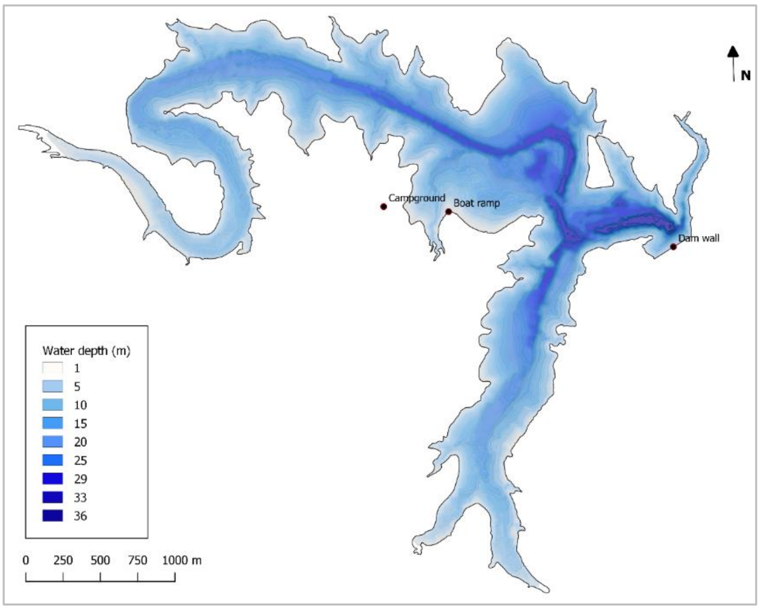
Freshwater fish attracting structures (FAS)

Evaluating a new tool to improve fishing quality and access to fisheries resources in Australian impoundments



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The Fisheries Research and Development Corporation plans, invests in and manages fisheries research and development throughout Australia. It is a statutory authority within the portfolio of the federal Minister for Agriculture, Fisheries and Forestry, jointly funded by the Australian Government and the fishing industry.

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Abbreviations

DAF	Queensland Department of Agriculture and Fisheries
EDA	Euclidean Distance Analysis
FAS	Fish Attracting Structure
FRDC	Fisheries Research and Development Corporation
FSL	Full supply level
GLM	Generalise linear model
KDE	Kernel Density Estimate
TDFSA	Toowoomba and District Fish Stocking Association
TRC	Toowoomba Regional Council

Executive Summary

The current project was the first to comprehensively investigate the potential use of fish attracting structures (FAS) to improve recreational fishing in Australian impoundments. Current management in Australia relies upon stocking and harvest control to regulate impoundment fisheries. Installing FAS into impoundments may provide an additional tool for fisheries managers and improve recreational fishing and the benefits impoundment fisheries generate for local communities. The results of this study indicated both a range of native Australian fish species and anglers, responded positively to the installation of FAS and broader uptake should be considered.

Background

Recreational angling is an extremely popular pastime in Australia and impoundment fishing is one fishery sector that is increasing in popularity and delivers significant socio-economic benefits to regional communities. To date, impoundment fisheries management in Australia has focussed on stocking and harvest limits. There has been surprisingly little research or attention given to managing the fish habitat in impoundments to improve angling.

To maximise the economic potential of impoundment fisheries, it is important to improve the reliability and quality of fishing to attract repeat visits by anglers and increase visitation rates. Whilst impoundment fisheries are well established in Australia, the quality of the fishery and the associated angler satisfaction with fishing, vary significantly between locations. One of the key differences between impoundments with high-quality and poor-quality fishing is often the quality and extent of structural habitat. There is convincing evidence from the USA that strategic fish habitat enhancement has positively influenced many of their impoundment fisheries and this has become a primary tool for fisheries managers. Habitat enhancement through the installation of FAS has broadscale potential to improve recreational fishing in Australian impoundments as well, but this approach has never been undertaken or evaluated at the impoundment scale. Critical information on fish attractor design, construction, placement, durability and effectiveness needs to be determined before the technique can be widely implemented in a cost-effective manner. Many fish stocking groups are looking for ways to enhance their impoundment fisheries through means other than stocking fish. Installing FAS has the potential to provide stocking groups and fisheries managers with the means to achieve this.

Aims and objectives

The project installed FAS into Cressbrook Dam to:

1. Evaluate the ability of three broad groups of fish attracting structures (timber, synthetic and suspended) to attract a range of native fish species in impoundments.
2. Evaluate the impacts of FAS installation on angler catch rates and angler satisfaction rates.
3. Evaluate the impact of FAS installation on angler visitation rates.
4. Develop best practice guidelines for installation of FAS in Australian impoundments.

Methodology

Baseline surveys and stakeholder engagement were used to develop a fish attraction plan for Cressbrook Dam. The plan outlined the type, number and location of FAS to be installed and defined the fixed monitoring sites. Detecting the fishery response to FAS installation at the impoundment scale can be difficult. We therefore employed a combination of methods to generate multiple lines of evidence and provide a clearer picture of the responses to FAS installation. Monitoring was ongoing throughout the project to evaluate trends pre, during and post FAS installation. Surveys of fish distributions and their use of FAS were complemented by creel surveys to provide an understanding of trends in fish behaviour, angler behaviour and fishing quality.

A total of 576 FAS were installed across 25 sites between February 2019 and January 2020. This was comprised of 182 synthetic spiders, 142 synthetic trees, 130 brush bundles, 44 Georgia cubes, 39 timber

cribs, 26 suspended FAS and 13 branch bundles. The FAS were constructed in conjunction with volunteers from the Toowoomba and District Fish Stocking Association and the general community.

The influence of FAS installation on fish distributions was assessed via twice yearly electrofishing surveys, quarterly targeted angling surveys and acoustic telemetry. The acoustic telemetry tracked the fine-scale movements of 30 Australian Bass and 30 Golden Perch for a period of 2 years using a Vemco VPS array. FAS condition and their use by fish were monitored using sonar after poor underwater visibility restricted the value of underwater video footage from a drone or fixed cameras. Creel surveys and counts of boat visitation were also used to collect information on visitation rates, angler effort, catch rates, knowledge of the project and use of FAS by anglers.

Results

The results of this study indicated that a range of native Australian fish species responded to the installation of FAS. The primary species targeted by anglers in Cressbrook Dam (Golden Perch and Australian Bass) were both observed to use the installed FAS. Smaller prey species were also commonly detected around the FAS, but the pre to post FAS installation trends were less clear due to significant general increases in abundance occurring across the entire impoundment.

Monitoring indicated the localised abundance of Australian Bass and Golden Perch increased around all FAS types following their installation. The observed trends varied between monitoring techniques. Electrofishing surveys detected the greatest increase at sites where timber FAS were installed, but positive trends were also observed around the synthetic and suspended FAS. In contrast, the acoustic tracking data indicated little use of timber structures, but this was confounded by a number of technical factors which limited our ability to effectively track fish within shallower bays where most of the timber FAS were located. The acoustic telemetry revealed the mean seasonal proximity of Australian Bass to the synthetic, suspended and mixed FAS sites all decreased following FAS installation, but the response was not quite statistically significant. The mean seasonal proximity of Golden Perch did not change with FAS installation. However, the kernel density analysis of detected fish positions clearly indicated localised hotspots for both species around most FAS types and indicated consistent use of deep-water FAS by both species.

All FAS types retained their structural integrity for the duration of the study, with no degradation evident. Unfortunately, the period of monitoring was insufficient to assess long term durability, but all FAS types tested appear suitable for use in other impoundments. Visual surveys using underwater cameras and an underwater drone provided limited quantitative data due to limited water clarity, but they did provide further evidence of sportfish use of FAS and showed aggregations of small prey species around some FAS. Sonar surveys provided adequate detail on the FAS condition and produced some information on the abundance of prey species and sportfish around the FAS.

Targeted angling surveys suggested that catch rates were moving in a positive direction, but the results were limited by very low catch rates and the observed trends were generally not statistically significant. Catch rates increased at synthetic and timber FAS sites whilst decreases were observed at the Control sites.

The creel survey results showed an overall trend towards improving angler attitudes to fishing in Cressbrook Dam and an improved perception of fishing quality post-installation of FAS. The creel surveys also demonstrated trends for improvements in fish capture rates and angler success rates, following installation of FAS. Among the anglers interviewed the median frequency of visitation to the dam increased three-fold from the pre- to the post-FAS installation periods. This provides evidence that installation of FAS has improved the attractiveness of the fishery in Cressbrook Dam. However, this study was hampered by falling water levels, frequent lengthy dam closures, a major bushfire and a pandemic, which all may have impacted on angler confidence to visit the dam and contributed to reduced sampling power. Further extension work is required to maximise the use and benefits to anglers from the installed FAS.

Boat arrivals did not increase post installation of FAS but remained relatively stable. Post closure of the dam due to blue green algae blooms, bushfires and Covid 19, it seems most of the visitation has been by people from the Toowoomba region. However, the fact that boat arrivals remained reasonably steady, despite multiple closures, the pandemic, falling water levels and subsequent poor boat ramp conditions, suggests that it is plausible that boat arrivals will increase when the dam refills and when effective promotion of the FAS is implemented.

Implications

The results from our study indicate that installing FAS into impoundments may provide an additional tool for fisheries managers to be used in conjunction with stocking and harvest restrictions to improve the recreational fishing opportunities and the value of these fisheries to local communities.

A potential concern raised by some fisheries managers has been that FAS may increase angler harvest to unsustainable levels. Most impoundments rely on stocking to support their fisheries and are designed to be put-grow-take systems. Recruitment is controlled by the number of fingerlings stocked and many anglers now practice catch and release. The risk of overharvest in impoundment fish populations through increased angler catch is therefore low and manageable.

Fish attracting structures hold the potential to help manage where anglers fish and improve angler access to fisheries resources. FAS can be used to create fishing hotspots outside of closed zones or in close proximity to launching points, to minimise boat travel distances and improve access for kayak fishers. Installing FAS to attract fish to points where shore anglers are allowed to fish could deliver better fishing and benefit mobility limited anglers.

The use of FAS in impoundments should be broadly applicable across Australia because many impoundments suffer from limited structural habitat complexity and most stocked fish species also show a high affinity for structural habitat and are expected to respond well to FAS installation.

The range of FAS examined in this study were chosen because they were modular, relatively light-weight, easy to construct, easy to deploy and relatively cheap. These criteria would enable FAS to be constructed and installed by community groups, such as fishing and stocking clubs, following the best practice guidelines.

Recommendations

Much of the knowledge on the outcomes of using fish attractors in impoundments comes from overseas. Research is needed to verify that the same principles will deliver similar results for Australian species and conditions. This study has demonstrated that a number of FAS types will work for Australian fish. Further investigation is required to optimize the use and cost-efficiency of FAS efforts in impoundments, but with the knowledge gained to date, significant improvements in fishing can be made if FAS are properly installed.

Assessment of the socio-economic impacts of FAS projects in Australia need to be undertaken to address critical knowledge gaps and enable comparison of the return on investment from utilising different FAS structures or deployment strategies. It is recommended that an economic assessment of the impoundment fishery's value be conducted prior to the commencement of any on-ground works and repeated after several years after habitat enhancement activities have been completed. This will enable cost-benefit analyses to accurately identify the most cost-efficient strategies for improving the fishery.

The use of hard plastic and rock structures is recommended where there are concerns on the impact on water quality from the introduction of fish habitat structures. These materials will not degrade and potentially introduce leachates, additional nutrients or fine debris into the water.

It is recommended that the opportunities for FAS installation presented by periods of low water level (e.g., drought or infrastructure maintenance) be capitalised on when they occur. Large quantities of FAS can be quickly deployed when vehicle assess is possible and larger structures can be used. It is recommended that this approach be encouraged as part of any new dam construction process.

It is recommended that specialist equipment and heavy machinery be used during larger FAS projects to increase transport and deployment efficiency. In particular, it is recommended that specialized trailerable habitat barges be used to transport and deploy FAS. These vessels allow greater numbers and sizes of structures to be deployed more safely and efficiently.

In town water supplies, timber and brush may not be permitted for use due to concerns over potential water quality issues. Synthetic materials and rock should be used in these scenarios. It is recommended that discussions with the impoundment operator be undertaken early on during project planning to define the scope of FAS types suitable for the waterbody.

Where possible, it is recommended that projects make opportunistic use of materials to decrease construction costs, particularly if funding is limited. Recycled or clean waste materials should be used where suitable to minimize project costs as long as they have not been in contact with any hazardous substances.

Prior to the commencement of any impoundment fishery improvement project, the current status of the fishery and habitat availability must be assessed. This baseline assessment will identify key impediments and deficiencies that need to be addressed in order for the fishery to be improved. The information collected will enable specific and targeted project objectives to be developed and form baseline data against which project progress and success can be measured.

It is recommended that all FAS projects implement a monitoring program to evaluate the effectiveness of their installation for both fish and anglers. The information collected can be used to adaptively manage the project to deliver the best return on investment.

Keywords

Fish attracting structures, impoundment, fishing, recreational angling, Golden Perch, Australian Bass, habitat, acoustic tracking, fish habitat usage, creel survey, electrofishing

General introduction

Impoundments can contain valuable recreational fisheries

Recreational angling is an extremely popular pastime in Australia and generates significant social and economic benefits, particularly in regional areas (Henry and Lyle 2003, Rolfe *et al.* 2005, Rolfe and Prayaga 2007, Gregg and Rolfe 2013, ABARES 2018). Nationally over three million Australians annually participate in recreational fishing (Baker 2018). For example, at the state level, recreational fishing participation in Queensland during 2019-20 was high, with the total number of Queenslanders fishing estimated at 943,000 (DAF 2020). In addition, significant numbers of interstate and overseas visitors travel to Queensland to fish. One report suggests around two million domestic and international visitors fished in Queensland whilst visiting in 2016 (Tourism Research Australia 2017).

Recreational angling in impoundments is one sector that is increasing in popularity. Unfortunately, information on angler participation in impoundment fisheries is not readily available in many states. However, there have been several studies on Queensland's impoundment fisheries. Impoundments with high-quality fishing attract tourists from all over Queensland, interstate and overseas (Rolfe and Prayaga 2007, Gregg and Rolfe 2013). It was estimated the economic value of individual impoundment fisheries were up to $10.42 million per year in Queensland (Gregg & Rolfe 2013). An economic assessment of 30 stocked Queensland impoundment fisheries estimated they delivered a combined annual economic value to local communities of $93 million (Gregg and Rolfe 2013). Rutledge *et al.* (1991) found that for every dollar invested into the stocking program at Tinaroo Dam near Atherton, there was a return of $31 to the local economy. A study by Hamlyn and Beattie (1993) at Lake Leslie near Warwick showed that for every dollar spent on fish stocking, tourist anglers spent $18 in the local economy. Much of this value is generated from visiting tourists coming to fish the lake, injecting essential money into the local community. There is little data available for impoundment fisheries in other parts of Australia, but they can be expected to deliver similar economic benefits to their local communities.

Given the popularity of impoundment fisheries in Australia, any decline in angler expenditure could have a significant detrimental impact on regional economies. However, there is also great potential to increase the benefits to communities by improving nearby impoundment fisheries. A study in central Queensland found that improving catch rates by 20% per annum at several Queensland impoundments would lead to estimated increases of the impoundment's value of between $120,000 and $390,000 per impoundment per year (Rolfe & Prayaga 2007).

Current fishery management practices

Despite their increasing socio-economic importance, management practices have changed little in most Australia impoundment fisheries. Management practice in Australia has focussed on stocking and harvest control through size and bags limits (Ingram *et al.* 2004, Norris 2016). Most recreationally targeted fish species do not spawn or spawn poorly in impoundments (Rowland 1995, Hutchison *et al.* 2006). Therefore, on-going stocking is required to create and maintain many of these put-grow-take fisheries. Despite the requirement for ongoing stocking, impoundments can produce exceptionally fast-growing fish and be very productive fisheries (Rowland 1995, MRAG 2014). Considerable research has gone into identifying optimal stocking strategies to get the best return on investment and minimise adverse impacts (e.g., Hutchison *et al.* 2006, Russell 2008). This research has helped improve the quality of recreational fishing in impoundments.

Harvest or bag limits are also used in impoundments to help prevent over exploitation of the fisheries. Recreational fishing regulations vary between states, but all outline the size and total number of each species of fish that can be harvested by recreational anglers. Size limits ensure fish grow to a minimum size before they are harvested and in impoundments aim to ensure stocked fish reach a size that is desirable to target for most anglers. Together with stocking, these restrictions are used to help maintain the quality of the fisheries.

Some anglers also regulate their take through the voluntary practice of catch and release fishing. This has become increasingly popular amongst recreational anglers, particularly in impoundments (Henry and Lyle 2003, Bartholomew and Bohnsack 2005). Catch and release significantly reduces harvest pressure on impoundment fish populations, although a small level of mortality still occurs (Hall *et al.* 2009). This practice means greater fishing pressure can be sustained in impoundments without leading to over-exploitation.

There has been surprisingly little research or interest on enhancing impoundment fish habitat to improve these fisheries. Very limited attention has been given to improving habitat necessary for enhanced survival, growth rates and carrying capacity of stocked fish. Additionally, management of fish distributions within a waterway to reduce angler use of closed zones or interactions between different impoundment user groups, may be possible through habitat enhancement but has rarely been considered. As Australia's population grows and access to wild fish stocks in rivers becomes more difficult, greater emphasis will need to be placed on directing fishing pressure towards stocked impounded waterways. More emphasis will be placed on managing dam, lake and reservoir fisheries to counter the additional fishing pressure. Impoundment habitat enhancement is a potential tool to increase the effectiveness and sustainability of this strategy, whilst also reducing pressure on wild river fish populations.

The link between habitat quality and fishery quality

A wide range of variables impact the success of an impoundment fishery, but a key limiting factor is often the condition and availability of the fish habitat (Miranda 2017, McCartney *et al.* 2018). Most impoundments have been built and operated for flood mitigation, town water supply, irrigation or to generate hydroelectric power, but often with little regard towards fisheries. In many cases the structural habitat was cleared prior to the initial flooding of a reservoir, leaving limited structural complexity. Another major challenge facing impoundment fisheries is the decline in waterway productivity and habitat due to the natural effects of reservoir aging. As impoundments age, the remnant woody habitat degrades over time but is not replaced. Ageing occurs in reservoirs at a much greater rate than natural lakes and this is accelerated where water storage levels fluctuate significantly (Miranda 2017). Quality fish habitat is vital to support strong fish communities and angling opportunities.

The availability of habitat is an essential requirement for fish to accomplish daily and seasonal survival tasks such as foraging, sheltering and reproducing (Jackson *et al.* 2001). When key fish habitat is absent, in poor condition or declines in quantity or quality, the associated impoundment fishery also declines. Consequently, the number of anglers using the impoundment and the benefits they bring to local areas also declines (Anderson 2001, Gregg and Rolfe 2013). As Australia's population grows, more pressure will be placed upon impoundment fisheries and early intervention is the most cost-effective strategy to develop and maintain fisheries productivity.

In waterbodies that lack natural structures, the addition of habitat has long been an established technique used by fisheries managers to concentrate and increase fish harvest (Pardue and Nielsen 1979, Wege and Anderson 1979, Johnson *et al.* 1988, Bolding *et al.* 2004, Miranda 2017). Fish are rarely randomly distributed around an impoundment. Many iconic angling species, such as Barramundi and Murray Cod, have a strong affinity towards structural aquatic habitat (Allen *et al.* 2003). Strategically improving the quantity and quality of structural habitat in an impoundment can be expected to create aggregation points for prey species and ambush locations for predators. This has the potential to improve fishing in and around these sites and create new fishing hotspots.

Improving structural habitat could also help sustain or even increase an impoundment's carrying capacity, especially for highly territorial species, such as Murray Cod.

Use of fish attractors overseas and their potential for Australian impoundments

Fishermen have practised aquatic habitat enhancement around the world for thousands of years. They realised that fish are captured more readily near structures such as rocks, reefs, fallen trees and floating debris, than in areas devoid of such structures. Artisanal fishers placed structures in waterways to attract fish and improve fishing efficiency (Seaman and Sprague 1991, Jensen *et al.* 2000, Bolding *et al.* 2004). Habitat enhancement to improve fisheries is still commonly practiced around the world today, particularly in the marine environment. Enhancement and restoration work has also been undertaken in freshwater systems, but this has mostly focussed on habitat in lotic rather than lentic waters. Fisheries habitat enhancement has less commonly been undertaken in reservoirs and lakes, but this trend is changing.

There is a convincing body of evidence from the USA that habitat enhancement in impoundments positively influences their fisheries (Norris 2016, Miranda 2017). Reservoir habitat enhancement has been occurring for more than 80 years in the USA to counter declining fisheries from reservoir degradation and is utilised in some form by almost all USA state fisheries agencies (Brown 1986, Tugend *et al.* 2002). Different strategies have been used in different states and across a wide range of scenarios. Some states have focused on installing habitat for fish attraction whilst others have aimed to increase reservoir productivity (Norris 2016). Both approaches have the potential for large-scale benefits to anglers and can be undertaken independently or in conjunction with each other.

The recreational fishery in many USA dams has been significantly improved, or even completely revitalised through the strategic use of fish habitat enhancement techniques. This has led to significant improvements in the number of tourists visiting or utilizing these impoundments and resulted in flow on benefits to the local communities (Norris 2016).

The best researched and reported impoundment habitat enhancement has occurred in the USA. A wide range of different approaches have been employed to improve habitat complexity in USA reservoirs and lakes (Miranda 2017). The objective of the habitat enhancement is generally to replicate the ecosystem functions of natural habitat utilised by fish in less disturbed environments (Bolding *et al.* 2004). Habitat enhancement can be used to aggregate fish, provide more food, increase growth rates, improve reproductive success, improve juvenile survival and recruitment, provide protection from predators and improve water quality (Miranda 2017). Habitat enhancement can also be used to attract fish to specific areas, to increase the likelihood of anglers catching fish and direct angler pressure to specific areas of the dams. This is best accomplished in structure-limited waters where the fish community is spread out (Prince and Maughan 1978). Water managers may benefit by passively keeping anglers out of closed areas or reducing interactions between different water user groups. Attracting fish to nearshore areas and within casting range of jetties and pontoon structures can also improve fishing for shore-bound or mobility limited anglers.

Several large, decadal-long projects have effectively used habitat enhancement to improve or in some cases even completely revitalise failing impoundment fisheries (e.g., Anderson 2001, Allen *et al.* 2014). These large multi-agency and sometimes multi-jurisdictional projects have attempted to address declining impoundment productivity, carrying capacity, natural fish recruitment and angler satisfaction. A combination of watershed management, installation of spawning habitat and the use of structural habitat as fish attractors were all fundamental components of these projects being successful.

One of the key questions regarding fisheries habitat enhancement is how effective different structures are at attracting fish or improving impoundment productivity factors. The principal role of most installed habitat structures is to concentrate fish to increase anglers' catch rates. The consensus in the USA was that in the absence of other habitat, all fish habitat structures will attract fish, but the relative effectiveness will vary between structure types and fish species (Norris 2016). There is a lack of data directly comparing the effectiveness of most habitat structure types. Habitat structures are frequently installed in mixed arrays and surveys of the fish response are not at a fine enough scale to identify the contributions of each structure type.

The use of synthetic materials to construct habitat structures has become far more common as waterway managers worry about the impacts on water quality from decomposing organic materials. It is well accepted that habitat structures made from synthetic materials are more durable than those made from brush and timber. However, it is less clear whether the synthetic structures are as effective at attracting fish compared to intact natural material structures. Research results and opinions are still divided on the issue.

Research and knowledge on structural enhancement of impoundments to improve fisheries is in its infancy in Australia, but many valuable lessons can be learned from overseas results. In Australia most of the impoundments are younger and less degraded than those in the USA and therefore we currently face fewer issues to address to improve Australian impoundment fisheries. Additionally, since most recreationally targeted fish species won't spawn in impoundments and the fisheries are supported by stocking, spawning habitat requirements are not a primary focus.

Not all Australian impoundment fisheries are of equal quality, and those recognised for great fishing typically have high-quality, structurally complex habitat present. Strategically installing complex structural habitat to attract and aggregate fish to make them easier to target for anglers has the potential to improve recreational fishing experiences. When adding habitat to an impoundment, the goal is to find the most cost effective and durable construction materials. A vast range of materials, designs, and deployment strategies have been used for installing habitat for fish in impoundments outside of Australia with varying degrees of success. Many of these could be suitable for use in Australian impoundments, so information on the most cost-effective fish attraction options for stocked Australian fish species is required.

Need

To maximise the economic potential of impoundment fisheries it is important to improve the reliability and quality of fishing to attract repeat visits by anglers and to increase visitation rates. Whilst impoundment fisheries are well established in Australia, the quality of the fishery and the associated angler satisfaction with fishing vary significantly between locations. One of the key differences between impoundments with good-quality and poor-quality fishing, is often the quality and extent of structural fish habitat. The fishery in many USA dams has been significantly improved, or even completely revitalised through strategic use of fish attracting structures and this approach has become a primary tool for fisheries managers. The outcomes of such projects have often resulted in significant increases in the number of angling tourists visiting or utilising these impoundments and led to flow-on socio-economic benefits to local communities (Anderson 2001, Norris 2016). Habitat enhancement through the installation of fish attracting structures has broadscale potential to improve recreational fishing in Australian impoundments as well, but this approach has never been undertaken or evaluated at the impoundment scale. Critical information on fish attractor design, construction, placement, durability and effectiveness needs to be determined before the technique can be widely implemented in a cost-effective manner.

Many fish stocking groups and management agencies are looking for ways to enhance their impoundment fisheries through means other than just stocking fish. During periods of low water, the stocking rates in some dams are greatly reduced or even halted. Alternative methods for enhancing the fishery would enable these groups to continue to develop the quality of their impoundment fishery during such times. Regulations on how funding in Queensland's Stocked Impoundment Permit

Scheme can be spent have recently changed to include habitat enhancement, but clear information and guidelines need to be developed. Fisheries managers see development of such best-practice guidelines as critical for widespread use of fish attractors to occur.

Waterway operators have expressed some reservations on the safety of enhancing impoundment fisheries via habitat enhancement and the installation of fish attracting structures. If installed incorrectly, habitat structures have the potential to shift during flow events and potentially damage important infrastructure. Structures placed in inappropriate locations could also pose a strike risk for boaters, water-skiers and other waterway users. The use of inappropriate construction materials or illegal dumping could also pose a potential risk to dam water quality and the cost of water treatment. Clear guidelines outlining suitable fish attractor designs, materials and deployment locations will minimise any such risk and have been requested by several of the key impoundment operators in Queensland (Seqwater and Sunwater) before fish attractors can be more widely used.

The downturn in the mining boom in regional Queensland, has led local governments to look to tourism to help generate business opportunities in their communities. A number of regional councils have identified recreational fishing as a means of attracting visitors to their shire. For sustained inflow of anglers, these regions need to offer dependable, high-quality fishing and easy access to the fishery resource. These regional areas have stocked impoundment fisheries which have the potential to achieve this, but sometimes these impoundments can prove difficult to fish for casual or visiting fishers. One potential reason for this is a lack of suitable habitat structure to attract and aggregate fish in areas where anglers can target them. Often the best fish habitat occurs around the dam walls and other water infrastructure. Fish are frequently found at these sites, but anglers are generally forbidden to fish there due to safety concerns and protection of the infrastructure. Additionally, some dams have only limited shore access for anglers, but these areas do not always correspond with good quality habitat where fish are likely to be found. Consequently, catch rates can be poor for shore-bound anglers, discouraging repeat visitation. The lack of structural habitat in many impoundments also means boat anglers often need to cover extensive distances to locate fish. Anglers new to an area or inexperienced anglers can have difficulty locating good fishing spots. Providing structural habitat through the installation of fish attractors and advertising their position can help such anglers more readily locate and catch fish and thus have a better fishing experience.

Objectives

1. Evaluate the ability of three broad groups of fish attracting structures (timber, synthetic and suspended) to attract a range of native fish species in impoundments.
2. Evaluate the impacts of FAS installation on angler catch rates and angler satisfaction rates.
3. Evaluate the impact of FAS installation on angler visitation rates.
4. Develop best practice guidelines for installation of FAS in Australian impoundments.

Enhancing structural complexity in Cressbrook Dam with fish attracting structures

This section of the report outlines the activities undertaken to enhance the structural complexity in Cressbrook Dam to enable evaluation of the value of the fish attractors. The steps outlined provided the blueprint for all subsequent activities and enabled the necessary approvals to be obtained and stakeholder engagement to occur. Detailed descriptions of the specific monitoring and evaluation processes and results are contained in subsequent chapters.

Cressbrook Dam

Cressbrook Dam was selected as the study site because there was strong support from the local community and local government to improve the quality of the fishery in the impoundment. Toowoomba Regional Council (TRC) was keen to improve recreational fishing to further develop tourism in the region and co-invested in the project. The local fish stocking group was also eager to improve the quality of fishing at this impoundment and explore alternative approaches to achieving this rather than solely through stocking fish.

Cressbrook Dam (27°15'28.9"S 152°11'48.6"E) is located on Cressbrook Creek an upper tributary of the Brisbane River, 43 km north-east of Toowoomba, Queensland (Figure 1). The dam is managed by TRC and was originally constructed in 1983 for town water supply. The 363 m long dam wall consists of a zoned earth fill embankment with a central clay core and contains an un-gated overflow spillway controlled by an ogee crest with open channel chute and flip bucket (TRC 2017). At full storage capacity (280 m AHD) the dam holds 81,800 ML and covers 517 ha. The dam has a catchment area of 326 km^2 consisting of moderately undulating country varying from patches of rainforest to lightly timbered, with some land originally cleared for dairy farming. During construction the dam basin was cleared of timber prior to filling (TRC 2017).

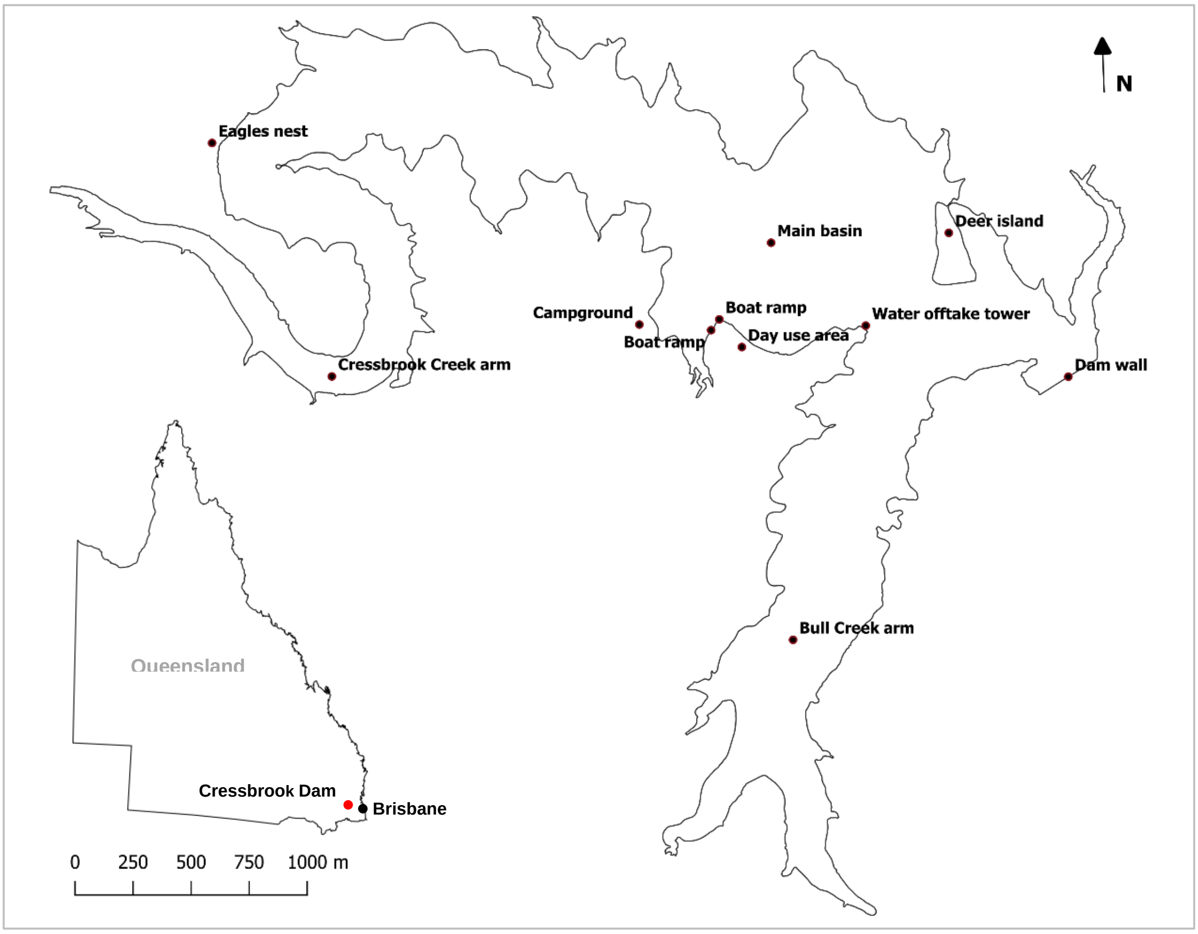


Figure 1 The main features of Cressbrook Dam

The hydrograph of Cressbrook Dam is dominated by flood-fill events. The dam typically only fills during significant flood events, followed by a steady decline in water level until the next major inflow (see Appendix 3 for more details). Historically in non-flood years the annual decline in water level has been approximately 2 m per year. Cressbrook Dam has had a long-term average useable storage volume of 71.8% of its full capacity, but there is high variability around this figure. The lowest storage volume recorded was 7.5% in February 2010 during the record decade-long drought. At commencement of the project, the dam was at 272.5 m AHD or approximately 54% storage capacity. Dam water levels then slowly declined until reaching approximately 35% storage capacity. At this point the connection to Wivenhoe Dam was activated and water was pumped in to slow the drop in supply capacity and maintain water levels above 30% supply capacity (Figure 2). By the end of the project the supply capacity had declined to 31.2%.

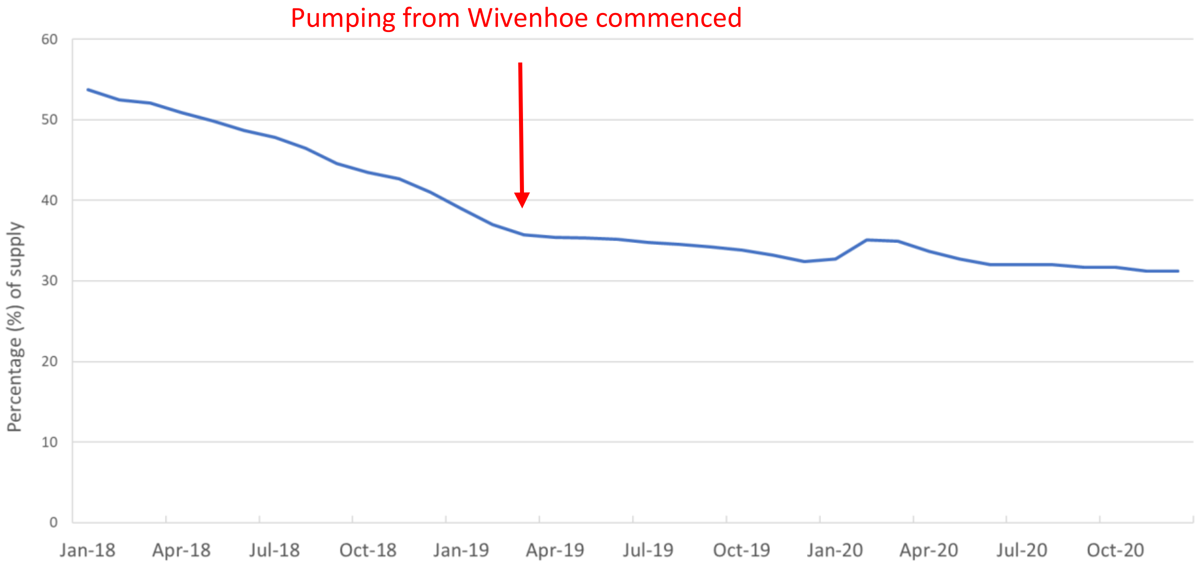


Figure 2 Cressbrook Dam water levels during the project period. Note the slowing of the decline in March 2019 when water began being pumped in from Wivenhoe Dam to top up supply capacity.

Although constructed for water supply, Cressbrook Dam is now also used for a range of recreational activities. A campground containing 30 sites is located on the shores of the lake to the west of the day use area and boat ramps. Fishing, boating, canoeing and sailing are all permitted on the dam, but swimming is prohibited. Outboard motors are permitted, however, under local law, boat speeds must be confined to 4 knots inshore and 8 knots offshore.

Cressbrook Dam contains a range of stocked and resident angling species (Australian Bass *Macquaria novemaculeata*, Golden Perch *Macquaria ambigua*, Silver Perch *Bidyanus*, Freshwater Catfish, *Tandanus,* Mary River Cod *Maccullochella mariensis*, Snub-nosed Garfish *Arrhamphus sclerolepis* and Saratoga *Scleropages leichardti*), but complex fish habitat is limited. It has long been recognised that poor-quality habitat has restricted the development of the fishery in this impoundment. Shore access is limited to a few locations and the quality of fish habitat is generally poor at these sites. The boat speed restrictions greatly reduced the navigational risk posed by installing habitat structures in an impoundment with fluctuating water levels. Cressbrook Dam therefore represented a great location to investigate whether fishing quality and angler visitation rates could be improved through strategic placement of fish attracting structures. The strong support from other fish stocking groups, key impoundment operators (Seqwater and Sunwater) and various regional councils, indicated it was highly likely that the findings from this research will lead to widespread uptake around Queensland.

Figure 3 The two primary targets for recreational fishing in Cressbrook Dam: a) Australian Bass and b) Golden Perch

Baseline surveys and data collection

Baseline surveys provided detailed information on the status of the impoundment prior to the commencement of enhancement activities and formed the basis against which the success of a project's objectives could be determined. Baseline surveys also provided data to identify the remedial actions necessary to achieve the project objectives. For example, if the baseline survey identified significant amounts of existing structural fish habitat, then it is unlikely that the addition of further similar habitat will have a significant impact. Conversely if structural habitat was limited, then the installation of this habitat type could be a priority.

The first phase of the project was to establish baseline data on the pre-existing habitat and fish distributions in Cressbrook Dam. This data was used with stakeholders to develop the Fish Attraction Plan and a monitoring and evaluation program prior to on-ground works commencing. A brief summary of baseline survey activities and results is contained below. The full details can be found in the Cressbrook Creek Fish Attraction Plan in Appendix 3.

A side-scan sonar survey was conducted by DAF on 15-18 January 2018 to map the bathymetry and assess existing fish habitat. A boat mounted Lowrance HDS 9 sonar unit using a Total Scan transducer set at 800 kHz was used to scan the entire impoundment. Side-scan transects were conducted at a boat speed <4 knots to ensure good image quality. Transect spacing ranged between 5 m and 20 m depending upon water depth and obstacles. The sonar data was examined using ReefMaster software (version 2.0.34.0, ReefMaster Software Ltd., West Sussex, UK) to develop a bathymetric profile for the impoundment. The side-scan data was also examined to detect all existing structural habitat complexity, such as submerged trees, sunken logs or boulders. These habitat features were classified and catalogued, and their positions recorded.

The sonar survey was conducted with the water level at 272.5 m AHD or approximately 54% storage capacity. The maximum observed depth in the impoundment during the survey was 36.0 m. The dam's habitat was found to be dominated by silt and gravel flats leading into deep rock ledges along the old creek channels (Figure 4). The dam also had a number of small steep bays that contained channels which frequently descended into deep water. The sonar survey was completed in summer and the thermocline was located between 5-6 m depth across most of the dam but was slightly shallower (4 m) in the Cressbrook Creek arm.

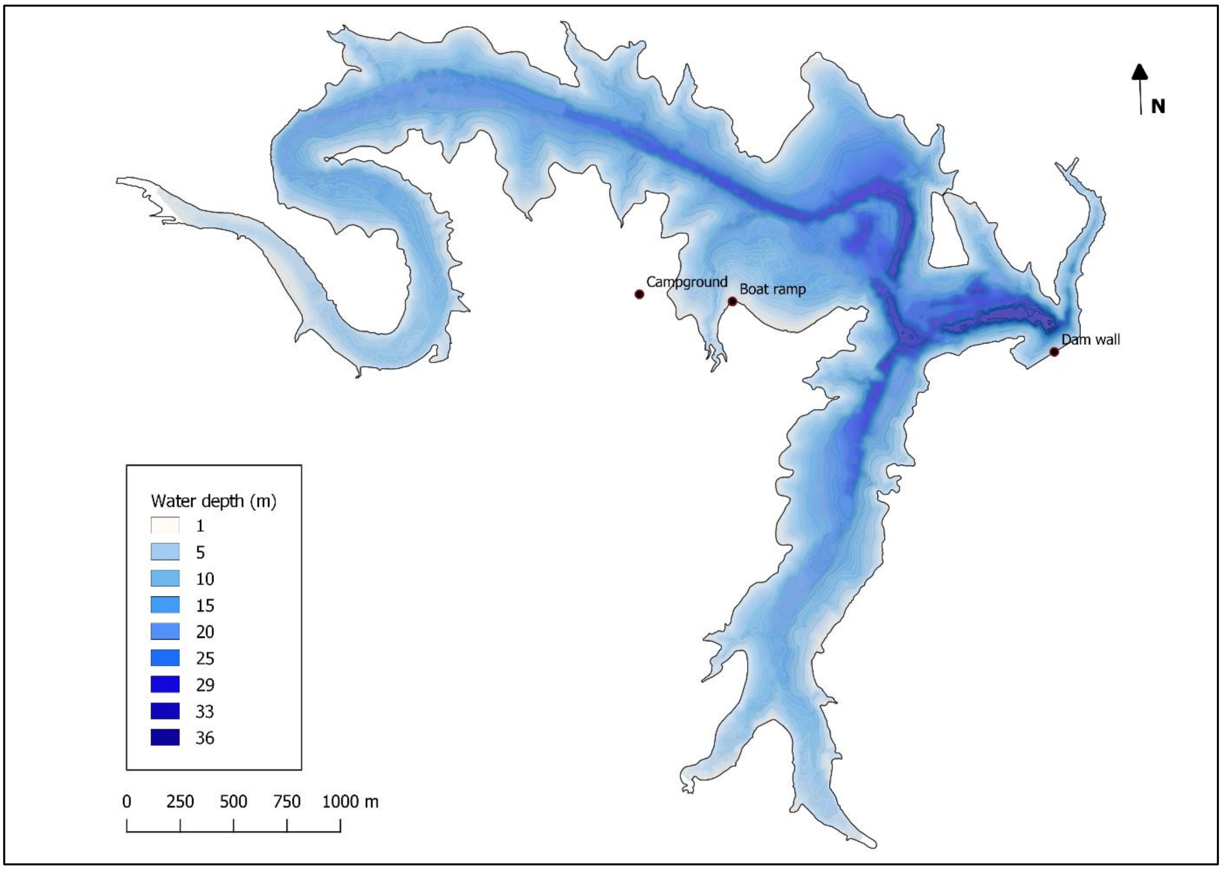


Figure 4 The bathymetric profile of Cressbrook Dam at a water level of 272.5 m AHD.

Marginal submerged macrophyte growth in Cressbrook Dam was dense to around 2 metres depth around much of the dam shoreline, with more scattered vegetation extending to 5 metres depth in parts. Simple tree trunks and logs were present in the vicinity of both major feeder creeks (Little Oaky Creek and Cressbrook Creek) and appear to have washed down during major flow events. However, these logs lacked structural complexity (no branching or apparent root balls) and were likely to offer little habitat value for most fish species. Only a few submerged trees with complex branching were observed. Small dead shrubs were also present along the margins down to 5 m in several sections of the dam, most notably along the steeper banks and points near the wall. These small shrubs offered some habitat complexity for fish, especially when they were in clusters.

The best fish habitat occurred in the Gorge to the north of the dam wall. This area is closed to public access. The steep rocky walls here extended into the relatively deep water and a marginal row of dead shrubs occurred along most of the shoreline in 1-3 m depth. There were numerous rocks, large boulders and rock crevices for predatory fish to utilize, as well as several complex fallen trees and large branches. Good quality fish habitat was also found along several steep rock walls and drop-offs in the Cressbrook Creek arm.

Electrofishing surveys were conducted at 27 sites around the impoundment between 29 January and 6 February 2018 to investigate the baseline distribution of fish. Standardised electrofishing procedures were used throughout this project to ensure data comparability. The electrofishing procedures are outlined in detail in Chapter 4. A total of 38 individual fish from recreationally targeted species were caught across all survey sites during the electrofishing survey, with the greatest number captured from the Gorge Reference site. Freshwater Catfish were the most abundant recreational fish species, followed by Australian Bass and Golden Perch. No clear aggregation points were detected in the baseline survey, but most fish were captured adjacent to areas with more complex local habitat (e.g., rocky points, remnant shrubs, boulders or aquatic vegetation). A range of prey fish species were broadly distributed around the impoundment, with no specific aggregation points observed.

Development of a Fish Attraction Plan

Robust planning and consultation are key aspects to successful large-scale habitat enhancement or restoration projects (Standards Reference Group SERA 2017). A clear process is even more essential when undertaking activities in aquatic environments, where unforeseen adverse events could have significant financial, ecological and social impacts. Most impoundment managers and engineers have historically been reluctant to permit the introduction of fish habitat into their waterways due to the perceived risks posed by water contamination, collision or damage to dam infrastructure. However, with robust planning these risks can be minimised or eliminated altogether.

A strategic Fish Attraction Plan (FAP) for Cressbrook Dam was developed in conjunction with key stakeholders (Appendix 3). The FAP outlined the goals of the project, identified potential risks and mitigation strategies, and provided a blueprint for all on-ground works, research and monitoring. Information from the baseline surveys of fish distributions and existing habitat were combined with hydrological data, research objectives, long-term goals and stakeholder input to create a robust framework to trial FAS in Cressbrook Dam and provide long-term fishery benefits. The number, type and location of FAS were determined in consultation with local anglers and the waterway managers, to ensure the needs of all parties were considered. All FAS were located out of the main creek channels to ensure they would not shift during major inflow events and potentially impact dam infrastructure or operations. This approach enabled compliance with the local management policies. The majority of FAS were located in bays and around points to enable monitoring and evaluation to occur, whilst still providing potential opportunities for anglers to use and benefit from their installation in the longer term.

Consultation was a core component of the FAP development. A broad range of stakeholders were consulted. The primary stakeholders for Cressbrook Dam included Toowoomba Regional Council (TRC) (co-investors and waterway and campground managers), Toowoomba and District Fish Stocking Association (TDFSA) (co-investors and local fish stocking and angling group), Fisheries Research and Development Corporation (co-investors) and the Department of Agriculture and Fisheries (co-investors, manage fish stocking, stocked impoundment permits and research). The low boat speed restrictions (<8 knots) in the dam mean that water skiing and wakeboarding is not permitted and thus these groups were not key stakeholders, as they may be in other impoundments. Anglers provided biologists with insight about the locations fish could already be found and areas where habitat could improve fish holding ability. Anglers also provided guidance related to the orientation, types of materials, and depths at which habitat would be most effective. A project steering committee was established to guide project progress, encompass the views of stakeholders and to provide an avenue for information dissemination. The steering committee contained members from all the key stakeholder groups plus a representative from a large Queensland impoundment operator (Seqwater) and a representative from external fish stocking groups interested in employing FAS.

The FAP provided details on the exact type and location of every FAS to be constructed and installed. One key aim of the project was to evaluate the relative durability and effectiveness of three different groups of FAS: timber and brush construction (installed on the bottom substrate), synthetic construction (also installed on the bottom substrate) and surface suspended synthetic structures. The FAP took the experimental design into consideration and outlined the monitoring and evaluation strategy. A project risk assessment was undertaken as part of the FAP process before approval was sought and received from the impoundment operator. This occurred prior to any construction and deployment work commencing.

Originally the FAP recommended that a total of 733 FAS be installed at 26 sites around Cressbrook Dam. This was comprised of 216 brush bundles, 188 synthetic spiders, 147 synthetic trees, 81 suspended FAS, 57 timber cribs and 44 Georgia cubes. The FAP was revised in 2019 due to the continuing low water levels, potential crowding with the suspended FAS and difficulty in sourcing sufficient timber for the cribs and brush bundles (Figure 5). The total number of FAS was reduced to 576, across 25 sites, and included 182 synthetic spiders, 142 synthetic trees, 130 brush bundles, 44 Georgia cubes, 39 timber cribs, 26 suspended FAS and 13 branch bundles (oversized brush bundles).

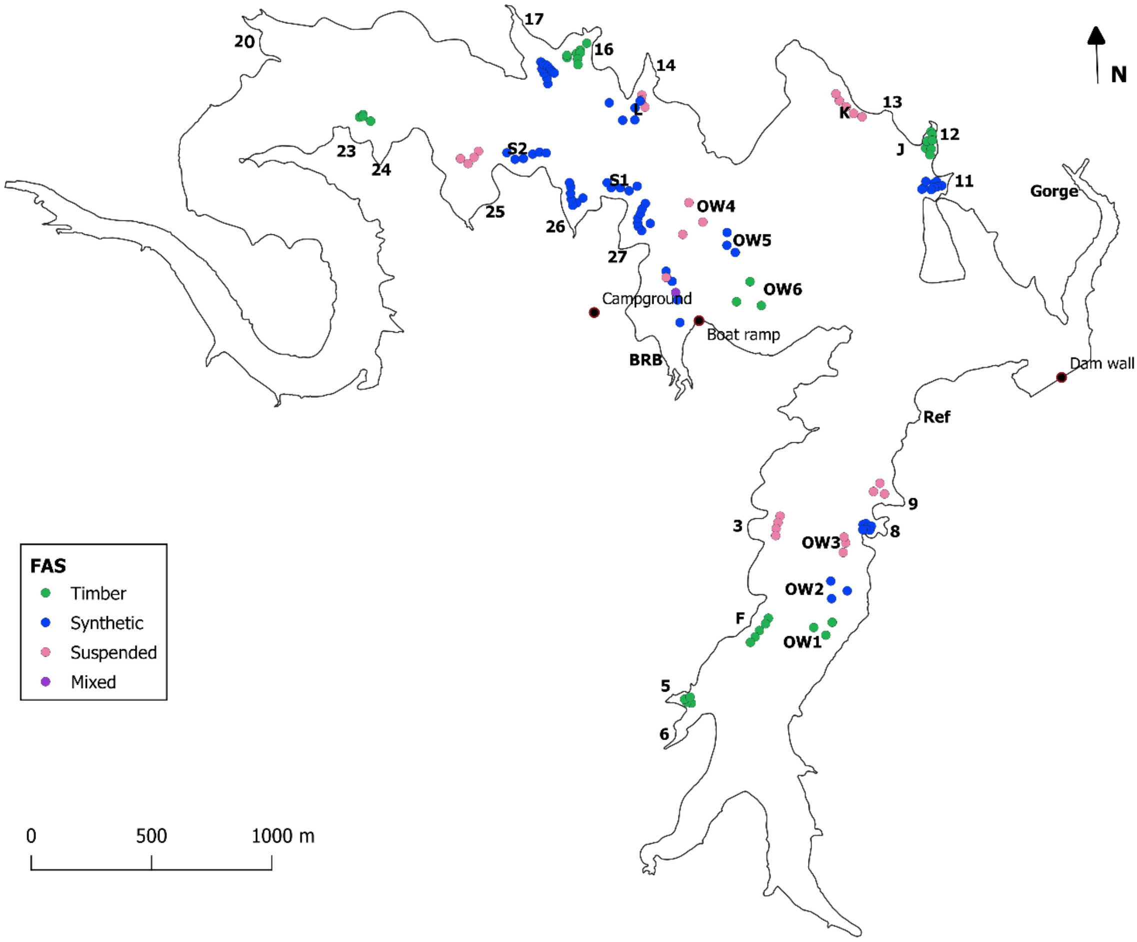


Figure 5 Map from the FAP of the final FAS cluster locations in Cressbrook Dam. The labels designate the bay (number), point (letter) or open water (OW) site names.

Monitoring and evaluation

The use of habitat enhancement to manage impoundment fisheries is not a new science; however, the outcomes of intervention activities often remain unclear. Knowledge on the benefits habitat enhancement provides under various conditions is essential for developing workable management strategies. Monitoring the impacts of habitat enhancement activities is vital to determine if project objectives are being met, as well as providing valuable information for optimising future endeavours. The suite of factors monitored should be guided by the specific project objectives, identified knowledge gaps and available resources. Monitoring should not be restricted to the biological system, but also include angler data, structure condition, economic response and social impacts.

Overseas experience has demonstrated that monitoring the fish and fishery response to the installation of fish attractors at the impoundment scale can be difficult (Jacobson and Koch 2008, Allen *et al.* 2014, Norris 2016, Miranda 2017). Few studies have had clear success using individual evaluation methodologies. To overcome these sampling difficulties, we employed a combination of methods to generate multiple lines of evidence and provide a more comprehensive picture of responses to the installation of FAS. Trends across all monitoring processes were considered collectively to evaluate wholistic changes generated by the installation of FAS. This was important when individual methods may have shown statistically insignificant trends or only marginal changes.

The project objectives included evaluation of the response of both fish and anglers to the installation of FAS. The monitoring and evaluation methodology was therefore divided into two groups to address these two themes.

Evaluation of the impacts of FAS installation on fish distributions was primarily undertaken using twice yearly electrofishing surveys and acoustic fish tracking. Sonar imagery and underwater videos were also utilised to supplement this data. These techniques and the results of the monitoring are described in Chapter 4.

A modified MBACI (multiple-before-after-control-intervention) model was employed to investigate changes in fish habitat preferences and distribution following FAS installation. Fish distributions were compared between FAS enhanced zones; Control, un-enhanced zones; and Reference sites with good existing habitat. To facilitate this model, 24 monitoring sites were established around the impoundment. Monitoring sites were grouped in clusters of four, where each site in a cluster contained similar geomorphology. The clusters were described as Bays, Steep bays, Long bays and Points (Table 1). Each cluster contained a Control site and one example of each FAS grouping (suspended, synthetic, timber). Two Reference sites with good quality existing habitat and two independent sites were also monitored.

Table 1 Design of the structured monitoring and evaluation program

Cluster	Site name	FAS type
Bays	Bay 3	Suspended
	Bay 5	Timber
	Bay 6	Control
	Bay 8	Synthetic
Steep bays	Bay 9	Suspended
	Bay 11	Synthetic
	Bay 12	Timber
	Bay 13	Control
Open bays	Bay 23	Timber
	Bay 24	Control
	Bay 25	Suspended
	Bay 27	Synthetic
Long bays	Bay 14	Suspended
	Bay 16	Synthetic
	Bay 17	Timber
	Bay 20	Control
Points	Point F	Timber
	Point J	Control
	Point K	Suspended
	Point L	Synthetic
Other sites	Ref Bay	Control
	Gorge	Control
	Boat ramp bay	Synthetic
	Bay 26	Synthetic

It is also important to monitor the condition of the habitat enhancement structures that have been deployed to determine whether they need maintenance or replacement. Structures made from brush and timber degrade over time and monitoring their condition will inform when replenishment or replacement is necessary to maintain their attractiveness to fish. Accurate condition assessment will enable the habitat in an impoundment to be managed most cost-effectively. Synthetic structures are less likely to deteriorate over time, but monitoring helps identify structures which are damaged or missing. Sonar and underwater cameras were employed to monitor the condition of the FAS. Details of these methods and the results of the monitoring are outlined in Chapter 4.

Directly measuring changes in the distribution of the fish community is often difficult and the results may be inconclusive. However, the management objectives of most impoundment habitat enhancement projects normally include improvements in angler catch and satisfaction. Changes in these can be readily assessed using angler creel surveys. This information has frequently been used to identify direct benefits to anglers and validate the costs of habitat enhancement projects (Miranda 2017)

At Cressbrook Dam, the impacts of FAS on angler attitudes, catch and fishing effort were important to capture. These parameters help understand the cost effectiveness of installing FAS, return on investment via tourism for councils looking to invest in FAS, and community satisfaction with FAS as an impoundment fishery management tool. Quarterly targeted angling surveys, monthly creel surveys and daily boat counts were employed to evaluate changes in these parameters after FAS were installed, using a BACI design. The targeted angling surveys used the same experimental design and monitoring sites as the electrofishing surveys. Details of the methodologies employed, and the results of the evaluations are reported in Chapter 5.

FAS designs, construction and deployment

USA fisheries managers have been using habitat enhancement structures in their lakes and reservoirs for more 80 years (Brown 1986, Tugend *et al.* 2002). During this period a significant body of evidence has been accumulated on successful and unsuccessful habitat enhancement structure designs (Miranda 2017). As knowledge in the field grows, more specialist habitats are being created to service specific needs of some species. This Chapter outlines the FAS types selected, their construction details and rational behind inclusion.

Historically the materials used for impoundment habitat enhancement were largely materials that were convenient, affordable, and readily available. Common habitat structure materials have included concrete, rock, limestone, steel, plastics, ceramics, wood, brush and PVC pipes (Houser 2007, Miranda 2017). Materials are selected based on durability, resistance to corrosion, and structure complexity. Further considerations include degradation of structures over time and any potential leaching effects that lead to harmful changes in the environment. Initial habitat enhancement was undertaken overseas using whatever materials were on hand. Potentially toxic structures such as old vessels, car bodies and tyre reefs were used to create artificial reefs. These materials can leach petrochemicals into the water and were an eyesore when water levels fluctuated (Birkholz *et al.* 2003, Derbyshire 2006). Other harmful materials include polystyrene, which is hazardous to fish from ingestion as it breaks down over time, and treated wood including creosote and copper naphthenate that can leach harmful chemicals into the water (Lukens and Selberg 2004, Derbyshire 2006). As environmental awareness increased and the use of such materials was banned, their installation ceased (Miranda 2017). Early application of FAS in the USA also focussed on the installation of recycled pine Christmas trees or cedar trees felled from lake shorelines. These natural materials were cheap and readily available but have limited lifespans due to deterioration (Allen *et al.* 2014, Miranda 2017). Larger whole trees or hardwood treetops appear to provide an acceptable combination between complex interstitial spaces and durability, but can be difficult to deploy and may require specialised equipment (Allen *et al.* 2014). Despite these limitations, the installation of whole trees and brush still forms the backbone of habitat enhancement projects in many impoundments across the USA.

Natural timber materials have been found to quickly develop algae and periphyton growth and attract a wide size range of fish (Allen *et al*. 2014, Jacobson and Koch 2008). The fine interstitial spaces between branches provide complex cover for smaller fish and prey species. These in turn attract the larger predatory species targeted by recreational anglers. Engineered or more complex timber designs have become increasingly common as fisheries managers sought ways to increase FAS longevity, struggled to find sufficient trees to fell, and to aimed to minimise potential impacts to water quality. Timber cribs have been found to be an effective habitat structure that can be easily constructed. Cribs last much longer than the finer branches from many trees and are now widely used in the USA (Houser 2007).

