Government of **Western Australia**
Department of **Water**

Acoustic tracking of freshwater cobbler, Tandanus bostocki, in the Harvey and Brunswick Rivers, south-west Western Australia

Securing Western Australia's water future

Water*Science*
technical series

Report no. WST 61
April 2016

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April 2016

ISSN 1836-2869 (print)
ISSN 1836-2877 (online)

ISBN 978-1-922124-48-7 (print)
ISBN 978-1-922124-49-4 (online)

Acknowledgements

The Department of Water would like to thank the following for their contribution to this publication. Paul Hillier, Dr Fran Stephen, Dr Rodney Duffy, Dean Meredith and Annique Harris (Department of Fisheries WA), Dr David Morgan (Murdoch University Freshwater Fish Group and Fish Health Unit), Wayne Koster (Department of Environment, Land, Water and Planning, Arthur Rylah Institute for Environmental Research, Victoria), Dr John Conallin (Murray Catchment Management Authority, NSW), Dr Jonathon Marshall (Department of Environment and Resource Management, Qld), Trent Wilkes (Water Corporation), Gillian White, Dr Helen Nice, Kelli O'Neill, Mike McKenna and Krish Seewraj (Department of Water, WA) and Terry and Judyth Salom, Darryl Helms, John Taylor, and Penny and Brandon Brooksbank (land holders).

Citation

Storer T, Bannister J, Beatty S, Crook D & Bennett, K 2016, *Acoustic tracking of freshwater cobbler, Tandanus bostocki, in the Harvey and Brunswick rivers, south-west Western Australia,* Water Science Technical Series, report no. 61, Department of Water, Western Australia.

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Cover photograph: Freshwater cobbler, *Tandanus bostocki*

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Summary

This study used acoustic tracking to examine the movement of freshwater cobbler (*Tandanus bostocki*) in two rivers within the south-west of Western Australia. It was designed to investigate the movement patterns and habitat preferences of *T. bostocki* (where and where they travelled, triggers for movement and characteristics of the habitats they used) and the hydrological requirements for accessing these habitats (bioconnectivity).

The study was conducted to inform management of water resources by the Department of Water. The Department is responsible for allocating water across Western Australia for social and economic use, while considering the needs for maintenance of a healthy aquatic ecosystem that supports biodiversity and associated ecosystem services. A sound understanding of flow-ecology linkages is needed for setting water requirements to support environmental values.

Flow is a critical component of species ecology, driving many aspects of water quality and governing the ability of a species to migrate within the system to access key habitats for breeding, foraging, spawning, nursery and drought-refuge. This includes accessing lateral habitats, such as floodplains and the shallow edges of streams, riparian and inundated vegetation or undercut-banks.

T. bostocki is a key indicator species for setting flow requirements as these fish are the largest bodied native fish in south-west WA and they are known to be active through drier periods, including within riffle zones, and therefore are at high relative risk from low flows.

Fifty fish were tagged in the Brunswick and Harvey rivers and monitored between April 2013 and April 2014. Release sites in the Harvey and upper Brunswick rivers were known or likely dry-season refuge pools, with little opportunity for *T. bostocki* to move out of the pools during the dry-season. Fish released into the lower Brunswick River were able to move outside the range of the acoustic receivers.

The tagged *T. bostocki* exhibited a predictable diurnal pattern of movement, remaining in shelter during the day and moving during the night. Most fish conducted their nocturnal activity in an area other than that used for shelter but there didn’t appear to be specific habitats used by all individuals for the same purpose. That is, separate individuals used the same habitat for different purposes (such as shelter and foraging). *T. bostocki* moved out of shelter immediately after dusk and returned before dawn, maximising their nocturnal activity.

Although most fish only moved locally (i.e. in the vicinity of release locations through the study period) some individuals moved more than 8 km in both systems. *T. bostocki* also moved at relatively high speeds at times (e.g. at least 2.66 km in 4 hours).

The importance of permanent-water refugia was clear, with *T. bostocki* shown to move into these areas during the dry season. However, deeper habitats were also frequently used during the year for both sheltering and foraging.

As flows increased following the dry season, many *T. bostocki* moved away from the pools they were released into. Some fish returned regularly whereas others returned periodically or in some cases not at all. Movements of *T. bostocki* out of dry-season habitats in the Harvey River correlated with flows of around 5 ML/day, which likely reflects the minimum flow

required to connect the system around the release sites. Similarly, fish released in the upper Brunswick River (BRUN-05) moved away from their dry-season habitat when flows were consistently above 3 ML/day. There was no clear flow-trigger at other sites, though this was likely due to greater connectivity regardless of flow. To determine the flows required to allow *T. bostocki* to move through the upper Brunswick River, further investigation considering the influence of natural and artificial barriers is warranted.

Maintaining deeper pools (and access to them) throughout the length of the system is particularly important in the Brunswick River along the Darling Range as connectivity is restricted by natural and artificial barriers. Given the low connectivity through the upper Brunswick (particularly the limited ability to travel upstream) and the existence of *T. bostocki* at a number of sites, the population is likely fragmented.

Although movement of *T. bostocki* was influenced by similar triggers, for example, moving away from hydrophone locations in winter as flows increased, there was no clear evidence to suggest that individual fish remained together for extended periods.

As *T. bostocki* occupy a niche at the top of the aquatic food-chain in many south-west streams, are the largest bodied native freshwater fish in the region, and are known to move through systems to breed and spawn during the dry season, protection of their dry-season habitats is critical to maintain ecosystem health.

The results of this study indicate that protection of *T. bostocki* requires maintenance of deeper pools, particularly permanent-water refugia, and ensuring appropriate access to those pools. This requires flows sufficient to allow *T. bostocki* to retreat to dry-season habitats and to maintain water quality and levels through the year (e.g. ~5 ML/day appears necessary for *T. bostocki* to move through the Harvey River study area). Further, summer flow provisions should account for bioconnectivity between daytime and night time habitats. The level of connectivity needed will be system-specific but should include access to nearby foraging habitats outside refuge pools through summer.

Assessment of winter flows should consider that some fish make migrations exceeding 8 km and likely significantly longer in larger systems and over longer periods (where connectivity allows). Allowing for these movements is important to increase the resilience of populations by preventing fragmentation and to ensure adequate genetic mixing. For the systems assessed, the Harvey River should be connected during late spring and early summer between the Harvey and Stirling dams. In the Brunswick River, bioconnectivity should be maintained along the Swan Coastal Plain though the requirements and practicalities of bioconnectivity on the Darling Scarp are unclear. Natural and artificial barriers will constrain upstream movement regardless of flow.

Further investigation is needed in larger, better connected systems to gauge the extent of movements of *T. bostocki* when not limited by barriers. This will help guide management of not only surface water resources, but also groundwater systems that can maintain surface flows in lotic systems during baseflow periods. Related to this is the need to better understand the ability of *T. bostocki* to negotiate barriers (e.g. minimum depth required).

1 Introduction

1.1 Water resource management in Western Australia

The Department of Water is responsible for allocating water across Western Australia for social and economic use. This includes provision of water to support biodiversity and in turn maintain the ecosystem processes and services[1] that depend on a healthy aquatic ecosystem.

Finding sufficient water to meet the needs of all users is increasingly challenging given the significant reductions in water availability over recent years, due both to decreasing rainfall (IOCI 2005) and the increasing water demand as the population grows. Accordingly, the department must continually adapt management to optimise water use efficiency.

Supporting environmental values in a highly competitive water market requires a clear understanding of ecological requirements. Knowledge of the movement patterns of freshwater fishes is critical for the development and effectiveness of conservation and management strategies, as well as for understanding how man-made stressors may be affecting populations (e.g. Magoulick & Kobza 2003). For example, as many species move within rivers as part of spawning migrations, determining spatial and temporal scales of movements can enable a better understanding of critical spawning grounds that need protection, how in-stream barriers may impede migrations, and to evaluate the adequacy of environmental flows in maintaining migration pathways.

Given their dependence on flow and the ecological importance of fish in maintaining a healthy ecosystem, the needs of fish are a primary consideration in understanding ecological requirements of riverine ecosystems. Understanding the habitat preferences of fish is important in managing waterways. The Department of Water uses this information in the water allocation process, for calculating the water needed to support habitat connectivity and quality. The information is also valuable for assessing requests to disturb the bed and banks of rivers[2], such as with the installation of in-stream structures (i.e. dams) that may affect bioconnectivity or habitat.

Characterising the specific habitat requirements of native fish allows the Department to optimise water delivery to rivers. This incorporates minimum summer flows to support water quality within dry-season refugia, provision of flow pulses at certain times of the year to facilitate movement of species to key habitats, and sufficient flow to inundate key habitats in specific periods (e.g. to ensure access to spawning or nursery habitats). Habitat preference data can also be used by river managers in developing best management practices and priorities for protecting and restoring waterways to conserve biodiversity.

[1] Ecosystem services include the maintenance of water quality for downstream users. A properly functioning aquatic ecosystem is integral in, amongst other things, nutrient cycling, sediment trapping, preventing secondary salinisation, bank stabilisation and maintenance of water temperature. Poor water quality may limit use or result in high treatment cost.

[2] Bed and banks permits are required for any disturbance in proclaimed surface water management areas, rivers and irrigation districts (Rights In Water Irrigation Act 1914).

1.2 Species selection (*Tandanus bostocki*)

Tandanus bostocki (Figure 1) is the largest of the 11 native freshwater fishes in south-western Australia (Morgan et al. 2011), reaching more than 500 mm total length (Department of Water unpublished data).

Tandanus bostocki were chosen for this acoustic tracking study as they may be at a particularly high risk from altered flow regimes that affect bioconnectivity. This is due to their large size and as they are known to be active during drier periods (Beatty et al. 2010; Norton et al. 2010; Storer et al. 2011; White & Storer 2012). The movement patterns of this species during baseflow in the Blackwood River have been shown to be positively related to the volume of flow through riffle zones and therefore *T. bostocki* could be an ideal indicator species of river connectivity (Beatty et al. 2010). Larger bodied species have been shown as particularly dependent on deep pool environments (e.g. Magoulick & Kobza 2003).

Further, a loss of bioconnectivity leading up to and during summer may affect the reproductive success of *T. bostocki* (e.g. interfering with access to mating/spawning habitats). A peak in gonadosomatic index in this species during spring has been revealed (Beatty et al. 2010), and spawning through late spring to early summer (Nov–Jan) has been reported (Morrison 1988; Hewitt 1992; Hutchison 1992).

T. bostocki were also selected as their larger body size (compared to other south-west species) was preferable to minimise and physical or behavioural effects due to the size and weight of implanted transmitters (recommended maximum bodyweight ratio of 2%, see Section 3.4 Methods). The use of acoustic transmitters (tags) has been successfully trialled in the congener species, *Tandanus tandanus,* which has a size and shape similar to *T. bostocki* (Koster et al. 2015, Jonathon Marshall pers. comm., unpublished data). Finally, *T. bostocki* are relatively well distributed across the south-west of Western Australia and therefore data from this trial will provide information relevant for a large area.

Figure 1 Freshwater Cobbler (Tandanus bostocki). Source: Gerald R Allen, WA Museum

2 Objectives

To characterise the movement of *T. bostocki* using acoustic telemetry in two rivers in south-west Western Australia to help establish the water regime required to support its life history.

Specific objectives were to define the:

- extent of movement (maximum distance travelled)
- habitat use (diurnal and seasonal patterns)
- timing of movement (correlation to environmental triggers)
- ability to move through a system (swimming speed and capacity to negotiate obstacles)
- variability in movement patterns based on size and sex
- existence of gregarious behaviour.

Finally, the study aimed to assess the effectiveness of acoustic tracking for monitoring the movements of *T. bostocki* and its appropriateness as an indicator species of bioconnectivity in rivers.

3 Method

Sampling was designed to track real-time movement of individual *T. bostocki* over an annual cycle between April 2013 and April 2014. This included monitoring flow (continuous) and aquatic habitat characteristics (including bioconnectivity). These patterns could then be used to describe important habitats, migration pathways, distances travelled and to identify cues for movement, such as relationships between movement and flow regime.

3.1 Acoustic tracking equipment

Acoustic (ultrasonic) transmitter tags

Acoustic transmitter tags were chosen to mark individual fish and track them continuously (within the range of hydrophones). A continuous dataset was needed to assess correlations with flow dynamics. The ability to distinguish individuals was important to elucidate size or sex-related preferences for specific habitats and to gauge the extent and speed of movement.

This technology was also selected as it does not necessitate recapture of fish[3], is not limited by a need to funnel fish through small areas[4] and is effective across the range of salinities present in rivers across the south-west of Western Australia (considering natural salinity, secondary salinisation or where species migrate between freshwater and estuarine environments)[5]. Although the reaches of the rivers selected for this trial were fresh (salinity less than 2000 mg/L), this provided scope for using this technology in future comparative studies in saline environments.

The limitations of acoustic tags include the relative inability to track fine-scale habitat use (that can be better achieved through radio-tracking) and reductions in performance under turbulent conditions (e.g. due to high flow, wind or boat traffic) or in areas of dense phytoplankton or macrophytes, though these conditions were not significant factors for this trial.

The use of acoustic tags to track fish movements has been shown to be effective in many Australian and overseas studies (e.g. Priede 1980; Koster et al. 2009; Crook et al. 2010) for describing habitat preferences, identifying triggers to movement (flow, depth, temperature), and the effects of in-stream barriers on movement.

A maximum transmitter to body weight ratio of 2% is suggested to minimise stress on test species (e.g. Moser et al. 1990; Knights & Lasee 1996). Vemco V6 180 kHz 6 mm coded transmitter tags (Figure 2) were chosen for this study as these were the smallest tags available at the time[6] (1.0 gram in air) and were within the required ratios for fish selected for

[3] Recapture is necessary for use of visible tags, such as Visible Implant Elastomer tags (explained in this report).

[4] Funnelling through small areas is essential for Passive Integrated Transponder tags. The detection range of hydrophones used in this study was sufficient to capture fish moving through test systems.

[5] Radio tags were not used as they are less effective in higher salinity conditions.

[6] Smaller (V5) tags were released soon after the study began; however, the V5 tag has a shorter battery life than the V6 tag (262 days versus 100 days).

this study (refer to Section 3.4). Note: 180 kHz also has a greater storage capacity of hydrophones (3 x the number of detections) compared to the 69 kHz, although storage was not limiting in this study.

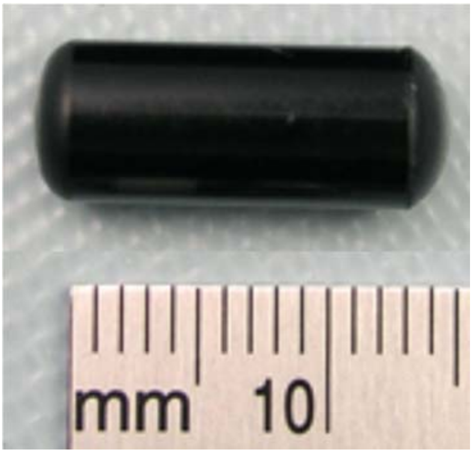


Figure 2 VEMCO V6 acoustic transmitters (fish tag)

Transmitters were set at a nominal delay of 130 seconds. This is a randomised delay with signals delivered at a minimum interval of 70 seconds and a maximum interval of 190 seconds. The maximum possible number of detections per hour was 203.

Acoustic sensors

VR2W 180kHz hydrophones (Figure 3) were used to detect signals from the V6 transmitters.

Acoustic hydrophones were placed at a number of sites in each river to provide a linear array through the main channel to track the spatial and temporal movement patterns of the species. Site selection is discussed in Section 3.3.

Detection range was assessed in the field using VEMCO range test transmitters placed every 10 m for a period of 3 minutes upstream and downstream of hydrophones until the signal was lost. Range testing confirmed that hydrophone stations were capable of detecting signals across the entire width and depth of all study sites. Detection range (100%) was in excess of 20 m upstream and downstream at all river sites (the extent of pools assessed in this study during the dry season), and more than 50 m within the dam site (see site descriptions in Section 3.3).

Note: tags were detected at over 100 m in a subsequent study in the larger Collie River in the south-west of Western Australia. Testing was conducted in a straight, open and deep (4 m+) section of river (Tim Storer unpublished data).

Figure 3 VEMCO VR2W 180kHz hydrophones in place at site HARV-07

3.2 Visible Implant Elastomer tags

Visible Implant Elastomer (VIE) tags were used to mark all fish to enable easy identification in the event of recapture.

VIE tags are a biocompatible, two-part, elastomer material that is injected under the skin of fish. The elastomer holds the pigment in a defined mark without damaging surrounding tissue. The tags are visible externally (through the translucent membranes of the fish) and fluoresce under a long-wave ultraviolet light (enhancing detection of the tags).

This was the first test of this technology in *T. bostocki*. Accordingly, tags were trialled in a number of locations to establish best practice (i.e. ease of implanting and subsequent identification). Two colours, pink and orange, were also trialled for the same purpose. Various tagging sites, colours and number of marks were used to distinguish individual fish.

The tags were supplied by Northwest Marine Technology Incorporated (www.nmt.us).

3.3 Site selection

Two river systems were chosen for this study: the Harvey and the Brunswick (Figure 4).

The Harvey River is highly fragmented and regulated, with two water supply dams in the upper catchment. The Brunswick River is unregulated, reflecting a more natural flow regime, although artificial barriers still occur.

These systems were chosen as between them they cover a range of habitats, barriers to fish movement (natural and man-made) and land uses. Elucidating the effects of these components on *T. bostocki* movements is important to inform management of water regimes.

Streamflows in both systems have been affected by factors such as abstraction, clearing and on-stream and off-stream dams, and are continuing to decline due to climate change. South-west Western Australia has experienced an approximate reduction of 10% in annual rainfall (comparing 1976–2003 with 1925–75) and a resulting decline in streamflow of around 50% in the same period (IOCI 2005)[7]. Based on predictions from climate modelling (using a 1975–2007 baseline), the suggested mean annual runoff in the Harvey to Preston region will fall by between 7 and 40% by 2030 (CSIRO 2009).

In addition, both systems have gauged flows (Figure 4) and known populations of *T. bostocki* (Beatty & Morgan 2006; Beatty et al. 2007; Morgan & Beatty 2008; Storer et al. 2011; White & Storer 2012).

[7] Changes in streamflow will vary considerably between systems due to a range of factors (e.g. groundwater interaction).

Figure 4 Harvey and Brunswick rivers in south-west Western Australia

Harvey River

Movement of *T. bostocki* in the Harvey River was assessed between the Harvey and Stirling dams in the upper catchment (Figure 5).

The study reach receives environmental flows from the Stirling Dam. The release regime currently includes maintenance of a minimum summer baseflow to maintain water quality and pool habitat, periodic higher flows to inundate macroinvertebrate and fish-spawning habitat, and periodic pulses to facilitate fish passage (DoW 2012). By timing fish pass releases with rainfall events it is also hoped to provide some scouring to help maintain channel form.

The current flow regime represents a significant departure from its natural condition and the regime has changed a number of times over the past 100 years. Modelled pre-European conditions (Streamtec 2001) suggested that flows would have been perennial, with peak rainfall in winter and minimum in summer. However, between 1948 (construction of the Stirling Dam) and 2001, flows through summer were increased to meet irrigation needs and minimal flows were released during winter. This situation resulted in a reversal of the pre-European regime (see the synopsis of hydrological conditions in White & Storer 2012). Since 2001, water from the Stirling Dam has been piped for public water supply; this resulted in a reduction in summer water releases to the river. The reduced releases to the reach below the Stirling Dam, coupled with declining streamflows in the south-west Western Australia due to reduced rainfall (IOCI 2005), prompted a number of assessments of environmental water requirements (e.g. Streamtec 2001; WRM 2010; White & Storer 2012). The results set the current flow regime, outlined in the Water Resource Management Operation Strategy (WRMOS) for the Stirling Dam (DoW 2012).

