines correspond to breaks in slope, which delineate velocity classes.

Table 9. The character of hydraulic patches identified in the study area.

<i>Velocity Class</i>	<i>Depth-Averaged Velocity ($m s^{-1}$)</i>	<i>Profiles in Each Class (%)</i>
1	< 0.04	6.29
2	0.04 – 0.13	41.08
3	0.13 – 0.24	33.93
4	0.24 – 0.43	14.83
5	> 0.43	3.86

The mean number of patches in individual sites was greatest in the November survey time (98 patches) and was also greatest in re-snagging sites (99 patches), whereas the mean patch size was similar between both times and treatments (Table 10). Whilst some variation can be seen in the individual patch mean variables in Table 10, the ANOSIM results suggest a poor separation of sites in multi-dimensional space; Global R = 0.041, $p < 0.05$, Global R = 0.123, $p < 0.001$ and Global R = 0.144, $p < 0.001$ for time, treatment and time*treatment type, respectively. This poor separation can be seen in the ordination plots displayed in Figure 23, where the data has been grouped by time, treatment and time*treatment. Global R-values greater than 0.7 suggest that the groups clearly differ, whilst those within the range of 0.5 to 0.69 suggest some overlap between groups but clearly differ, and R-values less than 0.5 indicate a high degree of overlap (Clarke & Warwick 1994).

Table 10. Summary patch metrics for each time and reach type in the study.

Patch Variable	Time		Treatment		
	May	Nov	Reference	Control	Re-snagging
Mean reach area (ha)	2.93	2.77	1.83	3.09	3.63
Mean number of patches (NP)	85	98	91	85	99
Mean patch density (N^0/Ha)	4153	4746	6119	4195	3035
Mean landscape shape index	6.93	7.53	7.37	7.25	7.06
Mean Simpson's diversity index	0.52	0.50	0.51	0.52	0.50
Mean Simpson's evenness	0.66	0.63	0.65	0.65	0.63
Mean patch area (ha)	0.03	0.03	0.02	0.04	0.04
Mean patch shape	1.32	1.29	1.30	1.29	1.31
Mean patch proximity (m)	64.28	36.74	37.88	29.62	84.03

To investigate the specific influence of re-snagging, analysis was undertaken on the re-snagged sites only and comparisons made between pre- (May) and post- (November) re-snagging survey times. The ANOSIM results suggest a higher degree of separation than when all sites were considered (Global R = 0.216, $p < 0.005$). However, considerable overlapping of the May and November groupings was evident on the MDS plot (Figure 24a). PCC analysis showed that only four patch variables; patch area, patch diversity, Simpson's diversity index and Simpson's evenness were responsible for influencing the position of re-snagging sites in multi-dimensional space at the 0.8 confidence level (Figure 4b). It appears that the post-re-snagging sites were associated with higher patch diversity (number of patches per ha), whereas the pre-snagging sites were associated with larger patch areas.

T-tests undertaken on individual patch variables for each treatment suggest that the re-snagging sites included significantly more patches after re-snagging than before at the 0.05 level. These patches were significantly smaller and higher in density post-re-snagging. For controls, there were significantly more patches in the November sampling time, and for reference sites, patch proximity (the average distance between similar patches) was lower in the November sampling time.

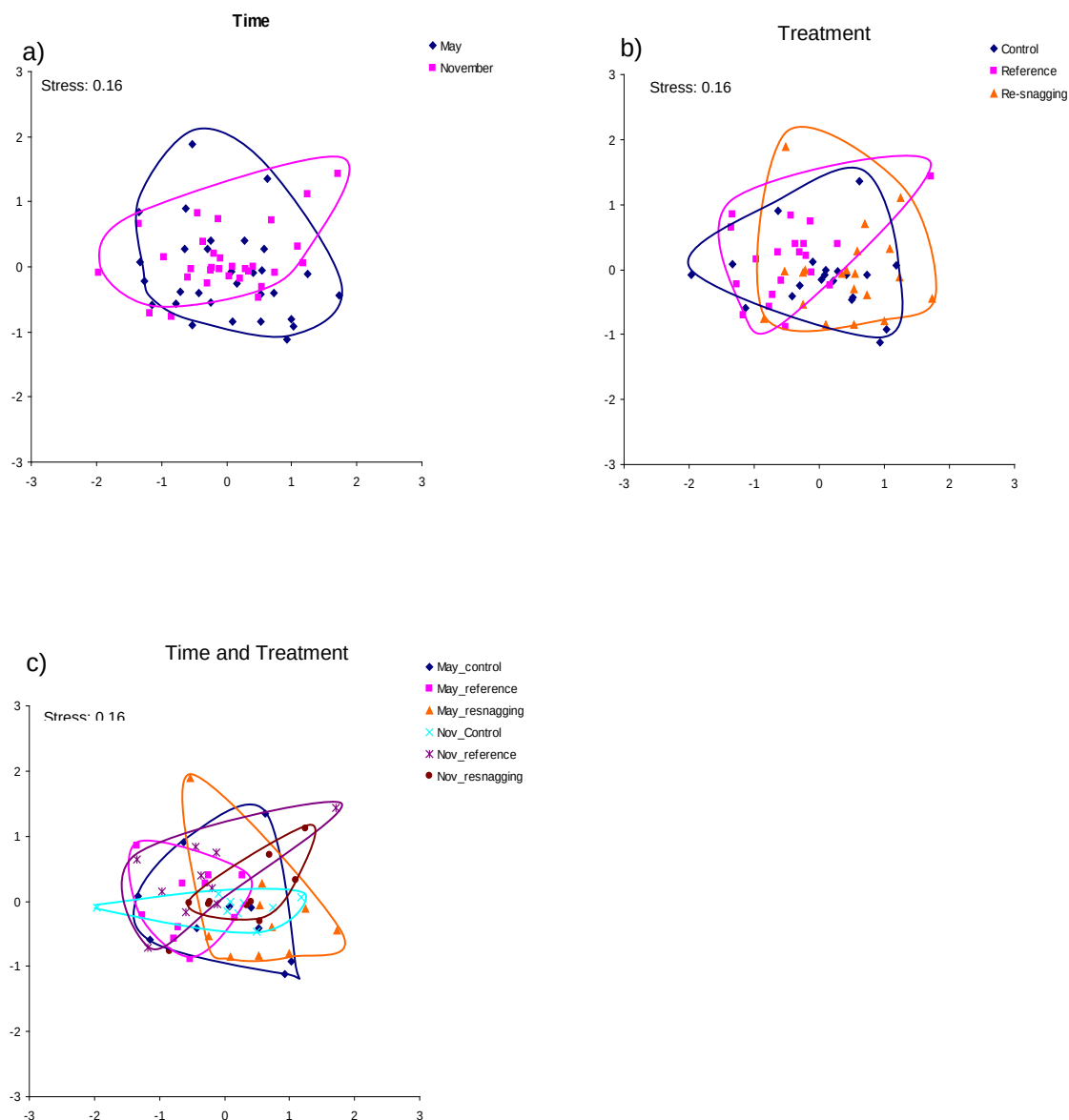


Figure 23. Graphical summaries of the multivariate analysis, including every study site. Ordinations are presented grouped by a) sampling time, b) treatment and c) time and treatment.

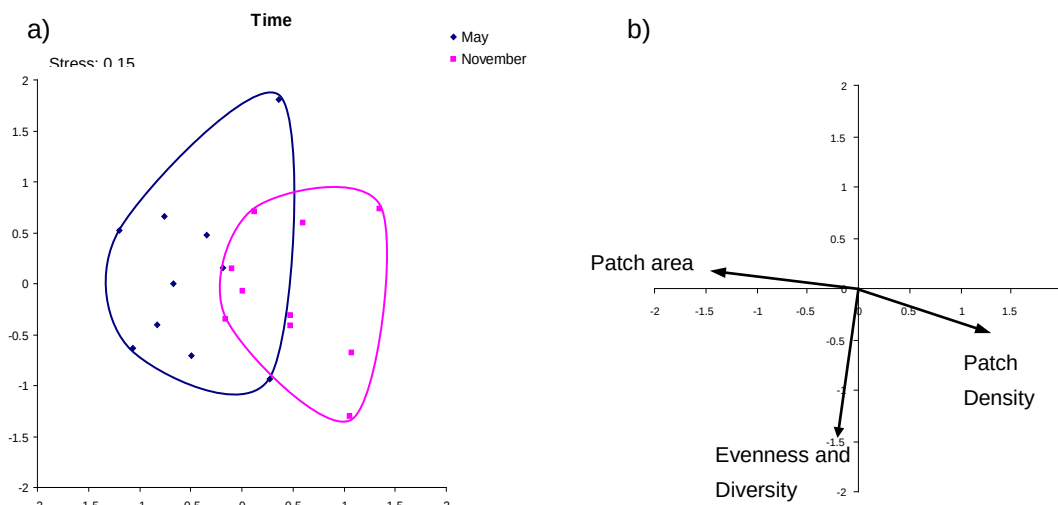


Figure 24A. Ordination of sites based on similarity in hydraulic character for re-snagging reaches only, showing B) primary variables explaining pattern (PCC).

6.4. Discussion

When addressing hypothesis 3a, the results are far from conclusive, and little evidence exists that re-snagging was responsible for changes in the bathymetry of individual sites recorded in this study. Although the majority of re-snagging sites did show a change in bathymetry, similar changes were also noted in the control and reference reaches. The results of this study suggest that the bathymetry of the study sites varied in both space and time. Depth appeared to be associated with position in reach, with both the control and re-snagging sites in the Bourke Weir pool being deeper than the reference sites, which were located in the middle reaches and characterised by shallower water. The significant differences witnessed between sampling times (pre- and post-re-snagging) are a little more difficult to explain. Flow conditions during both survey trips were generally similar and can be discounted as an explanation. In addition, no significant flow events occurred down the reach between the two survey trips that could have promoted bed scour and deposition and hence influenced the bathymetry of the study sites. It may be that these differences were a result of natural variation that was not fully captured in the sampling procedure used in the current study.

A diverse range of velocity readings were observed within the survey sites of the demonstration reach. These could be grouped into five distinct hydraulic classes based on the depth-averaged velocity cumulative frequency curve. Velocity readings observed in this study fit within the lower range of flows reported by Thoms *et al.* (2006) on the middle reaches of the River Murray, during a range of river flows ranging from 2000 MLD to 9000 MLD. For example, the most abundant velocity class in the current study was class 2 ($0.04 - 0.13 \text{ ms}^{-1}$), which accounted for 41 per cent of the total depth-averaged velocities recorded, compared to class 3 ($0.23 - 0.35 \text{ ms}^{-1}$) in the Thoms *et al.* (2006) study, which accounted for 48 per cent of all recordings. These comparatively low-flow velocities reflect the low-flow conditions present during both survey occasions.

Pieces of large wood are considered to be effective obstacles to river flow (Gippel *et al.* 1996b). Not only do they change flow in the downstream direction, but they also cause upwelling and turbulence, which can significantly alter the local hydraulic diversity around them (Hughes *et al.* 2007). The results suggest that re-snagging may be imparting some influence on the hydraulic diversity of the study sites; however, this result was far from significant and hypothesis 3b was not supported. The relatively low influence of large wood on hydraulic diversity observed in the current study may be a reflection of several important factors. First, large wood tends to have minimal influence on hydraulic diversity during low-flow conditions, with the relative influence increasing as flow levels increase (M. Thoms unpublished data). Therefore, as the current study was undertaken at low river flows, the influence of the re-snagging logs may have been underestimated when larger river flows are taken into account. Successive hydraulic surveys at larger flows would need to be undertaken to gain a full appreciation of the influence of the introduced large wood on the hydraulic diversity along these sites of the demonstration reach. Secondly, the majority of snags in the re-snagging sites were reintroduced in close proximity to the river banks. Hence, under low-flow conditions, the logs were surrounded by only shallow (<1m) water. The ADP used for these surveys had a non-detection distance of <50cm. Therefore, it does not record any data for the first 50cm from the water's surface. Thus, much of the water surrounding the new logs was beyond the recording range of the equipment used and was not included in the analysis. Inclusion of these areas may have strengthened the observed influence of the re-introduced logs in this study. This difficulty could once again be circumvented by surveying at higher river flows and this is currently being undertaken by the University of New England researches.

In conclusion, the present study suggests that whilst distinct hydraulic patches are present within the channel of the Bourke to Brewarrina Demonstration Reach, only small differences exist based on treatment and survey time. The introduction of snags appears to have had minimal influence on bathymetry and hydraulic diversity within these reaches. This is probably due to the low-flow conditions present during the two survey occasions and may not necessarily reflect the condition under elevated flows. A PhD project is currently underway involving hydraulic surveys at these sites over a larger range of river flows. This will improve our understanding of the influence of re-snagging on hydraulic diversity, thus providing a more complete picture of hydraulic diversity along the demonstration reach.

7. REACH-SCALE CONDITION MONITORING

7.1. Introduction

To be most effective, monitoring at demonstration reaches should involve both reach-scale condition, as well as sub-reach-scale intervention monitoring (Boys et al. 2009). It is the aim of condition-based monitoring to provide an overall account of demonstration reach-scale trends, without drawing any inference as to the relative contribution of multiple interventions (which include re-snagging, gully erosion works, riparian fencing and the provision of off-stream watering points). This chapter outlines the experimental design, sampling methods and preliminary results of the condition-based monitoring in the Bourke to Brewarrina Demonstration Reach to determine if there has been a trajectory of improvement in key fish community indicators. The specific hypotheses being tested were:

H3: Fish assemblage indicators (see below) measured across the demonstration reach changed during rehabilitation activities, suggesting a response in the demonstration reach relative to the control reaches.

Fish assemblage indicators:

- Ha) Total species richness (number)
- Hb) Species richness of native fish
- Hc) Species richness of alien fish (introduced or exotics)
- Hd) Native fish abundance
- He) Alien fish abundance
- Hf) 'Nateness' (proportion of native fish to alien fish abundance)

7.2. Methods

7.3. Study Sites

Surveys were undertaken at 31 sites within the demonstration reach and seven control sites in each of the Gwydir and Namoi Rivers (Figure 25 and Table 11). The only variation to this was in the last survey year (autumn 2011), when sampling effort in the demonstration reach was reduced to six sites, as the initial 30 sites were directly related to the intervention-based monitoring of re-snagging works, which was completed in the previous year (Chapter 4).

7.3.1. Experimental design and statistical analysis

Annual surveys were conducted for five years (Figure 26). Given that the interventions were introduced sporadically throughout the study period, it was meaningless to nest sampling years into a specified "before" versus "after" intervention period, typical in traditional BACI designs. Instead, it was only possible to examine the change in the indicators of interest in the demonstration reach through time (between years) in relation to change observed in the two control reaches. Hypotheses were evaluated using a mixed model two-factor ANOVA with the main effect factors being Reach (fixed, 3 levels – Bourke to Brewarrina, Namoi and Gwydir) and Year (fixed, 4 levels – 1 to 4). The replicate sites within each reach were treated as repeated measures. The interaction for

Reach*Year was of primary interest, as it indicates a differential change in reaches across years. Many of these interactions, however, may be of little relevance to the hypotheses (e.g. controls changing relative to each other). Further interpretation of the relative responses between study reaches and years was primarily undertaken visually by examining trends in the interaction mean plots, referring only to relevant sources of variation. Native and alien fish abundance indicators were $\ln(x+1)$ transformed prior to analysis to meet the assumptions of ANOVA.

7.3.2. Fish sampling

All of the Barwon-Darling River and those deeper sites in the Namoi and Gwydir Rivers were sampled using a five-metre, twin-hulled aluminium boat (research vessel *Electricus*) mounted with a Smith-Root 7.5 GPP electrofishing unit between summer and autumn of each year (Figure 27). Shallower sites in the Namoi and Gwydir Rivers were sampled with a smaller four-metre flat-bottom boat (research vessel *Pole Volt*) mounted with a Smith Root 2.5 GPP electrofishing unit. Both boats had two Wisconsin array anodes suspended from the bow, creating a semi-hemispherical underwater electric field. Pulsed (120 pulses per second) direct electrical current (DC) was used due to the reduced tendency to produce strong and harmful muscular contractions in fish compared with alternating current (Snyder 2003). All other electrofishing settings were not standardised and were adjusted to achieve optimal catch efficiency for the given water conductivity. A total of 1080 electrofishing seconds (on time) was performed at each site, with total fishing effort allocated across all samplable habitats. Fish were dip-netted from the water and placed in a live well to recover until data were recorded and then the fish were returned alive to the water. Any fish positively identified but not dip-netted was also recorded. A sub-sample of each species (up to 50 fish) was measured.

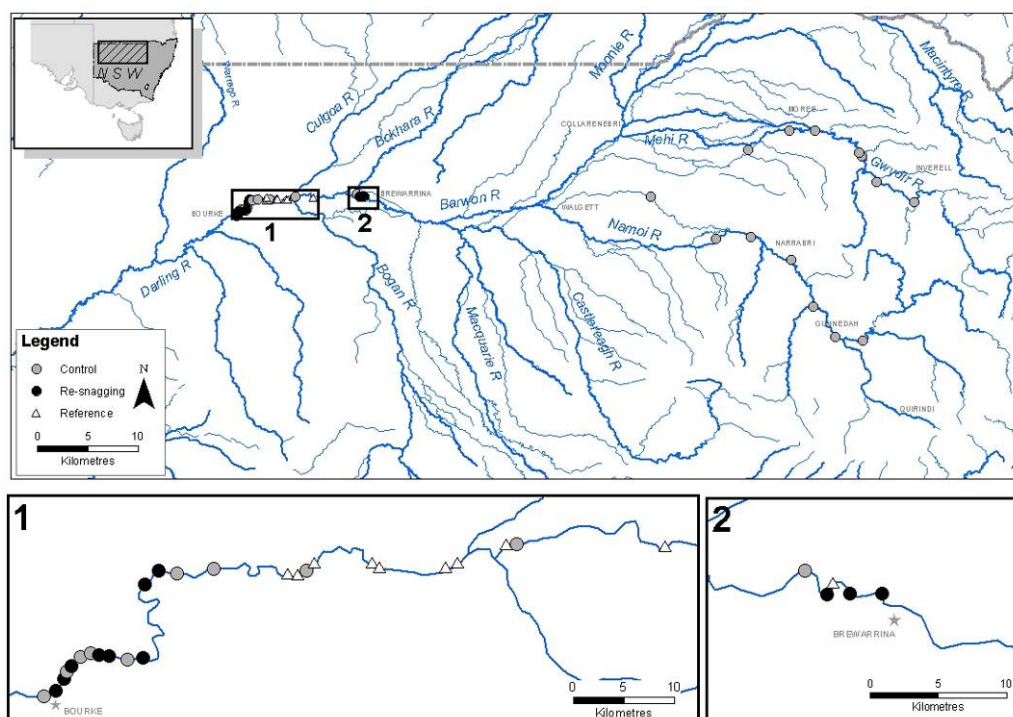


Figure 25. Electrofishing sampling sites within the demonstration reach and external controls in Namoi and Gwydir Rivers. Sites within inset 1 and 2 are considered part of the Bourke to Brewarrina reach treatment and their allocation was control, re-snagging or reference sites in reference to their use in the re-snagging experiments (Chapters 4 and 5).

Table 11. Study sites where annual fish surveys were carried out, showing their allocation to the different treatment reaches, as applicable to reach-scale condition monitoring.

Site Name	Lat.	Long.	Reach	Years	
				Sampled	Method
BTB006	-30.0873	145.93537	BTB	4	BE x 4
BTB008	-30.07946	145.94612	BTB	4	BE x 4
BTB010	-30.06202	145.95063	BTB	4	BE x 4
BTB011	-30.05433	145.95226	BTB	5	BE x 5
BTB012	-30.05535	145.95168	BTB	4	BE x 4
BTB014	-30.03888	145.97023	BTB	4	BE x 4
BTB017	-30.03911	145.98987	BTB	4	BE x 4
BTB019	-30.04505	146.00342	BTB	5	BE x 5
BTB021	-30.05535	145.95168	BTB	4	BE x 4
BTB022	-30.05077	145.95168	BTB	4	BE x 4
BTB023	-30.05535	145.95168	BTB	4	BE x 4
BTB037	-29.98254	146.02432	BTB	5	BE x 5
BTB040	-29.96636	146.03298	BTB	4	BE x 4
BTB043	-29.9732	146.05274	BTB	4	BE x 4
BTB047	-29.96877	146.08578	BTB	4	BE x 4
BTB058	-29.97404	146.1519	BTB	4	BE x 4
BTB060	-29.97162	146.1668	BTB	4	BE x 4
BTB062	-29.96511	146.17617	BTB	5	BE x 5
BTB064	-29.95071	146.15573	BTB	4	BE x 4
BTB076	-29.96251	146.22954	BTB	4	BE x 4
BTB078	-29.96368	146.23328	BTB	4	BE x 4
BTB086	-29.96824	146.2925	BTB	4	BE x 4
BTB089	-29.96417	146.30294	BTB	4	BE x 4
BTB098	-29.94476	146.34674	BTB	4	BE x 4
BTB100	-29.94696	146.35577	BTB	5	BE x 5
BTB126	-29.95155	146.49022	BTB	4	BE x 4
BTB194	-29.92843	146.80139	BTB	4	BE x 4
BTB197	-29.94912	146.81755	BTB	4	BE x 4
BTB200	-29.93447	146.81749	BTB	4	BE x 4
BTB202	-29.94308	146.83052	BTB	4	BE x 4
BTB205	-29.94317	146.85199	BTB	5	BE x 5
Benbraggie	-29.84344162	150.5242383	Gwydir	5	BE x 5
Keera	-29.98254542	150.7881344	Gwydir	5	BE x 5
Coulton	-29.65461367	150.4142416	Gwydir	5	BE x 5
Gum Flat	-29.4717901	150.0797671	Gwydir	5	BE x 5
Peach Trees	-29.63133	150.3994	Gwydir	5	BE x 5
Moree	-29.46958338	149.8997722	Gwydir	5	BE x 4, BPV x 1
Courallie	-29.61283	149.60136	Gwydir	5	BE x 4, BPV x 1
Vickery Bridge	-30.73385	150.0699	Namoi	5	BPV x 5
Kibah	-30.97618656	150.4242875	Namoi	5	BE x 1, BPV x 4
Yarral	-30.23301359	149.6228041	Namoi	5	BPV x 5
Old Weetawaa	-30.25134861	149.370822	Namoi	3	BPV x 3
Fingal	-30.94924	150.2247	Namoi	5	BE x 3, BPV x 2
Tarriaro TSR	-30.4006	149.91275	Namoi	5	BE x 4, BPV x 1
Noreen	-29.94585	148.9028	Namoi	5	BE x 4, BPV x 1

BE = Boat Electricus; BPV = Boat Pole Volt

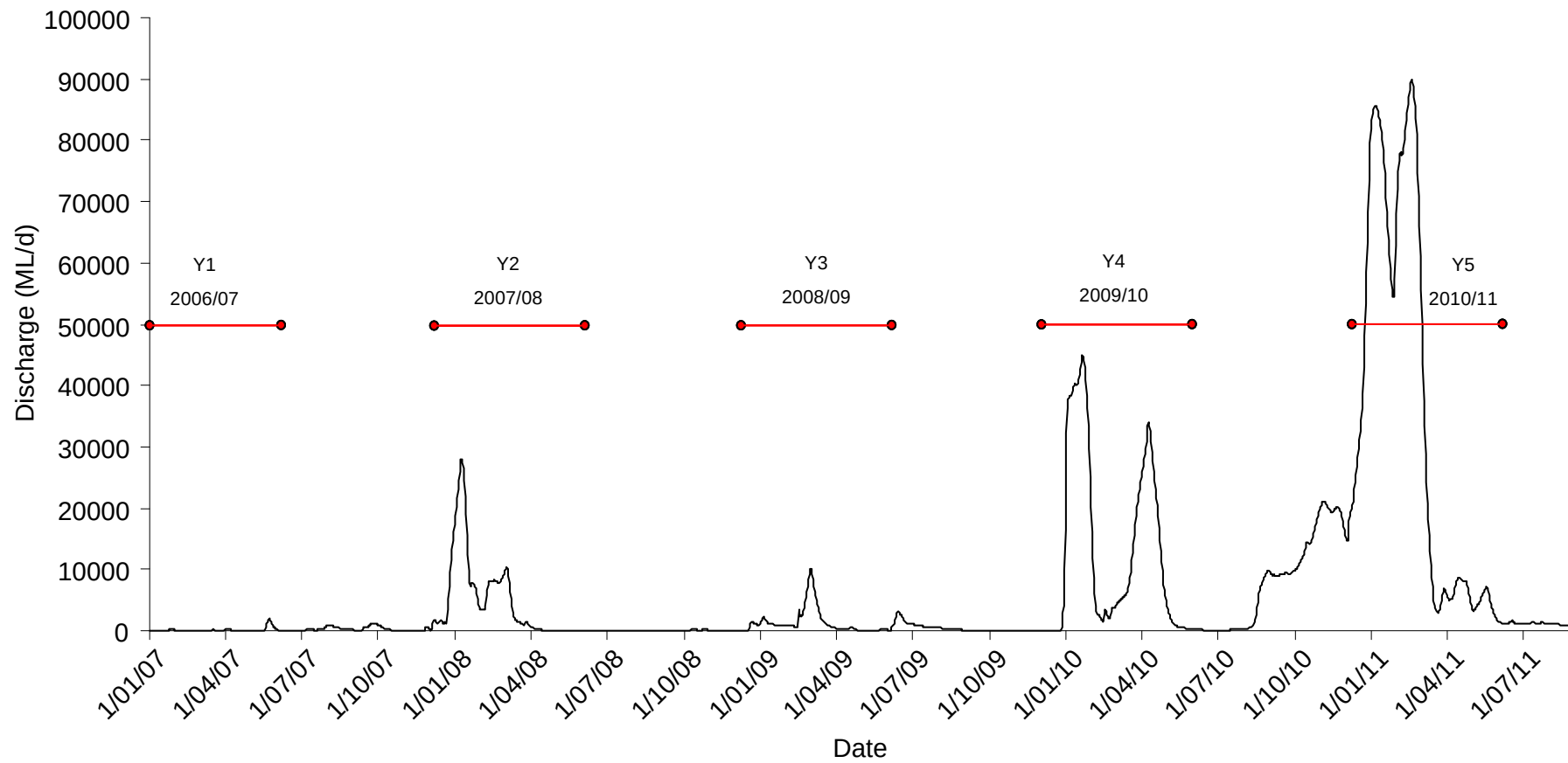


Figure 26. Hydrograph showing river flow at the Warraweena gauge (middle of the demonstration reach) and timing of the five annual sampling periods.



Figure 27. Boat electrofishing.

7.4. Results and preliminary discussion

A total of 43,804 fish from 18 species were caught from all study sites over the five survey years (Table 12). Within the demonstration reach, bony herring were the most abundant species, accounting for 48 per cent of the catch. Golden perch and Murray cod were sampled from most sites on most occasions and accounted for 3.7 and 0.6 per cent of the total catch in the demonstration reach, respectively. The alien species carp, goldfish and gambusia collectively accounted for a large proportion of the catch (46%), primarily due to the abundance of carp. Although small-bodied species such as gudgeon, rainbowfish, haryhead and smelt accounted for only 0.6 per cent of the catch across all years, their abundances were most likely underestimated by the boat electrofishing sampling method.