In some USA states, fisheries managers have shifted their efforts towards constructing FAS from synthetic materials such as PVC or polyethylene (Norris 2016). These structures have become increasingly popular for use in town water supplies or waterbodies with hydro-electric power stations, where they minimise the risk of debris becoming entrained in the turbine intakes. Decomposing organic material can react with the chlorination process for drinking water, creating trihalomethanes (Ferger and Spear 2010). Thus, structures made from old Christmas trees, brush or other organic materials may not be suitable for use in some drinking water reservoirs. Synthetic materials can be used to create structures with complex designs that are inert, relatively cheap, light weight, modular and extremely durable. Several companies commercially produce FAS in the USA, all of which are constructed with synthetic materials. With the incorporation of UV stabilisers, it has been suggested that synthetic structures should have a lifespan between 30 and 100 years if constructed correctly (Jones *et al.* 2015).

Very little research has been conducted on floating or suspended FAS. This style of fish attractor has commonly been used in marine applications for many decades to attract pelagic fish by providing structure in otherwise featureless waters. In the USA, many of the bass species targeted by anglers occur around piers, boathouses, boat ramp pontoons and floating wave attenuation structures (Clady *et al.* 1979, Norris 2016). Floating vegetation beds installed to improve water quality and provide bird habitat have also been found to be effective at attracting fish (Suresh 2000, Seo *et al.* 2013). However, floating structures appear to have rarely been installed with the specific intention of attracting fish to improve angling.

The use of FAS in impoundments has received limited research under Australian environmental conditions for Australian fish species. The little previous work undertaken has used large-scale riverine habitat enhancement techniques such as fish hotels or log piles (Norris 2016). Therefore, a range of FAS that have proven effective in the USA for warm-water sports fish species, which occupy similar ecological niches and display similar behavioural traits, were selected for trials in Cressbrook Dam. One of the key stakeholders interested in adoption of the use of FAS were the local fish stocking groups. These groups frequently have plenty of passion and drive, but often only limited funds and access to heavy machinery. To assist uptake and adoption, all the FAS trialled in Cressbrook Dam were relatively cheap, lightweight, modular structures that could be readily constructed and deployed by stocking groups.

The relative merits of natural and synthetic FAS for Australian fish species remains unknown. To gain an understanding of how fish in stocked Australian impoundments respond to FAS, structures made from both natural and synthetic materials were investigated. Both types of FAS utilised environmentally acceptable materials that will not cause harmful effects in aquatic environments. The results provide options for improving fisheries in all waterways, including those which are also primary sources for drinking water supply. Whilst most habitat enhancement structures are located on the impoundment substrate, there is also potential for suspended or floating FAS to be effective in Australian impoundments, especially where pelagic prey species such as Bony Bream or Hardyhead are prevalent. Therefore, a suspended FAS design was also included in the research framework. Suspended FAS also have the advantage of being able to be deployed such that they remain just on or above the thermocline in summer, when bottom structures could potentially be located in waters with low dissolved oxygen levels and limited use by fish.

A series of working bees were held to construct many of the FAS. The large number of FAS to be constructed and strong community support for the project, made this a cost-efficient approach to construction and provided an excellent extension opportunity. The working bees were held on-site at the TRC works depot. DAF staff provided safety briefings, technical oversight and assisted in construction. A large proportion of the volunteers were from TDFSA and the Crows Nest Fishing Club.

Timber FAS

The first group of FAS types evaluated were constructed from timber. In Cressbrook Dam two types were installed: brush bundles and timber cribs. Both structures provide a range of habitat requirements for many of the native fish stocked into Australian impoundments. They have been successfully used in river rehabilitation projects for stocked fish species (Norris 2016), are modular, easily constructed and deployed, and are good representative candidates for FAS made from natural materials.

The brush bundles consisted of parcels of branches between 2-5 m in length, tied together with polyester rope to form a complex structure. This FAS type mimics naturally deposited habitat from fallen trees and limbs and can have quite small interstitial spaces. Where possible, the materials for the brush bundles were collected from fallen hardwood branches around the impoundment's shoreline and catchment. Hardwoods are likely to provide the greatest durability and require the least anchoring to sink and hold in place. Initially collecting sufficient hardwood proved problematic due to recent extended drought conditions resulting in minimal growth and canopy structure on the trees surrounding the dam. The initial brush bundles therefore contained a mix of hardwood and medium to soft density timber, with much of the soft timber sourced off site. Care was taken to ensure that no brush was sourced from weeds or plant species potentially toxic to fish, such as oleander or tea-tree. A severe bushfire ravaged the Cressbrook Dam catchment in November 2019. Following the fire, sufficient hardwood branches were able to be collected from fallen trees and limbs. The materials for the brush bundles were transported via a trailer to a staging area near the dam shoreline where they were bundled together and had anchor weights attached. Due to a shortage of timber for building cribs, a larger form of brush bundles (branch bundles) was also used. These structures used larger, more solid branches, resulting in more open spaces, greater vertical profile, and slightly larger interstitial spaces. All up, a total of 130 brush bundles and 13 branch bundles were installed in Cressbrook Dam. The cost of materials to construct the brush and branch bundles was approximately $6.90 per unit.

The anchors used for this project were all comprised of concrete. Concrete is very dense which allows for a smaller volume of material to be used. Concrete is also made of natural materials and deteriorates very slowly; therefore, it does not negatively impact water quality. Pre-formed double-cell Besser blocks proved ideal as anchor weights. The Besser blocks weighed around 18 kg each and the hollow centres made it easy to connect them to the brush bundles (Figure 6). Several brush bundles were anchored using marine grade concrete blocks of approximately 15 kg. These concrete weights had been recycled from an old swimming enclosure and contained an inbuilt stainless-steel eyelet for attachment. Between two and three anchor weights were attached to each brush bundle, depending upon the bundle size. The anchors were attached to solid stems or branches sections to ensure they remained connected if finer branches snapped off or degraded over time.

Figure 6 A brush bundle assembled and ready to be deployed

The second timber FAS type were hardwood cribs. The design for the timber cribs was based on Porcupine Cribs developed by the Pennsylvania Fish and Boats Commission and successfully used across the USA (Houser 2007). The cribs are complex, long-lasting hardwood structures designed as refuge habitat. The cribs in Cressbrook Dam were each constructed from 48 lengths of rough-cut relatively green 1200 x 50 x 25 mm untreated native Australian hardwood (Figure 7). Initial attempts using 50 x 50 mm hardwood timber resulted in cribs that were too heavy to easily move and deploy. Pairs of the timber lengths were laid in alternate 90-degree orientations to create a crib like structure with the 50 mm profile in the vertical direction. The points of overlap between successive crib layers decreased towards the top. This gradually increased amount of overhang on each successive layer, improving habitat complexity and concentrating weight towards the structure's centre to improve stability. In the fourth row from the bottom two additional timber lengths were installed towards the middle of the layer to provide additional interior habitat complexity and points for attaching the Besser block anchors. The timber lengths were held in place at each crossover by 75 x 3.05 mm galvanised framing nails installed using an air-driven nail gun. Pilot holes were pre-drilled to prevent the timber splitting from the nails. Two lengths of heavy duty 400 kg breaking strain 19 mm UV-stabilised polypropylene packing bands were attached with galvanized steel crimps as secondary protection to ensure the nailed joints could not separate. The cribs were weighted by placing one Besser block at either end of the fourth-row cross pieces and lashing them in place with polypropylene rope. The weight of the hardwood timber and the concrete anchors caused the FAS to quickly sink on deployment. A rope looped beneath the packing bands at the top was used to ensure the cribs sank in an upright position. Once settled on the bottom the rope was pulled through to free it from the crib. The complex design should provide protection for juvenile fish and prey species, thus attracting larger fish, and also provide ambush locations for larger fish. A total of 39 timber cribs were installed in Cressbrook Dam. The cost of materials used to construct each crib was $132.75.

Figure 7 Timber cribs assembled on the deployment pontoon

Synthetic FAS

The versatility of synthetic materials means that a greater variety of synthetic FAS designs exist compared to timber structures. In the Cressbrook Dam project four of these designs were used to provide a diversity of synthetic habitat types.

The cheapest and easiest FAS to construct and deploy were synthetic spiders. The design mimics submerged shrubs and is intended primarily to create habitat in shallow water (Figure 8). The spider design is simple, consisting of lengths of flexible pipe concreted vertically into a base. In Cressbrook Dam the concrete base was moulded in round flexible buckets and weighed approximately 25 kg. The limbs consisted of 1.5 m lengths of 13-19 mm low density polyethylene pipe with 15-20 limbs used per spider. The limbs form a radial umbrella habitat around the base, providing shelter for small fish and ambush opportunities for larger predatory species. A total of 182 synthetic spiders were installed in Cressbrook Dam. The materials used to construct spiders cost $13.45 per unit.

Figure 8 Synthetic spider FAS ready for deployment

Synthetic trees were a larger FAS design which provided a greater vertical habitat profile. The synthetic trees replicated the structure provided by small upright trees which have become covered by water. In the USA, habitat structures with finer interstitial spaces have been found to attract more small fish, whilst more open structures are more effective at attracting the larger predatory fish typically targeted by anglers (Houser 2007). It has been suggested this is due to improved feeding success of the larger fish in the more open structures, since the prey find it more difficult to evade the larger fish. A slightly open density of the synthetic tree branches was chosen to provide adequate habitat for smaller fish to seek shelter, but still open enough that the larger predatory fish targeted by anglers could readily target prey. A total of 142 synthetic trees were installed in Cressbrook Dam.

The synthetic tree design used in Cressbrook Dam consisted of a 2 m long 100 mm diameter PVC pipe trunk, with 23 x 2 m long limbs made from 25 mm PVC pipe (Figure 9). The limbs were inserted transversely through the trunk in a spiralling pattern so that they protruded equally on each side. The limbs started approximately 400 mm up from the base of the trunk and continued to the top of the trunk. A 200 mm piece of 20 mm pipe was inserted across the trunk approximately 50 mm up from the lower end to secure the trunk firmly in the concrete base. The trunk was mounted in 15 L of concrete formed in a flexible 40 L round container and supported in the vertical position until the concrete had set. This created a stable 35 kg base to anchor the trees and keep them in an upright position. These structures are relatively snag free for anglers because hooks cannot penetrate or hook around the PVC. The cost of materials used to construct each synthetic tree was $70.32.

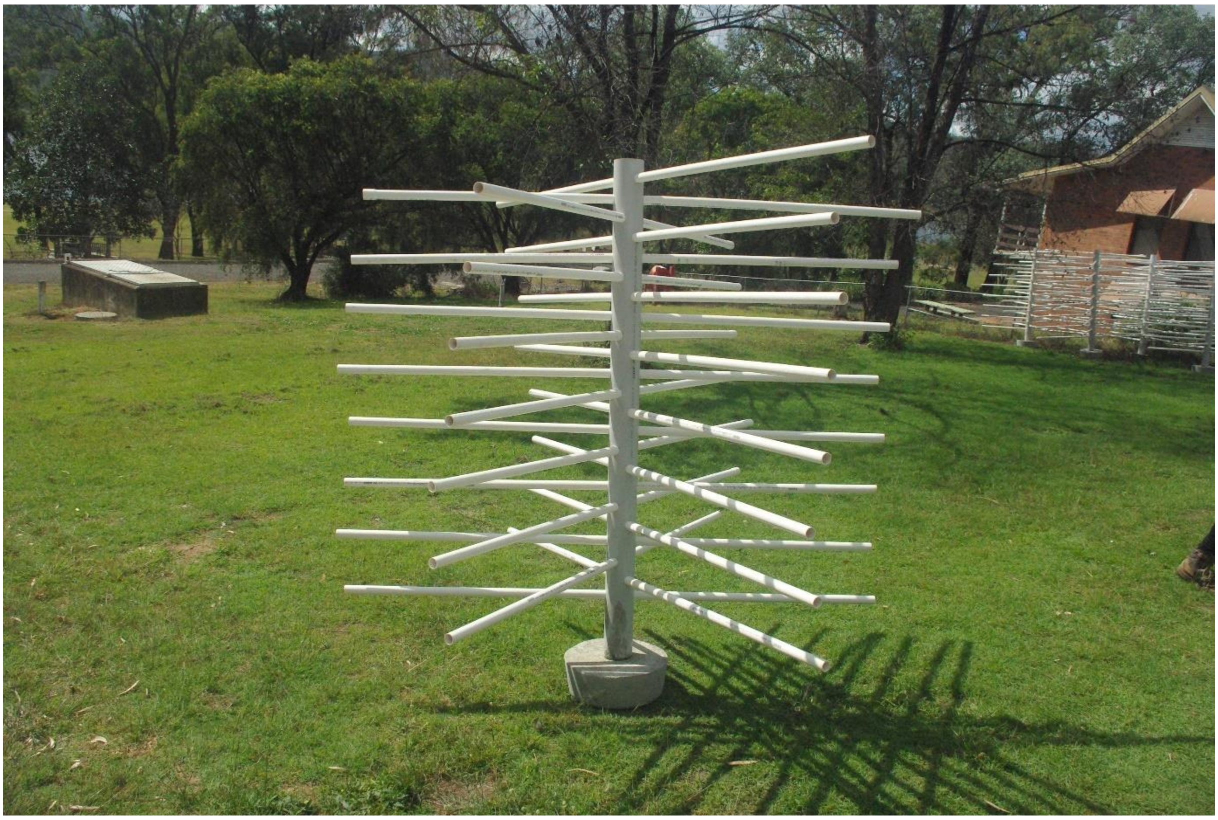


Figure 9 The synthetic tree design used in Cressbrook Dam.

The third FAS type constructed from synthetic materials were Georgia cubes. Developed by the Georgia Department of Natural Resources, each structure is a square frame made from PVC pipe upon which polyethylene corrugated drainpipe (agi-pipe) is fastened (Figure 10). Longer lasting than wood, as well as lighter and easier to transport, cubes were an innovative alternative to cribs made from timber. Georgia cubes create a complex habitat structure with a large surface area for algae and periphyton to attach to, and many crevices for both large and small fish. The design and pipe diameters used in the cubes also makes them relatively snag free for anglers. A total of 44 Georgia cubes were installed in Cressbrook Dam.

In Cressbrook Dam, the Georgia cubes were created around 1.2 m cubes constructed from 25 mm high pressure PVC pipe. Approximately 40 m of slotted corrugated drainage pipe was cut into short lengths and placed over the cube frame via holes drilled at each end. The pipe lengths were laid in alternate directions to create a complex pattern and habitat for fish. Once all the drainage pipe was used, the top frame of the cube was glued into place and holes drilled in the cube corners to enable the air inside to escape and water to enter the PVC pipe frame for additional ballast. Two Besser blocks were attached to diagonally opposite corners with polypropylene rope to sink the structure and anchor it in place. The cost of materials used to construct the Georgia cubes was $114.98 per unit.

Figure 10 Georgia cube

Suspended FAS

In Australia, the water level in many impoundments fluctuates significantly and strong thermoclines develop at certain times of the year. This combination can make the installation of FAS on the bottom substrate problematic for year-round use by fish. FAS located on the bottom substrate may become stranded as impoundment water levels fall. Alternatively, FAS may become located in a zone with decreased oxygen and reduced fish presence when strong thermoclines occur. FAS designed to be suspended in the upper portion of the water column in deeper water could prove valuable in this scenario as the habitat structures would be continuously available in the optimal zone, regardless of changes in water levels. Suspended FAS have not commonly been used. The manufacturers of several commercially produced fish attractors (e.g., Pond King Inc., Gainseville, Texas, USA) suggest their structures can be suspended beneath piers or mounted with an internal float from an anchor on the bottom. However, purposely designed and built surface-suspended FAS have not been employed in impoundments. A design was developed for suspended FAS at Cressbrook Dam because no existing options were available for evaluation.

The FAS consisted of a habitat structure hung at a fixed depth beneath a surface float and anchored in place using wire rope with sufficient length to ensure the float remained on the surface at all water levels (Figures 11-12). The habitat unit was similar to an oversized synthetic tree. This design created complex habitat, but minimised potential drag on the unit during flow events, ensuring the FAS would not shift. The structure contained a 3 m long trunk of 100 mm diameter PVC pipe, with 34 x 3 m long 25 mm diameter PVC pipe limbs inserted in a spiral pattern similar to that of a synthetic tree. The top four limbs had their ends capped watertight to assist the structure achieve only slightly negative buoyancy. A 300 mm polystyrene surface buoy was attached to the structure using 5 mm stainless wire. The wire passed through the trunk to a swivel located below a high-density polyethylene pivot plate. This plate fixed the depth of the bottom of trunk and limbs at 5 m below the surface float, typically placing the lower end near or on the thermocline in summer. A similar plate was crimped in place above the trunk to prevent the structure sliding up the wire towards the float and ensuring the top of the trunk remained 2 m below the surface and safe for navigation. The swivel was connected by 5 mm stainless steel wire to three 35 kg concrete anchors joined by chain. The length of this wire was determined specifically for each site to ensure the float would remain on the surface when the impoundment was at full supply level. The shackles used to join the chain lengths were seized shut with stainless steel fencing wire to prevent them from working loose. The cost of materials used to construct the suspended FAS was $317.71 per unit.

A total of 26 suspended FAS were installed at eight sites around Cressbrook Dam.

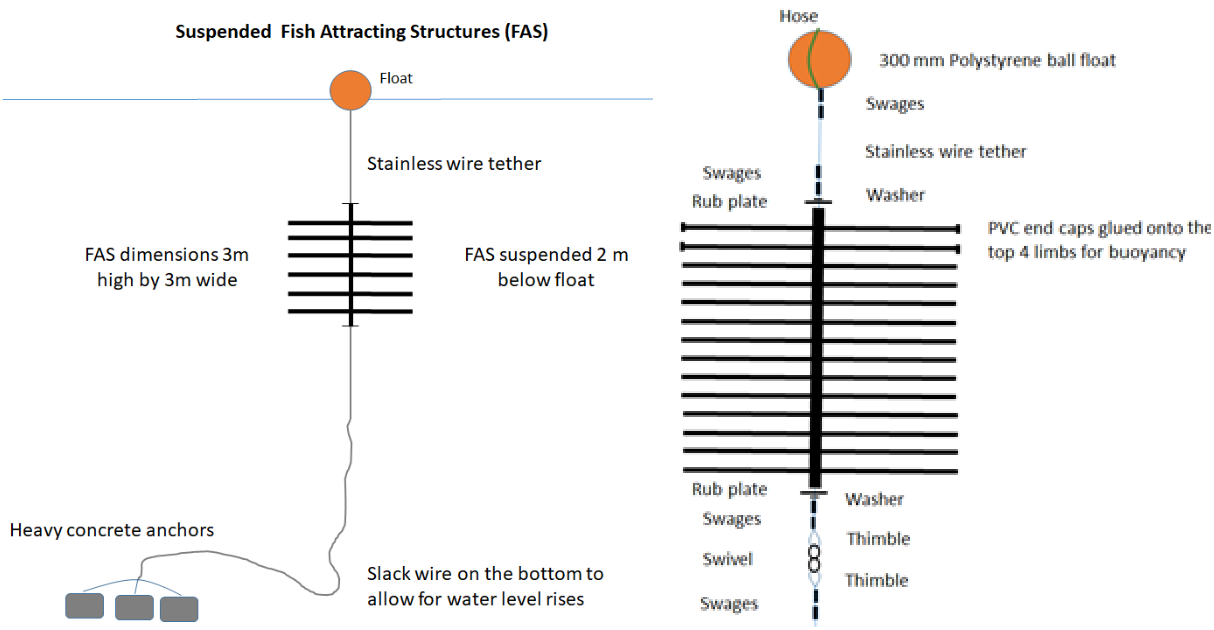


Figure 11 Suspended FAS design

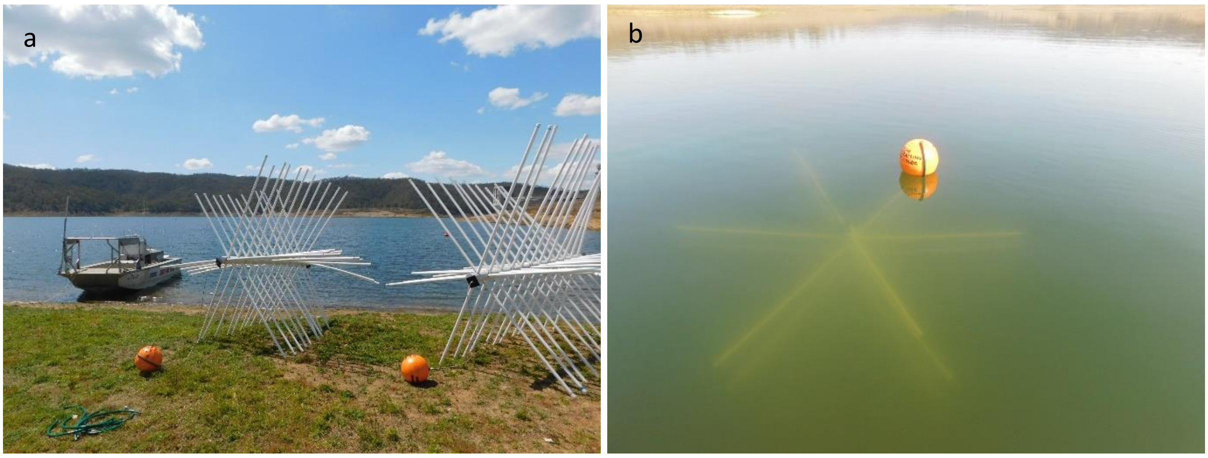


Figure 12 Suspended FAS ready for deployment (a) and installed (b).

FAS deployment

Most FAS were deployed during two main installation periods: April 2019 and November 2019. Prior to installation, FAS were transported from the construction and storage site down to the water's edge where they were staged until deployment (Figure 13). The staging sites had sufficient water depth so the vessels could be driven right to the shoreline to aid loading. Where necessary final assembly and the attachment of anchor weights was performed. Initially, the synthetic trees, spiders and brush bundles were loaded onto the gunwales and transported to their allocated installation sites. The larger cubes and suspended FAS were loaded onto the fore deck for transport and deployment. Where possible, all FAS for a cluster site were loaded at the same time to make deployment easier and ensure FAS were not deployed on top of each other. At the site, FAS were deployed off the vessel around a central point in the pattern specified in the FAP.

Figure 13 FAS staged on the shoreline awaiting deployment.

Deploying FAS directly from small vessels proved time consuming and limited the size and number of FAS that could be deployed in one trip. To expedite deployment and improve safety, a pontoon was utilised for deployments after August 2019. The pontoon was lashed securely to the side of a DAF vessel for tow and provided a large, flat and stable platform to assemble and deploy FAS from (Figure 14). A temporary plywood deck was installed on the pontoon to protect it during loading and deployment and a small ramp was employed to make loading quicker and safer. The size of the pontoon enabled brush and branch bundles to have their anchors attached once onboard, eliminating the need to carry heavy objects. Similarly, anchor weights to the timber cribs, Georgia cubes and suspended FAS were attached once they were positioned on the pontoon (Figure 15).

Figure 14 The pontoon moored to the shore awaiting loading for FAS deployment

Figure 15 The DAF crew preparing timber cribs on the pontoon for transport and deployment.

Synthetic trees, spiders, brush bundles and Georgia cubes were deployed by pushing them directly off the gunwale or pontoon (Figure 16). The hardwood timber cribs were heavy and to ensure they landed in an upright position they were lowered down with rope. The rope was then pulled through

Figure 16 Deploying synthetic trees off the pontoon.

and retrieved. The suspended FAS were deployed by first dropping the float and structure over the side and then slowly motoring the mooring weights up to the position where the FAS was to be deployed. The weights were then pushed overboard, and the heavy weight (~ 105 kg) pulled the suspended FAS over the mark as they sank.

On several occasions, FAS had to be deployed further from the shore than identified in the FAP due to dense aquatic vegetation growth or insufficient water depth above the FAS as the impoundment's water levels dropped. When FAS were deployed the coordinates of each structure were recorded using a hand-held GPS. All subsequent maps and analysis were based on the recorded positions rather than the positions outlined in the FAP.

Extension to increase project awareness and the location of FAS

A key component of the project has been the engagement of local stakeholders and extension to increase project awareness. As part of project development, meetings were held with the major water providers (Seqwater and Sunwater) in Queensland who manage many of the stocked impoundments. The meetings explored their attitudes towards the use of fish attractors in the dams they manage and the likely conditions under which installation would be permitted. After discussions, favourable consideration was obtained on the use of fish attractors in dams they manage, including permission to develop fish attractor trials at several locations.

A project steering committee was established to guide project development and extend progress and results to stakeholders. The committee consisted of representatives from key stakeholders, including Fisheries Queensland, Seqwater, Toowoomba Regional Council, Toowoomba and District Fish Stocking Association and Gary Fitzgerald (Somerset and Wivenhoe Fish Stocking Association).

Presentations on using fish attraction structures in impoundments were given to a broad range of stakeholders, including local and regional fish stocking groups, local government, state government agencies and waterbody managers. Presentations were also given at several conferences and forums, including Codfest 2017, Queensland fish stocking workshop 2018, and Reservoir Fisheries Habitat Partnership annual conference 2019 (USA).

At habitat construction working bees, community members were taught how to construct the different types of FAS and the reasons why they might be suitable in Australian impoundments. Working bees were also taken as an opportunity to share results of the project to date, including photographs of fish captured from FAS, sonar images of fish around FAS clusters, maps of deployment locations and tables of deployment coordinates.

Media releases, fishing magazine articles, a podcast and a media day were used to raise awareness in the broader community. The media day coincided with the deployment of the bulk of the remaining FAS and coverage from the event extended to a local TV station, media releases by DAF and TRC, an article in the FFSAQ monthly newsletter, and an article in Queensland Fishing Monthly magazine. Senior fisheries managers were also invited to the event to provide them with a better understanding of the project and its potential value as a fisheries management tool.

Angler's fishing Cressbrook Dam were provided with information about the project (including a map of deployed FAS and a table of location coordinates) after being interviewed for the project's creel survey. Temporary signage was also installed at Cressbrook Dam outlining the types of FAS, deployment locations and coordinates. The signage was regularly updated as FAS were deployed. Large blue signs were also installed along the shoreline above full supply level to identify the bays and points where FAS were installed (Figure 17). Due to unforeseen circumstances, these were only installed at the latter stages of the project.

The coordinates of the FAS will also be made available upon the Fisheries Queensland website, and links to this information will be located on the Toowoomba Regional Council's information page for the dam and several other recreational fishing information websites. The GPS coordinates will be available in a variety of formats so that anglers can download the points straight into their specific GPS unit. Publication of these coordinates was delayed until the end of the project to encompass a number of FAS sites that were only added in June 2021. The delay in making this information available online was to ensure that only a single, complete set of coordinates was available, rather than anglers needing to download multiple versions which may have led to some confusion.

Figure 17 An example of the 600 x 900 mm bright blue aluminium shore signs indicating the presence of FAS at a bay or point. This sign has been assembled prior and is ready for installation.

Throughout the project, information signs have been installed at the boat ramp to keep anglers up to date regarding the project's progress. These signs were continually updated as additional FAS were installed. Several additional FAS constructed from left over materials have also been deployed. Large, permanent sign boards, which include a map showing the location and GPS coordinates of all FAS sites, will be installed at the boat ramp, day-use area and campground (Figure 18). These fish attractor signs provide anglers with a starting point to improve their angling experience. An additional benefit to placing fish attractor signs is to heighten awareness of the project. These signs are highly visible and therefore should increase visitor knowledge of the fish attraction efforts in the impoundment.

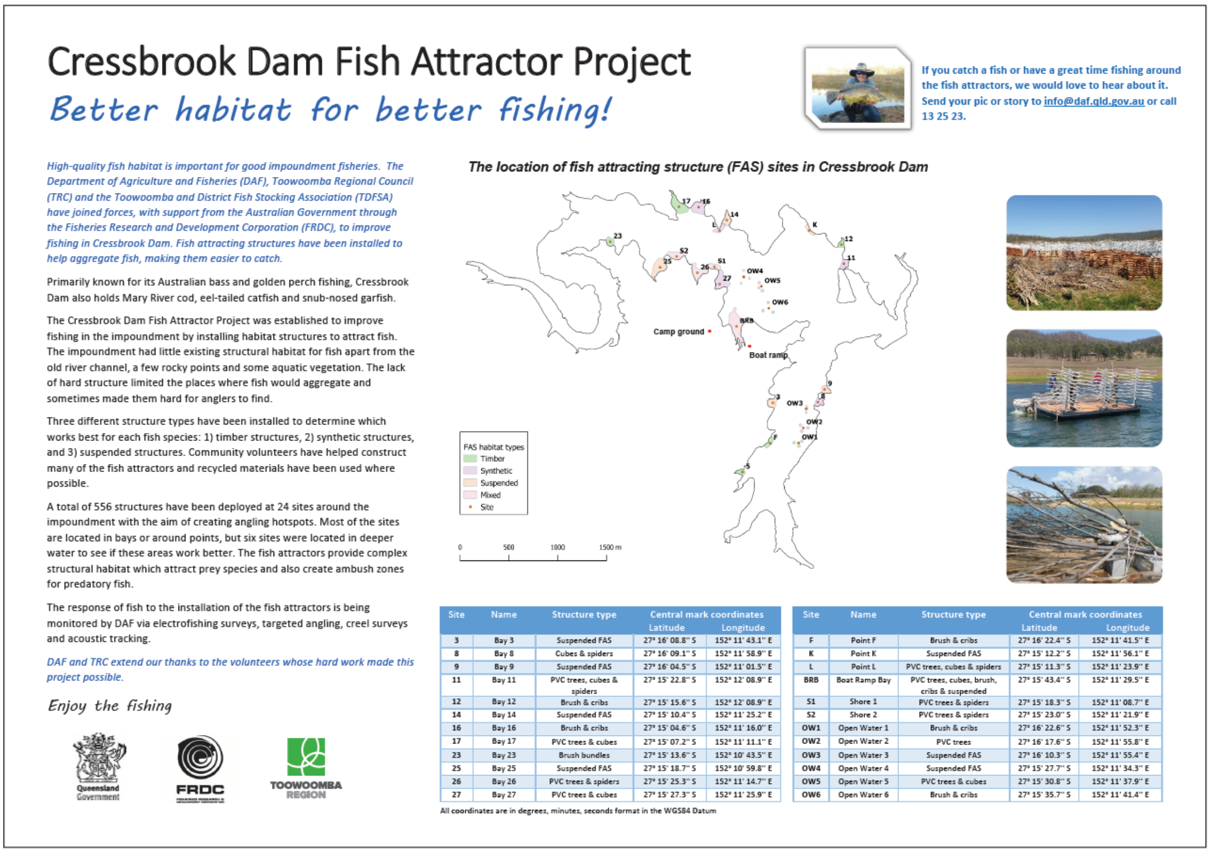


Figure 18 One of the temporary project information signs erected at the boat ramp to inform visitors about the FAS locations and project. Permanent metal signs will be erected once a number of additional FAS made from leftover materials have been deployed.

Develop recommendations and best practice guidelines

Details on how FAS should be installed to gain maximum benefit and minimise potential adverse impacts are essential before FAS can be widely utilised in Australian impoundments. One of the outputs from the current project was to develop best practice guidelines for the use of FAS in Australian impoundments for Australian fish species. The results from this study were combined with information and data from other FAS trial projects underway in Queensland, personal communications and a review of information on FAS use in the USA by Norris (2016). The guidelines outline a structured process for FAS projects, including planning, permissions required, site selection, FAS selection, construction and deployment methods, and monitoring and evaluation.

Impacts of fish attracting structures on fish distributions

Introduction

The lack of structurally complex habitat in many impoundments suggests that the introduction of habitat structures for fish should be beneficial and has the potential to attract fish to specific areas. In waterways with very limited or even no existing structural complexity, the type of structure introduced may not matter greatly. However, most dams retain some existing structural complexity. It is important to understand how different fish species respond to different structure types so that cost-effective enhancement approaches can be developed and tailored for specific fisheries management objectives.

It is common for fish in Australian impoundments to occur in areas of high structural complexity, particularly rocky dam walls and water management infrastructure (Smith *et al.* 2011, Harrison *et al.* 2012, Norris *et al.* 2020). These areas are frequently the only sites in impoundments with significant amounts of good-quality fish habitat, but unfortunately often occur within no-angling zones. Installation of structurally complex habitat also has the potential to attract fish, but into areas where anglers are permitted to target them. Aggregating fish around structure improves the probability that anglers can locate the fish (Wege and Anderson 1979). This increases the potential for anglers to achieve better catches, particularly those less skilled or more casual anglers who have rarely fished in a particular impoundment. Over-exploitation is generally not an issue because many impoundment anglers practice catch and release, and recruitment is not dependent on the retention of adult fish for spawning, because all fish are stocked.

A wide range of approaches have been used to aggregate fish and improve fisheries in impoundments (Miranda 2017). Since most sports fish species found in Australian impoundments do not breed in lentic conditions, the focus of improving habitat can be targeted towards feeding and shelter requirements rather than provision of spawning habitat. Management of aquatic vegetation has proven extremely effective at stimulating ecosystem productivity and attracting fish to particular areas (Cheruvelil *et al.* 2002, Conrow *et al.* 2011). However, this is a long-term approach most suited to waterbodies with relatively stable water levels. Many Australian impoundments experience significant annual and interannual water level fluctuations and active management of the aquatic vegetation to attract fish is unlikely to be successful. Instead, the introduction of structures to increase habitat complexity potentially provides a faster and more viable approach, and one which fish stocking and angling groups can more readily employ.

The materials used to construct fish attracting structures can have a significant bearing on their durability and cost-effectiveness (Bolding *et al.* 2004, Miranda 2017). Large-scale introduction of structural habitat to aggregate fish in impoundments has rarely been applied in Australia (Norris 2016), so information on the effective structure materials and types for Australian native fish species is therefore limited. A major knowledge gap is how Australian fish will respond to habitat structures made from natural versus synthetic materials. Studies in the USA have reported differences in fish use of structures made from different materials (Allen *et al.* 2014, Baumann *et al.* 2016, Miranda 2017), but the response varies between locations and fish species, and no clear national consensus has been reached. There can be many advantages of using synthetic materials such as PVC (polyvinyl chloride) or HDPE (high-density polyethylene) to construct fish habitat. They are inert, durable and can be readily made into a range of designs to suit the needs of specific fish species. However, if synthetic materials are not as effective at attracting Australian native fish, then their value for fish attracting devices may be limited. This information is crucial to inform management decisions regarding the use of FAS in Australian impoundments.

The first objective of this component of the project was to assess the overall response of stocked sportfish to the installation of FAS and investigate whether fish were more attracted to substrate-based FAS made from natural or synthetic materials, a combination of both, or suspended FAS made from synthetic materials.

Detecting a response in the fish community at the reservoir scale is extremely difficult (Allen *et al.* 2014, Miranda 2017). The large physical size of most systems and the number of potentially confounding factors generally necessitates the use of more than one monitoring technique. Absolute changes may not be detected by a single survey technique; however, combining the data from multiple techniques has better potential to generate sufficient evidence to draw conclusions with greater certainty. In this project a combination of active and passive monitoring of fish distributions was employed.

Habitat utilization by an organism reflects the spatial distribution of essential resources, the internal state of the organism, and its response to ambient conditions (Huntingford 1993). Sampling efficiency and variability in sampling gear efficiencies can make quantitative assessments of animal occurrence and abundance in structurally complex habitats difficult (Bayley and Austen 2002, Gu and Swihart 2004, Perez *et al.* 2017). For active monitoring, a combination of electrofishing and gill-netting is the most common approach used in the USA to conduct before and after surveys of reservoir fish communities (Perez *et al.* 2017). However, gill-netting can be highly destructive and lead to injury or death in target and non-target species and is not generally favoured by our team. Electrofishing is one of the most commonly used reservoir fisheries sampling techniques but is restricted to shallow water depths (<5 m, Reynolds and Kolz 2012). The technique provides an instantaneous snapshot of the fish community and works effectively on all sizes of fish. Electrofishing is effective at estimating fish abundance from within habitat structures, but slightly less successful in open water where the boat can scare fish away.

Active sampling identifies the distribution of fish at a small number of points in time. In contrast, the use of biotelemetry to passively track fish movements provides a more comprehensive understanding of fish use of habitat structures over a much greater time span. Several telemetry options are available, but acoustic tracking has the greatest potential for providing detailed, long-term fish movement data whilst avoiding disturbance of fish behaviour from chase boats (Skerritt *et al.* 2015). Acoustic tracking provides continuous information on the location of the fish and enables detection of diurnal and seasonal use of habitat structure and patterns of movement. Comparison of the use by fish of multiple habitat structure types can be achieved by installation of listening arrays around the structures and monitoring the time spent by fish in each habitat (Laffargue *et al.* 2006, Reynolds *et al.* 2010, Koeck *et al.* 2013). This helps identify preferred habitats, and those which were utilised less frequently.

There remain many knowledge gaps regarding the durability and attractiveness of different FAS types. Monitoring the condition of installed structures provides additional data to assist in determining the most cost-effective habitat enhancement strategies in the long-term. Combining knowledge on changes in the fish community with data on the available FAS will improve our understanding of the longer-term impacts of impoundment enhancement projects. The second objective of this component of the project was to evaluate the accumulation of organic growth and FAS condition to determine if these factors influenced attractiveness to fish and to inform future management decisions on FAS installation.

Monitoring the condition of deployed FAS helps determine whether they need maintenance or replacement. Degraded structures are unlikely to be as effective at attracting and holding fish (Allen *et al.* 2014). Such structures will also be more difficult for anglers to detect with sonar. Structures made from brush and timber naturally degrade over time (Aleen *et al.* 2014), so monitoring their condition will inform when replenishment or replacement is necessary to maintain their attractiveness to fish. Fish attractors constructed from synthetic structures are less likely to deteriorate over time but take longer for organic growth to accumulate (Baumann *et al.* 2016). These structures can still suffer damage due to boat strikes, anchoring, vandalism, excess accumulation of silt, debris or algae, drifting logs, or by anglers when retrieving snagged fishing tackle. Monitoring will help identify structures which are damaged or missing and assess the rates of accumulation of the organic growth. Accurate knowledge on synthetic FAS condition will enable more cost-effective management of fish attractor programs.

Various methods have been used to assess the condition of FAS. Inspection by SCUBA divers has been the most labour-intensive method but provides the most detailed information and can also capture data on fish usage (Dibble 1991, Dolloff *et al.* 1996, Jacobson and Koch 2008, Thurow *et al.* 2012). Habitat condition has also been assessed directly from a vessel using underwater cameras or sonar imaging. The use of sonar to assess fish habitat condition and use by fish has gained in popularity (Baumann *et al.* 2016). Sonar imagery allows visual evaluation of habitats in environments that are turbid, deep or have poor light levels where other methods of visual observation (e.g., SCUBA, cameras) are negatively affected (Magnelia *et al.* 2008, Thurow *et al.* 2012, Allen *et al.* 2014). This method may also be suitable for community groups to use when monitoring FAS they have installed.

Methods

A single monitoring technique was unlikely to provide sufficient information to gauge any changes in recreational impoundment fisheries following habitat enhancement in Cressbrook Dam. To overcome this, we chose to utilise multiple monitoring techniques and a weight of evidence approach. This research was conducted under Animal Ethics permit CA 2017/11/1125 and General Fisheries Permit number 186281.

Electrofishing

Boat electrofishing surveys of fish distributions in Cressbrook Dam were undertaken twice per year between January 2018 and December 2020. Electrofishing is the preferred non-invasive method to minimise harm to fish from sampling and provides an instantaneous representation of relative fish abundance at a site. Electrofishing involves pulsing DC current through the water to stun fish. The effective range of a boat-mounted electrofisher is 4 to 5 m for a 7.5 KVA unit. The technique is therefore most effective in shallow water and thus the FAS sites and monitoring locations were located in areas amenable to monitoring via this technique.

A standardised approach was used to survey fish distributions and habitat utilisation. The survey structure was based on the experimental monitoring sites and design outlined in Table 1. The 24 monitoring sites established around the impoundment were grouped in clusters of four, where each site in a cluster contained similar geomorphology. Each cluster contained a Control site and one example of each FAS grouping (suspended, synthetic, timber). Two Reference sites with good quality existing habitat and two independent sites were also monitored. All sites within a cluster were surveyed in a random order before moving to the next cluster. Electrofishing surveys were conducted twice yearly during summer and winter.

At each monitoring site, fish were actively targeted by electrofishing with a total power on time of 600 seconds. A double length shot (1200 sec) was used in the Boat ramp bay site due to its large size. A 7.5 KVA generator and Smith-Root 7.5 GPP electrofishing control box was used on a 5.1 m long custom electrofishing vessel for the surveys. The power was not applied continuously over each habitat but was employed in numerous short bursts. Stunned fish were dip-netted and placed in an aerated 300 L live-well on the boat. Only recreationally targeted fish species were captured. Categorical estimates of the abundance of stunned smaller prey species were made visually to investigate if their distributions were influenced by the installation of FAS. The categories used were: 0 – absent; Low – 1-20 fish; Medium – 21-100 fish and High - >100 fish. At the end of each electrofishing shot, all captured fish were sedated with AQUI-S at a concentration of 20 mg/L (Aqui-S

New Zealand, Lower Hutt, New Zealand) and measured. Sedated fish were measured to fork length (forked tail) or total length (convex tail) on plastic measuring boards. After measurement, fish were allowed to recover in fresh aerated water and returned to the impoundment within the area where they were captured.

Electrofishing data analysis

The electrofishing data was analysed using Generalised Linear Modelling (GLM) to address two key questions regarding fish distributions in Cressbrook Dam:

1. Did the electrofishing catch rate for key fish species increase significantly at sites where FAS were installed compared to Control and Reference sites?
2. How did different fish species respond to the installation of different types of FAS?

Genstat 19th Ed (VSN International Ltd, UK) was used to develop GLMs to evaluate the electrofishing catch rate of the key fish species and the combined catch of recreationally targeted species using a Poisson distribution with the log-link function. An over-dispersed model was used where the data displayed higher variation. Data was temporally pooled into pre-and post-FAS installation periods, designated as FAS installation status. Fitted terms in the regression analysis included electrofishing effort, season, site geography (cluster), treatment, FAS installation status and interactive effects for treatment x FAS installation status. Treatments in the first model compared changes in electrofishing catch rates between Control, Reference and FAS sites, whilst the second model was more specific and investigated changes in the catch rate between the different FAS types, Control and Reference sites. Fisher's Least Significant Difference (LSD) pairwise comparison tests were performed if a significant effect was found for any single or interacting factor and used to determine whether significant differences occurred between specific treatment combination types, including between before and after FAS installation. The level of significance (α) was set at 0.05 for all statistical tests.

Acoustic tracking

One of the most effective and least invasive methods for studying the behaviour and movements of fish is to use acoustic tracking. Acoustic receivers are deployed in a grid like array to monitor the fine-scale movement of fish. Small acoustic tags implanted into the abdominal cavity of fish then enable the position of tagged fish to be monitored by triangulating its position within the receiver array. The location of multiple fish can be tracked passively for as long as the tag batteries last to determine their seasonal movements and use of different habitat types.

Acoustic tracking was used to investigate the fine-scale movements and habitat use of Australian Bass (*Macquaria novemaculeata*) and Golden Perch (*Macquaria ambigua*) in response to the addition of fish attracting structures. A Vemco Positioning System (VPS; Vemco Amirix Systems, Halifax, NS, Canada) acoustic array was established in the middle reach of the main body of the impoundment to maximise coverage of FAS installation sites (Figure 19). The array tracked fish across approximately 170 ha, extending northwards from the line between the water off-take tower and the tip of Deer Island, to two-thirds of the way towards the Eagle's Nest cliff on the Cressbrook Creek arm. The array incorporated both shallow and deep-water habitat types, with a maximum depth of 28 m.

Range testing was conducted to determine the acoustic receiver array dimensions and optimal receiver positioning. Eight Vemco VR2W receivers were deployed on bottom moorings in a linear array at 50 m intervals out (50 -450 m) from a transmitting VR2Tx. The VR2Tx transmitter was configured to transmit at 90 sec intervals at a medium power setting to replicate the output of V13 acoustic fish tags. The receivers were deployed for one week to determine receiver detection distances and effectiveness across a range of ambient environmental conditions and boat traffic levels. The effective receiver reception range, defined as the distance where 60% detection probability is achieved, was between 400 - 450m. However, when establishing a VPS array the desirable receiver spacing should be the same distance where ~80% detection probability is achieved. This approach ensures time synchronisation can be achieved across the array (reliable detection of neighbouring synchronisation tags) under all weather conditions. A conservative maximum receiver spacing of 375 m apart was decided upon.

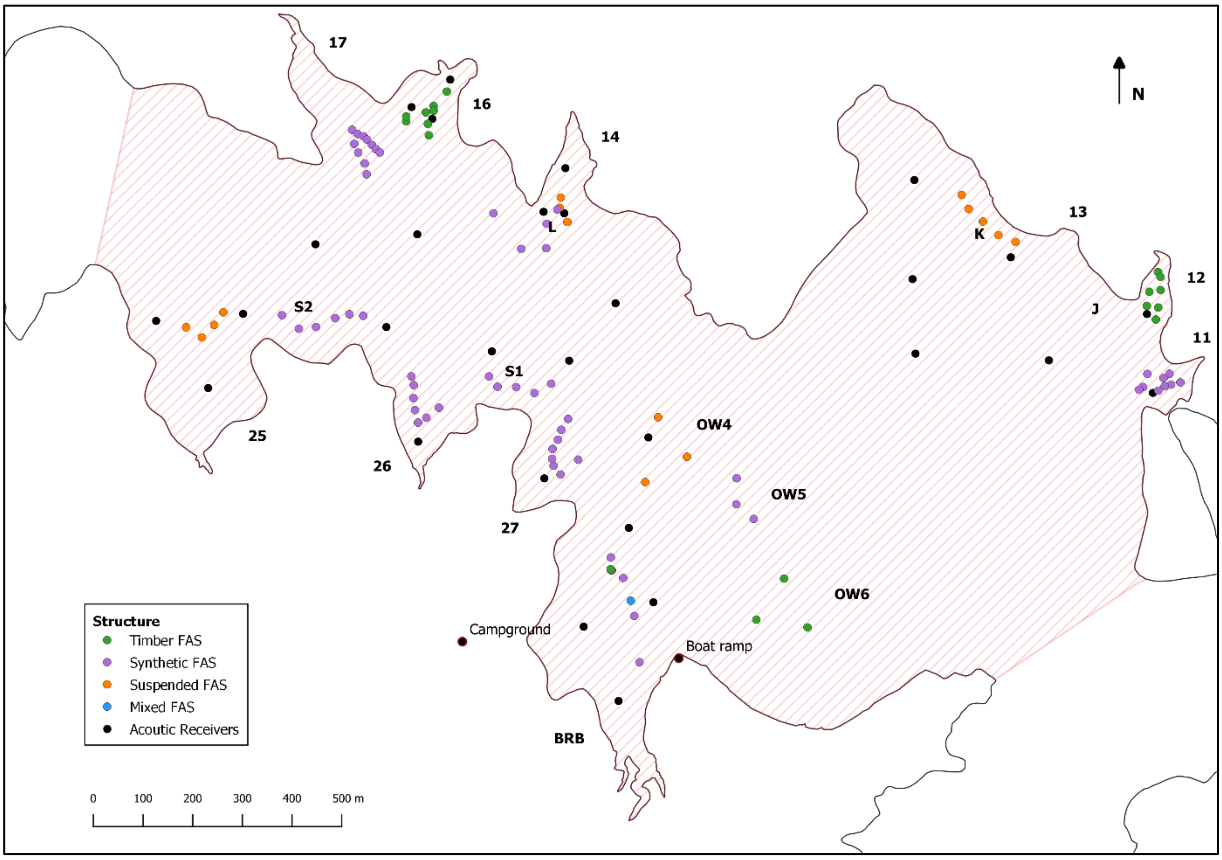


Figure 19 The VPS tracking area and configuration of the acoustic receiver array used to track Australian Bass and Golden Perch in Cressbrook Dam

The VPS tracking array comprised 30 acoustic receivers mounted on submerged anchored lines suspended off the substrate by small floats. The receivers were attached to the line 1 m up from the substrate and 1 m below the float. The array was comprised of 27 Vemco VR2W and 3 VR2Tx receivers. The VPS uses receivers with overlapping detection ranges to triangulate individual fish positions (Espinoza *et al.* 2011). Due to the shape of the shoreline, receivers were conservatively placed at 250 m centres in a series of sub-grids (triangles or squares) along the shore, with the gaps filled in the middle with receivers to join the sub grids. This design was expected to achieve good positional accuracy within the bounds of the receivers and well into the adjacent shoreline areas. The VPS array enabled fish positions within the array to be calculated by Vemco using their Time Difference of Arrival (TDOA) algorithm (Espinoza *et al.* 2011). Synchronisation tags (Vemco V16L or internal transmitters in the VR2Tx transceivers) programmed with a random delay of 500-700 s were co-located with 16 receivers in the acoustic array to calibrate and correct for time drift of the receiver's internal clock. The VR2Tx receivers had inbuilt temperature loggers to account for the influence of water temperatures on signal transmission speeds. The receivers recorded the time and date of each transmitter whenever a signal was successfully detected.

Thirty Golden Perch and 30 Australian Bass were tracked using Vemco V13 transmitter tags operating at 69kHz and using the low power setting. The tags were configured to transmit signals nominally every 2.5 minutes. Fish were all captured from within Cressbrook Dam via boat electrofishing using a 5.1 m vessel with a 7.5 GPP Smith-Root electrofishing system. Stunned fish were dip-netted and placed in an aerated 300 l live-well on the boat. The fish were then transported to a shore-based station for implantation of the transmitters. Two rounds of fish collection and surgery were undertaken to tag the fish. On 20th September 2018, 17 Australian Bass and 24 Golden Perch were captured and had the V13 acoustic tags surgically implanted. The remaining 13 Australian Bass and 6 Golden Perch were captured and tagged on 29th November 2018.

Surgery was performed onsite by a veterinarian assisted by DAF staff with experience in the surgical implantation of radio-transmitters. The implantation procedure was carried out on a purpose-built portable operating table. Each fish was sedated using 20 mg/L Aqui-S anaesthetic until loss of equilibrium. Fish were measured in length to the nearest millimetre (fork length for Australian Bass and total length for Golden Perch) and weighed to the nearest gram. The fish were then placed ventral side up onto the surgery table and a small bilge-pump and soft plastic hosing was used to maintain a constant flow of sedative solution over the gills of the fish during surgery. All surgical equipment was sterilised either by autoclaving or in 70% ethanol prior to surgery. Transmitters were inserted through a small incision in the abdominal cavity parallel to, and slightly off, the linea alba (van Wagner *et al.* 2011). The V13 acoustic tags were 36 mm long, and 13 mm in diameter and weighed less than 6 g. The transmitters weighed less than 2% of the body weight of the fish being tracked so as not to impact normal bodily functions, feeding or swimming behaviours (Winters 1996). The incision was then closed with dissolvable sutures and sealed with tissue adhesive. To prevent infection the sutured area was swabbed with iodine solution and the fish given an injection of OTC (oxytetracycline - a slow-release antibiotic) at a dose of 75 mg/kg body weight. Whilst the fish were sedated, a Hallprint dart tag was inserted between the dorsal pterygiophores to enable ready visual identification of acoustically tagged for anglers. Following surgery, fish were monitored in holding pens located in the impoundment for at least 15 min until fully recovered from the anaesthetic. They were only released once they exhibited normal swimming function and fright responses. The tagged fish were then released back into the impoundment within the VPS array.

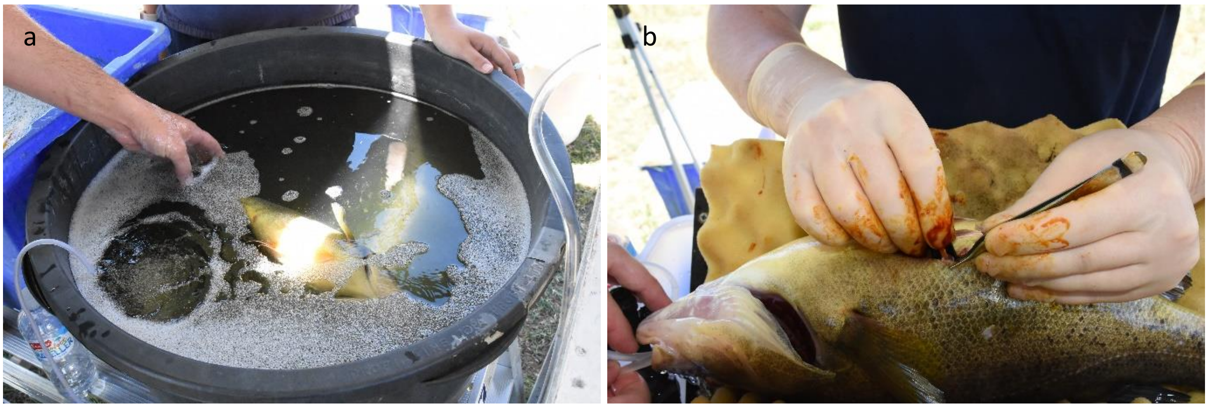


Figure 20 (a) Sedating a Golden Perch in Aqui-S solution prior to (b) surgical implantation of an acoustic tag.

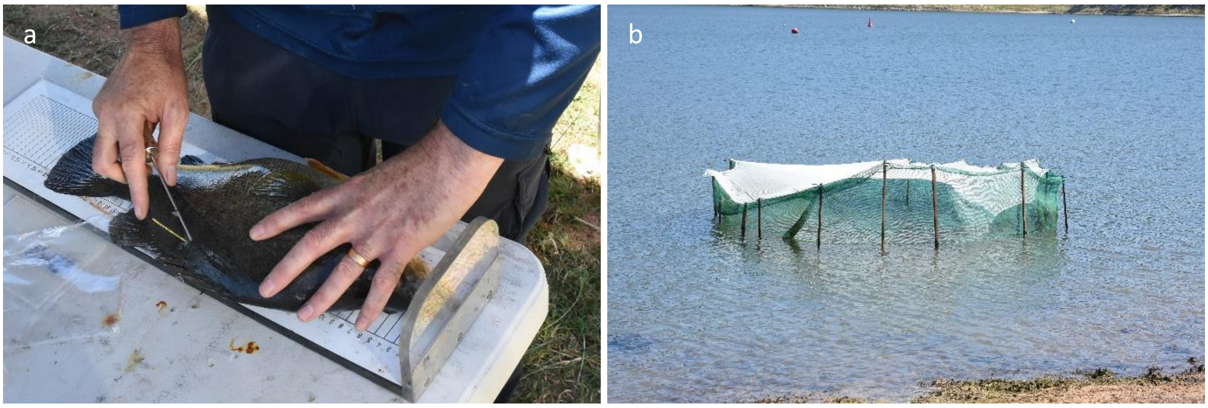


Figure 21 Inserting a dart tag into a Golden Perch (a) prior to placing in the recovery pen (b) before release.

The VPS array was deployed in August 2018 and tagged fish tracked from 29 September 2018 until 26 October 2020. Data from the acoustic receivers was periodically downloaded during this time. As water levels in the dam receded, the position of some near-shore receivers was shifted to ensure they were not smothered by the expanding band of littoral macrophyte growth. Unfortunately tampering with the receivers and equipment failures resulted in some failing to be retrieved, and the data on these receivers was lost. Three additional VR2Tx receivers were purchased and several more were borrowed to replace damaged or lost units so the experiment could be completed. The number of receivers in the array was reduced to 29 by the end of the tracking period, with only minimal loss of array coverage.

Acoustic tracking data analysis

Raw transmitter data were sent to Vemco for the calculation of fish positional estimates using their TDOA algorithm (Espinoza *et al.* 2011). The first day after surgery was excluded from the analysis to account for recovery time. Any estimated fish positions overlying land or outside the designated monitoring array were designated as outliers. Outliers occur when fish ventured further outside the geometric boundary of the acoustic grid array as a result of the three-receiver TDOA algorithm used to calculate position estimates (Niezgoda *et al.* 2002; Cooke *et al.* 2005a). The outliers were removed from the dataset and not included in further analysis.

Fish positional data was also filtered by horizontal position error (HPE), a relative, dimensionless measure of error sensitivity calculated by the TDOA algorithm (Espinoza *et al.* 2011). Only positions with a HPE ≤ 25 were included in the analysis. Analysis of the 16 static co-located synchronisation tags or VR2Tx transmitters indicated horizontal positional error was generally < 10 m (median = 2.4 m, mean = 4.74 ± 5.75 m) for calculated positions with HPE ≤ 25. Previous studies have used HPE threshold values between 5-20 (e.g., Espinoza *et al.* 2011). Technical issues and tampering with several of the acoustic receivers resulted in some sections in the VPS array having higher HPE. Visual inspection of the VPS fish position data in these areas made biological sense despite the lower theoretical position accuracy. Therefore, a slightly higher upper threshold of HPE ≤ 25 was utilised to ensure not too much data was omitted.

Euclidean distance analysis (EDA) was used to compare FAS habitat use by the tagged Australian Bass and Golden Perch within the VPS tracking area. This approach minimises habitat misclassification due to positioning error, whilst also identifying the influence of multiple habitats on a fish's position (Conner and Plowman 2001, Conner *et al.* 2003). The VPS tracking array area was used as the boundary delineating available FAS habitat in the EDA analysis. The area of the VPS array was seasonally updated as water levels changed the shoreline throughout the study period.

Seasonal EDA ratios from the VPS estimates were calculated using the distances from individual fish positions to each available FAS type (timber, synthetic, suspended or mixed) compared against the distances to these sites for a distribution of 1000 random points located within the VPS array tracking area (Conner and Plowman 2001). Ratios were calculated as the mean observed distance from fish positions divided by the mean expected distance (from random points) to each habitat site. A unique EDA ratio was calculated for each FAS type for each fish for each season. The same FAS habitat site coordinates were used in all EDA calculations to enable comparison of fish distributions before and after FAS installation. The individual fish was retained as the experimental unit to remove the effects of autocorrelation. If habitat use was completely random, the EDA ratio was expected to be equal to one. Ratio values > 1 indicate positions further from that FAS type than expected, representing less use by fish in that FAS type. Conversely, ratio values < 1 indicate positions closer to the FAS than expected, implying greater use of that FAS site.

Multivariate analysis of variance (MANOVA) was used to test for non-random habitat use by determining if EDA ratios differed significantly from 1 (Conner and Plowman 2001). If overall habitat use was found to be non-random, analyses of variance (ANOVA's) were performed for each species to determine which FAS type were disproportionately used. The magnitude of the difference between the EDA ratio and 1 is an indicator of the effect size.

Paired t-tests were used to examine the significance of changes in the EDA ratio that occurred between the pre- and post-FAS installation periods. The level of significance (α) was set at 0.05 for all statistical testing.

Kernel density estimates (KDE) were used to visualise the spatial distribution of tagged fish and describe a probabilistic area within which the fish may be located (Dance and Rooker 2015). Kernel density estimates were calculated in Q-GIS 3.6.0 using the Heatmap function, with the kernel smoothing bandwidth determined using the formula $Hopt = (\frac{2}{3n})^{1/4}\sigma$ where n = number of points and σ = standard distance of the points (Fotheringham *et al.* 2000). Seasonal KDE maps were produced for each species and their extent clipped to the shoreline for the season being investigated. The KDE maps were qualitatively assessed to identify hotspot areas of fish use for each species, and how fish use varied seasonally and in relation to installation of the different FAS types.

FAS condition assessment

A key aim of the project was to visually investigate the condition of the installed FAS, how algae and the local ecosystem developed, and use of the structures by fish. The initial approach was to use static underwater cameras placed near the FAS for 30 minutes. In 2019, DAF acquired a remotely operated underwater drone with auxiliary lighting (Deep Trekker DTG3 Expert ROV system, Metocean Services International, Tasmania). It was anticipated this system would provide better imagery and evaluation. Attempts were made using this device to survey the condition of the FAS and fish communities associated around them. Although several images and videos of fish and FAS condition were obtained, due to frequent poor underwater visibility, image quality and consistency were too poor to enable standardised, quantitative comparison between the different FAS types.