Land use through the catchment is approximately 83% conservation and natural resources, 14% grazing, and the remainder cropping, plantation forestry and seasonal horticulture (data collected in 2000 for the National Land and Water Resource Audit; Department of Agriculture and Food, Land use in Western Australia v2 dataset; Figure 4).

The reach appeared to be in relatively good ecological condition based on studies from 2005–07, 2010 and 2011 (Beatty & Morgan 2006; Beatty et al. 2007; WRM 2010; Storer et al. 2011; White & Storer 2011). It supports four species of native fish (*T. bostocki*, *Nannoperca vittata*, *Bostocki porosa* and *Galaxias occidentalis*). The riparian zone was largely intact (all structural layers present) and was dominated by *Agonis flexuosa* (peppermint), *Eucalyptus rudis* (flooded gum) and *E. patens* (blackbutt) along the river banks (jarrah-marri forest) over a mixed shrub understorey. The channel consisted of pool/riffle sequences, with a number of pools persisting over summer (greater than 1 m deep). Relatively large loads of woody debris were present in the channel, pools appeared to be well scoured (i.e. without excessive amounts of accumulated organic material), and a range of in-stream habitats was present. There was some evidence of erosion in the lower section.

Site selection

Three hydrophone sites were selected to monitor fish movement (Figure 5). The study reach was approximately 10 km in length (from the Stirling Dam to the Harvey Dam study site), with sites approximately 4 km apart.

The HARVDAM site was at the confluence of the Harvey River with the Harvey Dam and represented the downstream extent of possible migration within the riverine habitat of the reach. Sites HARV-07 and HARV-08 were pools previously identified by White and Storer (2012) as dry-season refugia. These sites were also chosen as breeding in *T. bostocki* is thought to occur between spring and summer and therefore these environments may also be important as spawning habitats. Site HARV-08 was immediately downstream of the Sunnyvale stream gauging station (AWRC 8002561; Figure 4).

Although a minimum baseflow is maintained (2 ML/day), the system is fragmented (in respect to movement of *T. bostocki*) through most of the summer and autumn by numerous natural rock riffles and shallow runs. A number of known barriers are identified in Figure 5, though many more are expected in the system. The two pools at HARV-07 and HARV-08 were the only significant areas of permanent water detected through the dry season (based on the assessment made at access points). A thorough investigation of permanent-water refugia and location of other barriers is warranted.

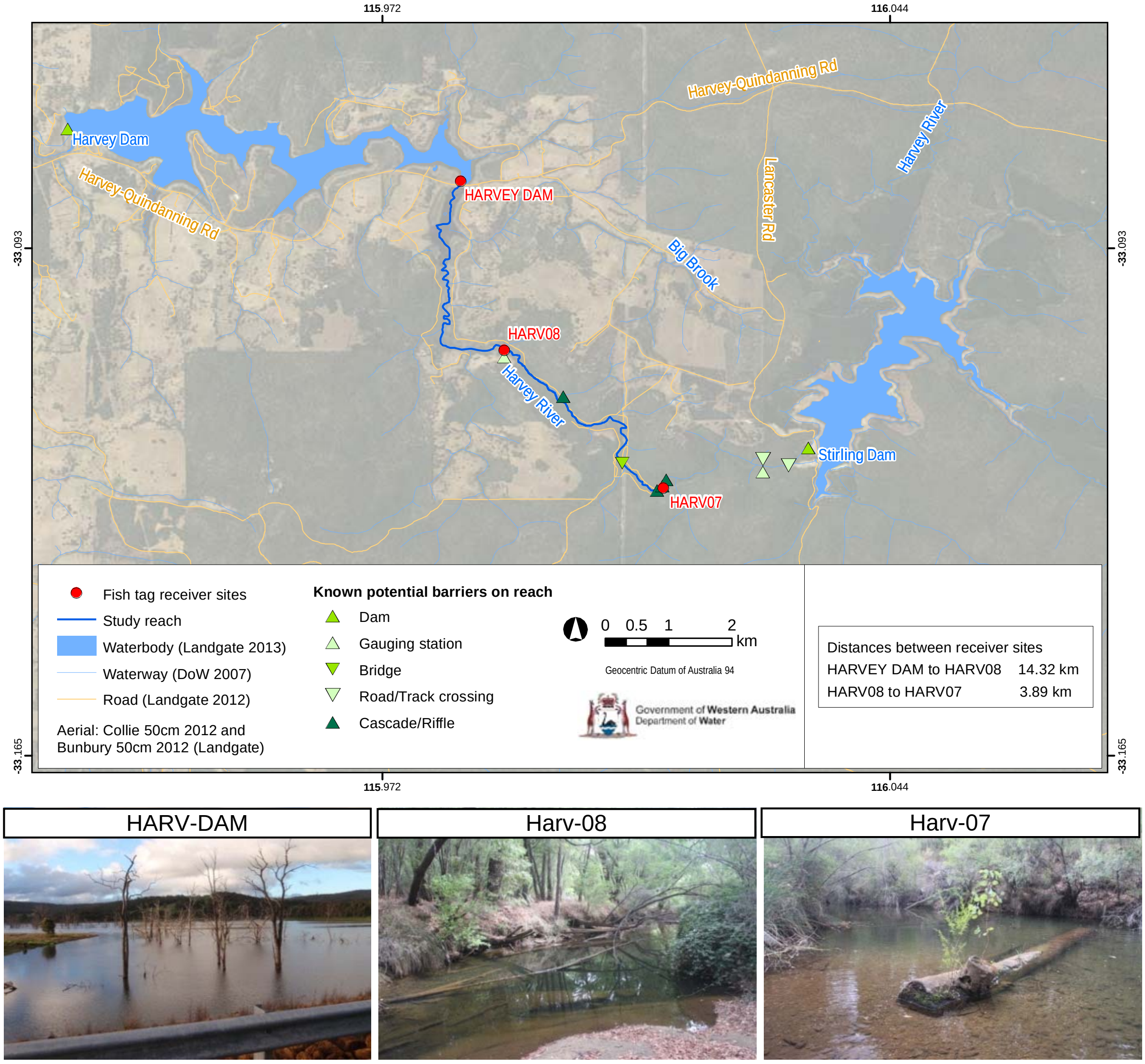


Figure 5 Harvey River land use and study sites

Brunswick River

The Brunswick River has a catchment of 286 km^2 (Donohue et al. 2009) and a length of 55 km from its origins on the Darling Plateau to discharging into the Leschenault Estuary via the Collie River.

The catchment is around 25% cleared in the upper catchment (comprising state forest and plantations) and 75% cleared in the lower catchment (transitioning from beef and dairy farming to urban nearer the coast; LCC 2007; Donohue et al. 2009; Figure 6).

Although the Brunswick River is unregulated, its bioconnectivity is affected by a number of natural and artificial barriers; some of the major barriers are identified on Figure 6 (other, smaller barriers are known and many more are expected in the system). Current and projected reductions in streamflow due to climate change (IOCI 2005) and abstraction place further pressure on bioconnectivity although total farm dam storage capacities as a proportion of mean annual flow only total 1% (CSIRO 2009).

Although the upper parts of the system are anecdotally suggested to stop flowing in drier years, for the most part, flow in the middle and lower parts of the catchment is permanent, with summer flows maintained by groundwater discharges (Annan 2006). The upper section of the system receives a small flow provision from the Worsley Dam via the Augustus River (Figure 6) though this is not expected to affect streamflows below BRUN-05 (Figure 6; Mike McKenna, pers. comm.).

A *River Action Plan* developed for the system in 2006 (LCC 2006) identified the following issues: loss of native fringing vegetation and degradation of remaining vegetation; weed invasion; erosion and sedimentation of the waterway; water quality issues, including nutrient enrichment, pollution and increased salinity; impacts of urban development on the water quality; impacts of feral animals and extraction on water quality. The Brunswick River also supports the four native fishes known from the Harvey River (Morgan & Beatty 2008; Storer et al. 2011).

Site selection

Five hydrophone sites were selected along the main channel of the Brunswick River. The study reach was approximately 34 km in length (between BRUN-01 and BRUN-05 sites), with distances between sites varying between 2.54 km and 14.32 km (Figure 6).

The hydrophone array encompassed most of the freshwater section of the main channel, with intrusion of saline water from the Leschenault Estuary via the Collie River not suggested to reach as far as the lowest study site: BRUN-01 (Mike McKenna, pers. comm.).

Hydrophones were deployed in sites that were assumed to be perennial based on their size and depth (i.e. likely dry-season refugia and breeding habitats). Site BRUN-05 (upper extent) and BRUN-03 were permanent water pools previously identified by Storer et al. (2011) as supporting *T. bostocki*. The other sites were chosen through discussions with landholders and site visits conducted during summer 2013.

Site BRUN-02 and site BRUN-04 were also chosen to observe movements of *T. bostocki* through the confluence with the Wellesley River and Lunenburg River, respectively.

Figure 6 Brunswick River land use and study sites

3.4 Fish tagging

Tags were implanted in April 2013 (late autumn) before any large-scale movements that may occur with higher streamflows through winter.

T. bostocki were collected from sites HARV-07 and HARV-08 on the Harvey River and sites BRUN-01 and BRUN-02 on the Brunswick River (using fyke nets deployed over 24 hours).

The fish tagged were 300–520 mm TL (mean = 387 ± 50 mm SD) and had a body weight 230–1050 g (mean = 504 ± 211 g; Appendix A). This ensured a maximum transmitter to body weight ratio of just 0.004%. Larger (mature) animals were deliberately selected to minimise the transmitter/BW ratio, maximise the chance of capturing movements related to breeding and to provide an indication of minimum flow/depth required for movement through various parts of the study systems.

Holding and depuration

Fish were held in in-stream cages for 24 hours before surgery at site HARV-07 (Harvey River) and site BRUN-01 (Brunswick River) to enable monitoring of their behaviour before surgery and to allow some time for depuration (reducing material in their gastrointestinal cavity to reduce the risk of regurgitation under anaesthesia and to aid in the insertion of tags). Tagging and releasing fish immediately after capture (to minimise handling time) has been successfully demonstrated in other studies (Koster & Crook 2008; Koster et al. 2015).

Anaesthetic and surgical technique (acoustic and VIE tags)

The fish tagging was conducted by Department of Fisheries and Department of Water staff trained in surgery and animal husbandry and experienced in anaesthesia, fish anatomy, recognition of stress in fish, wound healing, behavioural and physiological consequences of tagging, aseptic technique, suturing techniques, and choice of tag type and size relative to target species.

Nitrile powder-free Latex gloves were worn by all officers handling fish to prevent damaging the skin of fish and to prevent the transmission of zoonotic diseases.

Fish were transferred from in-stream cages to holding tanks 15 minutes before surgery, and then moved in small-batches (1–2 fish) to anaesthetic baths. Oxygen was maintained using aerators[8]. Water was regularly refreshed with stream water to maintain the ambient temperature (relative to stream) and prevent the build-up of metabolic by-products.

The fish were sedated with 40 mg/L AQUI-S® via water immersion in anaesthetic baths to a state of deep surgical anaesthesia.

The righting reflex[9] was lost approximately two minutes after exposure to anaesthetic. Baseline behavioural parameters (rate of operculum movement and response to surgical

[8] Pure oxygen was initially used however this resulted in higher than optimal levels of dissolved oxygen and was believed to be responsible for the poor recovery response in two fish. Note: these fish recovered and no further deleterious effects were observed when pure oxygen was removed.

[9] State of anaesthesia where the ability of fish to maintain equilibrium is lost (they do not maintain upright position).

manipulation) were observed throughout surgery to ensure the anaesthesia state was maintained.

Each individual was sexed, weighed and its total length measured before being placed upside down in a 'V'-shaped holding device to allow access to the ventral surface for tag implantation.

The gills were irrigated during surgery with 40 mg/L AQUI-S® to maintain the required state of anaesthesia and oxygen supply.

Acoustic transmitter tags

Prior to surgery, the incision site was swabbed with sterile saline to remove foreign material.

A 10–15 mm ventral incision was made parallel and 10 mm lateral to the *linea alba*, beginning at the caudal edge of the pectoral fin (following the principles in Brown et al. 2010). The incision avoided the *linea alba* to minimise subsequent physical damage due to contact with substrate (see CCAC 2005) which would be expected for the benthic *T. bostocki*. The underlying subcutaneous tissue was incised using blunt dissection.

The VEMCO V6 acoustic tag was sterilised with antibiotic (soaked for 20 minutes in 20 mg/L Oxytetracycline powder dissolved in sterile NaCl). Tags were then inserted into the peritoneal cavity (Figure 7) and the incision closed with 1–3 (depending on the size of the specimen) simple interrupted sutures using 3/0 absorbable Monosyn (Polyglyconate) swaged on, reverse cutting suture material. This suture material is high strength, inert, absorbable and non-hygroscopic.

Figure 7 Insertion of an acoustic transmitter into the peritoneal cavity

The incision was covered with a 1:10 dilution of iodine solution and poly-ox bandage gel to reduce wound contamination and ensure skin apposition. This was repeated twice (three layers of betadine plus poly-ox bandage).

Post-operative fish were observed to ensure tag size was not excessive (not obvious externally).

Visible Implant Elastomer (VIE)

The VIE tags were injected under the skin of fish using a hypodermic needle. The injection sites were swabbed with a 1:10 dilution of iodine solution before and after the procedure. Tag locations were varied between the base of the dorsal fin and along the ventral side of the caudal fin (posterior to the anal fin; Figure 8).

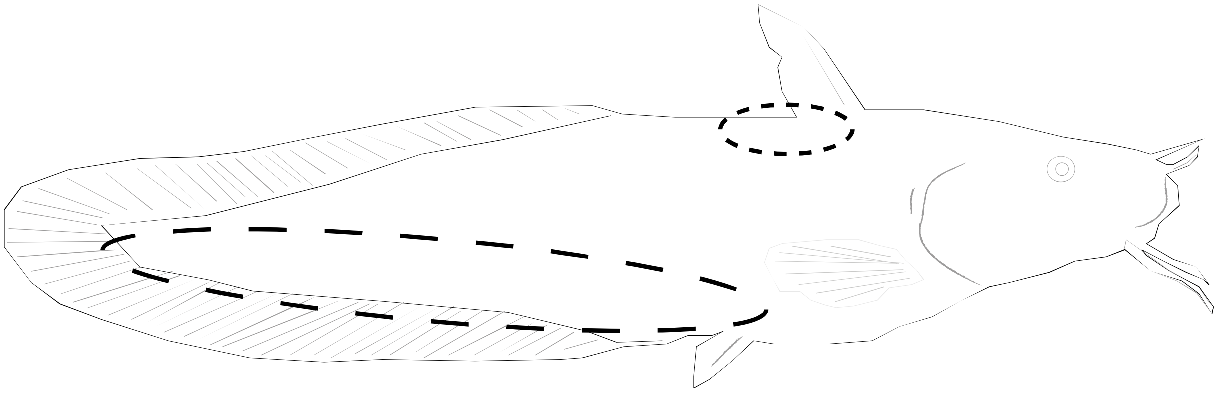


Figure 8 VIE tagging locations

Recovery

Following surgery, the fish were placed in recovery tanks containing fresh river water and aeration. The tanks were kept out of direct sunlight and lids used to reduce external stimuli.

The surgical procedure was completed within 5 minutes (from placement in anaesthetic baths to placement in recovery tanks).

The recovery of the fish was monitored by trained staff and assistance provided to improve water circulation over the gills. The righting reflex returned after approximately two minutes, after which fish were placed in holding cages within the river (see results in Section 4.3). The recovery rates are within optimal ranges described by Marking & Meyer (1985) and Bell (1987). The condition of the fish in cages was monitored periodically over a 24 hour period before they were released at the locations described in Section 3.5.

3.5 Release strategy

The fish were released at two sites on the Harvey River (site HARV-07 and HARV-08; Figure 5) and three sites on the Brunswick River (site BRUN-01, BRUN-03 and BRUN-05; Figure 6). The numbers of fish released at each site were: 13 at BRUN-01 and BRUN-05, 12 at BRUN-03, and 6 at HARV-07 and HARV-08.

An approximately even distribution of sizes and sexes was released at each site within each system. To investigate the potential for homing behaviour, some fish were released at the capture site while others were released away from the capture site. The distribution of fish is shown in Appendix A.

3.6 Environmental data

Flow was recorded daily over the study period at two sites in the Harvey River and two sites in the Brunswick River and water-release volumes were recorded daily from the Stirling Dam. The flow monitoring station locations are shown in Figure 4.

A range of supplemental data, including aquatic and riparian habitat features, catchment condition, water quality, presence of in-stream barriers and degree of bioconnectivity, were collected from each site at the start of the study period. The bioconnectivity of the system was reassessed bimonthly. These data were used for interpreting fish movement data and are not directly presented within this report.

4 Results and discussion

4.1 Hydrology

Harvey River

Flows below the Stirling Dam from May until late July 2013 were low (typically between 2 and 3 ML/day), after which flows increased following rain and releases from the Stirling Dam (Figure 9).

Flows recorded between late July and November 2013 at the Sunnyvale gauging station (at the HARV08 site, approximately 6.3 km downstream of the Stirling Dam, Figure 5) were considerably higher than release volumes – explained by rainfall in the catchment downstream (Figure 9).

A number of peaks in flow were recorded, including flows over 200 ML/day on 8 August, 4 September and 23–25 September 2013. These coincided with high rainfall periods and higher release volumes from the Stirling Dam on three occasions: 1–2 August (~110 ML), 3–4 September (~140 ML) and 24–25 September 2013 (~120 ML).

Rainfall recorded between May and late July (late autumn and winter) had a minimal impact on streamflows. This may be due to lower rainfall volumes (compared to spring and early summer), reduced runoff due to a dry catchment, and/or rain falling outside the immediate catchment. Note: most rainfall was recorded through late winter and spring.

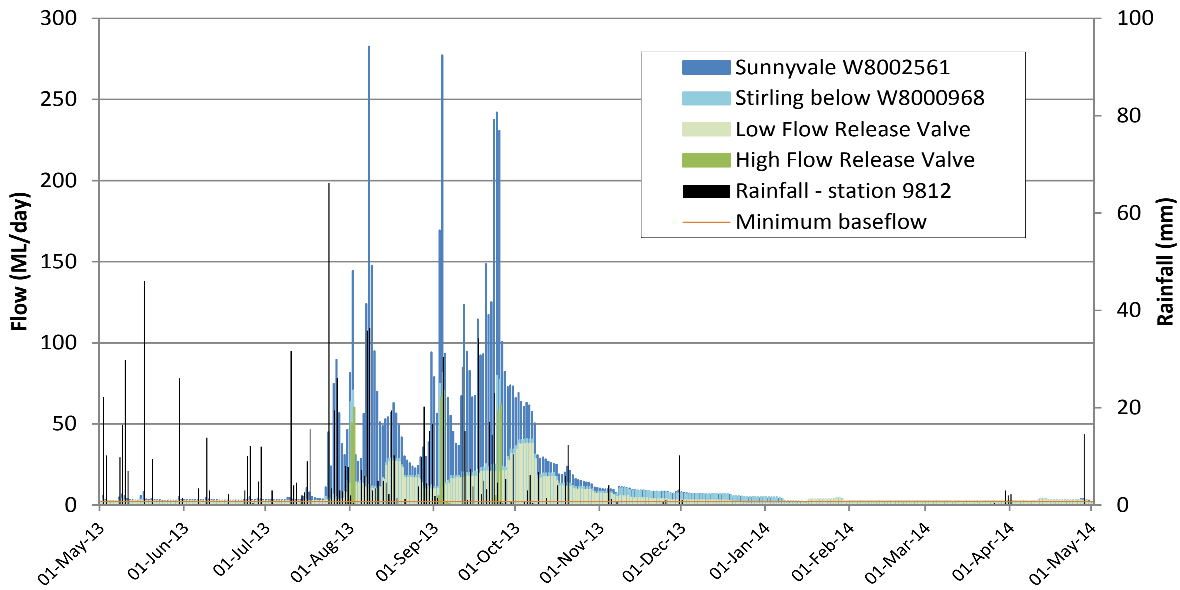


Figure 9 Streamflow in the Harvey River below the Stirling Dam (recorded at the Sunnyvale and Stirling gauging stations), discharge from the Stirling Dam (low and high release valves) and rainfall (BOM station 9812) recorded from 01 May 2013 to 01 May 2014

Flows remained above the minimum recommended flow of 2 ML/day (DoW 2012) with exception of 11 to 16 January 2014 (Sunnyvale gauge; Figure 10). The sub-2 ML/day flows were due to reduced release volumes preceding and during this period, attributed to a fault with the release valve. Flows reached a minimum of 1.41 ML/day.