The sampling of a single threatened Agassiz's glassfish (or olive perchlet) was a surprising find in the demonstration reach, as this species is not typically sampled from this stretch of river (personal observation and Lintermans 2007). It is likely that this single fish was a vagrant washed downstream by flooding in the 2009/10 sampling season (Figure 26) from a population in a northern tributary (such as the Macintyre River), where they are more commonly sampled (C. Boys, unpublished data). A similar explanation is likely for the nine Hyrtyl's tandan caught, which were most likely washed downstream from southern Queensland tributaries during the 2009/10 and 2010/11 floods. Silver perch were rarely caught and in very small abundances, and no freshwater catfish were sampled from the demonstration reach. This is consistent with past sampling efforts in the Barwon-Darling River (Boys *et al.* 2005, Boys and Thoms 2006, Boys 2007) and reflects their reduced abundance and distribution throughout many rivers of the Murray-Darling Basin (Harris and Gehrke 1997).

Table 12. Catch summary from five years of electrofishing surveys carried out in the demonstration reach (30 sites), and Namoi (7 sites) and Gwydir (7 sites) River control reaches between 2006 and 2011.

Common name	Scientific name	Bourke to Brewarrina						Gwydir						Namoi						Grand Total
		Y1	Y2	Y3	Y4	Y5	Total	Y1	Y2	Y3	Y4	Y5	Total	Y1	Y2	Y3	Y4	Y5	Total	
Agassiz's glassperch	<i>Ambassis agassizii</i>	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
Silver perch	<i>Bidyanus bidyanus</i>	8	0	3	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	11
Goldfish	<i>Carassius auratus</i>	31	66	39	342	96	574	1	8	3	7	63	82	31	25	13	15	205	289	945
Flyspecked hardyhead	<i>Craterocephalus stercusmuscarum</i>	6	5	0	0	0	11	18	11	46	2	7	84	6	4	1	6	0	17	112
Common carp	<i>Cyprinus carpio</i>	339	467	373	2733	11262	15174	42	50	63	62	93	310	68	487	88	104	166	913	16397
Gambusia	<i>Gambusia holbrooki</i>	311	13	26	25	0	375	5	1	9	0	3	18	12	155	230	2	0	399	792
Western carp gudgeon	<i>Hypseleotris klunzingeri</i>	0	0	0	0	0	0	1	0	0	0	0	1	4	0	0	0	0	4	5
Carp gudgeon	<i>Hypseleotris spp</i>	32	134	2	3	0	171	26	15	39	83	24	187	438	379	176	61	6	1060	1418
Lake's carp-gudgeon	<i>Hypseleotris sp5</i>	0	0	0	0	0	0	2	0	0	0	0	2	0	0	0	0	0	0	2
Spangled perch	<i>Leiopotherapon unicolor</i>	12	46	7	322	94	481	1	1	0	0	7	9	5	26	11	2	17	61	551
Murray cod	<i>Maccullochella peelii</i>	24	43	63	85	0	215	45	56	50	81	105	337	17	22	32	25	19	115	667
Golden Perch	<i>Macquaria ambigua</i>	147	226	288	624	27	1312	19	18	10	23	22	92	8	14	7	16	16	61	1465
Murray-Darling rainbowfish	<i>Melanotaenia fluviatilis</i>	4	7	1	16	0	28	176	24	46	25	63	334	56	76	84	188	9	413	775
Purple spotted gudgeon	<i>Mogurnda adspersa</i>	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1
Bony herring	<i>Nematalosa erebi</i>	6150	5068	373	4261	1066	16918	89	95	44	118	66	412	958	382	419	168	319	2246	19576
Hyrtyl's tandan	<i>Neosilurus hyrtlii</i>	0	0	0	5	4	9	0	0	0	0	0	0	0	0	0	0	0	0	9
Australian smelt	<i>Retropinna semoni</i>	8	0	0	4	0	12	233	15	29	2	5	284	13	14	3	4	1	35	331
Freshwater catfish	<i>Tandanus tandanus</i>	0	0	0	0	0	0	2	1	9	0	2	14	1	2	6	3	0	12	26
Grand total		7072	6075	1175	8421	12549	35292	660	295	348	403	461	2167	1617	1586	1070	594	758	5625	43084

Total and native species richness differed between reaches (Table 13, Reach $p < 0.05$) and was typically higher in the Namoi and Gwydir reaches than in the demonstration reach (Figure 28). One reason for this difference appears to be the presence of a large variety of gudgeon species (e.g. Lake's, carp and purple-spotted) and freshwater catfish in the Namoi and/or Gwydir reaches (Table 12). It is likely that this reflects the difference in habitat present between the demonstration reach and control reaches, with the controls being shallower and containing more structural habitat such as submerged and emergent macrophyte and fringing vegetation (C. Boys personal observation), which are favoured habitats of these species (Humphries *et al.* 1999, Lintermans 2007; Meaghan Rourke NSW DPI, unpublished data). This greater diversity of habitats will undoubtedly support more species at a given reach at any given time (Tonn and Magnuson 1982, Eadie and Keast 1984, Benson and Magnuson 1992). The difference in total and native species richness among reaches was not consistent among years (Table 13, Reach*Year $p < 0.05$). This was primarily due to an increase in the number of native species in Year 4 relative to the control reaches (Figure 28). As mentioned previously, the appearance of vagrant species such as Agassiz's glassfish and Hyrtl's tandan in the demonstration reach after flooding is the likely explanation of this increase (Table 12). The increase was transient (Figure 28) and represented an anomaly of background disturbance (flooding), rather than representing a response that could be attributable to any interventions in the demonstration reach.

Whilst the mean number of alien species per site differed between reaches, this difference was sporadic between years (Table 13, Reach $p < 0.05$ and Reach*Year $p < 0.05$) and showed no trend that would suggest any meaningful difference between reaches or responses at the demonstration reach relative to the controls (Figure 28).

Table 13. Results of mixed-model repeated measures ANOVA.

Variable	Source	Numerator DF	Denominator DF	F	P
Total species richness					
	Reach	2	42	14.87	<0.0001
	Year	4	141	1.61	0.1762
	Reach*Year	8	141	3.31	0.0017
Native species richness					
	Reach	2	42	24.83	<0.0001
	Year	4	141	1.69	0.1564
	Reach*Year	8	141	2.37	0.0202
Alien species richness					
	Reach	2	42	4.44	0.0177
	Year	4	141	0.98	0.4233
	Reach*Year	8	141	2.38	0.0193
Native abundance ln(x+1) transformed					
	Reach	2	42	5.31	0.0088
	Year	4	141	6.03	0.0002
	Reach*Year	8	141	3.48	0.0011
Alien abundance ln(x+1) transformed					
	Reach	2	42	60.02	<0.0001
	Year	4	141	23.88	<0.0001
	Reach*Year	8	141	13.55	<0.0001
Nativeness					
	Reach	2	42	2.33	0.1095
	Year	4	141	2.32	0.0601
	Reach*Year	8	141	1.56	0.1430

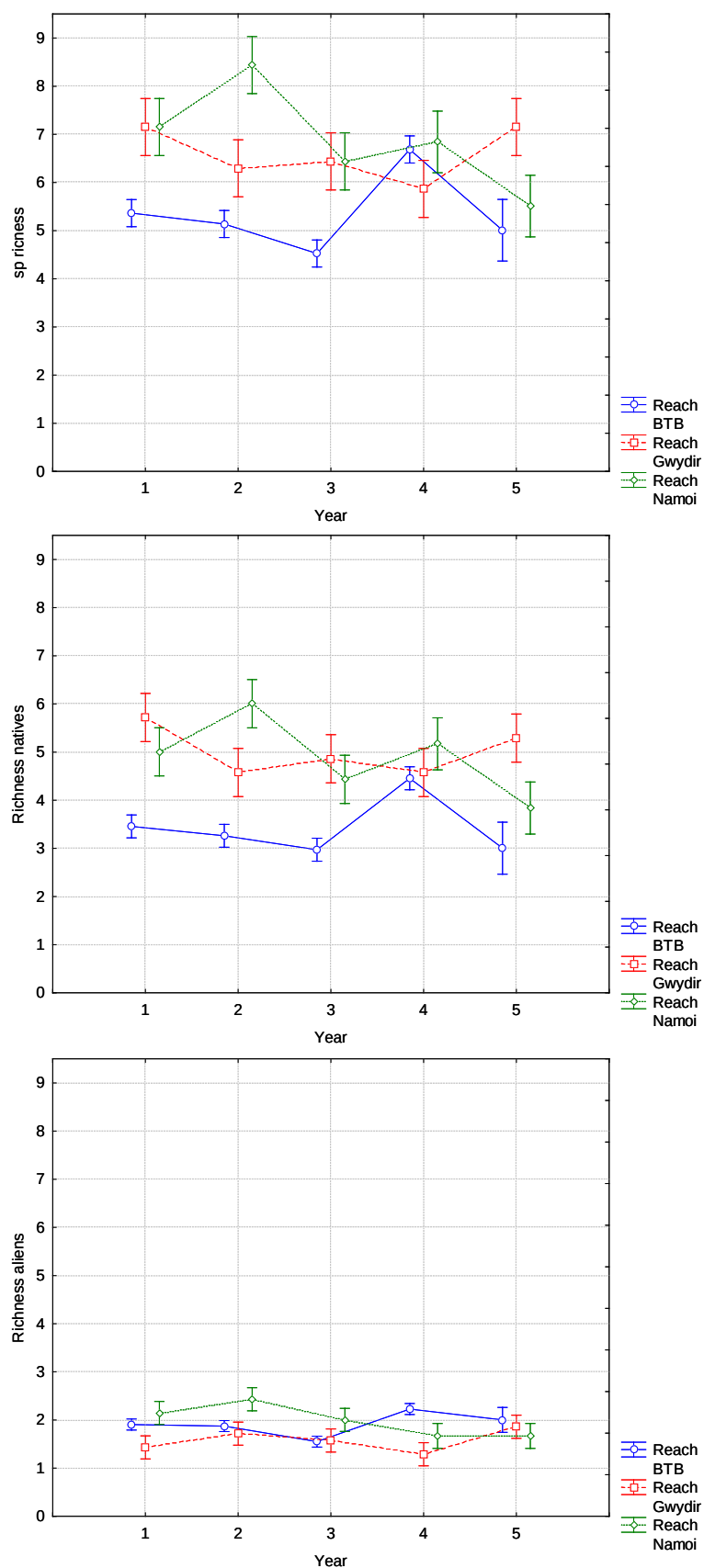


Figure 28. Interaction mean ($\pm$ S.E.) plots (mean values per site within reach) showing change in total species richness (top), native species richness (middle) and alien species richness (bottom) across the five study years at the Bourke to Brewarrina Demonstration Reach (B2B) and the Namoi and Gwydir River control reaches.

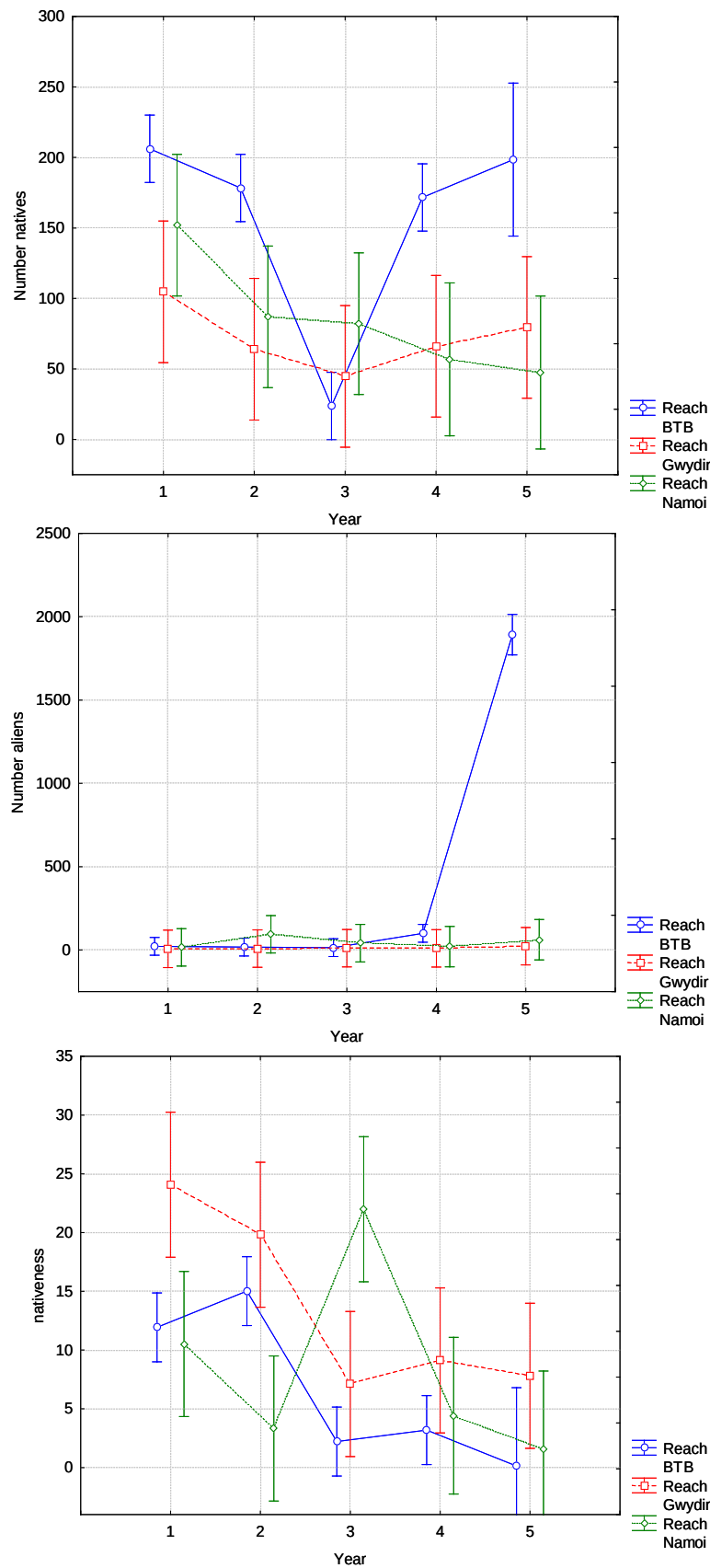


Figure 29. Interaction mean ($\pm$ S.E.) plots (mean values per site within reach) showing change in the total abundance of natives (top), aliens (middle) and proportion of natives to aliens or 'nativeness' (bottom) across the five study years at the Bourke to Brewarrina Demonstration Reach (B2B) and the Namoi and Gwydir River control reaches.

The abundance of both native and alien species differed between reaches and years (Table 13, Reach $p < 0.05$, Year $p < 0.05$), with the magnitude of difference varying significantly among years (Table 13, Reach*Year $p < 0.05$). Native species were generally more abundant in the demonstration reach, due to a higher mean number of bony herring per site (Figure 29). In the demonstration reach, the abundance of natives declined noticeably in Year 3 and then recovered (Figure 29). The transient nature of this response provides no evidence of an improvement in native fish numbers in the reach over successive years. Instead, the decline in Year 3 was driven primarily by a drop in bony herring abundance. The drop may be related to the noticeable fish kills of bony herring and confirmed outbreak of epizootic ulcerative syndrome (EUS or red-spot disease) that occurred in the demonstration reach during the previous year (see Appendix 5). A large decline in golden perch, Murray cod, spangled perch and bony herring in Year 5 (Table 12) similarly occurred the year after these species were seen affected by EUS and also followed within months of a large blackwater event and native fish kill upstream of Bourke (NSW DPI unpublished information). Although this association does not infer causality, the potential impact of EUS on native fish in the demonstration reach and throughout the Murray-Darling Basin in general warrants further investigation.

The abundance of alien fish differed between reaches and years (Table 13, Reach $p < 0.05$, Year $p < 0.05$), with the most obvious response occurring at Year 5 when alien fish numbers spiked at the demonstration reach but not at the controls (Figure 29, Table 13, Reach*Year $p < 0.05$). There is no reason to believe this response was at all related to any intervention in the demonstration reach, but rather reflected a huge recruitment of carp to the reach in that year, where numbers reached in excess of 1,700 carp per site (Figure 29 and Figure 30) and led to a significant decline in nativeness (Figure 29, Table 13, Year $p < 0.05$). This boom in carp numbers has been expected, given the two successive years of spring/summer flooding in the northern Murray-Darling Basin (Figure 26). Indeed, the increase in juvenile carp in the reach in years 4 and 5 (Figure 31) suggests that major carp breeding events had recently occurred.



Figure 30. A significant increase in carp abundance was observed in the demonstration reach during the 2010/11 (Year 5) sampling season.

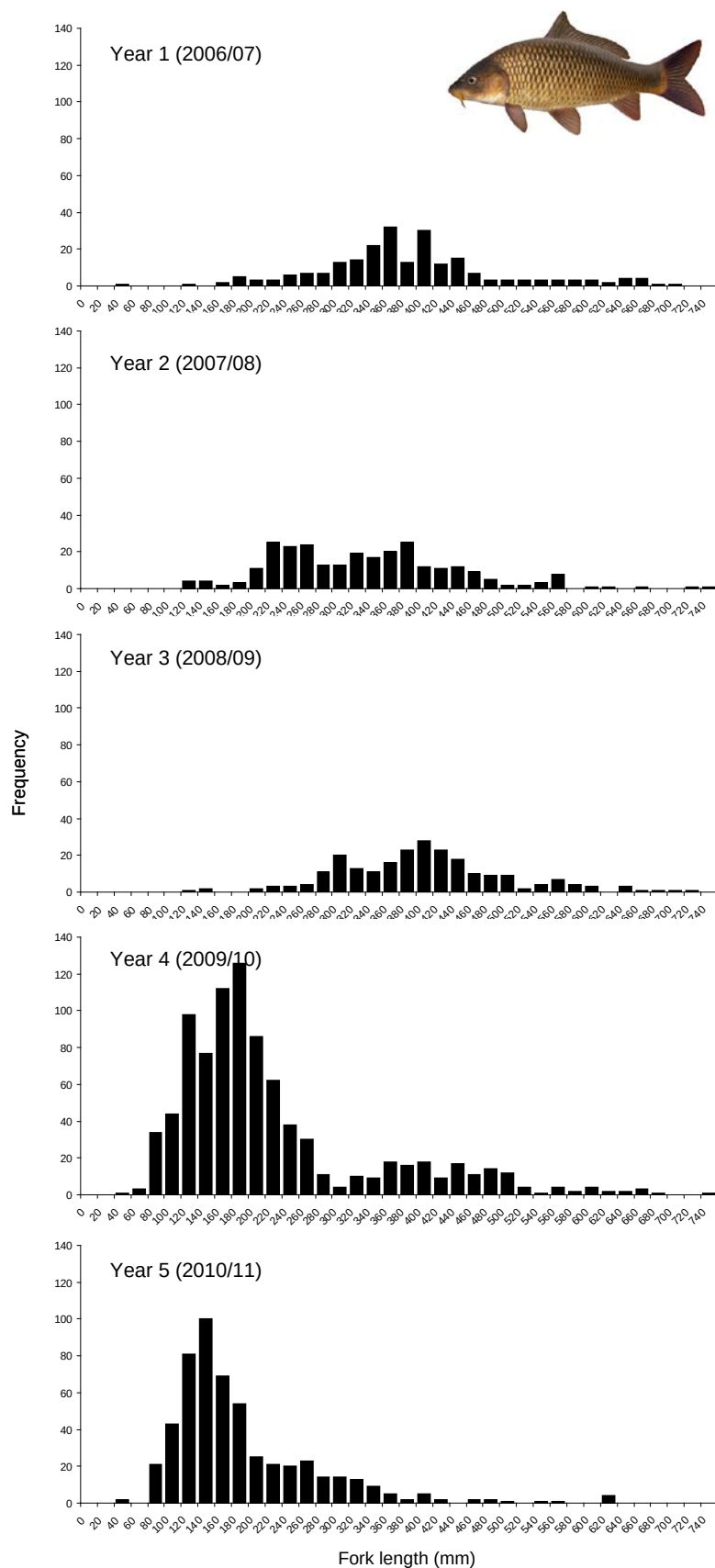


Figure 31. Length frequency histograms showing annual change in the size-class structure of carp sampled across all sites in the demonstration reach.

8. TAGGING PROGRAM

8.1. Objectives

A tagging program was initiated within the demonstration reach with the objective of:

1. Examining the scale of fish movements to better understand the potential scale across which interventions in the reach can influence populations within and beyond the demonstration reach.
2. Engaging the local angling community to increase awareness surrounding the demonstration reach and the Native Fish Strategy.

8.2. Methods

Tagging was carried out by researchers during routine electrofishing surveys (see Chapter 6). During processing, fish were identified, inspected for abnormalities and their length measured. A subset of native and alien fish larger than 150 mm were tagged with external angler return tags (Figure 32). Tag numbers, recaptures, biological and spatial information were recorded in the NSW DPI Freshwater Fish Research Database (Access). The tagging program was advertised throughout the Murray-Darling Basin (Figure 33), and anglers were given a hotline number (written on the tag) with which to report recaptures.



Figure 32. A Murray cod fitted with an externally protruding identification tag. Inset: tag being inserted next to the dorsal fin rays with a needle.

NSW DPI

FRESHWATER FISH TAGGING PROGRAM



**HAVE YOU
CAUGHT A
TAGGED FISH
OR KNOW OF
SOMEONE THAT
HAS?**

NSW DPI is currently undertaking research investigating freshwater fish movements in many waterways throughout NSW. If you happen to catch a fish with an external tag or a microchip in its shoulder *please call our tag return hotline on*

FREECALL 1800 185 027 or log on to
www.fisheries.nsw.gov.au/science/freshwater_tagging






and record your details.

All anglers who choose to assist will be rewarded with a prize and given the details of their tagged fish. Information gathered from tagged fish assists researchers to gain a better understanding about fish migration and habitat use within our rivers. The information is used in order to more successfully manage our fish stocks.

Your assistance is vital and highly appreciated!

Figure 33. Flyer advertising tagging program to anglers.

8.3. Results and preliminary discussion

Of the 1,923 fish tagged within the demonstration reach and the Namoi and Gwydir River control reaches, 3 per cent ($n = 58$) had been recaptured by researchers or anglers (Table 14). The most frequently recaptured species were golden perch ($n = 25$), Murray cod ($n = 18$) (Figure 34) and carp ($n = 14$).

The vast majority (all but 3 individuals) undertook upstream migrations (Figure 35). Golden perch were the most mobile species, undertaking large upstream migrations (Figure 36). Figure 35 shows that several tagged golden perch were caught below St George Weir (Condamine River) in Queensland and several tagged golden perch and a single cod at Goondiwindi (Macintyre River) immediately after significant flooding in these northern tributaries. This highlights that large-scale upstream migrations are undertaken by golden perch and Murray cod, often on the back of large floods, when passage is enhanced. The St George fish were caught on the back of flooding from southern Queensland in both 2009/10 and 2010/11, whereas the Goondiwindi fish were captured on the back of flooding in 2010/11. The vast majority of Murray cod were recaptured at their release point in subsequent years, with only one undertaking a large-scale migration (Figure 35 and Figure 36). This suggests high site fidelity, with the ability for large-scale migrations in response to environmental cues such as flooding. Such a 'shifting home range' concept has been proposed for golden perch and carp using data collected from radio-tagged individuals (Crook 2004). In this study, carp were often recaptured at their release point (Figure 36), with all individuals undertaking upstream migrations recaptured from the main-stem of the Barwon-Darling River, most under Brewarrina Weir (Figure 35). Similarly, multiple golden perch and Murray cod were caught within five kilometres below Brewarrina Weir (Figure 35). For golden perch, these recaptures occurred after large upstream migrations, indicating that Brewarrina Weir may be a significant obstacle to fish passage over a large range of flows.

As well as providing some interesting insight into the migration of native and alien species, this data informs the science of demonstration reaches in a number of ways. Firstly, the results demonstrate that fish passage could benefit immensely from the construction of the Brewarrina Fishway, which is currently underway. Secondly, it illustrates how localised river rehabilitation activities can have large-scale implications due to the large home range and mobility of fish populations. This raises a final consideration and concern for demonstration reach monitoring. That is, given the mobility of fish, designing a rigorous monitoring program is problematic given the lack of independence between restored and unrestored sections both within and between demonstration reaches. These results have demonstrated that fish have the ability to move between rehabilitated and non-rehabilitated control or reference sites within the demonstration reach, thus confounding 'within demonstration' reach monitoring programs. Furthermore, fish have demonstrated an ability to move between the Bourke to Brewarrina and Condamine Demonstration Reaches, potentially confounding findings in other demonstration reaches.

Table 14. Numbers of different fish species tagged with external dart tags within the demonstration reach and in the Namoi and Gwydir control reaches, showing the numbers recaptured by researchers or anglers.

Common name	Scientific name	Bourke -Brewarrina		Namoi		Gwydir		Total tagged	Total recapt.
		No. tagged	No. recaptured	No. tagged	No. recaptured	No. tagged	No. recaptured		
Silver perch	<i>Bidyanus bidyanus</i>	5	0	0	0	0	0	5	0
Goldfish	<i>Carassius auratus</i>	4	0	0	0	1	0	5	0
Common carp	<i>Cyprinus carpio</i>	820	12	66	2	102	0	988	14
Spangled perch	<i>Leiopotherapon unicolor</i>	1	0	0	0	0	0	1	0
Murray cod	<i>Maccullochella peelii</i>	128	6	85	9	35	3	248	18
Golden Perch	<i>Macquaria ambigua</i>	632	25	22	0	10	0	664	25
Freshwater catfish	<i>Tandanus tandanus</i>	0	0	5	0	7	1	12	1
Total		1590	43	178	11	155	4	1923	58



Figure 34. A tagged Murray cod recaptured by anglers in the demonstration reach.

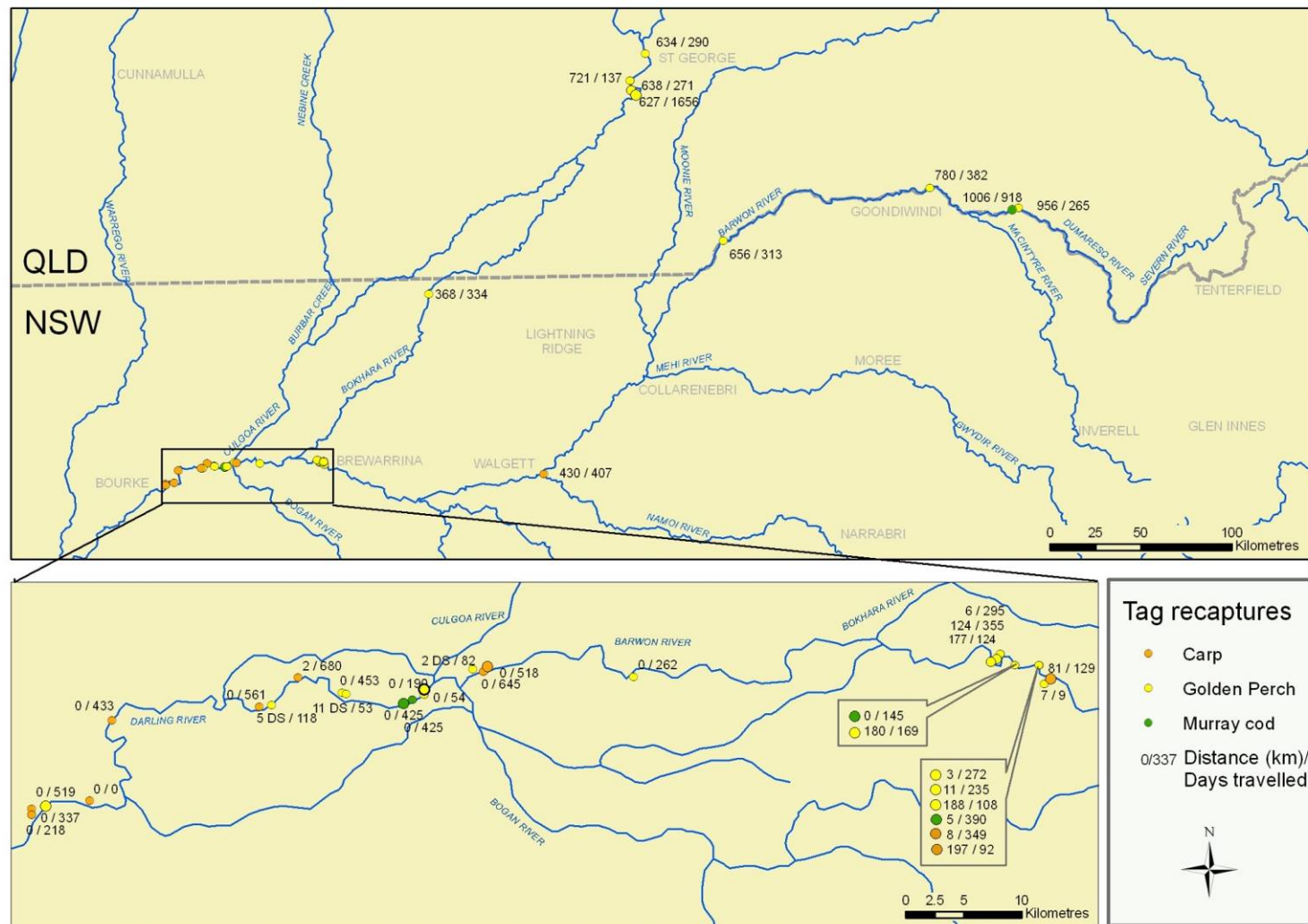


Figure 35. Location of tag recaptures within the demonstration reach and beyond, showing species and the distance travelled (Km) and days to recapture. DS refers to a downstream migration.