Sonar imaging was also employed to assess FAS condition and use by fish. A Lowrance HDS 9 unit using the Structure Scan 2 transducer was used to obtain sonar images of each FAS cluster. Annual surveys were conducted post FAS installation by slowly motoring over each FAS cluster and capturing screen shots from the sonar unit when the FAS and any fish associated with it were clearly within the display field. Where possible images were captured on the first pass to minimise disturbance of fish by the boat. However, multiple passes were often required to capture the best image quality. Sonar images could not be taken when water levels at the FAS site were too shallow for the boat to pass over or where aquatic vegetation had overgrown structures.

Results

Electrofishing surveys

A total of seven electrofishing surveys were conducted bi-annually at Cressbrook Dam between January 2018 and December 2020. The overall catch rates for recreationally targeted fish species were low (Table 2). However, the catch rates for the prey species these fish feed on were considerably higher.

Table 2 Total electrofishing catch of recreationally targeted fish species for each survey period

Survey period	Australian Bass	Golden Perch	Freshwater Catfish	Mary River Cod	Total rec species
Summer 2018	4	5	29	0	38
Winter 2018	3	0	17	0	20
Summer 2019	2	0	17	1	20
Winter 2019	6	1	6	0	13
Summer 2020	4	2	5	1	12
Winter 2020	7	5	14	1	27
Summer 2021	11	5	20	3	39
Total	**37**	**18**	**108**	**6**	**169**

Recreational target species

The introduction of the FAS significantly increased the electrofishing catch rates for the two fish species most targeted by recreational anglers in Cressbrook Dam, Australian Bass and Golden Perch. Generalised linear modelling identified an interaction effect between habitat group and the installation status of the FAS for the electrofishing catch rate of both species (Table 3). No such trend was observed in Freshwater Catfish and too few Mary River Cod were captured for the analyses to be conducted effectively.

Table 3 Recreational fish species GLM output results for electrofishing catch rate investigating the interaction effect between habitat group (FAS, Control or Reference) and FAS installation status (pre, post). The scale and significance of the change (Fishers LSD) in catch rate observed at the FAS sites following installation are represented. α = 0.05 for all GLMs.

Species	Interaction F prob	Change at FAS sites post installation	Was the change significant
All recreational species	0.056	+66%	No
Australian Bass	0.010	+630%	Yes
Golden Perch	0.008	+972%	Yes
Freshwater Catfish	0.369	-12%	No

Combined recreational species catch

The combined catch rates for recreationally targeted species were typically higher from Steep bays and Open bays, and least around the Points. No seasonal differences in the combined catch rates were detected. The combined electrofishing catch increased at FAS sites following their installation, but the change was not significant. During the same period, catch rates at the Control sites and Reference sites trended in the opposite direction and decreased.

For most species there was a general increase in abundance in the period post-FAS installation, but the response varied between the different FAS types. Differences in the electrofishing catch rates were observed between sites where different FAS types were installed, but the interaction effect between FAS type and installation status was only significant for Golden Perch (Table 4).

Table 4 Recreational fish species GLM output results for electrofishing catch rate investigating the interaction effect between FAS type and FAS installation status. α = 0.05 for all GLMs and significant values are highlighted in bold.

Species	Interaction F prob
Combined recreational species	0.073
Australian Bass	0.084
Golden Perch	**0.031**
Freshwater Catfish	0.439

The GLM for the combined recreational species catch found FAS type to be a significant factor (p = 0.005) influencing the electrofishing catch but the interaction between FAS type and installation status was almost significant (p = 0.073).

The combined recreational species catch rates at the Control and Reference sites declined slightly, but not significantly between the period prior to FAS installation and after they were installed (Figure 22). The general trend where FAS were installed was the opposite. The timber, mixed and synthetic FAS sites all experienced an increase in catch rate, but this was only statistically significant for timber FAS. No significant change was observed at the suspended FAS sites.

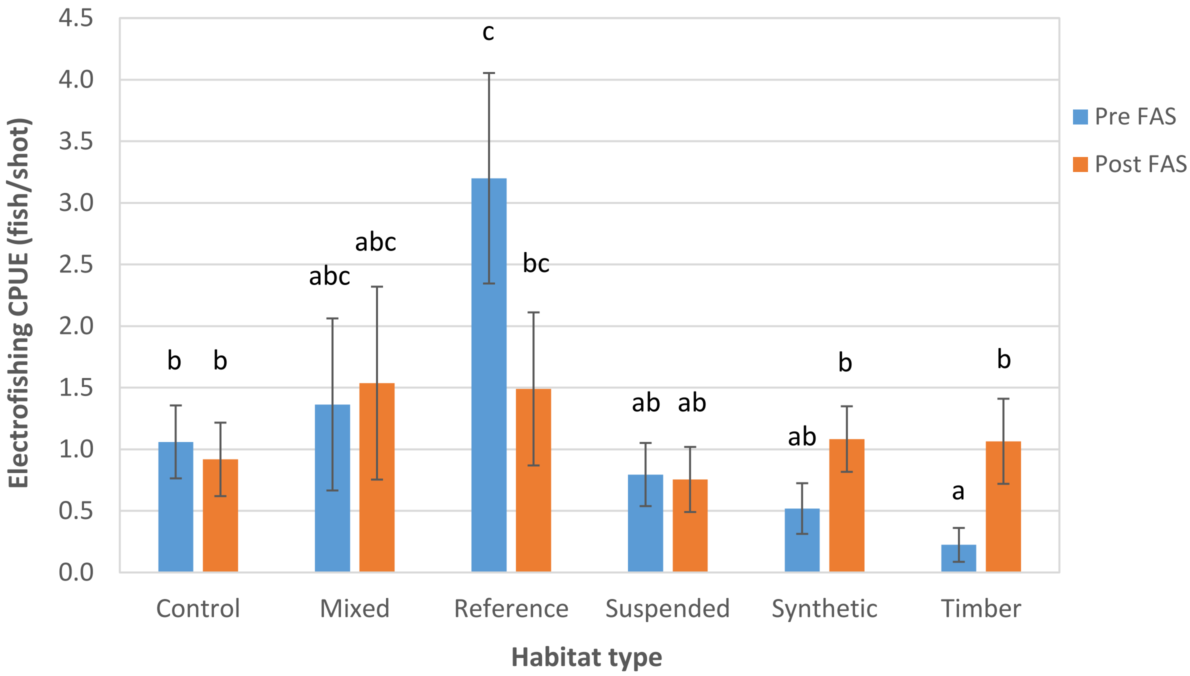


Figure 22 Combined electrofishing catch rates (± s.e.) for all recreational species pre and post FAS installation at the different FAS type sites. The letters above each column indicate which values were significantly different according to Fisher's LSD test. Values with the same letter are not significantly different.

Australian Bass

The Australian Bass electrofishing catch rate increased at both the Control and FAS sites following installation, but the increase was only significant at the FAS sites (Figure 24). The catch rate at the Reference sites decreased significantly during the same period. There was a significant interaction effect between FAS group and habitat installation status (p = 0.01, Table 3).

Figure 23 *An Australian Bass electrofished from the synthetic FAS in the background of the picture. This fish returned straight to the FAS immediately upon release.*

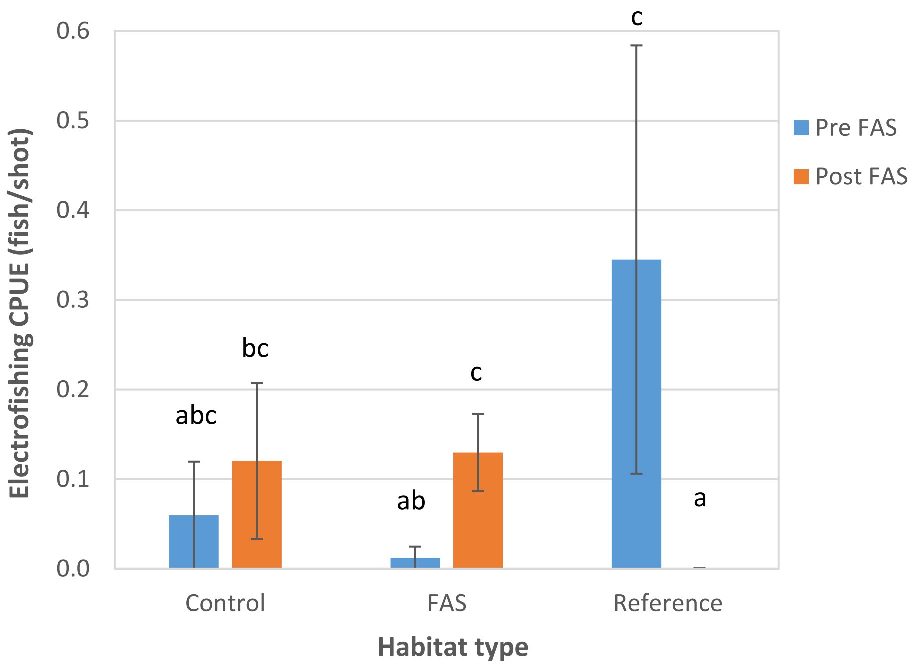


Figure 24 *Combined electrofishing catch rates (± s.e.) for Australian Bass pre and post FAS installation at the different habitat sites. The letters above each column indicate which values were significantly different according to Fisher's LSD test. Values with the same letter are not significantly different.*

FAS type was found to be a significant factor influencing the electrofishing catch ($p = 0.012$), but installation status was not ($p = 0.109$). The interaction between FAS type and installation status did not quite reach the level of statistical significance ($p = 0.084$). Australian Bass catch rates increased significantly at sites where synthetic and timber FAS were installed, and to a lesser degree (not significant) where suspended FAS were installed (Figure 25). A significant decline was observed in the catch rate at the Reference sites and a small, but not significant, increase was observed at the Control sites. No Australian Bass were captured by electrofishing from the mixed FAS.

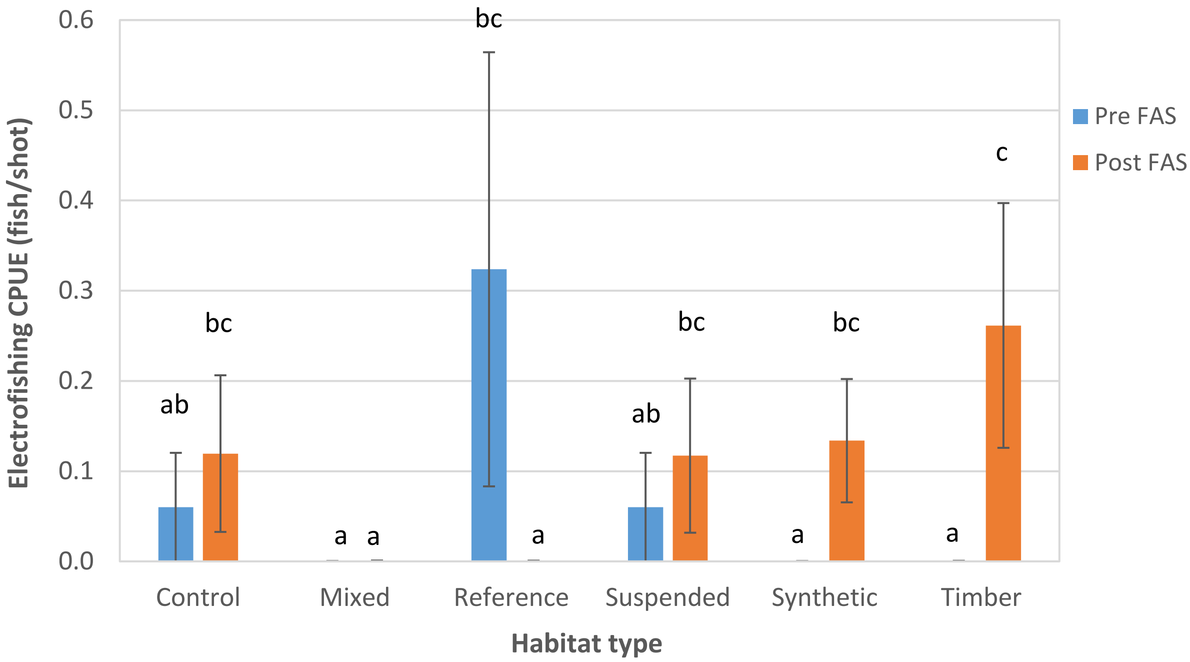


Figure 25 Combined electrofishing catch rates (± s.e.) for Australian Bass pre and post FAS installation at the different FAS type sites. The letters above each column indicate which values were significantly different according to Fisher's LSD test. Values with the same letter are not significantly different.

<u>*Golden Perch*</u>

The electrofishing catch rates for Golden Perch at the FAS and Control sites both increased following the installation of the FAS (Figure 26). However, the change was only statistically significant at FAS sites. During the same period, catch rates at the Reference sites showed the opposite trend and decreased substantially, but not significantly due to high variability between shots. A significant interaction was detected between the FAS group and habitat installation status (p = 0.0.09, Table 3).

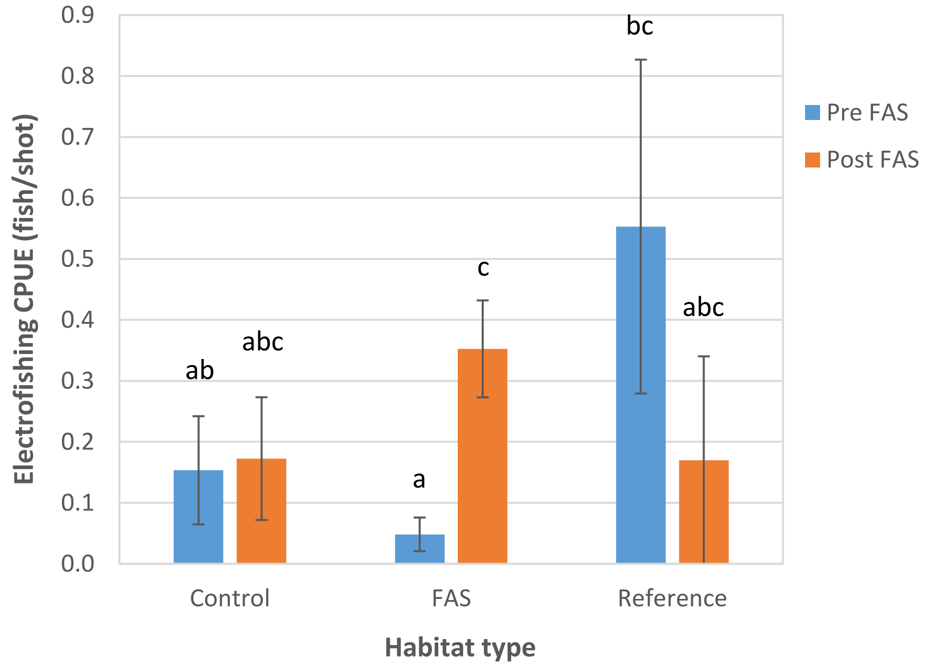


Figure 26 Combined electrofishing catch rates (± s.e.) for Golden Perch pre and post FAS installation at the different habitat sites. The letters above each column indicate which values were significantly different according to Fisher's LSD test. Values with the same letter are not significantly different.

The GLMs for the electrofishing catch of Golden Perch found FAS type was not a significant effect, but installation status (p = 0.004) and the interaction between FAS type and installation status were significant (p = 0.031) factors. Golden Perch catch rates increased significantly at all sites where FAS were installed, except for mixed FAS where the increase was not significant (Figure 27). Different trends were observed at the Control and Reference sites. Catch rates did not change significantly at the Control sites, but decreased 71% at the Reference site, although this decline was not statistically significant due to the high catch rate variation between shots.

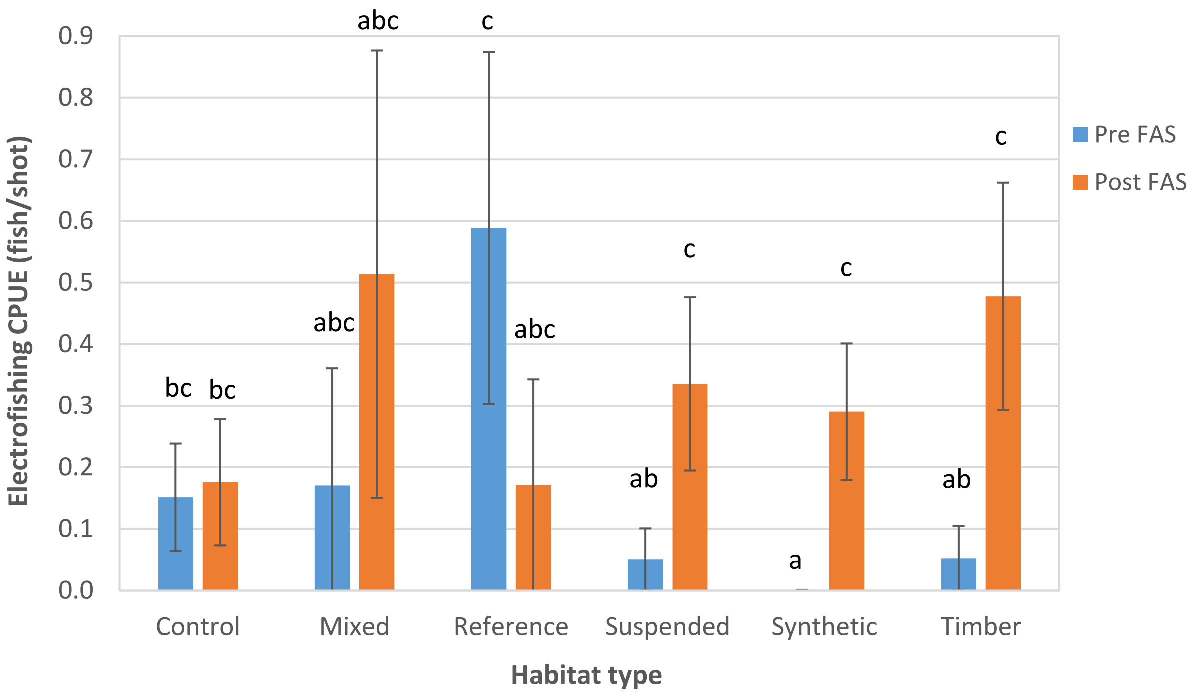


Figure 27 Combined electrofishing catch rates (± s.e.) for Golden Perch pre and post FAS installation at the different FAS type sites. The letters above each column indicate which values were significantly different according to Fisher's LSD test. Values with the same letter are not significantly different.

__Freshwater Catfish__

The electrofishing catch rates at Control, Reference and FAS sites all declined following the installation of the FAS, but the changes were not significant. There was no significant interaction between habitat group and habitat installation status (Table 3).

The GLM for the electrofishing catch of Freshwater Catfish found FAS type was a significant factor (p = 0.008), but installation status (p = 0.112) and the interaction between FAS type and installation status (p = 0.439) were not. The Freshwater Catfish catch rate did not change significantly at any of the FAS, Control or Reference sites. At the synthetic and timber FAS sites, the electrofishing catch rates increased, whilst at the mixed and suspended FAS sites catch rated declined slightly (Figure 28). The greatest declines were observed at the Reference and Control sites.

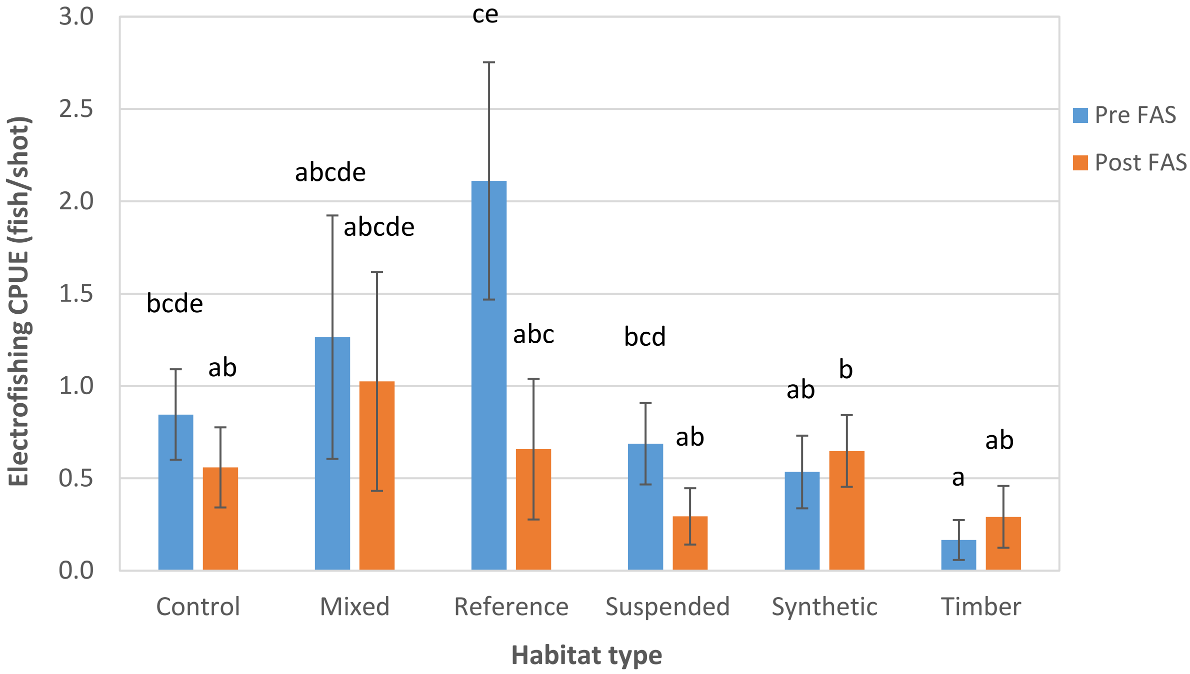


Figure 28 Combined electrofishing catch rates (± s.e.) for Freshwater Catfish pre and post FAS installation at the different FAS type sites. The letters above each column indicate which values were significantly different according to Fisher's LSD test. Values with the same letter are not significantly different.

Figure 29 A Freshwater Catfish caught electrofishing in Boat ramp bay.

Other fish species

For the smaller prey fish species, the electrofishing catch rates generally increased in the period following FAS installation. This increase does not seem to be linked to the introduction of FAS, but rather due to a wider-scale trend occurring across the entire impoundment. Similar changes were observed across sites with different FAS types, as well as at the Control and Reference sites. The catch rates for five of the prey fish species showed a significant interactive effect in the GLM between habitat group and FAS installation status (Table 5). Significant increases in the catch rates at FAS compared to the Control sites were observed for Snub-nosed Garfish, Olive Perchlet and Mosquitofish. Significant increases were also detected for Carp Gudgeon and Australian Smelt, but these were less substantial than those which occurred at the Control and Reference sites. The catch rates for Bony Bream and Barred Grunter were consistently high across all habitat types, except during the pre-FAS surveys at the Reference sites.

Table 5 Potential prey species GLM output results for the electrofishing catch rate investigating the interaction effect between habitat group (FAS, Control or Reference) and FAS installation status (pre, post). The scale and significance of the change (Fishers LSD) in catch rate observed at the FAS sites following installation are also represented. α = 0.05 for all GLMs.

Species	Interaction F prob	Change at FAS sites pre to post installation	Was the change significant
Bony Bream	<0.001	-1%	No
Snub-nosed Garfish	0.440	+245%	Yes
Barred Grunter	0.015	-4%	No
Unspecked Hardyhead	0.035	+68%	Yes
Australian Smelt	0.019	+410%	Yes
Carp Gudgeon	0.626	+1709%	Yes
Olive Perchlet	0.994	+740%	Yes
Mosquitofish	0.211	+2791%	Yes
Goldfish	<0.001	+203%	Yes

FAS type was a significant factor (P < 0.001) in electrofishing catch rate for Snub-nosed Garfish, Olive Perchlet, Australian Smelt, Mosquitofish and Goldfish. However, the interaction effect between the FAS type and installation status was only significant in four species (Table 6).

Table 6 Prey fish species GLM output results for electrofishing catch rate investigating the interaction effect between FAS type and FAS installation status. α = 0.05 for all GLMs and significant values are highlighted in bold.

Species	Interaction F prob
Bony Bream	**0.001**
Snub-nosed Garfish	0.640
Barred Grunter	0.092
Unspecked Hardyhead	0.120
Australian Smelt	**<0.001**
Carp Gudgeon	0.376
Olive Perchlet	**0.039**
Mosquitofish	0.597
Goldfish	**<0.001**

Bony Bream

The GLM for the electrofishing catch of Bony Bream found habitat group to be a significant effect (p = 0.008) but installation status was not (p = 0.388). However, the interaction between FAS type and installation status was significant (p = 0.001). This was driven by the comparatively low catch rate in the pre-FAS surveys at the Reference site (Figure 30). The Bony Bream electrofishing catch was typically quite high and very consistent across all FAS type sites. Catch rates only varied slightly following FAS installation with small, but not significant declines observed at the mixed, suspended and timber FAS sites. No change following installation was detected at the Control sites, while a small increase occurred at timber FAS sites.

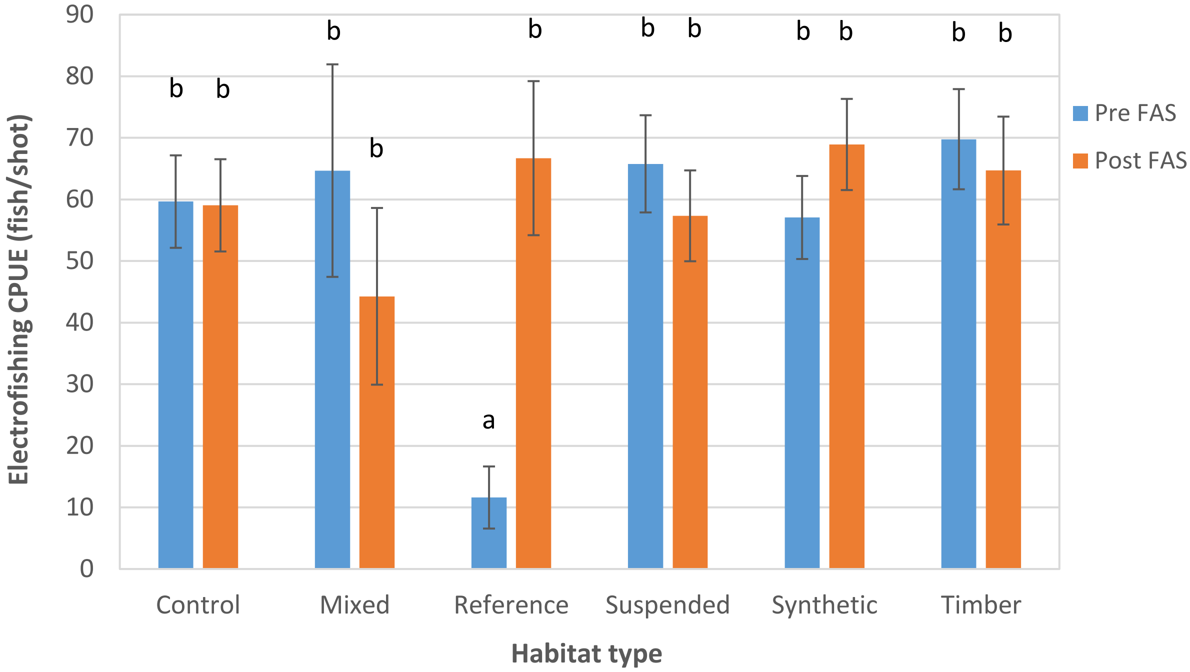


Figure 30 Combined electrofishing catch rates (± s.e.) for Bony Bream pre and post FAS installation at the different FAS type sites. The letters above each column indicate which values were significantly different according to Fisher's LSD test. Values with the same letter are not significantly different.

Snub-nosed Garfish

The GLM for the electrofishing catch of Snub-nosed Garfish found habitat group, installation status and season were all significant factors ($P < 0.001$), but the interaction between habitat group and installation was not ($p = 0.440$). The mean electrofishing catch rates for Snub-nosed Garfish was 18 times higher in summer compared to winter and lowest around the Point sites. Catch rates increased at FAS, Control and Reference sites following the installation of the FAS (Figure 31). However, the scale of the change was only statistically significant for FAS and Control sites.

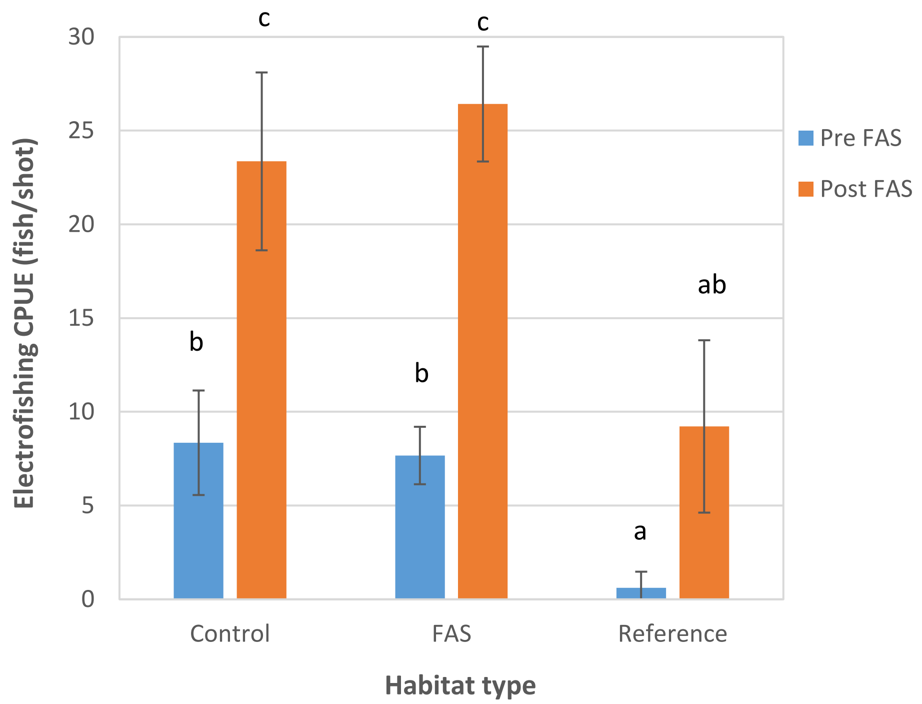


Figure 31 Combined electrofishing catch rates (± s.e.) for Snub-nosed Garfish pre and post FAS installation at the different habitat sites. The letters above each column indicate which values were significantly different according to Fisher's LSD test. Values with the same letter are not significantly different.

The GLM for the electrofishing catch of Snub-nosed Garfish found that although FAS type was a significant factor ($p < 0.001$), the interaction between FAS type and installation status was not significant ($p = 0.640$). The electrofishing catch rates increased substantially at all sites in the post FAS installation period. The scale of the increases was significant for all FAS types and the Control sites, but not the Reference sites (Figure 32).

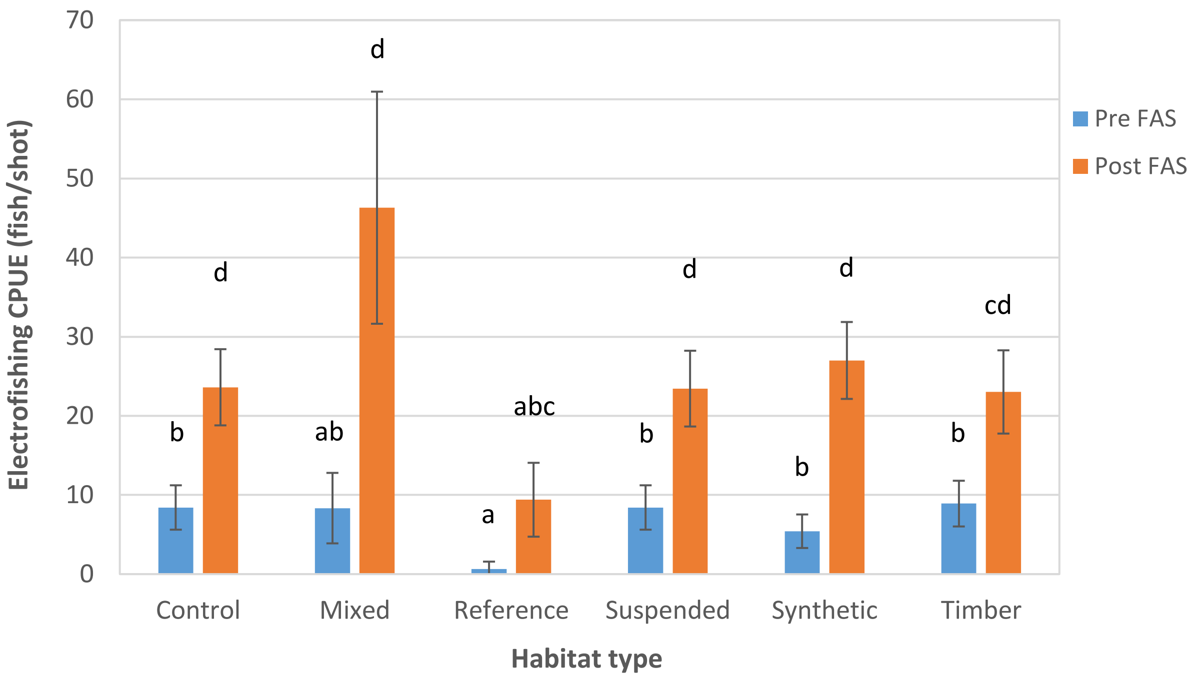


Figure 32 Combined electrofishing catch rates (± s.e.) for Snub-nosed Garfish pre and post FAS installation at the different FAS type sites. The letters above each column indicate which values were significantly different according to Fisher's LSD test. Values with the same letter are not significantly different.

Barred Grunter

The electrofishing catch rates for Barred Grunter followed very similar trends to those observed in Bony Bream. Neither habitat group nor installation status were significant factors, but the interaction between habitat group and installation was significant (p = 0.015). This was driven by the comparatively low catch rate in the pre installation surveys at the Reference site and consistently high catches at all other locations and periods. Neither FAS type or the interaction between FAS type and installation status were statistically significant (p > 0.092). The catch rate was consistently high across all sites, except the Reference sites, with the only significant change being the substantial increase in catch rate at the Reference site (Figure 33).

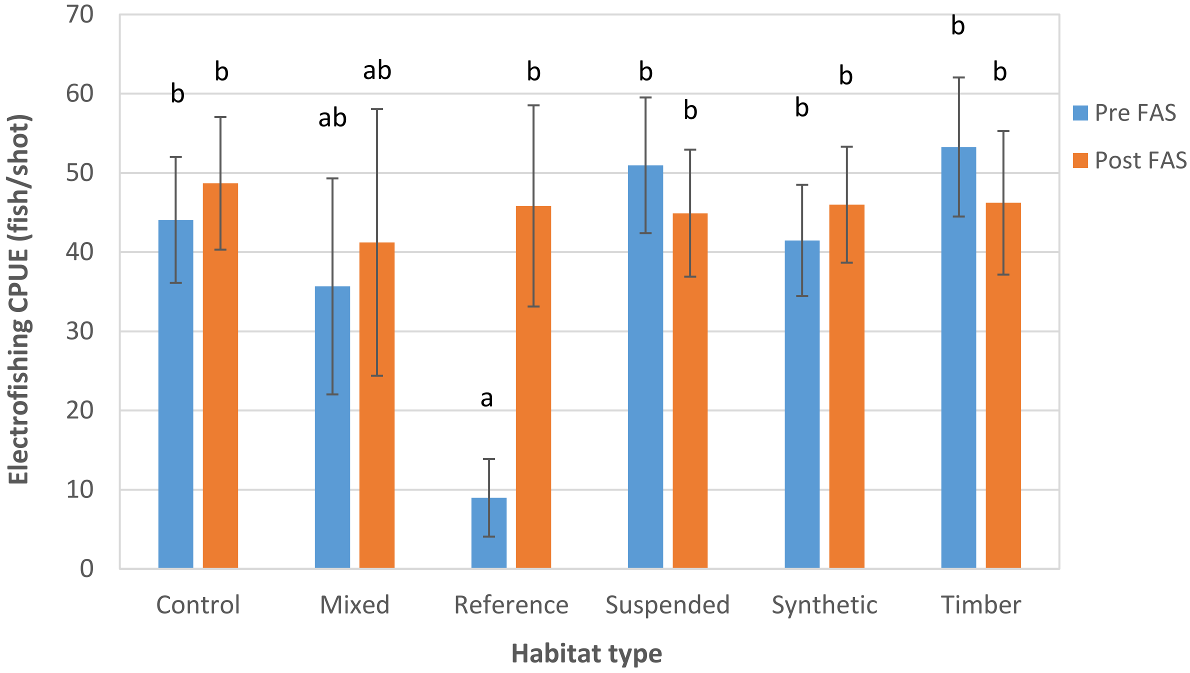


Figure 33 Combined electrofishing catch rates (± s.e.) for Barred Grunter pre and post FAS installation at the different FAS type sites. The letters above each column indicate which values were significantly different according to Fisher's LSD test. Values with the same letter are not significantly different.

Unspecked Hardyhead

The GLM for the electrofishing catch of unspecked Hardyhead found habitat group and season were not significant factors, but installation status (p < 0.001) and the interaction between habitat group and installation (p = 0.035) were significant. Significant increases occurred in all habitat groups post FAS installation (Figure 34).

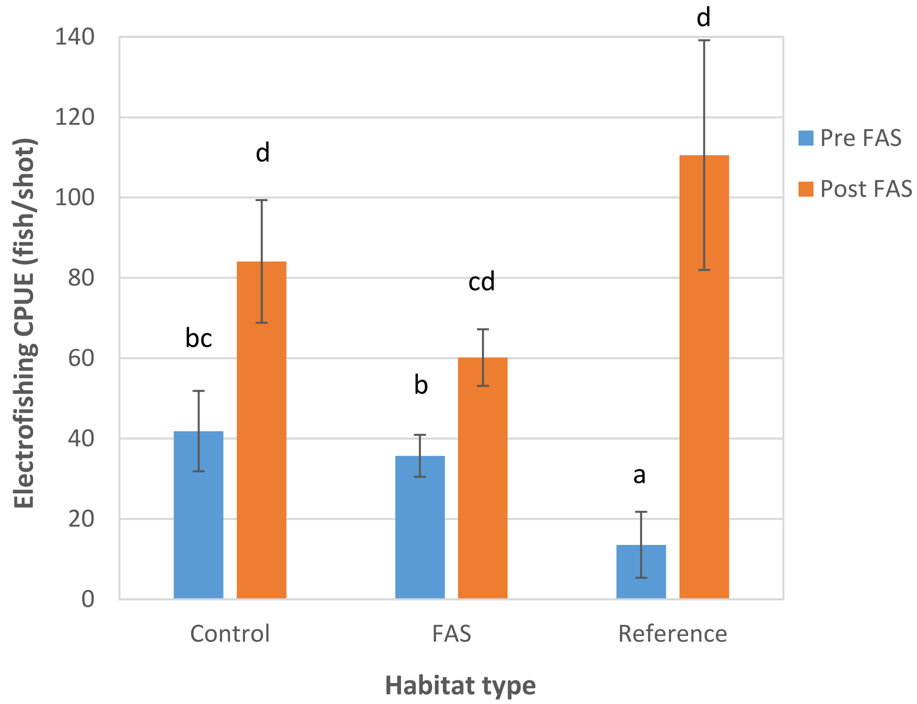


Figure 34 Combined electrofishing catch rates (± s.e.) for unspecked Hardyhead pre and post FAS installation at the different habitat sites. The letters above each column indicate which values were significantly different according to Fisher's LSD test. Values with the same letter are not significantly different.

FAS type and the interaction between FAS type and installation status were not significant ($p > 0.120$). The unspecked Hardyhead catch rate increased substantially at all sites in the post FAS installation period, but the scale of the increases was only significant for the Control, Reference and synthetic FAS sites (Figure 35).

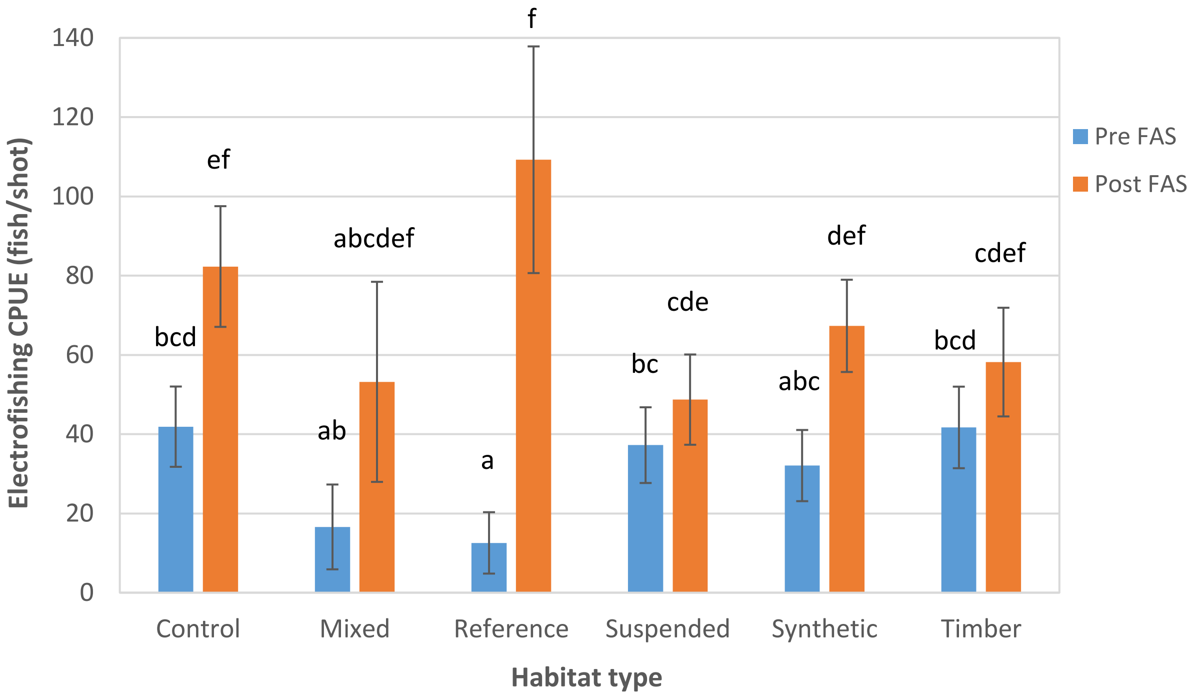


Figure 35 Combined electrofishing catch rates (± s.e.) for unspecked Hardyhead pre and post FAS installation at the different FAS type sites. The letters above each column indicate which values were significantly different according to Fisher's LSD test. Values with the same letter are not significantly different.

Australian Smelt

The electrofishing catch rate of Australian Smelt displayed significant seasonal ($p < 0.001$) and geographic ($p < 0.001$) trends. Catch rates were almost three times higher in winter and much higher in Steep bays than other cluster types. Catch rates at all habitat sites increased significantly in the period following the installation of the FAS (Figure 36). FAS sites showed the smallest increase, whilst the values and increases at the Control and Reference sites were similar.

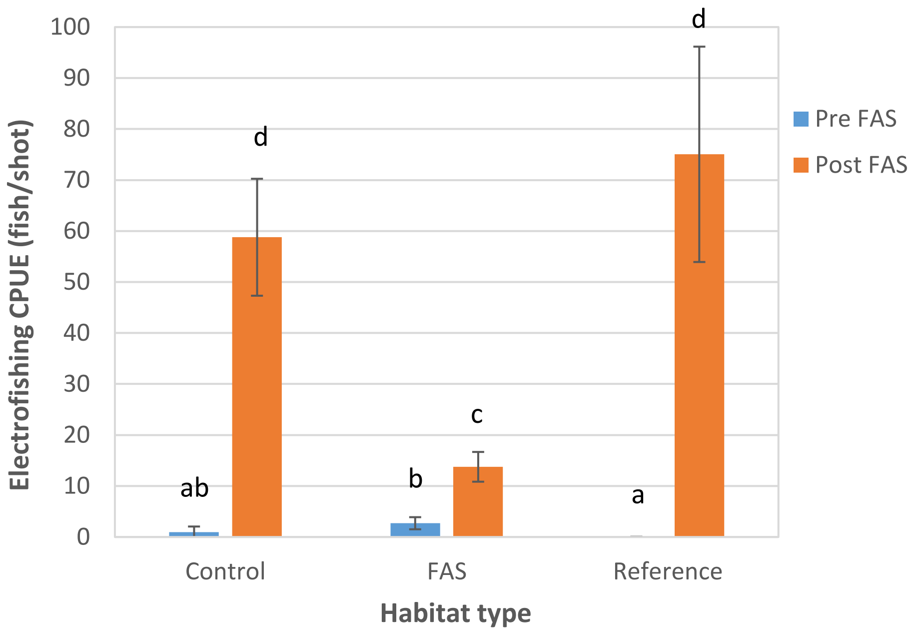


Figure 36 Combined electrofishing catch rates (± s.e.) for Australian Smelt pre and post FAS installation at the different habitat sites. The letters above each column indicate which values were significantly different according to Fisher's LSD test. Values with the same letter are not significantly different.

The GLM for the electrofishing catch of Australian Smelt found FAS type, installation status and the interaction between FAS type and installation status to all be significant factors ($p < 0.001$). The catch rates for Australian Smelt were highly variable between sites (Figure 37). The species was not detected at the mixed FAS sites, and only at low abundance at most other sites during the pre-FAS installation period. In the post FAS installation period, the catch rates increased significantly at both the Control and Reference sites. Much smaller, but still significant, increases occurred at the timber and synthetic FAS sites. The opposite trend was observed at the suspended FAS sites where catch rates decreased slightly, but not significantly.

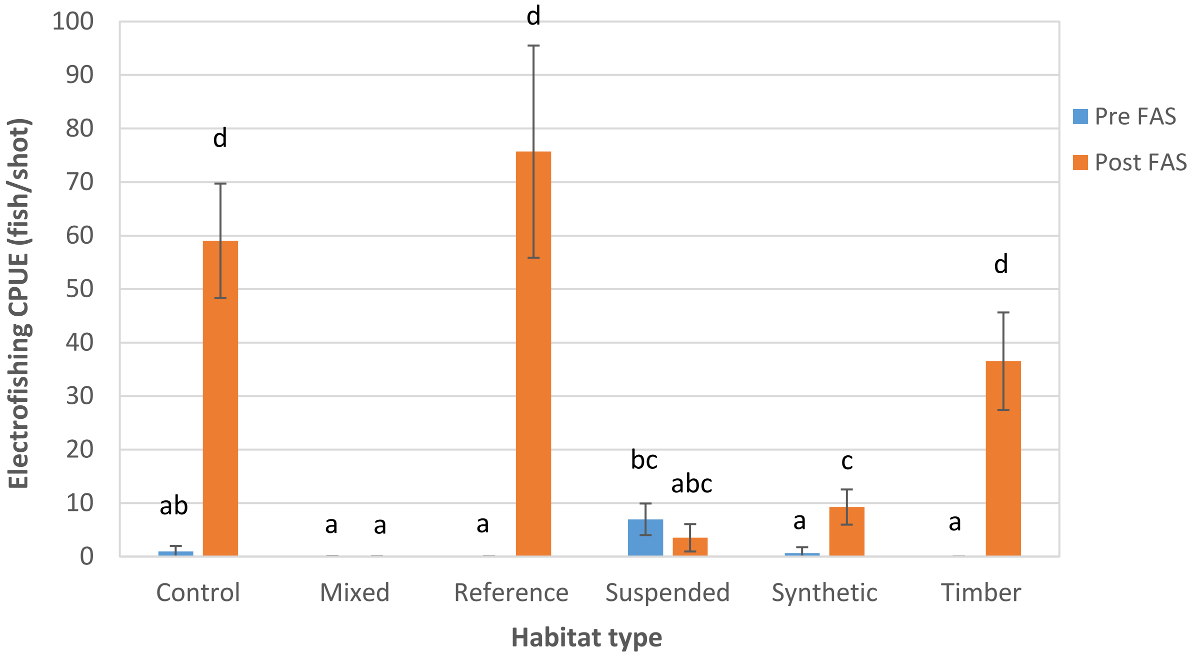


Figure 37 Combined electrofishing catch rates (± s.e.) for Australian Smelt pre and post FAS installation at the different FAS type sites. The letters above each column indicate which values were significantly different according to Fisher's LSD test. Values with the same letter are not significantly different.

Carp Gudgeon

The GLM for the electrofishing catch of Carp Gudgeon found season ($p < 0.001$) and installation status were significant factors ($p < 0.001$), but habitat group and the interaction between habitat group and installation were not significant ($p > 0.228$). Carp Gudgeon electrofishing catch rates were four times higher in winter and highest adjacent to deeper water at the Steep Bay and Point Cluster sites. The catch rates at all habitat sites showed the same trend and increased significantly in the period following installation of the FAS (Figure 38). Baseline levels of Carp Gudgeon were very low, whilst post-FAS installation catch rates were moderate to high all around the impoundment and in all habitat groups.

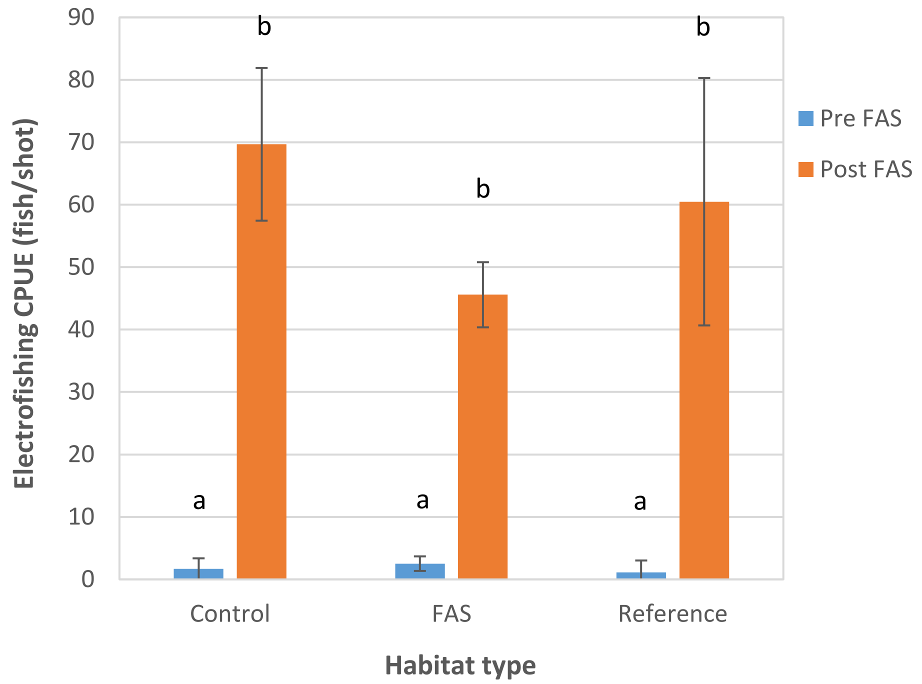


Figure 38 Combined electrofishing catch rates (± s.e.) for Carp Gudgeon pre and post FAS installation at the different habitat sites. The letters above each column indicate which values were significantly different according to Fisher's LSD test. Values with the same letter are not significantly different.

FAS type and the interaction between FAS type and installation status were not found to be significant factors ($p > 0.376$) in the electrofishing catch rate for Carp Gudgeon. Carp Gudgeon catch rates increased significantly at all sites in the post FAS installation period (Figure 39). There were no clear differences between the Control, Reference and different FAS sites, although catches were lowest at the synthetic and suspended FAS sites.

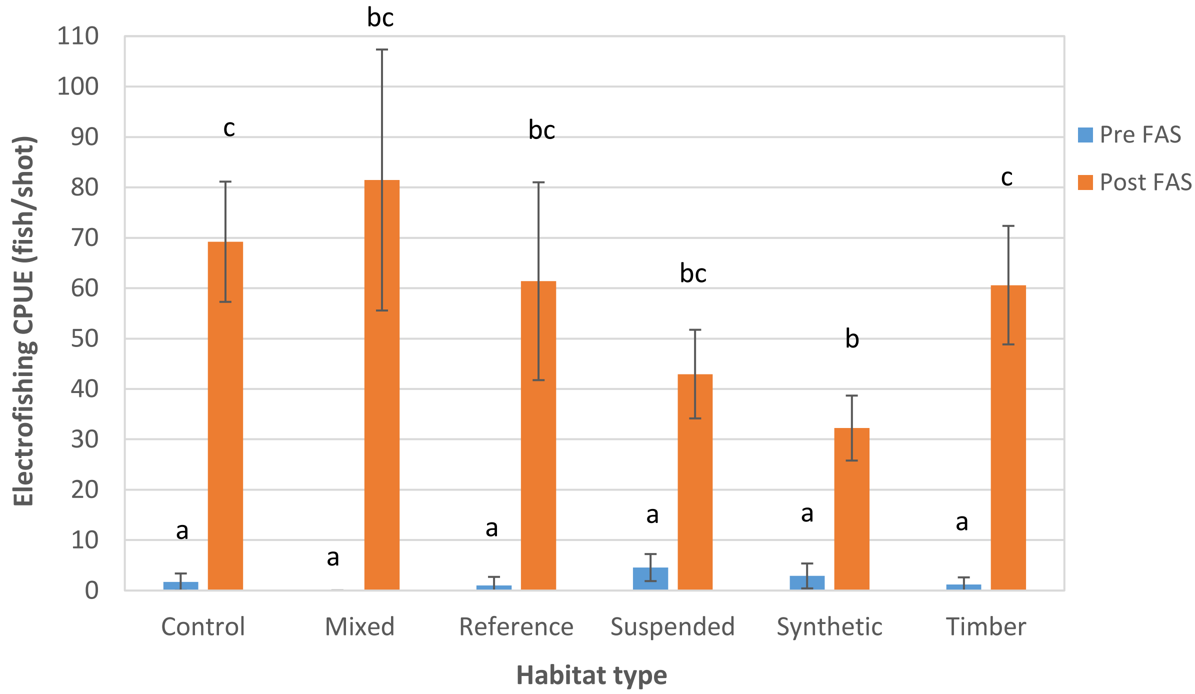


Figure 39 Combined electrofishing catch rates (± s.e.) for Carp Gudgeon pre and post FAS installation at the different FAS type sites. The letters above each column indicate which values were significantly different according to Fisher's LSD test. Values with the same letter are not significantly different.

Olive Perchlet

The GLM results for Olive Perchlet electrofishing catch rates found season, cluster, habitat group and installation status to all be significant factors ($p < 0.001$). Catch rates were 3.6 times higher in summer compared to winter, and highest in the Bay and Point clusters. The electrofishing catch rates for Olive Perchlet at the FAS and Control sites both increased significantly following the installation of the FAS (Figure 40) whilst no change occurred at the Reference sites.

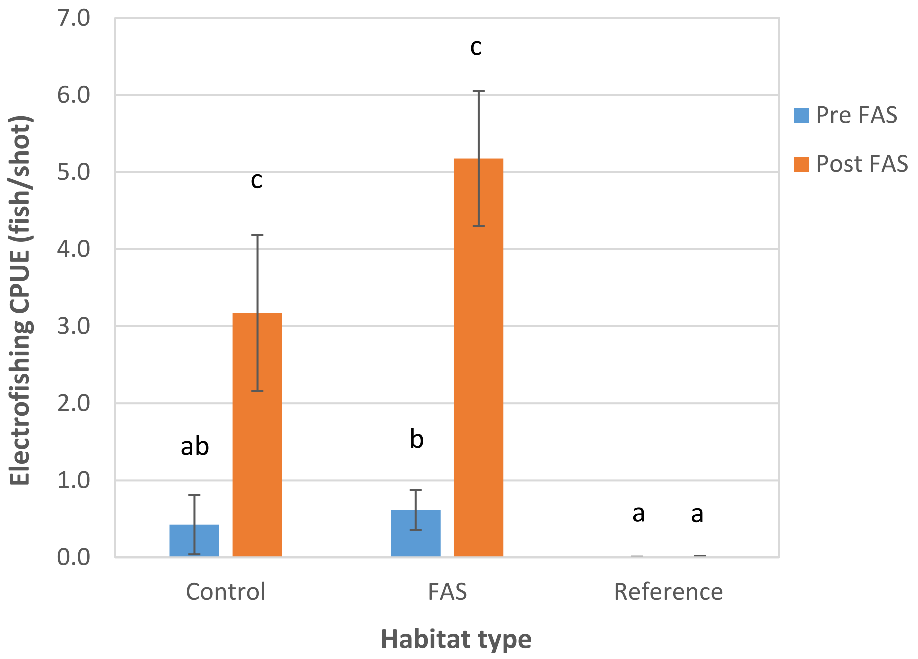


Figure 40 Combined electrofishing catch rates (± s.e.) for Olive Perchlet pre and post FAS installation at the different habitat sites. The letters above each column indicate which values were significantly different according to Fisher's LSD test. Values with the same letter are not significantly different.

The GLM found FAS type ($p < 0.001$) and the interaction between FAS type and installation status ($p = 0.039$) to both be significant factors influencing the electrofishing catch rate. Olive Perchlet were only captured at low abundance in Cressbrook Dam and were absent at the Reference site. At the Control, synthetic FAS and timber FAS sites, the catch rates increased significantly in the post FAS installation period (Figure 41). No changes were observed at the Reference or suspended FAS sites, whilst the increase at the mixed FAS was not significant in scale.

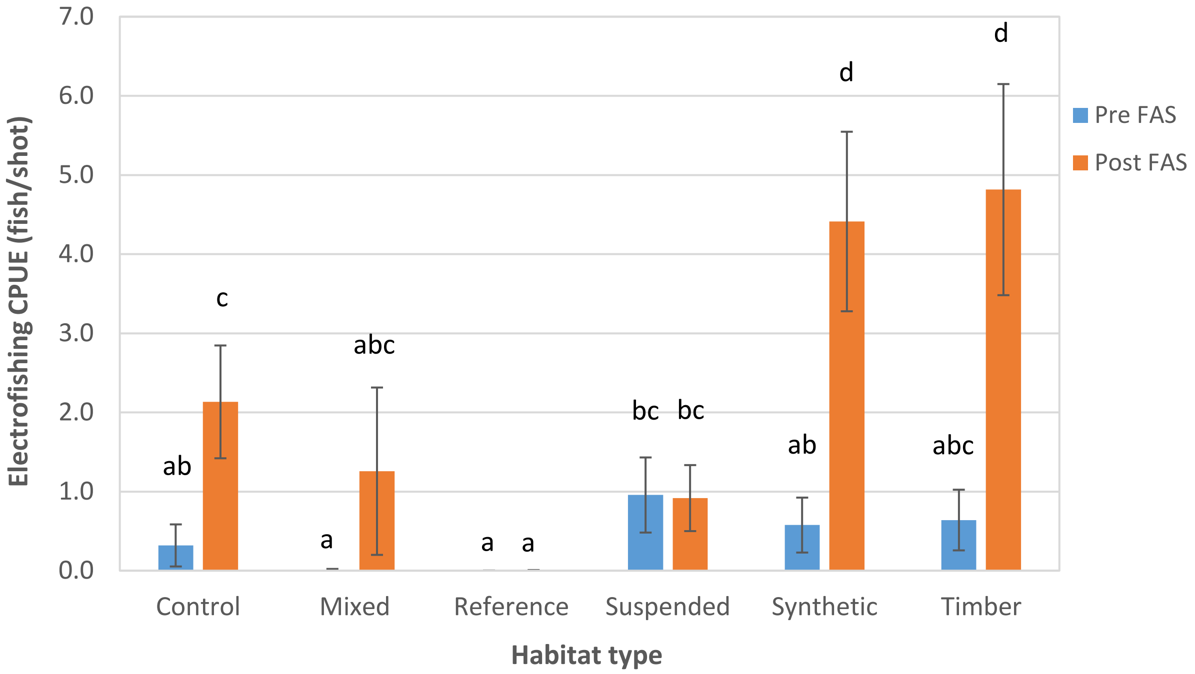


Figure 41 Combined electrofishing catch rates (± s.e.) for Olive Perchlet pre and post FAS installation at the different FAS type sites. The letters above each column indicate which values were significantly different according to Fisher's LSD test. Values with the same letter are not significantly different.