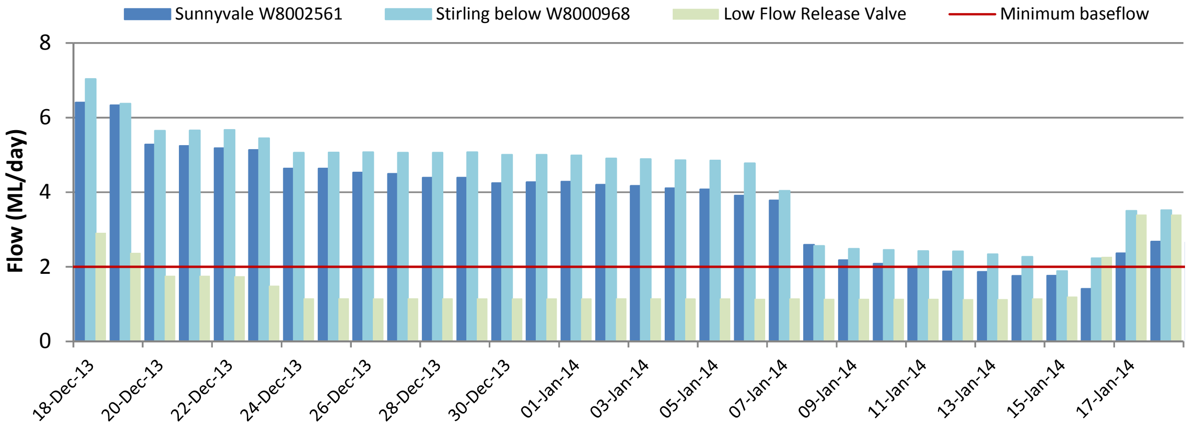


Figure 10 Flows in the Harvey River downstream of the Stirling Dam in relation to the recommended minimum flow; based on the Water Resource Management Operation Strategy for Stirling Dam (DoW 2012)

Brunswick River

Flows in the Brunswick River, recorded at two gauging stations (Figure 6), followed a similar pattern to that in the Harvey River, with the highest flows from late July through to October at both stations (Figure 11). Flows increased markedly around 24 July 2013.

Flows were highly responsive to rainfall, increasing quickly after events and subsiding to pre-event levels over the subsequent 10–14 days (in the absence of additional rain). This stronger response of flow to rainfall compared to the Harvey River study reach was likely due to a higher proportion of cleared land in the catchment of the Brunswick River study reach.

Flows at the 612032 gauging station (bottom of catchment) were understandably higher than those recorded at 612022 (top of catchment). Streamflow in the top of catchment before July 2013 was typically 2–3 ML/day however from late January 2014 flows were consistently below 1 ML/day and appeared to cease flowing on 26 February 2014.

A number of peaks in flows were recorded through the study period, including flows over 2000 ML/day on 27 July, 7 August, 4 September and 23 September 2013. The latter three events coincided with the three highest rainfall events in the Harvey River.

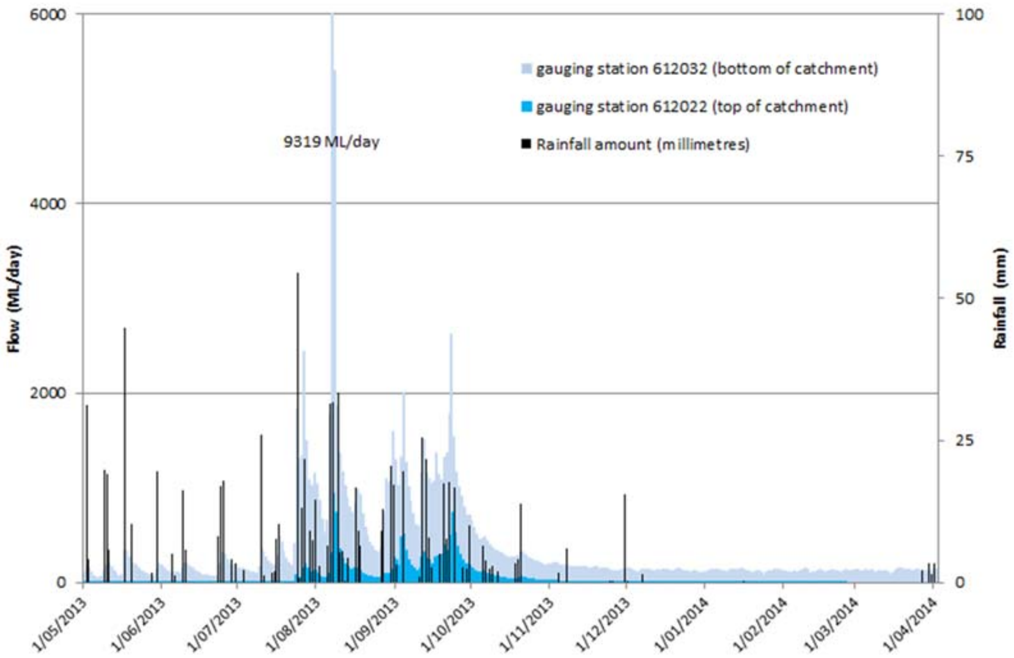


Figure 11 Rainfall and flow (measured at two gauging stations) for the Brunswick River.

4.2 Visible implant elastomer tags

Inserting the VIE tags at the base of the dorsal fin and in several locations along the ventral side of the caudal fin was effective.

Under ultraviolet light, the pink dye (Figure 12) was more obvious than the orange though both were suitable. Both colours were difficult to detect under natural light.

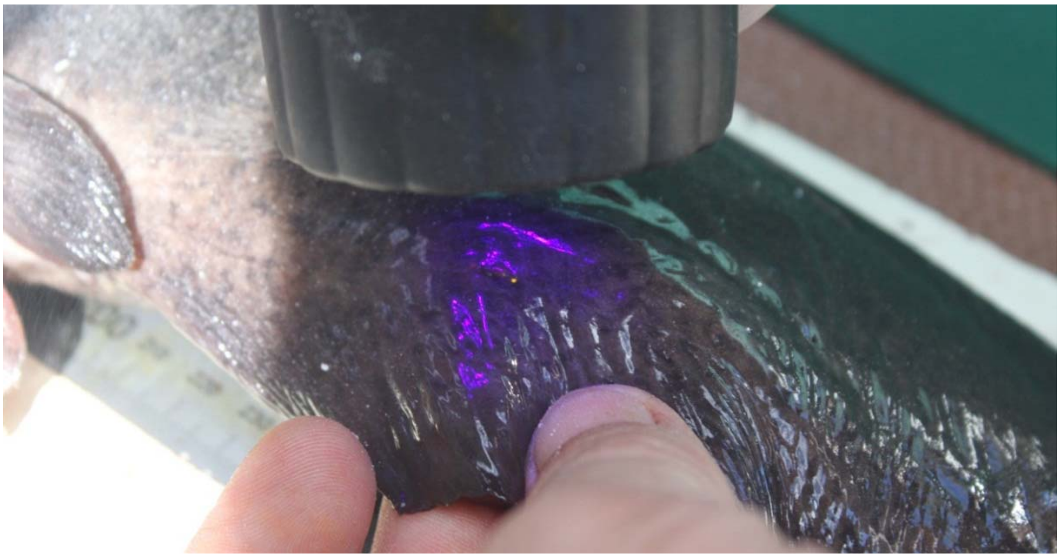


Figure 12 VIE tag (pink) inserted at the base of the caudal fin of a T. bostocki under ultraviolet light

4.3 Survival, acoustic tag retention and battery life

Tagged fish recovered quickly after surgery, based on observations of their behaviour while in recovery tanks and over the 24 hour monitoring period in holding cages within the receiving environments.

Skin apposition and suture retention were excellent 24 hours post-surgery and there was no evidence of inflammation at the incision site (Figure 13).

All of the tagged fish were shown to be active for at least the first two weeks of the study period (refer to Appendix B), demonstrating a 100% survival rate and tag retention over this period.

Active movement was recorded in over 90% of fish past July 2013 in both systems (more than 3 months post-surgery; Appendix B) and in 60% of fish in the last 3 months of the trial from the Harvey River and BRUN-01 and BRUN-02 sites. Only 17% of fish released in the upper Brunswick River (BRUN-03 to BRUN-05) were detected towards the end of the trial; this was expected given the restricted movement due to barriers (fish were unable to return to hydrophone sites). While it was not possible to quantify mortality rates (a fish no longer detected may have simply not passed by a hydrophone rather than being dead), it was assumed from the available data that there was limited long-term effects to the health of the fish from the tagging procedure. Further, the battery life of tags appeared to be sufficient for at least 1 year of continuous data[10].

Figure 13 Wound status 24 h post-surgery

4.4 Maximum distance and speed of travel

Eleven of the 50 tagged fish (22%) visited two or more hydrophone sites, which provided some indication of the distance and speed of travel of *T. bostocki* through the study systems (see minimum distances travelled for each fish in Appendix C and movement patterns for each fish in Appendix B).

[10] This was based on 10 of 50 fish still being detected one year after the tags were activated. .

The longest distance travelled by a single individual during the study was over 22.72 km, moving between all the hydrophone sites in the Harvey River.

Within the Harvey River, *T. bostocki* were shown to travel up to 8.21 km upstream (HARVDAM to HARV-07) and 4.3 km downstream (HARV-08 to HARVDAM; Figure 14). This represents movement of *T. bostocki* along the entire connected reach between the Stirling and Harvey dams[11]; demonstrating complete bioconnectivity of the study reach at least during higher flows.

Within the Brunswick River, *T. bostocki* were shown to travel up to 2.66 km upstream (BRUN-01 and BRUN-02) and 9.36 km downstream (BRUN-05 to BRUN-04). These maximum movement distances within the Brunswick River are underestimates of total movement (particularly on the deeper Swan Coastal Plan section) as data reflects the distances between hydrophone stations only. Movement, particularly upstream, is probably constrained by a number of natural and artificial barriers (e.g. no upstream movement was recorded above BRUN-02). The influence of barriers on natural movement through the system is unclear and will change based on streamflow.

The fastest movement of *T. bostocki* was 2.66 km upstream in 4 hours (665 m/hour). This was recorded in the Brunswick River between BRUN-01 and BRUN-02. Within the Harvey River, one fish travelled 3.91 km downstream in 4 days (HARV-07 to HARV-08) and another fish travelled 8.21 km upstream over 23 days (HARVDAM to HARV-07). The speed of movement could only be gauged based on the time taken for the fish to pass between hydrophone stations, so the results probably underestimate maximum speeds.

It is also noteworthy that 40% of the fish released at HARV-07, HARV-08 and BRUN-01 were shown to move to other hydrophone sites during the study period (minimum of 2.66 km). Connectivity through these sites was greater than between BRUN-02 and BRUN-05, permitting movement of fish between sites for over 4 months within the Harvey study area and having permanent connectivity between BRUN-01 and BRUN-02. This suggests that a considerable percentage of a population of *T. bostocki* may move relatively large distances if conditions allow.

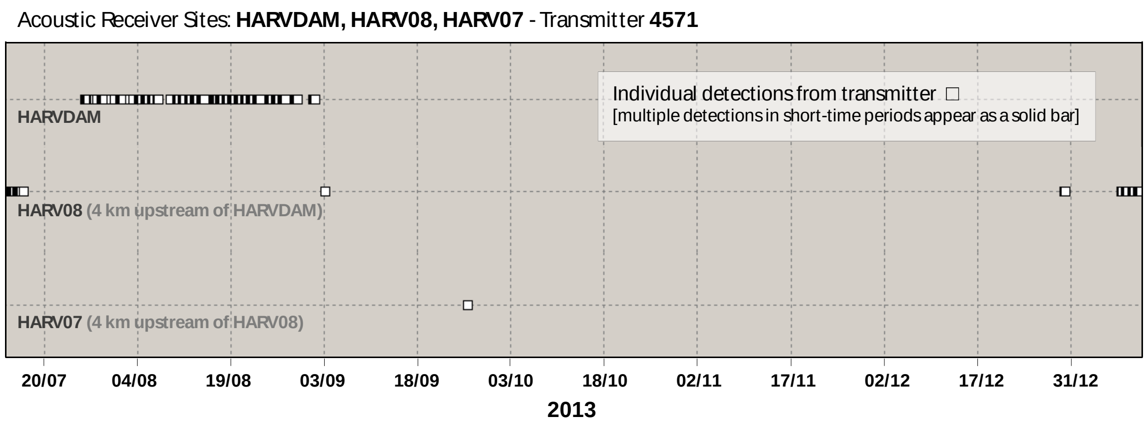


Figure 14 Movement of one fish through the Harvey River between Jul and Dec 2013

[11] Upstream movement is not expected above HARV07 due to a large natural rock barrier.

4.5 Diurnal patterns

Most *T. bostocki* (approximately 90% of the fish that remained within the range of hydrophones) moved between separate day and night habitats following a consistent diurnal pattern (examples in Figure 15 and Figure 16). Movement between habitats was only recorded during night periods, with most fish moving to night habitats around dusk and returning to day habitats by dawn (Figure 15–Figure 17). Furthermore, there were more sporadic detections during nocturnal periods (indicating greater movement) and constant detections during the day (less movement; Figure 18) suggesting that most fish were sheltering in one area during the day and foraging in others at night.

Data indicated that specific habitats were not used for single purposes by all fish. Rather, the same sites were used as daytime habitats by some individuals and nocturnal habitats by others (compare Figure 15 and Figure 16).

Short-term localised movements to access habitats for foraging or to seek thermal refuges have been demonstrated in a number of fish species (e.g. Kaya et al. 1977; Power 1984; Clapp et al. 1990 Koster & Crook 2008) including *T. bostocki* (Beatty et al. 2010).

Only two of the 50 *T. bostocki* tagged were shown to remain at the same site through the entire diurnal period (e.g. Figure 18). In both cases this happened during the dry season and may reflect a restricted ability to move between habitats due to in-stream barriers.

One *T. bostocki* was shown to move from one hydrophone location to another (2.5 km apart) within a single nocturnal period and return to the original location the following night (Figure 19). This showed that *T. bostocki* can move large distances during a night. As this behaviour was only observed in one animal, typical diurnal movement patterns are likely to be more localised. Note: the receiver at BRUN-02 was offline between May and November 2013 so tagged fish may have moved undetected between BRUN-01 and BRUN-02.

Variable *behavioural syndromes* between individuals are common within telemetry studies of fish. Therefore, a few individuals travelling greater distances than the majority of the population and accessing different habitats was not unexpected (e.g. Smithson & Johnson 1999; Schaefer 2001).

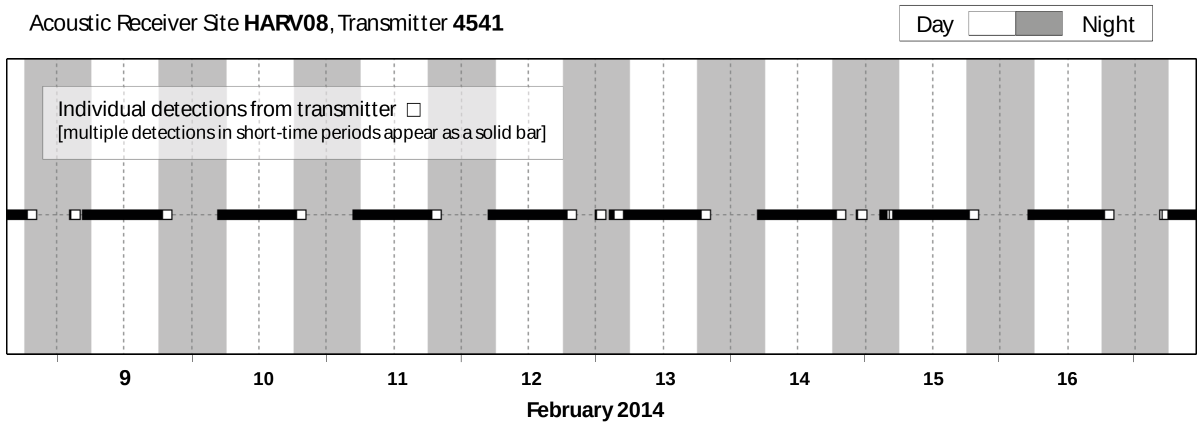


Figure 15 Example of the presence of T. bostocki *at one site during day and absence during the night. Data from one fish recorded at HARV-08 between 9 and 17 February 2014.*

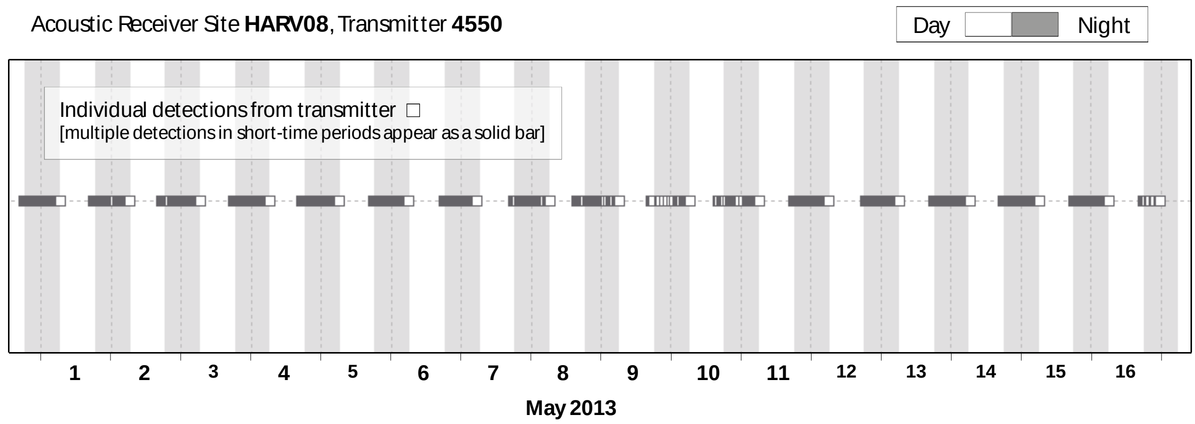


Figure 16 Example of the presence of T. bostocki at one site during the night and absence during the day. Data from one fish recorded at HARV-08 between 1 and 17 May 2013.