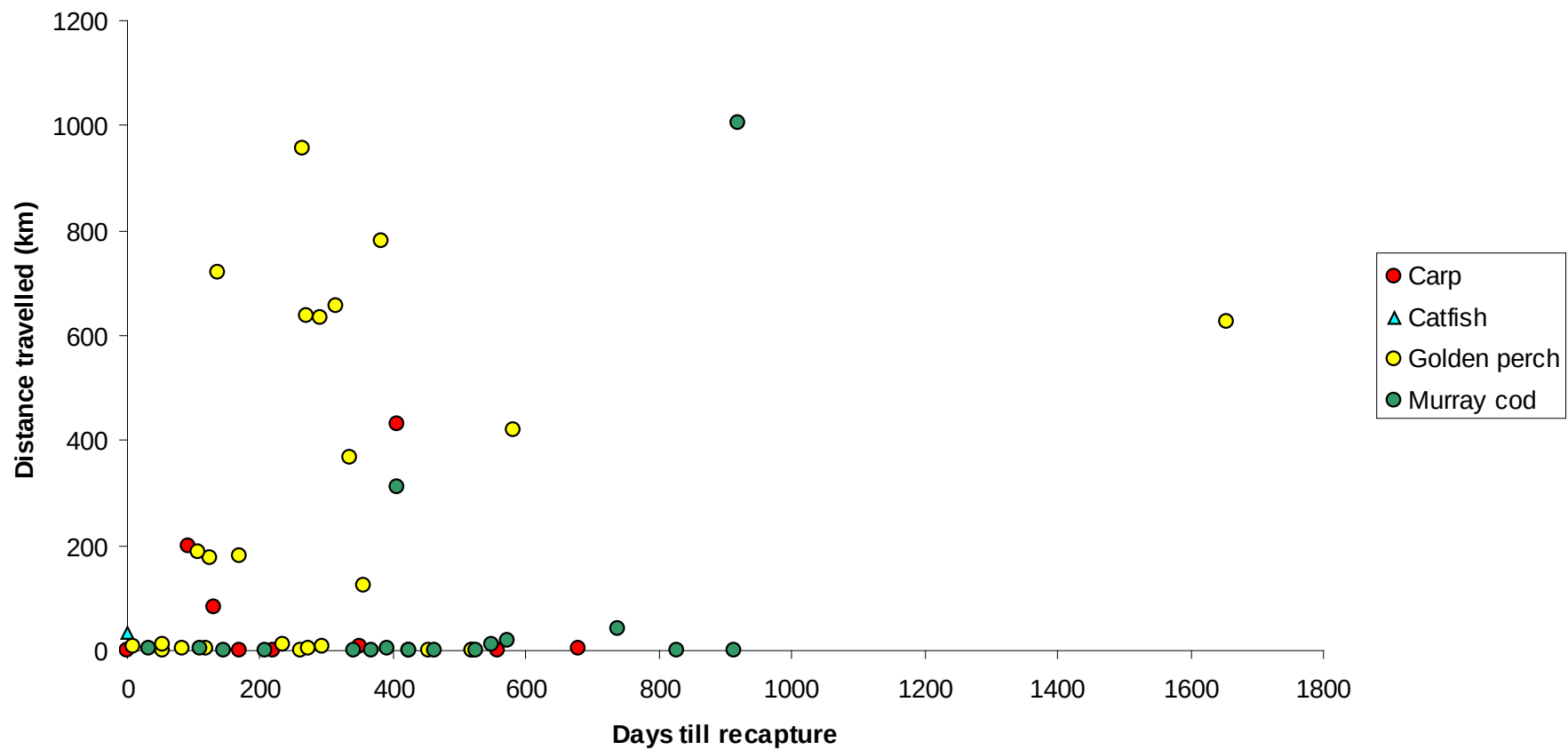


Figure 36. Scatter plot showing the distance between tagging and recapture sites plotted against the number of days between tagging and recapture.

9. SYNTHESIS AND GENERAL DISCUSSION

9.1. Effectiveness of re-snagging

Previous research (Boys and Thoms 2006) has shown that within the Barwon-Darling River (and this demonstration reach), golden perch and Murray cod are most frequently found in close proximity to large wood. It has also been shown through detailed mapping of large wood throughout the demonstration reach (Chapter 3) that in many parts of the reach (particularly at either end), this type of habitat is below the levels seen in upstream reference reaches (Boys 2007). Based on these observations, it was predicted that by increasing large wood loading to reference levels, subsequent improvements in the abundance of native fish such as golden perch and Murray cod would occur, potentially improving the proportion of native fish relative to alien fish (nativeness).

This study provided no evidence of such a response in golden perch or Murray cod abundance, or nativeness to re-snagging (Table 15 and Chapter 4). This does not mean that native fish did not aggregate on reintroduced snags, as both golden perch and Murray cod were captured on snags within 12 months of their placement (Figure 37). It does, however, indicate that across a suite of replicated re-snagging sites, there was not a consistent measurable response relative to natural background and inter-annual variability.



Figure 37. Murray cod captured off snags that were introduced in the previous year.

To date, reports on the success of re-snagging projects have been less than consistent (Lester and Boulton 2008). The evaluation of experimentally reintroduced large wood has demonstrated positive responses in biota in some instances (Hilderbrand *et al.* 1997, Brooks *et al.* 2001, Bond and Lake 2005, Nicol *et al.* 2005, Lester *et al.* 2007), variable response in others (Larson *et al.* 2001, Brooks *et al.* 2006, Coleman 2006, Howell *et al.* 2010) and on the rare occasion, negative effects (Spanhoff *et al.* 2006). Results of the current study, when viewed alongside those of other studies, demonstrate that, at the very least, the success of re-snagging can be context-specific. Therefore, projects need to be evaluated where possible to identify successes and failures and better understand when and where alternative solutions to instream rehabilitation may be more appropriate (Bond and Lake 2005).

There are a number of possible explanations as to why a measurable response in native fish was not detected in the current study. The first is that the works were not sufficient to influence fluvial processes. It is generally assumed that large wood creates habitat complexity by affecting hydraulics and geomorphology (Marsh *et al.* 2001, Hughes *et al.* 2007). During elevated flows, increased turbulence around large wood creates scour and fill, which can create complex habitat that attracts biota (Marsh *et al.* 2001). In the absence of elevated flows, these fluvial processes are unlikely to occur (Bond and Lake 2005). In the Barwon-Darling River, low flows are often insufficient to create hydraulic diversity around large wood (Thiem 2002). This was observed during the current study (Table 15 and Chapter 5). Within the first 12 months following re-snagging, there was no significant high-flow event, and localised increases in depth (suggesting scour processes) were not observed in re-snagging reaches relative to control reaches (Table 15 and Chapter 5). Since the completion of the hydraulic surveys, there have been two high-flow events and further bathymetric and hydraulic surveys are now underway over a larger range of flows as part of a current PhD project being funded as part of this monitoring program.

A second possible reason for a lack of response may be that rehabilitation efforts were not made at an appropriate scale. Biota can fail to respond to riverine rehabilitation if the efforts are done at inappropriate scales (Bond and Lake 2003, Pretty *et al.* 2003). The current study used the approach of reintroducing large wood at ten 300-m sites in order to increase large wood loading to levels equivalent to the reference sites. The prediction that this would increase the abundance of golden perch and Murray cod may be flawed in a number of ways. Re-snagging in this way resulted in small 'pockets' of reference-state loading, within a landscape often devoid of large wood. This is not an equivalent state to reference sites, which were surrounded by large stretches of river with a significantly greater loading of large wood. A significantly larger re-snagging effort across larger stretches of river would be required to achieve a more 'natural' reference state. Not only was this beyond the capacity of the current demonstration reach program, but it would also exceed the resources of rehabilitation programs typically undertaken in large lowland river systems like the Barwon-Darling River.

This raises the question of what is an effective scale for re-snagging in a large lowland river such as the Barwon-Darling River. In the current study, golden perch abundance was not found to be higher in reference locations than in control or re-snagging locations. This suggests that reach-scale re-snagging may have a limited impact on the abundance of this species. Tagging results (Chapter 7) show that golden perch were highly mobile, capable of traversing not only the different treatment sites, but often moving beyond the demonstration reach itself. Therefore, whilst golden perch will frequently associate with large wood at the meso-habitat scale, this relationship weakens as the spatial scale of association increases. Hence, over large spatial scales, large wood loading is a poor predictor of native fish abundance (Boys and Thoms 2006). This mobility has important implications for the design of rehabilitation studies, since it makes it extremely difficult to assume that treatment sites are independent. Despite this, it is not uncommon for fish habitat rehabilitation studies to consider sites within close proximity of each other to be acting independently of each other (Bond and Lake 2005).

Based on this reasoning, a more appropriate indicator species for evaluating responses to re-snagging may be Murray cod. Although Murray cod can undertake large-scale migrations (Koehn and Nicol 1997), they also display strong site fidelity, with tagged fish being found within the vicinity of the same snag when recaptured in subsequent years (Chapter 7). This may explain why Murray cod appeared in significantly larger abundances in reference reaches than control reaches. The lack of response in Murray cod abundance following re-snagging may therefore be a better indication that the re-snagging activities failed to produce an ecologically measurable response.

9.2. Whole-of-demonstration reach responses

Demonstration reach-scale condition monitoring failed to detect a response in key fish assemblage indicators that could be attributed to rehabilitation interventions (Table 15 and Chapter 6). This is hardly surprising given the lack of response to re-snagging and the sparse nature with which re-snagging (about 3 km in a 210 km reach), riparian and gully erosion measures were applied across the demonstration reach. Furthermore there was a lack of interventions targeting carp, and restricted fish passage at the bottom end (due to Bourke Weir) and the top end (due to Brewarrina weir) of the reach. It is acknowledged that remediating barriers to fish passage can lead to some of the largest and quickest responses in the recovery of fish populations compared to most other riverine rehabilitation strategies (Roni et al. 2005).

Changes in key fish indicators that did occur in the demonstration reach between years were clearly related to inter-annual differences in environmental disturbances rather than rehabilitation interventions (Table 15). For example, two successive floods in the summer of 2009/10 and 2010/11 resulted in the significant recruitment of juvenile carp into the demonstration reach in the latter years of monitoring (Chapter 6). The 2010/11 flood was also followed by a black water event and significant native fish kill (NSW DPI, unpublished information). This, combined with fish kills in previous years, possibly relating to repeated and severe epizootics of epizootic ulcerative syndrome (EUS) (Appendix 5), undoubtedly contributed to lower native fish abundances in recent years.

Rehabilitation programs can fail to create or detect a biotic response when faced with large-scale disturbances (Bond and Lake 2005). When rehabilitating sand-slug effected reaches in the Granite Creeks system (Victoria) with large wood, Bond and Lake (2005) observed that rehabilitation of the fish community was flow-related, with sustained responses being constrained by drought. Whilst it is highly unlikely that floods in the current study constrained rehabilitation responses in the Bourke to Brewarrina Demonstration Reach, the inter-annual variation created by large-scale environmental disturbances such as this can make it more difficult to test for significant treatment*time interactions. This makes it difficult to discern rehabilitation responses from background environmental 'noise' within an MBACI design. In addition, fish can undertake large-scale migrations, making it difficult to define an appropriate sampling frame, which can confound experimental designs. A prime example of this is the recapture of golden perch tagged in the Bourke to Brewarrina Demonstration Reach in the vicinity of the Condamine Demonstration Reach (Chapter 6).

9.3. Implications for this and other demonstration reaches

Monitoring is most effective when it feeds back directly into management, making it responsive and adaptive (Gray and Jensen 1993). Without such adaptive management and the acknowledgment of both successes and failures, rehabilitation science will fail to progress (Palmer et al. 2005). Comprehensive and regular reviews of rehabilitation findings are therefore required not only to fine-tune monitoring and rehabilitation programs, but also to avoid perpetuating costly

and ineffective rehabilitation practices that are based on untested assumptions, rather than being informed by an evidence-based approach.

This report marks a significant milestone for the implementation and evaluation of demonstration reaches in the Murray-Darling Basin. Being the most progressed monitoring program of all the Basin's demonstration reaches, it is the first opportunity to scientifically evaluate ecological outcomes arising from the program, resourcing constrained monitoring in the Bourke to Brewarrina Demonstration Reach to one intervention (re-snagging) in combination with reach-scale condition monitoring. After five years of monitoring (incorporating multiple years of pre-intervention monitoring), there was no evidence of eco-hydraulic response in relation to re-snagging or the general suite of interventions applied at the reach scale.

A fundamental premise of demonstration reaches is being able to engage the community and demonstrate that systematically addressing multiple key threats to river health can have a positive impact on native fish. Critical to this is that improvements need to be measurable and monitored. Whether a failure to detect a response to activities in the Bourke to Brewarrina Demonstration Reach was related to an inability to apply interventions at a sufficient scale to induce a response or due to difficulties associated with detecting responses in a highly variable system, the findings highlight a critical need to take stock and revisit the demonstration reach concept. The findings contained within this report should not be viewed in isolation, as rehabilitation success can be context-specific. Just as rehabilitation science benefits from a multiple-lines-of-evidence approach, made possible by comparing the findings of different studies across different contexts (Downes et al. 2002), the current findings need to be critically examined alongside those of other demonstration reaches in the Basin as they emerge.

Practitioners involved in the Bourke to Brewarrina Demonstration Reach now face certain decisions about how to apply the findings of the current study. Does monitoring continue in expectation of delayed or 'lag' effects? Does investment need to be intensified in an attempt to induce a larger measurable response? Or does the feasibility of undertaking such a diverse rehabilitation program over such an ambitious spatial scale need to be reconsidered? One option is to temporally scale back monitoring in the Bourke to Brewarrina Demonstration Reach, until such time that major works, with a likelihood of inducing a measurable response to native fish in the reach and completed. Construction of Brewarrina and Bourke Fishway is a likely example of such an activity. This report has documented the spatial and temporal monitoring design, methodologies, results and conclusions to date. This report will be critical in ensuring that monitoring can be restarted at a later date without a loss of 'institutional memory'.

It is recommended that researchers and managers involved in the Native Fish Strategy critically examine the findings presented in this report alongside the findings of other demonstration reaches as they emerge. It is hard to argue with the general principles and theory behind demonstration reaches (Barrett 2004) and the benefits that can be gained through active community involvement in simultaneously addressing multiple threats to native fish. However, in light of the current findings and given that being able to 'demonstrate' a response is a critical part of demonstration reach success, it is necessary to objectively and critically assess whether the demonstration reach model is, in fact, the 'best' way to engage the community about native fish habitat rehabilitation. It is also worth revisiting the demonstration reach monitoring framework (Boys et al. 2009) in light of some of the experimental difficulties that this report has identified.

Regardless of the future direction of the demonstration reach concept, or individual demonstration reaches, one should not doubt their valuable contribution in stimulating debate and challenging some untested assumptions of rehabilitation practice within the Murray-Darling Basin. By doing this, they will undoubtedly inform the sound investment of natural resource managers in ongoing aquatic rehabilitation and improve how rehabilitation projects are monitored. Critical to this is

ensuring that the methods and findings are documented in reports such as this and made publically available.

Table 15. Summary of key findings associated with testing rehabilitation hypotheses in the Bourke to Brewarrina Demonstration Reach.

Indicator type	Hypothesised response of indicator	Key findings	Evidence to support hypothesis?
Sub-reach re-snagging			
Fish assemblage	H1a: The abundance of Murray cod changed in re-snagging sites following re-snagging, suggesting a response to rehabilitation relative to the control and reference reaches.	Murray cod abundance showed a trend (albeit non-significant) of increasing abundance across all treatments in successive years. The biggest response was seen in reference reaches, which had significantly more Murray cod than the control or re-snagging reaches, particularly post-intervention. This suggests a preference of Murray cod for reference reaches, and an inability of re-snagging to replicate this.	No
Fish assemblage	H1b: The abundance of golden perch changed in re-snagging sites following re-snagging, suggesting a response to rehabilitation relative to the control and reference reaches.	Golden perch abundance increased significantly in successive years, but the response was equivalent across the re-snagging, control and reference treatments, suggesting no response to re-snagging.	No
Fish assemblage	H1c: 'Nativeness' (proportion of total native fish to alien fish) changed in re-snagging sites following re-snagging, suggesting a response to rehabilitation relative to the control and reference reaches.	Decreased across all treatments in the last two years, driven by a reach-scale reduction in abundance of bony herring and gudgeon species and reciprocal increase in carp and goldfish unrelated to re-snagging.	No
Geomorphic/bathymetric	H2a: Re-snagging resulted in a change in mean depth relative to reference and control sites, suggesting scour effects from large wood placement.	Reference sites tended to be shallower, reflecting their position within the mid-sections of the reach. A small change was observed in mean depth across all treatment sites and provided no evidence of a differential response at re-snagging sites relative to control and references.	No

Hydraulic	H2b: Re-snagging resulted in a change in the hydraulic character relative to reference and control sites, suggesting a response to large wood placement.	A small but non-significant change in hydraulic character was observed in the re-snagging sites relative to controls and references, providing little if any evidence of a response to re-snagging.	No
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General reach-scale condition monitoring

Fish assemblage	H3a: Total species richness measured across the demonstration reach changed during rehabilitation activities, suggesting a response in the demonstration reach relative to the control reaches.	Gwydir and Namoi control reaches typically had more species than the demonstration reach, primarily being driven by the presence of more gudgeon species and freshwater catfish. This most likely reflects a difference in the structural complexity of habitat between the demonstration reach and the controls. The difference was not consistent in all years and in Year 4, the presence of some upstream vagrant species (Hyrtyl's tandan and Agassiz's glassfish) washed into the demonstration reach after flooding provided a transient increase in species richness that was unrelated to any demonstration reach activities.	No
Fish assemblage	H3b: Native species richness measured across the demonstration reach changed during rehabilitation activities, suggesting a response in the demonstration reach relative to the control reaches.	The native species richness response is described above, since it drove total species richness patterns.	No
Fish assemblage	H3c: Alien species richness measured across the demonstration reach changed during rehabilitation activities, suggesting a response in the demonstration reach relative to the control reaches.	The mean number of alien species per site differed between reaches, but this was sporadic between years and showed no trend that would suggest any meaningful difference between reaches, or responses at the demonstration reach relative to the controls.	No

Fish assemblage	H3d: Native fish abundance measured across the demonstration reach changed during rehabilitation activities, suggesting a response in the demonstration reach relative to the control reaches.	The abundance of native fish differed between reaches and years, with the magnitude of difference varying significantly among years. Native species were generally more abundant in the demonstration reach, due to a higher number of bony herring (a reflection of their distribution). Native abundance noticeably declined in the demonstration reach in Year 3 and then recovered, possibly related to fish kills of bony herring and a EUS outbreak in the previous year. A similar drop in abundance occurred in Murray cod, golden perch, spangled perch and bony herring in Year 5, again within a year of these species being involved in a EUS epizootic in the reach. There is little evidence that the transient nature of these responses reflects any more than interannual responses to environmental disturbances.	No
Fish assemblage	H3e: Alien fish abundance measured across the demonstration reach changed during rehabilitation activities, suggesting a response in the demonstration reach relative to the control reaches.	Alien fish abundance differed significantly between reaches and years, with a significant spike in abundance in Year 5 relative to the control reaches driven by two successive years of strong recruitment of juvenile carp to the demonstration reach. This response is likely related to two years of spring summer flooding following an extended drought.	No
Fish assemblage	H3f: 'Nativeness' measured across the demonstration reach changed during rehabilitation activities, suggesting a response in the demonstration reach relative to the control reaches.	There was a decline in nativeness across reaches for the reasons described above. However, there was no change in the demonstration reach relative to the control reaches that would suggest any response unique to the demonstration reach.	No

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11. APPENDICES

Appendix 1: Re-snagging Targets

Pre-intervention large wood loading and differential between loading and reference benchmarks. Positive differentials indicate the number of large wood pieces required to achieve reference targets, whereas a negative differential indicates a surplus of large wood above reference benchmarks. Reaches with missing data at the time of re-snagging are not shown. Green indicates an experimental re-snagging reach, amber indicates an experimental control and pink indicates an experimental reference reach.

Reach ID	Current large wood loading			Minimum number required to reach mean reference benchmarks	
	Low-flow available	High-flow recruitable	Total in-channel	Low-flow available	Total in-channel
6					
7					
8	0	2	2	6	30
9	3	15	18	3	14
10	4	15	19	2	13
11	4	1	5	2	27
12	2	9	11	4	21
13	0	15	15	6	17
14	2	13	15	4	17
15	3	22	25	3	7
16	0	30	30	6	2
17	0	15	15	6	17
18	1	12	13	5	19
19	1	8	9	5	23
20	5	22	27	1	5
21	1	8	9	5	23
22	2	9	11	4	21
23	0	9	9	6	23
24	5	20	25	1	7
25	7	16	23	-1	9
26	2	17	19	4	13
27	2	22	24	4	8
28	2	18	20	4	12
29	6	17	23	0	9
30	1	23	24	5	8
31	2	28	30	4	2
32	3	21	24	3	8
33	3	24	27	3	5
34	4	21	25	2	7
35	2	13	15	4	17
36	3	24	27	3	5
37	3	15	18	3	14
38	3	21	24	3	8
39	6	24	30	0	2
40	1	28	29	5	3
41	1	11	12	5	20
42	3	11	14	3	18

43	3	29	32	3	0
44	0	20	20	6	12
45	2	25	27	4	5
46	3	17	20	3	12
47	2	21	23	4	9
48	0	14	14	6	18
49	2	21	23	4	9
50	7	19	26	-1	6
51	2	27	29	4	3
52	2	15	17	4	15
54	2	26	28	4	4
55	0	38	38	6	-6
56	4	54	58	2	-26
57	8	42	50	-2	-18
58	1	46	47	5	-15
59	6	37	43	0	-11
60	4	43	47	2	-15
61	2	30	32	4	0
62	4	26	30	2	2
63	7	27	34	-1	-2
64	4	41	45	2	-13
65	5	39	44	1	-12
66	5	25	30	1	2
67	7	35	42	-1	-10
68	1	41	42	5	-10
69	5	31	36	1	-4
70	5	28	33	1	-1
71	2	41	43	4	-11
72	1	30	31	5	1
73	5	39	44	1	-12
74	1	27	28	5	4
75	6	35	41	0	-9
76	9	32	41	-3	-9
77	3	35	38	3	-6
78	5	61	66	1	-34
79	4	47	51	2	-19
80	2	41	43	4	-11
81	5	30	35	1	-3
82	5	49	54	1	-22
83	3	38	41	3	-9
84	2	38	40	4	-8
85	3	31	34	3	-2
86	4	34	38	2	-6
87	5	27	32	1	0
88	6	41	47	0	-15
89	8	32	40	-2	-8
97	10	57	67	-4	-35
98	10	67	77	-4	-45
99	8	42	50	-2	-18
100	7	45	52	-1	-20
101	5	44	49	1	-17
102	1	26	27	5	5
103	7	39	46	-1	-14
104	9	60	69	-3	-37

105	5	49	54	1	-22
106	8	30	38	-2	-6
107	3	37	40	3	-8
122	5	31	36	1	-4
123	4	38	42	2	-10
124	7	29	36	-1	-4
125	6	40	46	0	-14
126	1	22	23	5	9
127	0	32	32	6	0
136	4	48	52	2	-20
137	4	34	38	2	-6
155	3	13	16	3	16
156	3	36	39	3	-7
157	9	31	40	-3	-8
158	1	23	24	5	8
159	1	22	23	5	9
160	3	44	47	3	-15
161	2	18	20	4	12
162	2	30	32	4	0
163	0	18	18	6	14
181	4	39	43	2	-7
182	0	16	16	6	16
183	3	22	25	3	10
184	2	19	21	4	13
185	2	30	32	4	2
186	4	23	27	2	9
187	3	13	16	3	19
188	2	20	22	4	12
189	0	10	10	6	22
190	1	18	19	5	14
191	0	21	21	6	11
192	1	7	8	5	25
193	0	12	12	6	20
194	4	15	19	2	17
195	3	11	14	3	21
196	1	12	13	5	20
197	1	14	15	5	18
198	0	8	8	6	24
199	0	14	14	6	18
200	3	33	36	3	-1
201	6	12	18	0	20
202	4	14	18	2	18
203	0	6	6	6	26
204	2	23	25	4	9
205	9	14	23	-3	18
206	0	4	4	6	28
207	2	4	6	4	28

Appendix 2: Re-snagging Experimental Sites

Note: Annual sampling was conducted at B2B010. However, this was a 'back-up' site and was not included in the data analysis to ensure symmetry in the experimental design.