Mosquitofish

The GLM results for the electrofishing catch rates of Mosquitofish found season, cluster, habitat group and installation status to all be significant ($p < 0.001$) effects. Catch rates for Mosquitofish at the FAS and Control sites both increased significantly following the installation of the FAS (Figure 42). No Mosquitofish were detected at the Reference sites or around Points. The electrofishing catch rates were approximately five times higher in summer and far greater in Bay and Steep Bay cluster sites.

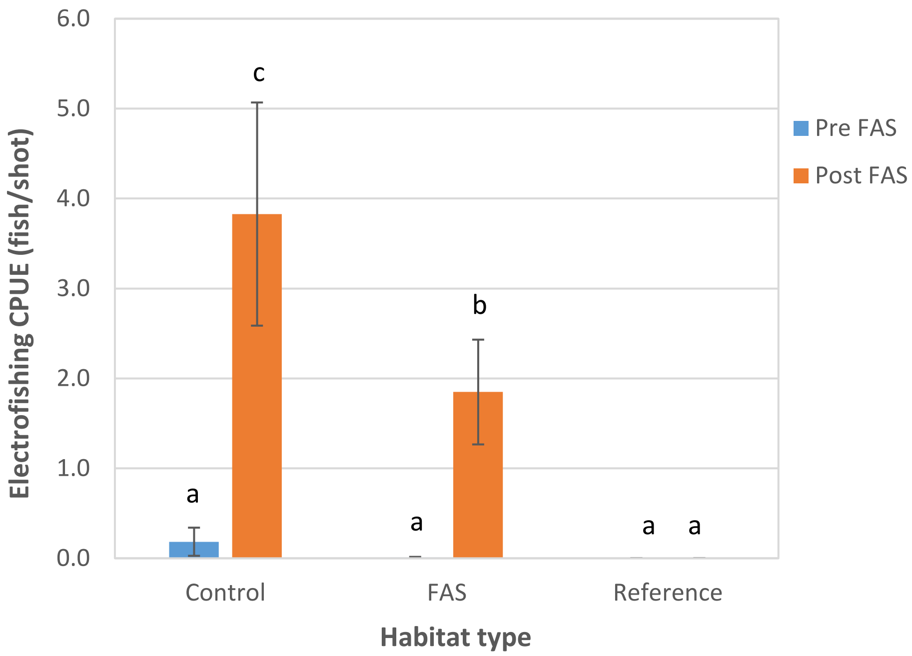


Figure 42 *Combined electrofishing catch rates (± s.e.) for Mosquitofish pre and post FAS installation at the different habitat sites. The letters above each column indicate which values were significantly different according to Fisher's LSD test. Values with the same letter are not significantly different.*

The GLM for the electrofishing catch of Mosquitofish found FAS type to be a significant factor ($p < 0.001$), but the interaction between FAS type and installation status was not ($p = 0.597$). Mosquitofish were only captured in low abundance at all sites. Where present, the Mosquitofish catch rates increased significantly at all sites in the post FAS installation period (Figure 43).

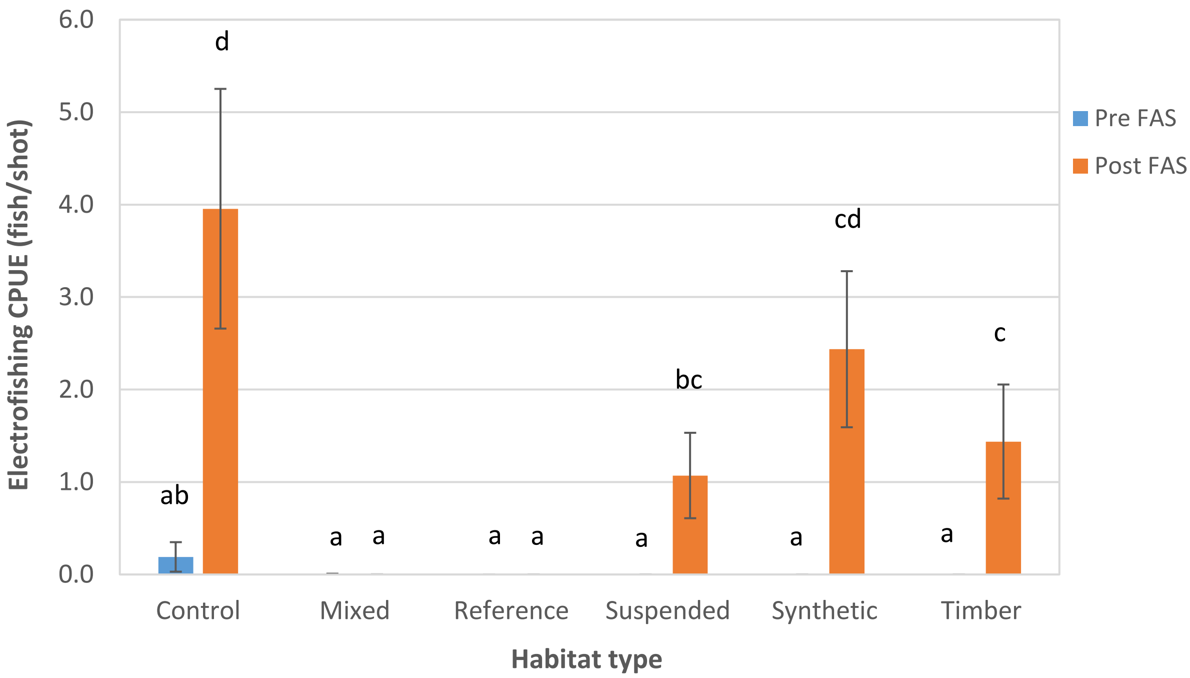


Figure 43 *Combined electrofishing catch rates (± s.e.) for Mosquitofish pre and post FAS installation at the different FAS type sites. The letters above each column indicate which values were significantly different according to Fisher's LSD test. Values with the same letter are not significantly different.*

Goldfish

The electrofishing catch rates for Goldfish were very low in Cressbrook Dam. The GLM for the electrofishing catch found season, habitat group and the interaction between habitat group and installation status to all be significant factors ($p < 0.001$). At the FAS and Reference sites the catch rate increased in the period after FAS installation, whilst at the Control site the catch rate decreased significantly (Figure 44).

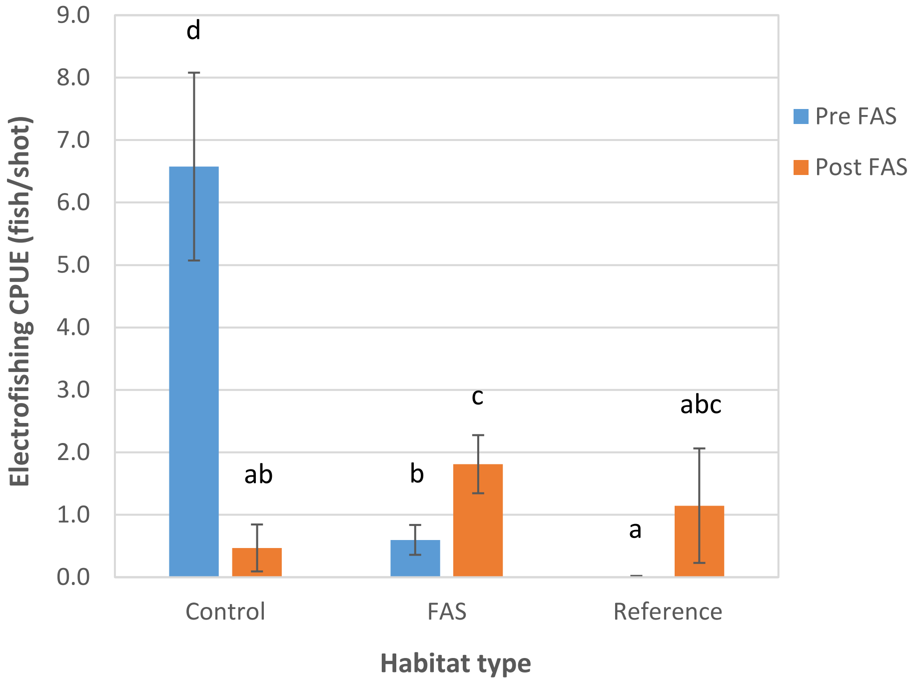


Figure 44 Combined electrofishing catch rates (± s.e.) for Mosquitofish pre and post FAS installation at the different habitat sites. The letters above each column indicate which values were significantly different according to Fisher's LSD test. Values with the same letter are not significantly different.

The GLM for the electrofishing catch of Goldfish found FAS type and the interaction between FAS type and installation status to both be significant factors ($p < 0.001$). Goldfish were absent at many sites in the baseline surveys, but showed small, not significant, increases at the Reference, suspended, synthetic, and timber FAS sites (Figure 45). At the Control sites the catch rate decreased significantly in the post-FAS installation period.

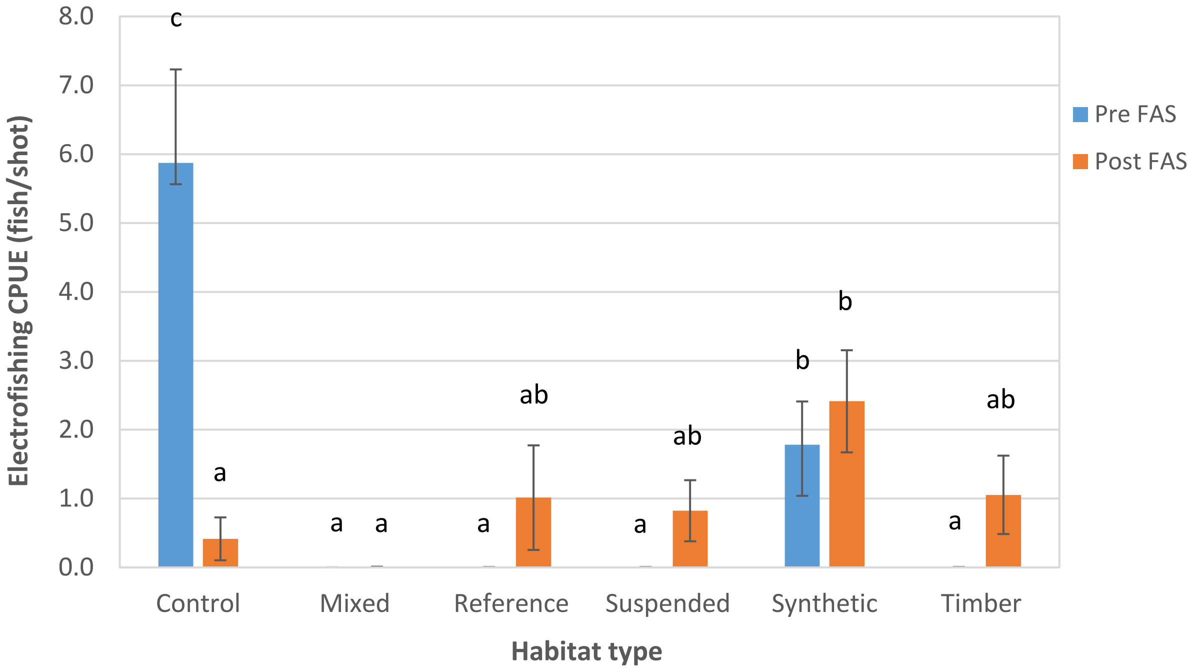


Figure 45 Combined electrofishing catch rates (± s.e.) for Goldfish pre and post FAS installation at the different FAS type sites. The letters above each column indicate which values were significantly different according to Fisher's LSD test. Values with the same letter are not significantly different

Acoustic tracking results

A total of 30 Golden Perch (360-517 mm TL) and 30 Australian Bass (306-480 mm FL) were tagged and released in September and November 2018 (Tables 7-8).

Table 7 Attributes of the Australian Bass acoustically tagged and the injected dose of slow-release antibiotic, oxytetracycline (OTC).

Tag	Date	Length (mm)	Weight (g)	OTC (ml)
A69-1602-27532	20/09/2018	398	1082	0.20
A69-1602-27533	20/09/2018	350	816	0.16
A69-1602-27534	20/09/2018	421	1436	0.28
A69-1602-27535	20/09/2018	373	876	0.17
A69-1602-27536	20/09/2018	370	904	0.18
A69-1602-27537	20/09/2018	450	1644	0.30
A69-1602-27538	20/09/2018	388	910	0.18
A69-1602-27539	20/09/2018	410	1298	0.26
A69-1602-27540	20/09/2018	424	1434	0.28
A69-1602-27541	20/09/2018	358	820	0.16
A69-1602-27542	20/09/2018	382	986	0.20
A69-1602-27543	20/09/2018	465	1796	0.36
A69-1602-27544	20/09/2018	395	1180	0.24
A69-1602-27545	20/09/2018	365	840	0.17
A69-1602-27546	20/09/2018	370	824	0.16
A69-1602-27547	20/09/2018	455	1656	0.33
A69-1602-27548	20/09/2018	480	2134	0.43
A69-1602-27549	29/11/2018	434	1480	0.09
A69-1602-27550	29/11/2018	373	962	0.06
A69-1602-27551	29/11/2018	374	820	0.05
A69-1602-27552	29/11/2018	472	1788	0.10
A69-1602-27553	29/11/2018	457	1590	0.10
A69-1602-27554	29/11/2018	406	1114	0.07
A69-1602-27555	29/11/2018	463	1942	0.13
A69-1602-27556	29/11/2018	410	1328	0.08
A69-1602-27557	29/11/2018	412	1082	0.07
A69-1602-27558	29/11/2018	427	1357	0.09
A69-1602-27559	29/11/2018	418	1302	0.09
A69-1602-27560	29/11/2018	372	852	0.06
A69-1602-27561	29/11/2018	306	518	0.03

Table 8 Attributes of the Golden Perch acoustically tagged and oxytetracycline (OTC) injection dose.

Tag	Release date	Length (mm)	Weight (g)	OTC (ml)
A69-1602-25028	20/09/2018	509	2308	0.46
A69-1602-25029	20/09/2018	430	1136	0.28
A69-1602-25030	20/09/2018	419	1000	0.20
A69-1602-25031	20/09/2018	360	674	0.13
A69-1602-25032	20/09/2018	460	1694	0.34
A69-1602-25033	20/09/2018	410	980	0.20
A69-1602-25034	20/09/2018	423	1082	0.21
A69-1602-25035	20/09/2018	410	1170	0.24
A69-1602-25036	20/09/2018	392	808	0.17
A69-1602-25037	20/09/2018	468	1592	0.32
A69-1602-25038	20/09/2018	433	1178	0.22
A69-1602-25039	20/09/2018	430	1090	0.20
A69-1602-25040	20/09/2018	398	900	0.19
A69-1602-25041	20/09/2018	425	1166	0.21
A69-1602-25042	20/09/2018	410	926	0.19
A69-1602-25043	20/09/2018	403	870	0.17
A69-1602-25044	20/09/2018	435	1298	0.26
A69-1602-25045	20/09/2018	449	1100	0.22
A69-1602-25046	20/09/2018	367	654	0.13
A69-1602-25047	20/09/2018	399	1006	0.20
A69-1602-25048	20/09/2018	427	1018	0.20
A69-1602-25049	20/09/2018	517	2770	0.54
A69-1602-25050	20/09/2018	485	1910	0.39
A69-1602-25051	20/09/2018	410	1028	0.20
A69-1602-25052	29/11/2018	484	1982	0.13
A69-1602-25053	29/11/2018	402	882	0.06
A69-1602-25054	29/11/2018	398	1110	0.07
A69-1602-25055	29/11/2018	423	1248	0.08
A69-1602-25056	29/11/2018	467	1902	0.13
A69-1602-25057	29/11/2018	466	1844	0.13

The number of tagged fish detected in the VPS tracking area varied between seasons. Twenty-two Golden Perch and 17 Australian Bass were detected every season (Table 9). One Golden Perch was not detected in the array at any time and four Golden Perch were detected in two or fewer seasons.

Figure 46 One of the acoustically tagged Golden Perch recaptured during an electrofishing survey 18 months after tagging and release. Note the yellow dart tag used to help anglers easily visually identify the acoustically tagged fish.

Table 9 Total number of tagged fish detected in the acoustic array each season.

Period	Australian Bass (n=30)	Golden Perch (n=30)
Spring 2018	25	29
Summer 2019	24	27
Autumn 2019	23	26
Winter 2019	23	26
Spring 2019	22	25
Summer 2020	22	24
Autumn 2020	20	25
Winter 2020	20	25

A total of 3,730,777 fish positions were able to be calculated by the VPS from receiver detections: 2,230,475 positions for Golden Perch and 1,500,302 positions for Australian Bass. After data filtering for horizontal position error, the initial acclimation period and outliers, 72% of the overall fish positional data was retained. For Golden Perch 69% (1,538,080) of VPS positions and for Australian Bass 77% (1,158,976) of VPS positions were available for statistical analysis.

Both fish species moved comprehensively around the entire tracking area, enabling site preferences to be determined. EDA ratios were used to statistically compare changes in the fish proximity to different habitat types pre and post-FAS installation, whilst KDEs were used to visually represent area utilisation intensity and the probability of fish being present at a site. Together, these provided a thorough examination of fish utilisation of FAS and changes in fish distribution following FAS installation. A seasonal trend in movement patterns was observed for both species, likely related to spawning cues associated with temperature and photo-period changes.

Habitat use within the VPS tracking array was non-random for both Australian Bass and Golden Perch, and there was a significant interaction between habitat type and installation status (MANOVA; $p < 0.01$). This indicates fish use of the FAS differed significantly pre and post-installation between the FAS types.

Comparison of EDA between Control and FAS sites

Univariate tests indicated that the baseline mean proximity of Australian Bass to both Control sites (EDA: 0.80) and sites where FAS would be installed (EDA: 0.77) was significantly ($p < 0.01$) closer than expected from random (Table 10). In Golden Perch the mean proximity to Control sites did not differ from random (EDA: 1.05), but the proximity to sites where FAS would be installed was significantly less than expected from random (EDA: 0.45, $p < 0.001$). This indicated a strong baseline preference for positions near the shore in Golden Perch.

Table 10 Mean EDA ratios of Australian Bass and Golden Perch to Control and FAS habitat sites pre and post-FAS installation.

Species	Installation status	Control	FAS
Australian Bass	Pre	0.8019	0.7737
	Post	0.9022	0.8391
Golden Perch	Pre	1.0484	0.4543
	Post	1.1037	0.4354

Australian Bass

In Australian Bass, the ANOVA identified FAS installation ($p = 0.005$) and season ($p < 0.001$) to be significant factors in the fish positions detected. A significant interaction between season and habitat group ($p < 0.001$) was also observed and the interaction between habitat group and installation was almost statistically significant ($p = 0.081$). Habitat, the interactions between habitat and installation status, and the interaction between habitat, installation status and season were not all significant ($p > 0.124$).

The Australian Bass EDA ratios for both FAS and Control sites increased after the installation of FAS (Figure 47). The increase was greatest (+13%) and significant ($p = 0.015$) for the Control sites, and lower (+8%) and not significant ($p = 0.112$) for the FAS sites.

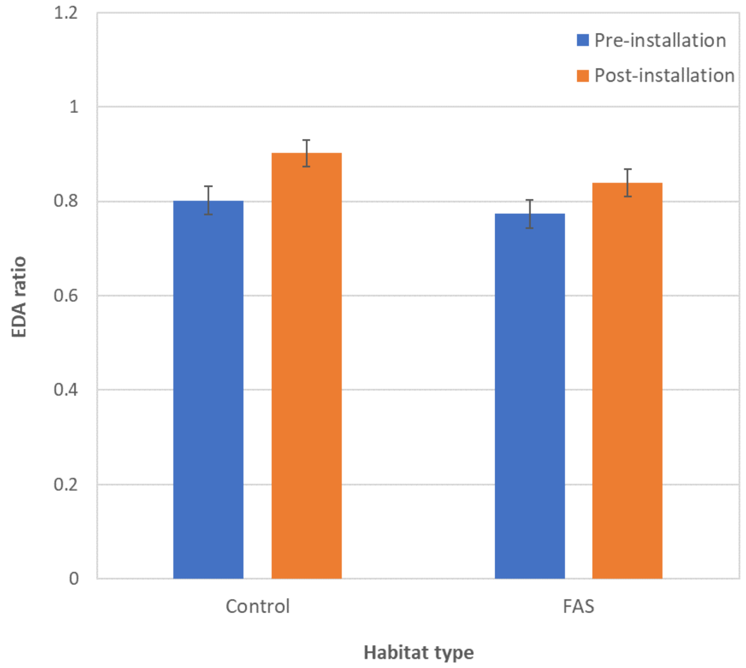


Figure 47 Mean EDA proximity ratios (± s.e.) for FAS and control sites for Australian Bass pre and post habitat installation. An EDA ratio of 1 indicates random use. A ratio < 1 indicates closer proximity than random and a ratio > 1 indicates further proximity than random.

The seasonal changes in mean EDA ratios were varied for Australian Bass (Figure 48). Fisher's LSD test found the mean EDA to Control sites decreased slightly (-1%), but not significantly ($p = 0.921$) in autumn from following FAS installation. Conversely the mean EDA to Control sites increased significantly after FAS installation for summer (+38%, $p = 0.014$) and spring (+30%, $p = 0.019$) and insignificantly for winter (+3%, $p = 0.936$). The mean EDA ratios to FAS sites followed a slightly different pattern. Fisher's LSD test found the mean EDA ratios increased slightly, but not significantly, following FAS installation for spring (+14%, $p = 0.176$), summer (+15%, $p = 0.129$) and autumn (+6%, $p = 0.542$). Conversely the mean EDA to FAS sites decreased slightly, but not significantly, for winter (-38%, $p = 0.721$) after FAS installation.

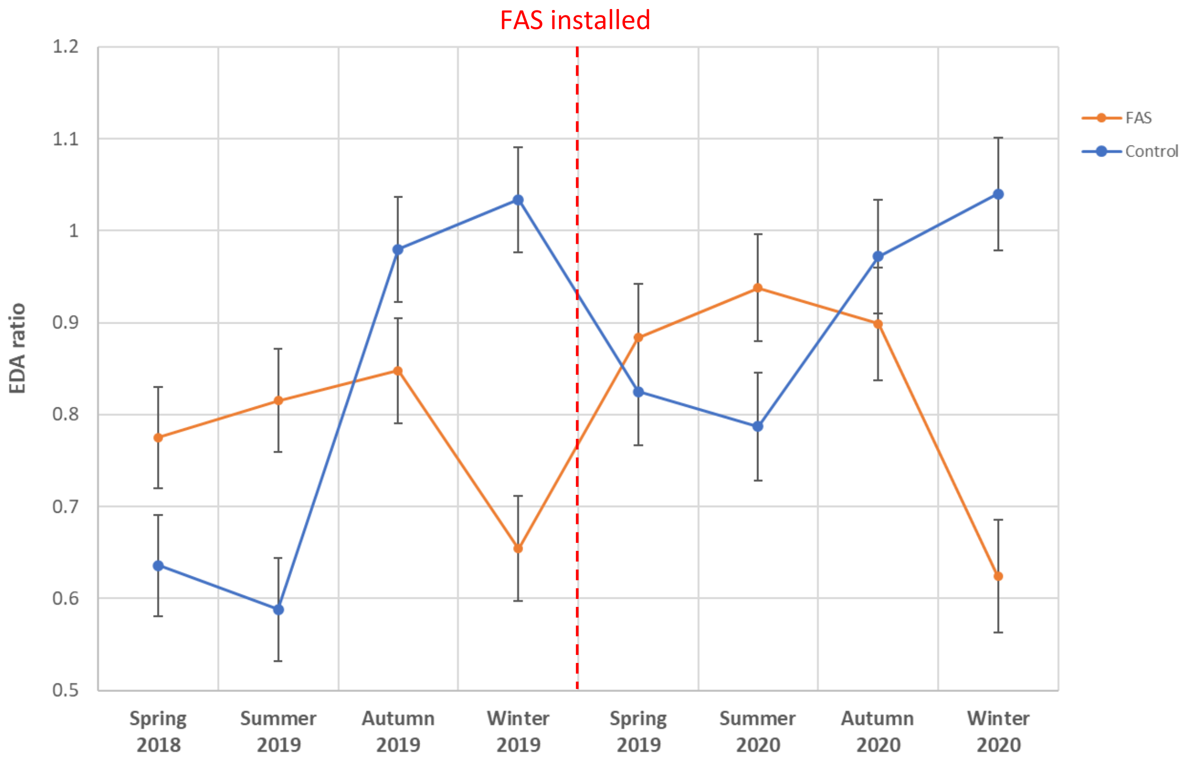


Figure 48 Mean seasonal EDA proximity ratios (± s.e.) for FAS and control sites in Australian Bass. An EDA ratio of 1 indicates random use. A ratio < 1 indicates closer proximity than random and a ratio > 1 indicates further proximity than random. Spring 2018 to Winter 2019 were classed as pre-FAS installation, whilst Spring 2019 to Winter 2020 were classed as post-FAS installation.

<u>Golden Perch</u>

For Golden Perch, the mean proximity to Control sites increased slightly, but not significantly (+6%, $p = 0.268$, Table 8), following FAS installation. The opposite trend was observed in Golden Perch proximity to the FAS sites, where the mean proximity decreased slightly, but not significantly (-2%, $p = 0.699$).

The ANOVA identified only habitat type was a significant factor ($p < 0.001$) in the position of Golden Perch. Installation status, season and the interactions between these factors were all not statistically significant ($p > 0.294$). Very little change was observed between pre and post-installation of the FAS ($p = 0.592$) or between seasons ($p = 0.776$), and there were no significant interaction effects.

The mean EDA ratios for both FAS and Control sites did not change significantly ($p = 0.258$ and $p = 0.699$ respectively) following FAS installation, although different trends were observed (Figure 49). Post-installation mean EDA ratios increased slightly for Control sites (+5%), but decreased slightly for the FAS sites (-4%).

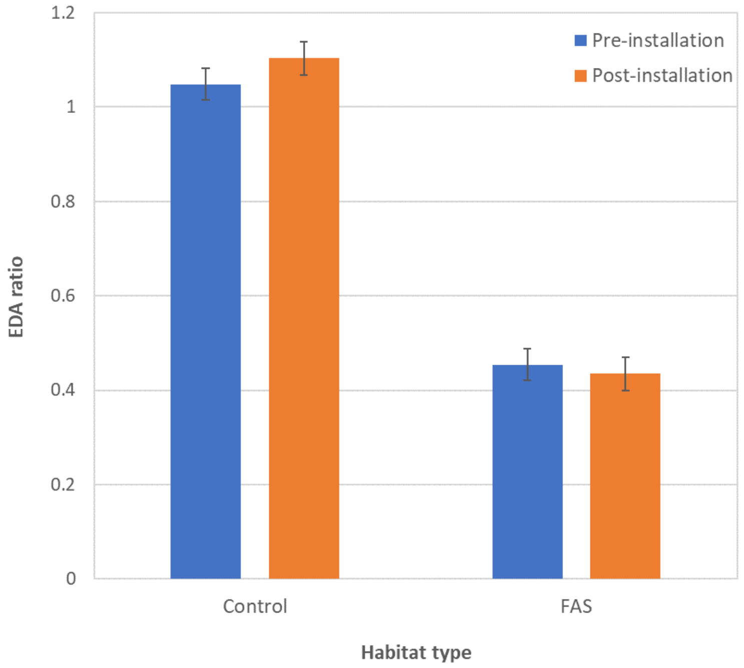


Figure 49 Mean EDA proximity ratios (± s.e.) for FAS and Control sites for Golden Perch pre and post habitat installation. An EDA ratio of 1 indicates random use. A ratio < 1 indicates closer proximity than random and a ratio > 1 indicates further proximity than random.

The mean seasonal EDA ratios were variable for Golden Perch (Figure 50). Mean EDA ratios remained much lower for FAS sites. Fisher's LSD test found the mean EDA ratios for Control sites decreased slightly (+1%, p = 0.846), but not significantly in autumn after FAS installation. Conversely the mean EDA to Control sites increased, but not significantly, following FAS installation for summer (+38%, p = 0.113) and spring (+30%, p = 0.126), and less so for winter (+3%, p = 0.278). The mean EDA ratios to FAS sites followed a slightly different pattern. Fisher's LSD test found the mean EDA ratios increased slightly, but not significantly following FAS installation for spring (+14%, p = 0.992), summer (+15%, p = 0744) and autumn (+6%, p = 0.597). Conversely the mean EDA to FAS sites decreased, but not significantly, for winter (-38%, p = 0.932) after FAS installation.

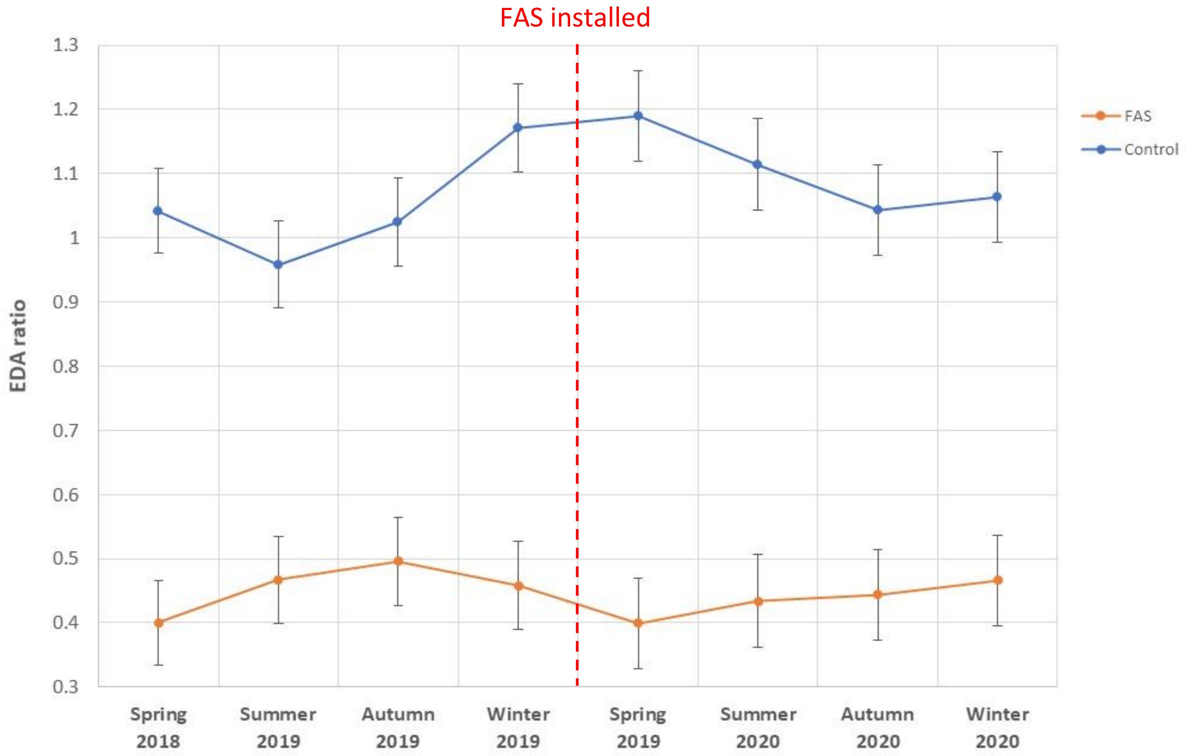


Figure 50 Mean seasonal EDA proximity ratios (± s.e.) for FAS and control sites in Golden Perch. An EDA ratio of 1 indicates random use. A ratio < 1 indicates closer proximity than random and a ratio > 1 indicates further proximity than random. Spring 2018 to Winter 2019 were classed as pre-FAS installation, whilst Spring 2019 to Winter 2020 were classed as post-FAS installation.

Comparison of EDA between different FAS types

The baseline mean proximity of Australian Bass to Control sites (EDA: 0.819) indicated fish were closer to the Control sites than expected from random. Similar baseline trends were observed for the timber, synthetic and suspended FAS sites (Table 11). However, the mean baseline proximity of Australian Bass to the mixed FAS site was greater than one, indicating a slight avoidance of the area. In Golden Perch, the mean proximity to Control sites did not differ from random (EDA: 1.05), but the proximity to sites where FAS would be installed were significantly less than expected from random. The baseline preference was strongest for proximity to sites where the suspended FAS were to be installed.

Table 11 EDA ratios of Australian Bass and Golden Perch to different habitat type sites pre- and post- FAS installation.

Species	Installation status	Control	Timber	Synthetic	Suspended	Mixed
Australian Bass	Pre	0.8019	0.9445	0.8099	0.8821	1.1239
	Post	0.9022	0.9641	0.7809	0.8191	0.9752
Golden Perch	Pre	1.0484	0.9519	0.7476	0.6003	0.9486
	Post	1.1037	0.9546	0.7517	0.6016	1.0086

<u>*Australian Bass*</u>

The ANOVA results for Australian Bass indicated significant influence on fish position for habitat type ($P < 0.001$), the interaction between habitat type and installation status ($P < 0.001$) and the interaction between habitat type and season ($P < 0.001$). There was also a significant higher order interaction between all three terms ($P = 0.022$). Installation status, season and the interaction between installation status and season were all not significant effects (p > 0.105). The interaction between habitat and installation status indicates fish use of the FAS differed significantly before and after FAS installation and the trends varied with the type of habitat.

A range of trends were observed in the Australian Bass mean EDA ratios to the various FAS types following their installation (Figure 51). At the Control site the mean EDA increased significantly (+13%, p = 0.015) post FAS installation. A similar trend was observed at the timber FAS, but the change was small and not significant (+2%, p = 0.5582). The mean EDA ratios for synthetic, suspended and mixed FAS sites all declined following FAS installation. For the mixed FAS, the mean EDA before FAS installation was greater than one indicating slight avoidance of these sites. Following FAS installation, the mean EDA ratio decreased significantly (-13%, p < 0.001) to less than one, indicating a slight preference for the mixed habitat type. The suspended FAS sites displayed a similar EDA ratio trend, but the result was almost, but not statistically significant (-7%, p = 0.06). The observed decrease in the mean EDA ratio at sites where synthetic FAS were installed was also not significant (-4%, p = 0.3864).

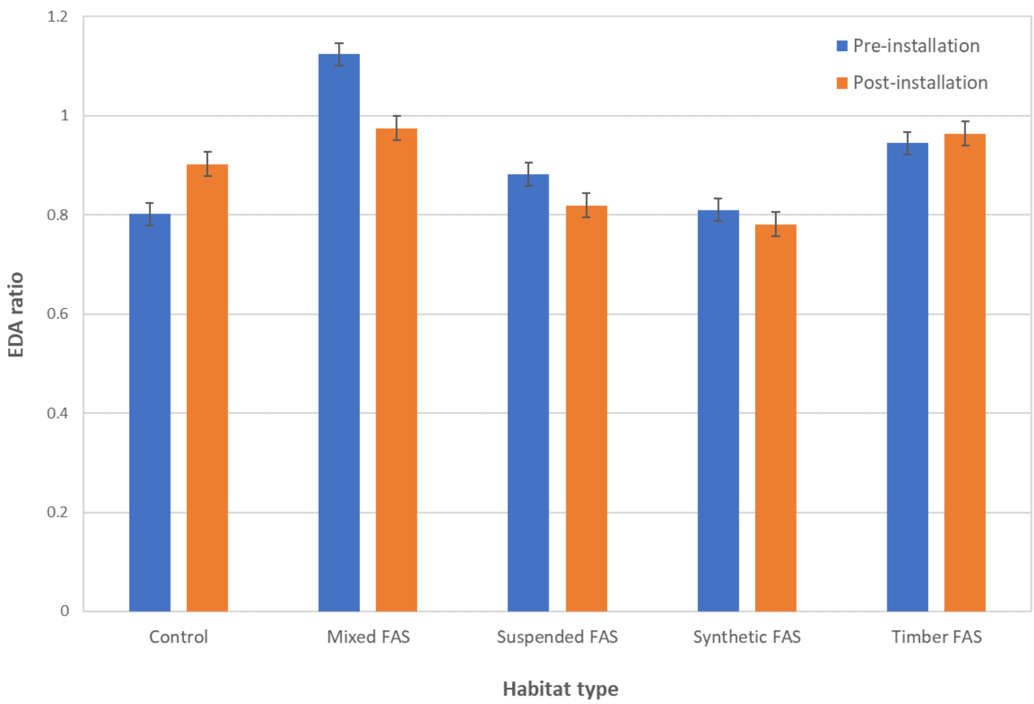


Figure 51 Mean EDA proximity ratios (± s.e.) to different FAS types for Australian Bass pre and post habitat installation. An EDA ratio of 1 indicates random use. A ratio < 1 indicates closer proximity than random and a ratio > 1 indicates further proximity than random.

The seasonal trends in fish position before and after FAS installation were relatively consistent in Australian Bass, with all the significant differences occurring during the spring and summer seasons (Figure 52). The same seasonal trends in EDA ratios occurred at the Control sites both pre and post FAS installation. However, post- installation, Fisher's LSD tests revealed mean EDA ratios increased significantly at the Control sites in both spring (+30%, p = 0.004) and summer (+34%, p = 0.003). Despite declining post-installation, no significant seasonal changes in mean EDA ratios were detected for timber FAS or synthetic FAS. The mean EDA ratios for suspended FAS significantly decreased before and after FAS installation during spring (-20%, p = 0.001). Significant declines in mean EDA ratios occurred following FAS installation for mixed FAS between corresponding springs (-18%, p = 0.001) and summers (-19%, p = 0.001).

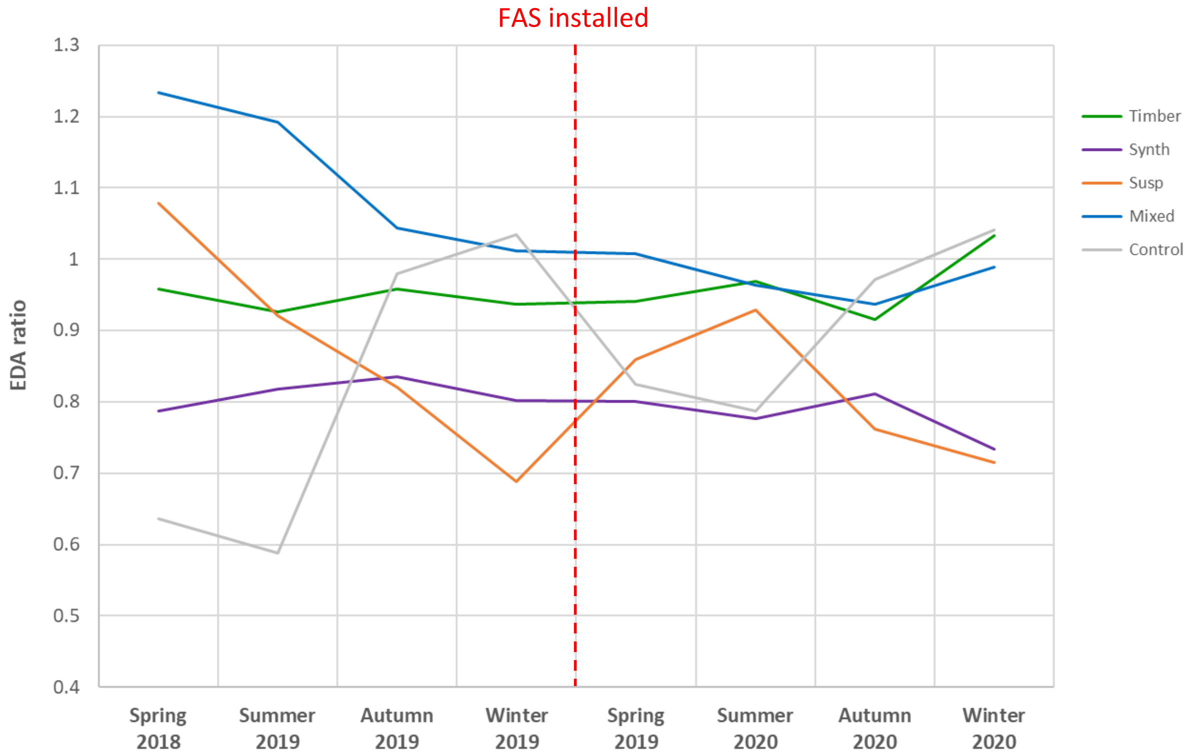


Figure 52 Mean seasonal EDA proximity ratios (± s.e.) to different FAS types for Australian Bass. An EDA ratio of 1 indicates random use. A ratio < 1 indicates closer proximity than random and a ratio > 1 indicates further proximity than random. Spring 2018 to Winter 2019 were classed as pre-FAS installation, whilst Spring 2019 to Winter 2020 were classed as post-FAS installation.

Golden Perch

In Golden Perch, the ANOVA identified only habitat type as being a significant factor ($p < 0.001$) in the fish positions detected. Installation status ($p = 0.258$) and season ($p = 0.438$) had no significant influence on the Golden Perch mean EDA ratios and there were no interactive effects ($p > 0.675$).

The mean EDA ratios for all FAS type sites did not change significantly ($P > 0.242$ for all sites) following FAS installation (Figure 53).

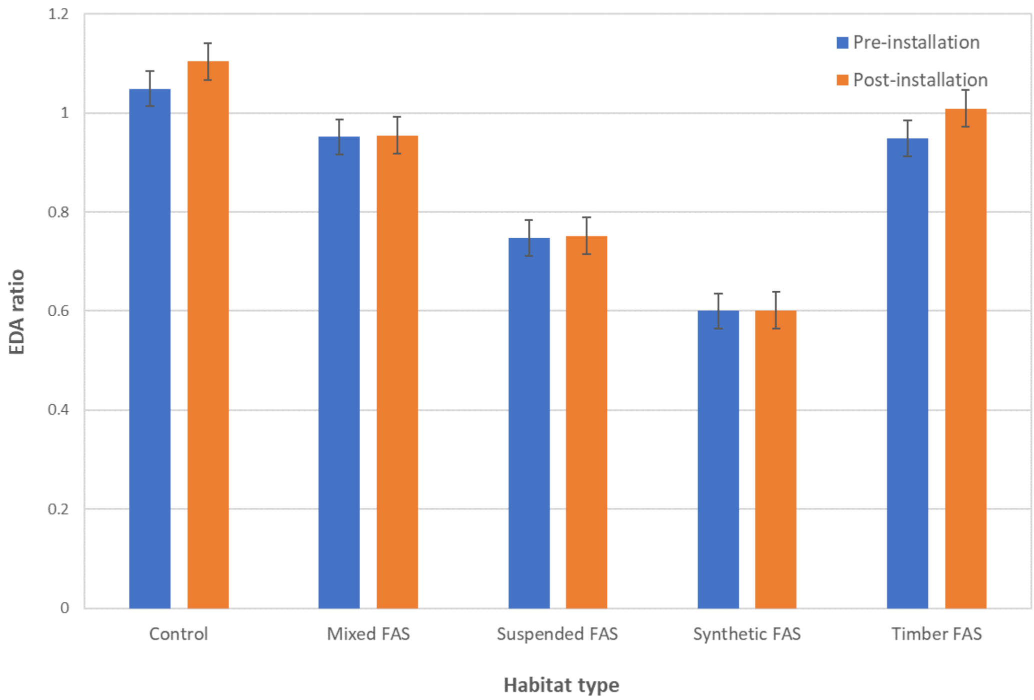


Figure 53 Mean EDA proximity ratios (± s.e.) to different FAS types for Golden Perch pre and post habitat installation. An EDA ratio of 1 indicates random use. A ratio < 1 indicates closer proximity than random and a ratio >1 indicates further proximity than random.

There were no significant differences in the Golden Perch mean EDA ratios between seasons pre or post-FAS installation ($p > 0.131$, Figure 54).

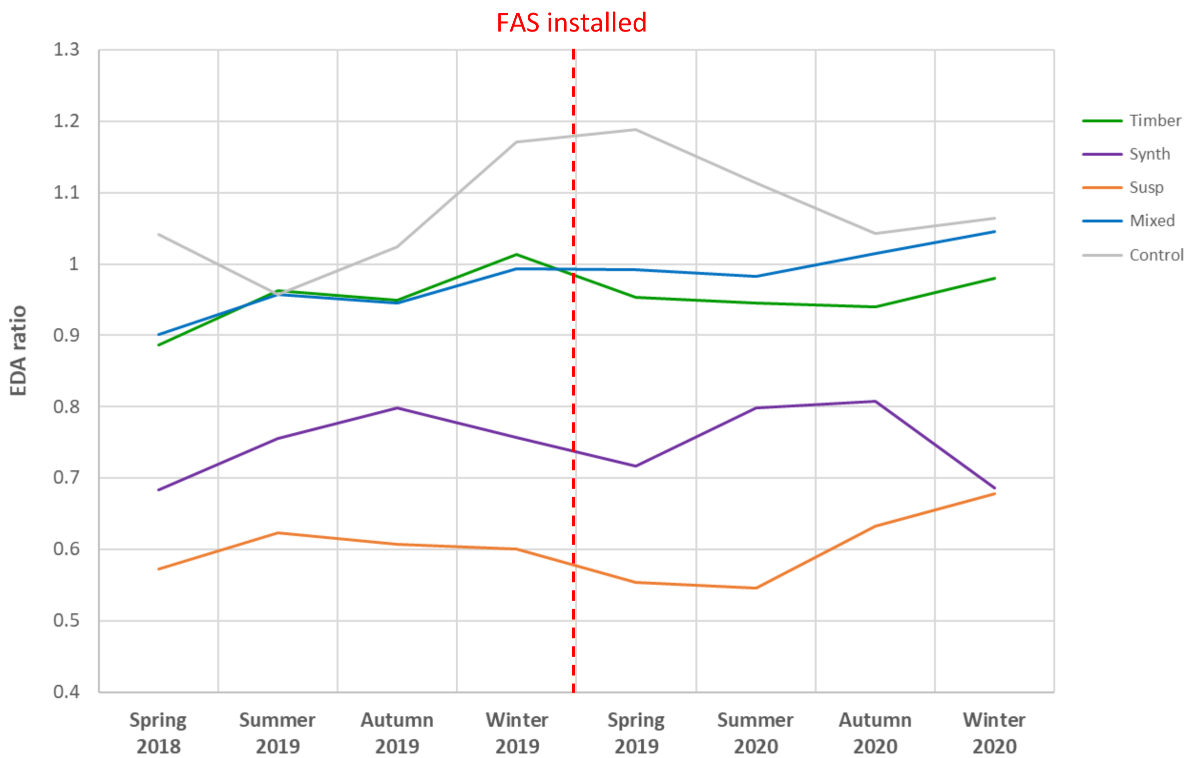


Figure 54 Mean seasonal EDA proximity ratios (± s.e.) to different FAS types for Golden Perch. An EDA ratio of 1 indicates random use. A ratio < 1 indicates closer proximity than random and a ratio > 1 indicates further proximity than random. Spring 2018 to Winter 2019 were classed as pre-FAS installation, whilst Spring 2019 to Winter 2020 were classed as post-FAS installation.

Kernel Density Estimates for tracked fish movements

The KDEs for the distribution patterns of both Australian Bass and Golden Perch varied with season and the installation status of the FAS (Figures 55 - 56). The qualitative results below compare changes in KDE between seasons and between corresponding seasons (before and after) following an increase in the number of FAS installed at that time. Overall, Golden Perch showed a greater affinity for utilising near-shore habitats, whilst Australian Bass utilised both open water and near-shore habitats in almost equal proportions. Both species showed positive utilisation of many of the installed FAS structures, particularly the suspended and synthetic FAS. Timber FAS elicited the least aggregation response. Fish attractors set in deeper water seem to more consistently have achieved higher fish aggregation/utilisation rates.

<u>Australian Bass</u>

The baseline distribution of Australian Bass was very similar in spring 2018 and summer 2019, showing a strong preference for the deeper waters at the north-eastern end of the tracking (Figure 55). The distribution was relatively even across both open water and marginal zones, including sections of the old creek channel. In spring 2018 small hotspots were also identified off Point L and the next point to the north, but these disappeared in summer 2019 and were replaced by several small hotspots along the southern shoreline between Shore 1 and Shore 2. The first few synthetic FAS installed did not result in any major shift in the fish distribution, although two of the FAS clusters at Point L had slightly higher utilisation densities than the surrounding areas.

As the water temperature cooled, the main distribution of fish shifted further up the dam towards the middle and western end of the tracking area and position density levels were slightly higher nearer to the shore. However, the most intense habitat usage occurred over the old creek channel at the western end of the tracking area. In autumn 2019, a clear hotspot was evident around four of the five synthetic FAS clusters installed at Point L and to a lesser degree around the three FAS clusters at Open Water 5. Several isolated hotspots also occurred between Shore 1 and Bay 27.

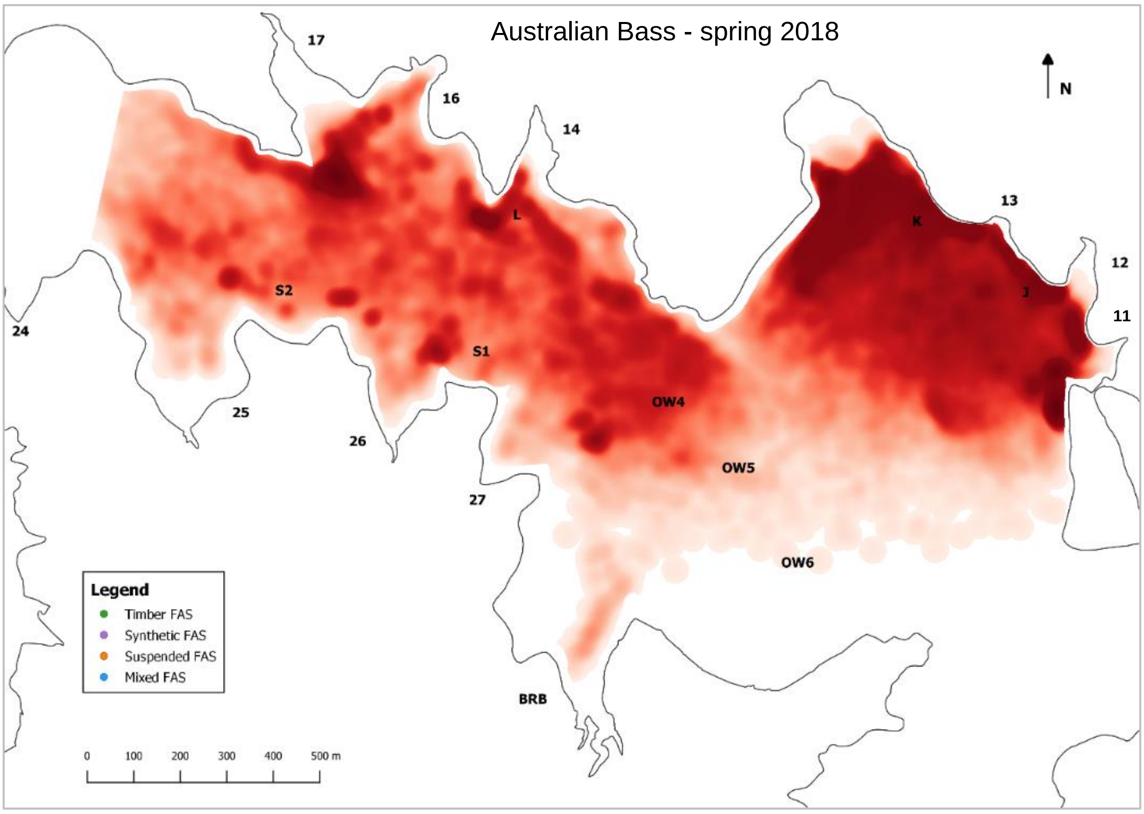
During winter 2019, the fish distribution generally shifted slightly closer to the shoreline, but with reduced usage over the old creek channel at the western end of the tracking array. The hotspots between Shore 1 and Bay 27 intensified, and further hotspots started to develop around the synthetic FAS in the Boat ramp bay and Bay 11. Some aggregation may have also been occurring near the FAS in Bay 17. There is evidence of fish following the shoreline from Point K to Bay 11 and around the large point on the northern side of the impoundment directly opposite the boat ramp.

By spring 2019, most FAS were installed, and the KDE was very different to that observed in spring 2018. The overall fish distribution was concentrated closer to the shoreline and spread along much of the tracking area. There was much less open water habitat use by the Australian Bass. Intense usage of the southern side of the tracking area between Shore 2 and Bay 27 occurred, but most of this was further from the shore than where the FAS were installed. Quite defined hotspots remained around the four synthetic FAS clusters at Point L and the outermost synthetic FAS in Bay 11. The intensity of fish use of some of the synthetic FAS in Bay 17 increased, and a small hotspot occurred around one of the suspended FAS in Bay 14. Fish appeared to move along the margins of the dam in the deeper north-eastern section of the tracking area, including amongst the suspended FAS at Point K. A slight increase in fish position density was observed near two of the three newly installed suspended FAS at Open water 4, and strong intensification was seen around the synthetic FAS at Open water 5.

In summer 2020, the overall fish distribution was more concentrated in the middle reaches of the tracking area, compared to the summer 2018 distribution. Australian Bass were also using a relatively even mix of open water and near-shore habitat. Very localised hotspots were observed around multiple FAS sites. Clear usage patterns were evident around and between the suspended FAS at Open water 4. An intense hotspot also occurred in Boat ramp bay around the suspended FAS and nearby timber FAS. Very localised patterns of increased fish use occurred around three of the suspended FAS at Point K and the two outermost synthetic FAS in Bay 11. The intense hotspots remained around the four synthetic FAS at Point L and the outer FAS in Bay 17. Fish position intensity was generally quite high in the vicinity of Open water 5, but only one of the three synthetic FAS clusters displayed a hotspot. A small, moderate-intensity hotspot also occurred around the deepest timber FAS at Open water 5. The hotspot along the southern shoreline between Shore 2 and Bay 27 disappeared, with only a few isolated patches still showing intense fish use.

In autumn 2020, the fish distribution was generally well spread out, but with several hotspot areas, and was most intense in the middle reach of the tracking area. A very intense hotspot for Australian Bass occurred around each synthetic FAS at Point L and the suspended FAS at nearby Bay 14. Similarly, fish use of the outermost synthetic FAS in Bay 17 was quite intense. Distinct localised usage of the suspended FAS at Open water 4 occurred, although there appeared to be limited movement of fish between the individual FAS. The southern-most synthetic FAS at Open water 5 also displayed and intense localised hotspot of fish use. There was some evidence of fish moving along the deeper shoreline between Point K and Bay 11, with the greatest usage around the suspended FAS at Point K, off the Control site at Point J and several of the outer synthetic FAS in Bay 11. Limited usage of the Boat ramp bay and most of the FAS on the southern shoreline was detected.

In winter 2020 Australian Bass distribution densities were highest in the middle section of the tracking area. The greatest intensity occurred along the shorelines, but usage of open water habitat was still common. Fish distribution hotspots occurred around many (62%) of the FAS sites in the tracking array. By comparison, in winter 2019, hotspots in fish usage would have occurred in approximately 44% of FAS sites, of which 29% already had synthetic FAS in place. During winter 2020, the hotspot surrounding all five of the suspended FAS at Point K was very strong. It did not spread along the shoreline beyond the extent of the FAS, as had been observed in the past. The outermost synthetic FAS in Bay 11 was also a localised hotspot. A hotspot formed in Bay 16 around the timber FAS in winter 2020, but a similar hotspot occurred in winter 2019 when there were no FAS installed. Therefore, this hotspot may be a reflection of seasonal fish movement rather than attraction to the FAS. The intensity of the hotspot around the synthetic FAS at Point L was greater in winter 2020 than in winter 2019. A similar trend was observed around the suspended FAS in Bay 14. The hotspot in winter around the three synthetic FAS clusters at Open water 5 reduced in size, but not intensity, between 2019 and 2020. In 2019 the hotspot covered all three FAS clusters, whilst in 2020 the hotspot only covered the deepest FAS cluster. Fish usage in winter 2020 around the suspended FAS in Open water 4 was greater than the surrounding area and greater than in winter 2019 when there were no FAS. However, the hotspots were not as intense or localised as those observed in autumn 2020. In winter 2020, there was a strong fish distribution hotspot along the entire southern shoreline from Shore 2 to Bay 27, and even part way into Boat ramp bay. This utilisation hotspot was further offshore than where the fish attractors were installed along this stretch of the impoundment. Only light usage around the FAS was observed, except for two synthetic FAS clusters, one in Bay 26 and the other in Shore 1. Both of these FAS clusters were set in slightly deeper water. Very few positions were recorded in the Boat ramp bay during winter 2020 and there were no hotspots around any of the FAS.