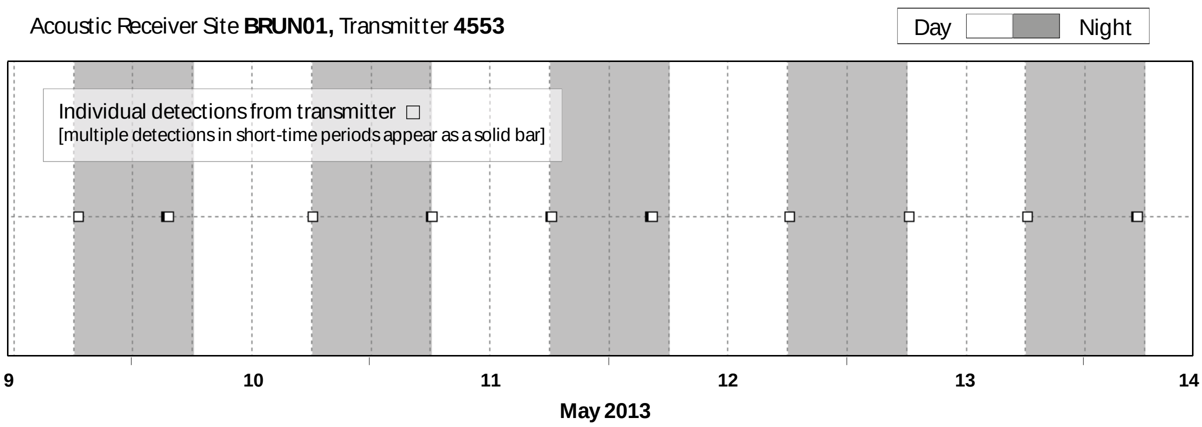


Figure 17 Example of fish moving through a hydrophone site at dusk and dawn (moving between day and night habitats in a consistent diurnal pattern). Data from a fish recorded at BRUN-01 between 9 and 14 May 2013.

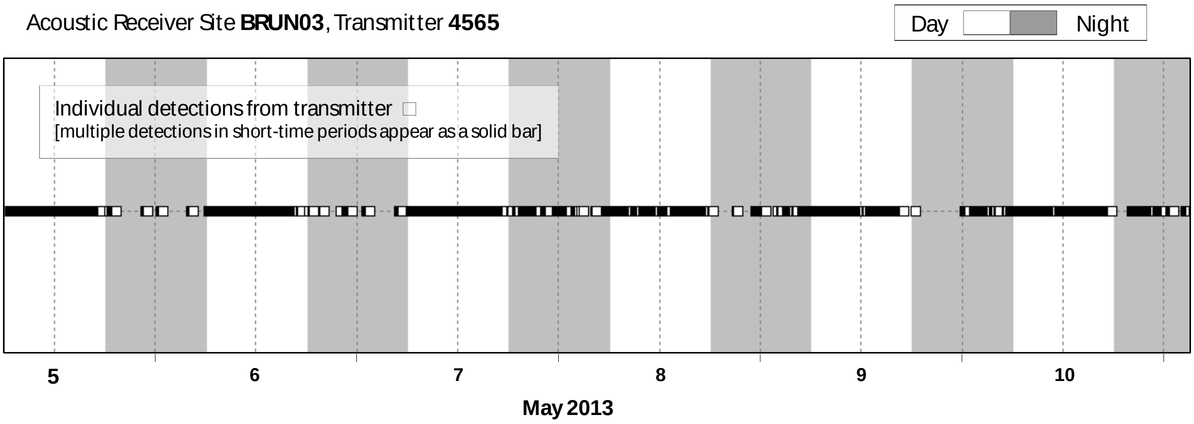


Figure 18 Example of greater activity of T. bostocki at night (sporadic detections) compared to day (constant detection). Data from one fish recorded at BRUN-03 between 5 and 11 May 2013.

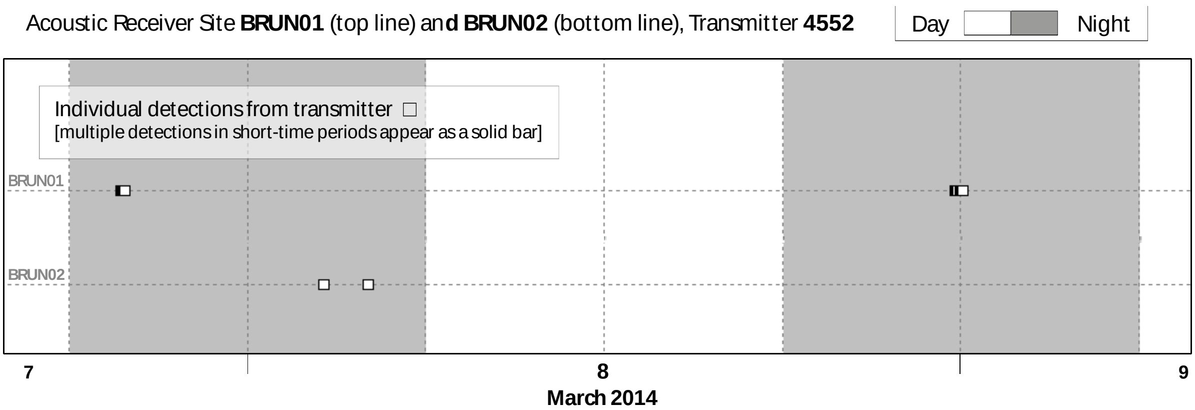


Figure 19 Example of a T. bostocki moving between different hydrophone sites during the night

4.6 Seasonal or event-based patterns

The movement of fish during the dry season was limited at all sites except between BRUN-01 and BRUN-02 (Figure 20; Figure 21). With the exception of BRUN-01, more than 90% of the fish remained around their release sites until July (~3 months from the release date), which corresponded with the onset of increased flows in both systems (Figure 9; Figure 11). At BRUN-01, 50% of the fish had moved away for a significant proportion of time during this period.

At the Harvey sites, fish began to move away from release locations when flows were above ~5 ML/day, however as the increase in flow from dry-season levels (around 2.5 ML/day) was rapid, an accurate flow threshold could not be defined. Similarly, fish moved away from BRUN-05 when flows were consistently above ~3 ML/day, though given many barriers through the system, further investigation is required to decide the flows needed to allow movement of the fish throughout the system.

Detections became more sporadic between July and November (Figure 22), corresponding with the higher seasonal flows and thus the greatest bioconnectivity. This was particularly clear in the Harvey River where conditions allowed movements in both directions through this period (Figure 20).

Based on these data, it appears *T. bostocki* moved when river connectivity allowed it and that connectivity during baseflow was insufficient to enable movements in either system (except between BRUN-01 and BRUN-02). Therefore, under historically higher flow regimes we would have expected greater movement. Our findings suggest that, under the reduced flow scenarios projected due to climate change in this and other rivers of south-west Australia (CSIRO 2009), the movement of this and several other south-west fish species (Beatty et al. 2013) will be further impeded (i.e. in-stream barriers will be inundated to a shallower depth for a shorter time).

The ability to move through the systems through late spring and summer is likely important for breeding success. Beatty et al. (2010) demonstrated greater movement of *T. bostocki* in late spring and summer in the Blackwood River coinciding with a sharp increase in mean gonadosomatic index of mature females between August and September (peaking in October and declining in December). A similar peak movement period has been identified by other authors (refer to Section 4.7). Spawning through summer (November–January) has been reported by Morrison (1988), Hewitt (1992) and Hutchison (1992). Moreover, localised movements outside the breeding period are also undoubtedly necessary for foraging.

In some instances, *T. bostocki* moved away from the hydrophone site when flows increased and returned again when flows subsided (e.g. five fish released at HARV-08; Figure 23), whereas other *T. bostocki* did not return to the site of release (e.g. 13 fish released at BRUN-05; Figure 21). A few fish visited their site of release regularly across the entire study period, while others appeared to leave for the entire wet season before returning at the start of the dry season (compare tagged fish 4551 and 4549 in Appendix B).

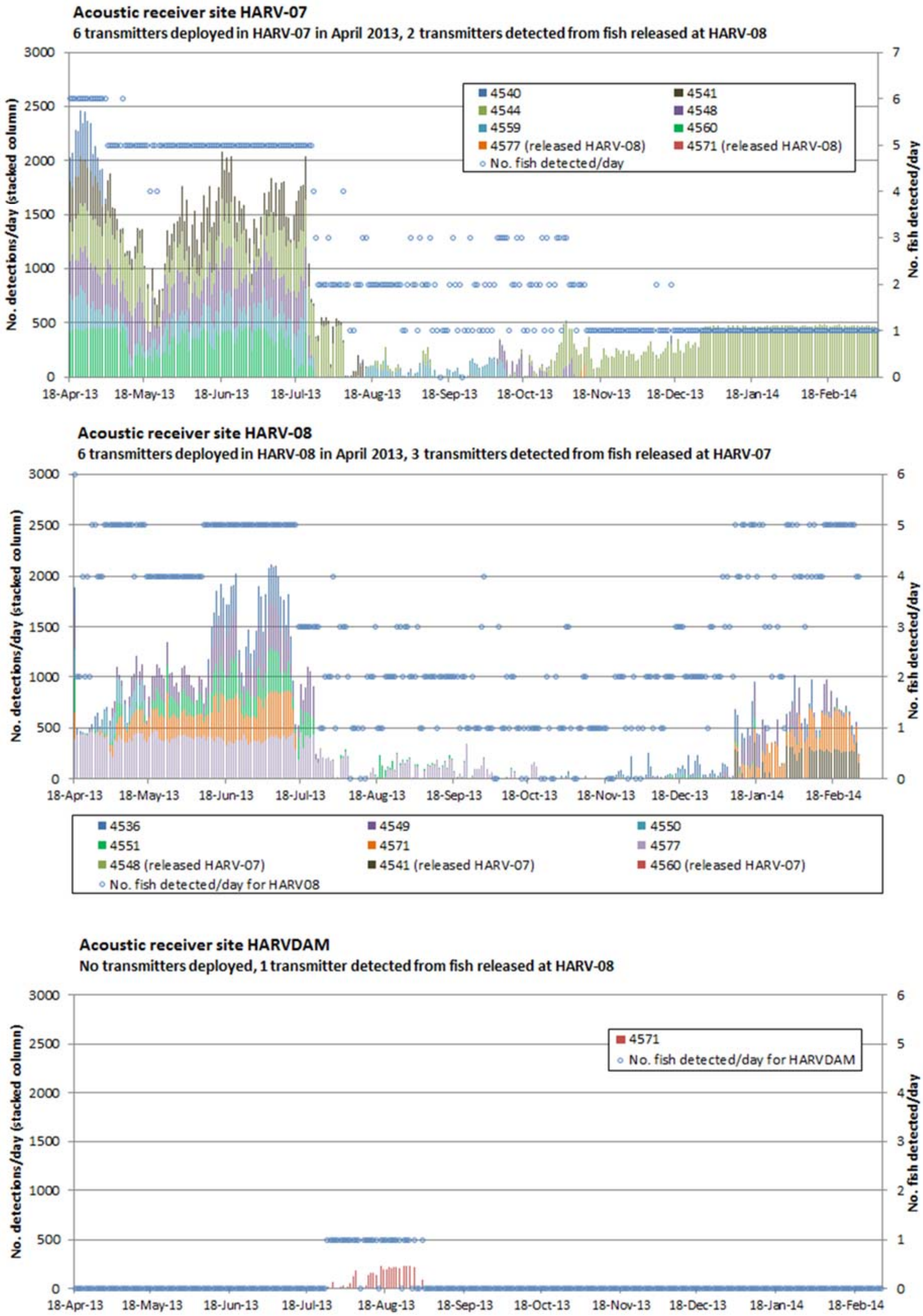
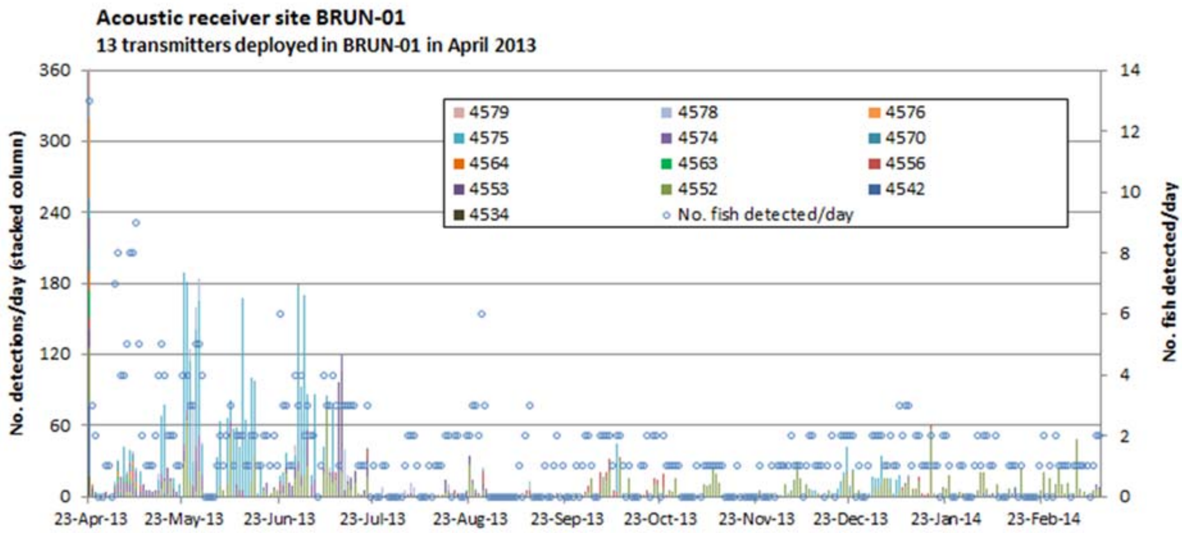
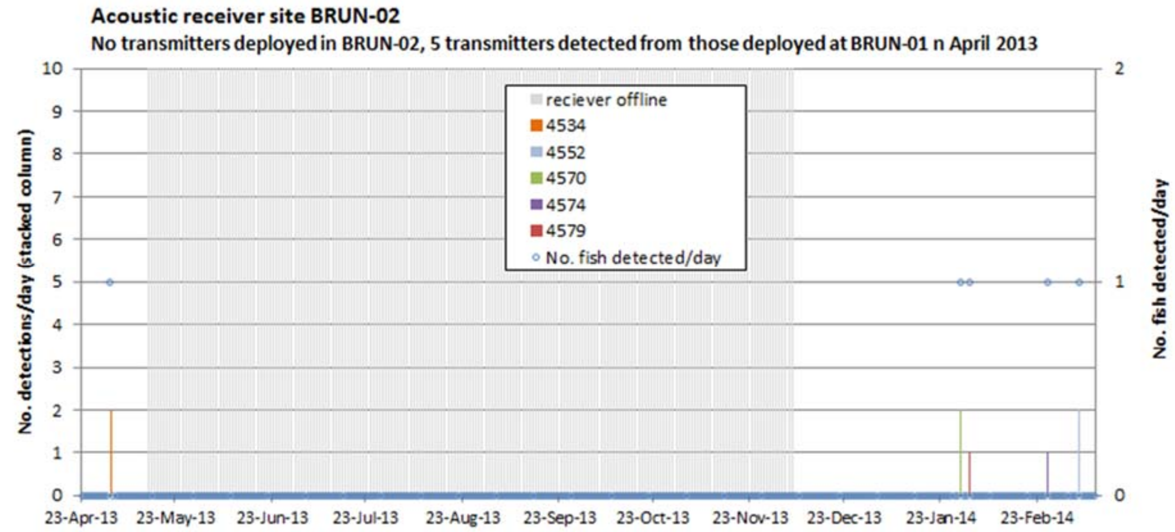
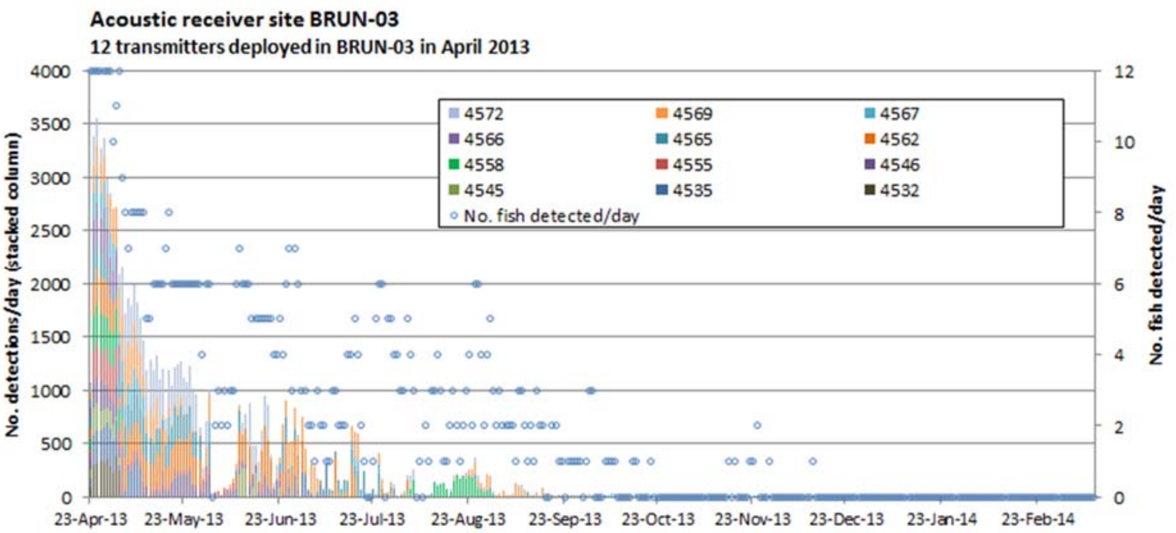


Figure 20 Number of individual fish visiting each hydrophone each day in the Harvey River during the study


Acoustic receiver site BRUN-01
13 transmitters deployed in BRUN-01 in April 2013
No. detections/day (stacked column)
No. fish detected/day
4579
4578
4576
4575
4574
4570
4564
4563
4556
4553
4552
4542
4534
No. fish detected/day
23-Apr-13 23-May-13 23-Jun-13 23-Jul-13 23-Aug-13 23-Sep-13 23-Oct-13 23-Nov-13 23-Dec-13 23-Jan-14 23-Feb-14


Acoustic receiver site BRUN-02
No transmitters deployed in BRUN-02, 5 transmitters detected from those deployed at BRUN-01 n April 2013
No. detections/day (stacked column)
No. fish detected/day
reciever offline
4534
4552
4570
4574
4579
No. fish detected/day
23-Apr-13 23-May-13 23-Jun-13 23-Jul-13 23-Aug-13 23-Sep-13 23-Oct-13 23-Nov-13 23-Dec-13 23-Jan-14 23-Feb-14


Acoustic receiver site BRUN-03
12 transmitters deployed in BRUN-03 in April 2013
No. detections/day (stacked column)
No. fish detected/day
4572
4569
4567
4566
4565
4562
4558
4555
4546
4545
4535
4532
No. fish detected/day
23-Apr-13 23-May-13 23-Jun-13 23-Jul-13 23-Aug-13 23-Sep-13 23-Oct-13 23-Nov-13 23-Dec-13 23-Jan-14 23-Feb-14