Bourke to Brewarrina Demonstration Reach: Resnagging Monitoring Site BTB006



Site location

Control reach

Number of snags required: 0



Bourke to Brewarrina Demonstration Reach: Resnagging Monitoring Site BTB008



Site location

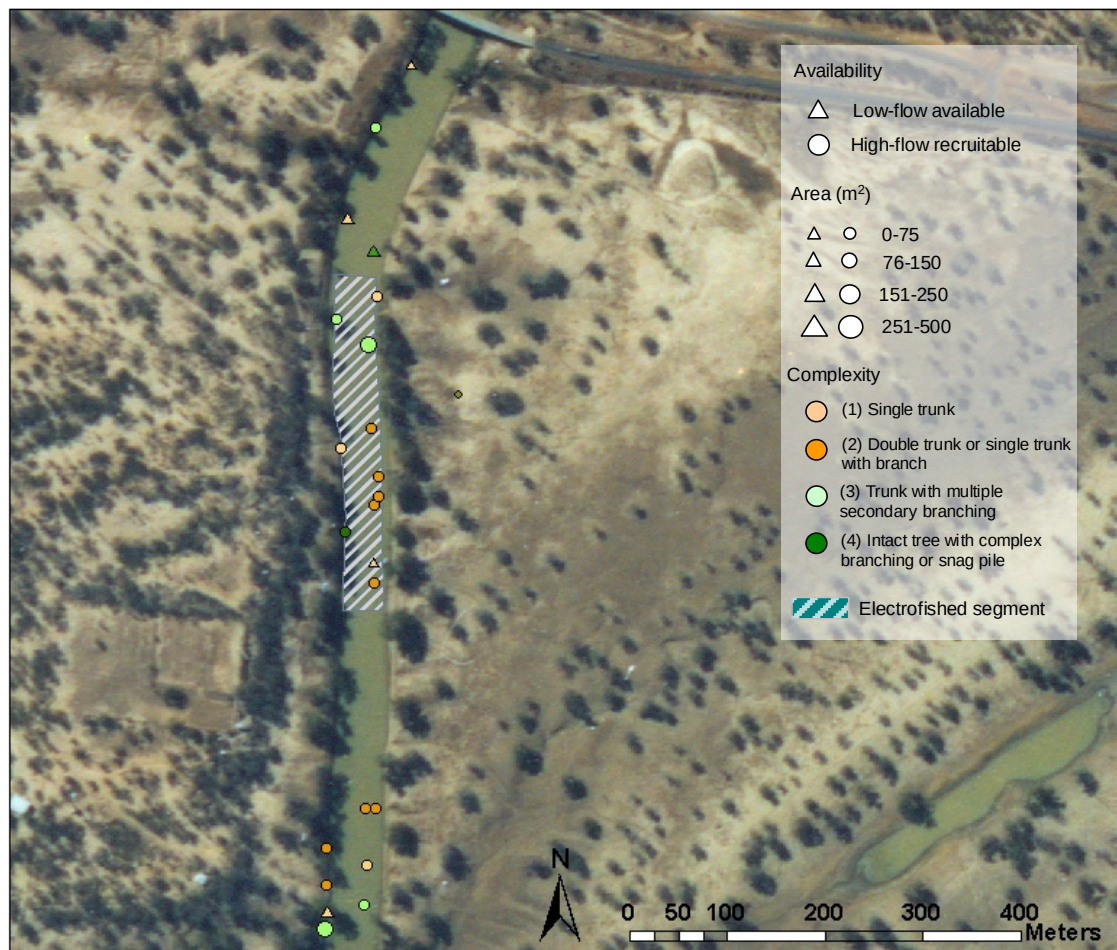


Site photo

Re-snagging reach

Number of snags required: 30

Bourke to Brewarrina Demonstration Reach: Resnagging Monitoring Site BTB010



Site location

Re-snagging reach

Number of snags required: 13

Bourke to Brewarrina Demonstration Reach: Resnagging Monitoring Site BTB011



Site location

Control reach

Number of snags required: 0

Bourke to Brewarrina Demonstration Reach: Resnagging Monitoring Site BTB012



Site location

Re-snagging Reach

Number of snags required: 21

Bourke to Brewarrina Demonstration Reach: Resnagging Monitoring Site BTB014



Site location

Control reach

Number of snags required: 0

Availability

- △ Low-flow available
- High-flow recruitable

Area (m²)

- △ ○ 0-75
- △ ○ 76-150
- △ ○ 151-250
- △ ○ 251-500

Complexity

- (1) Single trunk
- (2) Double trunk or single trunk with branch
- (3) Trunk with multiple secondary branching
- (4) Intact tree with complex branching or snag pile

Electrofished segment

Bourke to Brewarrina Demonstration Reach: Resnagging Monitoring Site BTB017



Site location

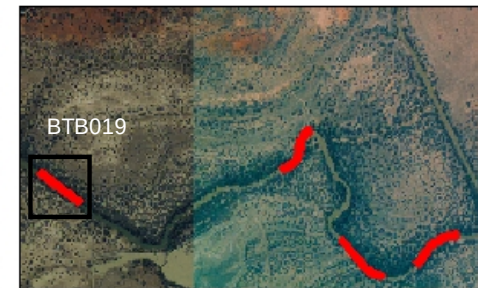


Site photo

Control reach

Number of snags required: 0

Bourke to Brewarrina Demonstration Reach: Resnagging Monitoring Site BTB019



Site location

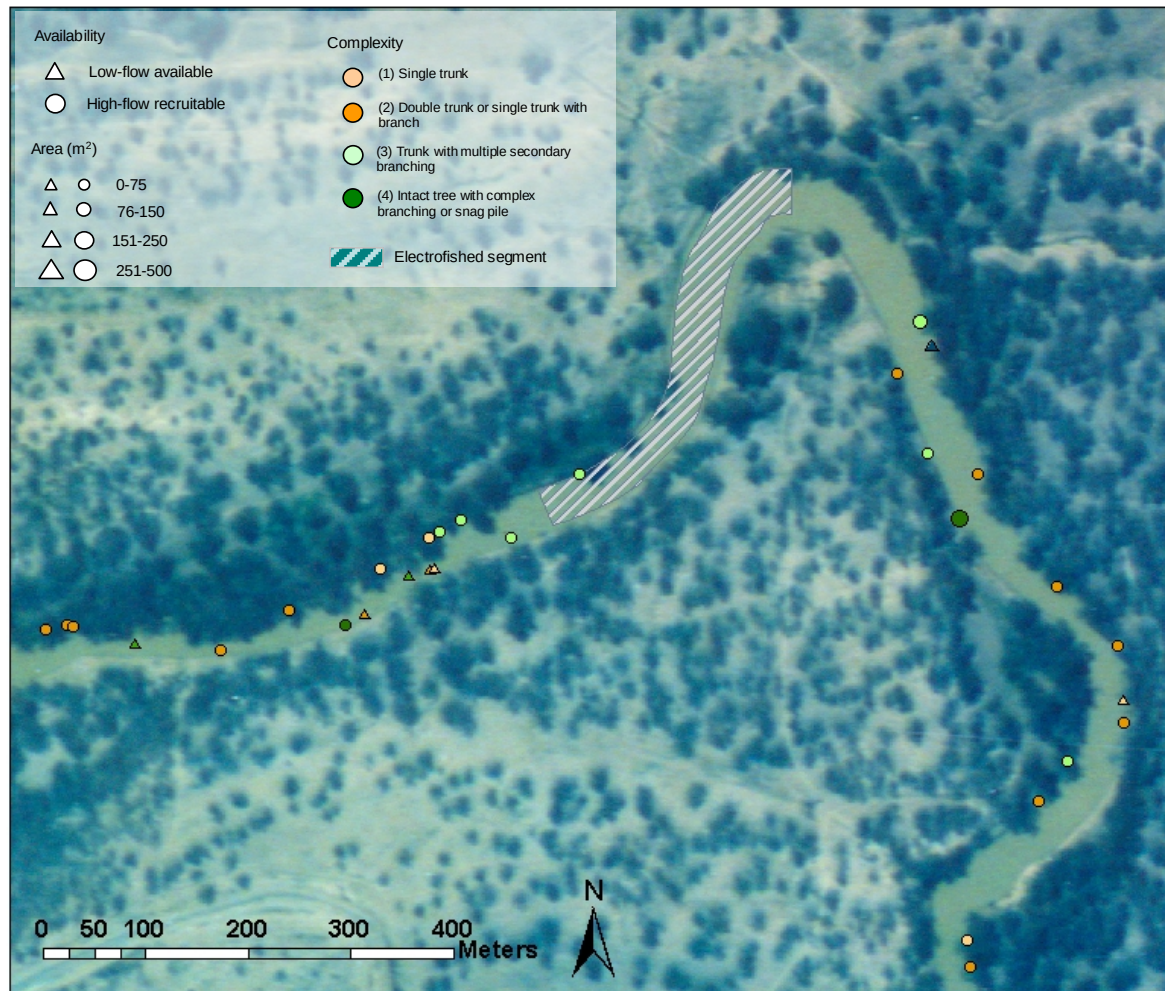


Site photo

Re-snagging reach

Number of snags required: 23

Bourke to Brewarrina Demonstration Reach: Resnagging Monitoring Site BTB021



Site location

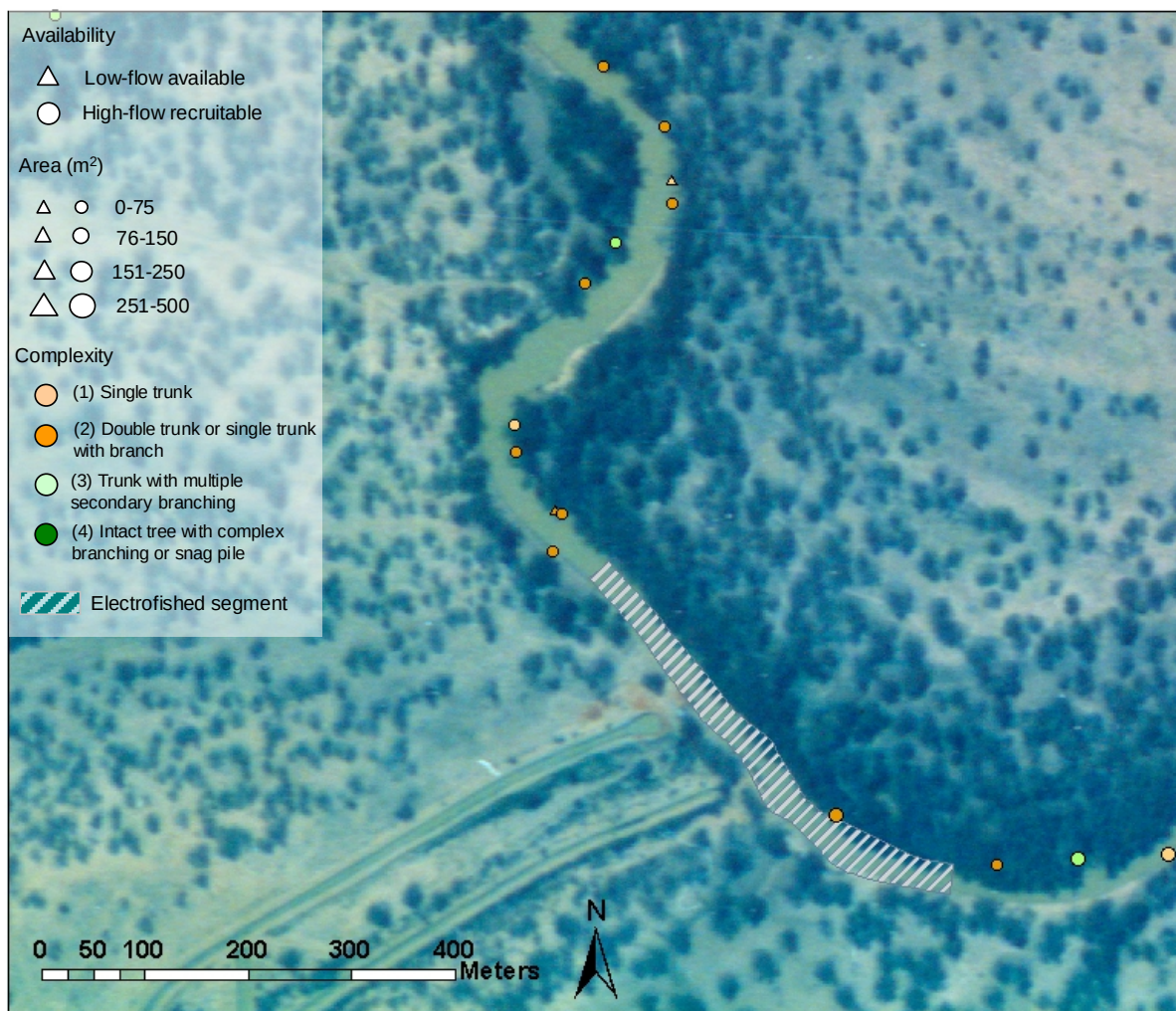


Site photo

Re-snagging reach

Number of snags required: 23

Bourke to Brewarrina Demonstration Reach: Resnagging Monitoring Site BTB022



Site location

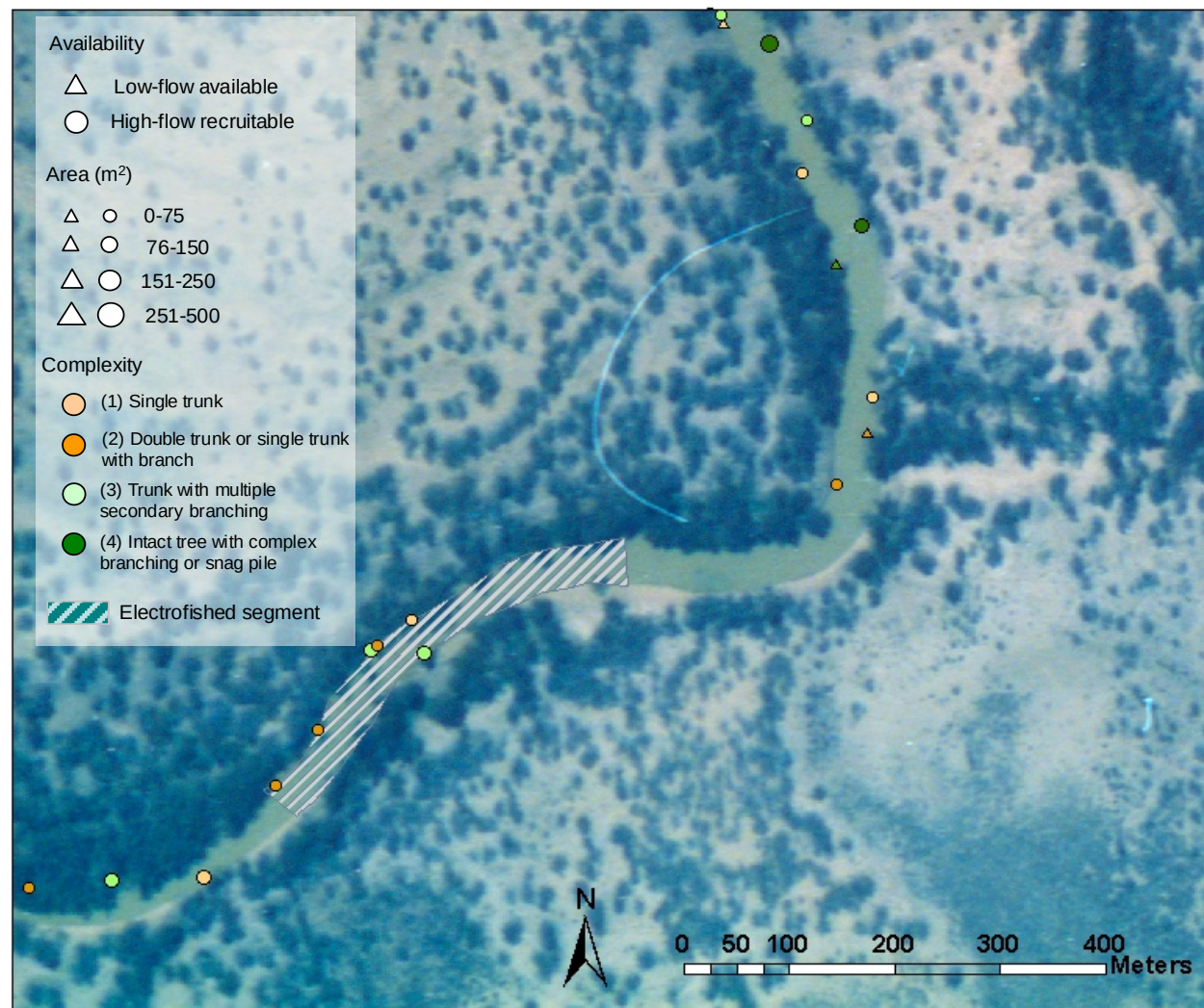


Site photo

Control reach

Number of snags required: 0

Bourke to Brewarrina Demonstration Reach: Resnagging Monitoring Site BTB023



Site location



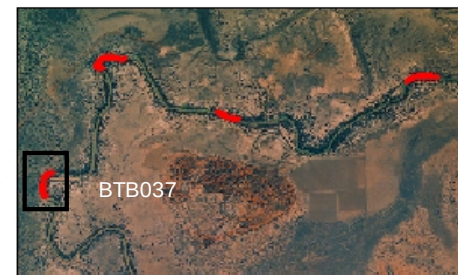
Site photo

Re-snagging reach

Number of snags required: 23



Bourke to Brewarrina Demonstration Reach: Resnagging Monitoring Site BTB037



Site location

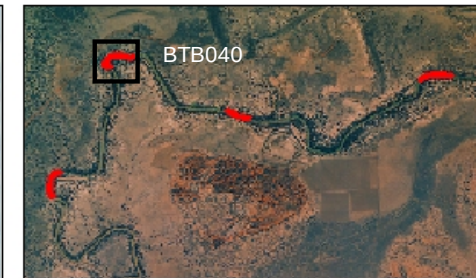
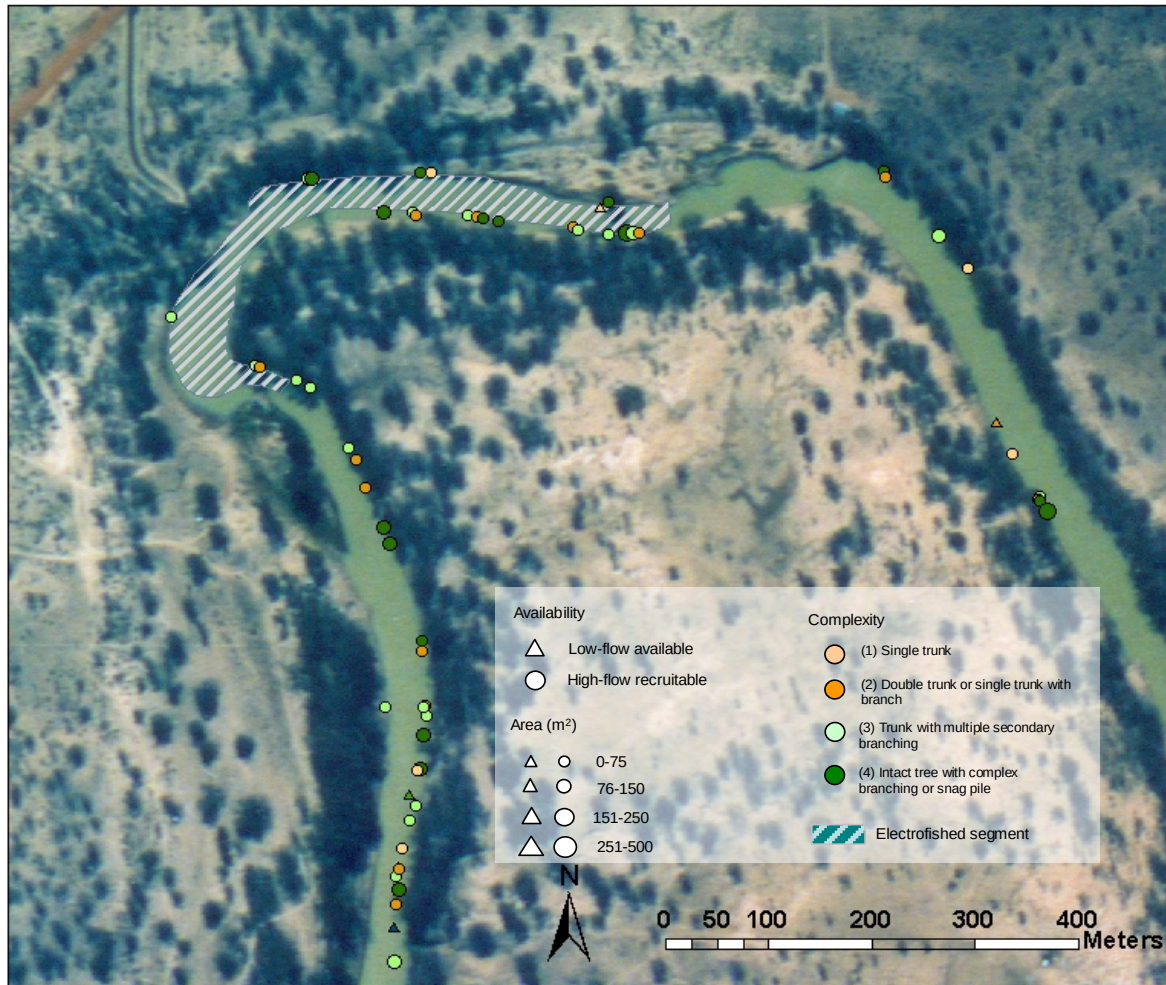


Site photo

Re-snagging reach

Number of snags required: 14

Bourke to Brewarrina Demonstration Reach: Resnagging Monitoring Site BTB040

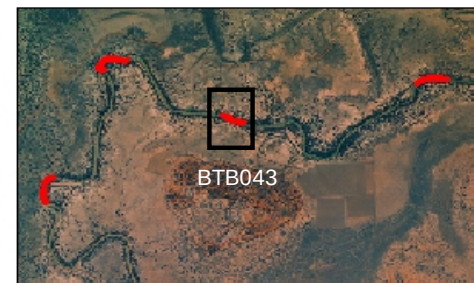
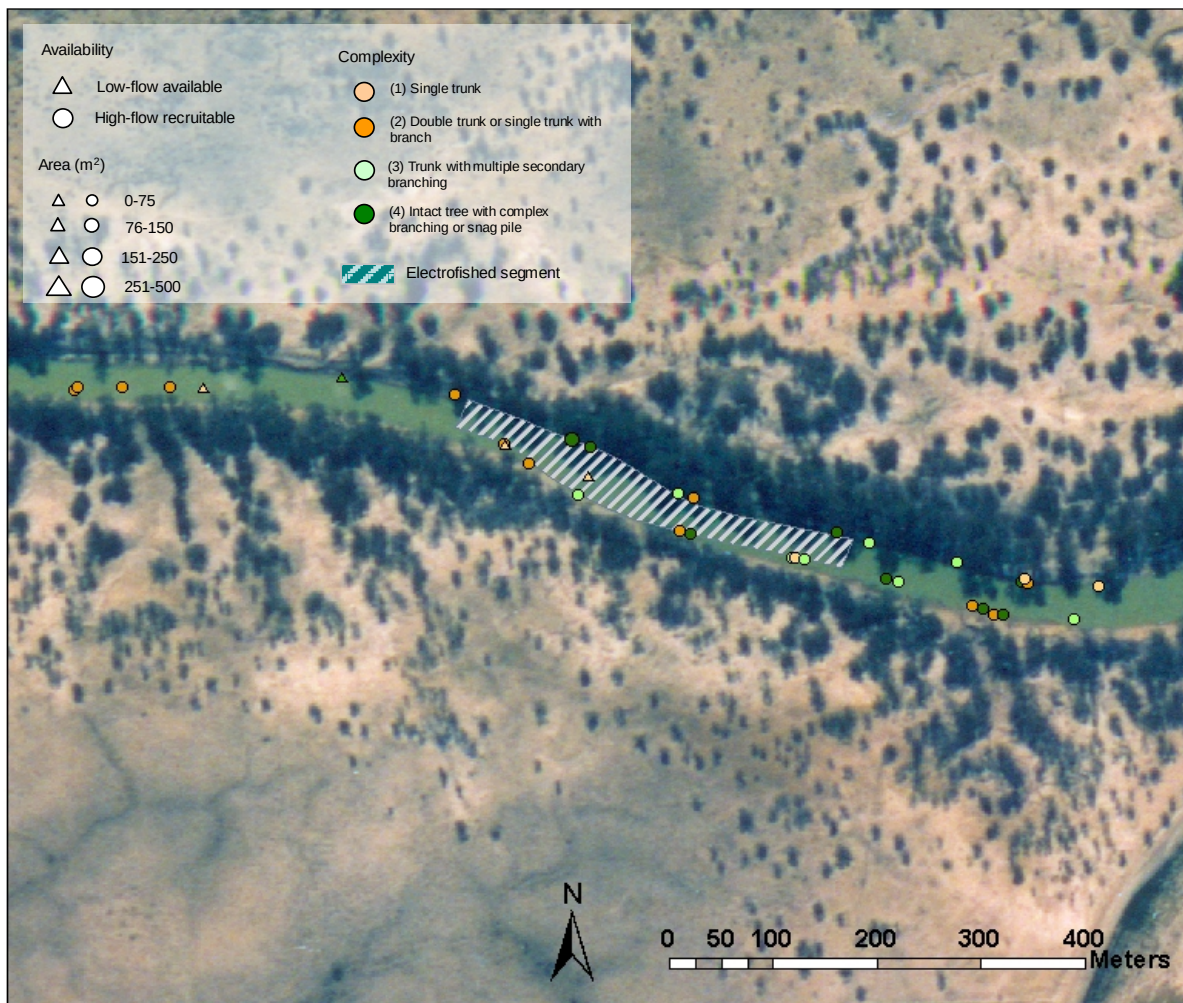