Australian Bass - spring 2018
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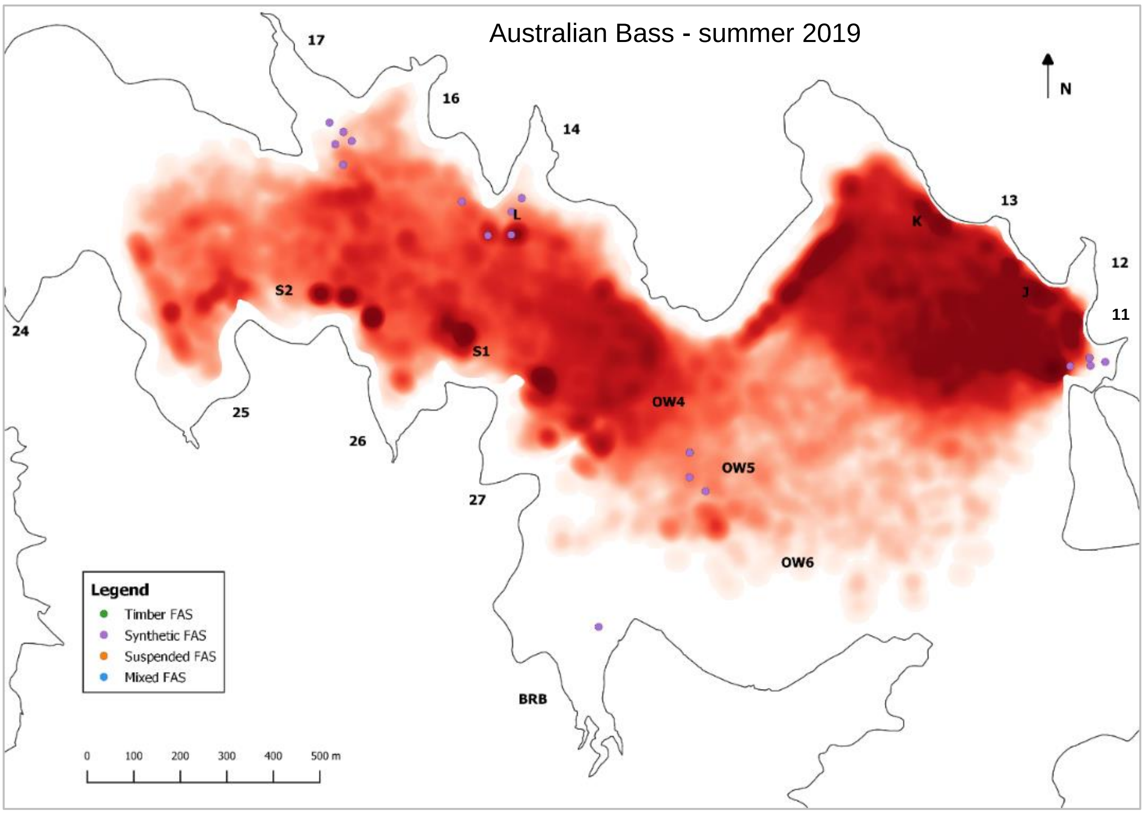
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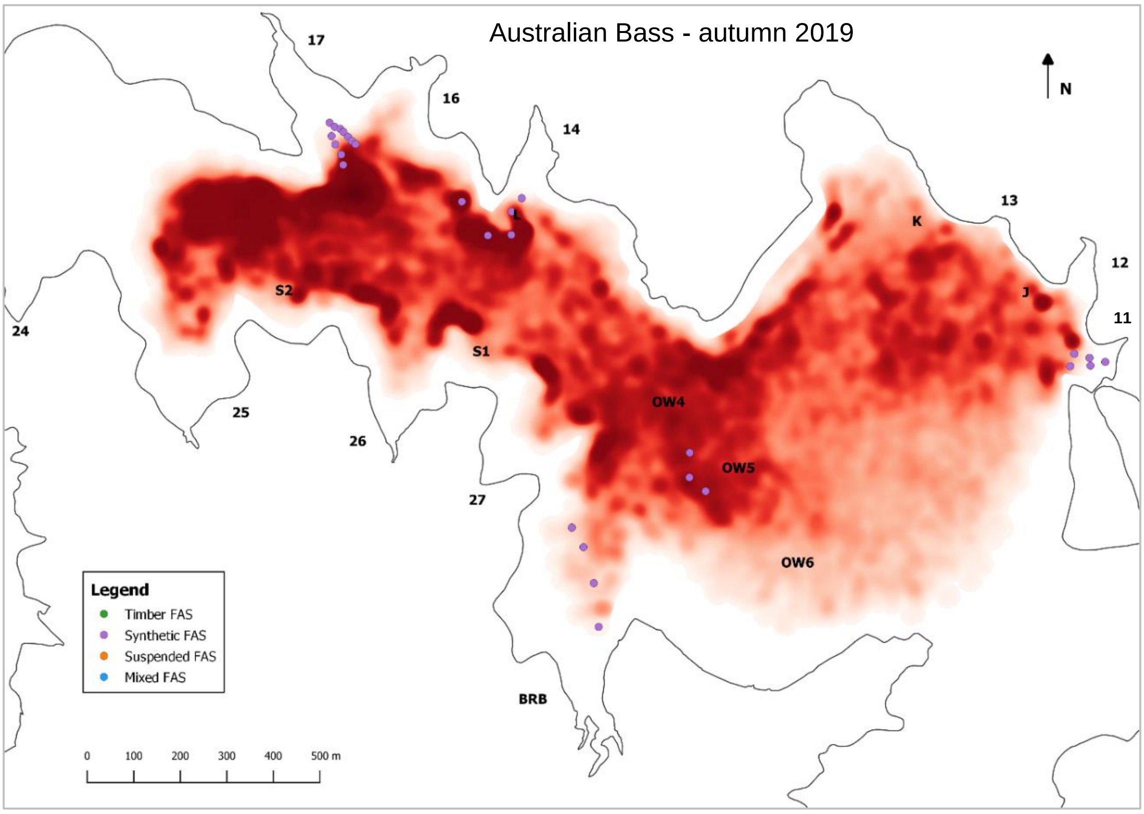
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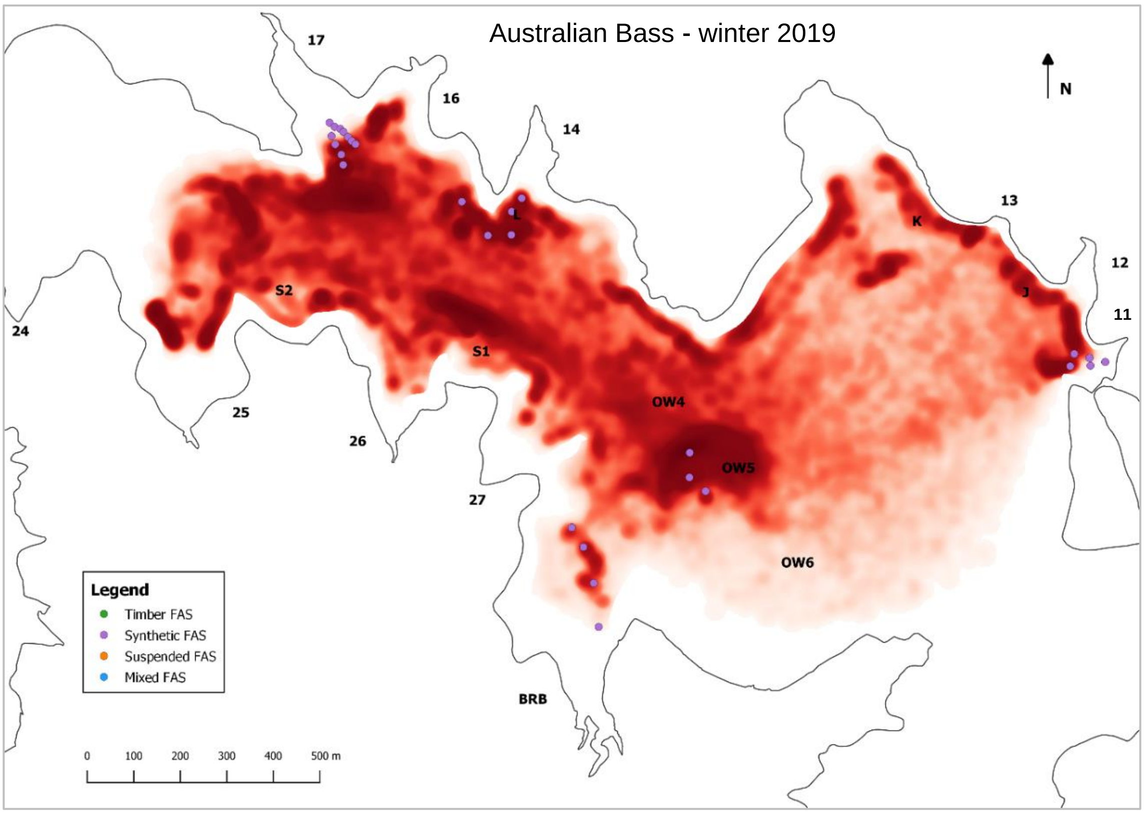
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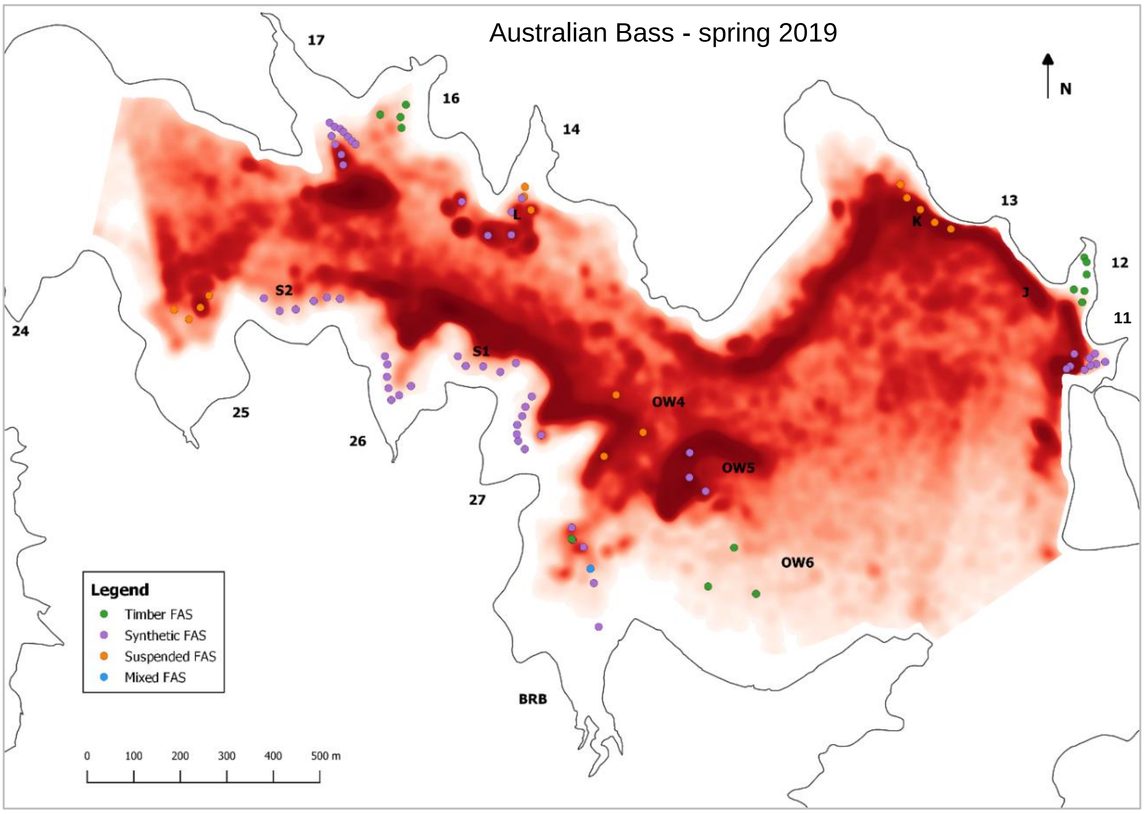
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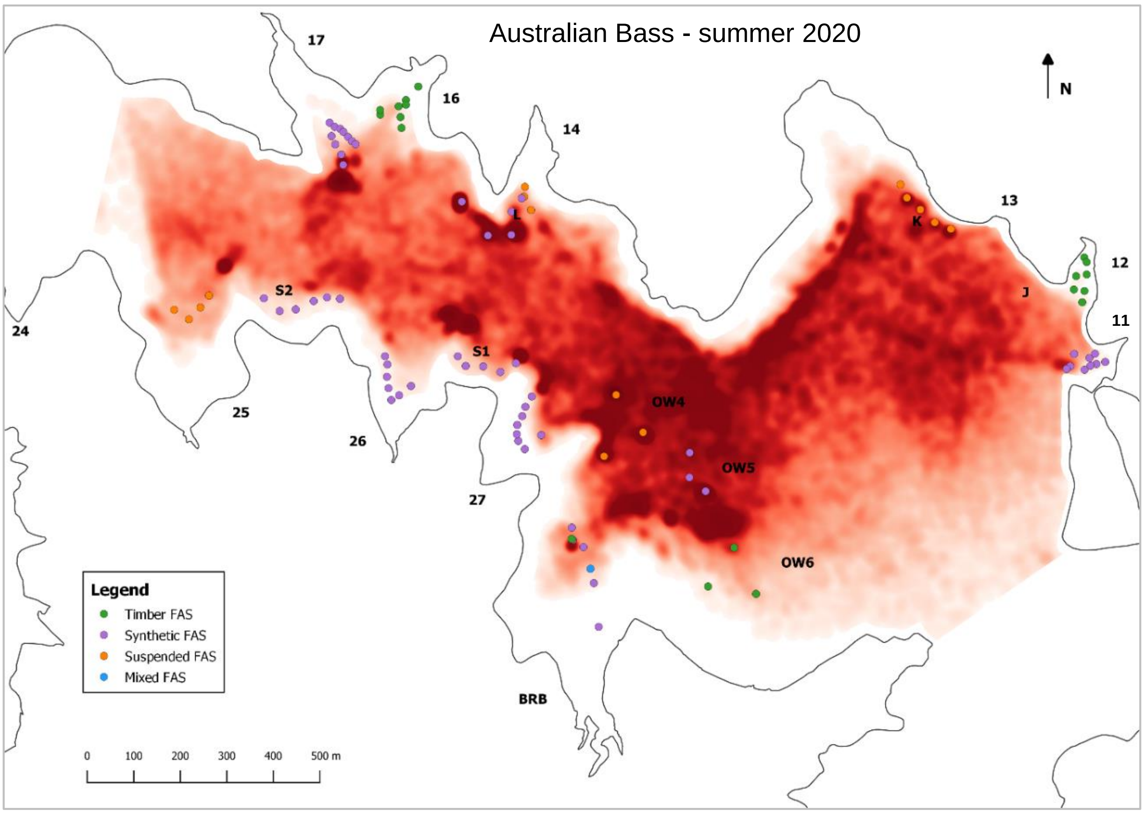
Australian Bass - summer 2020
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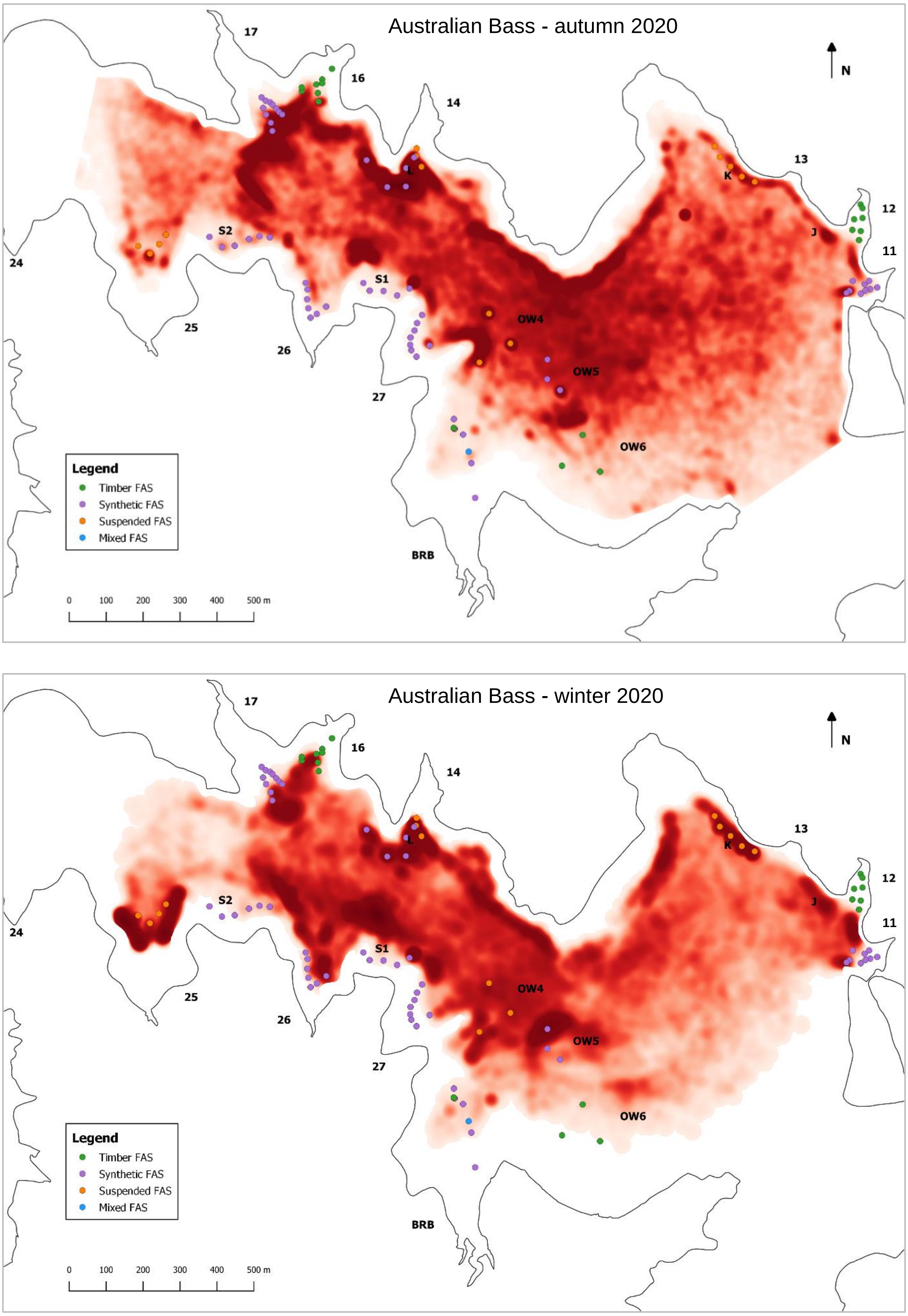


Figure 55 Seasonal kernel density estimates (KDE) for Australian Bass (n=30) movements within the Cressbrook dam acoustic tracking array.

Golden Perch distributions

The baseline distribution of Golden Perch was very similar in spring 2018 and summer 2019. Golden Perch displayed a preference for the shallower, marginal areas in the middle to western section of the tracking area, but were also consistently found in deeper waters through this region (Figure 56). The distribution intensity was slightly higher along the southern shoreline. Nearly all bays and points in the tracking area were well utilised, including the shallower creek-like section of the Boat ramp bay. Bay 17 was the exception with minimal fish usage in both seasons. The installation of the synthetic FAS at Point L in summer 2019 increased the intensity of fish use in the immediate vicinity of the structures, whilst no changes in fish distribution were observed around the synthetic FAS installed at Open water 6, Bay 11 and Boat ramp bay.

The fish distributions became more concentrated near the shoreline in autumn 2019. The majority of the fish positions still occurred in the middle reach of the tracking area, but open water use declined. The hotspots around the synthetic FAS at Point L remained strong and distinct, but there was no increase in fish activity detected at Bay 17 following the installation of synthetic FAS at that site. Slightly more fish activity was recorded in the main basin to the east of the boat ramps, including an increase around the synthetic FAS at Open water 5. Fish activity levels around the synthetic FAS in Boat ramp bay increased following the addition of three more clusters of FAS.

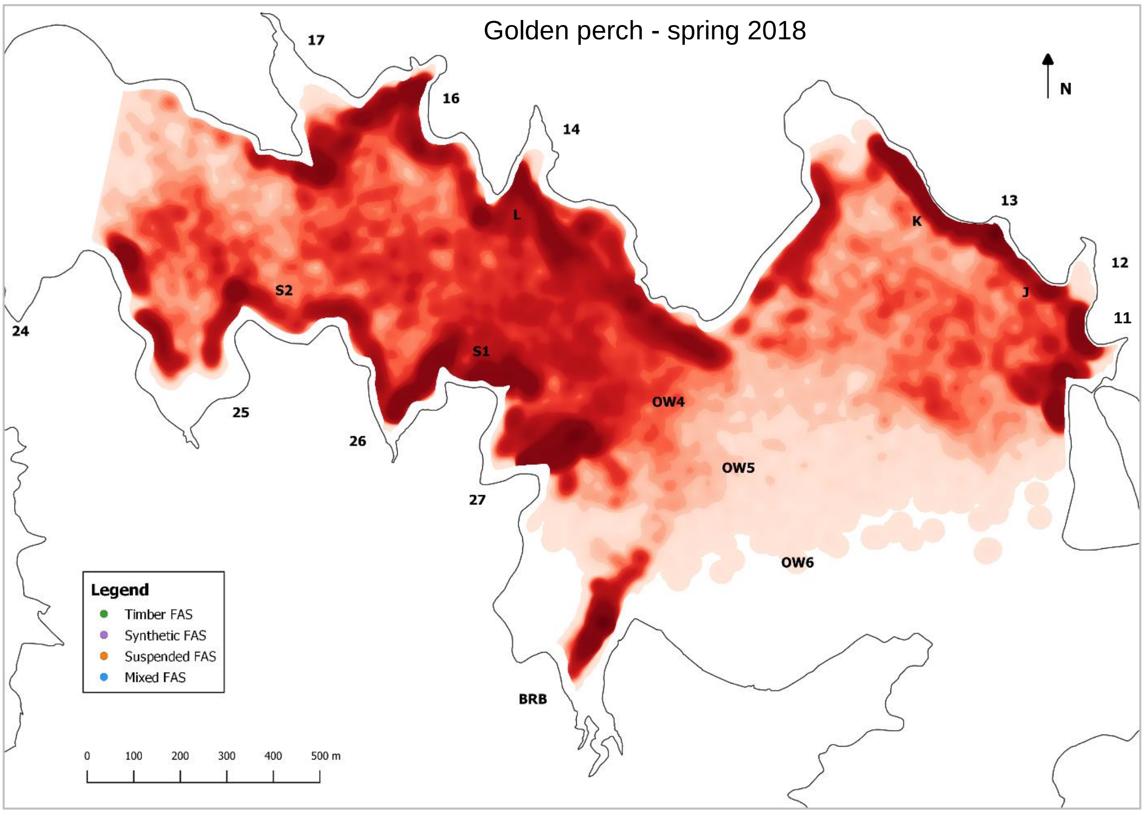
The Golden Perch distribution displayed a similar pattern in winter 2019, although utilisation became more concentrated along shoreline areas and intensity in the middle reaches of the tracking area was more dispersed. Some use of open water areas still occurred and was relatively evenly distributed across the entire tracking area. The fish distribution intensity increased around several of the synthetic FAS clusters in Bay 11, and also increased slightly around the synthetic FAS in Bay 17. The hotspot around the synthetic FAS at Point L increased in size and intensity.

By spring 2019, the majority of FAS were installed, and the KDE was very different to that observed in spring 2018 when there were no FAS. The density recorded for fish lessened in the northern central and eastern sections of the tracking area. The shoreline between Shore 2 and partway into the Boat ramp bay was a continuous hotspot for fish activity which had increased in width towards deeper water. Despite these high utilisation levels, Golden Perch activity among the more shoreward synthetic FAS in this region was minimal. Fish movement instead occurred slightly further offshore where the water was marginally deeper. A concentrated hotspot was detected around one of the suspended FAS in Bay 25, and the hotspots remained around the synthetic FAS at Point L. A small hotspot was also recorded around one of the suspended FAS in the adjacent Bay 14. A substantial increase in fish activity was observed around all three synthetic FAS clusters at Open water 5. A hotspot occurred along most of the suspended FAS clusters installed at Point K, but this pattern had not changed significantly from any of the previous seasons. There was limited utilisation of the suspended FAS installed at Open water 5 and the synthetic FAS at Bay 17 and Bay 11. Activity in the Boat ramp bay was minimal during this season.

The distribution of Golden Perch in the tracking area was similar between summer 2019 and summer 2020, although activity in both the open water and near-shore areas of the western section decreased. The width of the hotspot band along the southern shoreline form Shore 2 to Bay 27 increased, corresponding to an increase in the width of aquatic vegetation in this region. Small hotspots developed around all four suspended FAS in Bay 25 in summer 2020. Tight, but intense hotspots were also recorded around one of the timber FAS clusters in Open water 6, one of the synthetic FAS at Open water 5 and the suspended FAS next to the timber FAS in the Boat ramp bay. The band of high activity around Point L became more concentrated around the synthetic FAS and two of the suspended FAS in Bay 14. The intensity of fish activity at these sites was higher than that observed in summer 2019. All three suspended FAS at Open water 4 developed tight activity hotspots centred around them. One of the largest changes from spring 2019 was a substantial change in fish use of the synthetic FAS installed along the southern shoreline between Shore 2 and Bay 27. More than half of these FAS clusters experienced high Golden Perch activity in summer 2020. The fish activity patterns at Point K were focussed around the suspended FAS. In summer 2019 fish activity was more widely spread, potentially indicating that FAS had concentrated the fish activity area.

The general distribution of Golden Perch was similar between autumn 2019 and autumn 2020. The main differences in 2020 were a thinning in the hotspot band located along the north-east shoreline, a widening of the hotspot band near Shore 1, and more patchy fish distribution hotspots. Areas with the highest fish activity levels mostly occurred around sites where FAS had been installed, except around the large bed of aquatic vegetation near Shore 1. Very concentrated and distinct hotspots occurred around each of the suspended FAS at Open water 4. The five suspended FAS at Point K also formed a hotspot band and the suspended FAS at Bay 14 extended the intense hotspot observed around the synthetic FAS at Point L. No clear hot spots of Golden Perch activity were identified around the synthetic FAS at Open water 5 nor the timber FAS at Open water 6 during autumn 2020. A small hotspot occurred around the suspended/timber FAS combination in the Boat ramp bay and one of the suspended FAS in Bay 25. More than half of the synthetic FAS installed along the southern shoreline between Shore 2 and Bay 27 continued to experience high Golden Perch activity.

The Golden Perch distribution patterns were quite different between winter 2019 and winter 2020. In 2020 the distribution is much patchier and not focussed along the entire length of the shoreline. Significantly more intense fish activity occurred in the open water around the suspended FAS at Open water 4 in winter 2020 than in winter 2019. Not only did the activity levels increase for the site, but very intense activity hotspots were also recorded around each of the suspended FAS. Reasonably compact hotspots were also recorded around the synthetic FAS clusters at Open water 5 and around Point K. The intense hotspot covered all five suspended FAS at Point K but did not extend to the nearby shoreline. A similar, but smaller hotspot occurred at the Point J Control site. The deeper, outermost synthetic FAS at Bay 11 also occurred within a small hotspot. Few of the synthetic FAS along the southern shoreline of the tracking area between Shore 2 and Bay 27 experienced a high degree of fish activity. Strong hotspots for fish movement occurred in Bay 25 but most of the activity happened along the margin of the aquatic vegetation rather than in the immediately adjacent suspended FAS. Limited Golden Perch activity was observed in Bays 14, 16 and 17 during winter 2020.


Golden perch - spring 2018
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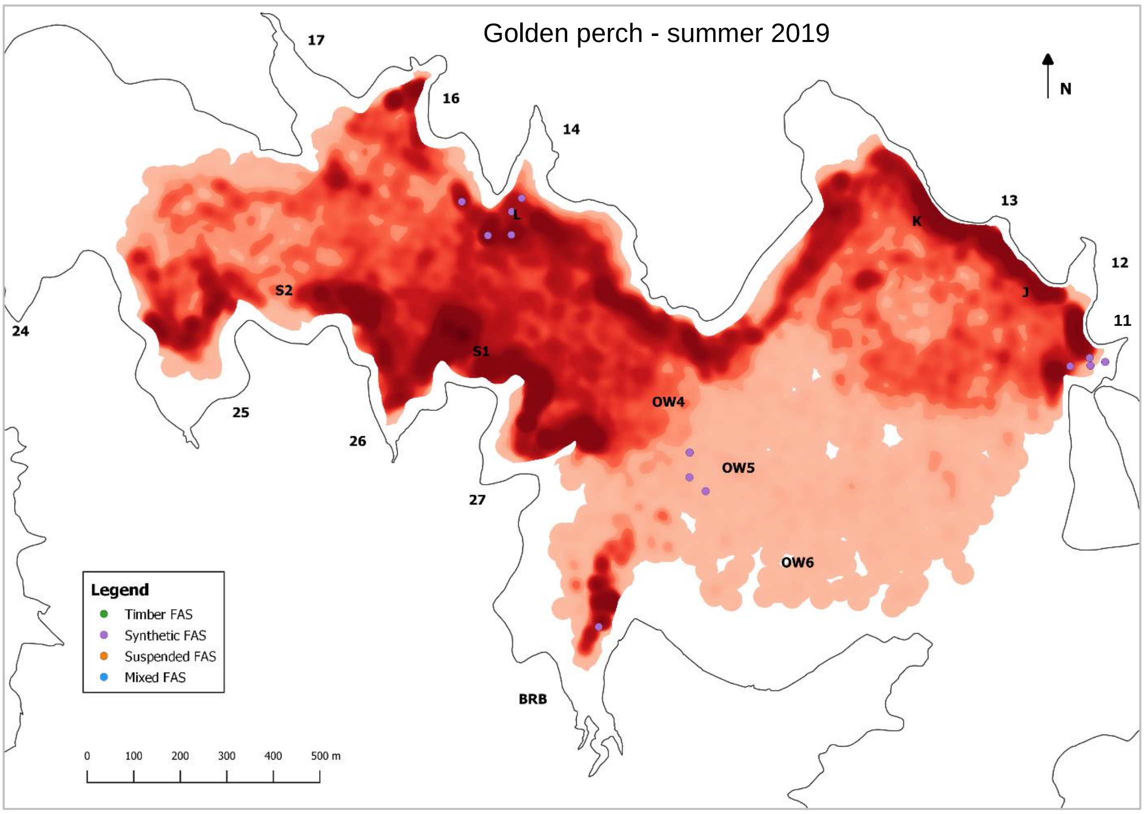
Golden perch - summer 2019
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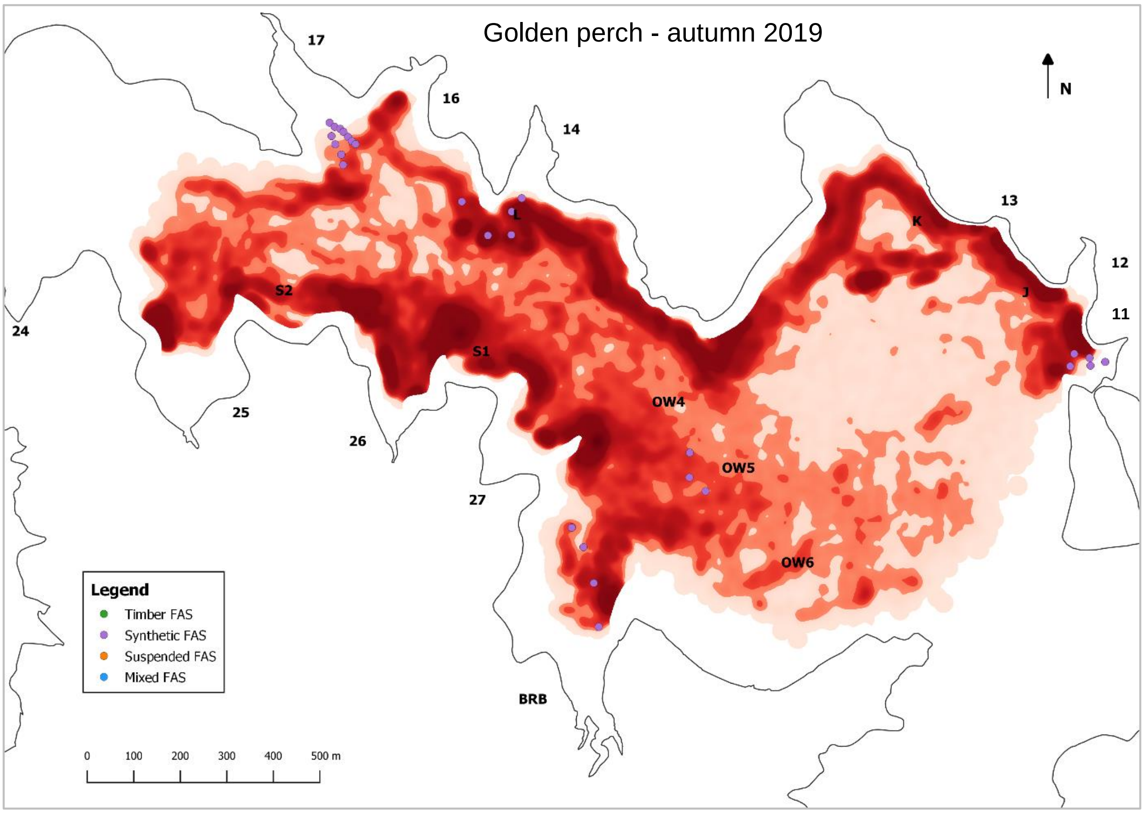
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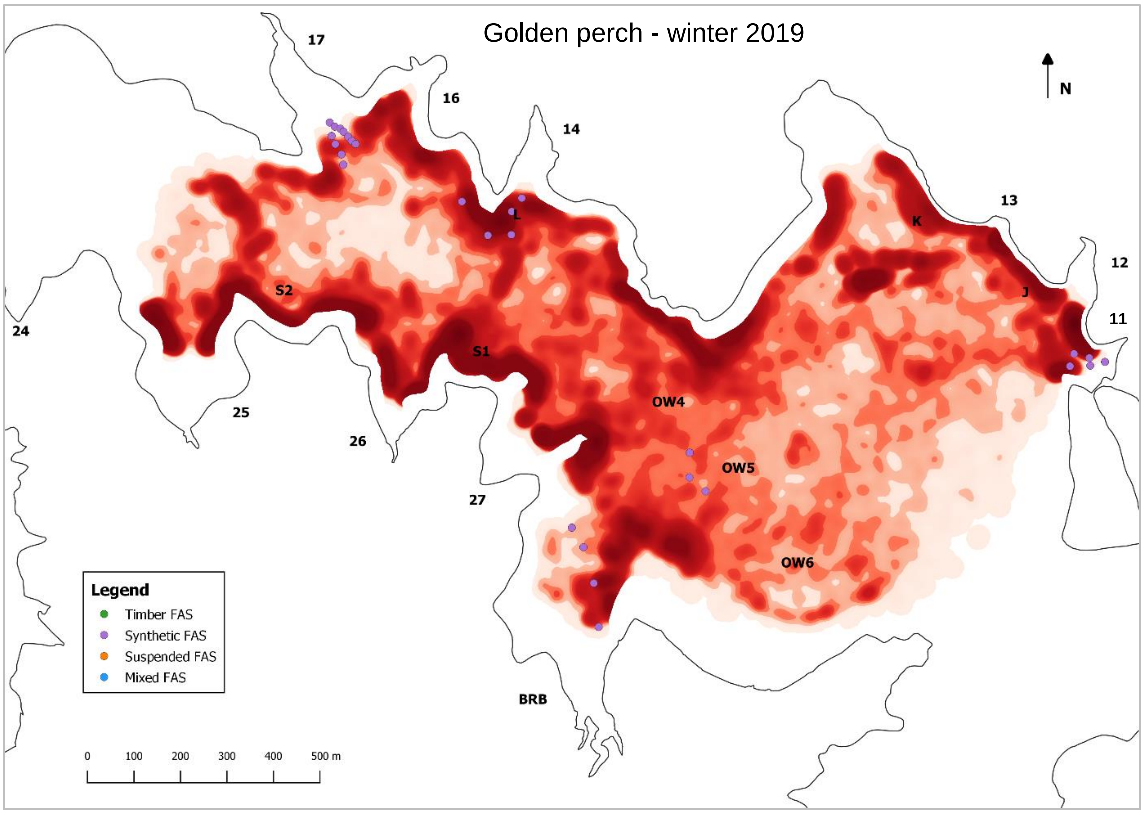
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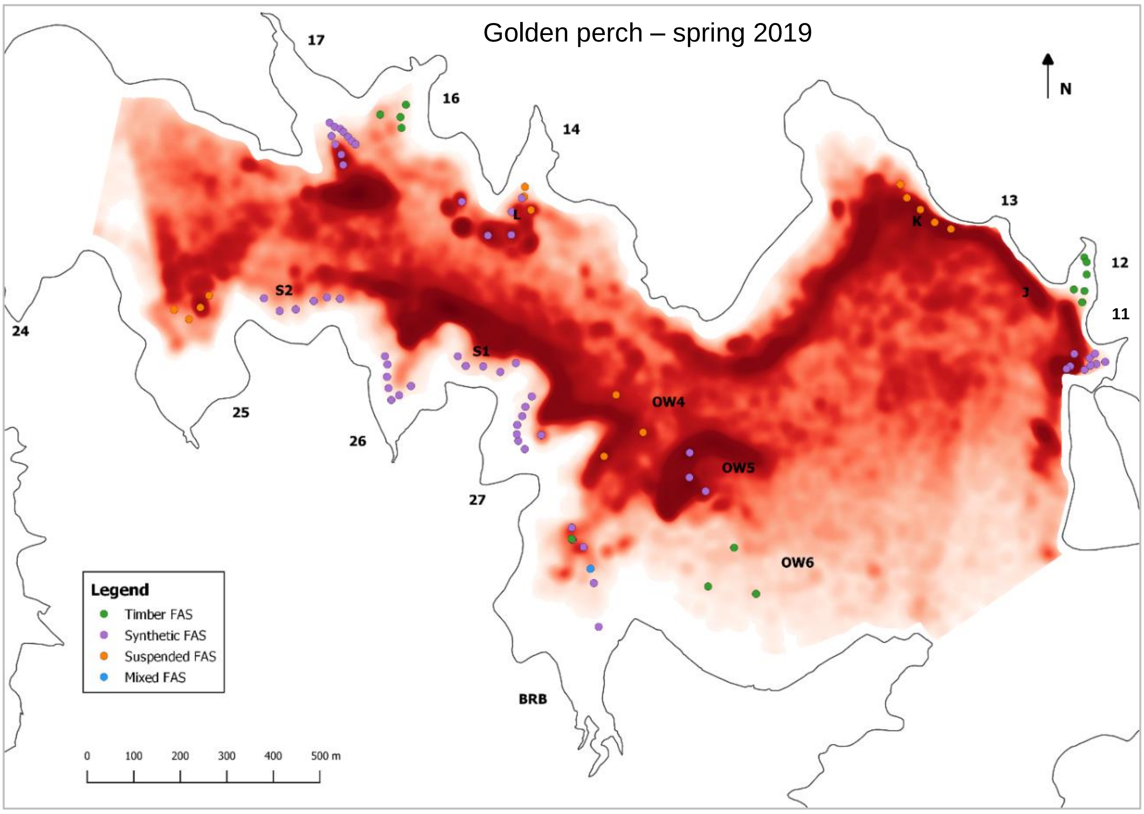
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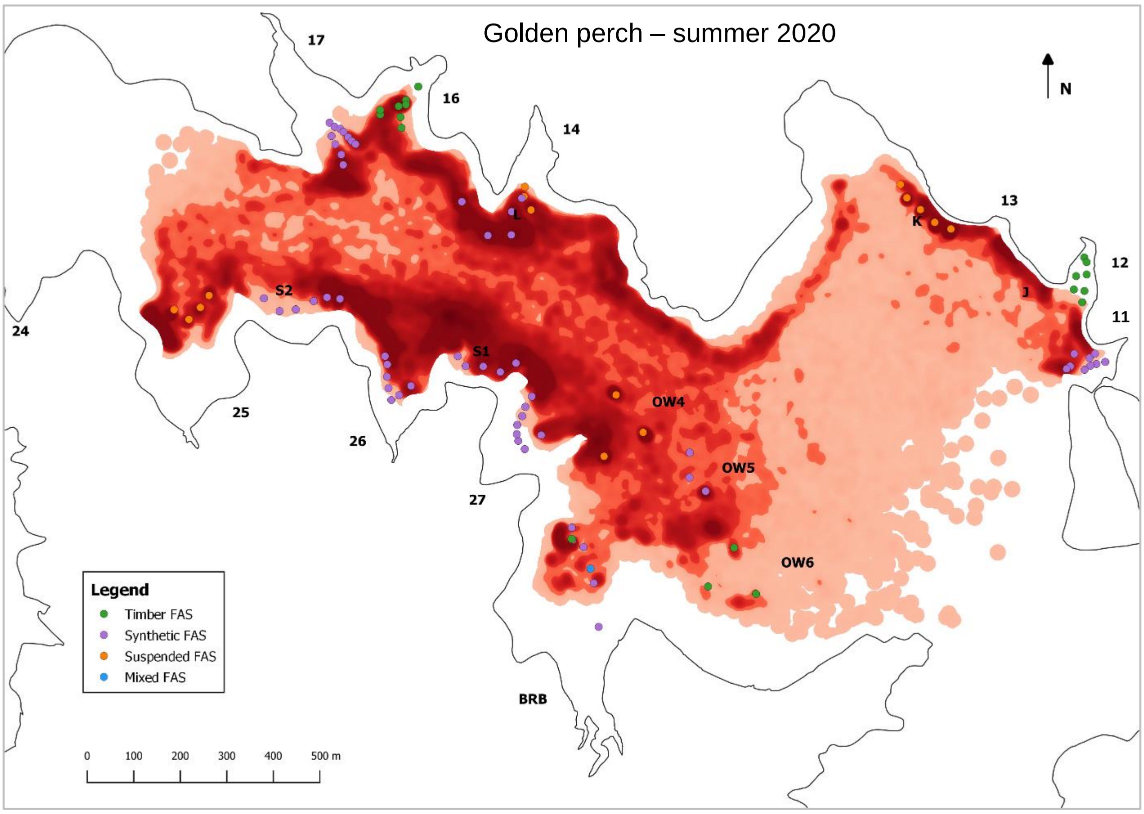
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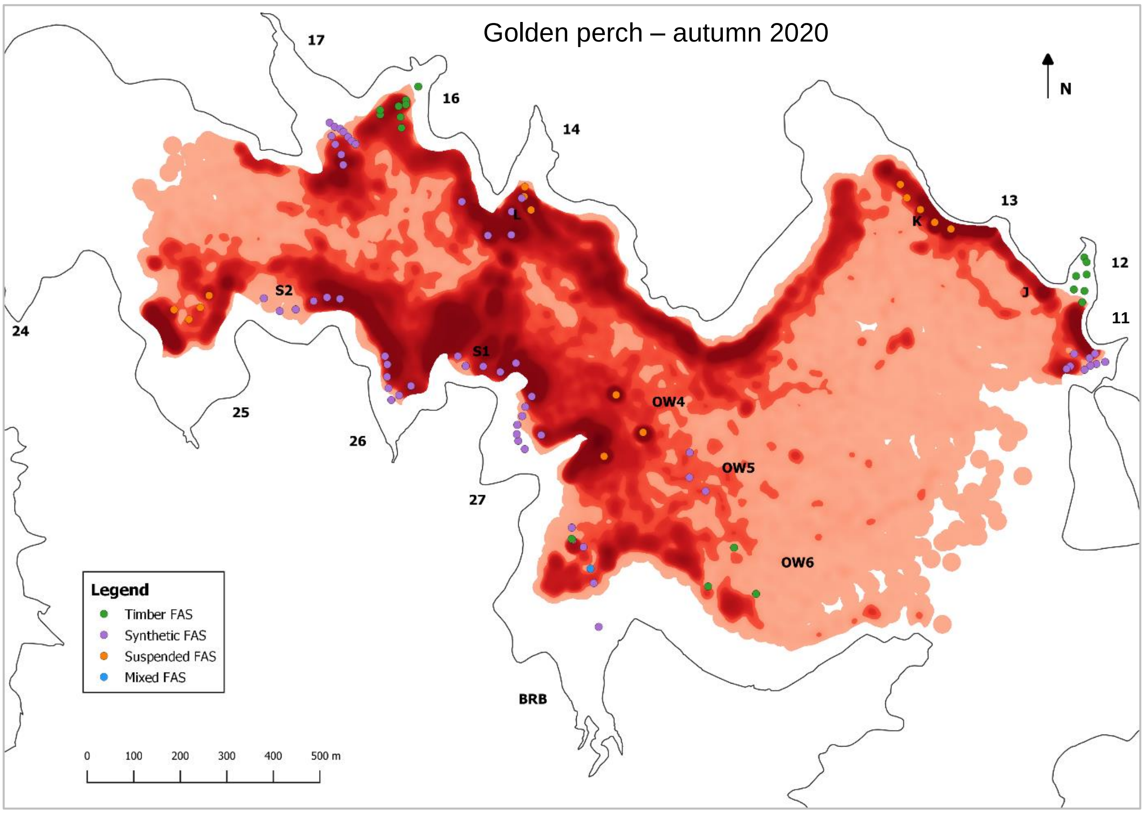

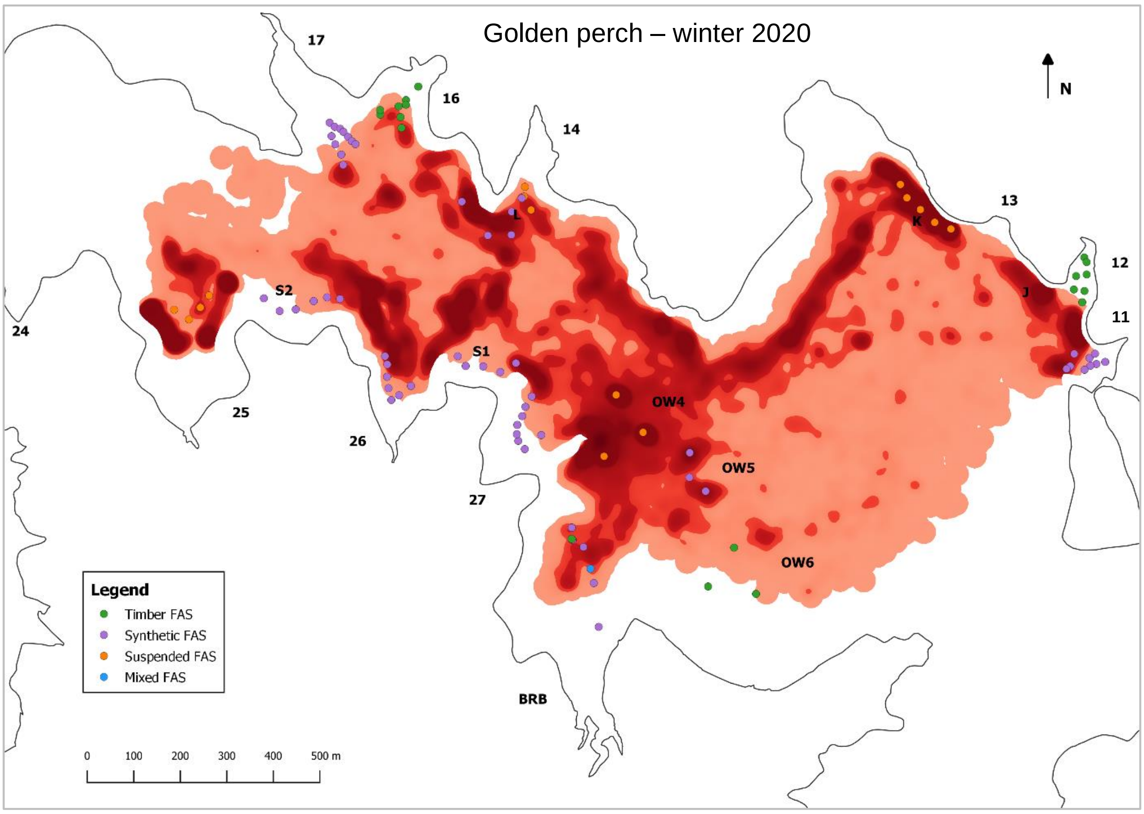

Figure 56 Seasonal kernel density estimates (KDE) for Golden Perch (n=30) movements within the Cressbrook dam acoustic tracking array.

FAS condition assessments

High turbidity prevented the collection of imagery of sufficient quality for evaluation from static cameras or the underwater drone. Several short videos with poor image quality were collected, showing both Australian Bass and Golden Perch using FAS. These images were mostly from footage at the suspended FAS and were used in extension and promotion. In one video a Golden Perch was seen searching around a suspended FAS and then striking at small prey hiding near the trunk of the structure. Example images and stills from the video footage can be seen in Figures 57-59. Smaller fish species were more commonly seen around the FAS on the video footage, at times forming quite high densities amongst the FAS habitat (Figures 60-62)

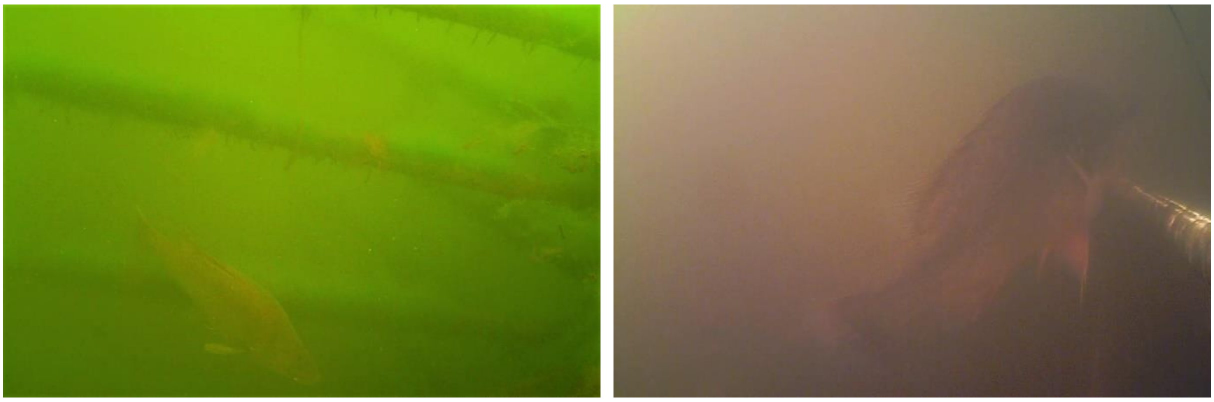

Figure 57 Large Golden Perch moving amongst suspended FAS.

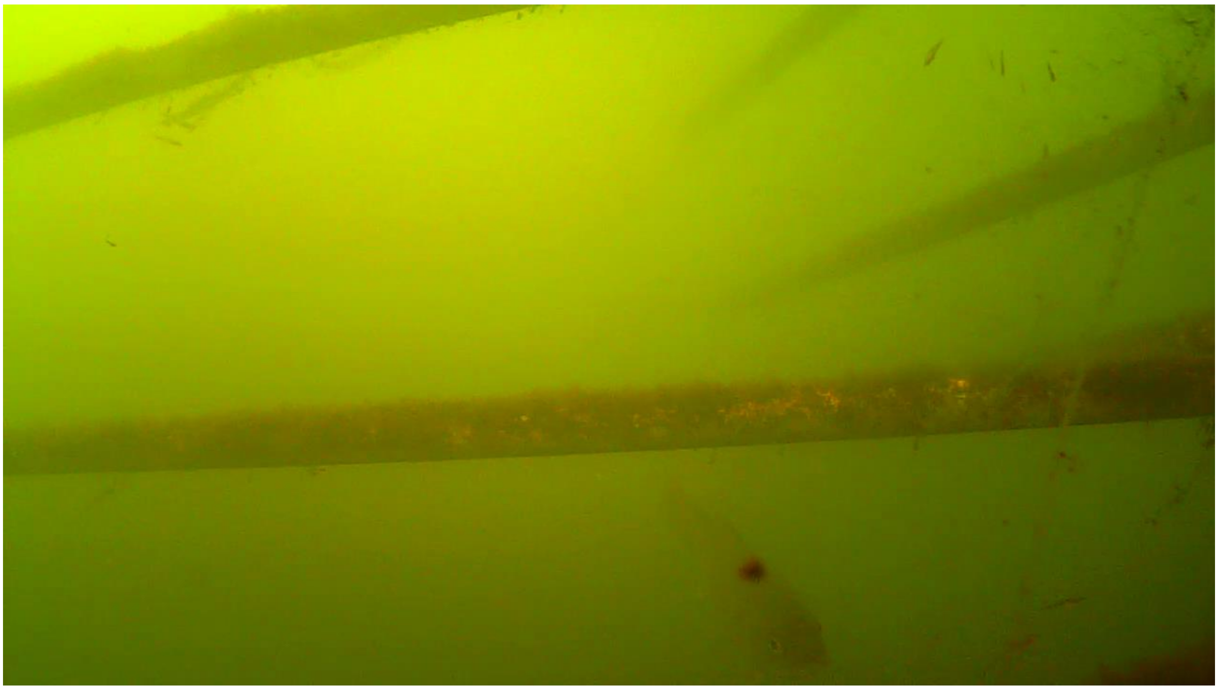

Figure 58 An Australian Bass lurking around a suspended FAS with smaller prey fish near the trunk of the structure in the top left of the image.

Figure 59 Two large Golden Perch moving around a suspended FAS in deep water. This level of underwater visibility was typical for much of the project duration.

Figure 60 Smaller prey fish aggregating around a suspended FAS.

Figure 61 Smaller prey fish (mostly Olive Perchlet and Carp Gudgeon) around a Georgia cube.

All FAS types remained in good condition during the period following installation until the end of the project. Algal growth was most rapid on the brush bundles, but also occurred on structures made with synthetic materials (Figure 63). Filamentous algae attached to several FAS and was most prominent on the upper limbs. Some of the FAS installed in bay sites became overgrown by submerged aquatic vegetation as the vegetation beds grew in extent in response to stabilising water levels (Figures 64-67). The smothering of the FAS does not appear to have impacted their structural integrity. Fish, including Australian Bass and Golden Perch were still captured from partially overgrown FAS during the electrofishing surveys. All of the FAS remained in place and did not shift. Several of the synthetic trees were observed to be partially fallen over (Figure 68). The limbs kept the trees in a mostly upright position and ensured they provided good habitat complexity even when sitting in this manner. It was not possible to determine whether the synthetic trees fell over during deployment or at a later date.

Figure 62 Smaller prey species around a synthetic tree several months after installation. Note the commencement of algal growth on the pipe.

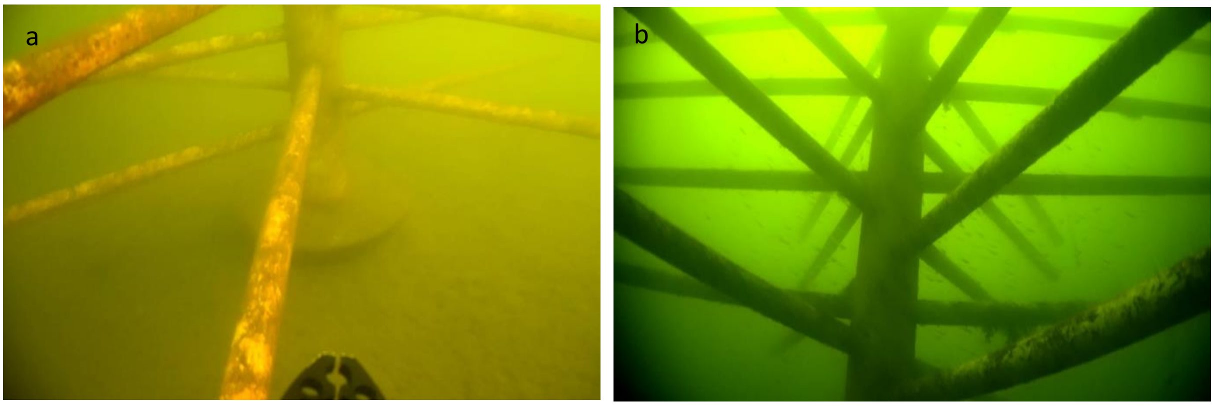

Figure 63 Underwater drone image of the algal covering developing on the limbs of deep-water synthetic tree FAS a) after 6 months and b) after 18 months. Smaller prey species can also be seen amongst the limbs and were likely attracted by the growth. Note the bare substrate which typified much of the habitat across the impoundment.

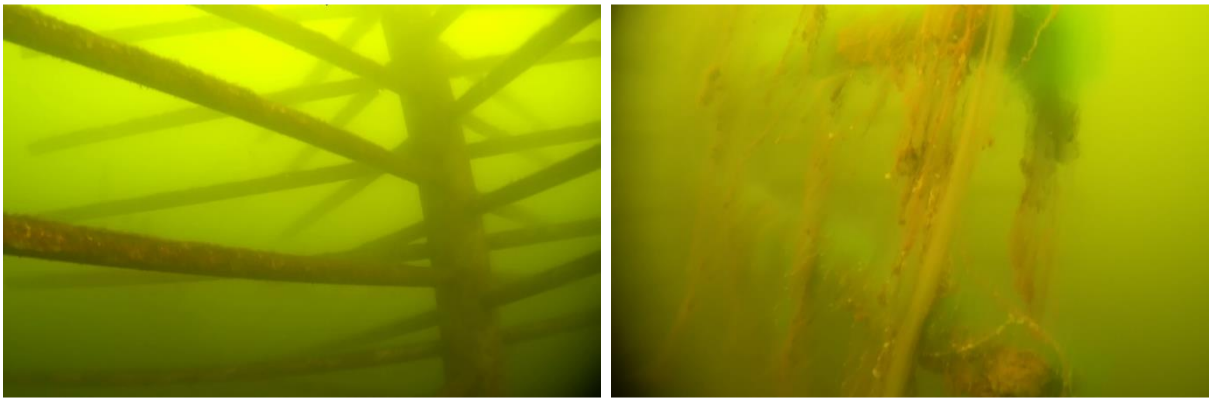

Figure 64 Periphyton growing on the trunk and limbs of suspended FAS. Note the thick algae growing on the upper branches (right). Algal growth was faster and denser on the upper limbs of the structures, especially the suspended FAS which had a vertical length of 3 m and started 2 m below the surface.

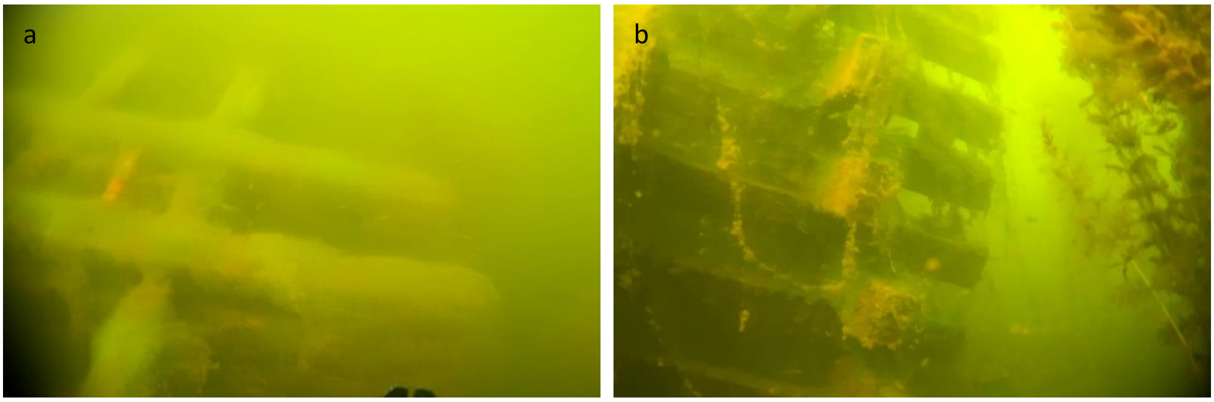

Figure 65 Timber cribs were relatively quickly coated in aquatic growth. a) Covered in filamentous algae and b) algae growing on a timber crib FAS adjacent to submerged aquatic plants.

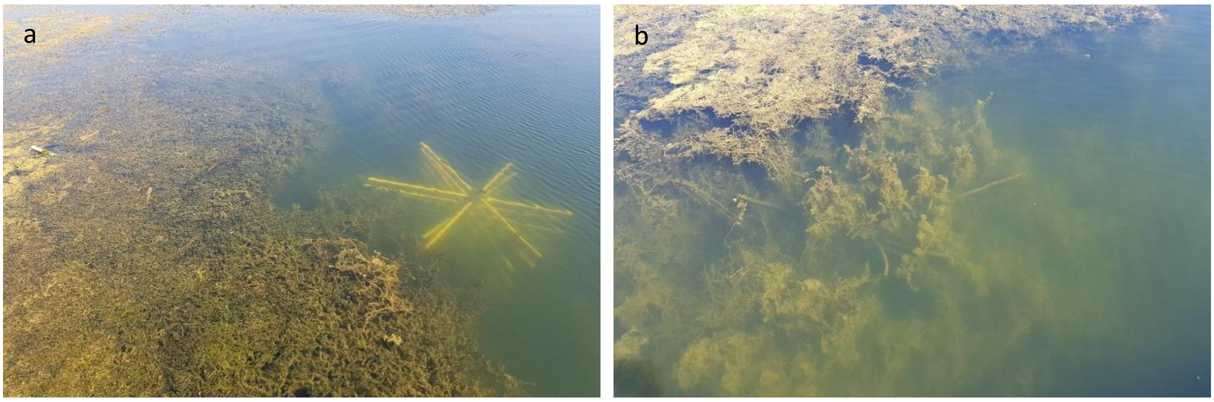

Figure 66 Marginal submerged aquatic vegetation engulfing FAS as the water levels fell. a) A synthetic tree with 3 adjacent spiders covered by the vegetation, and b) a synthetic spider covered by aquatic vegetation.