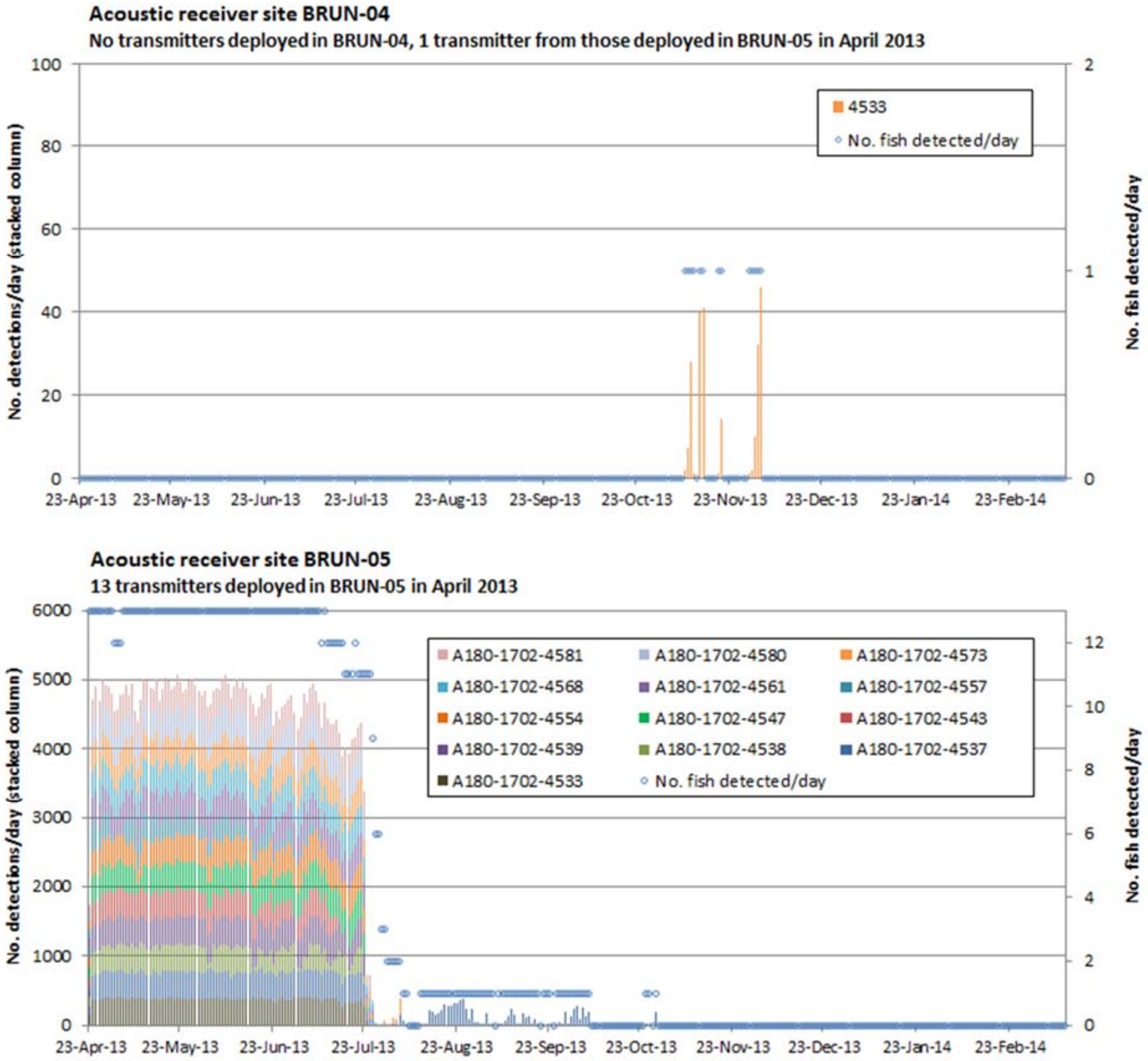


Figure 21 Number of individual fish visiting each hydrophone each day in the Brunswick River during the study (note: axis ranges differ between sites)

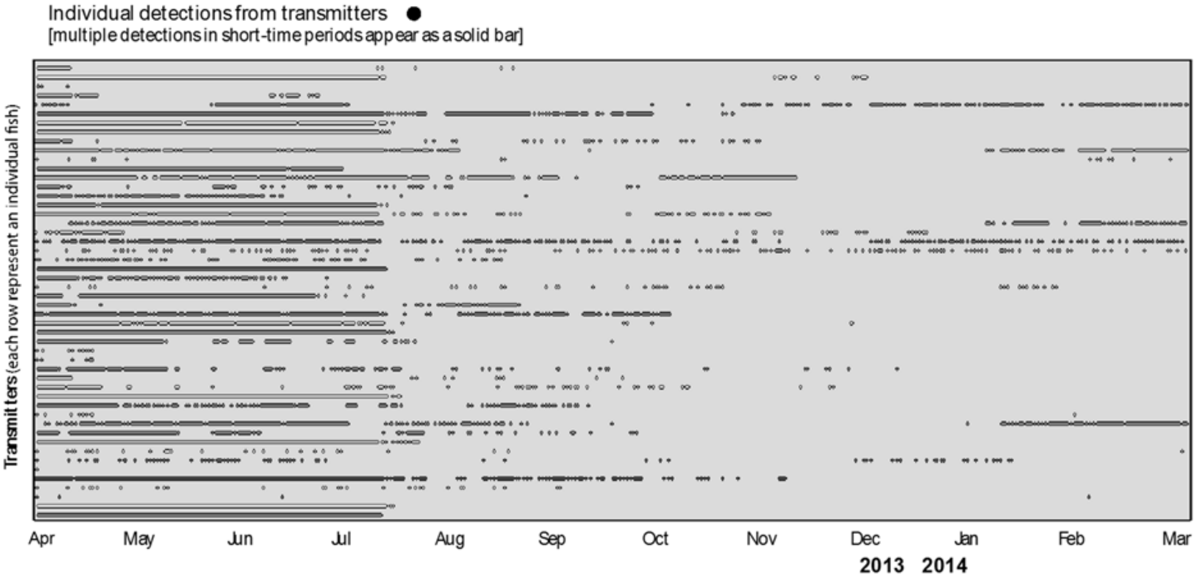


Figure 22 Detections of all fish in the Harvey and Brunswick rivers between April 2013 and April 2014 (rows represent individual fish).

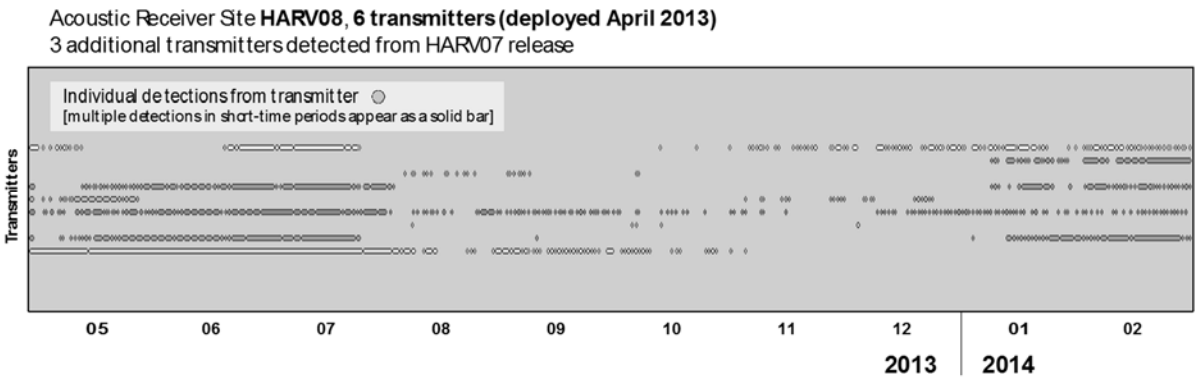


Figure 23 Fish detected at the HARV-08 hydrophone site through study period

4.7 Gregarious behaviour

T. bostocki have been shown to move together in large numbers in several rivers (Department of Water unpublished data, Beatty et al. 2010). Examples include: 800 fish in one fyke-net (moving upstream) in the Blackwood River in November 2007; 750 fish in one fyke-net in the Moore River in October 2008 (moving downstream); 297 fish caught in one fyke-net over one night in the Gingin Brook in October 2008 (swimming upstream); and 161 fish caught in one fyke net in the Collie River in January 2010. Observation of *T. bostocki* behaviour in the field and also in earthen ponds (0.1 ha) show that fish will swim together in tight schools (T. Storer unpublished data).

Sections 4.5 and 4.6 highlight some common patterns of movement which support this behaviour though there was no clear evidence of individuals moving or staying together for significant periods. That is, fish moved away and returned to sites at similar diurnal and seasonal periods, but no evidence was found of fish moving in unison. Smaller individuals than those assessed in this study (i.e. shorter than 300 mm) may display different behaviour.

4.8 Homing behaviour

A number of fish were shown to return to their place of capture in the 2014 dry season (after an extended period away from site during the higher flow period). This includes fish released at and away from their site of capture.

Within the Harvey River study area, where bioconnectivity was demonstrated across the entire study reach, seven of the 12 fish released (58%) returned to their place of capture. Two fish remained in or around a site that was different from the capture location and the three remaining fish were not detected after the wet season.

Within the Brunswick River study area, interchange of fish was only demonstrated between BRUN-01 and BRUN-02. Five of 13 fish released at BRUN-01 returned in the 2014 dry season, of these 3 were originally captured from this location. Five fish visited BRUN-02 during the study, with 3 of these originally caught from BRUN-02 and 2 from BRUN-01. No fish remained in the area after the wet season (refer to Appendix B).

No fish released at BRUN-03 or BRUN-05 returned following the wet season and none returned to their capture locations (BRUN-01 and BRUN-02). Therefore, unlike in the lower catchment, fish did not return to refuge pools in the upper catchment; this could be due to a tendency to prefer downstream pools (with a greater chance of permanency) coupled with the influence of barriers preventing them returning to upstream sites.

From the distances of movement recorded in this study, the home range of *T. bostocki* may exceed 8 km. However, as these distances were only traversed by a few individuals it is likely that movement for most *T. bostocki* is predominantly more localised. In better connected systems, the home range may greatly exceed what was recorded in this study.

In a previous study in the larger, better connected, Blackwood River using t-bar tags, over 20% of 437 individuals were recaptured at least once with all but one fish (that moved downstream 15.5 km in ~3 months) recaptured from the same location (Beatty et al. 2010). This supports the generally localised migrations revealed in the current study. It is likely that home ranges and site fidelity may vary depending on variability in the flow regime and availability and quality of refuge pools.

4.9 Movement patterns based on size or sex

No clear differences in movement patterns were evident between sexes or size-classes of fish (Figure 24; and refer to Appendix C for minimum distances travelled). It is possible that different movement patterns may be evident in smaller individuals than assessed in this study (where the minimum size of fish was 300 mm and minimum weight was 230 g). For instance, smaller individuals in other fish species are known to move larger distances in search of new home ranges (better opportunity for food and shelter), new partners, or to avoid high temperatures, high flows or predators (Bustard & Narver 1975; Cederholm & Scarlett 1981; Gowan et al. 1994).

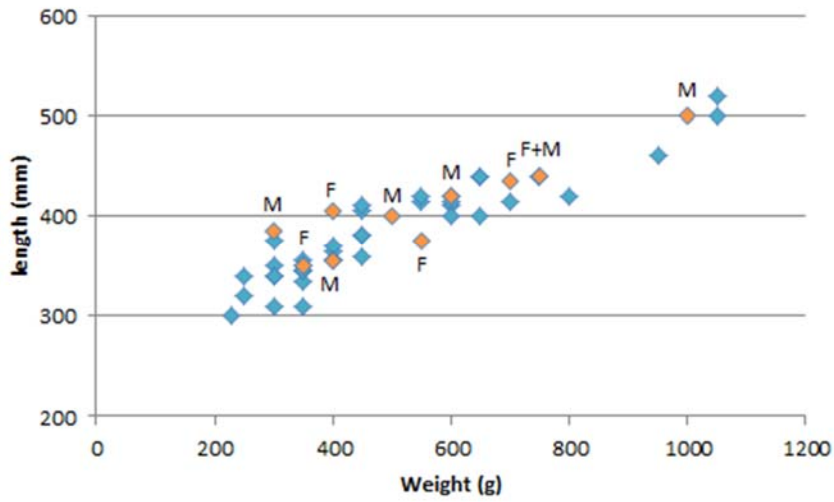


Figure 24 Movement between receiver locations based on size – weight (g) and length (mm) – and sex. Orange indicates fish that moved between hydrophone locations.

4.10 Important habitats in the study systems

Harvey River

- HARV-08 and HARV-07 (Figure 20) were shown to function as dry-season refugia, with 50% of tagged fish entering these sites as flows subsided and then remaining during the 2014 dry season. This supports findings from White and Storer (2012). As six fish were unaccounted for during the 2014 dry season it is possible that other refugia exist in the system, although White and Storer (2012[12]) suggested that much of the system outside these pools is shallow and impassable by *T. bostocki* most of the dry season.
- HARV-07 and HARV-08 were shown to act as both daytime shelters and nocturnal foraging grounds, with fish remaining within the sites during the day and actively moving within the areas during the night (typically different individuals using the sites for separate purposes).
- The Harvey Dam (HARVDAM) was also shown to be used as a diurnal shelter by one fish through late July and August. It is unclear why this large permanent water body was not more used by *T. bostocki* in this study, particularly given the apparent lack of permanent water refuge in the upstream environment. This may be due to absence of preferred habitat, particularly for breeding and spawning (expected to occur through late spring and summer; Morrison 1988; Hewitt 1992; Hutchison 1992; Beatty et al. 2010). The use of artificial dams as habitat for native

[12] Many areas are not easily accessible. Comments are based on the area observed and the extrapolation is based on physical form and flow dynamics.

fish has been previously demonstrated (Koster & Crook 2008). See the recommendations in this report.

- Juvenile *T. bostocki* were collected in April at HARV-08 demonstrating its use as nursery habitat and the successful recruitment of the species in the system.

Brunswick River

Upstream movement of *T. bostocki* in the system above the Swan Coastal Plain was not detected and is expected to be minor, given the many in-stream barriers (Figure 25). As many of the barriers present are natural, this is likely indicative of a natural movement pattern (under higher historic flows and before the existing dams were constructed). Due to this, the upstream populations of *T. bostocki* will rely heavily on permanent pools. Several natural and artificial pools were observed (e.g. Figure 26), however identifying other natural barriers and critical refugia needs detailed surveillance of the stream length including a combination of aerial and ground surveys (e.g. Beatty et al. 2013).

None of the hydrophone sites in the upper Brunswick River (BRUN-03, BRUN-04 and BRUN-05) appeared to be priority refugia as fish did not remain in these areas.

T. bostocki are expected to move through much of the connected area of the Swan Coastal Plain, with fish detected swimming between BRUN-01 and BRUN-02 and spending considerable time outside the hydrophone locations.

There is a large area between BRUN-01 and BRUN-02 where the Brunswick River branches and produces a number of backwaters and flooded bank habitats (Figure 27). This area is uncharacteristic of the rest of the system, which is primarily a single-channel, and may form an important nursery or foraging ground given the diversity and uniqueness of habitats present. This area requires further investigation.

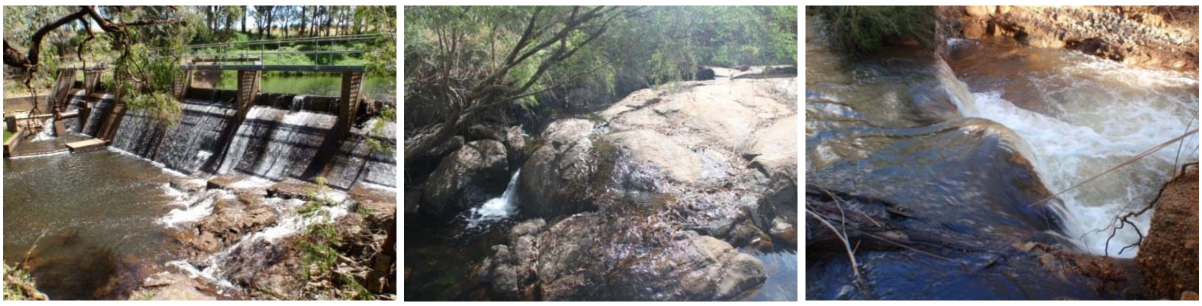


Figure 25 Top left: Beela Dam 0.46 km above BRUN-04; Top right: rocky cascades below BRUN-05; Bottom left: barrier created due to erosion at road crossing (upper catchment)

Figure 26 Left: pool at Beela Dam, immediately upstream of BRUN-04; Right: small permanent pool at BRUN-05

Figure 27 Unique habitat between BRUN-01 and BRUN-02

5 Conclusions

This study was the first to acoustically track a native freshwater fish species in southern Western Australia and has identified some aspects of *T. bostocki* behaviour which will be useful for water resource management in Western Australia (summarised below).

While a degree of variability in the movement patterns of *T. bostocki* would be expected depending on the physical characteristics of the system and its hydrology, the results should be transferable across many south-west systems and certainly those associated with the Integrated Water Supply Scheme and scheme irrigation dams (where there is a greater control over flows).

More work is needed to evaluate behaviour in systems with varying degrees of connectivity (such as the larger and more connected Murray, Blackwood and Moore rivers).

5.1 Summary of movement behaviour

Long-distance travel and speed

A few individuals were shown to migrate considerable distances through the study systems. These occasional long-distance movements may be important in maintaining the distribution and persistence of the species (e.g. recolonisation), as well as for gene flow. Such movements also highlight the importance of maintaining connectivity of habitats and the potential impacts of in-stream barriers.

The distances travelled were more than 8 km in both systems, which equated to a large proportion of the connected area (e.g. 100% of the Harvey River study area). These longer-distance movements were made in the wetter periods, probably reflecting opportunistic movements during periods of river connectivity. As these longer movements were only seen in some individuals they were unlikely to be due to a common life-history requirement.

Importantly, 40% of the fish released at HARV-07, HARV-08 and BRUN-01, where connectivity allowed upstream and downstream movement of fish between hydrophones, were shown to move between hydrophones (minimum of 2.66 km). This demonstrates that a significant proportion of *T. bostocki* will move considerable distances within rivers if conditions allow.

T. bostocki are capable of moving through the system at relatively high speeds, with individuals recorded moving up to 2.66 km in 4 hours.

Swimming speed and maximum distances travelled are also underestimated here as they are limited by the number of hydrophones.

Diurnal movement patterns

T. bostocki movement was typically localised, moving from a common daytime habitat to a nocturnal habitat following a predictable diurnal pattern.

As expected from a nocturnal species, *T. bostocki* appeared to be stationary during the day and very active during the night. Movements of the only other member of the genus, the freshwater catfish, *Tandanus tandanus*, in Victoria, are also typically much greater at night than during the day (Koster et al. 2015).

Moving to and from daytime habitats was typically recorded immediately after dusk and before dawn respectively: maximising foraging time during the nocturnal period.

Some *T. bostocki* were shown to travel over 2.66 km in a night before returning to a common daytime habitat.

Given that the nocturnal habitats included shallow riffles and runs adjoining the pools where receivers were deployed, and that these shallower habitats are particularly high risk places under reduced flows, protection of these habitats is important.

Seasonal movement patterns

T. bostocki movements in the Harvey River followed a distinct seasonal pattern. Fish remained predominantly around the hydrophone sites (permanent water pools) through the dry season, and moved through the system during the wetter months, in many cases travelling many kilometres to other hydrophone site locations. This finding is consistent with previous observations of large numbers of *T. bostocki* moving through systems through winter and spring (refer to Section 4.7). *T. bostocki* were shown to move away from pools with the onset of flows, around July in 2013, and generally return in early summer, around mid-December 2013[13]. These return movements highlight the importance of maintaining connectivity of habitats to allow fish to return to dry-season habitats.

This seasonal pattern was consistent with data from BRUN-05, with fish remaining at the site through the dry season and only moving away with the onset of flows in July. However, the same patterns were not as clear at the other release sites in the Brunswick River (BRUN-01 and BRUN-03), with fish moving in and out of these areas throughout the dry season. This finding probably reflects the greater connectivity at the BRUN-01 and BRUN-03 sites (compared to BRUN-05 and the Harvey River sites) and suggests that movement is largely a function of opportunity. There was also no clear period of return in any of the Brunswick River sites. For BRUN-03 and BRUN-05, this is consistent with the inability of fish to return to these sites (given the presence of in-stream barriers), whereas in BRUN-01 and BRUN-02 *T. bostocki* appear to be moving freely through the area independent of season.

No evidence of *T. bostocki* migrating to specific breeding habitats was found in either system. This may suggest that breeding/spawning may be occurring at various locations throughout the system (see later comments on behavioural plasticity).

Flows of around 5 ML/day appeared necessary to allow *T. bostocki* within the Harvey River study area to move out of pools. Flow requirements for the Brunswick River were less clear. Flows consistently exceeding 3 ML/day appeared to be needed for *T. bostocki* to move away from the receiver site in the upper Brunswick (BRUN-05), whereas flows did not appear to be limiting at the other sites (particularly BRUN-01).

[13] Based on data from HARV-08 only as the HARV07 hydrophone wasn't operational during this period.