Site location

Re-snagging reach

Number of snags required: 3

Bourke to Brewarrina Demonstration Reach: Resnagging Monitoring Site BTB043



Site location



Site photo

Control reach

Number of snags required: 0

Bourke to Brewarrina Demonstration Reach: Resnagging Monitoring Site BTB047



Site location

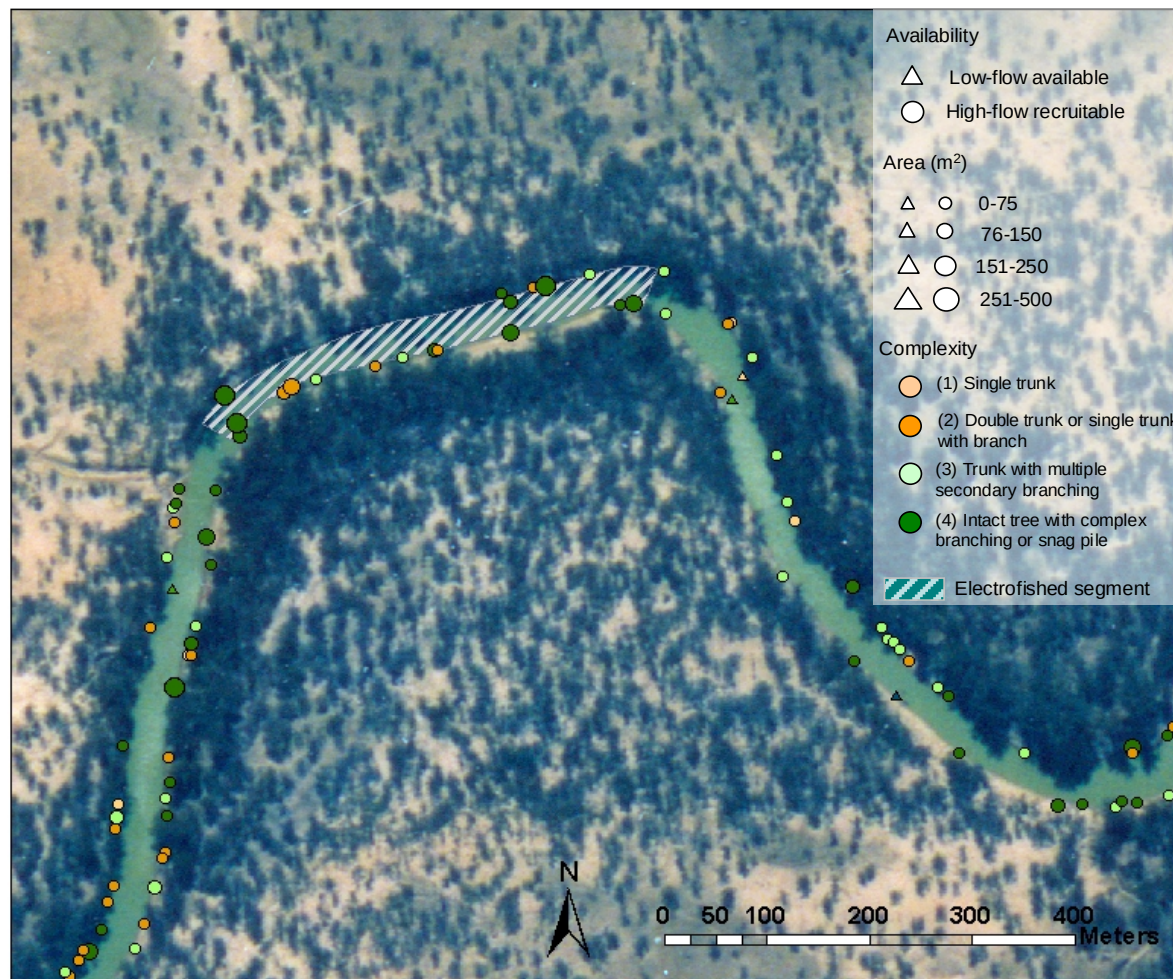


Site photo

Control reach

Number of snags required:0

Bourke to Brewarrina Demonstration Reach: Resnagging Monitoring Site BTB058



Site location

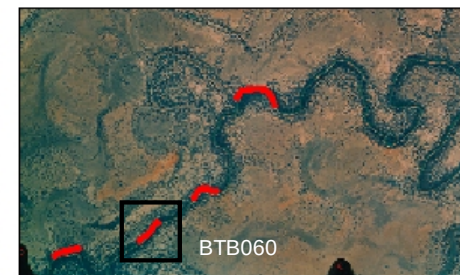
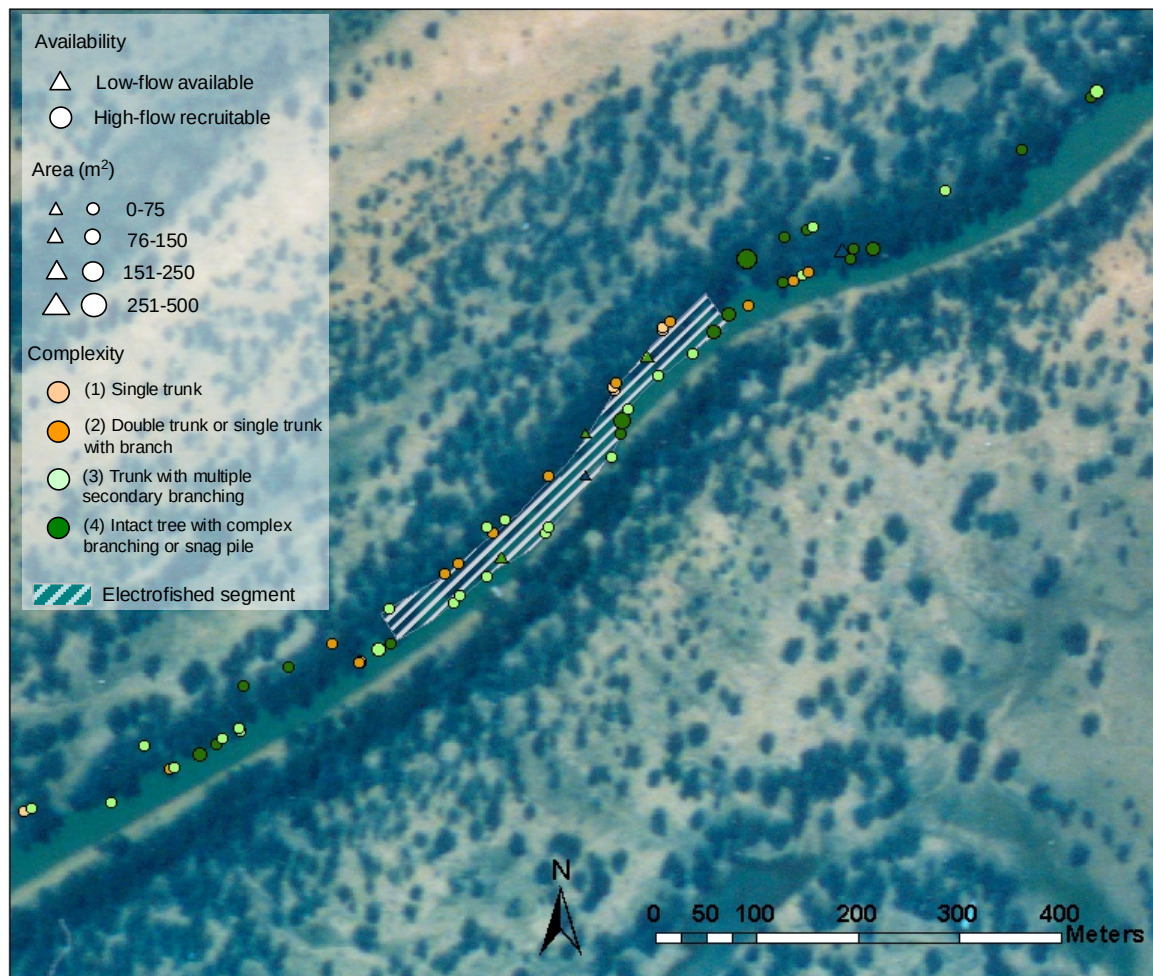


Site photo

Reference reach

Number of snags required: 0

Bourke to Brewarrina Demonstration Reach: Resnagging Monitoring Site BTB060

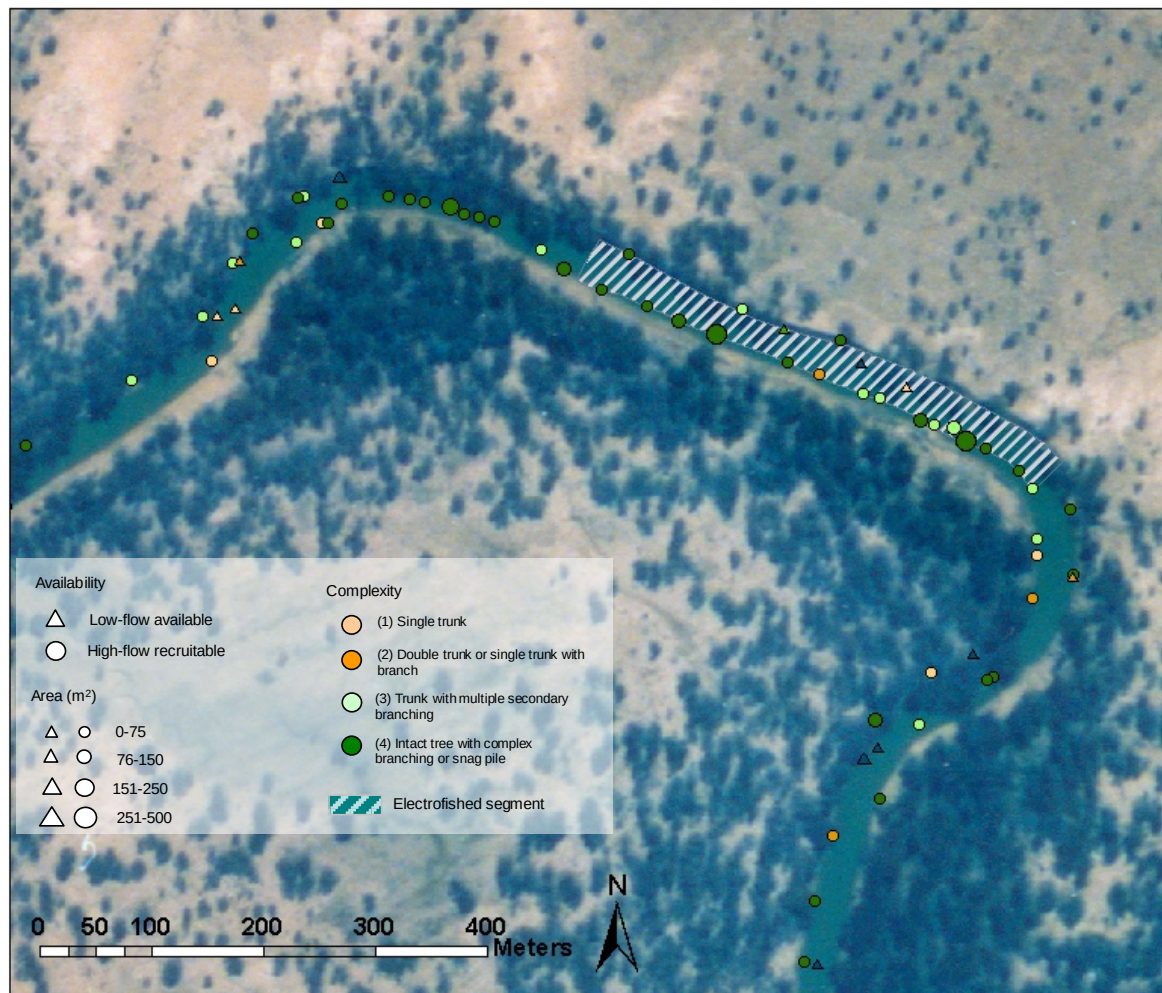


Site location

Reference reach

Number of snags required: 0

Bourke to Brewarrina Demonstration Reach: Resnagging Monitoring Site BTB076



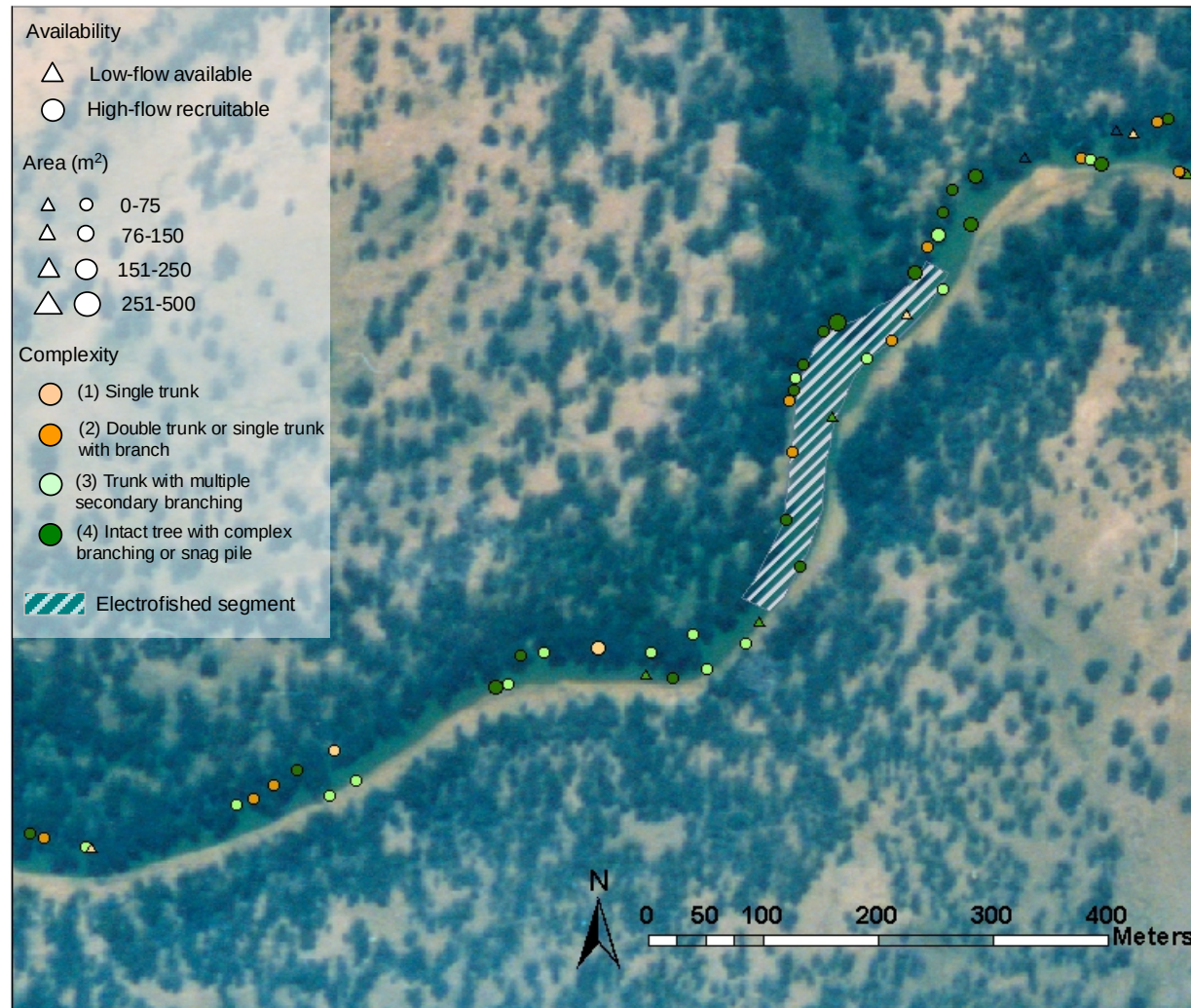
Site location

Reference reach

Number of snags required: 0



Bourke to Brewarrina Demonstration Reach: Resnagging Monitoring Site BTB086



Site location

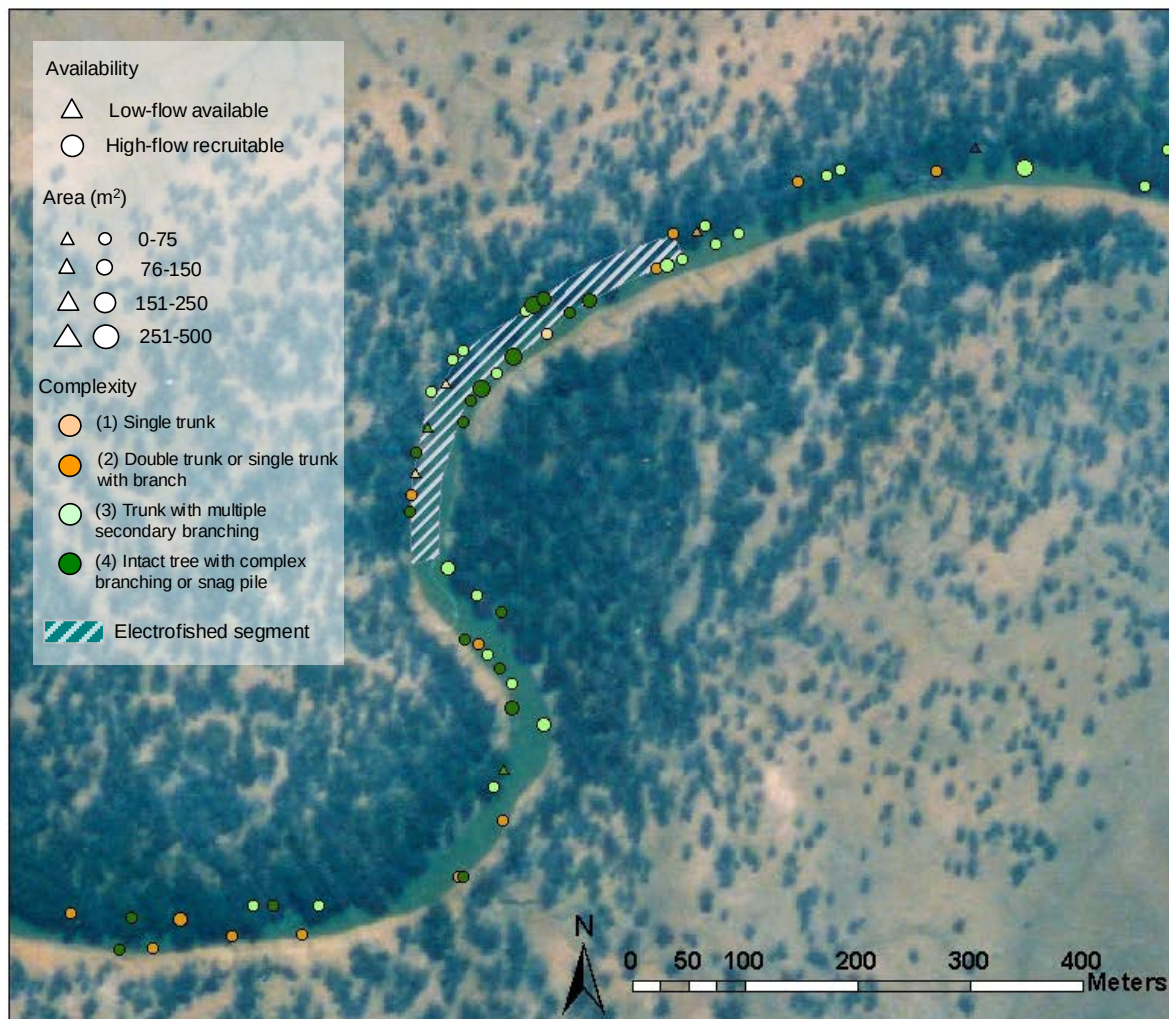


Site photo

Reference reach

Number of snags required: 0

Bourke to Brewarrina Demonstration Reach: Resnagging Monitoring Site BTB089



Site location

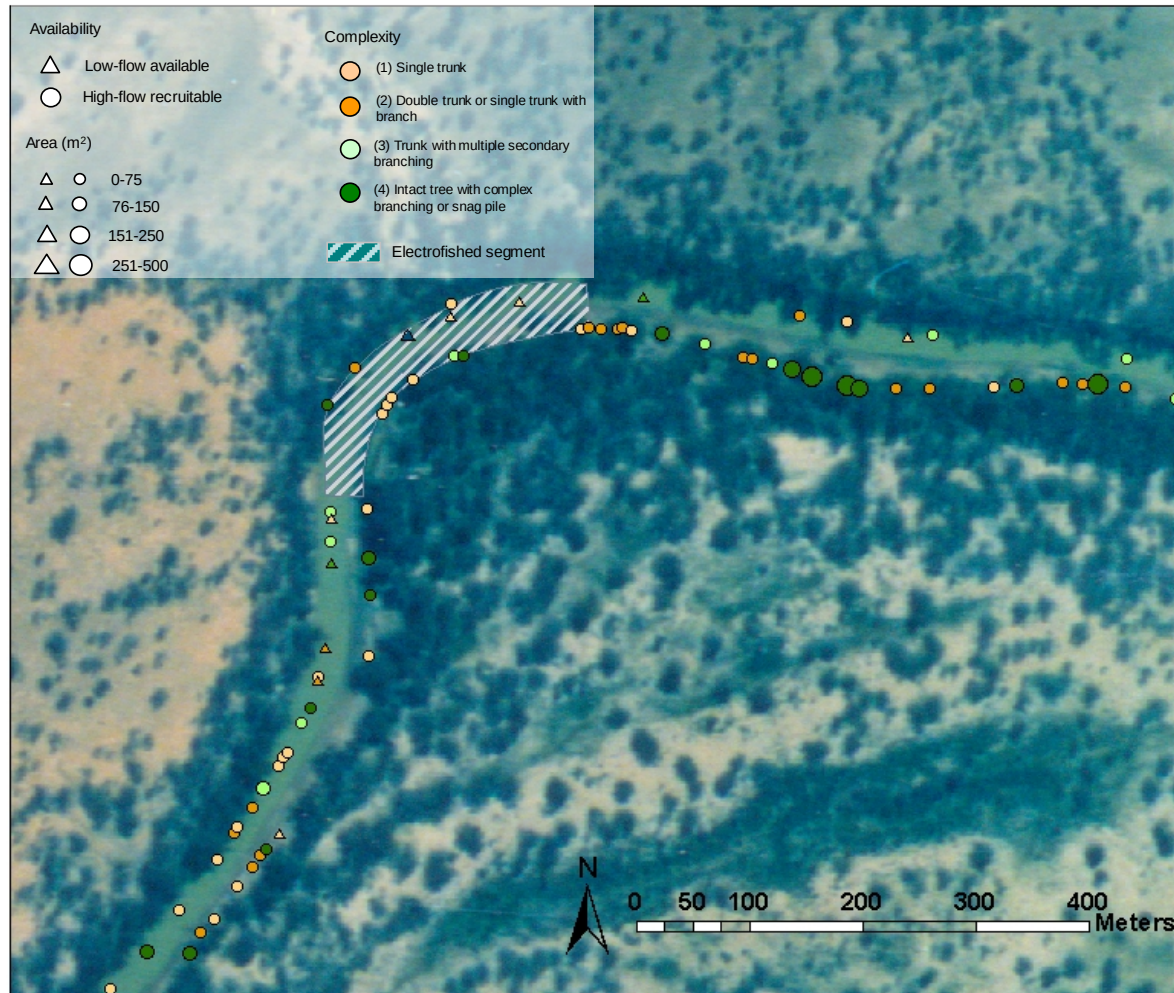


Site photo

Reference reach

Number of snags required: 0

Bourke to Brewarrina Demonstration Reach: Resnagging Monitoring Site BTB098



Site location

Reference reach

Number of snags required: 0

Bourke to Brewarrina Demonstration Reach: Resnagging Monitoring Site BTB100



Control reach

Site location

Number of snags required: 0

Availability

- △ Low-flow available
- High-flow recruitable

Area (m²)

- △ ○ 0-75
- △ ○ 76-150
- △ ○ 151-250
- △ ○ 251-500

Complexity

- (1) Single trunk
- (2) Double trunk or single trunk with branch
- (3) Trunk with multiple secondary branching
- (4) Intact tree with complex branching or snag pile

Electrofished segment



Bourke to Brewarrina Demonstration Reach: Resnagging Monitoring Site BTB126

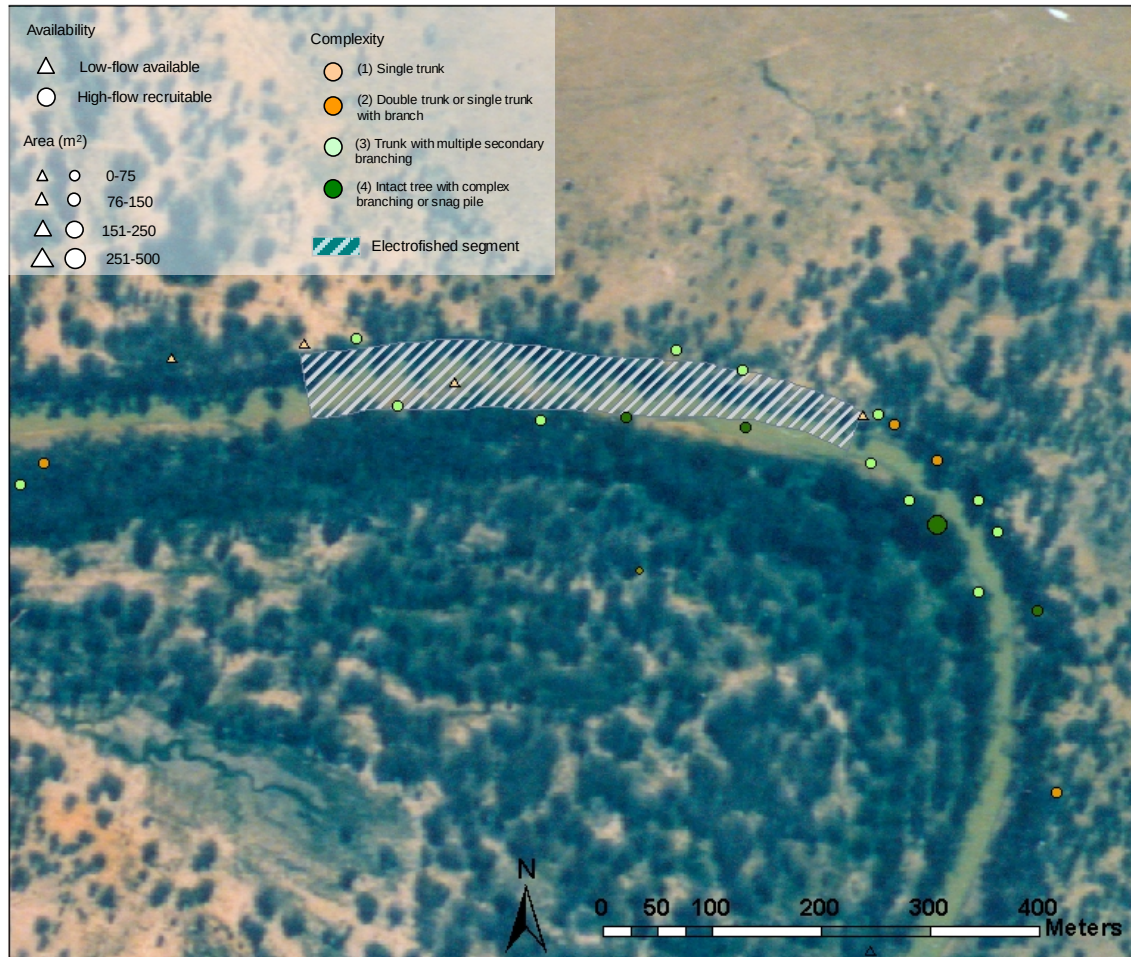


Site location

Reference reach

Number of snags required: 9

Bourke to Brewarrina Demonstration Reach: Resnagging Monitoring Site BTB194



Site location



Site photo

Control reach

Number of snags required: 0

Bourke to Brewarrina Demonstration Reach: Resnagging Monitoring Site BTB197



Site location

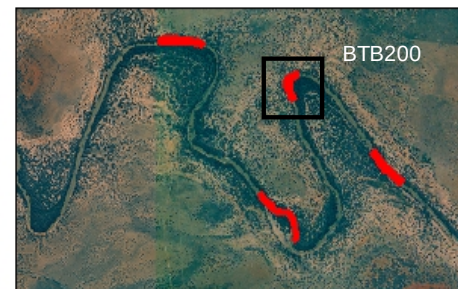
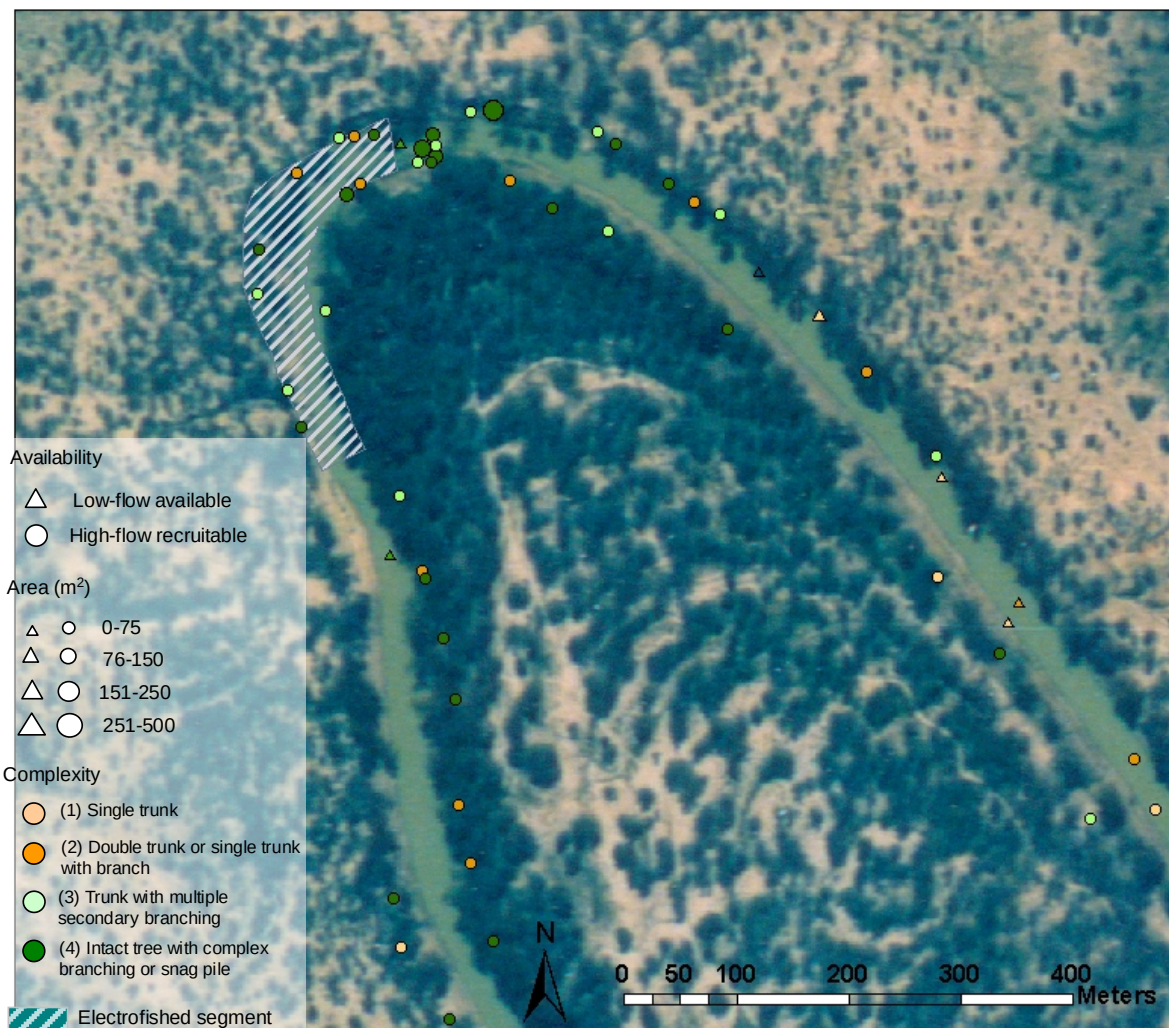