Figure 67 These synthetic trees still provided valuable structure for fish despite being partially covered by the aquatic vegetation. An Australian Bass was electrofished off these structures and when released swam straight back into them.

Figure 68 Several of the synthetic trees had partially fallen over. However, their design means they still provide great structural complexity and vertical relief even when laying partially on their side.

Most of the FAS were readily detected using recreational angler-level sonar. This is important if anglers want to find FAS when out fishing. Spiders were the most difficult to locate and were often covered in aquatic vegetation. The spiders appeared on the sounder like a series of disconnected pom-poms around a solid base. The nature of all other structure types could be clearly identified on the sonar images. Fish were frequently detected in close proximity to the FAS on the sonar images, but the species composition and abundance could not be reliably determined or quantified. Many of the images showed schools of smaller fish species aggregating on or around the FAS, sometimes with fewer, larger fish also in the vicinity. These larger fish were thought to be Australian Bass or Golden Perch, since the prey fish species do not grow that large and have a different sonar signal. Fish were seen around some of the FAS within 24 hr of installation. The reliability of fish presence increased with time up to three months post installation, from which point little additional change was observed. In the selection of FAS sonar images below, Figures 69-71 show both standard sonar and Lowrance Downscan™ images, whilst Figures 72-84 contain only the higher resolution Downscan™ images.

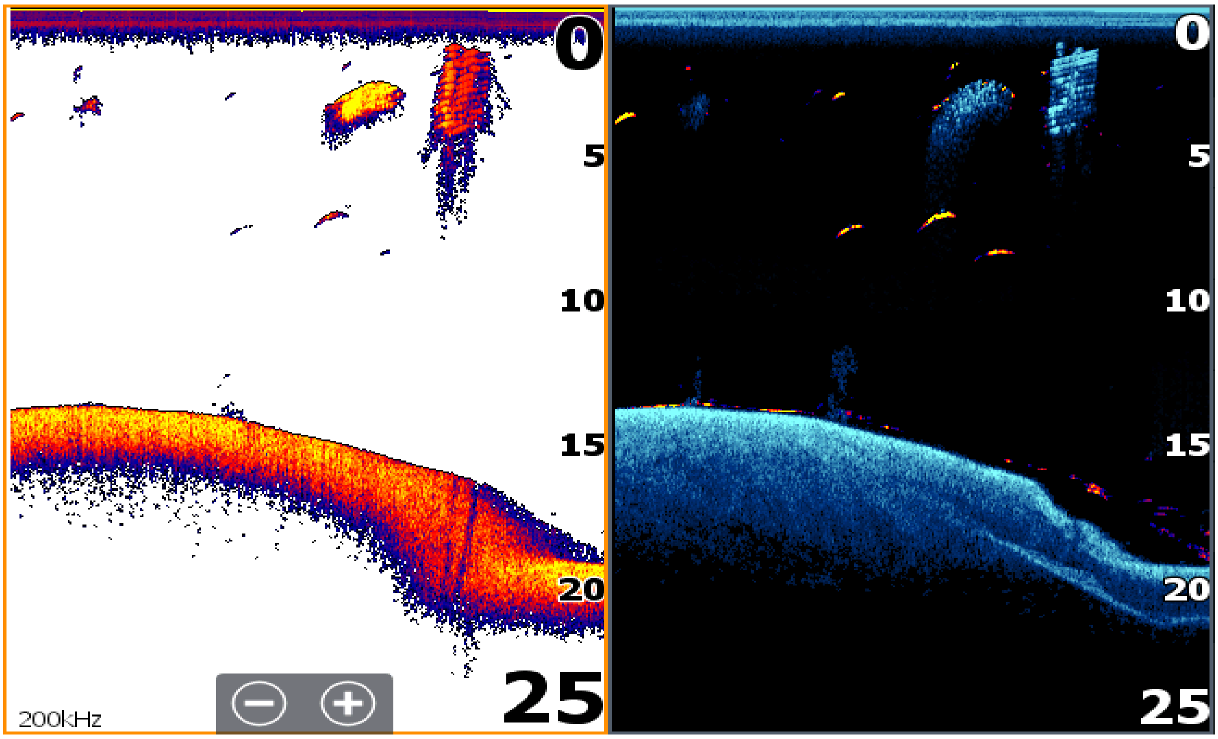

Figure 69 A school of small prey fish near one of the Open water 4 suspended FAS. Note the larger predatory fish around the prey fish. These were likely to be Australian Bass.

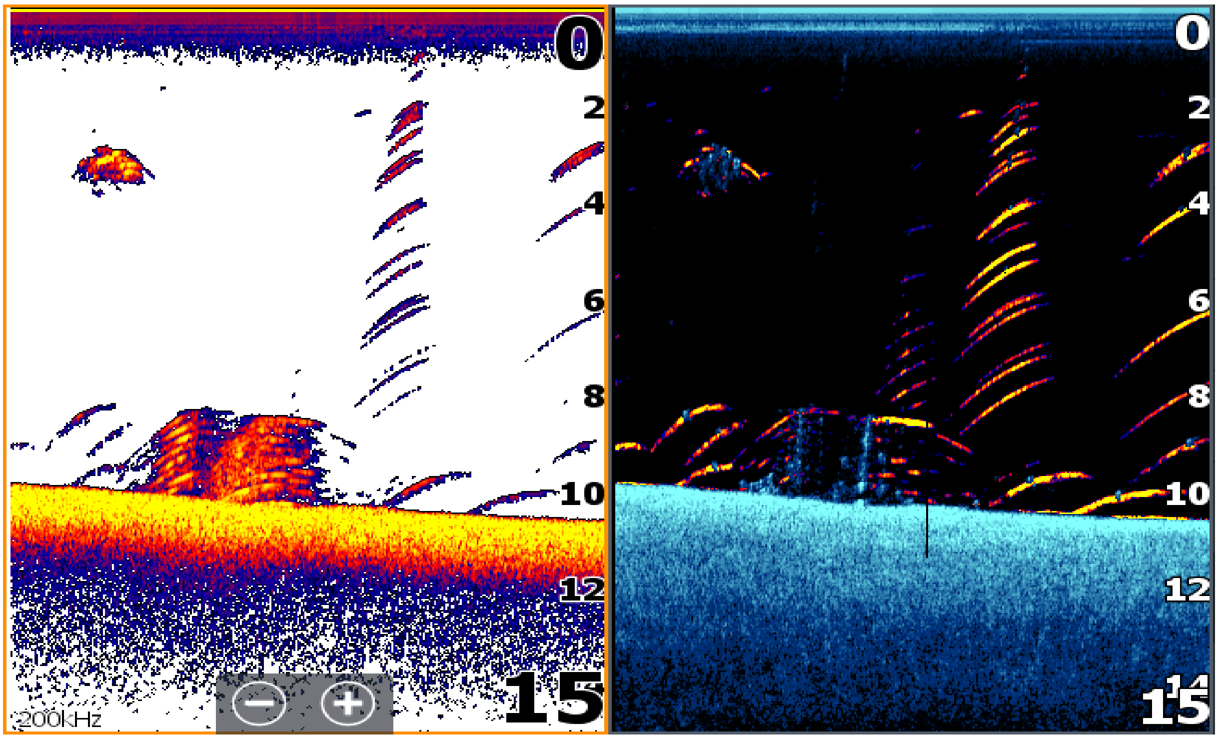

Figure 70 A school of Australian Bass and a bait ball near a cluster of synthetic trees at Open water 5. Note the Australian Bass around both the prey fish and the FAS.

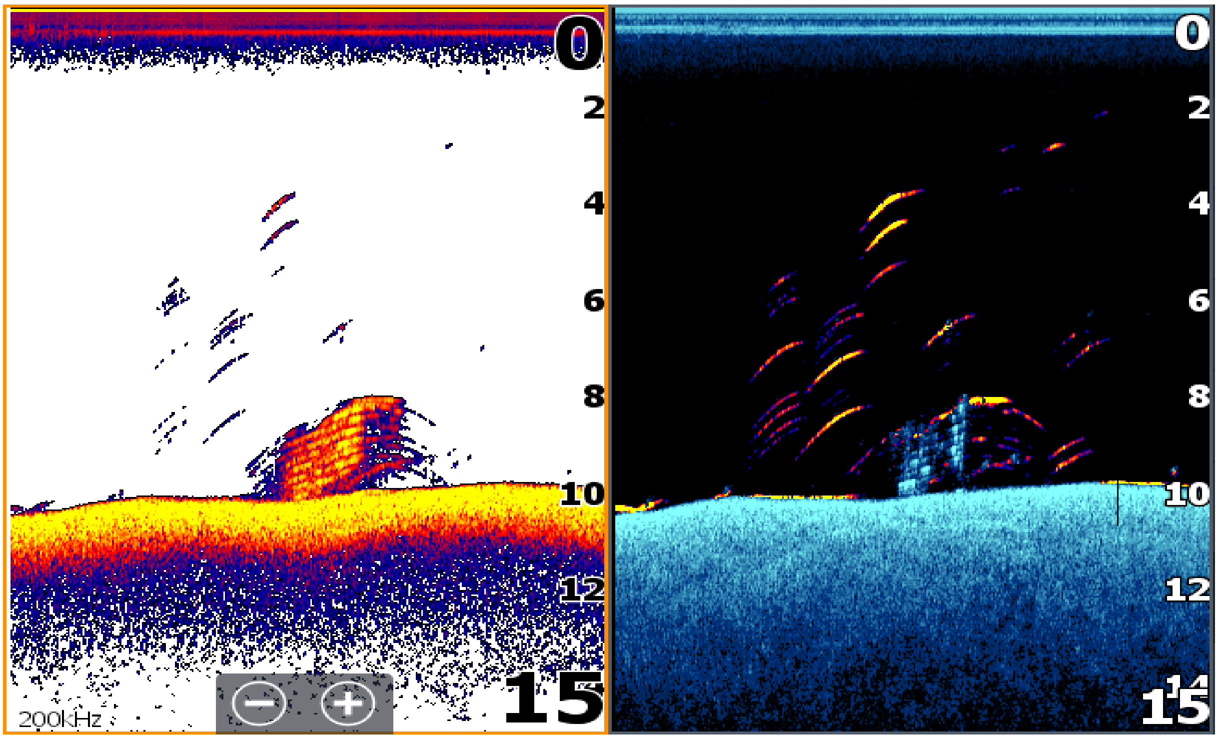

Figure 71 Australian Bass around a Georgia cube at Open water 2.

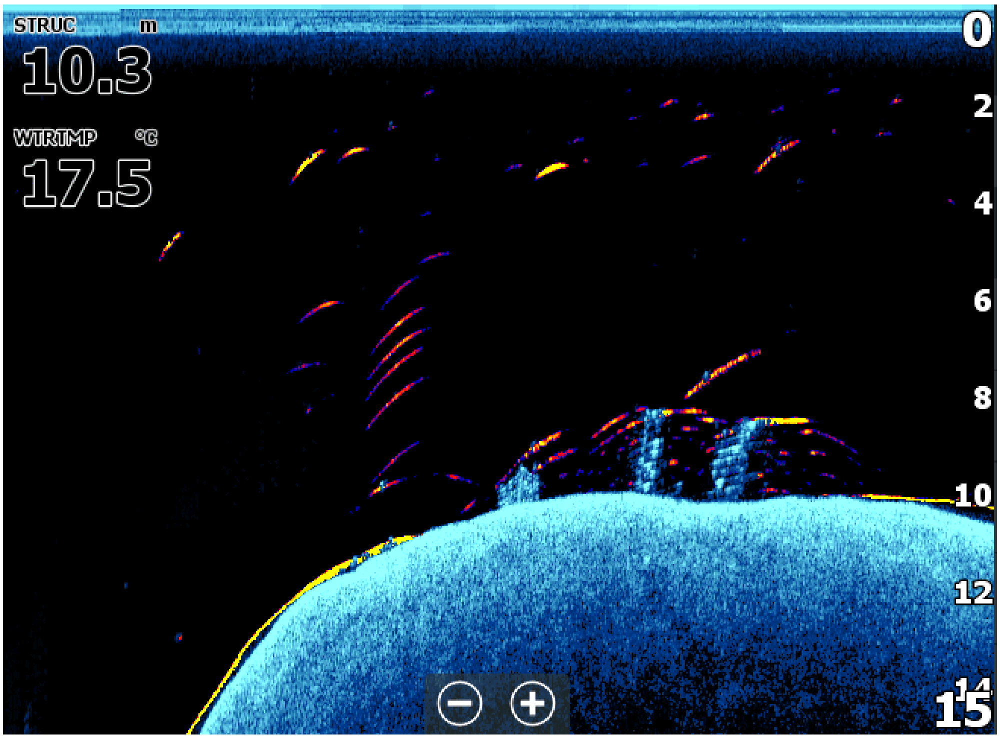

Figure 72 Australian Bass around a cluster of synthetic trees and a Georgia cube at Open water 5.

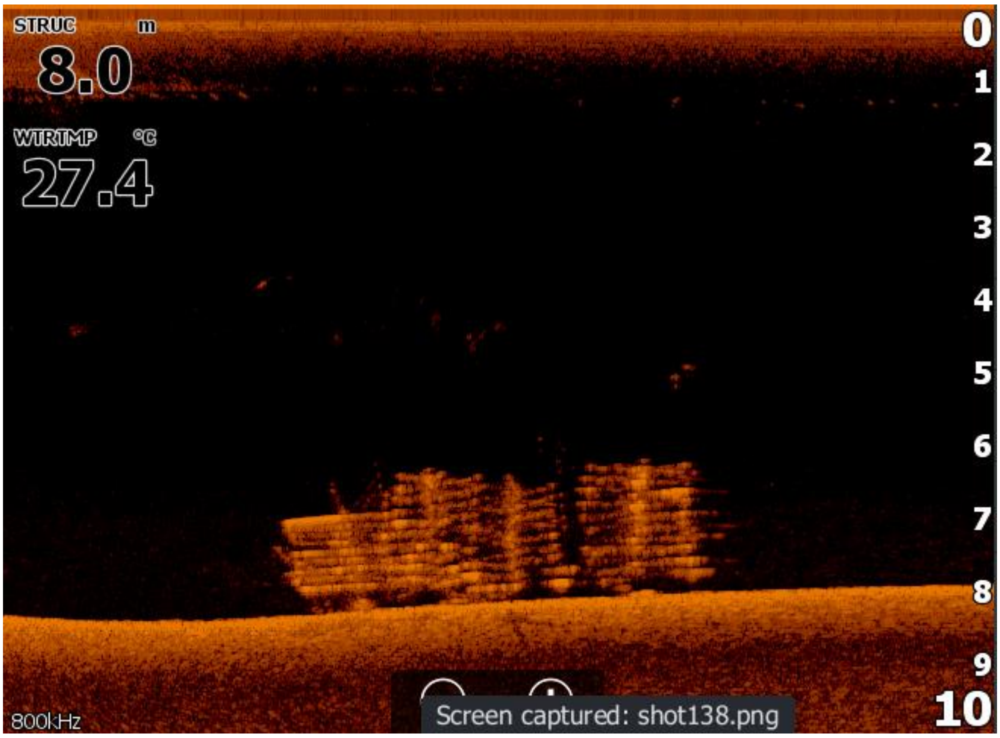

Figure 73 A cluster of synthetic trees and a Georgia cube at Open water 2.

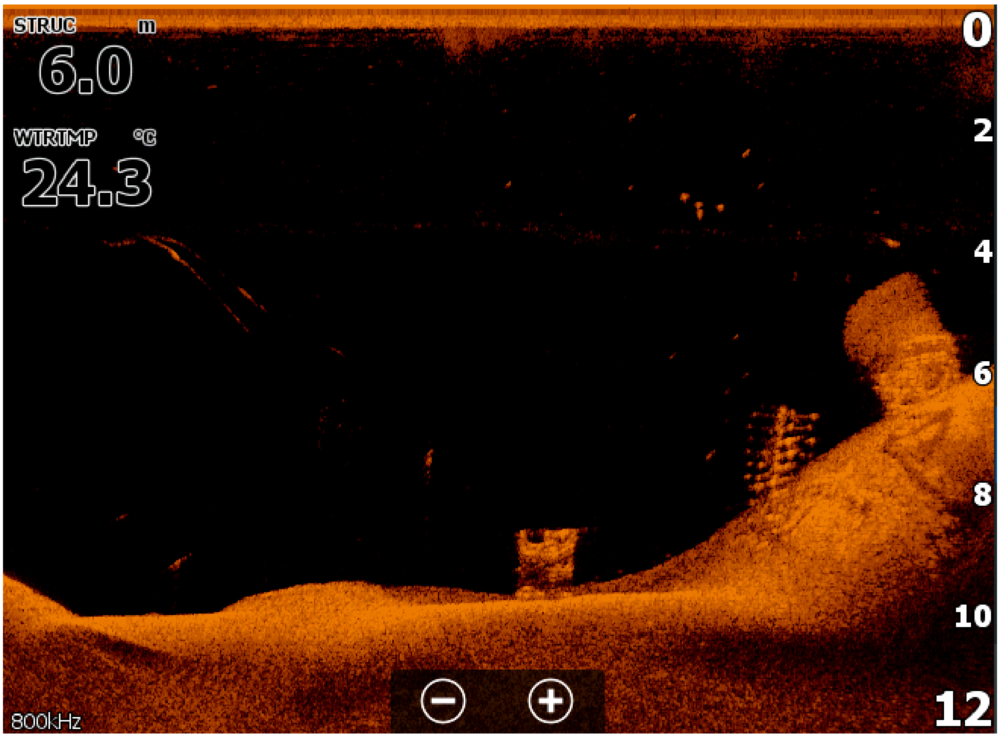

Figure 74 Several synthetic trees and a Georgia cube in Bay 17.

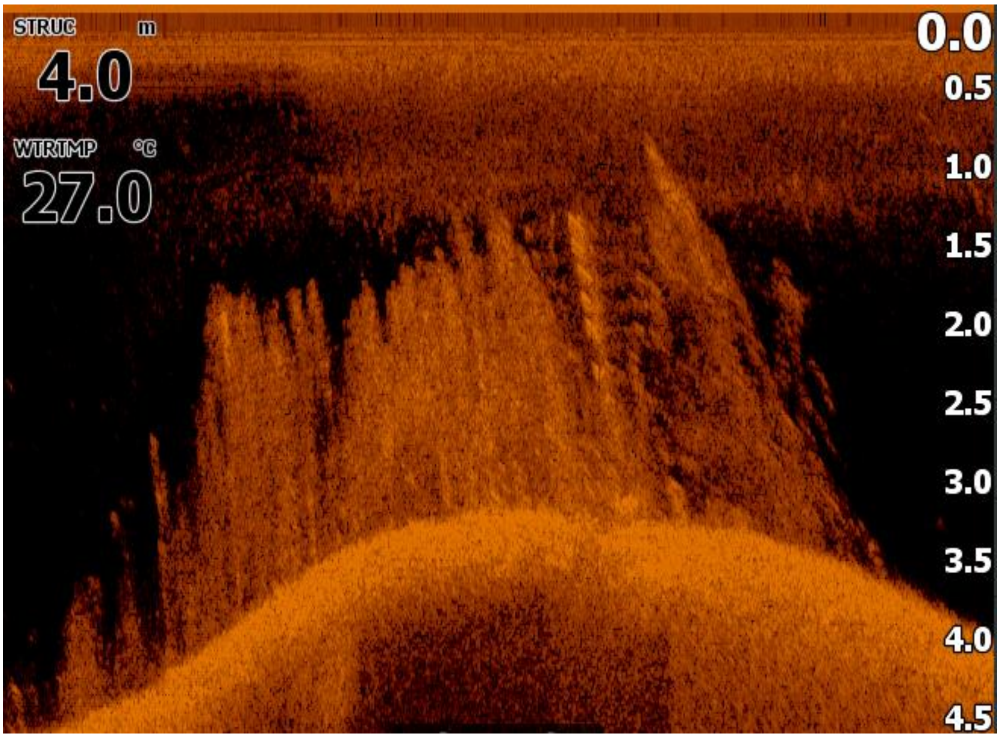

Figure 75 A synthetic tree from Shore 2 covered in aquatic vegetation growth.

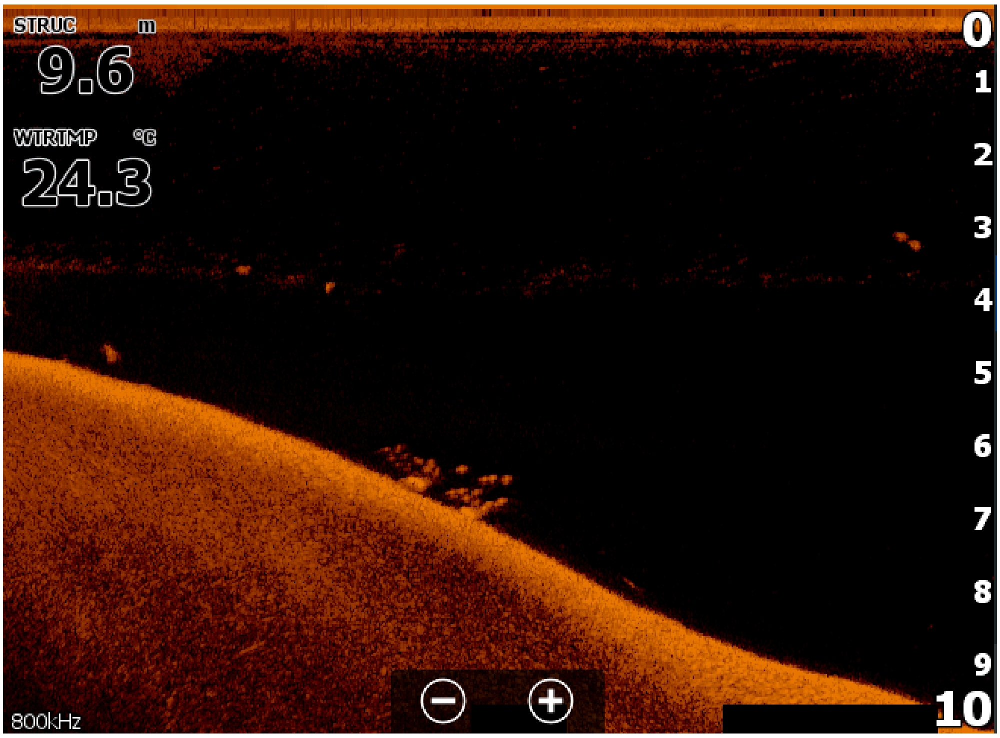

Figure 76 Spider FAS were quite difficult to detect with sonar. The structure most frequently appeared as a close cluster of dots above a solid base, like these ones from Bay 17.

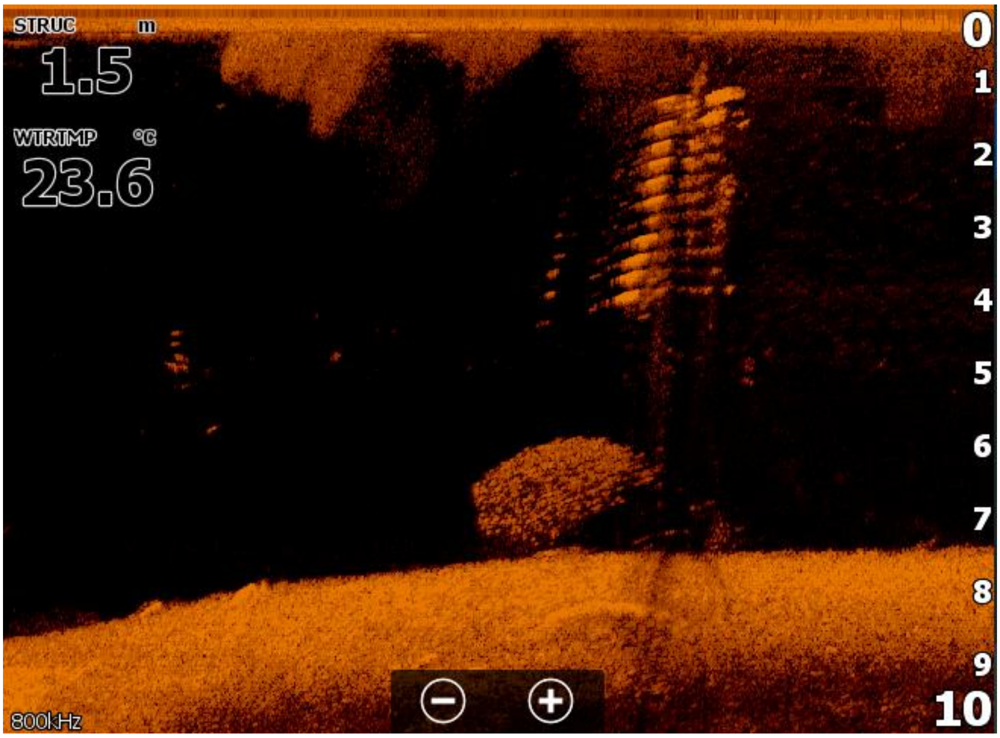

Figure 77 A suspended FAS from Point K with a large bait ball beneath.

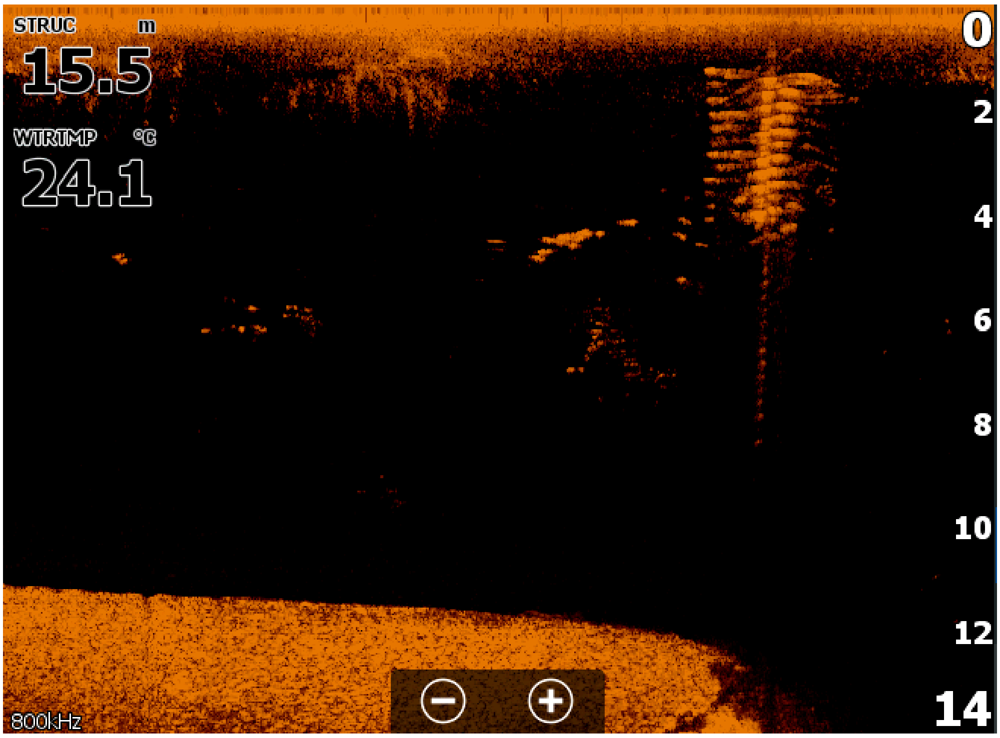

Figure 78 Smaller prey fish and larger predatory fish around one of the suspended FAS at Open water 3.

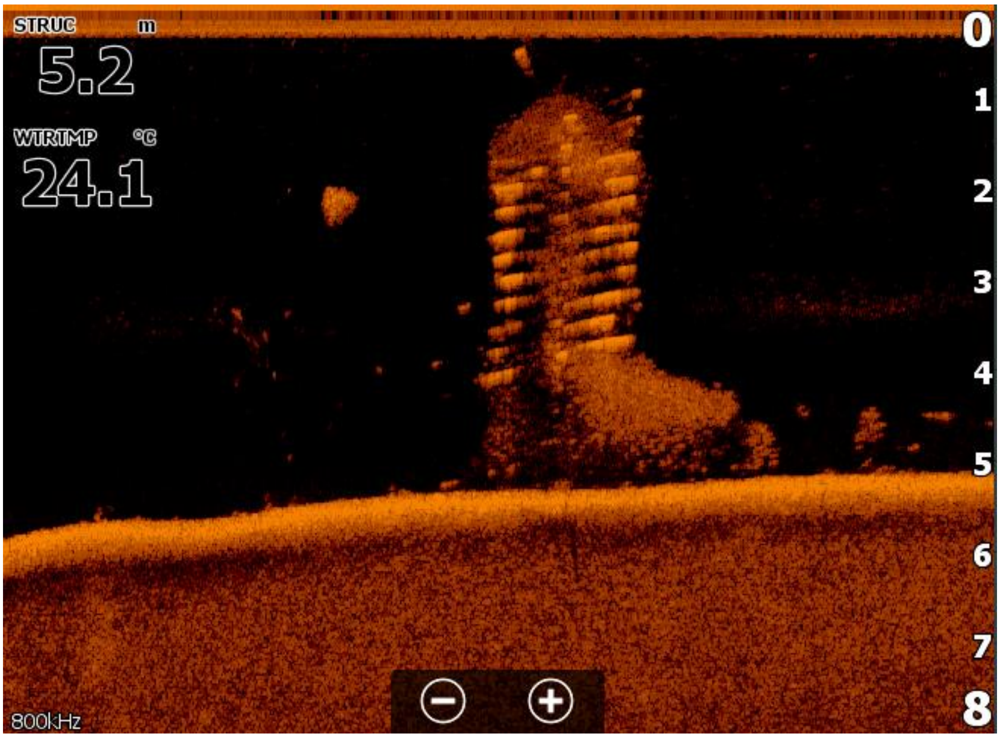

Figure 79 Many of the suspended FAS set in the shallower waters in bays had significant algal and aquatic vegetation growth on them. This suspended FAS was located at Bay 25.

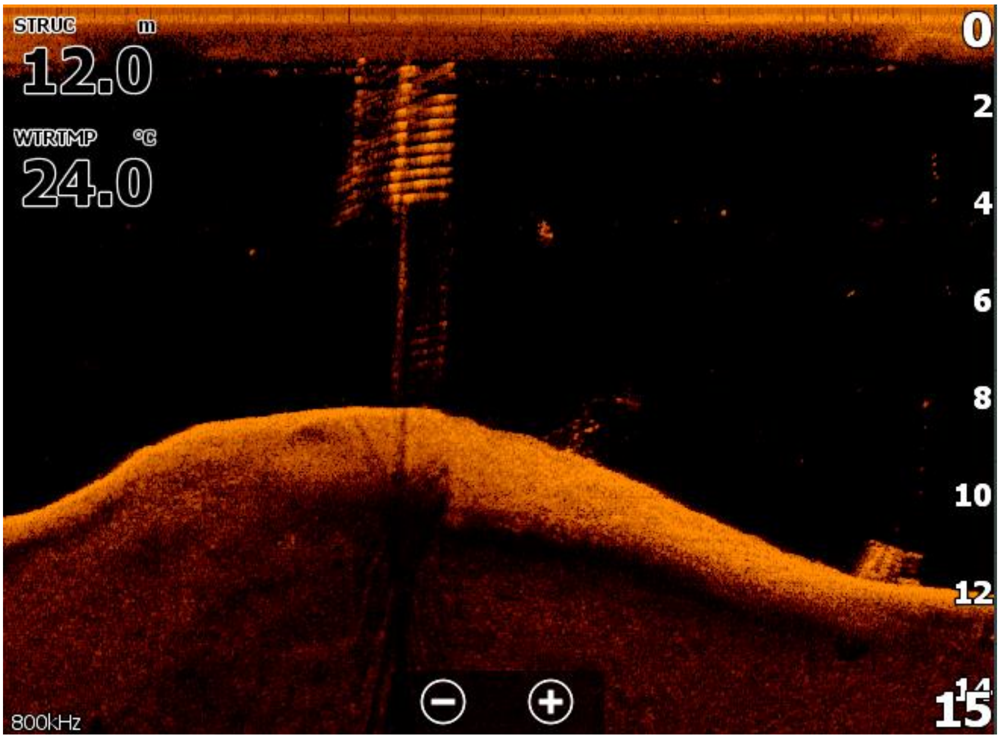

Figure 80 A suspended FAS and timber crib located in the Boat ramp bay

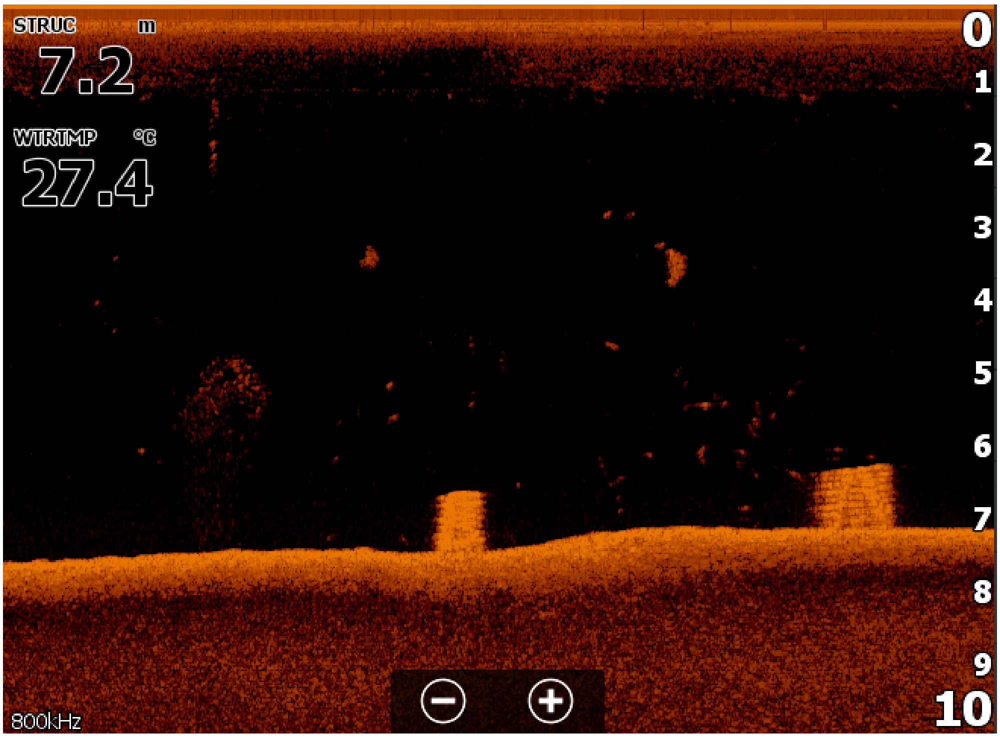

Figure 81 Two timber cribs at Open water 1 with a scattering of fish around them.

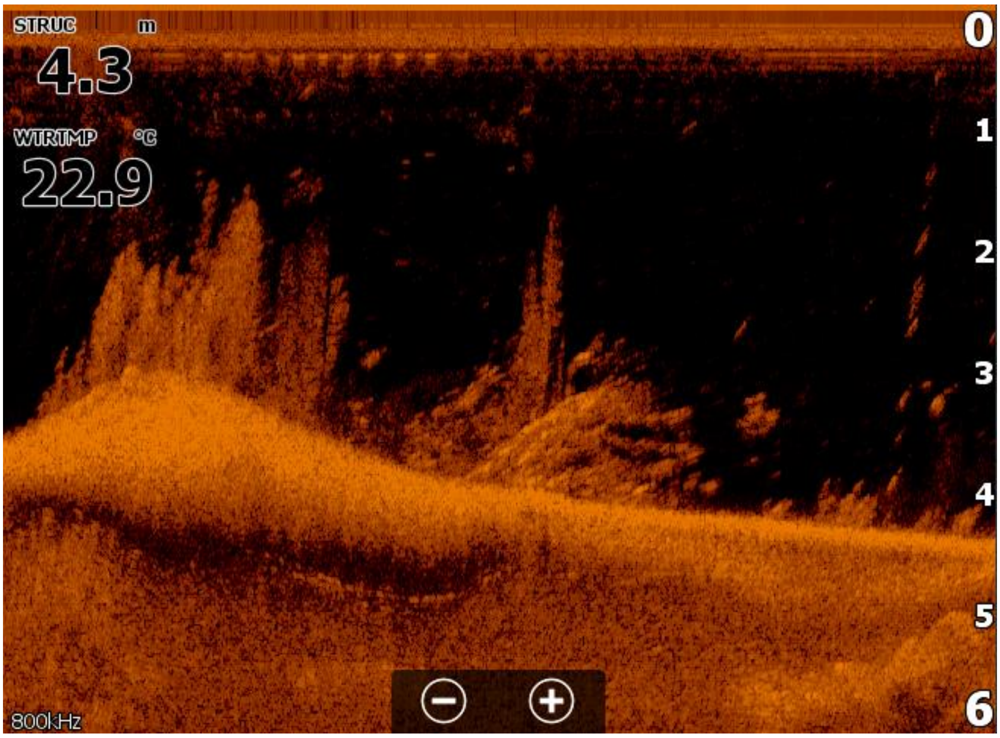

Figure 82 Brush and branch bundles were sometimes difficult to detect because they appeared like aquatic vegetation on the sonar images or were actually covered in vegetative growth. This brush bundle was in Bay 16.

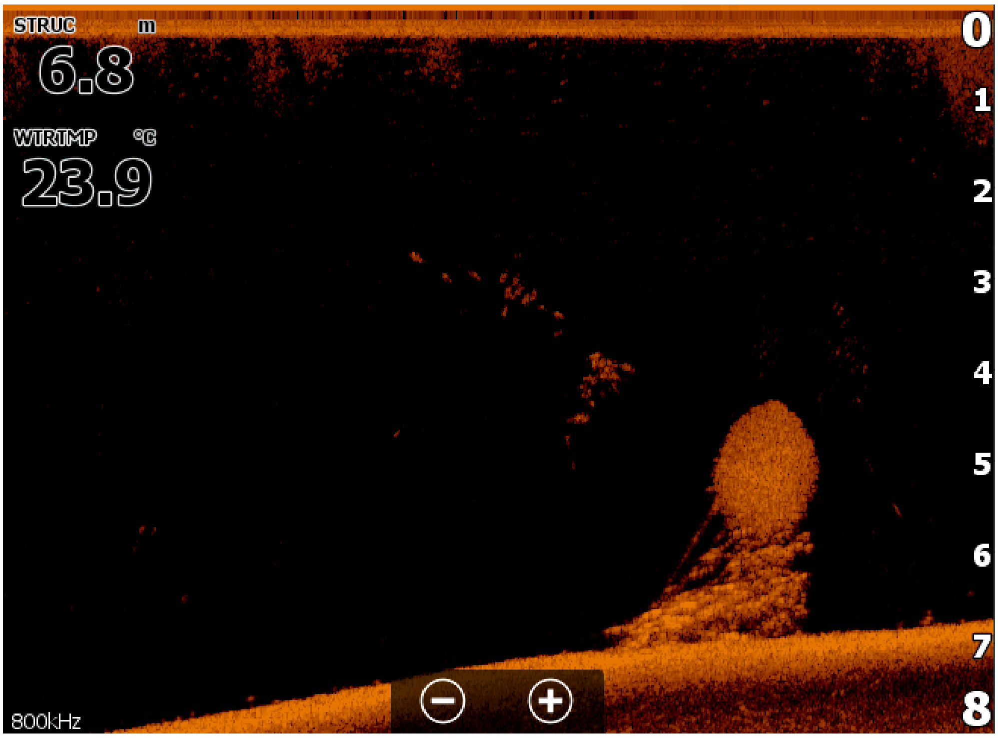

Figure 83 In deeper water the brush and branch bundles were generally easier to identify because they had limited aquatic vegetation growing on or around them. This brush bundle in Bay 23 had a dense school of prey fish associated with it and several larger fish were detected in the vicinity.

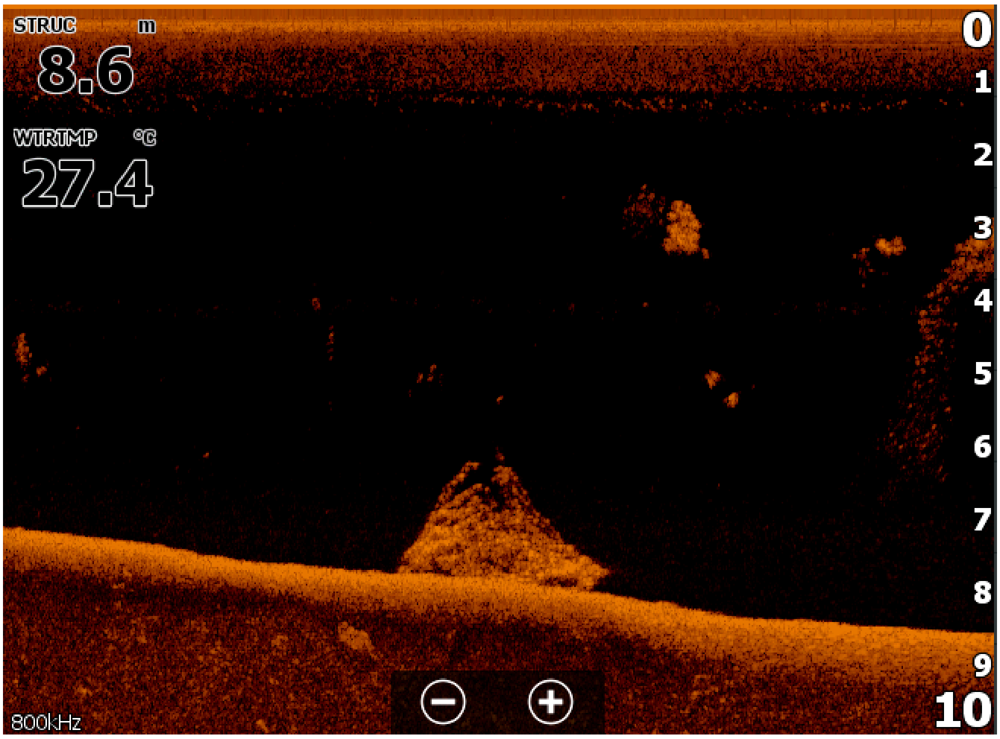

Figure 84 A brush bundle at Open water 1 with fish above it.

Discussion

This is the first study to directly quantify the response of Australian native fish species to the installation of fish attracting structures in Australian impoundments. The results suggest that the addition of structural habitat (FAS) to impoundments may influence habitat selection and distributions in Australian fish species. Structural attributes of aquatic ecosystems can play a large role in determining the distributions, movement patterns, and feeding ecology of fish populations (Scheuerell and Schindler 2004). It has been well documented that fish distributions are strongly influenced by habitat type and availability (Phillip and Ridgeway 2003, Allen *et al.* 2008, Miranda 2017). Interactions between habitat quality and species-specific preferences can drive the fine-scale distribution of fish (Hayes *et al.* 1996, Rosenfeld 2003, Smith *et al.* 2011). Understanding the influence of structural complexity on fish distributions and movement patterns will lead to better impoundment fisheries management. The opportunity exists to utilise habitat installation as a fisheries management tool. In waterbodies such as Cressbrook Dam, where natural cover is limited or deteriorating, installed habitat structures may provide much needed structural complexity for fish and could attract fish to specific areas for recreational anglers. The results from the electrofishing and acoustic tracking indicated several fish species utilised the FAS installed in Cressbrook Dam and installation had an influence on their distributions.

Response of fish to FAS installation

The primary sports fish targeted by anglers in Cressbrook Dam are Australian Bass and Golden Perch. The electrofishing survey and acoustic tracking results indicated that both species roamed widely and utilised a broad range of habitats in both littoral and open water areas. Australian Bass and Golden Perch are both highly structure-oriented, utilising structural habitat for cover and hunting in their natural riverine environments (Allen *et al.* 2003). However, in impoundments where structural complexity is limited, site fidelity may be lower and movement broader and less focussed on specific sites (Smith *et al.* 2011). Knowledge of where fish are likely to aggregate enables anglers to better predict where fish are located and target them more effectively. The installation of FAS in Cressbrook Dam resulted in fish spending more time at sites where FAS were installed than they did prior to installation. This created new spots for anglers to target fish.

The installation of FAS in impoundments has not been well investigated in Australia, but the positive response of stocked native sportfish species to FAS was expected. Australian Bass and Golden Perch occupy similar ecological niches to many north American Centrarchid fish, particularly the black bass species (*Micropterus spp*., largemouth, smallmouth, spotted) and temperate bass species (*Morone spp.* striped, white) which are the focus of most reservoir fisheries in the USA (Coutant 1985, Wanjala *et al.* 1985, Sammons and Bettoli 1999, Allen *et al.* 2003, Phillip and Ridgeway 2003, Cooke *et al.* 2005b, Ahrenstorff *et al.* 2009, Smith *et al.* 2011, Harris 2012). Centrarchids and temperate bass species are also highly habitat-oriented and habitat enhancement programs have reported their abundance to increase around a variety of the installed habitat structure types (Bolding *et al.* 2004, Allen *et al.* 2014, Daugherty *et al.* 2014, Baumann *et al.* 2016, Norris 2016, Miranda 2017, Harris *et al.* 2018).

The debate on whether fish prefer natural structures (e.g., brush piles, woody debris, wood structures, rock piles, etc.) or synthetic structures (e.g., plastic, steel, concrete etc.) is ongoing. Numerous overseas studies have found natural structures to be more effective at attracting fish for anglers (Jenkins and Forsythe 1984, Bassett 1994, Richards 1996, Rold *et al.* 1996, Bolding *et al.* 2004, Santos *et al.* 2011). Other studies have documented synthetic structures to be better at attracting and holding fish over time (Thompson 2015, Baumann *et al.* 2016). Regardless of the debate, both natural and synthetic habitat structures have been successful at improving impoundment fisheries outside of Australia.

In Cressbrook Dam, periphyton growth (and the associated invertebrate fauna) varied depending on the structural complexity of FAS designs. This may be a key factor in determining long-term FAS effectiveness. Durability is another key factor, but the monitoring timeframe was too short to adequately examine how this varied between structure designs.

Optimal foraging theory predicts that fish will maximize energy intake and growth by minimising energetic losses through foraging and handling costs, while also avoiding predation risk (Werner *et al.* 1983, Townsend and Winfield 1985). Installation of structures which potentially increase food resources, whilst also providing cover from predators should attract a range of smaller fish species. These in turn are likely to attract larger predatory species. In Cressbrook Dam, the installation of FAS resulted in localised increases in food resources through the periphyton growth that occurred on their hard surfaces. Periphyton plays an important role in the functioning of lakes and reservoirs, contributing significantly to primary production and nutrient cycling (Vadeboncoeur and Steinman 2002). This microhabitat also attracts shrimp and other invertebrates on which fish feed (Jones *et al.* 1998, Hemminga and Duarte 2000). In impoundments overseas, the increase of periphyton growth and aquatic invertebrates on installed habitats has been reported as an attractant to fish (Rold *et al.* 1996, van Zwieten *et al.* 2011, Miranda 2017).

The accumulation of periphyton and the associated faunal communities varied between FAS types and sites in Cressbrook Dam. Accumulation was greatest on FAS installed in shallow water and much slower on deep water structures. This trend was most evident on suspended FAS where the top limbs of the structure were often densely covered in algae, whilst the lower limbs contained only a light covering. Light penetration is a critical factor in periphyton growth and water clarity in Cressbrook Dam would have influenced the rates at which the periphyton grew at different depths (Francoeur *et al.* 1999). Periphyton growth was also much quicker on the timber FAS compared to the synthetic materials (PVC and LDPE). This faster growth could lead to fish becoming attracted sooner to timber structures.

It was anticipated that the localised abundance of algal grazers, such as Bony Bream and Snub-nosed Garfish, would increase at FAS sites as their food resources became more abundant. Both these species are prey for Australian Bass and Golden Perch in impoundments (Harris 1985, Smith *et al.* 2011) and increases in their local abundance would likely attract the predatory sportfish. Significant increases of Snub-nosed Garfish were observed where suspended, synthetic and mixed FAS were installed, potentially suggesting attraction to FAS constructed from synthetic materials. The increase at FAS sites was greater than at the Control and Reference sites. However, Snub-nosed Garfish abundance increased broadly at all sites across the impoundment, so it is difficult to draw any firm conclusions.

In contrast, the installation of FAS had no significant influence on Bony Bream catch rates in the electrofishing surveys. This species was consistently captured in high numbers at all sites across the impoundment, indicating a strong existing population. There was no clear evidence of attraction to the FAS. However, sonar imaging around the FAS sites, particularly suspended FAS and those set in deeper water, frequently detected large schools of prey fish around the structures. These fish were most likely Bony Bream. Larger fish (presumably Australian Bass and Golden Perch) were often observed lurking in the vicinity of these prey schools. This could indicate that Bony Bream may have been using some of the FAS, possibly as a means of cover from predation. Unfortunately, water clarity was too poor to confirm the species compositions using the underwater cameras, and the fish occurred too deep for electrofishing to be effective.

The limited response from Snub-nosed Garfish and Bony Bream to the installation of FAS may indicate their food and shelter resources were not limited and thus not a key factor influencing their distribution. During the project water levels partially stabilised and the quantity of submerged marginal aquatic vegetation and periphyton increased significantly. The expansion of this food source would mean that the algal grazers would not need to venture to or stay around the FAS in search of food. Instead, they could remain in the safety of the dense vegetation.

Structural habitat complexity provides many fish species with shelter from predation (Barbarosa and Castellanos 2005, Hauzy *et al.* 2010, Klecka and Boukal 2014, Enefalk and Bergman 2015, Yeagar and Hovel 2017). Fish often need to compromise between optimal feeding strategies and predator avoidance (Townsend and Winfield 1985). This is hypothesised to be one of the reasons complex substrates provide better habitat for macroinvertebrates (Smokorowski *et al.* 2007). Previous studies have linked structure size and interstitial spacing with the ability of smaller fish to evade predators (e.g., Johnson *et al.* 1988, Lynch and Johnson 1989, Walters *et al.* 1991, Crook and Robertson 1999). Habitats with smaller interstices are suggested to be preferentially selected by small fish. Conversely, larger fish have been found to prefer habitat with medium to large interstices, providing them with a better balance between hiding from prey and having sufficient opportunity to ambush and capture their food successfully (Allen *et al.* Miranda 2017). Wootton (1998) reported that the presence of larger predators may restrict habitat use by smaller predators or prey. This suggests that some habitats may support fewer, larger predatory fish, while others may support more numerous, smaller individuals.

In Cressbrook Dam, interstitial spacing varied between the different FAS types, but all structures provided both ambush opportunities for predators and some degree of cover for prey. Use of FAS with different sized interstitial spaces appeared to vary slightly between fish species of different sizes. Timber FAS contained the greatest structural complexity. The finer branches in the brush bundles provided the smallest interstitial spaces and the log cribs contained areas difficult for large fish to enter. The abundance of smaller prey species at timber FAS sites increased following their installation. Carp Gudgeon, Australian Smelt and Olive Perchlet were all significantly more abundant at sites where timber FAS had been installed, including at the mixed FAS sites. In the electrofishing surveys, the catch rates for Australian Bass and Golden Perch were also greater at sites with timber FAS, although most were captured from near the timber cribs rather than the brush bundles. Most of the timber structures were deployed quite late in the project, so the response by fish may not yet be fully realised as the organic growth on the timber is likely to still be developing. These results are similar to those observed in Lake Havasu, Arizona. Norris (2016) observed that in Lake Havasu large bundles of brush contained fish of a greater range of sizes than similar sized, but more open synthetic structures. The smaller fish were found tight amongst the structure where they could hide, whilst the largest fish were found patrolling the open water in close vicinity to the structure.

The low catch rates for the sports fish during the electrofishing surveys limited investigation into species-specific size-class trends for preferential use of the more open structures. In the synthetic FAS the interstitial spaces were typically larger, although the hollow ends of pipes provided refuge areas for smaller fish and crustaceans. Significant increases in the abundance of Australian Bass and Golden Perch were observed at sites where the synthetic FAS were installed. The abundance of unspecked Hardyhead, Snub-nosed Garfish and Mosquitofish all increased significantly post installation at the synthetic FAS sites and were the highest amongst the different FAS types. Underwater camera and drone images also showed large schools of Carp Gudgeon and Olive Perchlet present around synthetic structures.

Synthetic FAS are commonly used for habitat enhancement in the USA (Tugend *et al.* 2002, Norris 2016). They have proven to be effective at attracting a wide range of sports and table fish, from crappie to largemouth bass and giant flathead catfish (Miranda 2017). In some states synthetic materials are preferred for habitat enhancement projects because they have no impact on water quality in reservoirs which supply town water and do not release debris that could clog hydro-electric power turbine intakes (Norris 2016). The Georgia cube was identified as being one of the most effective synthetic structure designs for attracting fish. The design has been further refined to create the Shelbyville cube which is now the preferred fish attracting structure for several state fisheries agencies (Figure 85, pers. comm. Illinois Department of Natural Resources).

Figure 85 The new Shelbyville cube design awaiting deployment in Lake Shelbyville, Illinois. Image: US Army Corps of Engineers, St Louis District.

The suspended FAS contained the most open structural design but had some smaller spaces in the open ends of the horizontal pipe limbs. Evidence from the electrofishing surveys, acoustic tracking and limited underwater camera footage all indicated Australian Bass and Golden Perch were using the suspended FAS. The acoustic tracking data revealed concentrated hotspots around these structures, although this changed seasonally. When the water was clear enough, underwater camera footage detected the presence of individual or pairs of Australian Bass or Golden Perch using the suspended FAS. These fish would swim near or through the gaps in the horizontal limbs. One Golden Perch was even observed striking at and consuming a small prey, confirming the sportfish were actively feeding around the structures. There were no clear patterns of strong attraction or habitat use for prey species. Only Snub-nosed Garfish, Bony Bream and Barred Grunter were detected at moderate to high levels, but their abundance at the synthetic FAS was not significantly different to those at other sites. Suspended fish attractors have rarely been used before in open impoundment waters. The unique design developed for Cressbrook Dam was specifically intended to attract pelagic prey species and predatory sportfish in open water areas. In the USA structures are sometimes suspended from fishing piers or boat docks to attract fish, but rarely placed in deeper open waters near the surface. Black bass species (*Micropterus spp.*) utilise the structure created by floating pontoons and wave attenuators to ambush prey (Barwick *et al.* 2004) and these are popular areas for anglers to target. It is therefore surprising the use of suspended FAS has not received more attention.

Daugherty *et al.* (2014) urged a degree of caution when selecting FAS designs based primarily on interstitial space size. The authors suggest that many FAS habitat designs typically used in habitat enhancement may not improve angler catch rates of desirable-sized fish. The finer interstitial spacing of evergreens and fresh brush bundles may attract more fish, but the dense, complex structures that offer competitive advantages to prey may not attract larger predators due to reduced feeding efficiency. They concluded that management objectives associated with attracting the larger fish desired by most anglers, should consider designs that reduce interior space and structural complexity, whereas efforts to improve habitat for early life stages and prey populations should emphasize these characteristics.

Structural durability is a key component in evaluating the suitability of different type of FAS for use in Australian impoundments. Durability impacts how the effectiveness of FAS changes over time, and the period until when supplementation or replacement is necessary. These two factors are key components when considering the cost-effectiveness of using different FAS types.

In Cressbrook Dam, limited evidence of FAS degradation was observed in any of the FAS types. However, the duration of the monitoring period was relatively brief due to the project timeframe. The first synthetic FAS were installed in summer 2019, whilst timber and suspended FAS were first introduced in spring 2019. Therefore, observations on FAS durability were limited to a 15 month to two-year period.

Declining water levels and expansion of the submerged aquatic vegetation beds resulted in examples of all FAS types becoming overgrown. When water levels rise and the vegetation senesces, the impact to the FAS will become evident. Anecdotal observations suggest the synthetic trees, timber cribs and spiders are likely to experience little damage. The suspended FAS which have contacted the bottom and become engulfed by vegetation seem to have suffered some bending of their longer horizontal limbs. This damage may be only cosmetic unless the PVC has been creased, in which case there is a low chance for sections of the limbs to snap off. Loss of a small number of limbs or limb sections is unlikely to impact the function of the suspended FAS. No Georgia cubes were smothered by vegetation, so damage is unlikely to have occurred. Brush bundles are the FAS type most at risk of degradation through natural breakdown and damage from both anglers and vegetation growth. However, no damage or degradation was evident during the observation period. Leaves were removed prior to installation to minimise potential impacts on water quality and hardwood branches were used where possible to increase durability.

Previous studies have generally reported that synthetic materials provide long-term FAS durability, whilst many structures consisting of natural materials have comparatively shorter lifespans (Bolding *et al.* 2004, Allen *et al.* 2014, Daugherty *et al.* 2014, Jones *et al.* 2015, Baumann *et al.* 2016, Miranda 2017). Evergreen structures, such as whole green cedar trees or recycled Christmas trees, have formed the basis for many fish habitat enhancement programs in USA reservoirs. However, they are reported to have quite short lifespans (3-9 years) and require frequent replenishment or replacement (Bilby *et al.* 1999, Walters *et al.* 1991, Rogers and Bergersen 1999, Jacobson and Koch 2008, Miranda 2017). Larger trees remain functional for a longer time, but the interstitial spacing size increases with time as the finer limbs degrade (Allen *et al.* 2014). Bamboo has been used to provide slightly more durable natural structures containing fine interstitial spaces. Jones *et al.* (2015) suggested bamboo crappie condos should persist between 6-10 years before needing replacement. Solid timber structures such as cribs, root balls and large tree trunks and limbs have proven more durable and estimated to last between 10-30 years (Allen *et al.* 2014, Jones *et al.* 2015, Miranda 2017).

In marine systems, durability and design versatility have led to concrete and steel structures becoming the most common materials used in artificial reefs (Lemoine *et al.* 2019). These materials have been less popular in freshwater waterbodies, possibly because they can be more difficult and expensive to deploy (Allen *et al.* 2014). Rock and rubble piles have frequently been deployed to attract fish (Miranda 2017), but specifically designed concrete reef modules have not yet gained wide acceptance. An increase in the use of reef balls (custom concrete modules design to provide fish habitat) is starting to occur. These structures have been placed in several reservoirs in the USA, but the results from their installation are yet to be reported. One of the advantages of rock and concrete structures is their extremely high durability and long-term lifespan (100+ years, Jones *et al.* 2015). The use of these materials can be highly effective in impoundments where water levels fluctuate significantly. The repeated exposure to air can lead to rapid degradation of other materials (Norris 2016). Rock and concrete structures can be more safely, easily, and cost effectively deployed in impoundments during the construction phase or when water levels are low during seasonal fluctuations, droughts or during dam wall maintenance. This approach is recommended where possible.