Population connectivity

T. bostocki in the Brunswick River east of the Swan Coastal Plain appeared isolated from downstream populations due to natural and artificial barriers. In particular, the population at or upstream of the uppermost site (BRUN-05) could be regarded as self-sustaining (little or no immigration of fish from elsewhere in the system). However, unidirectional recruitment to subpopulations downstream in the Brunswick River from the upstream population is possible.

The observation that some fish travelled large distances while others displayed a more localised range may suggest that *T. bostocki* populations are semi-fragmented with only periodic dispersal interchange of some individuals. More work is needed to test this in better connected systems and to find out how much mixing is needed to maintain population fitness and resilience; for example, working out the rate of recolonisation should a loss of the species occur within a river reach (through a stochastic fish-kill event).

Preference for deeper permanent water habitats under low flows

The importance of deeper environments (e.g. permanent pools) was clear, with *T. bostocki* shown to move into these environments with subsiding flow, and remain in the vicinity of these habitats until higher flow resumed. Measures to protect these habitats, such as the provision of environmental flows to maintain adequate depths and prevent the development of poor water quality (e.g. low dissolved oxygen) in pools are important management considerations (see the summary of management outcomes in Section 5.2).

Note: this study showed, supporting previous studies (e.g. Koster & Crook 2008), that where possible fish will leave pool environments during the night, probably to forage in adjoining habitats such as riffles and runs. These shallower habitats are particularly vulnerable to reduced flows and therefore need to be considered in setting environmental flow requirements.

Behavioural plasticity

Considerable variability was apparent in habitat selection between individuals. In particular, various individuals were shown to use a specific habitat for different purposes; that is, as both a shelter during the day and a foraging ground during the night. This suggests that habitat selection may be non-specific at the population-scale and therefore indicate behavioural plasticity that enables *T. bostocki* to adapt to changing conditions.

Further, around 80% of *T. bostocki* in the Brunswick River were not detected at the end of the trial period (summer). This suggests (assuming they were still alive) that *T. bostocki* were residing in areas outside the hydrophone locations, providing additional evidence of behavioural plasticity (regarding habitat selection).

Gregarious behaviour

T. bostocki individuals were shown to follow similar patterns of movement related to environmental cues, both on a diurnal cycle (e.g. moving to and from shelter around dawn and dusk to a nocturnal habitat, i.e. for foraging) and seasonal (moving out of pools when flows increased). Tagged individuals were not shown to move together; that is, they were not moving in schools. Maybe some individuals, including earlier (smaller) life stages (e.g. less than 300 mm long) do move together but were not tagged in this study.

5.2 Outcomes for the management of rivers in south-west Western Australia

Use of acoustic tracking to inform river management

The current study demonstrates that acoustically tracking the movement of south-western Australia's largest native freshwater fish provides valuable data directly applicable to the management of the region's water resources. *T. bostocki* responded well to the implantation of the VEMCO V6 180 kHz acoustic tags, with rapid recovery following surgery and no obvious long-term health issues detected. This is based on observations of behaviour and wound healing over the 24 hours post-surgery, with 90% of the individuals active after 3 months in both systems, and more than 40% of the individuals active at the end of the trial period (almost 1 year) in the Harvey River[14].

The VR2W hydrophones detected the acoustic tags through the entire width and depth of the study systems and would be expected to perform equally well in the largest streams across the south-west.

The acoustic tracking technology provided continuous data on individual fish movements that enabled the relationships between fish movements and key variables such as flow regimes and photo period to be assessed.

The battery life of the V6 tags was enough to provide at least 1 year of data, which enabled capture of an entire annual cycle.

After the initial capital outlay for hydrophones, the technology is relatively cost effective, particularly compared to the costs of obtaining similar data using visible tags (which require considerable field work to recapture the tagged fish).

Management of deeper permanent water habitats

Given the reliance of *T. bostocki* on deeper permanent-water habitats during low-flow periods, ensuring adequate water quality and habitat availability (amount and complexity) is critical for the protection of the species and the dependent ecosystem.

Water and habitat quality can be managed, to some extent, through the provision of flow; however, broader landscape features must also be considered (e.g. riparian condition which affects shading, bank stability, allochthonous inputs relating to food source and habitat, and buffers against contaminant inputs from surrounding land uses). Note: management of these habitats is not limited to the drier, warmer months in south-west WA, as the regulation can produce low-flow periods through any part of the hydrological cycle.

Shelter (e.g. large woody debris) should be provided in as many areas as practical through the stream to provide habitat areas to support *T. bostocki* travelling through the system. As

[14] Data from the Harvey River was used as individuals have fewer options for dispersal so data provides a better indication of survival.

individuals were not shown to target one area for shelter it is likely that they would take advantage of any appropriate habitat along their migration pathway.

For systems that disconnect, the flow regime should also be sufficient to allow *T. bostocki* time to retreat to refuge habitats. The time required for retreat will be system dependent, but can be estimated based on the distance between refugia, travelling speed of the *T. bostocki* (e.g. this study showed cobbler could travel at least 600 m in one hour), minimum depth requirements for *T. bostocki* to move through systems (suggested to be a minimum of 100 mm based on the body depth of larger individuals), and how responsive the system is to loss of flow (how quickly the depth of the system falls below the minimum requirements in the absence of flow).

As previously stated, this does not suggest that the shallower habitats (riffles and runs) are not important and, given that these habitats are at the highest risk under reduced flows, must be a key consideration for any flow management decisions.

Management of localised movements

Provided the opportunity, *T. bostocki* were shown to move into and out of the deeper habitats following (for the most part) a predictable diurnal pattern. In some instances, *T. bostocki* were shown to move more than 2 km during the night. Interestingly, different individuals presumably used the same habitat for different purposes; that is, as a shelter during daylight or as a nocturnal foraging habitat. This behaviour may be important for, among other things, preventing competition and allowing for a greater diversity in diet, and therefore should be supported where possible.

Understanding that many *T. bostocki* move between habitats on a daily time-step means that the connection between day-time and night-time shelters is an important consideration when setting water provisions.

Management of long-distance movements

Although most fish appeared to remain within the same general area over the study period, some were shown to move longer distances. For example, fish in both systems travelled more than 8 km from their release location (and up to 22.72 km in total), which corresponded to 100% of the connected area in the Harvey River and 25% of the study area in the Brunswick River. The distance travelled in the Brunswick River is restricted by natural and artificial barriers, and is expected to be an underestimate given the limited hydrophone locations. The maximum distance *T. bostocki* travel would also likely be significantly longer in larger and better-connected systems.

Longer migrations are an important behaviour in many species for finding mates, accessing seasonal habitats (e.g. foraging, spawning and nursery grounds), colonisation of new habitats, and for gene flow. As longer movements were only seen in a few individuals, it appears that life history requirements can be met through localised movements. However, allowing for the exchange of genes between populations is important for population fitness in adapting to change or to move to more suitable habitats should the current refuge habitats decline under future flow scenarios.

As *T. bostocki* appear to be able to traverse longer distances rapidly, providing this opportunity may be possible with relatively short provisions of higher flows.

Flows around 5 ML/day or more appear to be required for fish in the Harvey River to move out of dry-season refuge pools whereas flows in the Brunswick River only appeared to be limiting at the upper BRUN-05 site. Although fish moved away from BRUN-05 when flows were seen to consistently exceed 3 ML/day, given the many barriers through the system the relationship between flow and connectivity through most of the system is unclear.

5.3 Recommendations and knowledge gaps

1. Flow provisions through low-flow periods should consider the need for bioconnectivity between daytime and night time habitats. The importance of any habitats adjacent to dry-season refuge pools (e.g. riffles, runs or other nearby pools) should be assessed on a system-specific basis, as not all systems may need the same degree of connectivity. This information should be considered in setting ecological flow requirements within the Department's water allocation planning process.
2. Flow provisions through higher-flow periods should consider the propensity for some fish to make migrations which, for the systems assessed in this study, may cover the entire length of the naturally connected channel. Distances travelled in the study reaches were in excess of 8 km and would likely be longer if examined over multiple years (capturing wetter years) and in larger systems. The swimming speeds recorded in this study (i.e. up to 600 m/h) should be considered when deciding the duration of flow pulses to achieve the required connectivity.
3. For the Harvey River between the Harvey and Stirling dams, flows above 5 ML/day should be used as a guide to deciding winter baseflows and summer pulses that are designed to allow fish to swim through the system. The minimum duration of the flows should consider the responsiveness of the system (see White & Storer 2012), the swimming speed of fish (not just *T. bostocki*) and their ecological requirements. More work is required to establish the flow-connectivity relationships and requirements for the upper Brunswick River.
4. Follow the surgical method outlined here in future fish tagging studies. This method was developed through advice from experts in the fields of veterinary science and animal husbandry and experienced in anaesthesia, fish anatomy, recognition of distress in fish, wound healing, behavioural and physiological consequences of tagging, aseptic technique, suturing techniques, and choice of tag type and size relative to target species.
5. In future studies, apply acoustic tracking to achieve the following:
    a. Assess the ability of *T. bostocki* to negotiate in-stream structures. This information will provide guidance for flow management, better engineering solutions for in-stream structures (e.g. weirs) and for creating low-flow bypass structures around weirs.
    b. Evaluate variability in system-specific requirements in larger, better connected systems.

c. Investigate the minimum requirements for survival in more intermittent systems. This needs field observations of refuge habitat quality and water depth requirements to negate in-stream barriers.

d. Assess the use of on-stream dams (from water reservoirs through to smaller on-stream farm dams) by freshwater fish species; specifically their use as habitats for reproduction and foraging, and as refugia through the dry season.

e. Combine with field assessments of reproductive condition and habitat type to elucidate habitat requirements at various life stages.

f. Assess movement in earlier (smaller) life stages, which may travel further than mature adults in search of new habitats.

g. Use radio-tracking or finer-scale acoustic tracking to examine habitat preference patterns at meso-habitat scale (e.g. choice of shelter during the day and foraging habitat during the night).

Appendices

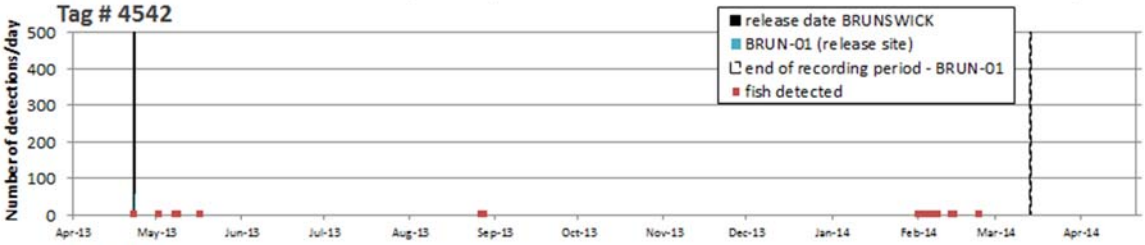
Appendix A — Size, sex, capture and release locations and dates

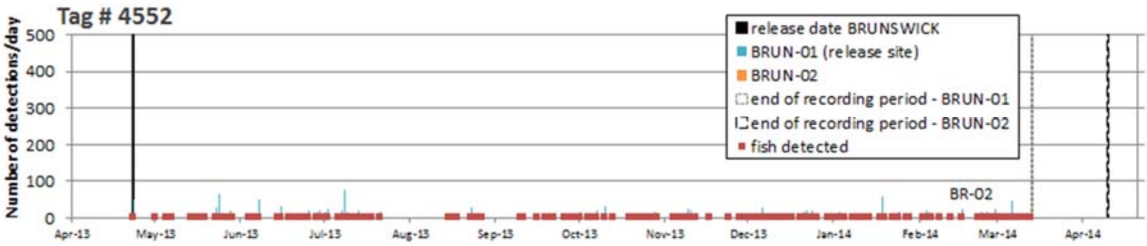
Fish #	Size (g)	Size (cm)	Sex	Capture location	Release location	Date of release
4532	450	380	m	BRUN-01	BRUN-03	23-Apr-13
4533	400	405	f	BRUN-02	BRUN-05	23-Apr-13
4534	300	385	m	BRUN-01	BRUN-01	23-Apr-13
4535	450	380	m	BRUN-01	BRUN-03	23-Apr-13
4537	350	335	f	BRUN-02	BRUN-05	23-Apr-13
4538	350	345	f	BRUN-02	BRUN-05	23-Apr-13
4539	300	350	f	BRUN-02	BRUN-05	23-Apr-13
4542	550	415	f	BRUN-01	BRUN-01	23-Apr-13
4543	250	340	m	BRUN-02	BRUN-05	23-Apr-13
4545	400	355	f	BRUN-01	BRUN-03	23-Apr-13
4546	400	365	f	BRUN-01	BRUN-03	23-Apr-13
4547	350	350	f	BRUN-02	BRUN-05	23-Apr-13
4552	700	435	f	BRUN-02	BRUN-01	23-Apr-13
4553	400	370	f	BRUN-01	BRUN-01	23-Apr-13
4554	300	340	f	BRUN-02	BRUN-05	23-Apr-13
4555	400	355	m	BRUN-01	BRUN-03	23-Apr-13
4556	450	360	f	BRUN-01	BRUN-01	23-Apr-13
4557	1050	500	m	BRUN-02	BRUN-05	23-Apr-13
4558	250	320	m	BRUN-01	BRUN-03	23-Apr-13
4561	350	345	m	BRUN-02	BRUN-05	23-Apr-13
4562	650	440	f	BRUN-01	BRUN-03	23-Apr-13
4563	300	375	m	BRUN-02	BRUN-01	23-Apr-13
4564	700	415	m	BRUN-01	BRUN-01	23-Apr-13
4565	650	440	f	BRUN-01	BRUN-03	23-Apr-13
4566	350	345	m	BRUN-01	BRUN-03	23-Apr-13
4567	350	345	m	BRUN-01	BRUN-03	23-Apr-13
4568	550	420	m	BRUN-02	BRUN-05	23-Apr-13
4569	350	310	f	BRUN-01	BRUN-03	23-Apr-13
4570	500	400	m	BRUN-01	BRUN-01	23-Apr-13
4572	600	410	f	BRUN-01	BRUN-03	23-Apr-13
4573	1050	520	m	BRUN-02	BRUN-05	23-Apr-13
4574	750	440	f	BRUN-02	BRUN-01	23-Apr-13
4575	600	415	f	BRUN-01	BRUN-01	23-Apr-13
4576	600	420	m	BRUN-01	BRUN-01	23-Apr-13
4578	450	405	f	BRUN-01	BRUN-01	23-Apr-13
4579	750	440	m	BRUN-02	BRUN-01	23-Apr-13
4580	450	410	f	BRUN-02	BRUN-05	23-Apr-13
4581	350	355	m	BRUN-02	BRUN-05	23-Apr-13
4536	600	400	f	HARV-08	HARV-08	18-Apr-13
4540	300	310	m	HARV-07	HARV-07	18-Apr-13
4541	600	420	m	HARV-08	HARV-07	18-Apr-13
4544	950	460	m	HARV-08	HARV-07	18-Apr-13
4548	350	350	f	HARV-07	HARV-07	18-Apr-13
4549	800	420	m	HARV-08	HARV-08	18-Apr-13
4550	230	300	f	HARV-08	HARV-08	18-Apr-13
4551	300	340	f	HARV-08	HARV-08	18-Apr-13
4559	650	400	m	HARV-08	HARV-07	18-Apr-13
4560	1000	500	m	HARV-08	HARV-07	18-Apr-13
4571	400	355	m	HARV-08	HARV-08	18-Apr-13
4577	550	375	f	HARV-08	HARV-08	18-Apr-13

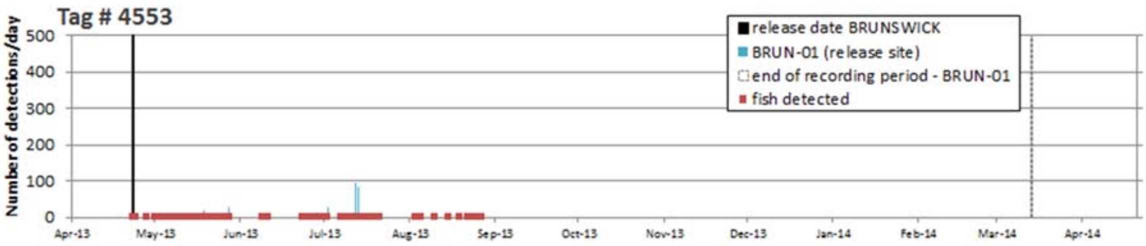
Appendix B — Movement of individual fish