Site photo

Re-snagging reach

Number of snags required: 18

Bourke to Brewarrina Demonstration Reach: Resnagging Monitoring Site BTB200



Site location

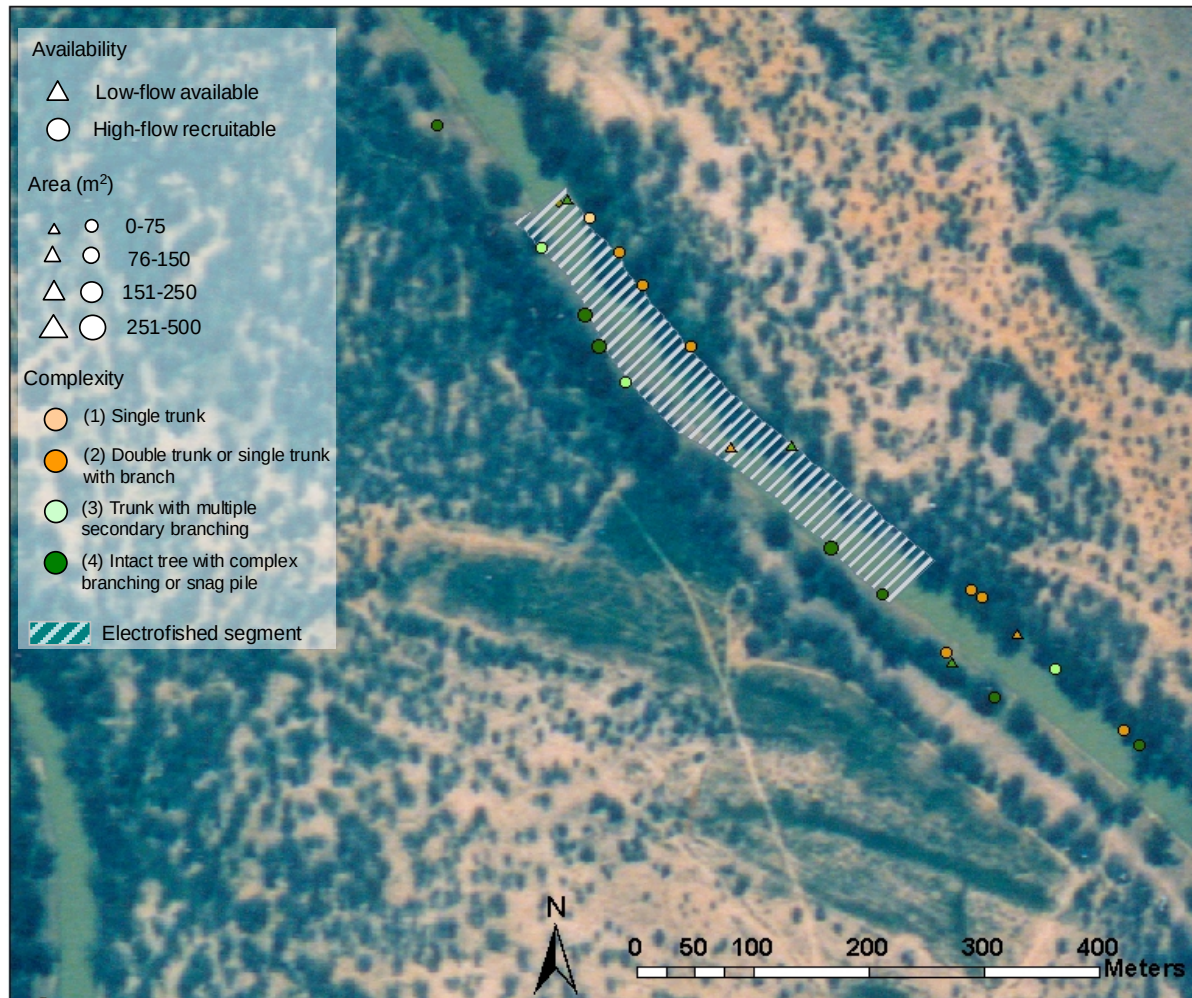


Site photo

Reference reach

Number of snags required: 0

Bourke to Brewarrina Demonstration Reach: Resnagging Monitoring Site BTB202



Site location



Site photo

Re-snagging reach

Number of snags required: 18

Appendix 3: Power Analysis for Re-snagging Experiment

Power analysis was used to determine the minimum of a technique used to address the question of how to best allocate sampling effort within the study area. That is, what level of effort (number of replicate sites) was required to give the greatest level of precision (smallest standard error) and therefore the greatest level of power to detect change. Precision and power will continue to increase as effort increases. This improvement in precision eventually diminishes with increased effort and at some point in time, increases in precision only serve to provide power to detect what may be ecologically insignificant differences. An important part of optimising a cost-effective design was therefore determining at which level of sampling effort much of the potential gain in precision was achieved.

For the purpose of comparing precision obtained by studying a different number of sites, abundance data for Murray cod, golden perch, carp and bony herring were obtained for 14 sites on the Barwon-Darling River (NSW DPI 2012). Standard error was used as a measure of precision, and a formal calculation of “power” was avoided due to the uncertainty of the magnitude of the ecological response that may be expected from re-snagging works. This informal type of power analysis was too complex to perform on a full rehabilitation model (incorporating reference sites). Hence, it was simplified by using a model that only included two treatments: impact and control.

The fundamentals of the power analysis can be summarised as follows. “CR” is a two-level factor that classifies sites as control or re-snagging. There is also a two-level factor “BA” to classify the observation times as before or after re-snagging. That is, the observations from the study can be organised as follows:

Site	CR	BA	Observation
1	Control	Before	.
1	Control	After	.
2	Re-snagging	Before	.
2	Re-snagging	After	.

The conceptual linear model for the expected response at a given combination of sites, CR and BA, is: response = baseline + effect due to re-snagging sites + effect due to after re-snagging times + effect due to after re-snagging at re-snagging sites + effect due to site + error.

Mathematically, the observation under CR level i and BA level j at site k is:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \gamma_k + e_{ijk}$$

The success of re-snagging will be rated by the level of interaction between the CR and BA factors, which in this particular case, resolves to a test of the hypothesis that the single coefficient $(\alpha\beta) = 0$. This hypothesis will be rejected if:

$$\frac{|(\alpha\beta)|}{se(\alpha\beta)} \geq t_{critical}$$

where $se(\alpha\beta)$ is the standard error of the estimate, which in this case, resolves to: $\sqrt{\frac{4s^2}{r}}$

s^2 = estimate of the within-site (temporal) error variance, r = the number of replicates and $t_{critical}$ is the quantile from the t-distribution with degrees of freedom corresponding to the within-site error

variance degrees of freedom ($2(r-1)$ in this case). Thus, the minimum detectable effect size can be written as a function of the within-site error variance, the number of replicates of the control and re-snagging sites and the corresponding t statistic. It is important to note that the preceding calculations depend on equal replication of the control and impact sites.

The historical catch data was then used to find a reasonable estimate of s^2 and examine how the detectable effect size reduces as the number of replicates increases. Sample means and variances were:

	Mean	Variance
Murray Cod	1.5	4.1
Golden Perch	4.4	10.4
Carp	17.4	123.2
Herring	251.7	34604.8

The variance estimates in this table represent the spatial variability in fish counts. Figure A3.1 shows the minimal detectable effect sizes for each species under the possibly conservative assumption that the temporal error variance equals the spatial variance and under the less conservative assumption that temporal variance is half the spatial variance. Whilst the level of change to be expected is unknown, it is evident that, regardless of species, most of the improvement in efficiency due to extra replication is obtained by 7 replicates of each re-snagging and control reach. It is good practice to build a contingency in any design to allow for the loss of sites throughout a study. Therefore, it was decided to sample a minimum of 11 re-snagging, 10 control and 10 reference sites.

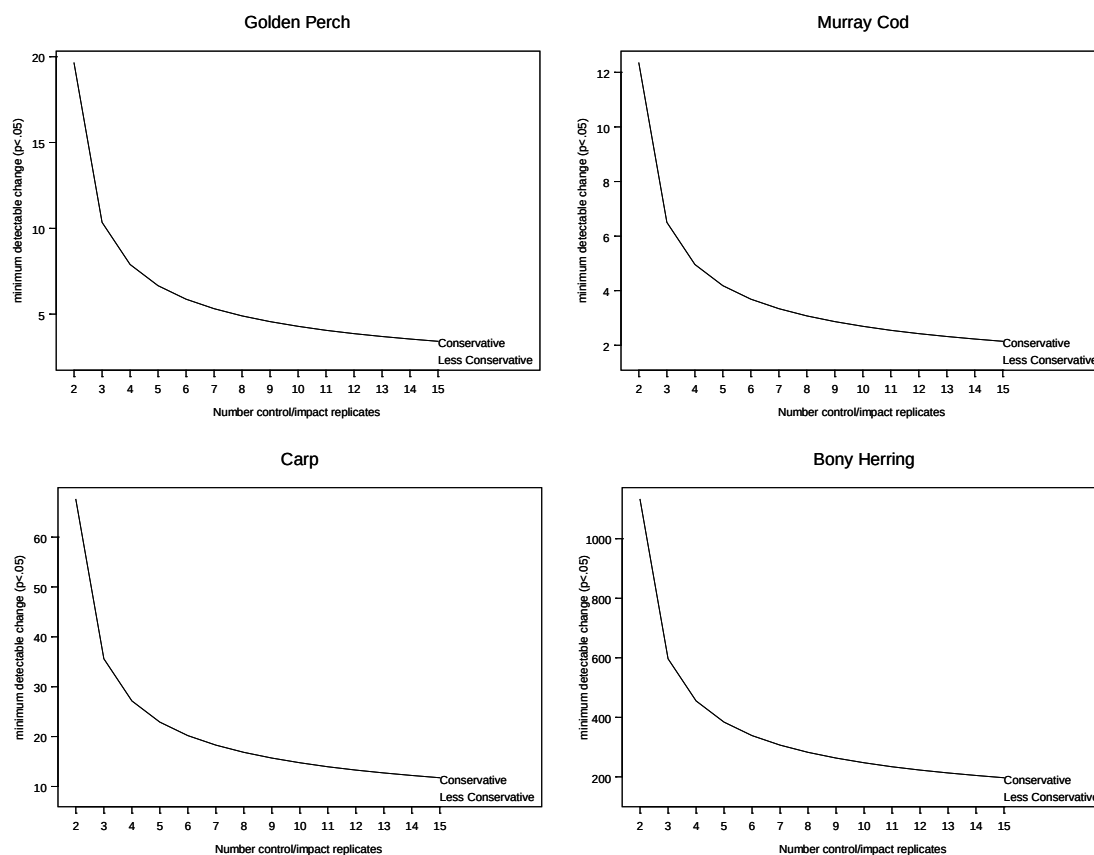
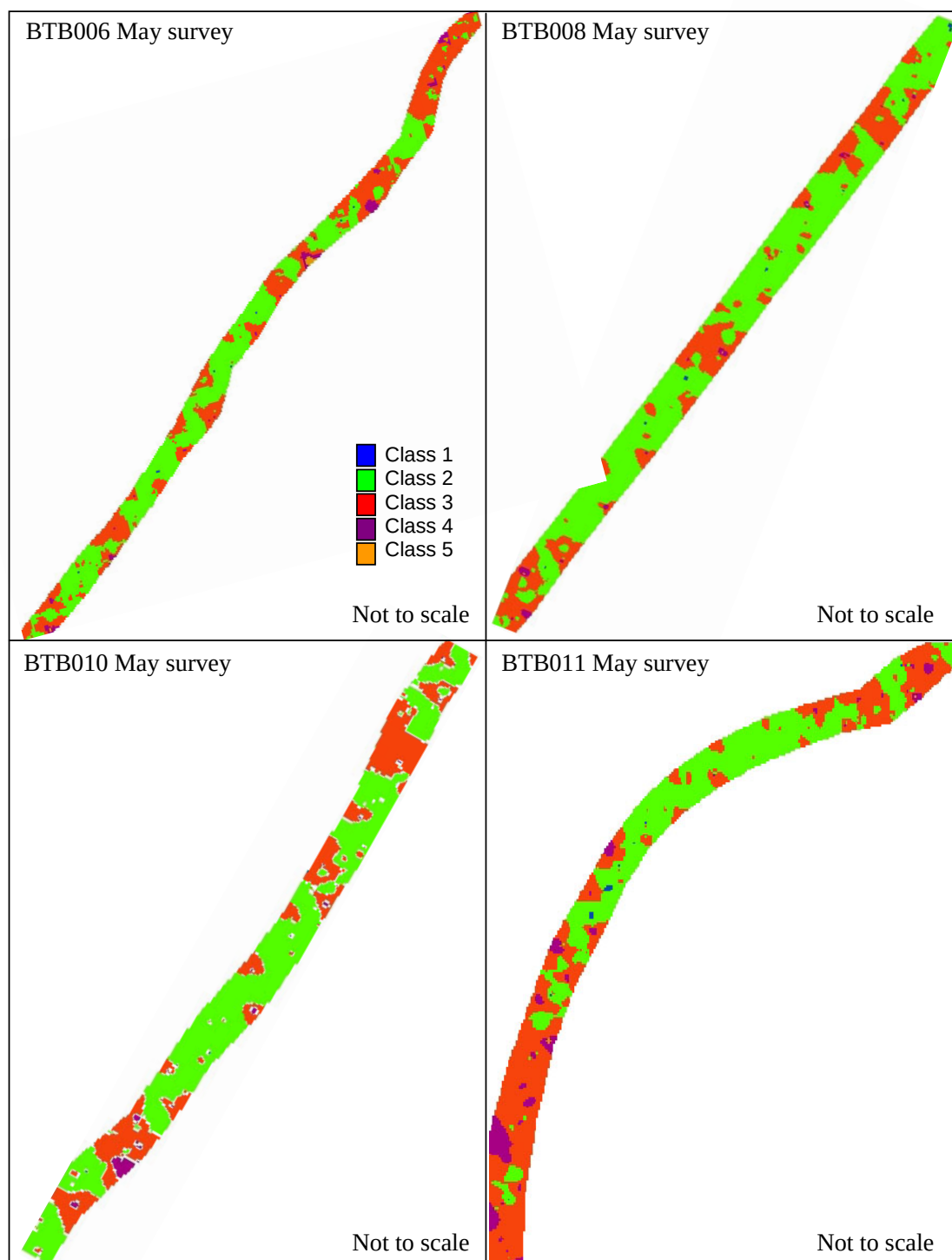
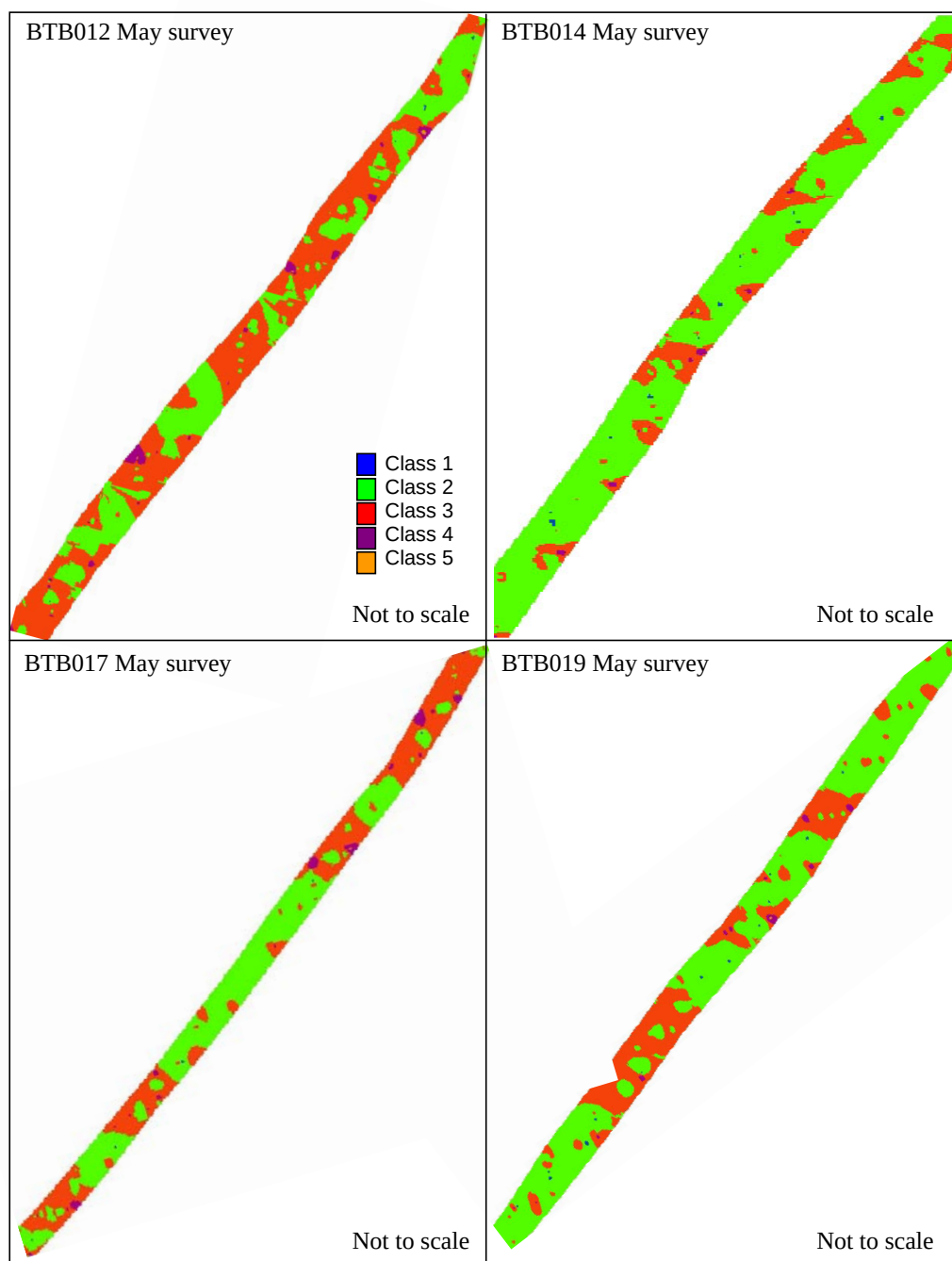
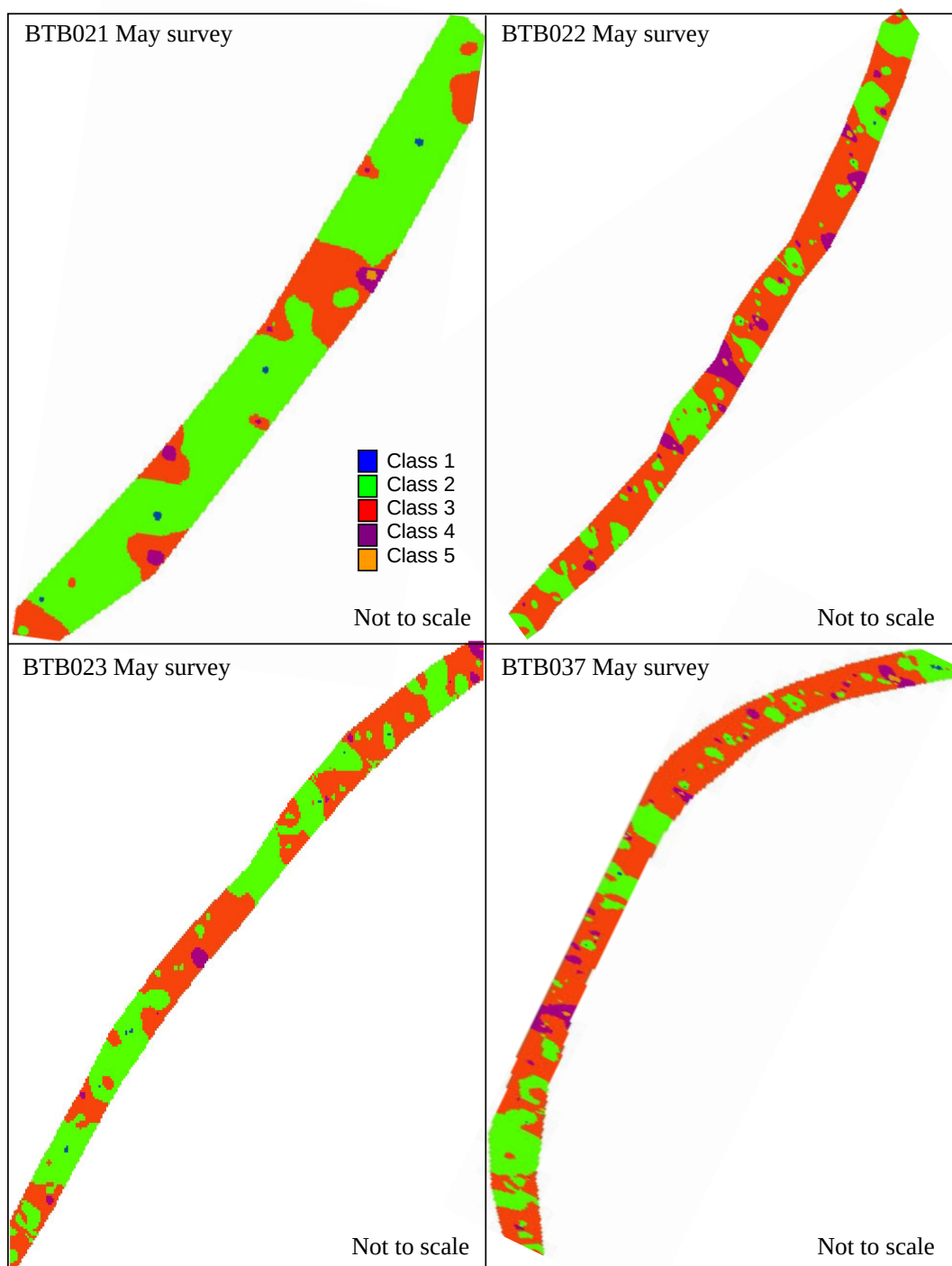
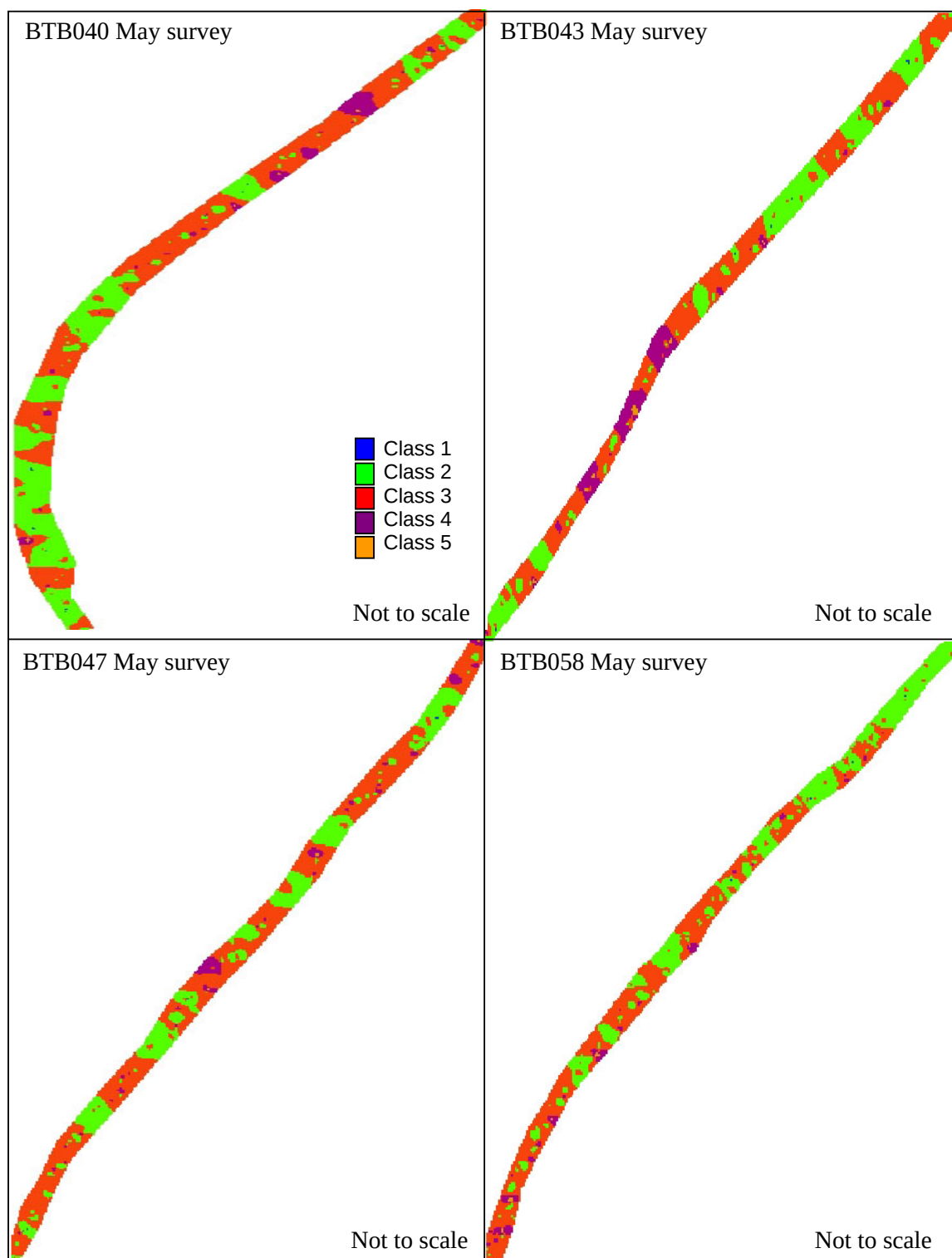


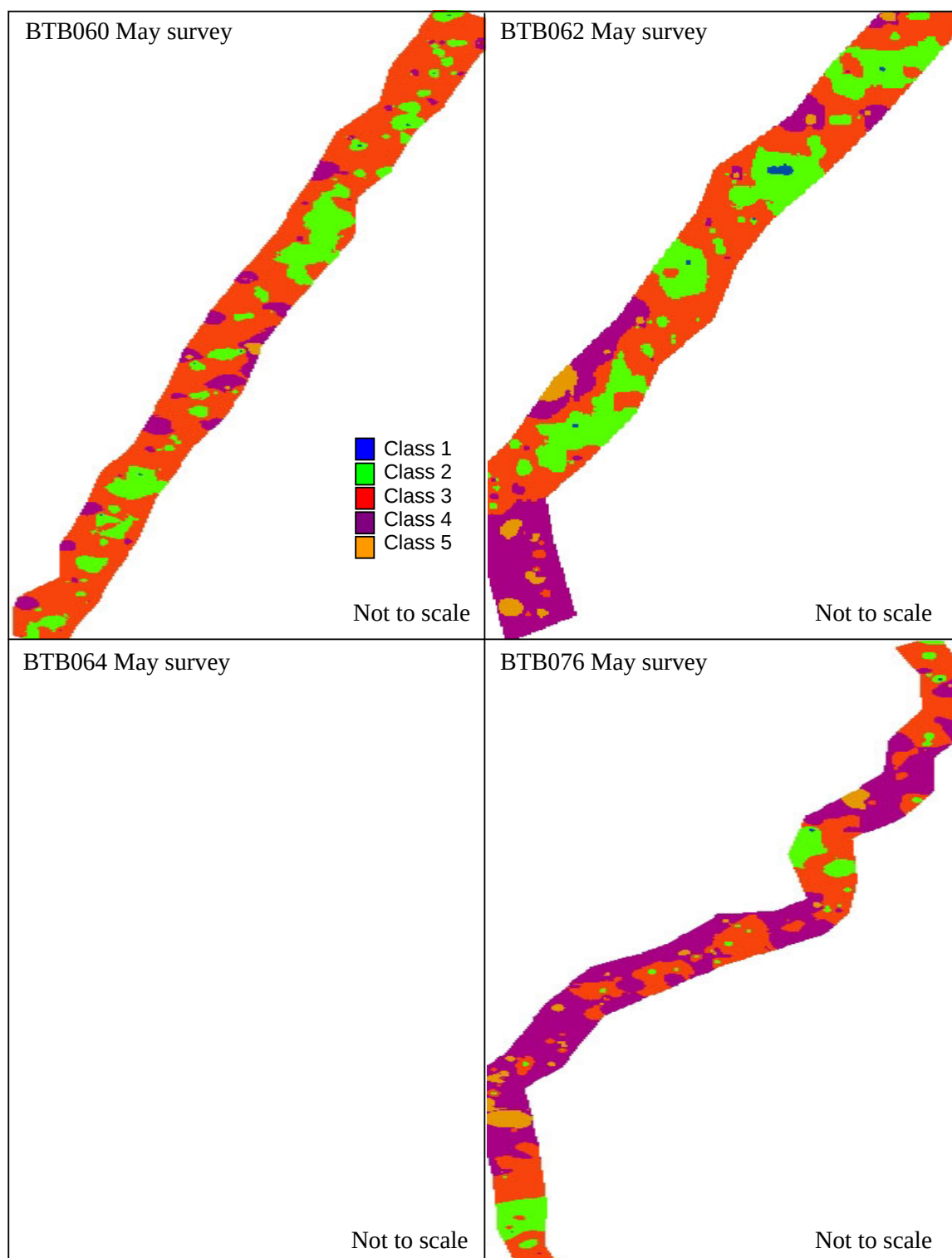
Figure A3.1. Number of replicate sites required to detect different changes in abundance (at $p < 0.05$) of a variety of species.