Visual monitoring of FAS condition and fish use

Visually monitoring the condition of FAS and their use by fish in Cressbrook Dam proved difficult due to consistently low visibility. Even during late winter and early spring, when algae and phytoplankton densities were lowest and with secchi depths above 300 cm, image quality from the underwater cameras was of limited value for quantitative surveys. Visual surveys of fish distributions and habitat use in impoundments using divers and underwater cameras have been used in the past (Loffler 1997, Cappo *et al.* 2007, Jacobson and Koch 2008, Allen *et al.* 2014). Varying water clarity and diver avoidance have been identified as key confounding factors when analysing the results (Dolloff *et al.* 1996, Jacobson and Koch 2008, Allen *et al.* 2014). Norris (2016) found the general consensus amongst the fisheries biologists in the USA was that visual surveys were ineffective at providing long-term assessments for habitat enhancement. The main reasons given were that visual counts using SCUBA divers, underwater cameras and time-lapse photography were highly confounded by underwater visibility and cryptic fish behaviour. Data from these techniques was found to be inconclusive due to high variability between counts and the techniques are no longer used for periodic fish surveys, even in clear lakes. In many Australian impoundments the water clarity is unlikely to be conducive to quantitative visual surveys. Alternative approaches need to be utilised.

When compared to other commonly used fish sampling techniques, hydro-acoustics provide a non-invasive and logistically feasible sampling method for deeper water or turbid applications. Sonar can observe fish and habitat in a way comparable with visual observations, without the restrictions of turbidity (Holmes *et al.* 2006, Maxwell and Gove 2007). Current high-end recreational-level sonar units have the ability to provide clear images of fish abundance, habitat complexity and substrate composition beneath a vessel. However, they typically do not provide enough detail to accurately identify most fish to the species level. The sonar images of the FAS in Cressbrook Dam were suitable for providing an assessment of habitat condition and growth of submerged vegetation. In Australia many fisheries boats, and even boats belonging to recreational anglers, have sufficient sonar systems for habitat condition assessment to be undertaken with little additional resourcing. Sonar is a useful tool for groups installing FAS to monitor their condition and the general aggregation of fish around them. The image quality of recreational sonar units is rapidly improving, and several brands now offer active scanning imaging (e.g., Lowrance Active Target, Garmin Live Scope). These units offer similar features to many commercial multi-beam sonar systems, but at a fraction of the cost. They provide monochromatic video-like live views of fish and habitat, but image quality is still limiting for analysis. The level of detail possible with sonar images (Figure 86) lends this form of condition monitoring to broader use.

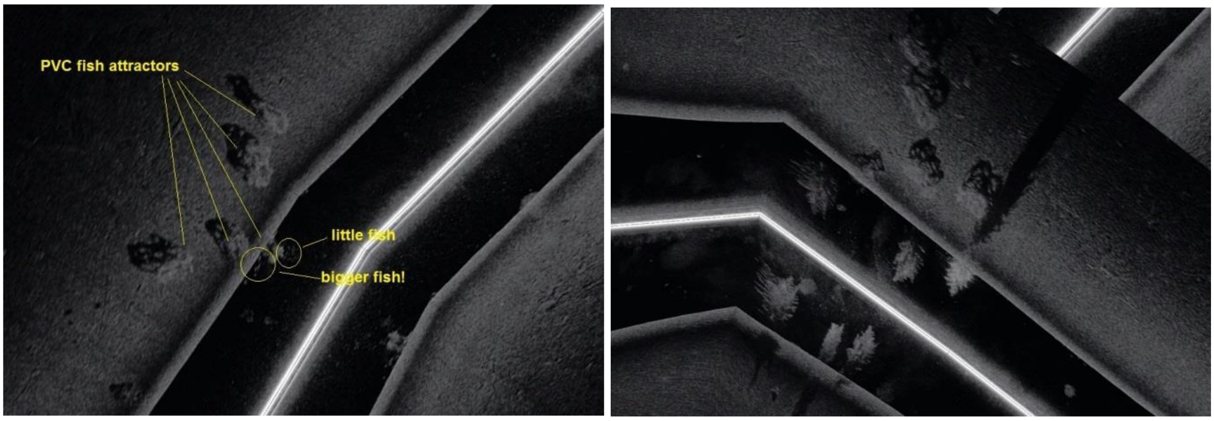

Figure 86 Screen shots from a high-quality side-scan sounder showing PVC and pine fish attracting structures (images courtesy of TPWD)

Multi-frequency sonar has been widely used in fisheries management as a tool for assessing habitat and fish biomass in marine systems. This commercial-level advanced version of sonar is gaining popularity amongst USA reservoir fisheries managers to monitor fish use and structural condition of FAS. Multi-frequency systems provide more detail than single frequency sonar but are more expensive and logistically more difficult to operate. Sonar imagery is limiting when a fish lacks distinguishing morphology, including size, making species identification unreliable (Mueller *et al.* 2010), or when multiple fish inhabit the same sonar beam (Holmes *et al.* 2006), which affects detectability. Current research using machine learning and artificial intelligence to identify individual fish holds great promise for monitoring FAS (Allken *et al.* 2019). The active scanning provides live views which enable detailed investigation on how fish use FAS. Multi-frequency sonar was effectively used to visually evaluate four artificial fish habitat designs and their effectiveness in concentrating fish in turbid North Carolina reservoirs (Baumann *et al.* 2016). Dual frequency identification sonar (DIDSON) was used to capture detailed images of the different habitat types over a 3-year period. The level of detail was sufficient to clearly identify the deterioration rate of evergreen tree bundles and determine the size and number of individual fish using the FAS at any point in time.

The ability of multi-frequency sonar to operate over a wide range of depths and in turbid water suggests this technique could be highly useful for monitoring the effectiveness of different FAS in Australian impoundments. Electrofishing is non-invasive and can be highly effective, but catch rates are influenced by water clarity, temperature and conductivity and the technique is limited to shallow waters. Currently the only technique which could reliably operate in turbid or deep water is gill netting, but this method can have a detrimental impact on the health of captured fish (Zale *et al.* 2013). It is recommended that future studies on FAS consider the use of multi-frequency sonar as part of a monitoring toolbox.

Impacts of water levels and aquatic vegetation growth

Stabilisation of the water level at Cressbrook Dam was potentially a confounding factor in the investigations into the distribution of fish and their use of FAS. Cressbrook Dam typically only fills during well-above average rainfall events, followed by a historical annual decline of approximately 2 m per year. The variable water levels have historically led to only narrow bands of littoral submerged aquatic vegetation around the dam. Continually falling water levels in the dam prompted TRC to turn on the pipeline connection to Wivenhoe Dam in January 2019. Pumping from Wivenhoe Dam ensured water levels did not drop too low and town water supply requirements could be met. Water levels were maintained above 30% for the remaining period of the project. The more stable water levels resulted in a significant expansion in the extent of the aquatic vegetation. This created several potential issues for the project.

Water depth and clarity influence the extent of submerged aquatic vegetation (Canfield *et al.* 1985). The outer extent of submerged aquatic vegetation in Cressbrook Dam generally occurred around 3 m depth. When water levels were continually falling the vegetation at this depth was relatively short and patchy. As water levels stabilised, this vegetation had longer to grow, became denser and grew almost to the surface. To minimise the risk of FAS becoming overgrown by the submerged vegetation, they were deployed in 5 m water depth or greater. However, as the water levels continued to fall throughout the project, the band of vegetation extended beyond where some of the FAS were located.

When water levels stabilised and the vegetation density increased, FAS in some locations became partially or completely overgrown by vegetation. This would have reduced their functionality and attractiveness, and thus likely use by fish. The dense vegetation also made surveying fish distributions difficult. The electrofishing boat could not readily access some of the FAS that were covered by vegetation. Additionally, stunned fish in dense vegetation do not always rise to the surface making detection and dip-netting difficult. Together, these factors may have led to an underestimate of fish use of the FAS amongst dense vegetation.

The vegetation also impacted the effectiveness of acoustically tracking the Australian Bass and Golden Perch. Detection of signals from acoustic tags is problematic amongst aquatic vegetation (Swadling *et al.* 2020, Weinz *et al.* 2021). Physical obstructions such as submerged aquatic vegetation or topography can block, reflect, or distort signals (Hightower *et al.* 2001, Simpfendorfer *et al.* 2008, Cagua *et al.* 2013). Fluctuations in the amount of aquatic vegetation may cause drastic temporal fluctuations in the performance of acoustic telemetry equipment. Weinz *et al.* (2021) reported acoustic signal detection rates could drop by up to 96% in dense submerged aquatic vegetation.

The aquatic vegetation in Cressbrook Dam prevented placement of the acoustic receivers in close proximity to the shorelines with aquatic vegetation. This resulted in limited coverage of tagged fish movements in many of the shallower sections of bays. Additionally, fish could not be tracked when they moved through areas with aquatic vegetation. As the vegetation beds expanded, the area where fish could not be reliably tracked increased. This included bays and some shallower FAS which became overgrown by the vegetation. The acoustic receivers also had to be shifted deeper several times to ensure they were operating in open water. This is likely to have resulted in under-representation of fish use of these littoral areas in the acoustic tracking results.

Weinz *et al.* (2021) concluded changes in submerged aquatic vegetation could affect activity spaces and designation of core use areas based on kernel density estimates. Vegetated habitats are relevant to studies of fish movements and behaviour, because they provide structural complexity for fish seeking refuge from predation, abundant invertebrate food resources, habitats for spawning and nursing, and protection from wave energy (Randomski *et al.* 2019). Brownscombe *et al.* (2020) developed a method that involved using reference receivers and tags to determine the maximum detection range and monitor variance in detection efficiency to generate correction factors that could then be determined for all receivers in the array using random forest models. This approach could be considered in future impoundment fish tracking projects where aquatic vegetation is likely to be an issue.

Expansion of the aquatic vegetation in Cressbrook Dam changed the productivity and potentially the distributions of sportfish species. The significant increase in abundance of all smaller fish species across the impoundment correlated with the increasing in extent and density of the submerged aquatic vegetation. An increase in periphyton also would have corresponded to the increase in aquatic macrophytes (Thomaz *et al.* 2008). These provide key food resources for many small freshwater fish species and thus the observed rise in abundance was most likely driven by increased food availability.

The increase in the prey fish abundance, together with increased periphyton and invertebrates around the aquatic vegetation, likely had a significant impact on the distribution of Australian Bass, Golden Perch and Freshwater Catfish in Cressbrook Dam. Sport fish may be attracted to habitat because they experience improved foraging efficiency that ultimately leads to increased growth rates (Crowder and Cooper 1979, Wege and Anderson 1979, Rold *et al.* 1996). The macrophytes can provide a predatory advantage to the sportfish, particularly along the edge of the vegetation or where the vegetation is more scattered. Fish can use the structure and shade to ambush prey species which venture too far from cover (Helfman 1981). The Australian Bass and Golden Perch likely spent more time in the vicinity of the vegetation beds than they would have, had the vegetation been more confined in extent (as has historically been the case). This may have reduced their use of FAS. Once water levels begin to rise again and the extent of aquatic vegetation contracts, it is predicted fish use of the FAS may increase.

Limitations due to low electrofishing catch rates

The electrofishing catch rates of Australian Bass and Golden Perch were very low in Cressbrook Dam. Anglers also typically report low catches at this dam, which may indicate that the abundance of stocked fish is generally low. The catch rates during the electrofishing surveys were generally zero-biased, which resulted in high inter-survey variation. Low numbers of fish were captured from each FAS type which weakened the power of the general linear models comparing their effectiveness. Comparison of FAS in an impoundment with higher abundance of sportfish would strengthen statistical confidence in the trends observed and provide greater insight into how fish are utilising the FAS.

Factors confounding the acoustic tracking results

The tag detection and position calculations from the acoustic tracking were partially confounded by the influence of FAS locations, aquatic vegetation, receiver placement and tampering with equipment. Bays and points were selected as the primary sampling unit for the different FAS in Cressbrook Dam because they allowed discrete monitoring units to be established. A suite of monitoring techniques was utilised, but electrofishing formed the core component of the monitoring program. Therefore, many FAS were set in shallow areas suitable for electrofishing (<5 m). However, placement of the structures in the bays made it difficult to establish good coverage with the acoustic receivers. Aquatic vegetation limited where the receivers could be placed and also attenuated signal strength from tagged fish when they moved within the vegetation (see discussion above). The location of receivers in bays meant that significant sections sometimes fell outside the limit of direct line-of-sight between the receivers. Locating fish in the area outside of the line-of-sight receiver array boundary leads to greater positional error and less probability positions can be calculated (Espinoza *et al.* 2011, Roy *et al.* 2014). Additionally, the apex of most bays could not be effectively monitored due to the shadow effect behind the innermost receivers (Figure 87, Smith 2013).

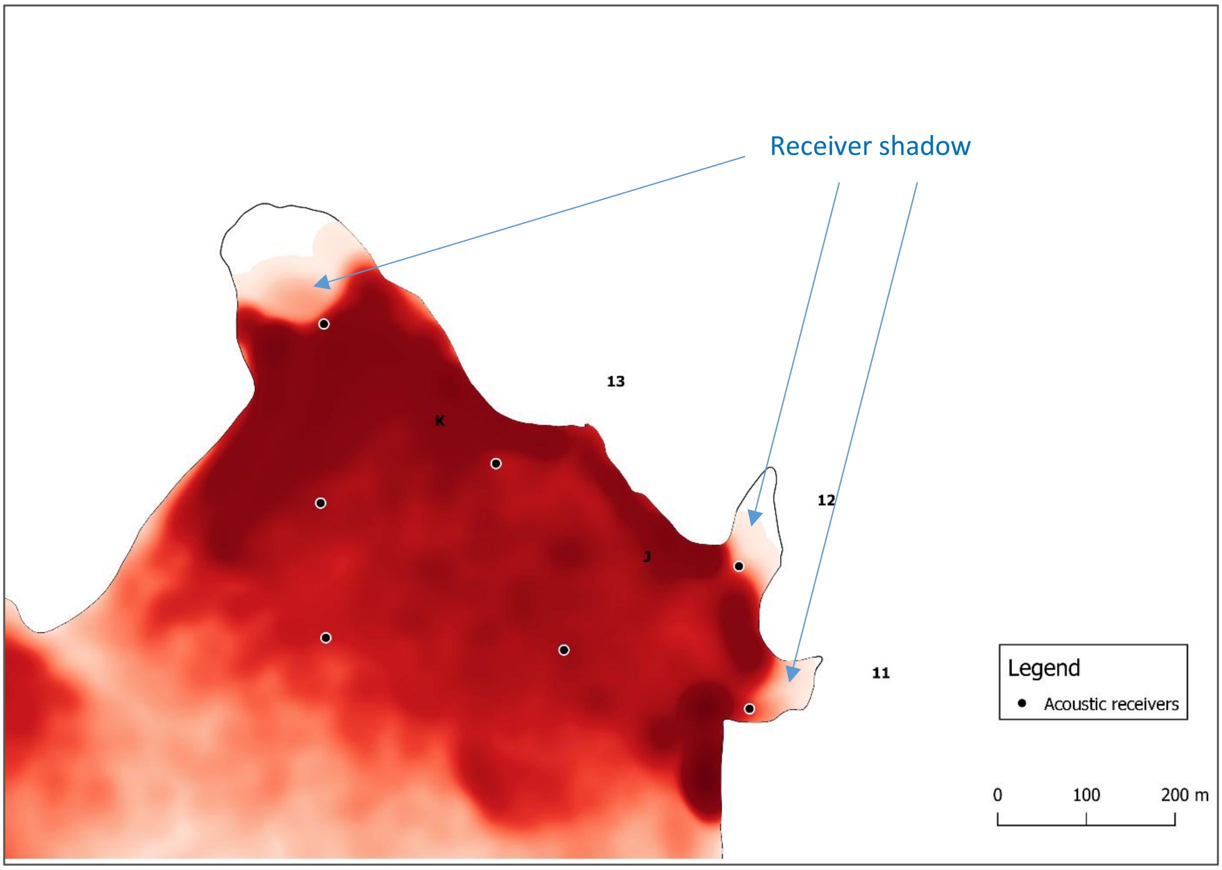

Figure 87 Examples of the effect of acoustic receiver shadow

There are trade-offs between positional accuracy and the geographic coverage and geometry of the receiver array in which the VPS can effectively position a tag. The number, layout and proximity of acoustic receivers and synchronizing transmitters significantly influence animal positioning, and ultimately the performance of the VPS (Espinoza *et al.* 2011). In Cressbrook Dam the size of the acoustic array was chosen to represent the different FAS types as equally as possible. Higher positional accuracy may have been achieved with a greater number of receivers or by reducing the area covered. Using the minimum number of receivers and synchronisation tags to cover the area may have led to a higher degree of positioning error and an increase in missed position triangulations. The area around the Open water 6 site was just outside of the acoustic array. It is likely that fish positions would have been difficult to triangulate in this areas and horizontal position error would have been higher than elsewhere within the telemetry zone. When the data was filtered by horizontal error prior to analyses being conducted, many fish positions around Open water 6 were filtered out. One or two additional receivers located in the eastern portion of the telemetry array would have rectified this issue but were not available.

Another issue influencing the acoustic tracking results was tampering with equipment. During the study multiple receivers went missing, several were located thrown up on the shoreline, but four were never recovered. The missing data resulting from removal of these receivers from the array, created gaps in the tracking coverage. During the final receiver retrieval, the innermost receivers could not be retrieved from Bay 12 and the Boat ramp bay. This resulted in an almost absence of data for fish use of most of Bay 12, and that which was detected has high horizontal positioning error. Similarly, coverage was extremely limited in the Boat ramp bay and most likely led to a major underestimation of fish activity at that site. In future projects, the design of the receiver array should be revised to minimise the likelihood of tampering where possible. Deployment and retrieval via diving would minimise the risk of angler's lines entangling on the equipment and thus potentially reduce tampering.

The results from the Euclidean distance analysis (EDA) and kernel density analysis (KDE) showed slightly different responses by fish to the installation of FAS. These differences are likely explained by the spatio-temporal scales at which each technique examined the data. The EDA looked at the importance at the habitat scale, whilst KDE provided more individual site or structure-scale information. In the EDA the mean proximity of Australian Bass at sites where synthetic, suspended and mixed FAS were installed decreased following structure installation. Conversely the proximity to the Control sites increased over the same period. No changes in proximity to the different sites were detected in Golden Perch. These results suggest some use of the FAS by Australian Bass, but not by Golden Perch. However, the EDA compared mean seasonal proximities to a habitat type and thus short-term use of specific structures may have been masked.

KDE's produce a probabilistic distribution of the animal's position based on the density and distribution of detections (Skerritt *et al.* 2015). In Cressbrook Dam the KDE enabled finer-scale analysis of the use of individual FAS clusters by fish. These clearly highlighted use of specific FAS by both species, but information on whether this occurred during a few long visits or many short stopovers is not apparent. The small, intense hotspots in use around the FAS may not have been at sufficient scale to influence the seasonal EDA values. Combining the EDA and KDE results enabled better insight into the spatial distribution patterns of the tracked fish.

Receiver location, receiver shadow and aquatic vegetation probably led to an under-representation of FAS use by tagged fish. A lack of detections in the littoral margins is likely to have resulted in under-representation of the use of FAS sites set towards the apex of bays or in shallower water. This may have been reflected in the different usage patterns for the timber FAS observed between the electrofishing and acoustic tracking results. Electrofishing found positive use of the FAS by tagged fish, whilst in the acoustic tracking, fish use appeared low, and the EDA suggested that the proximity of Australian Bass to sites where timber FAS were installed actually decreased following their installation. Increasing the number of receivers in the array may address some of these issues, but in future tracking studies, mapping of the detection rates and positioning probabilities should be incorporated where fluctuating water levels and aquatic vegetation occur, or limited receiver numbers are available.

Conclusion

The results of this study indicated a range of native Australian fish species responded to the installation of FAS. The primary species targeted by anglers in Cressbrook Dam (Golden Perch and Australian Bass) were both observed to use the installed habitat structures. Smaller prey species were also commonly detected around the FAS, but the pre to post-installation trends were less clear due to significant increases in abundance occurring across the entire impoundment.

Trends for the sportfish from the different monitoring approaches were not completely conclusive in their own right, but when considered together provided a more comprehensive understanding. Low electrofishing catch rates for Australian Bass and Golden Perch reduced the power of the generalised linear models, but the trends observed indicated an increase in their abundance for all FAS types. The greatest increase occurred at sites where timber FAS were installed, but positive responses were also observed around the synthetic and suspended FAS.

In contrast, the acoustic tracking data indicated little use of timber structures. Several technical factors regarding signal transmission through vegetation, receiver locations and equipment tampering appear to have confounded the ability to effectively track fish within bays where most of the timber FAS were located. This may explain the apparent limited use recorded for that FAS type. Euclidian distance analysis of the acoustic telemetry data found the mean proximity of Australian Bass to the synthetic, suspended and mixed FAS sites all decreased following installation. These changes were not quite statistically significant. The mean proximity of Golden Perch did not change with FAS installation. However, the kernel density analysis indicated localised hotspots for both species around most FAS types. The acoustic telemetry indicated increased use of deep water FAS sites by both species, which was not detected in the electrofishing surveys.

All FAS types retained their structural integrity for the duration of the study, with no degradation evident. Unfortunately, the period of monitoring was insufficient to assess long term durability, but all FAS types tested appear suitable for use in other impoundments. Visual surveys using underwater cameras and an underwater drone provided limited quantitative data due to restricted water clarity. However, they did provide further evidence of sportfish use of FAS and showed aggregations of small prey species around some FAS. Sonar surveys provided adequate detail on the FAS condition and produced some information on the abundance of prey species and sportfish around the FAS.

Impacts of FAS on angling effort, catch rates and fishery perception

Introduction

Golden Perch and Australian Bass are highly prized recreational angling species. Both species have a long history of stocking in impoundments, both within their natural range and beyond. They respond readily to a variety of lures and different angling methods. The popularity of Australian Bass in particular, has given rise to a substantial fishing culture that has generated numerous TV shows, tackle innovations and fishing tournaments.

Tournament anglers may be able to readily locate and catch fish in most impoundments, but many other anglers have difficulty in finding fish. If anglers can spend more time fishing and less time looking for fish, they are likely to enjoy their fishing experience more. Angler satisfaction has been positively related to catch rate (e.g., Miko *et al.* 1995, Hutt and Jackson 2008). Installing FAS into impoundments may help achieve this.

The ultimate goal of installing FAS in impoundments is to improve angler catch rates and the quality of their fishing experience. This would benefit local anglers, as well as encouraging visiting anglers to travel further or visit more often. It has been estimated that improving catch rates by 20% at several Queensland impoundments would lead to increases in the economic value of each impoundment by up to $340,000 p.a. (Rolfe and Prayaga 2007). These benefits would help support regional economies adjacent to the impoundments.

Directly measuring changes in the fish community is often difficult and the results frequently inconclusive. However, the management objectives of most impoundment habitat enhancement projects normally include improvements in angler catch and satisfaction, and these changes can be readily assessed using both angler creel surveys and targeted angling surveys.

Angler creel surveys were used at Cressbrook Dam to monitor angler catches and to evaluate the effectiveness of extension activities in promoting awareness of the installed structures. Extension activities included stories in the print media (both newspapers and fishing magazines), television news items, publicity on the Fisheries Queensland Facebook site, promotion through fishing clubs and angler newsletters and signage at the boat ramp and camping ground.

Targeted angling has been used abroad as a tool to monitor the impact of habitat enhancement projects in both rivers and impoundments (Rogers and Bergersen 1999, Wills *et al*. 2004). Targeted angling surveys provide the opportunity to directly quantify any improvement in angler catch rate after the introduction of FAS, using a systemic and standardised approach. This survey gathered angling catch rate data using angling styles and equipment commonly employed on Cressbrook Dam.

Targeted angling and angler creel surveys were used as part of a multi-strands of evidence approach to evaluate the effectiveness of FAS installation in Cressbrook Dam at improving Australian Bass and Golden Perch fishing. These techniques provided fisheries-dependent data and investigated angler knowledge and attitudes regarding the FAS project and its outcomes. The number of boats using Cressbrook Dam was also monitored using a trail camera to evaluate if installation of the FAS had increased angler visitation.

This chapter assesses the targeted angling and angler survey data collected prior to installation of FAS, through the period of partial installation of FAS and post full-installation of FAS.

Methods

Targeted angling trials

Survey frequency and duration

Targeted angling surveys were conducted quarterly (summer, autumn, winter, spring) to incorporate seasonal variation in angler catch rates and assess temporal changes as FAS aged following their installation. Ten surveys were completed over the course of the project between March 2018 and August 2020.

Each survey was conducted over a period of three days, usually commencing mid-morning on the first day to allow survey participants to travel out to Cressbrook Dam. Sampling continued throughout the second day, with the survey fully completed by midday on the third day. All angling occurred during daylight hours with two anglers participating in each survey, using a DAF electrofishing vessel as the fishing platform.

Survey sites and clusters

The monitoring sites for the targeted angling survey were the same as those used in the electrofishing surveys (Table 1). These were grouped into five clusters according to common site characteristics, with each cluster including one representative site from each of the four different FAS classifications: suspended FAS, synthetic FAS, timber FAS and Control (no FAS). Four additional sites of special interest were also sampled, including two Reference sites where significant natural habitat was already present. Bay 26 and the Boat ramp bay were sampled from the shore because FAS had been installed near the bank with a view towards improving angling for shore-based anglers.

One of the additional sites, the Boat ramp bay was a mixed FAS site, containing synthetic and timber structures, along with one suspended FAS. This site was sampled twice each sampling round, once from the boat and once from the shore. A total of 24 sites were sampled during each survey, with the extra shore-based survey at the Boat ramp bay bringing the total to 25 sampling points overall.

Sampling procedure

The targeted angling survey method used in this study was based on similar surveys employed in the USA to monitor catch rates of recreational species on introduced structures in freshwater impoundments (Rogers and Bergersen 1999, Wegener *et al.* 2017). Angling occurred for a thirty-minute period at each site, from commencement of casting. The thirty-minute period included time spent changing lures, positioning the boat, and landing and measuring fish. Start and finish times were recorded on a site data sheet, along with weather conditions, secchi depth, and any other relevant comments about the site. All catches were measured to the nearest millimetre (total length (TL) for Golden Perch and fork length (FL) for Australian Bass), along with the date and time of capture, angler name, species, site, and lure used. Any significant details relevant to the capture were also recorded. When fish were captured directly over installed FAS, the details of that specific cluster of installed FAS were recorded.

The sampling order of both the clusters and sites within each cluster were randomly allocated prior to the beginning of each survey. All sites within a cluster were sampled consecutively on commencement of that cluster to ensure that temporal factors were minimised.

Anglers brought their own rods and reels for the surveys to ensure that they were comfortable with the equipment being used. Each angler had two rods for the survey, which enabled seamless switching between two different lure types. Anglers were able to choose between five designated lure types and were free to change between the types as they wished. The lures used were Jackall TN/60 vibe (HL purple), Halco RMG Poltergeist P50 hardbody (diving to 3m +, R24 deep purple), TT

Lures ½ ounce Vortex Spinnerbait (V16 purple/Blue Scale), 20g Flasha metal spoon (Silver), and Z-Man 3-inch soft plastic minnow (Mood Ring colour with assorted jig head sizes: 1/4oz, 3/8oz and 1/2oz). These different styles of lure provided anglers with the versatility to alter their technique or presentation depending on the depth and prevailing weather conditions at each site. The five lures designated for this survey were effective on both species and had been recommended by an experienced and respected local angler based on a history of success at Cressbrook Dam.

At FAS sites, angling effort was generally targeted to near the structures, resulting in the occasional snagging of the lures. When synthetic structures were fished, the lures generally bounced through the structures without becoming ensnared, bearing testament to their relatively snag-less design. Anglers had the choice of either six or eight pound fluorocarbon leader. All fish captured during the surveys were quickly and carefully unhooked, measured and released unharmed, generally within thirty seconds of capture.

The boat was positioned at each site to maximise angling opportunities. In light wind conditions this generally involved positioning the boat upwind of the site and then drifting through, allowing anglers to cover a broad area and to target multiple FAS clusters within the site. This method also enabled anglers to approach the site quietly so as not to spook the fish. In moderate wind conditions drifting through the site occurred more rapidly, necessitating more frequent repositioning of the boat - sometimes at five-minute intervals. When wind conditions were too strong for drift fishing, an anchor was deployed to enable consistent casting in the vicinity of installed FAS. The location of all installed FAS clusters was clearly marked on the boat's GPS. The vicinity of FAS locations was approached by the angling vessel, so that angling effort could be focussed atop or adjacent to the structures.

A variety of fishing styles were employed depending on lure type, with the aim of getting the lures into the strike zone around installed FAS clusters. In deeper water, metal spoons were cast away from the boat and allowed to sink to the bottom, with a short fast retrieve before being allowed to sink to the bottom again. This pattern was repeated until the lure had been fully retrieved. Spinnerbaits were allowed to sink to the bottom and then slow rolled across the dam floor. This method was particularly effective on Golden Perch around FAS in shallower water. Jackalls were allowed to sink to the dam floor before being retrieved at a slow and steady pace or, alternatively, jigged back to the boat by raising the rod in a long, steady pull before allowing the lure to fall again. Soft plastics were sometimes cast and allowed to fall alongside suspended FAS, as this method had proven successful among other anglers fishing the suspended FAS at Cressbrook Dam who had communicated this to the project team.

Trolling was also employed, with Halco RMG poltergeists towed behind the vessel at low speed, particularly at sites where FAS clusters were deployed in a straight line. Every effort was made to troll the lures directly over the structures. Trolling was also undertaken around suspended FAS, with the vessel operated to pass the lures as close to the structures as possible.

When fishing the shore-based sites, anglers proceeded on foot, moving along the bankside and fanning out their casts to cover a broad area. The approximate location of installed FAS clusters was noted prior to disembarking so that anglers could focus their efforts on those areas.

Angler creel surveys

Pre-installation angler creel surveys

To obtain baseline data, monthly creel surveys were conducted with anglers at Cressbrook Dam prior to FAS being installed. All interviewees remained anonymous. The creel surveys were conducted on either Saturday or Sunday between 10 am and 2 pm. Weekends increased the probability of encountering anglers, and it was assumed anglers who had arrived early in the morning to fish, were likely to leave sometime between 10 am and 2 pm, giving an opportunity to assess angler catches. A series of pre-installation questions were used to gauge the anglers' knowledge of the proposed installation program and their attitude towards it. Several other questions evaluated angler behaviour. For example, the amount of time spent fishing that day, the distance travelled to fish at Cressbrook Dam, whether participating in bait or lure fishing or shore-based or boat- based fishing, the frequency of fishing in general and the frequency of fishing at Cressbrook Dam. Other questions sought to find out how anglers viewed the quality of fishing at Cressbrook Dam and whether they intended to fish Cressbrook Dam again or would recommend fishing at Cressbrook Dam to others. One question investigated if the anglers sought out bottom structure for their fishing activities. Anglers were also asked how many fish of different species they had caught that day, the size of the fish and whether they had kept or released them. Anglers who had not started fishing were excluded from any catch per unit effort analyses.

Most attitudinal questions used an ordinal 5-point scoring system. For example, perceptions of fishing quality ranged from very poor (1) to very good (5). Other attitudinal statements like “I plan to fish at Cressbrook Dam again” were scored ranging from strongly disagree (1) to strongly agree (5). Scores less than three were considered negative responses and scores greater than three as positive responses. Most questions relating to angler behaviour used continuous measures such as frequency of visits, fishing time in hours and travel time to Cressbrook Dam. Some questions were simple categorical yes or no questions. For example, have you finished fishing today? These were assessed by the proportion of anglers answering yes or no.

The full pre-installation questionnaire is presented in Appendix 4.

Post-installation angler creel surveys

After installation of FAS commenced in Cressbrook Dam, creel surveys were continued with anglers to detect changes in catch, behaviours and attitudes. Creel surveys in 2019 covered the partial installation period when some, but not all of the FAS were installed. By 2020 all FAS had been installed so the creel surveys in 2020 covered the full post-installation period. It was planned to extend these creel surveys into early 2021, but cyanobacterial (blue green algae) blooms forced closure of the dam to anglers. There were extended periods from 2018 through to 2021 when the dam was closed to anglers due to cyanobacterial blooms and additionally due to bushfires and Covid 19 shutdowns and this impacted on the number of opportunities to interview anglers in all phases of the project.

During the partial and full FAS installation periods, many of the same questions asked in the pre-installation surveys were used to monitor angler visitation frequencies, perceptions of the quality of the fishery, travel times and fishing times. Additional questions were also included. These related to whether anglers were aware of the FAS installations in the dam, and if so whether they were aware of the locations of the FAS. Other questions related to whether anglers were actively targeting bottom structure (these anglers may have targeted FAS even if they were not aware it had been installed). If anglers were aware of FAS in the dam, there were questions relating to whether they targeted FAS or not. These were scored using the same 5-point scale system as used in the pre-installation surveys.

Anglers were also asked (if they knew) what type of FAS they had been targeting and the type of habitat or structures from which they caught the most fish for the day. The options included a range of FAS types and natural habitats. Anglers were also asked to score the quality of different habitats (using a 5-point scale) for fishing in Cressbrook Dam. This was an opportunity for more regular anglers to bring in the experience of several recent fishing trips to their answer. Anglers were also asked whether they agreed with the statement “I plan to fish at Cressbrook Dam more frequently since installation of fish attracting habitat.” Their answers were scored using a 5-point scale ranging from 1 (strongly disagree) to 5 (strongly agree). As for the pre-installation creel surveys, angler catch (species and numbers caught) and size of fish caught was also recorded. Hours of fishing effort was recorded for each fishing group (in the pre, partial and post-installation periods) so that catch per unit effort could be standardised. The full questionnaire used in the partial and post FAS installation periods is in Appendix 4.

Boat arrival surveys

Boat arrivals were monitored by a trail camera, set adjacent to the gated entrance on the road leading to Cressbrook Dam's only boat ramp. From this position the camera could detect towed boats (or cars carrying kayaks or roof-top boats) travelling directly to the boat ramp from the dam entry road, or from the campground to the boat ramp. The assumption was that most boats and kayaks arriving at the dam, were being used for fishing. High-speed boating activities such as water skiing are not permitted at the dam. Although a minority of boats may have been used just for leisure and not fishing, we believe that boat arrivals can be used as a reliable indicator of trends in fisher numbers arriving at the dam. Occupants of vehicles without boats may also have been participating in shore-based fishing activities, but as there were picnic areas, beach volleyball courts and other potential activities on offer for non-boaters, cars without vessels were excluded from any analyses.

The camera used for monitoring the boat arrivals was a Primos Proof Gen 2-03 Blackout trail camera. The camera was set to photo mode with a photo burst of two with a one second delay. However, after a thunderstorm this camera developed a fault and was not reliably detecting all vehicles. The camera was then replaced with a Blaze Video A262 trail camera, which required some adjustments to its sensitivity settings before it began to reliably detect arriving vehicles. At the high sensitivity setting the camera was detecting movements of vegetation and filling the memory card too quickly.

Data analyses

Targeted angling trials

Catch rates from the targeted angling surveys were compiled in a database, with records of habitat deployment used to allocate a pre, partial, or post installation status for each site during every survey. Golden Perch and Australian Bass data were both analysed separately, but due to low catch rates and the high prevalence of zeroes, data was also pooled for both species (no other recreational species were caught during the targeted angling surveys). The combined data was evaluated as overall catch. There were a large number of angling sites with zero captures during each sampling event and catch numbers were low when they occurred. To accommodate this in the statistical analyses a binomial model using the proportion of angler success (fish were caught or not) instead of catch number was applied. A generalised linear model (GLM) with a binomial distribution and a logit link function was used in Genstat™ 18th edition to evaluate the angler success for overall catch and individual species data. Angler success was the dependent variable and installation period (pre, partial and post), season, cluster type (by geomorphology) (see Table 1 in Chapter 2) and FAS type were factors in the model.

The predict function was used to obtain back-adjusted mean values and standard errors of the mean for the proportion of angler success for different factors. Fisher's least significant difference (LSD) test was used for post-hoc pairwise comparison between FAS habitat types.

Angler and creel surveys

Anglers gave various responses to indicate frequency of fishing (e.g., once per month, twice per year, twice per week). These were standardised to a yearly rate prior to analyses. For example, once per month was standardised to 12, and once per week was standardised to 52. Twice per year was kept as 2. Given that there were unexpected dam closures due to blue-green algae blooms and other causes, it is highly unlikely that some of the higher yearly rates were realised within the dam across each year, but it was a way of standardising visit frequency scores for the periods the dam was open. Travel times were converted to minutes for all responses prior to analyses.

Non-parametric methods are recommended for evaluating ordinal survey data (Cooper and Johnson 2016). Therefore, all data with ordinal scores were compared between installation periods using the non-parametric Mann-Whitney U test (Sokal and Rohlf 1981) in Genstat™18th edition. Scores were evaluated as two-sample comparisons (e.g., pre installation with post-installation, pre-installation with partial installation and partial installation with post-installation) to test the null hypothesis that responses between each of the periods was equal. Data for these responses were also plotted as bar graphs to enable readers to visualise trends in the responses between periods, particularly for cases where statistically significant results ($p < 0.05$) were obtained.

For binary yes-no response data and categorical data (e.g., types of structures or habitats fished, awareness of FAS locations) the results were presented as frequencies of response. Unfortunately, when anglers were asked to rate the fishing quality at the different habitats or structures where they caught their fish, most anglers said they did not know. Therefore, these data were not analysed because the numbers were too low to show meaningful differences.

For the continuous variables (e.g., travel times, angler group size, and fishing frequency), data were checked for normality in Genstat™ 18th edition. Where such data were not normally distributed, $\log_{10}(n+1)$ or square root transformations were applied, and data retested for normality. If the data were normally distributed or could be successfully normalised, two sample t-tests were used to test the null hypothesis of equal means between different installation periods. If the data could not be successfully normalised, the non-parametric Mann-Whitney U-test was applied to test the null hypothesis of equality of the two samples. In such cases the median values are also presented to provide the reader with some idea of the trends in the data.

The catch data for interviewed anglers was evaluated in two ways using Genstat™ 18th edition. The catch of each species was analysed using a generalised linear model (GLM) with a Poisson distribution and a log-link function. Catch was the dependent variate, installation period a factor and hours fished used as a covariate in the model. A binomial GLM with logit-link function was run to evaluate angler success rates (i.e., proportion of anglers catching fish) between installation periods. Hours fished was used as a covariate in the model. Back-transformed mean success rates were calculated using the predict function and were adjusted for the mean fishing time of 3.5 hours. All models were run for catches of Australian Bass, Golden Perch and the combined catch of all recreational species (excluding Snub-nosed Garfish).

Boat arrivals

Boat arrivals data were plotted as mean daily arrivals per month (by years) and as mean daily arrivals per season (by years). Unfortunately, due to extended dam closures caused by blue green algae blooms, bushfires and Covid 19 restrictions, some months had no data and other months very limited data. Overall, almost 12 months of data were lost due to dam closures. For this reason, analyses were completed using seasonal data to increase the number of samples. Further data had to be culled due to camera failures (either total failure or failure to detect a proportion of vehicles). Around 90 days of data were lost over the three-year period due to camera faults. Failures were realised when known vehicles were not detected by the camera (e.g., regular council vehicle arrivals, researcher vehicle arrivals). Weather conditions may have triggered some camera failures. The camera failures were corrected by replacement of batteries, altering camera settings or replacing the camera.

The filtered seasonal data were analysed in R (version 4.0.2), by one-way ANOVA, followed by a post-hoc Tukey pairwise comparison test. In the Tukey tests, like seasons were compared between the years to test the null hypothesis of no significant difference in boat arrivals between paired years (installation periods) for a given season.

Results

Targeted angling surveys

Overall catch

The targeted angling surveys yielded a total catch of 10 Golden Perch and 21 Australian Bass over the course of the ten surveys, with an average of 3.1 fish per survey.

The 25 sites used for the targeted angling survey were sampled ten times each, with 250 data points being available for analysis. Of these data points, 226 recorded a catch of zero fish, 19 recorded a catch of one fish, and the remaining three sample points were single catches of two, three and seven fish

The results from GLM (binomial distribution) for the overall catch found season ($p = 0.204$), cluster ($p = 0.869$), habitat type ($p = 0.057$), installation period ($p = 0.579$) and their interactions were not significant ($p > 0.44$). However, the probability for habitat type was close to being significant and this factor was most likely to have an impact on overall catch rate. The interaction between habitat type and installation period could not be fully included in the model because three of the parameters were aliased with terms already in the model.

There was a steady increase in catch rate for the synthetic FAS across installation periods (Figure 88), whilst timber FAS dipped to nothing during partial installation and then rose to higher than the pre-installation level. The catch rate in mixed habitat peaked during partial installation and then fell away, although it should be noted that the mixed habitat type is poorly represented in the targeted angling survey, with two sites occurring in the same bay (Boat ramp bay – boat, and Boat ramp bay – shore). The Reference habitat type also incorporates two sites, although these two sites are in separate areas, with one site (the Gorge) containing excellent natural habitat in a zone where public access is not permitted.

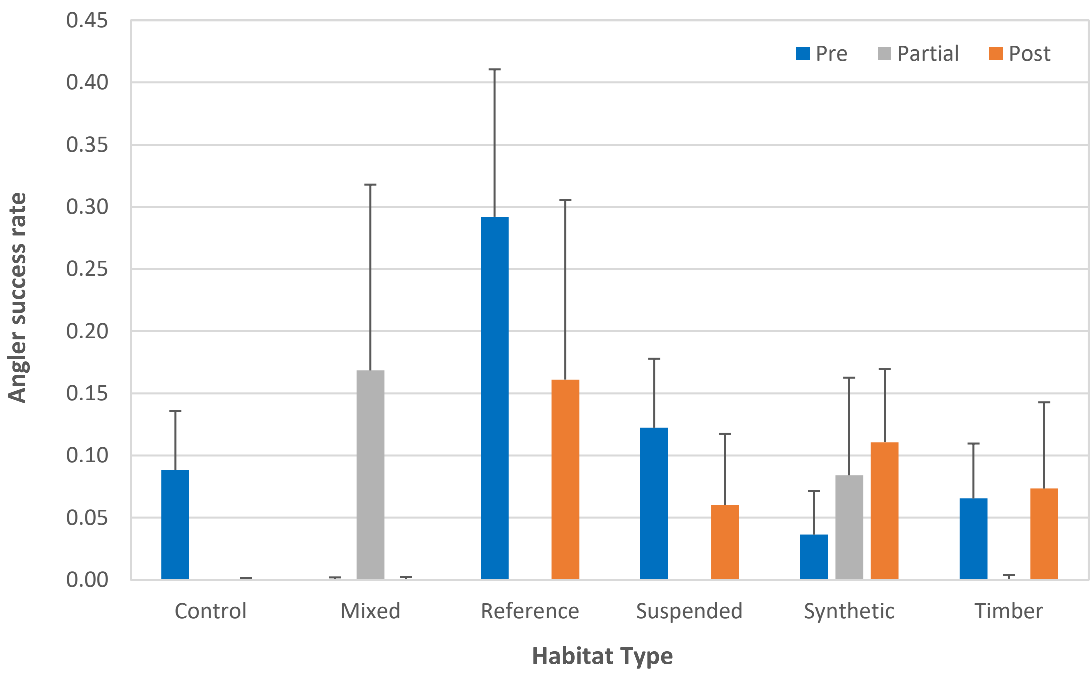

Figure 88 Proportion of angler success for the overall catch at the different habitat types across installation periods. Error bars show one SEM

Changes in the angler success rate further demonstrates the high proportion of catches at Reference sites during both the pre and post-installation periods (Figure 89). The angler success at Control sites and pooled FAS sites are similar in the pre-installation period. However, angler success at Control sites falls to zero while at pooled FAS sites it remains higher.

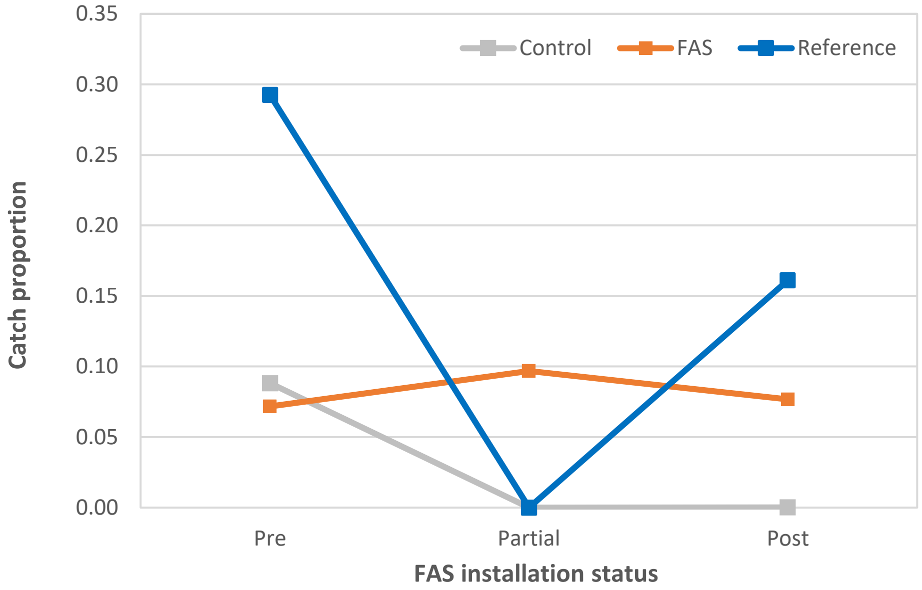

Figure 89 Proportion of angler success for the overall catch at the different habitat groups across installation periods. Error bars show one SEM.

Golden Perch

A total of ten Golden Perch were captured during the targeted angling surveys. No factors were found to have a significant influence on Golden Perch catch ($p > 0.176$ for all factors). The interaction between habitat type and installation period could not be fully included in the model because three of the parameters were aliased with terms already in the model.

The synthetic FAS showed an increasing trend in angler success for Golden Perch across installation periods (Figure 90). Similarly, success rates at timber FAS sites were poor during pre and partial-installation, but improved considerably during the post-installation surveys. Angler success rate in mixed habitat peaked during partial installation and then declined, although it should be noted that the mixed habitat type is poorly represented, with two targeted angling sites occurring in the same bay (Boat ramp bay – boat, and Boat ramp bay – shore). Reference sites did not exhibit good angler success rates for Golden Perch in any of the installation periods. Poor angler success on suspended FAS sites were evident in both the partial and post installation periods.

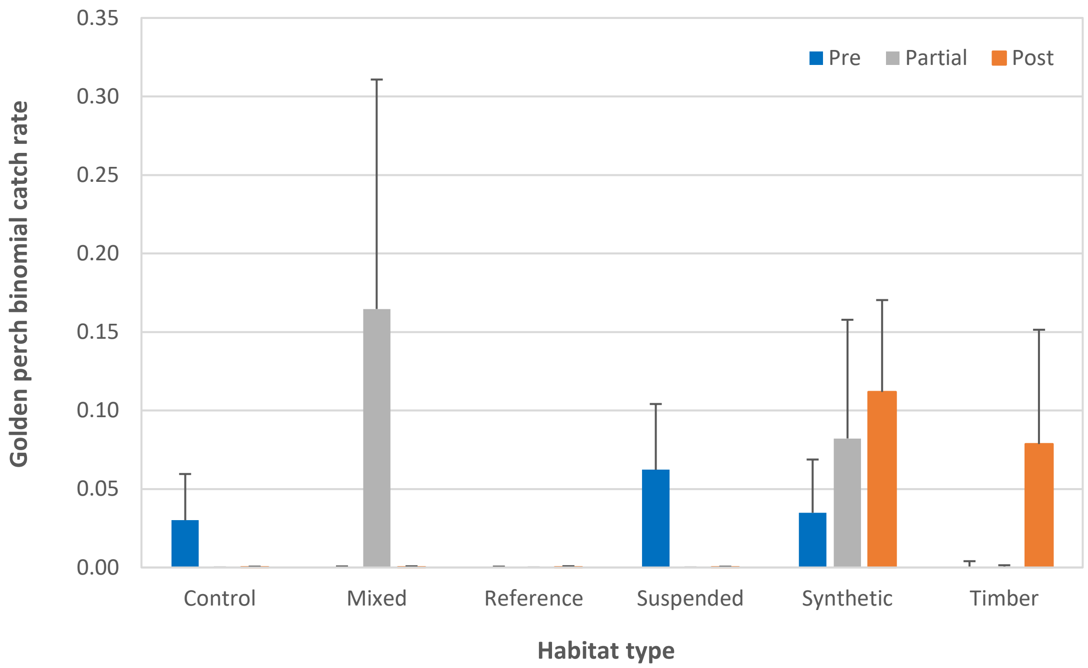

Figure 90 Proportion of angler success for Golden Perch at the different habitat types across installation periods. Error bars show one SEM

Australian Bass

A total of twenty-one Australian Bass were captured during the targeted angling surveys. Habitat type was the only factor to have had a significant effect on the catch of Australian Bass ($p = 0.003$). The effects of all the other factors were insignificant ($p > 0.333$). The interaction between habitat type and installation period again could not be fully included in the model because three of the parameters were aliased with terms already in the model.

There was an absence of catch data at both mixed FAS and synthetic FAS sites for Australian Bass (Figure 91). In timber FAS and Control habitat types, Australian Bass were caught in the pre-installation period, but no catches were recorded in either the partial or post installation periods. Angler success was higher in the Reference sites where naturally existing habitat was abundant. The angler success rate on suspended FAS sites was similar in both the pre and post-installation periods.

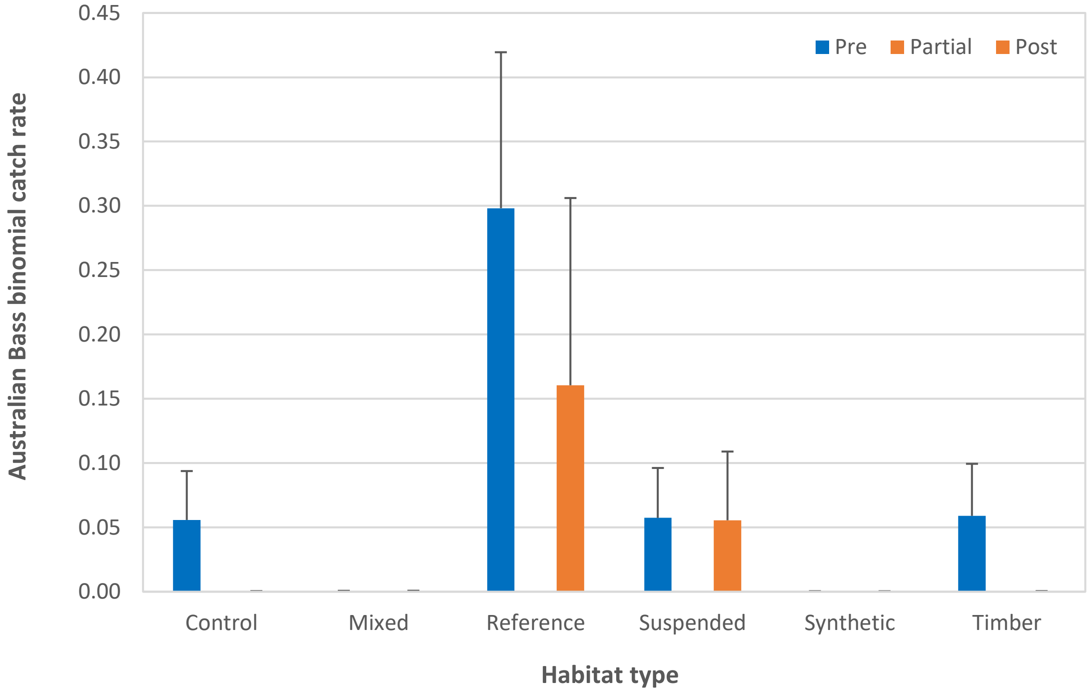

Figure 91 Proportion of angler success for Australian Bass at the different habitat types across installation periods. Error bars show one SEM

Angler attitudes

Satisfaction with fishing at Cressbrook

The rank sum of angler satisfaction with fishing at Cressbrook Dam post installation (n = 39) was higher than that at pre-installation (n = 42), but was not statistically significant (p = 0.371). The lowest ranked angler satisfaction score disappeared by the post installation period and the proportion of responses for scores *neutral* and *satisfied* had increased by the post-installation period (Figure 92).

Angler satisfaction in the partial-installation period (n = 25) had a higher rank sum than for the pre-installation period and a lower rank sum than for the post-installation period but neither result was statistically significant.

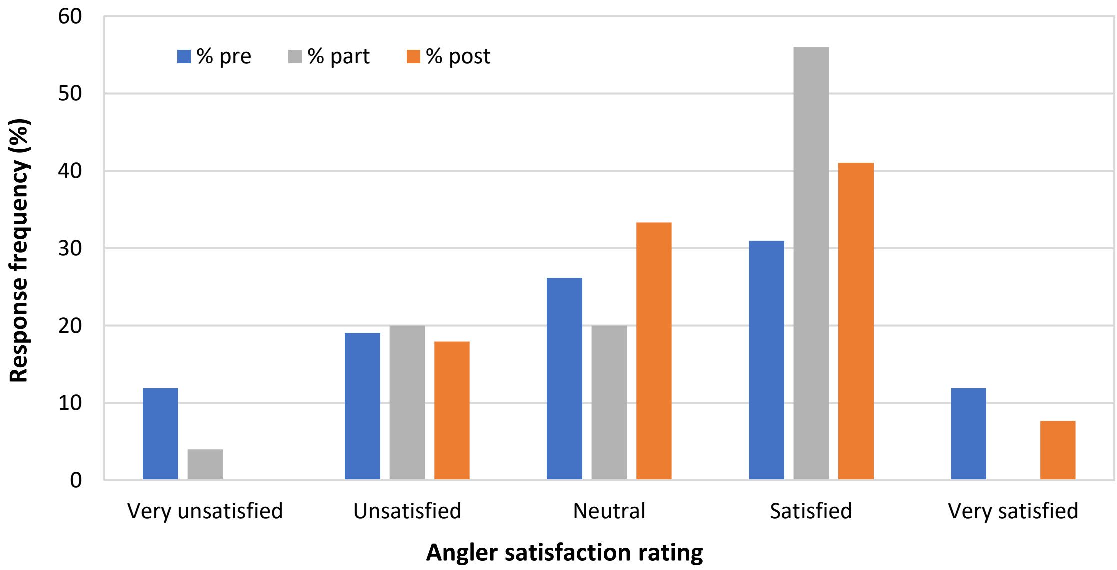

Figure 92 Angler satisfaction rating of the fishing in Cressbrook Dam across the FAS installation periods.

Perception of fishing quality

Anglers ranked fishing quality significantly higher (p = 0.039) in the post installation period (n = 39) compared to the pre-installation period (n = 39). Fishing quality scores for the partial installation period (n = 25) were not ranked significantly different to the pre (p = 0.336) or post-installation period (p = 0.583), although the partial-installation period had a higher rank sum than the pre-installation period (Figure 93). The lowest ranking had disappeared by the post-installation period.

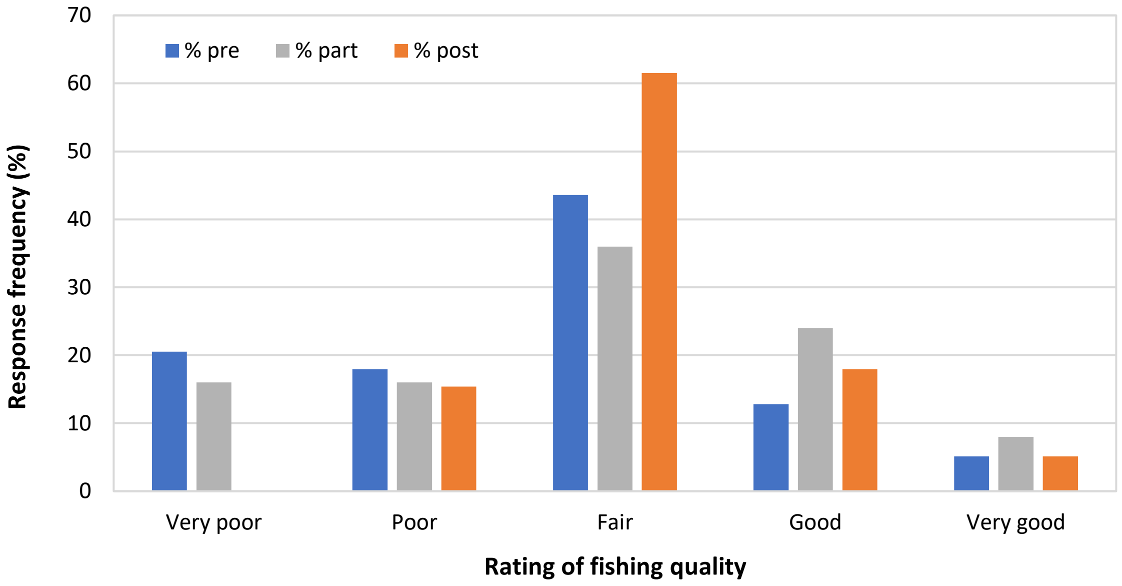

Figure 93 Fishing quality rating as scored by anglers across the different FAS installation periods.

Willingness to fishing in Cressbrook Dam again

Although the willingness to fish Cressbrook Dam again in the post-installation period (n = 39) had a higher rank sum than in the pre-installation period (n = 42), this was not statistically significant (p = 0.108, Figure 94). The partial installation period responses (n = 25) also had rank sums higher than the pre installation period which was statistically significant (p = 0.015). There was an absence of the two lowest rankings during the partial and post installation periods, and the highest scored ranking (5) had increased in frequency in the post-installation period compared to the pre-installation period. The highest ranking was selected most frequently in the partial installation period.

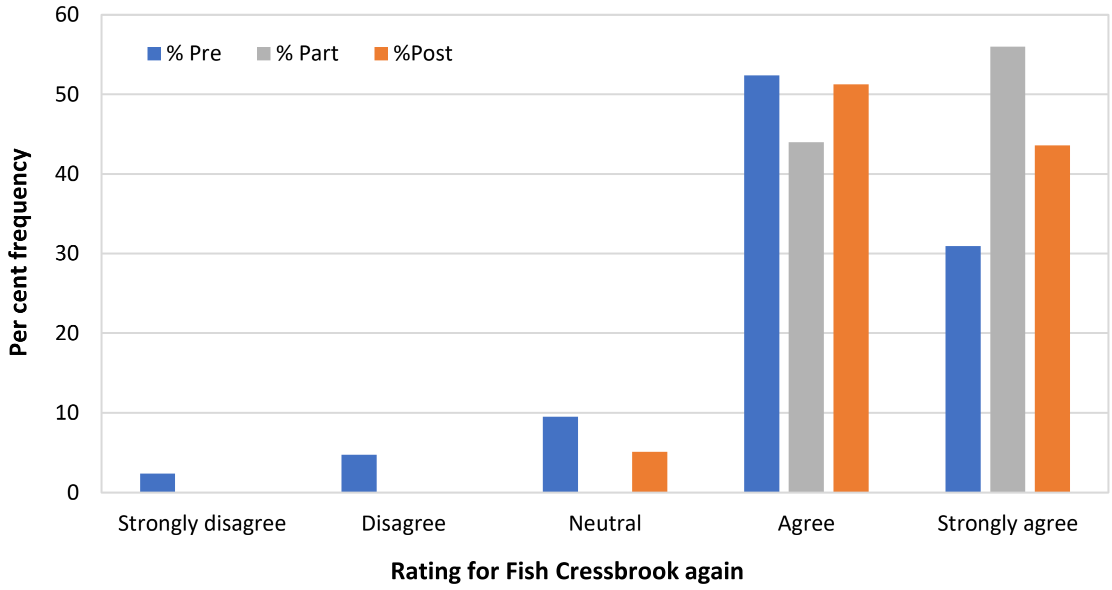

Figure 94 Level of agreement with the statement "I plan to fish in Cressbrook Dam again" during the pre, partial and post-installation periods for FAS.