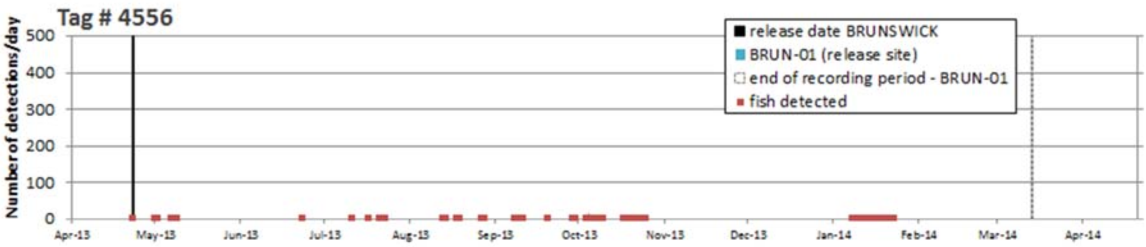
Brunswick River

FISH RELEASED AT BRUN-01









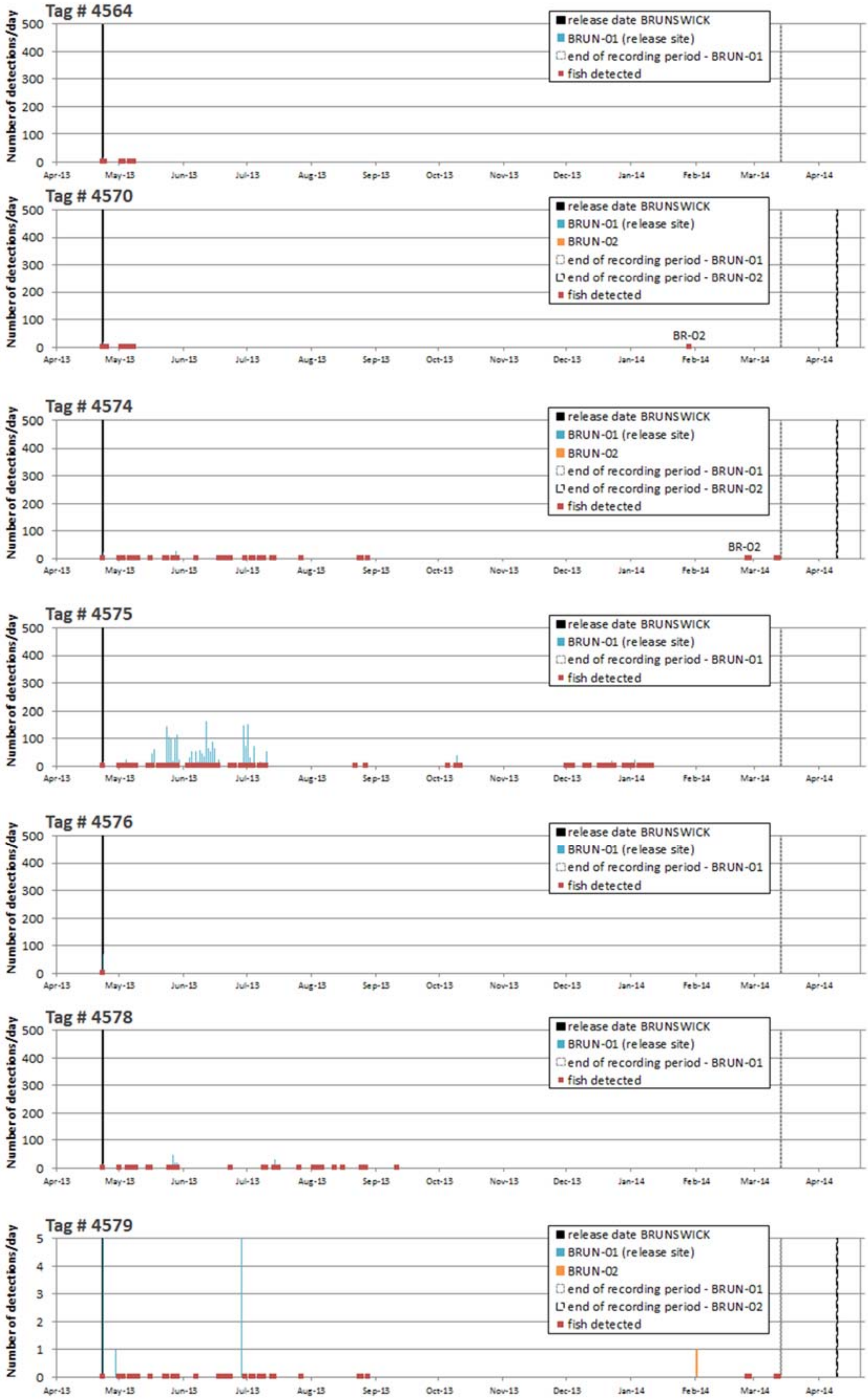
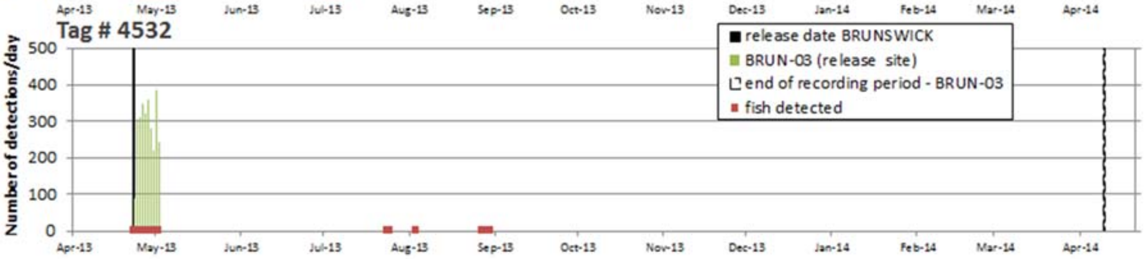
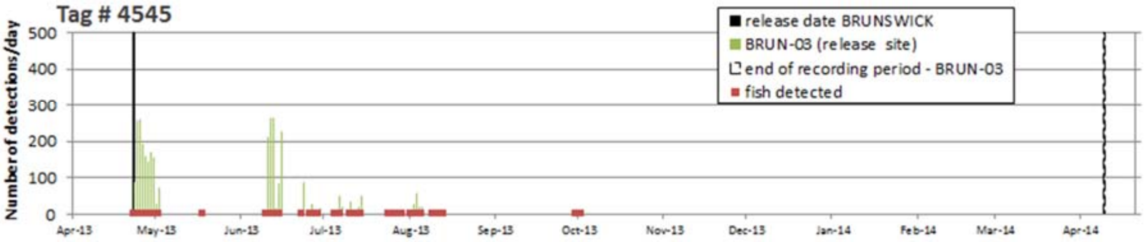
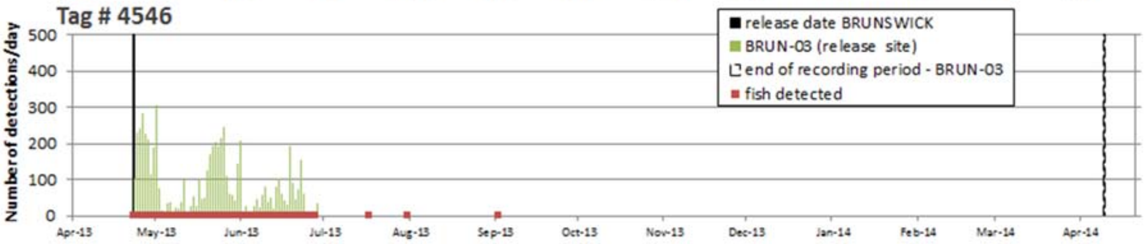


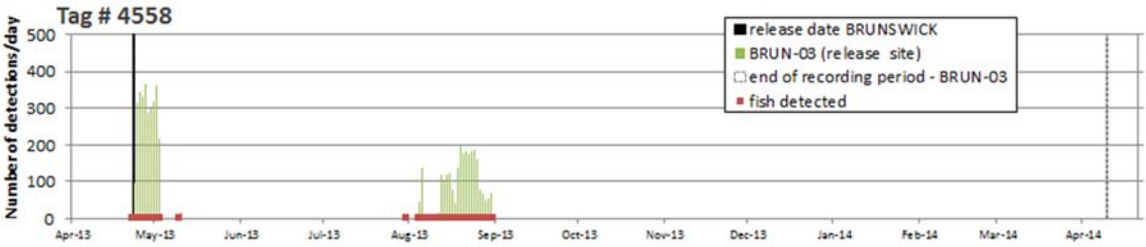
Figure 28 Location of individual fish released at BRUN-01 within the Brunswick River through the study. Note: BRUN-02 hydrophone was offline from 14 May to 06 Dec 2013.

FISH RELEASED AT BRUN-03









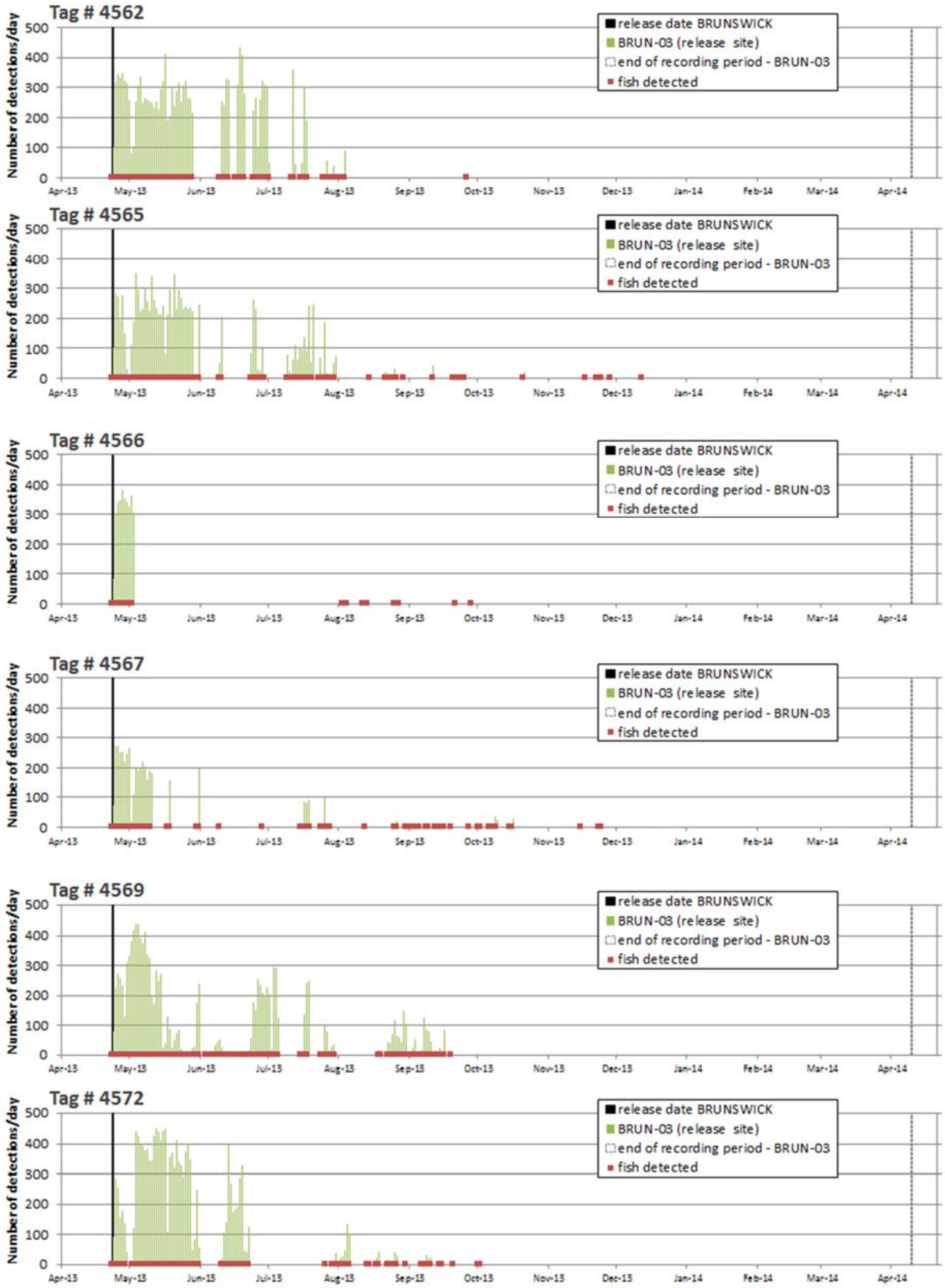
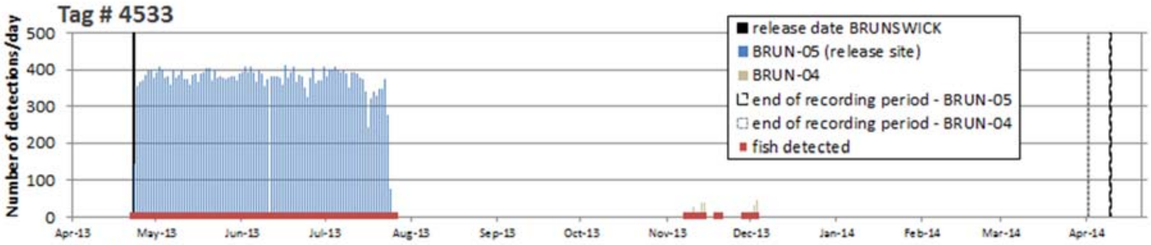
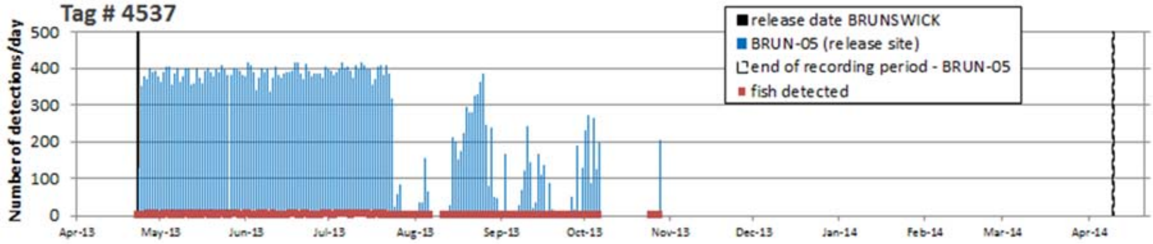


Figure 29 Location of individual fish released at BRUN-03 within the Brunswick River through the study

FISH RELEASED AT BRUN-05





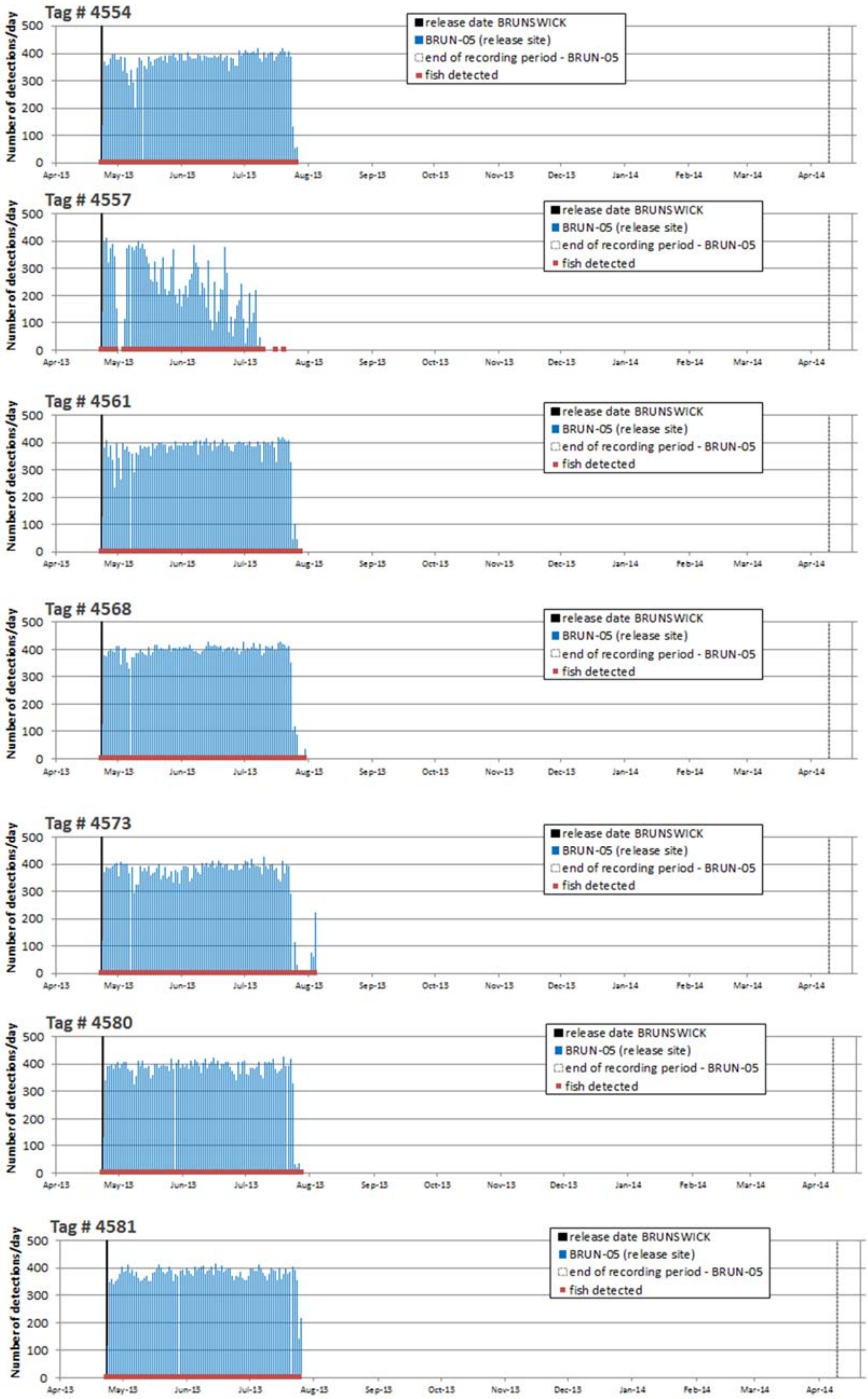


Figure 30 Location of individual fish released at BRUN-05 within the Brunswick River through the study

Harvey River

FISH RELEASED AT HARV-07

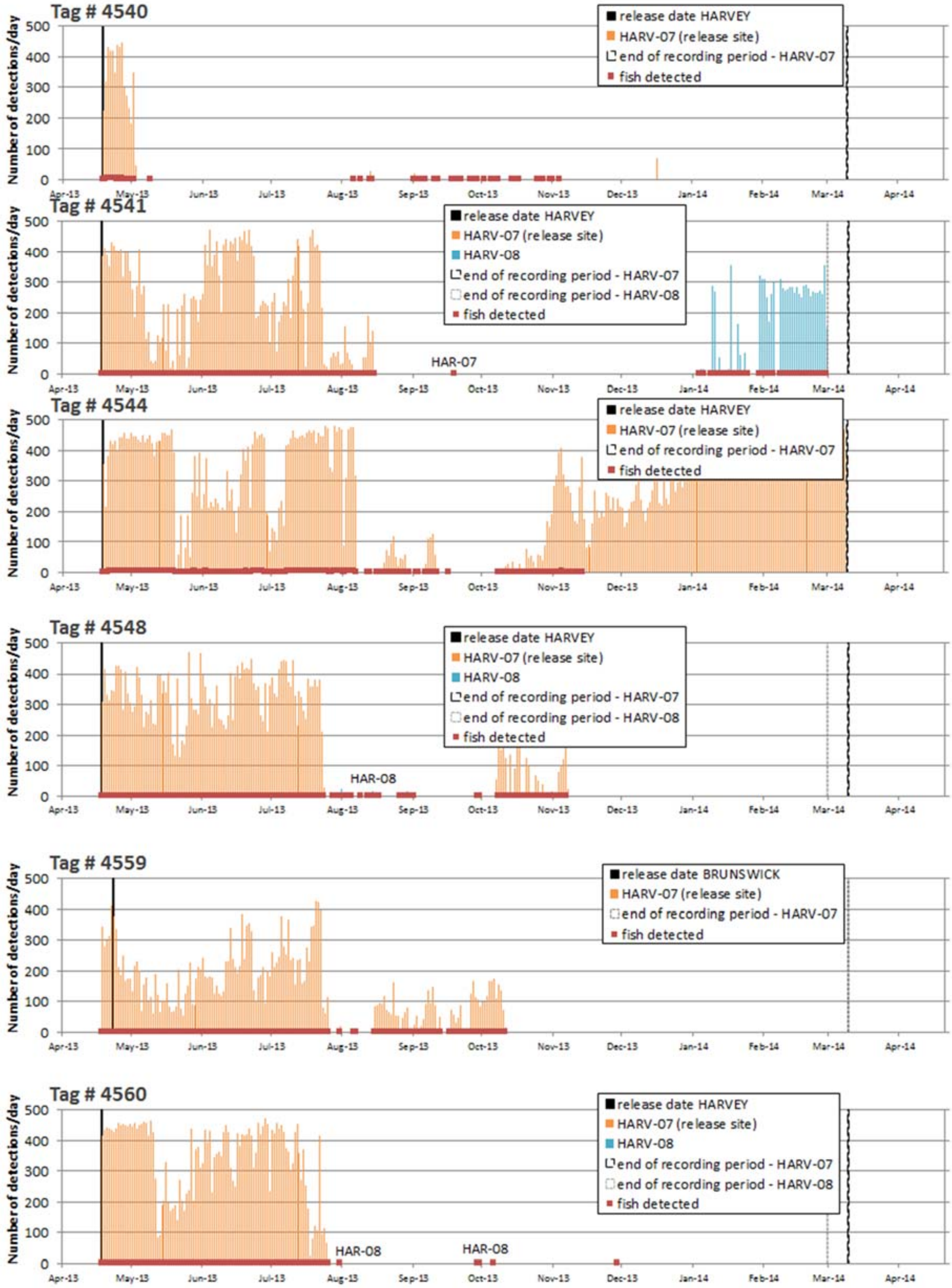


Figure 31 Location of individual fish released at HARV-07 within the Harvey River through the study