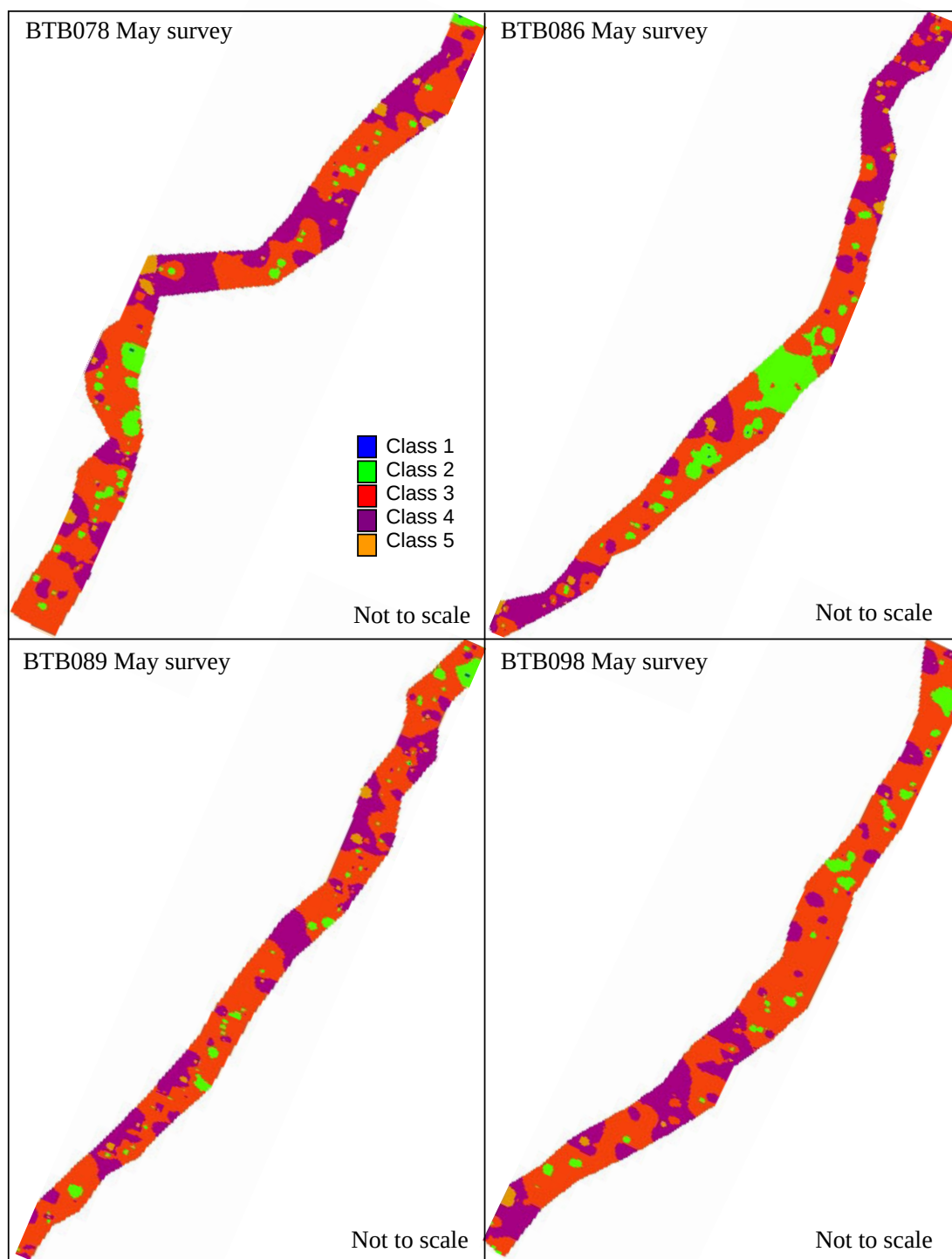
Appendix 4: Hydraulic Maps of Study Sites