FISH RELEASED AT HARV-08

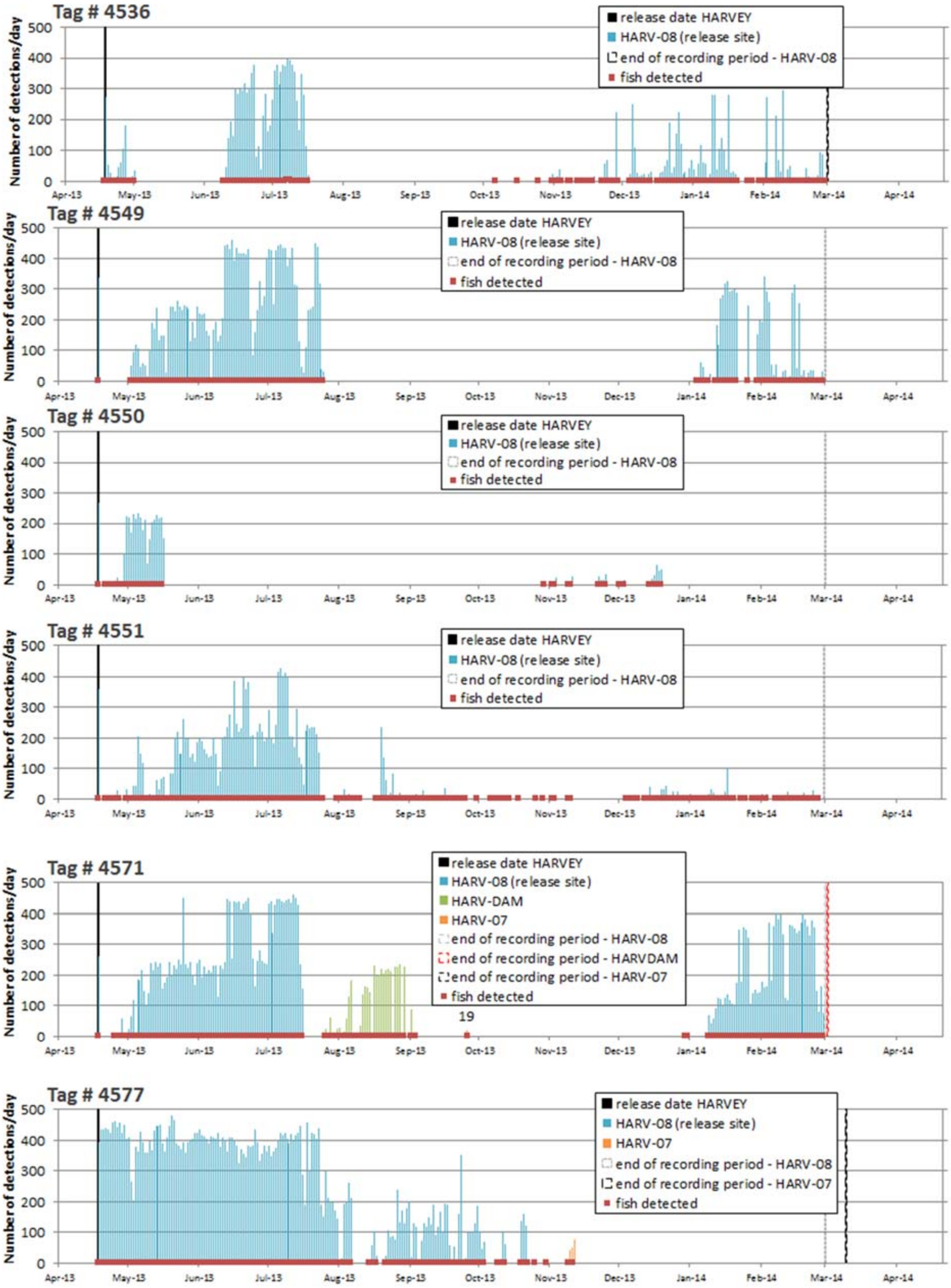


Figure 32 Location of individual fish released at HARV-08 within the Harvey River through the study

Appendix C — Minimum distance travelled by individual fish through the study period

Table 1 Minimum distance (km) covered by individual fish (D_{min}) during the trial. D_{min} are the absolute values of the stream distance between hydrophones. NB: The actual distance covered is likely to be much longer as movements outside the detection range of the hydrophones cannot be measured. Further, interpretation of data should consider the limitation on connectivity, particularly between BRUN-03 and BRUN-05.

Brunswick Transmitter number	D_{min} (km)
4532	0
4533	9.36
4534	2.66
4535	0
4537	0
4538	0
4539	0
4542	0
4543	0
4545	0
4546	0
4547	0
4552	5.32
4553	0
4554	0
4555	0
4556	0
4557	0
4558	0
4561	0
4562	0
4563	0
4564	0
4565	0
4566	0
4567	0
4568	0
4569	0
4570	2.66
4572	0
4573	0
4574	5.32
4575	0
4576	0
4578	0
4579	2.66
4580	0
4581	0

Harvey Transmitter number	D_{min} (km)
4536	0
4540	0
4541	3.91
4544	0
4548	7.82
4549	0
4550	0
4551	0
4559	0
4560	3.91
4571	22.72
4577	3.91

Appendix D — Map disclaimer and data acknowledgements

The maps in this publication were produced by the Department of Water with the intent that they are used as illustrations in this report only. While the department has made all reasonable efforts to ensure the accuracy of this data, it accepts no responsibility for any inaccuracies and persons relying on this data do so at their own risk.

The Department of Water acknowledges the following datasets and their custodians in the analysis of data and production of the maps:

Dataset name	Custodian acronym	Metadata year
Aerial photo: Bunbury 2010 50 cm	Landgate	2010
Aerial photo: Bunbury 2012 50 cm	Landgate	2012
Aerial photo: Collie 2012 50 cm	Landgate	2012
Coastline, Western Australian	DoW	2006
Hydrography linear (hierarchy)	DoW	2007
Hydrography – Inland waters – waterpolygons (from Topographic Database, Hydrography)	Landgate	2013
Land use in western Australia, version 2	DAFWA	2001
Road centrelines	Landgate	2014
Towns, Western Australian	Landgate	2013
Water information network (WIN) sites	DoW	2013

The maps have been produced using the following data and projection information:

Vertical Datum: AHD (Australian Height Datum)

Horizontal Datum: GDA 94 (Geocentric Datum of Australia 1994)

Projection System: GDA 94

Original ArcMap documents (*.mxd):
J:\gisprojects\Project\B_Series\B5047\000_related_tasks\017_Fish_tagging_Harvey_Brunswick

Glossary

Abstraction (water)	Taking water from a watercourse, wetland or aquifer.
Acoustic tags	Small sound-emitting devices often attached to animals to track movement; allows detection in three dimensions.
Allochthonous (input)	Relating to inputs originating from the same area as found. For example, organic material entering the river from streamside vegetation.
Anaesthetic	A substance that induces insensitivity to pain; incorporates various levels from localised loss of sensation to unconsciousness.
Antibiotic	A medicine that inhibits growth of (or destroys) organisms.
Apposition (skin)	The positioning of things side by side. The degree of skin apposition relates to the neatness and completeness of the bond following suturing.
Aseptic	Free from contamination caused by bacteria, viruses or other microorganisms; surgically sterile.
Behavioural plasticity	The ability of an organism to alter its behaviour to suit changing conditions without suffering excessive stress.
Behavioural syndrome	A correlated suite of behavioural traits. This is assessed at the population or species level, while the phenotype of the behavioural syndrome an individual shows is its behavioural type. For example, a population may show a behavioural syndrome that includes a positive correlation between foraging behaviour and mating behaviour. An individual may be more or less aggressive than another individual within this behavioural syndrome and this aggressive or passive phenotype is that individual's behavioural type.
Bioconnectivity	The connectedness of the system in respect to the movement of fish (compared to connectivity for other purposes such as flushing of nutrients or sediments).
Congener (species)	Organisms within the same genus.
Ecology	The study of the interrelationships between living organisms and their environment.
Ecological requirements	Requirements to maintain the ecological values of water dependent ecosystems. For example, the required flow regime to support biodiversity.
Environmental water provisions	The water regimes that are recommended as a result of the water allocation decision-making process. Considers ecological, social and economic impacts. They may meet in part or in full the ecological water requirements. Compare Environmental water releases.
Environmental water releases	The water regimes that are provided to meet environmental water provisions. They may meet in part or in full the ecological water requirements. Compare Environmental water provisions.
Fluoresce	To glow. Visible (or invisible) radiation produced from certain substances as a result of incident radiation of a shorter wavelength (e.g. ultraviolet light).

Gonadosomatic Index (GSI)	The calculation of gonad mass as a proportion of total body mass. A tool for measuring the sexual maturity of animals.
Gregarious	Living in flocks or loosely organised communities.
Habitat	The environment where an organism, population or community lives (includes soil, water, climate, other organisms and communities)
Hygroscopic	Readily taking up and retaining moisture
Intramuscular	Within a muscle
Intraperitoneal cavity	Within the abdominal cavity. The peritoneum is the serous membrane lining the cavity.
Linea alba	A fibrous band running the length of the ventral abdominal wall receiving the attachments of the oblique and transverse abdominal muscles. Also called the white line.
Macrophytes	Aquatic plants big enough to see with the naked eye.
Membrane (fish)	A thin layer of tissue that covers a surface, lines a cavity or divides a space or organ.
Metabolic by-products	The products produced from metabolism, e.g. water, carbon dioxide and salt.
Monosyn™	A brand of synthetic, fast-absorbed, flexible monofilament suture made of polyglyconate (see polyglyconate definition). Trademark of B. Braun Australia.
Nitrile gloves	Gloves made with an organic compound containing a cyanide group (CN bound to an alkyl group). Provide resistance to a number of chemicals and are generally safe for people who are allergic to Latex (alternative).
Operculum (fish)	A structure (hard bony flap in teleost fish) that covers and protects the gills.
Perennial (flow)	Permanent flow, no cease to flow period through a typical annual cycle.
Polyglyconate	Polyglyconate is a synthetic, fast-absorbed, flexible, high-tensile strength monofilament suture made of glyconate (see polyglyconate). Glyconate is a copolymer made of 72% glycoside, 14% trimenthylene carbonate and 14% caprolactone. This copolymer degrades through hydrolysis.
Phytoplankton	Microscopic (up to 1–2 mm in diameter) free-floating or weakly mobile aquatic plants e.g. diatoms, dinoflagellates, chlorophytes, blue-green algae.
Righting Reflex	A reflex that corrects the orientation of the body when it is taken out of its normal position.
Riparian	The zone along or surrounding a waterway where the vegetation and natural ecosystems benefit from and are influenced by the passage and storage of water.
Unregulated (water)	No regulated activities (e.g. water supply dams or licenses to abstract) that affect the flow of water through a system (surface water and groundwater).

References

Annan, K 2006, A comparison of techniques for investigating groundwater-surface water interactions along the Brunswick River, Western Australia, Honours thesis, University of Western Australia.

Beatty, S, Allen, M, Lymbery, A, Storer, T, White, G, Morgan, D & Ryan, T 2013, *Novel methods for managing freshwater refuges against climate change in southern Australia: Evaluating small barrier removal to improve refuge connectivity: A global review of barrier decommissioning and a process for southern Australia in a drying climate*, National Climate Change Adaptation Research Facility, Gold Coast, ISBN: 978-1-925039-54-2, 73p.

Beatty, S, McAleer, F & Morgan, D 2007, *Environmental water provisions for fish and crayfish communities of Samson Brook and Harvey River: Annual monitoring report 2007*, Centre for Fish & Fisheries Research, Murdoch University report to the Water Corporation of Western Australia.

Beatty, SJ & Morgan, DL 2006, *Monitoring the adequacy of Environmental Water Provisions for fish and crayfish communities of Samson Brook, Harvey River and Harris River*, report to the Water Corporation WA.

Beatty SJ, Morgan DL, McAleer FJ & Ramsay, AR 2010, 'Groundwater contributions to baseflow maintains habitat bioconnectivity for Tandanus bostocki (Teleostei: Plotosidae) in a south-western Australian river', *Ecology of Freshwater Fish,* vol. 19, pp. 595–608.

Bell, G 1987, *An outline of anaesthetics and anaesthesia for salmonids, a guide for fish culturists in British Columbia*, Canadian Technical Report of Fisheries Aquatic Sciences No. 1534, 16p.

Brown, RS, Cooke, SJ, Wagner, GN & Eppard, MB (eds) 2010, *Methods for surgical implantation of acoustic transmitters in juvenile salmonids, A review of literature and guidelines for technique*, prepared for the US Army Corps of Engineers, Portland District, available to the public from the National Technical Information Service, US Department of Commerce.

Bustard, DR & Narver, DW 1975, 'Aspects of the winter ecology of juvenile coho Salmon (Oncorhynchus kisutch) and steelhead trout (*Salmo gairdneri*)', *Journal of the Fisheries Research Board of Canada*, vol. 32, pp. 667–680.

CCAC (Canadian Council on Animal Care) 2005, *CCAC guidelines on: the care and use of fish in research, teaching and testing*, Canadian Council on Animal Care, Ottawa, Ontario, Canada.

Cederholm, CJ & Scarlett, WJ 1981, 'Seasonal immigrations of juvenile salmonids into four small tributaries of the Clearwater River, Washington, 1977–1981, in EL Brannon & EO Salo (eds), *1981 Salmon and Trout Migratory Behavior Symposium*, Washington Department of Natural Resources, Forks, Washington, pp. 98–110.

Clapp DF, Clark Jr. RD, Diana, JS 1990, 'Range, activity, and habitat of large, free-ranging brown trout in a Michigan stream', Transactions of the American Fisheries Society, vol. 119, pp. 1022–1034.

Crook, DA, Koster, WM, Macdonald, JI, Nicol, SJ, Belcher, CA, Dawson, DR, O'Mahony, DJ, Lovett, D, Walker, A & Bannam, L 2010, 'Catadromous migrations by female tupong (*Pseudaphritis urvillii*) in coastal streams in Victoria, Australia', *Marine and Freshwater Research*, vol. 61, pp. 474–483.

CSIRO (Commonwealth Scientific and Industrial Research Organisation) 2009, *Surface water yields in south-west Western Australia*, a report to the Australian Government from the CSIRO south-west

Western Australia sustainable yields project, CSIRO Water for a healthy Country Flagship, Australia.

Donohue, R, Green, A, Bennett, K, Pauli, N, Lynas, J & Storey, A 2009, *Ecological water requirements of the Brunswick River,* Department of Water, Government of Western Australia, Environmental Water Report No. 7.

DoW (Department of Water) 2012, *Water Resource Management Operating Strategy for Logue Brook, Stirling and Harvey Dams and Wokalup Pipe-head Dam, Licensee Water Corporation*, Department of Water, Western Australia, unpublished report.

Gowan, C, Young, MK, Fausch, KD & Riley, SC 1994, 'Restricted movement in resident stream salmonids: a paradigm lost?', Canadian Journal of Fisheries and Aquatic Sciences, vol. 51, pp. 2626–2637.

Hewitt, MA 1992, Biology of the south-western Australian catfish *Tandanus bostocki* Whitley (Plotosdiae), Honours thesis, Murdoch University, Perth, Western Australia.

Hutchison, MJ 1992, 'Probable spawning site of the freshwater cobbler *Tandanus bostocki* located in the Murray River, Western Australia', *Western Australian Naturalist,* vol. 19, no. 1, pp. 25–30.

IOCI (Indian Ocean Climate Initiative) 2005, *How our rainfall has changed – the south-west*, Climate note 5/05, Indian Ocean Climate Initiate, available at: http://www.ioci.org.au/pdf/IOCIclimatecnotes_5.pdf (accessed 25 August 2011).

Kaya, CM, Kaeding, LR & Burkhalter, DE 1977, 'Use of a cold-water refuge by rainbow and brown trout in a geothermally heated stream', *Progressive Fish Culturist*, vol. 39, pp. 37–39.

Knights, BC & Lasee, BA 1996, 'Effects of implanted transmitters on adult bluegills at two temperatures', *Transactions of the American Fisheries Society*, vol. 125, pp. 440–449.

Koster, W & Crook, DA 2008, 'Diurnal and nocturnal movements of river blackfish (*Gadopsis marmoratus*) in a south-eastern Australian upland stream, *Ecology of Freshwater Fish,* vol. 17, pp. 146–154.

Koster, W, Crook, D & Dawson, D 2009, *Lower Goulburn Fish Communities Project, 2009 Annual Report,* Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment, Heidelberg, Victoria.

Koster, WM, Dawson, DR, Clunie, P, Hames, F, McKenzie, J, Moloney, PD & Crook, DA 2015, 'Movement and habitat use of the freshwater catfish (*Tandanus tandanus*) in a remnant floodplain wetland', *Ecology of Freshwater Fish*, 10.1111/eff.12159.

LCC (Leschenault Catchment Council) 2006, *River Action Plan for the Brunswick River*, Leschenault Catchment Council.

Magoulick, DD & Kobza, RM 2003, 'The role of refugia for fishes during drought: a review and synthesis', *Freshwater Biology,* vol. 48, pp. 1186–1198, doi:10.1046/J.1365-2427.2003.01089.X

Marking, LL & Meyer, FP 1985, 'Are better anaesthetics needed in fisheries?', *Fisheries,* vol. 10, no. 6, pp. 2–5.

Morgan, DL & Beatty, SJ 2008, 'Fishes and freshwater crayfishes of major catchments of the Leschenault Estuary: Preston and Brunswick River, including first record of a freshwater gudgeon (Eleotridae) from south-western Australia, *Journal of the Royal Society of Western Australia,* vol. 91, pp. 155–161.

Morgan, DL, Beatty, SJ, Klunzinger, MW, Allen, MG & Burnham, QF 2011, *A Field Guide to the Freshwater Fishes, Crayfishes and Mussels of South-western Australia,* Lotterywest and South East Centre for Urban Landcare, Perth, Western Australia, 69p.

Morrison, PF 1988, Reproductive biology of two species of plotosid catfish, *Tandanus bostocki* and *Cnidoglanis macrocephalus*, from south-western Australia, PhD Thesis, University of Western Australia, 187p.

Moser, ML, Olson, AF & Quinn, TP 1990, 'Effects of dummy ultrasonic transmitters on juvenile coho salmon', *American Fisheries Society Symposium*, vol. 7, pp. 353–356.

Munz, JT & Higgins, CL 2013, 'The influence of discharge, photoperiod, and temperature on the reproductive ecology of cyprinids in the Paluxy River, Texas', *Aquatic Ecology*, vol. 47, pp. 67–74.

WRM (Wetland Research and Management) 2010, *Environmental flows for Harvey River below Stirling Dam using trial releases to set summer and winter baseflows*, report by Wetland Research & Management to Harvey Water and the Water Corporation, Western Australia, September 2010.

Norton, S, Storer, T & Galvin, L 2010, *Ecological study of the Lower Canning River environmental water releases*, Water Science Technical Series, report no. 35, Department of Water, Perth.

Power, ME 1984, 'Habitat quality and distribution of algae grazing catfish in a Panamanian stream', *Journal of Animal Ecology,* vol. 53, pp. 357–374.

Priede, IG 1980, 'An analysis of objectives in telemetry studies of fish in the natural environment', in CJ Arnlaner & D W MacDonald (eds) *'A Handbook on Biotelemetry and Radio Tracking. Proceedings of an International Conference on Telemetry and Radio Tracking in Biology and Medicine,* Oxford, 20–22 March 1979', pp. 105–18, Permagon Press.

Schaefer, JF 2001, 'Riffles as barriers to interpool movement by three cyprinids (*Notropis boops*, *Campostoma anomalum* and *Cyprinella venusta*)', *Freshwater Biology*, vol. 46, pp. 1–10.

Smithson, EB & Johnston, CE 1999, 'Movement patterns of stream fishes in a Ouachita Highlands stream: An examination of the restricted movement paradigm', *Transactions of the American Fisheries Society*, vol. 128, pp. 847–853.

Storer, T, White, G, Galvin, L, O'Neill, K, van Looij, E & Kitsios, A 2011, *The framework for the assessment of river and wetland health (FARWH) for flowing rivers of south-west Western Australia: project summary and results, Final report*, Water Science Technical Series, report no. 39, Department of Water, Perth [Related data in Department of Waters Water Information Network project-code WA-C-SWAFARWH].

Streamtec 2001, *Ecological water requirements of the Harvey River: Stirling Dam to New Harvey Dam,* Report AT 10/00, Streamtec Pty Ltd, Nedlands.

White, G & Storer, T 2012, *Assessment of ecological health and environmental water provisions during summer in the Harvey River (between Stirling Dam and Harvey Reservoir), 2010–2011 dry season*, Water Science Technical Series, report no. 44, Department of Water, Perth.

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