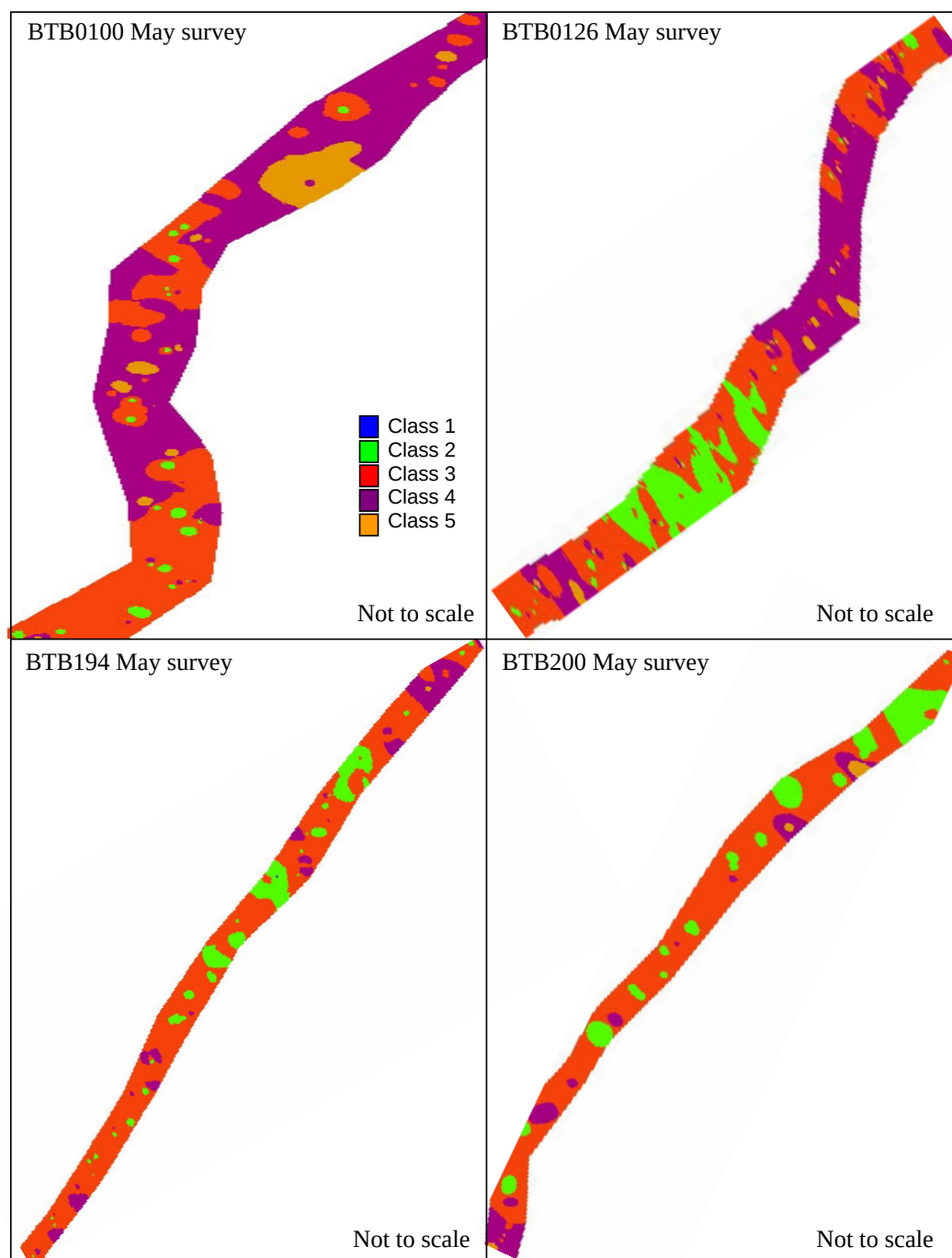


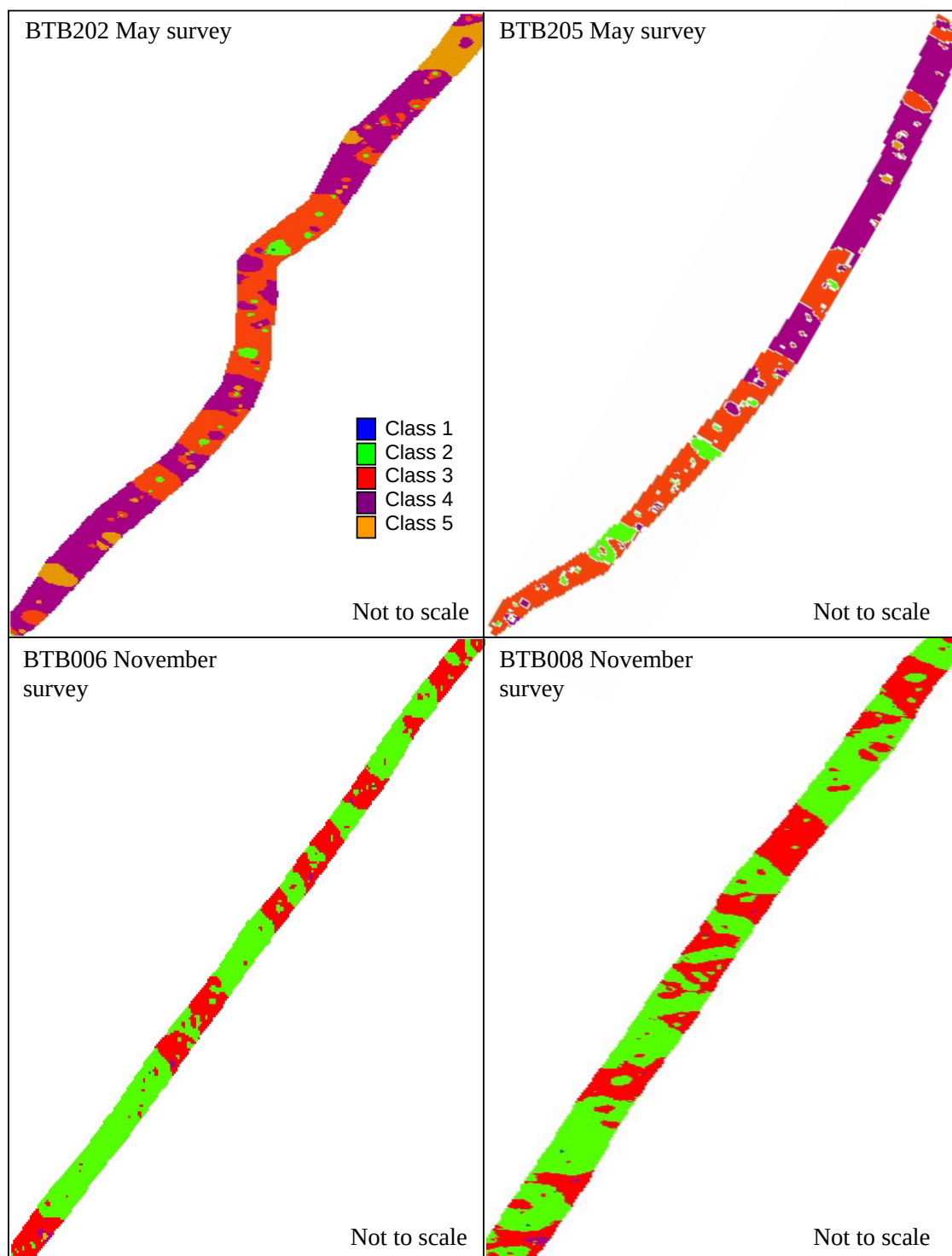


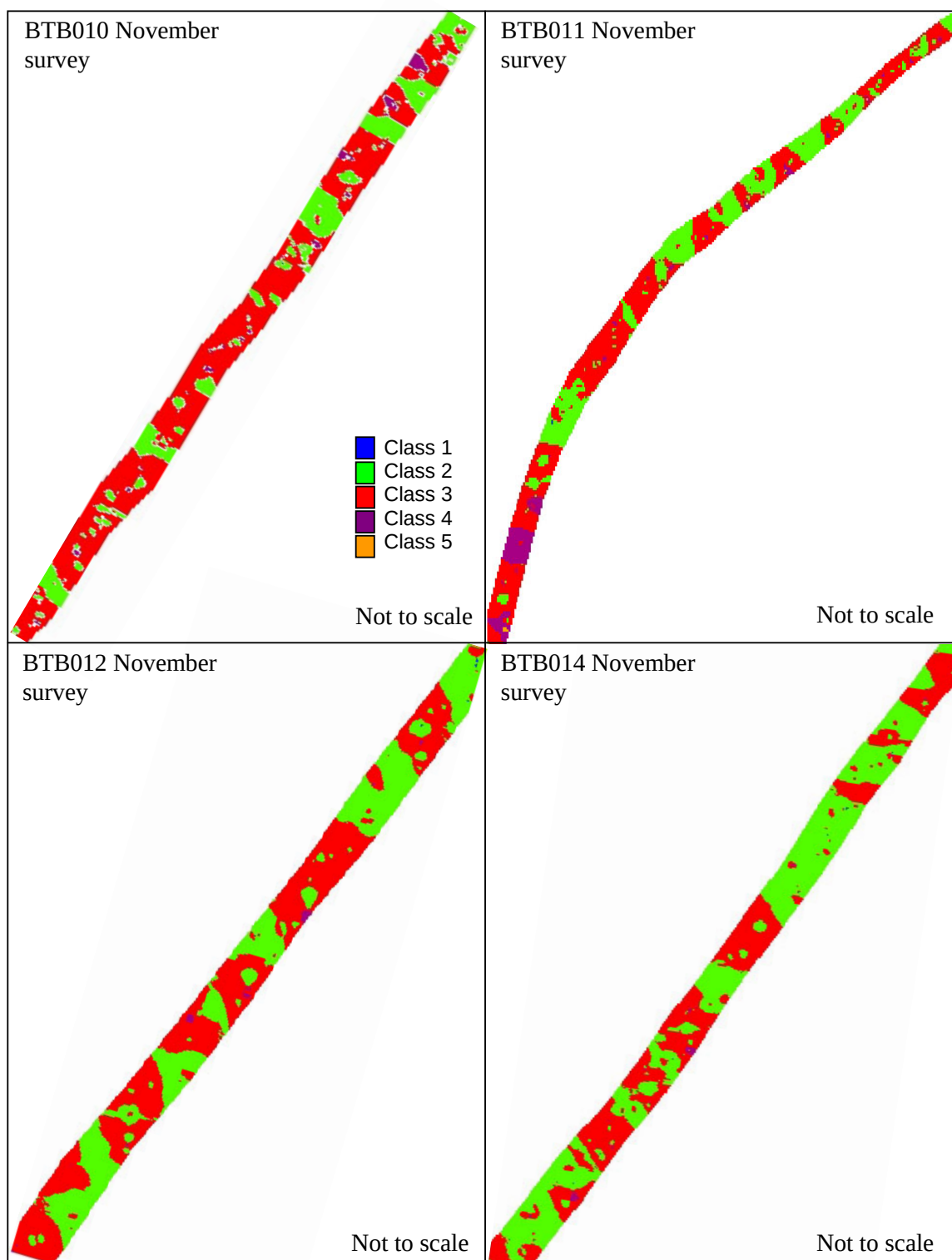


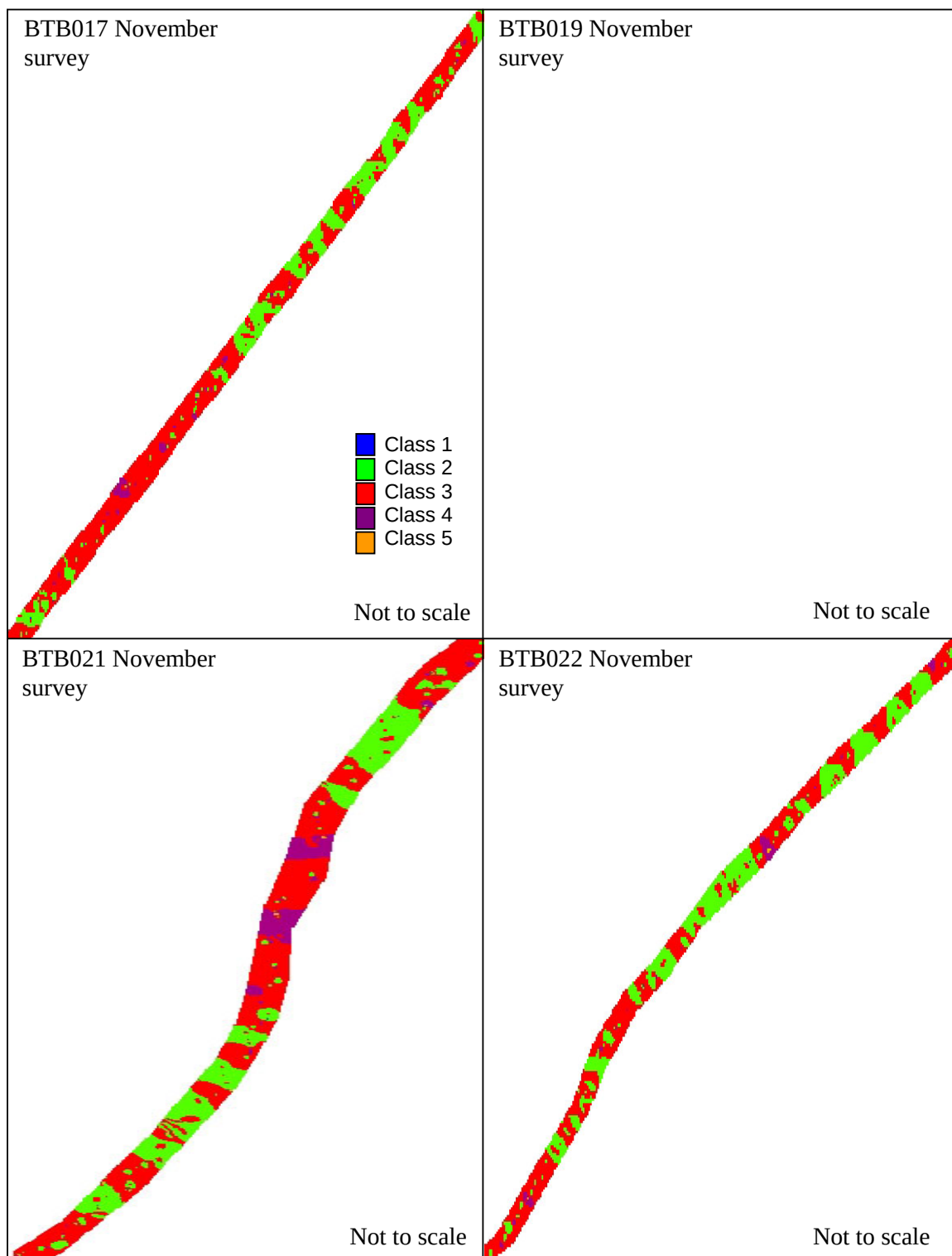


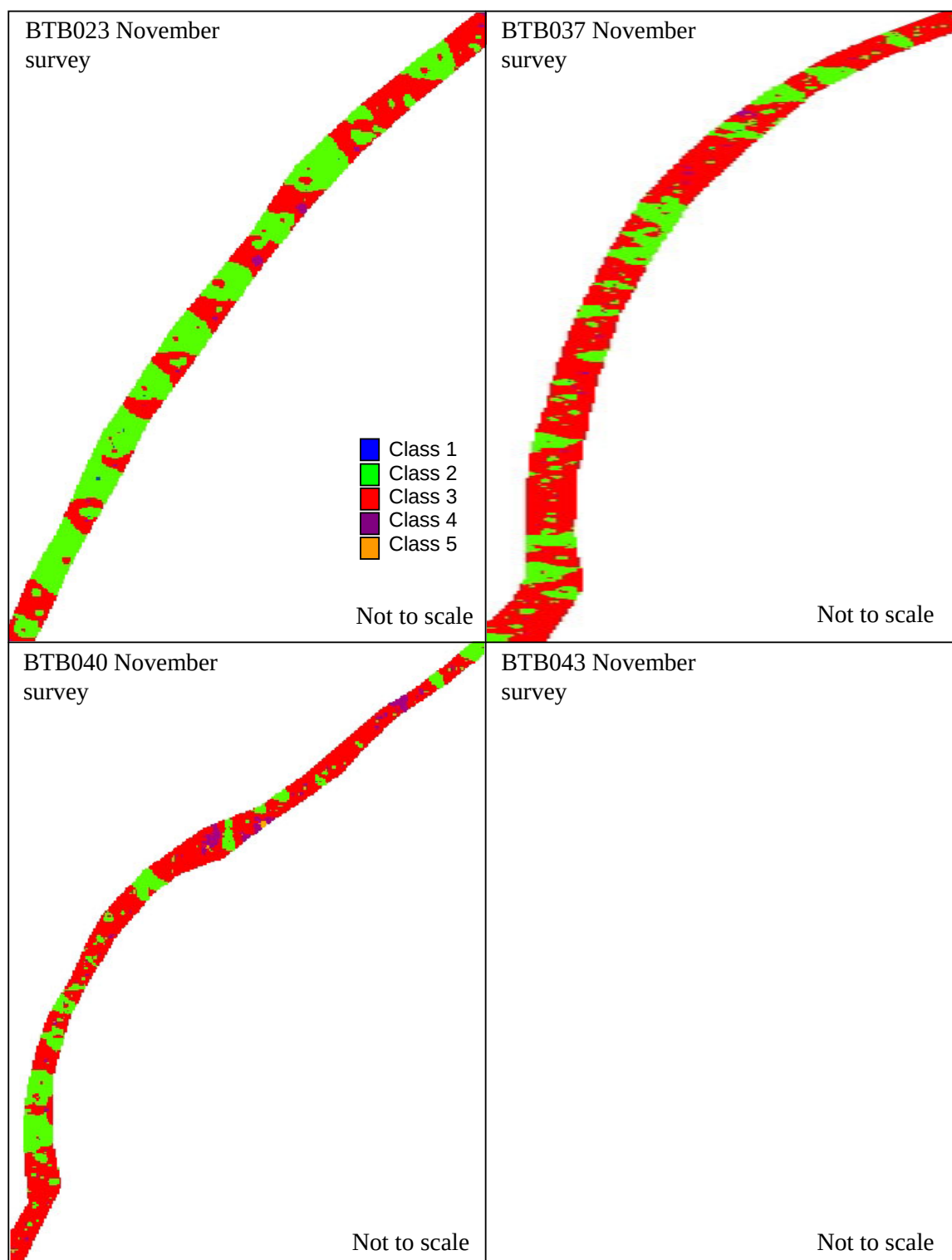


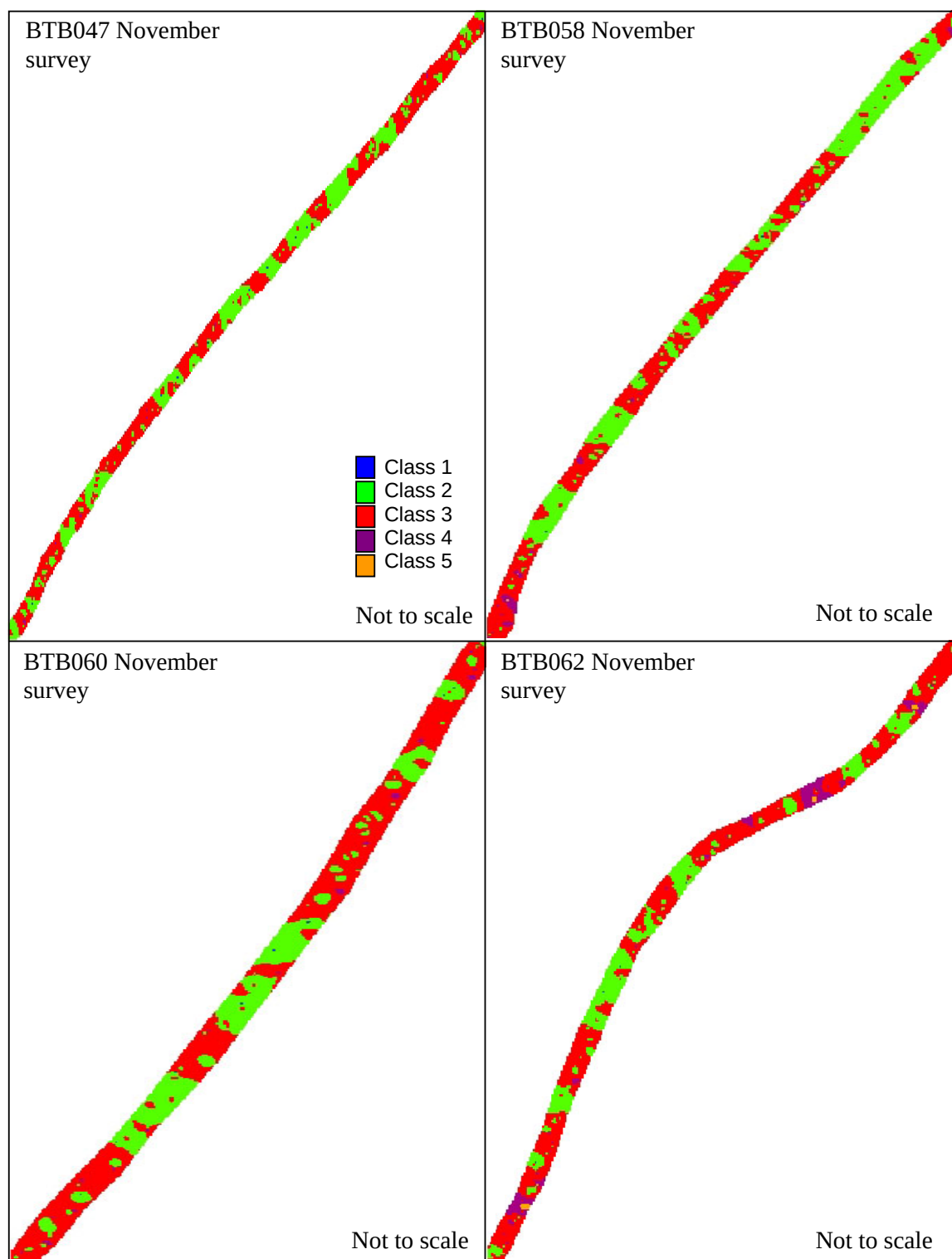


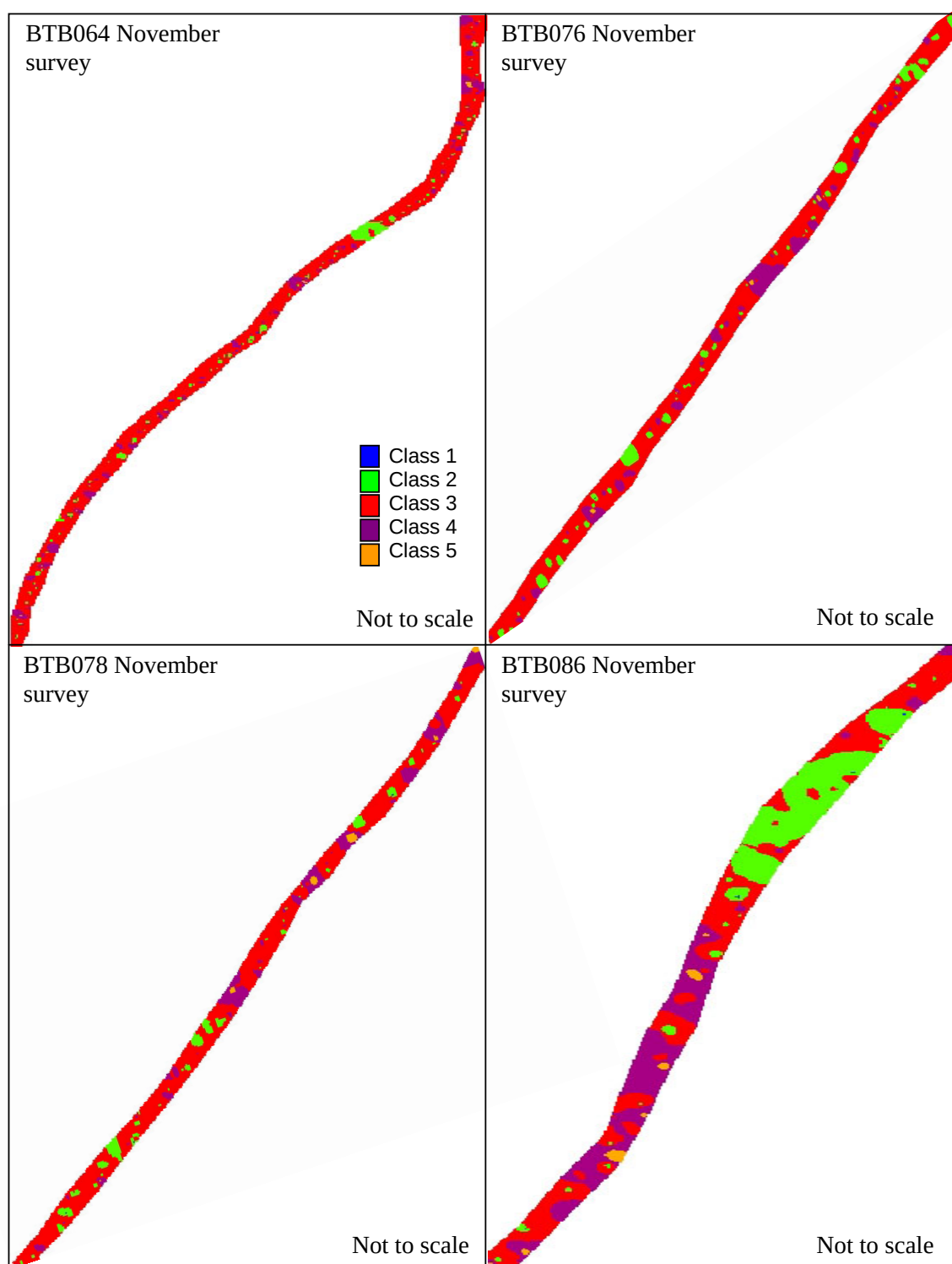


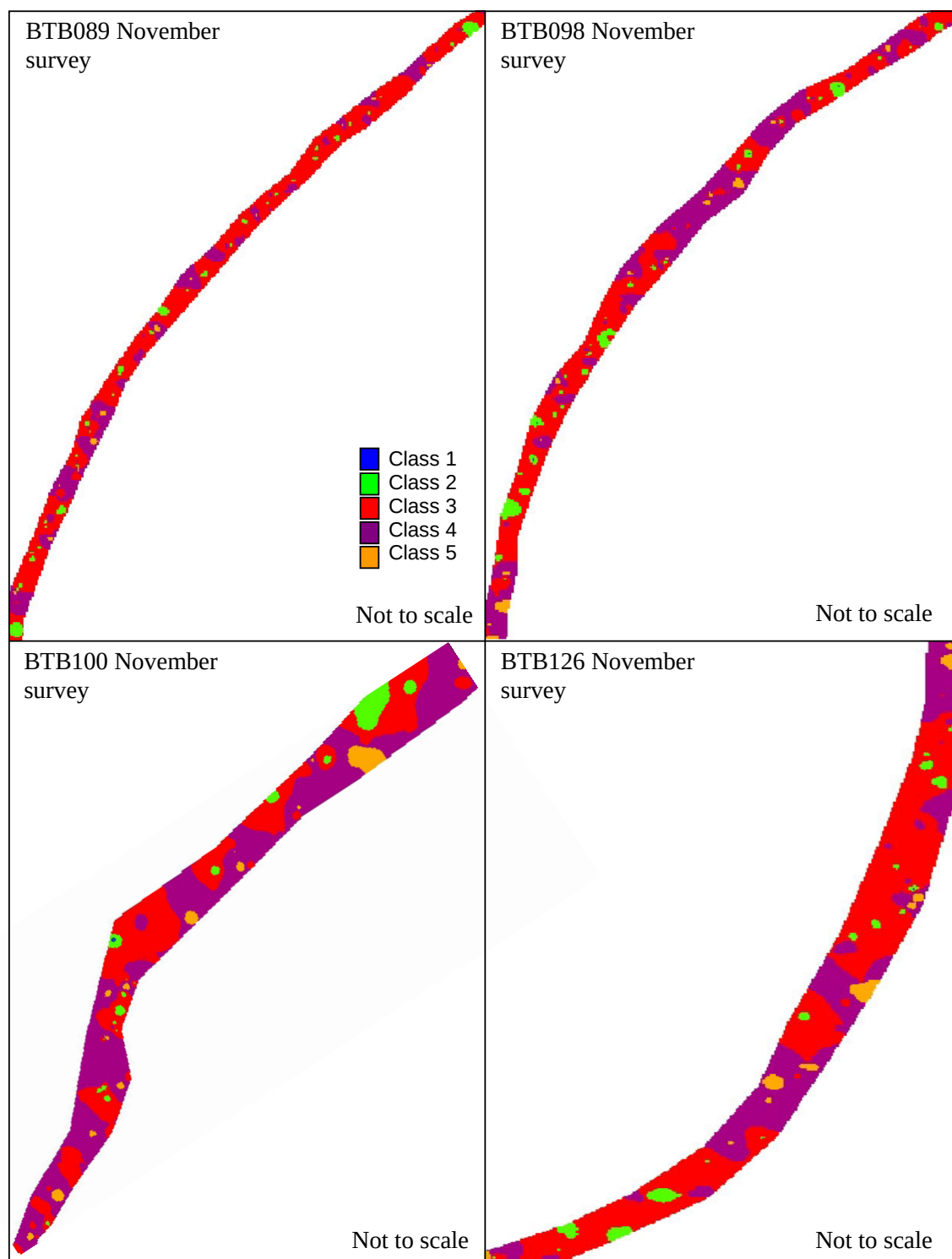


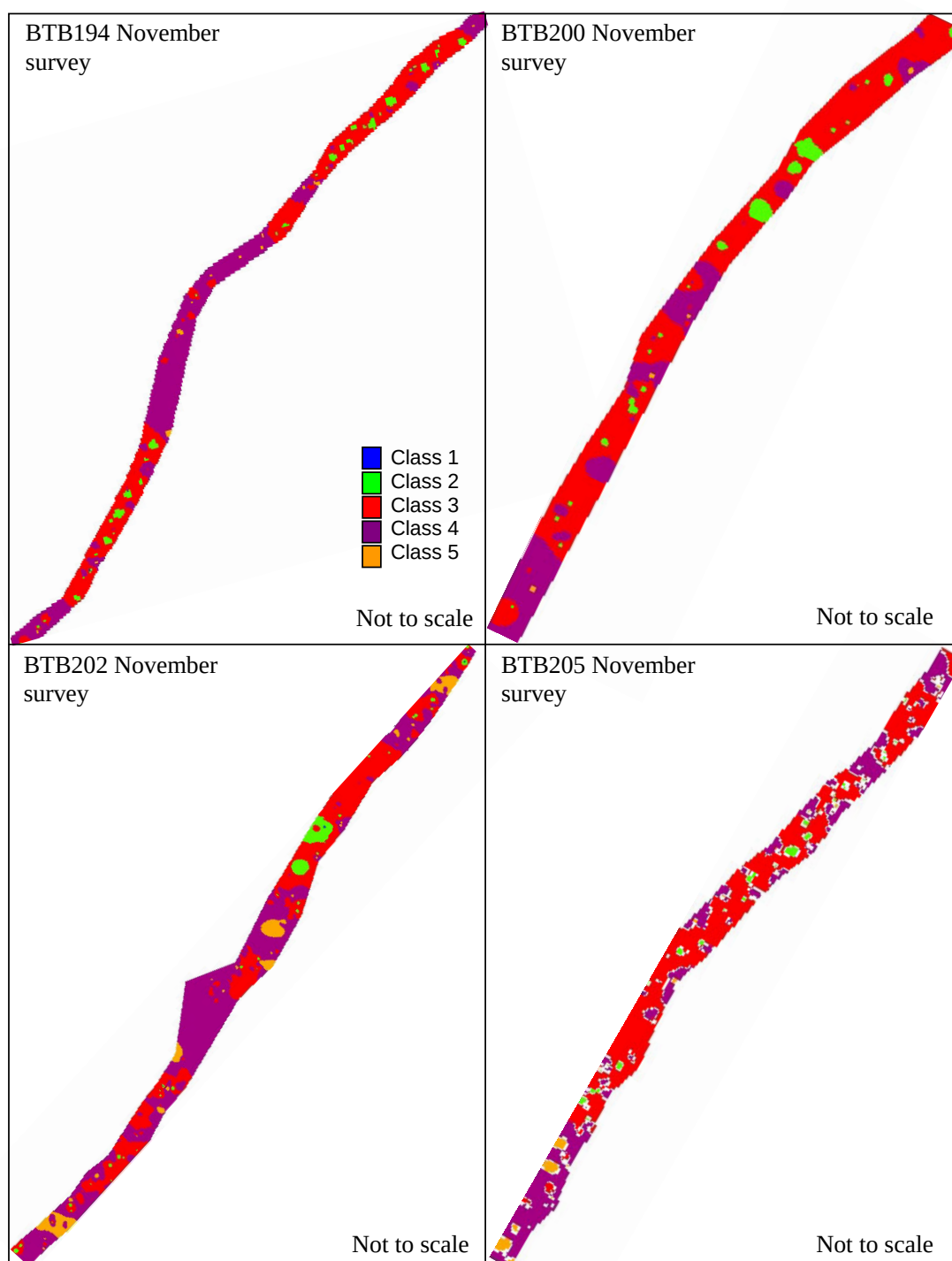












Appendix 5: Red-spot Disease in the Demonstration Reach

(With direct contribution from Jeffery Go, Mel Gabor, Les Gabor and Stephen Hum for pathology)

During the 2007/08 and 2009/10 fish surveys in the demonstration reach, four species (bony herring (*Nematalosa erebi*), golden perch (*Macquaria ambigua*), Murray cod (*Maccullochella peelii*) and spangled perch (*Leiopotherapon unicolour*)) were sampled with lesions or severe ulcers (Figure 38). Laboratory tests confirmed infection by the fungus-like pathogen *Aphanomyces invadans* and the reportable disease epizootic ulcerative syndrome (EUS). Previously, EUS has been recorded in the wild only from coastal drainages in eastern, northern and western Australia. The epizootic was restricted to bony herring in 2008, but infected more hosts in 2010. This is the first confirmation of *A. invadans* in the Murray-Darling river system, and is the first report of EUS in these native species. Carp were sampled with ulcers, but found not to contain *A. invadans*, supporting past reports from elsewhere in the world that this species has immunity to the disease.

The lack of previous clinical evidence, the large number of new hosts, the geographic extent and prevalence of this disease (Figure 39 and Table 16), the severity of ulceration (Figure 38) and apparent high pathogenicity suggest a relatively recent invasion by *A. invadans*. This has important biosecurity implications, as it has been shown to impact wild fisheries and aquaculture industries throughout the world. Hence, it should be considered a key threat to native fish in the demonstration reach. Due to the significance of this finding, a paper has been submitted for publication.

Further information on the outbreak of this disease can be found in Boys *et al.* (2012), available as open access at: <http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0035568>

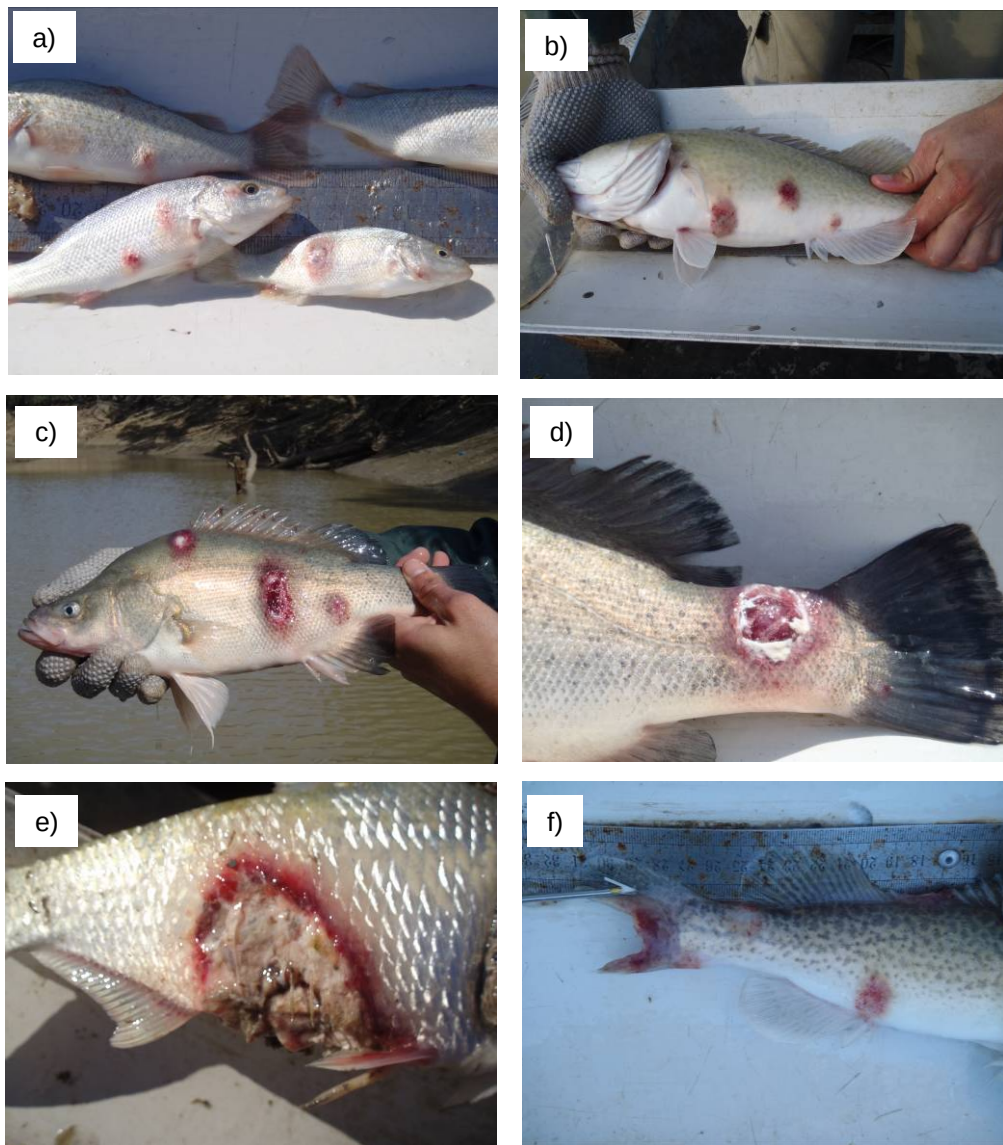


Figure 38. Diseased fish collected from the Barwon-Darling River between Bourke and Brewarrina weirs in June 2010. Pictures show (a) spangled perch, (b) Murray cod with raised lesions, (c, d) golden perch with deep ulceration, (e) bony herring suffering severe ulceration and tissue necrosis, exposing the peritoneal cavity and internal organs, and (f) Murray cod with deep ulceration and muscle or fin necrosis.

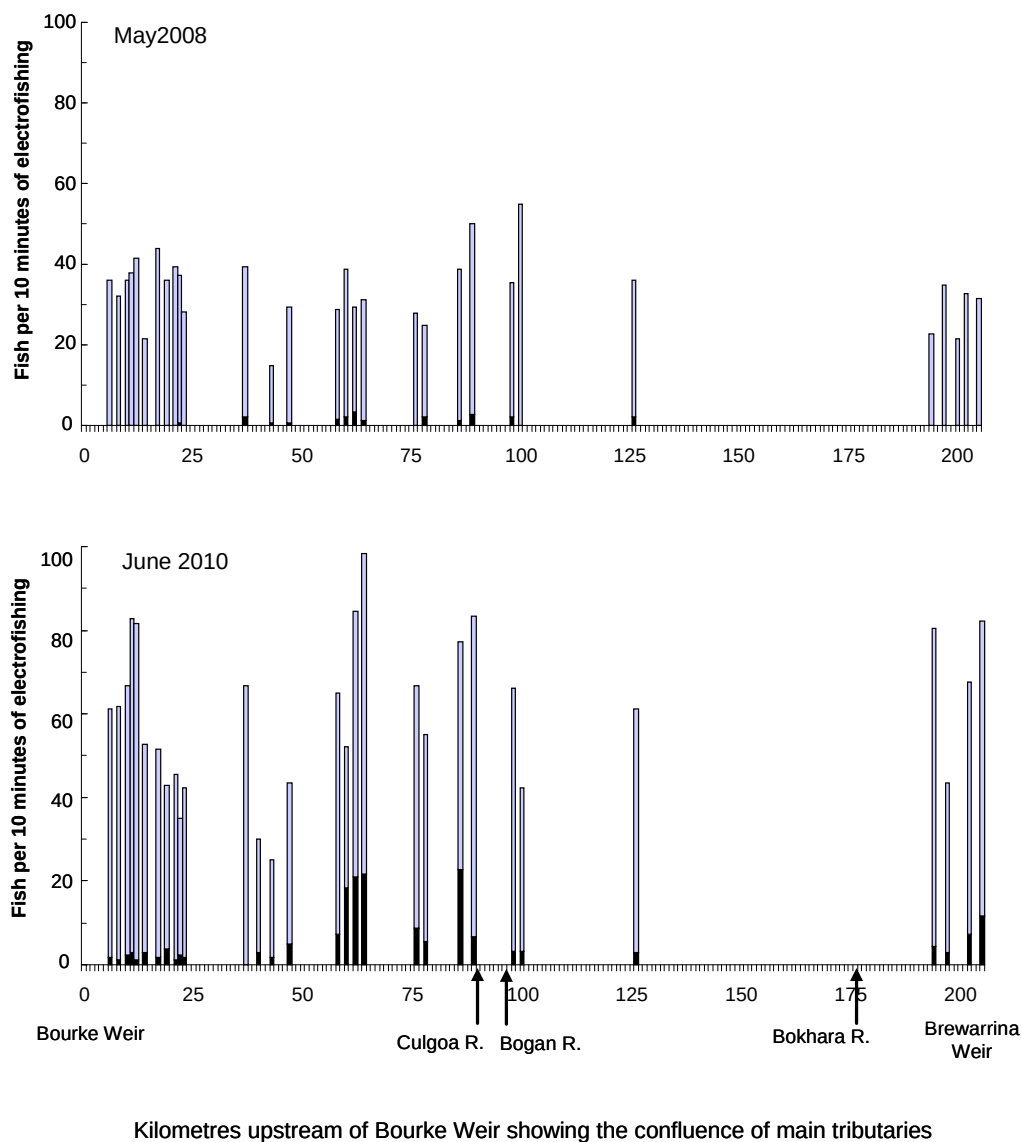


Figure 39. Distribution of fish with ulcers (black) and without ulcers (grey) in the Barwon-Darling River between Bourke and Brewarrina weirs in 2008 and 2010.

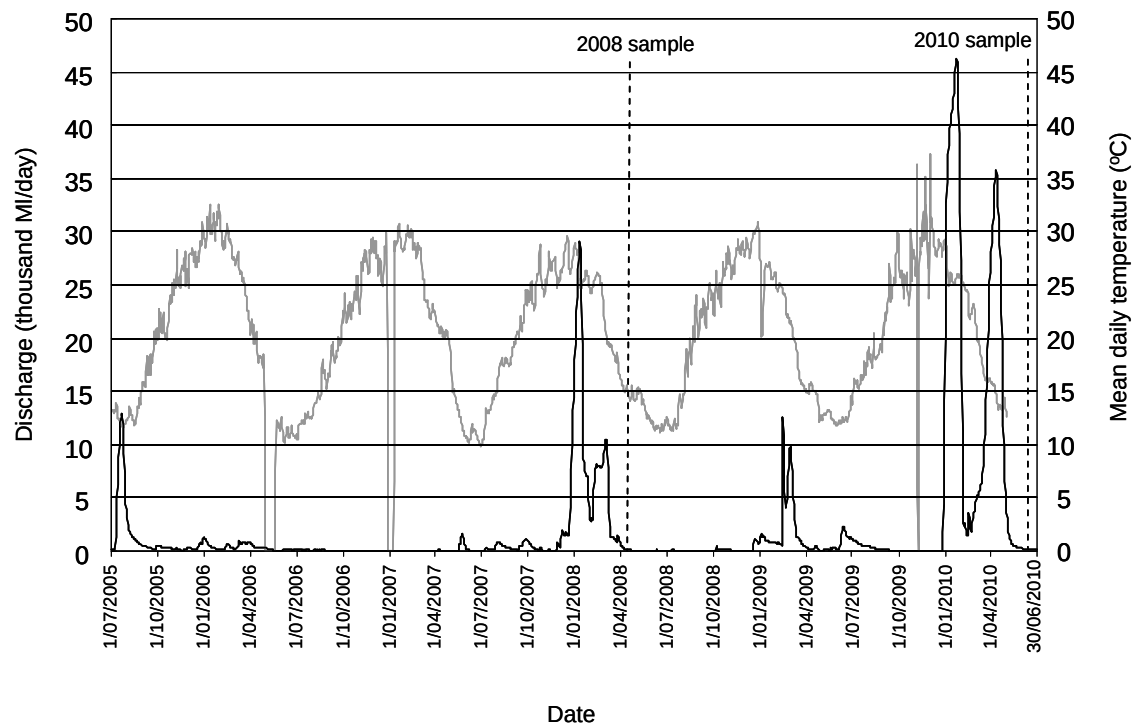


Figure 40. Daily discharge (black line) and mean daily water temperature (grey line) recorded at the Bourke gauge (425003) between July 2005 and July 2010; dotted lines show when the 2008 and 2010 fish samples were collected.

Table 16. Number of ulcerated fish from the assemblage of species collected from 30 locations in the Barwon-Darling River between Bourke and Brewarrina weirs in May 2008 and June 2010.

Common Name	Scientific Name	May 2008	June 2010
Olive perchlet	<i>Ambassis agassizii</i>	-	-
Silver perch	<i>Bidyanus bidyanus</i>	-	-
goldfish	<i>Carassius auratus</i>	-	2 (<1%)
Un-specked hardyhead	<i>Craterocephalus stercusmuscarum</i>	-	-
Carp	<i>Cyprinus carpio</i>	7 (3%)	7 (<1%)
Mosquito fish	<i>Gambusia holbrooki</i>	-	-
Carp gudgeon	<i>Hypseleotris</i> spp.	-	-
Spangled perch	<i>Leiopotherapon unicolor</i>	3 (8%)	50 (21%)
Golden perch	<i>Macquaria ambigua</i>	3 (2%)	40 (8%)
Murray cod	<i>Maccullochella peelii</i>	-	4 (5%)
Murray-Darling rainbowfish	<i>Melanotaenia fluviatilis</i>	-	-
Bony herring	<i>Nematalosa erebi</i>	28 (<1%)	216 (16%)
Hyrtl's tandan	<i>Neosilurus hyrtlii</i>	-	-
Australian smelt	<i>Retropinna semoni</i>	-	-
Total number individuals ulcerated		41 (2%)	319 (10%)
Total number of species ulcerated		4 (29%)	6 (32%)

Data in parentheses are the proportion of sampled individuals of each species that were ulcerated. Bold type identifies species in which EUS was confirmed using histopathology. No data means that the species was caught, but no specimens were ulcerated.