Willingness to recommend fishing in Cressbrook Dam to others

The willingness of anglers to recommend fishing in Cressbrook Dam to others increased from the pre-installation (n = 43) period to the post-installation period (n = 39). The post-installation period had a significantly higher rank sum (p = 0.023), than the pre-installation period (Figure 95). The responses for the partial-installation period (n = 25) also had a higher rank sum than the pre-installation period, but this was not statistically significant. The partial-installation period was also not significantly different to the post-installation period.

In the post-installation period, all anglers indicated a neutral or positive response regarding willingness to recommend fishing at Cressbrook Dam to others, with no negative responses recorded. The frequency of agree and strongly agree ratings was higher in the post-installation period than in the pre-installation period and ratings of strongly agree were more frequent in the partial-installation period than in the pre-installation period.

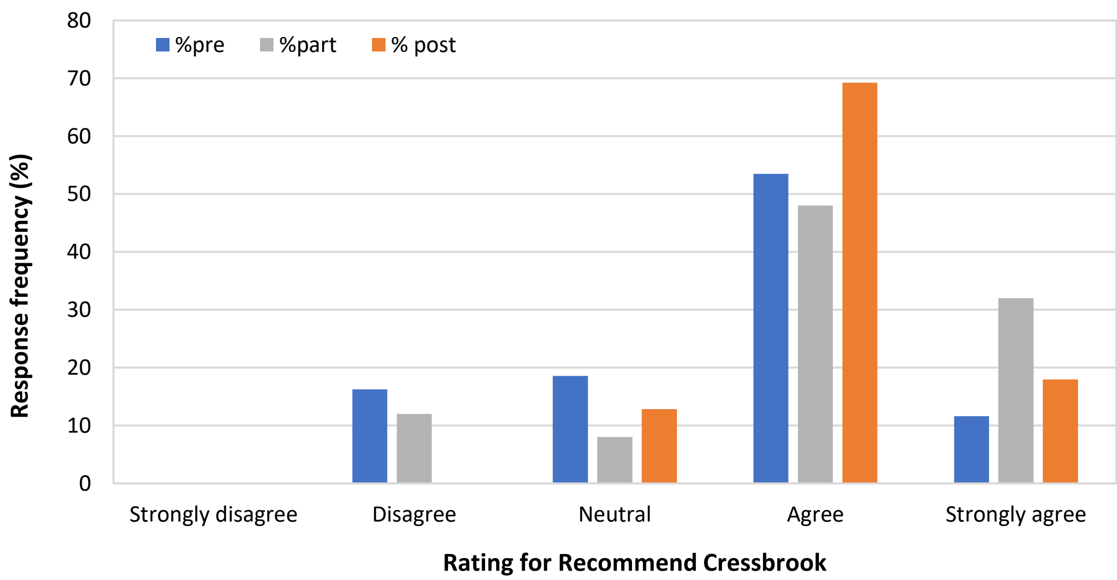

Figure 95 Level of agreement with the statement "I would recommend fishing in Cressbrook Dam to others" during the pre, partial and post FAS installation periods.

Fishing bottom structure

There were no significant differences between the rank sums for angler responses for fishing bottom structure between the FAS installation periods. The probability value was greater than p = 0.500 for each of the pairwise comparisons. A combined total of more than 50% of anglers either agreed or strongly agreed that they targeted bottom structure in each of the installation periods (Figure 96).

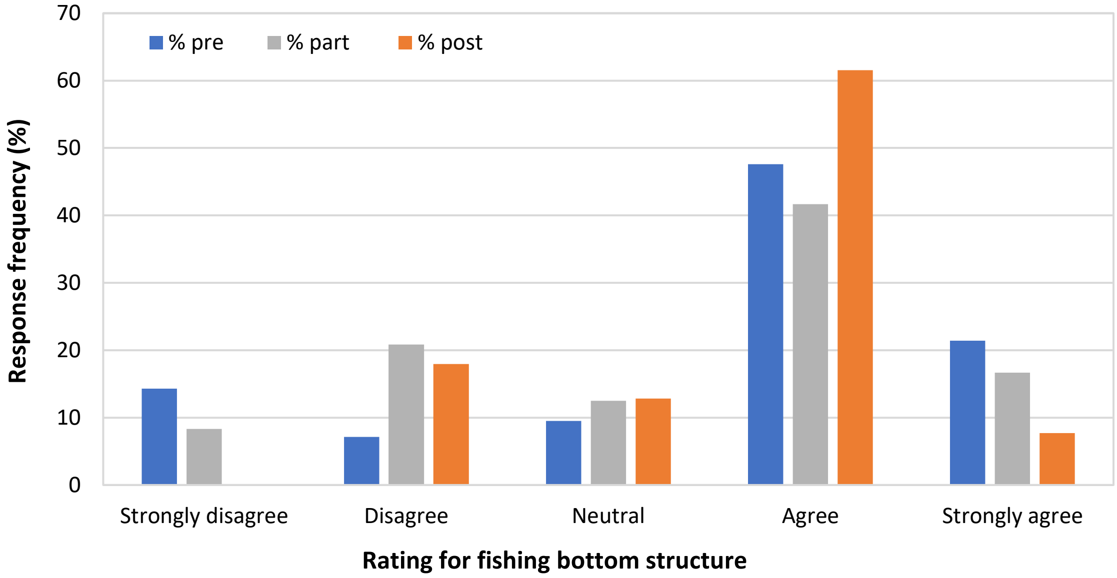

Figure 96 Level of agreement with the statement "I fish bottom structure" during the pre, partial and post FAS installation periods.

Fishing Cressbrook Dam because of installed FAS

The rank sum for anglers fishing Cressbrook Dam because of installed FAS in the post-installation period (n = 39) was higher than the rank sum for anglers fishing in the partial installation period (n = 25). This was statistically significant (p < 0.001). The rating of "I came to fish at Cressbrook because of installed FAS" changed between the two installation periods (Figure 97). There was a decrease in anglers disagreeing or strongly disagreeing with the concept, and an increase in those who were neutral or either agreed or strongly agreed by the post installation period.

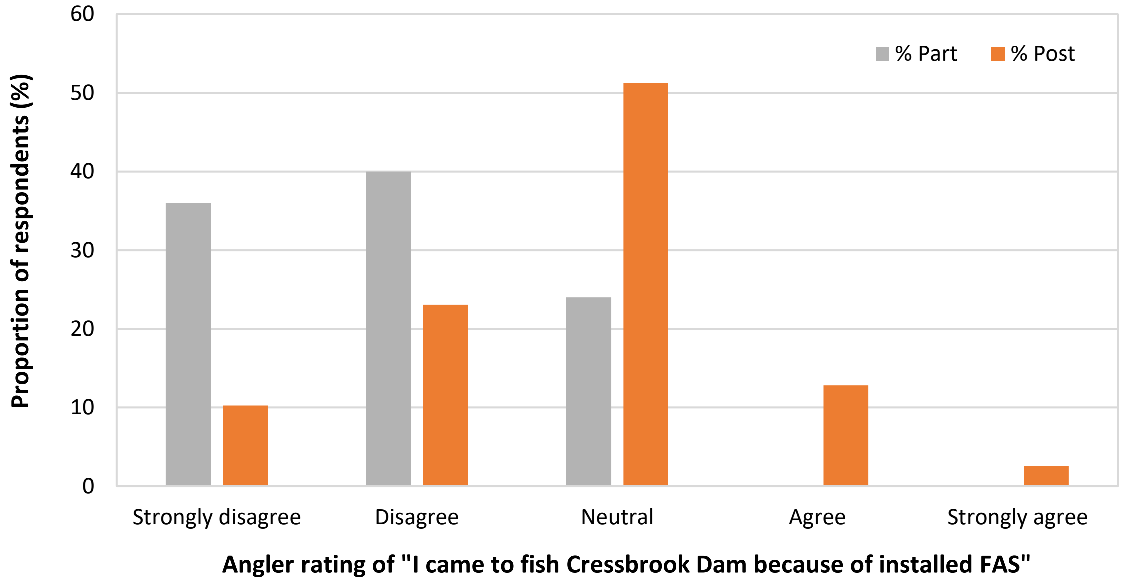

Figure 97 Angler response to "I came to fish Cressbrook Dam because of installed FAS" in the partial and post FAS installation periods.

Angler effort and catch

First-time anglers at Cressbrook Dam.

The proportion of interviewed anglers fishing Cressbrook Dam for the first time was 34.9% in the pre-installation period, 4% in the partial-installation period and 12.8% in the post-installation period.

Types of fishing

During the pre-installation period, (n=42) 69% of interviewed anglers were fishing with lures only, 7.1% with bait only and 23.9% were using both methods. In the partial-installation period (n=25) 76% of interviewed anglers fished with lures only and 24% used both bait and lures. Of the anglers interviewed during the post-installation period (n=39) 66.7% used lures only, 12.8% bait only and 20.5% used both bait and lures.

In the pre-installation period, 88.4% of anglers interviewed were fishing from a boat or kayak only, 9.3% from the shore only and 2.3% were fishing from both a boat and the shore. During the partial-installation period, 100% of interviewed anglers were fishing from a boat or kayak, and during the post-installation period, 82.2% fished from a boat only, with 15.3% fishing from the shore only and 2.5% from both a boat and the shore.

Awareness of FAS installation

Less than 30% of anglers were aware of plans to install FAS during the pre-installation period. By the partial and post-installation periods, well over 60% of anglers were aware that FAS had been installed (Figure 98). However, more than 40% of anglers, despite being aware that FAS had been installed, did not know where it was located during the partial-installation period, and more than 30% did not know where the FAS were located during the post-installation period (Figure 99). Therefore, even by the post-installation period, over 60% of anglers were either unaware of FAS or aware that it was in the dam but did not know where the structures were located. This was despite temporary signage at the boat ramps and magazine articles showing the FAS locations.

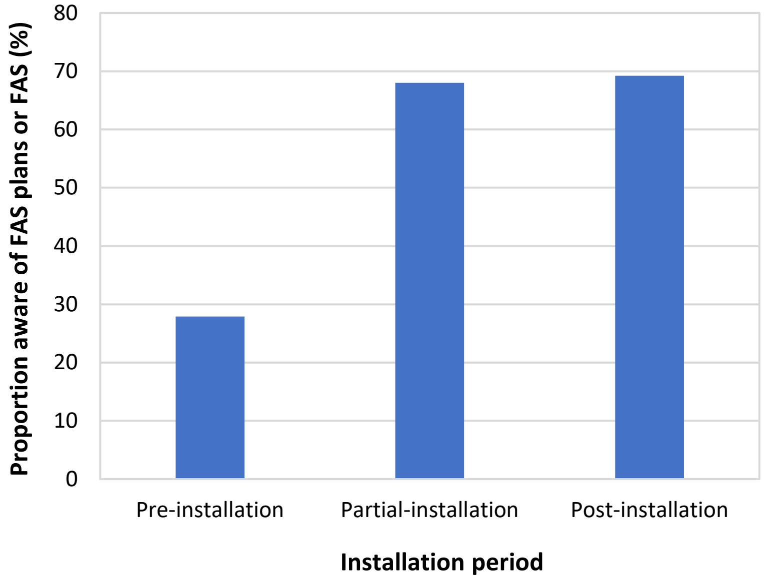

Figure 98 Angler awareness of plans to install FAS (pre-installation period) or installation of FAS (partial and post-installation periods).

Of those anglers who knew where the FAS was located, the majority were targeting it some or most of the time. A minority preferred to avoid FAS (Figure 99). When anglers who were unaware of the FAS or the FAS locations were asked to show on a map the locations they had fished that day, it was clear many had unknowingly been fishing FAS sites. These anglers mostly fished locations where they had seen shows of fish or structure on their sounder.

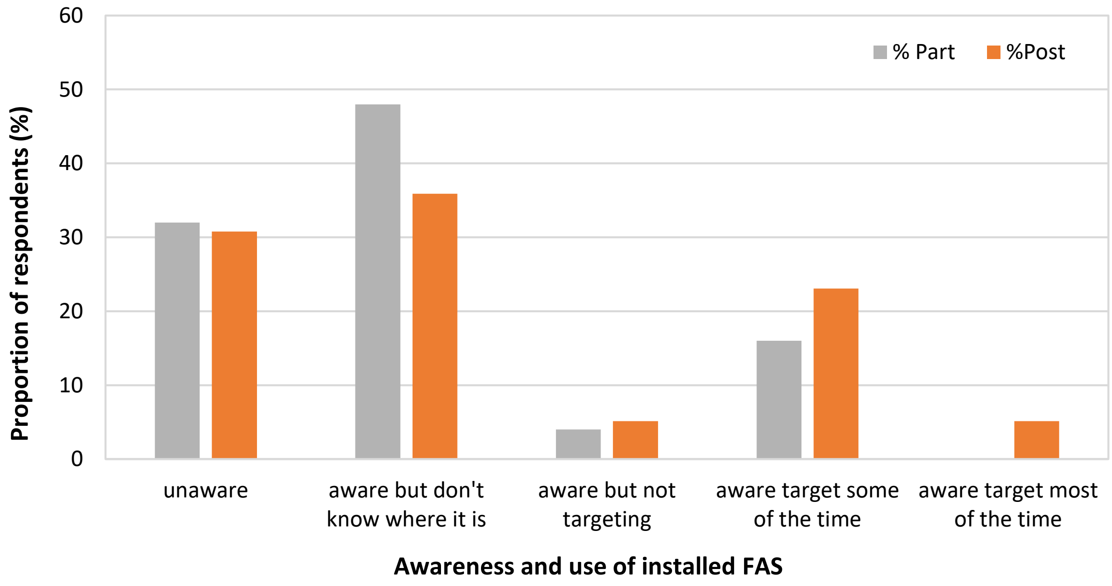

Figure 99 Angler awareness and targeted use of FAS in partial and post-installation periods.

Structures and habitats fished by anglers

In the partial installation period, more than half the anglers claimed to have fished no structure (open water), while more than 20% fished natural structure and suspended FADs (Figure 100). By the post installation period, the proportion of anglers fishing no structure had declined to less than 40%, and the range of FAS structure types being fished had increased. Some anglers fished more than one type of habitat.

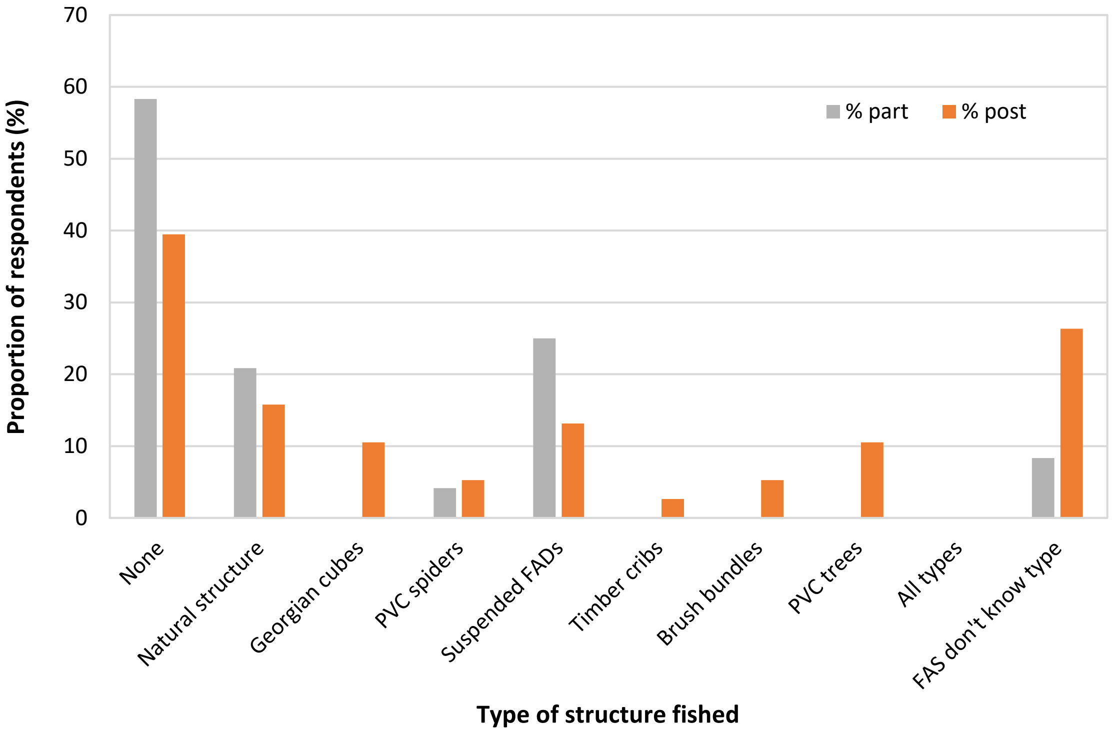

Figure 100 Structure and habitat types anglers reported to fish in the partial (n=24) and post-installation (n=38) periods. Anglers could report fishing more than one type.

Some anglers who were unsuccessful on the current trip they were being interviewed for, reported successful captures on habitats from a recently completed successful trip (Figure 101). For the partial-installation period, over 50% of the anglers captured fish from open water, but this had fallen by the post-installation period, with successful anglers beginning to catch fish from a range of FAS types. There was also a decline in success rates from natural structures, but angler success rates remained constant from weed beds. Over 25% of anglers in the post-installation period reported they didn't know the kind of habitat they caught their fish from. Some anglers reported more than one habitat type for successful fishing.

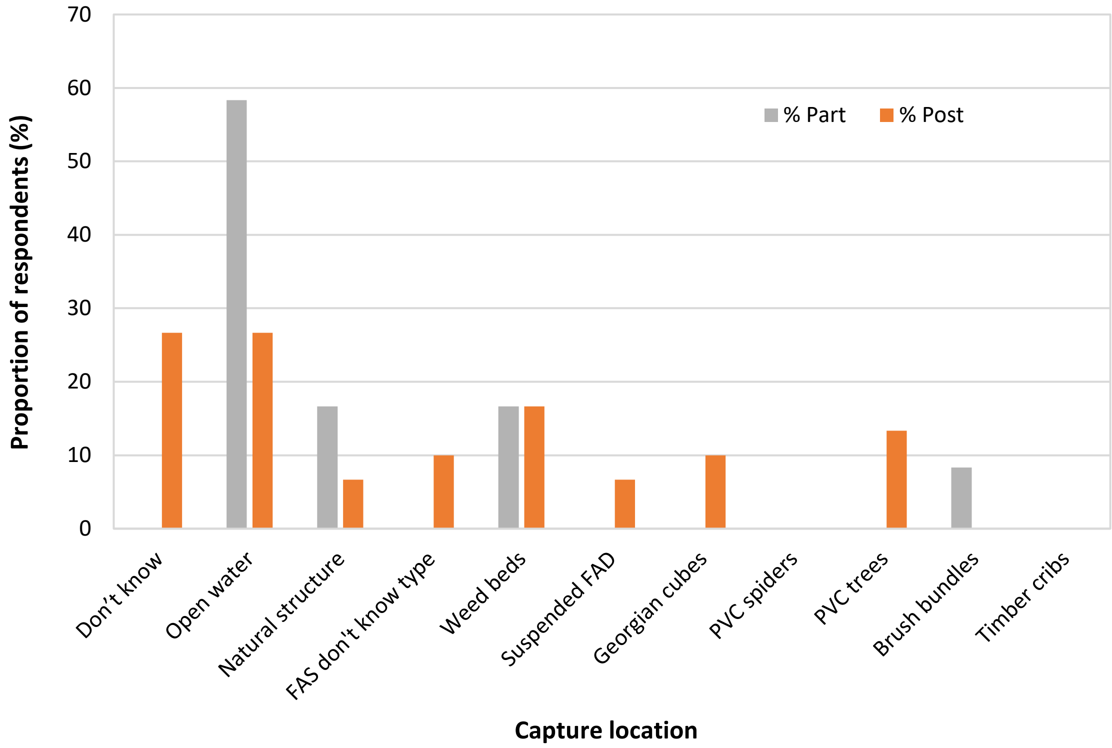

Figure 101 Structures and habitats where successful anglers reported catching fish in the partial (n=12) and post-installation (n=30) periods. Some anglers may have been referring to successful trips prior to the day they were sampled and some may have reported more than one habitat or structure type.

Fish length and angler harvest

The proportion of legal-sized fish captured in the pre-installation period was 46.5%. By the partial-installation period this had risen to 100% and remained high at 96.2% in the post-installation period. The bulk of the recreational fish catch was Australian Bass and most fish were released. In the pre-installation period 72.0% of fish were released. This increased in the partial and post-installation periods to 87.5% and 80.6% respectively. Snub-nosed Garfish were not included in this analysis as there is no minimum size for that species.

Angler group size

There were no significant differences between $\log_{10}(n+1)$ transformed mean angler group sizes between the pre and post-installation periods ($p = 0.981$), the partial and post-installation periods ($p = 0.104$), or the partial and pre-installation periods ($p = 0.077$). Untransformed mean group sizes (± SEM) were 2.317 ± 0.18, 1.840 ± 0.15 and 2.359 ± 0.22 for the pre, partial, and post-installation periods respectively.

Frequency of fishing

The median frequency of fishing visits to Cressbrook Dam reported by anglers was 4 times per year in both the pre and partial-installation periods. This increased to 12 times per year in the post-installation period. Reported frequency of visitation in the post-installation period had a significantly higher rank sum than for the pre and partial-installation periods, with Mann-Whitney U-test exact probabilities of $p = 0.008$ and $p = 0.009$ respectively.

Travel times to Cressbrook Dam

Most travellers fishing Cressbrook Dam were from within the Toowoomba region. There were no significant differences between $\log_{10}(n+1)$ transformed mean travel times between any of the FAS installation periods ($p > 0.40$ for all comparisons). However, there were significant differences between the travel time variances of the partial and post-installation periods compared to the pre-installation period ($p < 0.001$), with the variance being higher in the pre-installation period. The back-transformed means in minutes were 42.05, 48.43 and 48.12 for the pre, partial, and post-installation periods respectively.

Catch data

Australian Bass catch

Angler fishing effort in the creel surveys was a significant covariate ($p = 0.009$) in the GLM model examining the effects of FAS installation period on the catch rates of Australian Bass (Table 15). Installation period was not significant ($p = 0.653$), but there was a trend for increasing Australian Bass catches from the pre-installation period to the post-installation period (Figure 102).

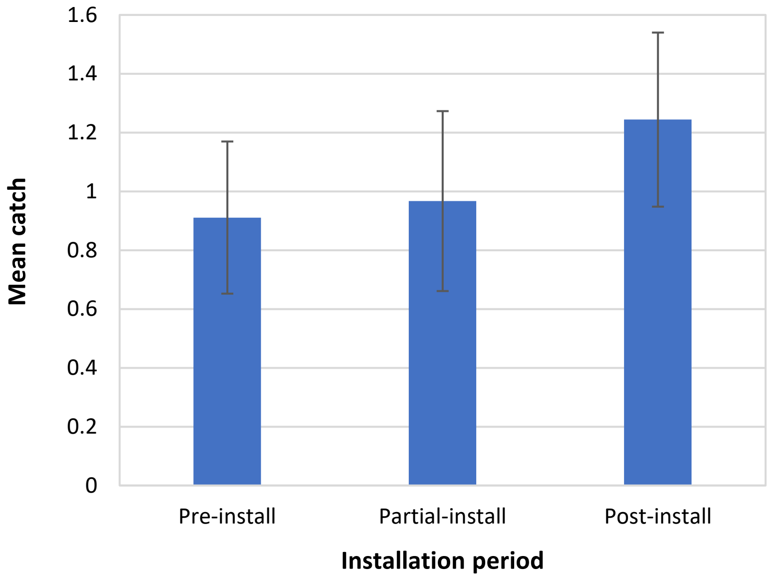

Figure 102 Adjusted (back-transformed) mean Australian Bass catch reported by anglers across the different periods of FAS installation. The mean catches are adjusted for an average fishing time of 3.5 hours and error bars show one standard error of the mean.

Golden Perch catch

Angler fishing effort in the creel surveys was a significant covariate ($p = 0.009$) in the GLM model examining the effects of FAS installation period on the catch rates of Golden Perch. Installation period was not significant ($p = 0.526$), but there was a trend for increasing Golden Perch catches from the pre-installation period to the post-installation period (Figure 103). Catch rates were much lower than for Australian Bass.

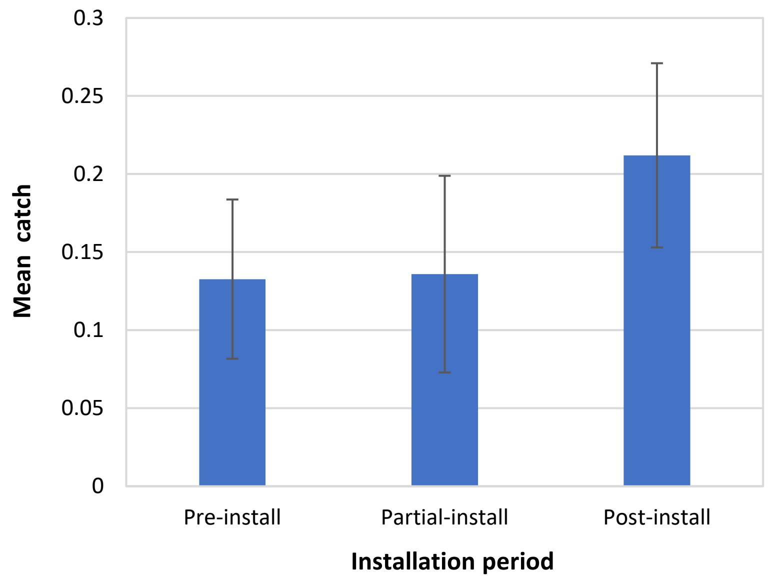

Figure 103 Adjusted (back-transformed) mean Golden Perch catch reported by anglers across the different periods of FAS installation. The mean catches are adjusted for an average fishing time of 3.5 hours and error bars show one standard error of the mean.

Combined recreational catch

Combined recreational catch included Australian Bass, Golden Perch, Freshwater Catfish and Silver Perch. Angler fishing effort in the creel surveys was a significant covariate ($p = 0.009$) in the GLM model examining the effects of FAS installation period on the combined recreational catch rates. Installation period was not significant ($p = 0.666$), but there was a trend for increasing combined recreational catches from the pre-installation period to the post-installation period (Figure 104).

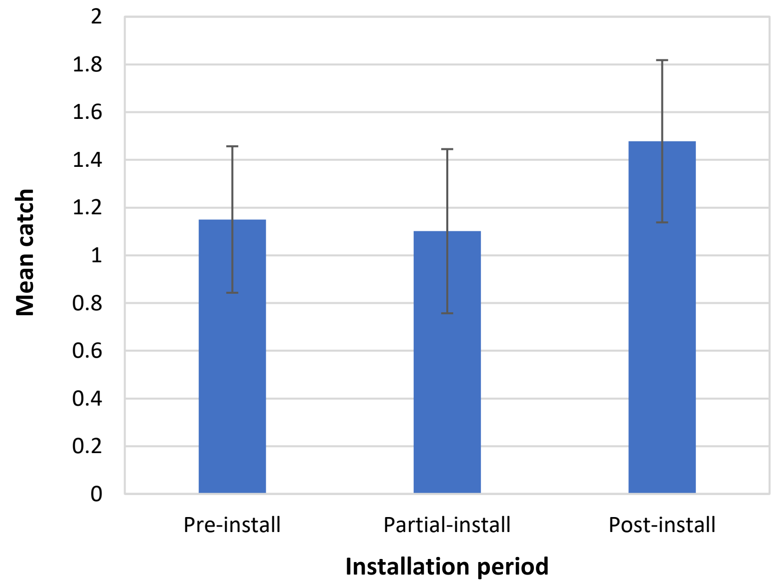

Figure 104 Adjusted (back-transformed) mean combined recreational catch reported by anglers across the different periods of FAS installation. The mean catches are adjusted for an average fishing time of 3.5 hours and error bars show one standard error of the mean.

Angler success rates

Australian Bass

The GLM (Binomial distribution with Logit link function) results indicated the hours fishing was not quite a significant covariate ($p = 0.078$) for angler success in catching Australian Bass. Installation period was also not significant in the model ($p = 0.215$), but there was a trend for increasing Australian Bass catch success rates from the pre-installation period to the post-installation period (see Figure 105).

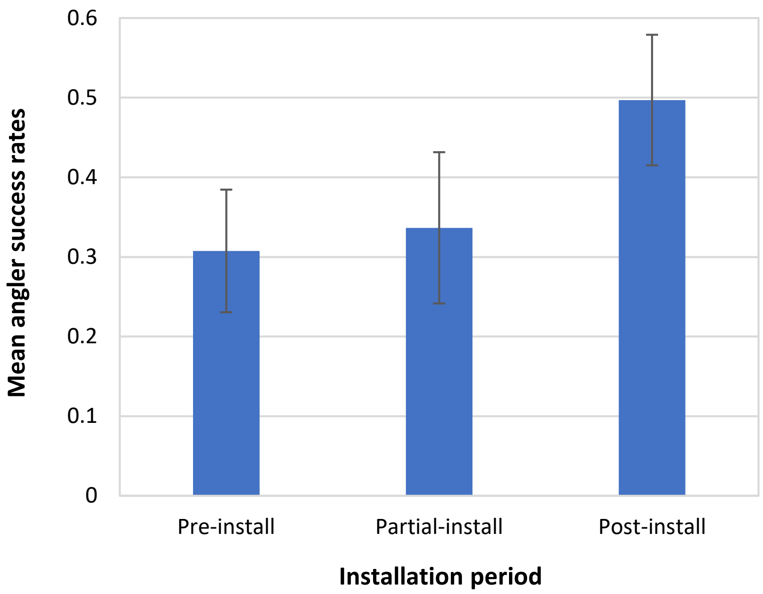

Figure 105 Adjusted (back-transformed) mean angler success rates for catching Australian Bass by installation period. Mean success rates are adjusted for an average fishing time of 3.5 hours. Error bars show one standard error of the mean. A success rate of 0.3 indicates 30% of anglers were successful at catching at least one Australian Bass per fishing trip.

Golden Perch

The GLM (Binomial distribution with Logit link function) results indicated the hours fishing was a significant covariate ($p = 0.019$) for angler success in catching Golden Perch. Installation period was also not significant in the model ($p = 0.898$), but there was a trend for increasing Golden Perch catch success rates from the pre-installation period to the post-installation period (see Figure 106).

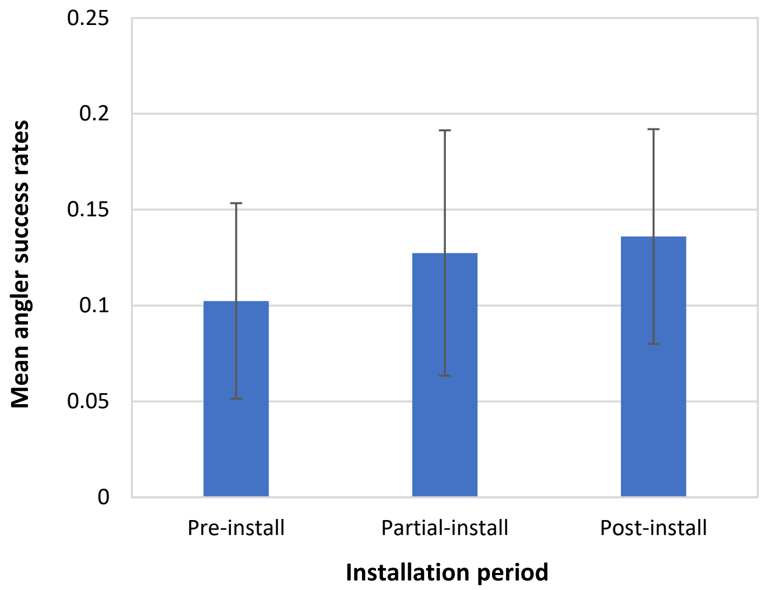

Figure 106 Adjusted (back-transformed) mean angler success rates for catching Golden Perch by installation period. Mean success rates are adjusted for an average fishing time of 3.5 hours. Error bars show one standard error of the mean. A success rate of 0.3 indicates 30% of anglers were successful at catching at least one Golden Perch per fishing trip.

Combined recreational catch

The GLM (Binomial distribution with Logit link function) results indicated the hours fishing was right on the cusp of being a significant covariate (p = 0.050) for angler success in catching any recreational fish species. Installation period was also not significant in the model (p = 0.384), but there was a trend for increasing recreational fish species catch success rates from the pre-installation period to the post-installation period (see Figure 107).

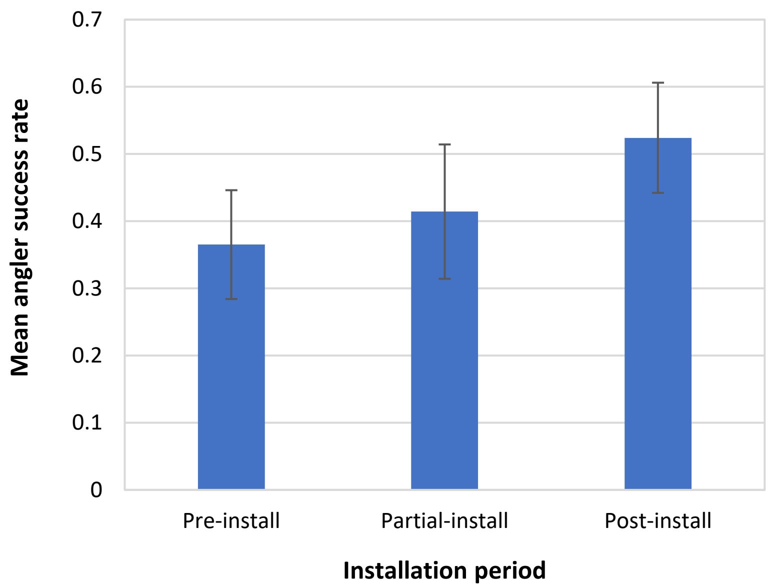

Figure 107 Adjusted (back-transformed) mean angler success rates for catching any recreational fish species by installation period. Mean success rates are adjusted for an average fishing time of 3.5 hours. Error bars show one standard error of the mean. A success rate of 0.3 indicates 30% of anglers were successful at catching at least one fish from a recreational fish species per fishing trip.

Boat arrivals

Boat arrivals could not be recorded continuously because there were periods when the dam was closed to anglers and periods when the monitoring camera suffered from technical issues (Figure 108). The dam was closed to anglers from part-way through January 2019 until the end of June 2019, then from November 2019 until nearly the end of May 2020. There were camera faults in November 2018, extending into part of December 2018, then again from part-way through July until late October 2020. The dam also closed to anglers from late December 2020 and remained closed throughout January 2021, preventing further collection of boat arrival data.

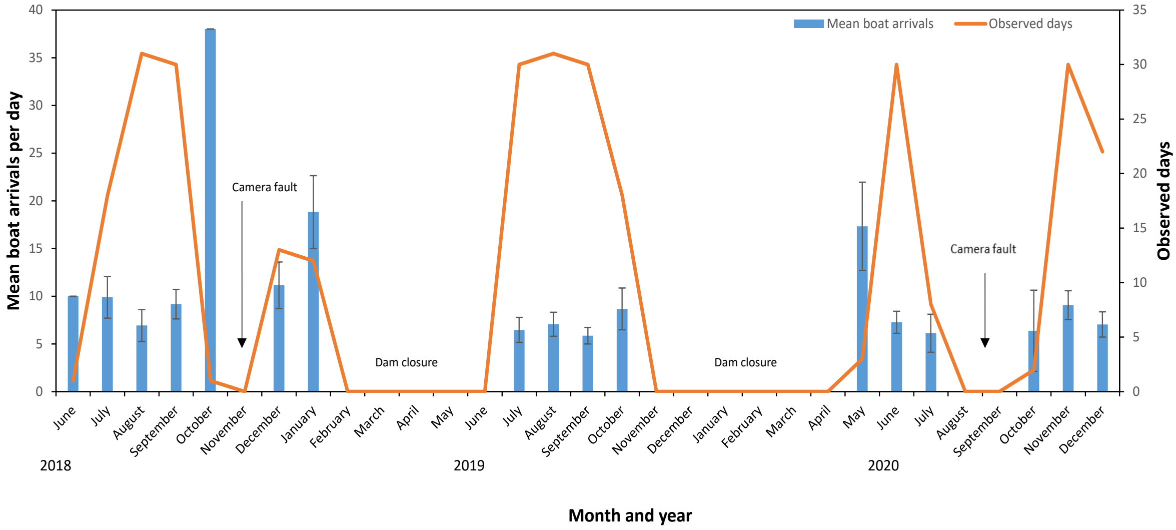

Figure 108 Mean daily boat arrivals by month. The orange line and the second y-axis indicate the number of days per month with usable trail camera data. Some months had low numbers of days where boat arrivals could be recorded due to dam closures or camera faults. Error bars show one standard error of the mean.

The only seasons for which meaningful pairwise comparisons could be made between all years (installation periods) were winter and spring (Figure 109). A reasonable amount of data was collected for these seasons across all three years. Summer could also be compared between the pre and post-installation periods. No data was available for autumn across all years, apart from three days of data from May 2020.

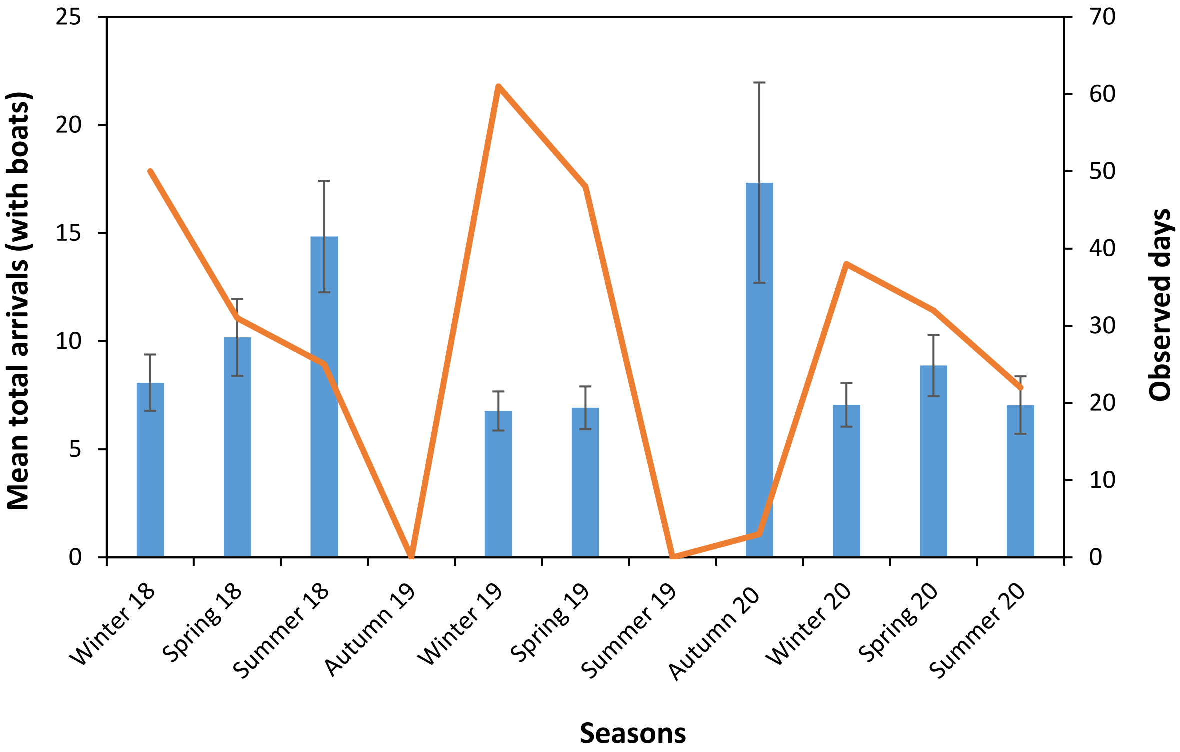

Figure 109 Mean daily boat arrivals to Cressbrook Dam by season and year. Error bars show one standard error of the mean. The orange line and the second y-axis indicate the number of days per season with usable trail camera data. Summer 20 contains data for December 2020 only.

The pre-installation period for boat arrivals encompassed 2018, with 2019 the partial-installation period and 2020 the post-installation period. The ANOVA comparing the effect of seasons by year was statistically significant (P = 0.006). The Tukey tests revealed that mean daily boat arrivals in spring 2019 were significantly lower compared to spring 2018 and 2020; and mean daily boat arrivals in summer 2018-19 were significantly higher to those in summer 2020-21 (Table 12). However, summer 2020-21 did not include data from January, unlike summer 2018-19.

Table 12 Post-hoc Tukey pairwise test results for like seasons over the period 2018-2020. Pre-installation period is 2018, partial-installation is 2019 and post-installation is 2020. Significant values (α = 0.05) are highlighted in bold.

Linear hypothesis	Estimate	Standard error	P (>|z|)
Winter 19 - Winter 18 =0	-0.17702	0.07033	0.185
Winter 20 - Winter 18 =0	-0.13993	0.07919	0.638
Winter 20 - Winter 19 =0	0.03709	0.07853	0.999
Spring 19 - Spring 18 =0	0.38575	0.08001	**<0.001**
Spring 20 - Spring 18 =0	-0.13644	0.08313	0.721
Spring 20 – Spring 19 =0	0.24930	0.08083	**0.042**
Summer 20-21 - Summer 18-19 =0	-0.74494	0.09564	**<0.001**

Discussion

Targeted angling

Fish use of different FAS types

The low catch rates from the targeted angling surveys made it difficult to discern any conclusive patterns from the dataset. Very few significant results were evident. However, there are some encouraging trends, with post-installation catches on FAS sites higher than those at Control sites. The angler success rates for habitat type also show some differences between the FAS preferences of each species.

For Golden Perch, there was a trend towards increasing catches on synthetic FAS over the pre, partial and post-FAS installation periods, suggesting this species was increasingly utilising this FAS type. In comparison, no Golden Perch were caught at Reference sites over the course of the surveys, despite the abundance of good quality habitat. This does not indicate an absence of Golden Perch at Reference sites, as electrofishing surveys here have yielded Golden Perch at these locations (see Chapter 3). Similarly, Golden Perch were only caught by targeted angling at suspended FAS sites prior to the installation of FAS. However, underwater video footage of suspended FAS showed that Golden Perch were actively feeding on these structures. The electrofishing surveys and the acoustic telemetry also indicated they use this structure type. The sample size for Golden Perch was particularly poor across all sites, making it difficult to draw any sound conclusions from these targeted angling results. The poor catch rates at timber FAS during the partial installation period can be explained by the fact that most timber structures were installed late in the project and within a short time frame. This meant only three timber sites were fished during the partial installation period.

The sample size for Australian Bass was much larger, and the results indicate that habitat type was a significant factor for catches of this species. The findings suggest that Australian Bass may prefer different FAS types than Golden Perch. No Australian Bass were caught from synthetic FAS, but the acoustic telemetry and electrofishing data suggest that Australian Bass do use this structure type. Australian Bass displayed an affinity toward the good quality habitat at Reference sites, while suspended FAS also supported some Australian Bass catches. The Reference sites did not have any public access, and the naivety of fish to lures may in part help to explain why the catch rate there were so high in relation to other habitat types. However, the acoustic telemetry demonstrates that Australian Bass move widely around the dam, and therefore the increased catch here is more likely to be related to habitat characteristics.

The targeted angling survey did not monitor any of the deeper open-water FAS installations in Cressbrook Dam. Large shoals of fish were often detected by sonar in close proximity to structures and these may have produced good catch rates. The open water sites are productive fishing areas and extremely popular with anglers. Vessels were frequently observed in the area, and there were numerous reports of fish captured from here. Perhaps the most popular of these sites is Open Water 5, which is comprised entirely of synthetic cubes and trees. Anglers frequently target Australian Bass in this area, and underwater drone footage has shown this species to be actively feeding on baitfish there. The acoustic telemetry (Chapter 3) found Australian Bass used some of the open-water structures. A future angling survey that included open water sites may prove to be useful in demonstrating the efficacy of FAS, particularly synthetic FAS. This would be most beneficial after a few years of establishment, where fish have had ample time to incorporate FAS into their normal movement patterns and behaviour.

Limitations in the targeted angling surveys

Although systematic angling surveys have previously been used as a sampling tool to evaluate angler catch rates following the introduction of fish attracting structures, studies in other countries have observed mixed results with the technique. When using angling to evaluate fish attracting structures, standardization can be difficult due to angler skill levels, weather, snags, and bait presentation problems (Johnson and Lynch 1992, Hayes *et al.* 2012). Rogers and Bergersen (1999) demonstrated a significant increase in catch rates of largemouth bass after the introduction of synthetic structures in a reservoir, while Wills *et al.* (2004) were unable to demonstrate any change in angler catch rates of smallmouth bass following habitat enhancement.

The regimented nature of the targeted angling survey was necessary to enable statistically valid comparisons between sites. However, the poor catch rates are unlikely to be a reliable indicator of the catch rates that anglers would expect when fishing Cressbrook Dam under normal recreational conditions. Fishing within the constraints of the survey probably did not reflect normal angler behaviour. Opportunities to catch fish at FAS sites were constrained by the tight timeline, as the allotted thirty minutes provided only a narrow window in which to catch fish. This was especially obvious when numerous fish were detected in close proximity to FAS by sonar, with the perception that the chances of hooking a fish at that site were quite high. In these situations, the thirty-minute sampling period seemed to elapse quickly, with anglers moving onto the next site reluctantly. Further, if fish had been caught at a site during the sampling period, then anglers were forfeiting further opportunities to catch fish at that site by moving after thirty minutes, whereas regular anglers would probably target the site for longer.

The surveys did not always correspond with ideal angling conditions. The randomised order that sites were fished meant that anglers fished in areas that were unfavourable owing to wind direction, muddy water etc. In this regard the targeted angling survey was not entirely indicative of normal angler behaviour. Norris (2016) reported that targeted angling surveys lost favour with many fisheries agencies in the USA due to these reasons. The trend has been to increasingly rely on fisheries-dependent data from creel surveys (Zale *et al.* 2013), although targeted angling still does have potential as a fisheries monitoring tool. To improve catch rates and statistical power, longer fishing times could be used at each site or fishing effort focussed to the two hours from dawn and the two hours before dusk. This additional angling effort could create logistical issues and would result in extended time in the field. At sites where daily travel time is minimal this approach would be suitable, but it may prove problematic where overnight stays are required.

The vessel used for this survey had been designed primarily for electrofishing, and therefore did not have the attributes of dedicated impoundment fishing boats. The vessel provided a good platform for casting from, but the bare deck and aluminium hull were more likely to transmit loud noises into the water column, as opposed to the Carpeted casting decks that many impoundment anglers prefer. Furthermore, many serious lure anglers fishing in impoundments have bow-mounted electric motors in addition to their stern-mounted petrol outboard motors. These electric motors are very quiet during operation, enabling anglers to stealthily approach sites without alerting fish to the presence of anglers. Tournament anglers on Cressbrook Dam have noted the importance of casting a long way from the boat, as fish beneath the boat are aware of its presence and are less likely to strike at a lure (Jason Ehrlich, pers. comm, 2019). While the anglers participating in this survey were able to cast a long way from the boat, we did not have an electric motor and could not approach the sampling sites with the same degree of stealth.

Angler avoidance is also likely to have compounded from decades of fishing pressure at Cressbrook Dam. Australian Bass in particular are generally a slow-growing catch and release species, so it is likely that many fish in this impoundment have had previous exposure to lures and anglers and have already attached negative connotations to certain noises and lures. Further, most of the styles of lures used during our survey have been popular among impoundment anglers for at least the last fifteen years, so the incidence of fish familiarity with certain lure types may have been a contributing factor to our poor catch rates, with very few naïve fish left in the population.

Most serious impoundment anglers also have a 'position-lock' device fitted to their electric motors, enabling them to mark schools of fish on the sounder and then quietly hover on or adjacent to that school, which allows a consistent casting effort without the constant need to reposition the boat. Survey anglers did not have access to an electric motor or a spot-lock device, instead having to rely exclusively on a four-stroke 60hp Yamaha outboard. This necessitated the need for anchoring or drifting through the site before repositioning, with both options creating unnecessary noise that may have spooked fish. Cressbrook Dam is quite exposed to the wind from most directions, with windy conditions often experienced whilst drifting through a site, which required more frequent repositioning. Not only was this wasted fishing time, but a faster drift also added more urgency to retrieves and led to difficulties in getting the lures down deep around the structures. These factors may have had an impact on our catch rates.

Previous studies have demonstrated that 'angler avoidance' contributes to poor catch rates in impoundments (Wegener *et al.* 2017), and it is possible that this was a contributing factor to the poor catch rates experienced in this survey. However, it is more likely that the poor catch rates experienced were simply a reflection of the low numbers of fish in Cressbrook Dam. This suggestion is supported by the poor catch rates recorded in the electrofishing surveys.

Angler Experience and Behaviour

Angler experience has been shown to have a significant effect on catch rates (Van Poorten and Post 2005, Heermann *et al.* 2013), and this may have contributed to catch rates in this survey. The lure fishing experience amongst the survey anglers was variable. Unfortunately, the same anglers were not available for every survey, with a total of seven different anglers participating in targeted angling over the course of ten surveys. The constant changing of participating anglers between surveys did not present the ideal approach in terms of consistency, although it should be noted that the majority of anglers participating in this survey were competent and accomplished anglers, with considerable lure-fishing experience. Differences in the level of angler experience would not have impacted the relative catch rates between different habitat types within a survey period because the same anglers surveyed all sites. However, the changing of survey anglers and the variability in angler experience could have been a contributing factor to the outcomes for comparisons between installation periods. Hall *et al*. (2019) found it beneficial to use a specialized fishing approach, using only a select few highly-skilled and devoted anglers for an angling survey, and this approach may have proved more beneficial in this instance.

Although the targeted angling survey was not designed to monitor angler behaviour, there was a noticeable difference in attitude and enthusiasm levels among the anglers participating in this survey when comparing FAS sites with non-FAS sites. Thirty minutes fishing in barren Control sites seemed quite onerous, whilst angler enthusiasm and expectation was much higher when fishing in FAS sites, especially when visual cues were evident in the form of multiple fish arches on the sounder. The perceptions among survey anglers were that the chances of catching fish were higher when fishing sites where FAS had been installed, even though catch rates by them were not shown to significantly increase after the introduction of FAS.

Angler perceptions and catch rates

Most of the angler survey metrics and the angler catch data from the creel surveys indicated a trend towards improved fishing or perception of fishing at Cressbrook Dam post-installation of FAS. For example, angler perception of fishing quality and willingness to recommend fishing in Cressbrook Dam to others improved significantly. At Lake Havasu in the USA, habitat degradation resulted in a significant decline in the fishing quality, and by the 1980s anglers described fishing there as poor

(Anderson 2001, Follmuth *et al.* 2019). Following 8 years of extensive habitat improvement, the average score by anglers of the improvement of fishing quality was 4.1 on five-point scale (Anderson 2001), where 5 is the highest improvement in quality. We used a similar 5-point scale at Cressbrook Dam to rate fishing quality, but chose not to average ordinal scores. However, had we used average scores, the mean score would have started below 3 in the pre-installation period, and exceeded 3 after two years of habitat enhancement. Parameters that were not significantly different between the pre and post-installation periods, such as angler satisfaction were still all trending towards improvements in angler perception, with higher rank sums recorded for the post-installation period than the pre-installation period. The more negative perceptions reduced or vanished by the post-installation period. Similarly, willingness to fish Cressbrook Dam again was significantly greater in the partial-installation period than in the pre-installation period, and willingness to fish in Cressbrook Dam again also increased. Angler satisfaction is generally driven by fishing quality, access to fishing sites and lack of crowding at a fishing location (Birdsong *et al.* 2021). We believe improved fishing has driven improved angler perceptions at the Cressbrook Dam. Visitation rates to Cressbrook Dam amongst anglers interviewed increased significantly in the post-installation period, with the median visitation frequency tripling.

Angler catch rates were not statistically significantly higher in the post-installation period compared to the pre-installation period, but there was a consistent trend across Golden Perch, Australian Bass and the combined recreational fish catch for catches to be higher in the post installation period. Likewise, the proportion of anglers catching fish trended in the same direction. These multiple lines of evidence all point towards improved catch rates. The angler surveys were hampered by frequent closures of the dam, leading to smaller sample sizes than would have been preferred and a loss of statistical power. Had it been possible to sample more frequently, it is plausible that the catch trends observed may have been shown to be statistically significant. Cressbrook Dam is reputed to be more difficult to fish during low water levels (Peter Taylor pers comm.), therefore having recreational fish catch rates trending upwards despite this tendency, is an indicator that FAS could have contributed positively to the fishery.

The observed increase in the proportion of legal sized fish captured in the partial and post-installation periods, probably cannot be attributed to FAS installation. Although it is probable that FAS provided some additional feeding opportunities for large fish by aggregating small-bodied fish species (see Chapter 3), the FAS were probably not installed at a sufficient scale to significantly influence growth rates. It is more likely that the low water levels, stabilised by water transfer from Wivenhoe Dam, enabled development of extensive (difficult to fish) aquatic macrophyte beds around the margins of the dam that may have increased small fish and macro-invertebrate abundance and therefore the food supply for recreational species (see Chapter 3). Another possible explanation for an increase in the proportion of legal sized fish could have been a cessation of stocking, leading to fewer juvenile Australian Bass and Golden Perch in the dam. However, fish stocking records for the dam show there was no significant pause in stocking that could have contributed to the increased proportion of legal-sized fish being caught by anglers.

Anglers' catch rates and attitudes in response to fish habitat installations in impoundments have not been reported as frequently as the response of fish to habitat enhancement. In those cases where installations have been evaluated, the results have shown some positive trends. For example, at the 17.4 ha Cottonmill Lake in Nebraska, a combination of dredging, installation of structures and breakwaters was used to improve fish habitat and angler access. The mean angler catch rates for combined species increased from 0.5 fish per hour pre-restoration, to 1.5 fish per hour post restoration (Spirk *et al*. 2008).

Another example comes from Table Rock Lake, a 17,442 ha impoundment on the Missouri-Arkansas border (Allen *et al.* 2014). From 2007 to 2013, over 2000 fish habitat structures were installed in the lake to improve fishing. The location of these structures was made available to the public on a web site. Angler perception was that the installation of structures had improved their quality of fishing and there was strong support for the program.

Lake Havasu is a very large (7,800 ha) impoundment on the Colorado River in the USA and the site of one of the largest fish habitat enhancement projects ever undertaken. Commencing in 1992, tens of thousands of habitat structures were installed in the lake, with at least 324 ha of habitat constructed by 2001 (Anderson 2001). This enhancement is on a much bigger scale than that in Cressbrook Dam. At Lake Havasu, 97 per cent of anglers agreed that fishing had improved in quality since the start of the program. Fishing pressure tripled over this time, but fish size and quality also both improved (Anderson 2001).

All of these studies suggest installation of fish habitat structures can improve the quality of fishing or perception of fishing quality by anglers. The data from Cressbrook dam is trending in a similar direction to these previous studies.

Angler knowledge of FAS

In the creel surveys the angler visitation to Cressbrook Dam because of installed FAS, increased significantly from the pre-installation period to the post-installation period, suggesting the FAS helped attract some anglers to the dam or to fish there more frequently. However, a considerable proportion of anglers were either unaware of the installed FAS or knew about the FAS program but did not know exactly where the FAS were installed. This was despite signage at the dam boat ramp with the FAS locations shown on a map and GPS coordinates of the FAS provided. The lack of awareness about FAS locations suggests ongoing extension work and more effective signage is required to improve angler use of installed FAS. Such signage was in late 2021. In Lake Havasu, USA, 84% of visiting anglers were aware of the habitat Improvement program after eight years of installation (Anderson 2001), compared to over 60% awareness at Cressbrook Dam after two years of installation. Increasing awareness of the FAS project and their installation sites should generate greater interest in Cressbrook Dam and lead to more use of FAS sites by anglers.

Many anglers in Cressbrook Dam assumed that FAS were only located where the surface buoys of the suspended FAS were located. This meant that they did not know where the majority of FAS were situated, nor actively fished them. Adding marker buoys to all of the FAS clusters was considered, but this would have been expensive and potentially made it more difficult for anglers to fish around the structures and may have deterred anglers from fishing those sites. A better balance between the number of floats marking the FAS and the amount they impact ease-of-fishing may lead to greater FAS utilisation. Highly visible signs were installed on the shoreline (Figure 17 in Chapter 2) to indicate locations where FAS had been deployed, but due to unforeseen delays, the signs were only installed towards the end of the project. A range of methods have been used to mark FAS locations in overseas impoundments (Figure 110, Norris 2016). No consensus has been reached on the best approach, but the signage/buoyage used needs to take into consideration the size and deployment patterns of the FAS. Where a single large reef of FAS is deployed, a surface marker buoy may be sufficient. However, where FAS are more dispersed in an area, shore signs or the use of buoys to mark the boundary of the FAS would be more appropriate. A single buoy has been used at each enhancement site in the FAS trial in North Pine Dam, Queensland (Noel Frost, PRFMA pers. comm.) whilst in the trials at Mt Morgan Dam No 7, Queensland, the boundary of each FAS zone was marked with surface buoys (Michael Hutchison pers. comm.).

Figure 110 Examples of how the position of FAS are marked in overseas impoundments. a) Surface marker buoy from a North Carolina reservoir, and b) tree mounted sign from Table Rock Lake Missouri (images from Norris 2016).

The locations for FAS clusters in Cressbrook Dam will also be made available online. The online information will contain a summary of the project and a map showing the FAS locations. The GPS coordinates for the FAS will also be listed and made available for download in the common GPS/sounder formats. Online interactive maps for fish habitat enhancement activities have proven extremely popular in the USA (Norris 2016). The majority of state fisheries agencies undertaking fish habitat enhancement activities now establish websites for all of their major fishing reservoirs and lakes which include these details. Angler use of these websites has been extremely good and interactive maps where anglers can bring up the number, type and employment date of FAS at each site appear to be most popular (Jeff Boxrucker, RFHP, pers. comm.).

The survey data suggested that a large proportion of anglers target fish over bottom structure. It appears that some anglers were fishing over FAS without being aware at the time that they were fishing over installed structures. They were drawn to the FAS by shows of bottom structure and fish on their boat's echo-sounders. This may account for the improving trends in fish captures as anglers were inadvertently targeting FAS. If targeting of FAS was more intentional by more anglers, then it is possible that further improvements in fish catch rates may have been achieved. The proportion of the catch coming from FAS increased by the post-installation period, with a falling proportion of fish coming from natural structures. Catch rates from weed beds remained stable despite the significant increase in the extent of this habitat type.

Boat Arrivals

The use of a trail camera to record boat arrivals is a useful way to estimate angler effort rate changes over time. The trail cameras provided a cost-effective way to monitor boat arrivals at Cressbrook Dam and worked well apart from a few technical failures. Dutterer *et al.* (2020) found that motion triggered game cameras at boat ramps produced similar estimates of fishing effort to roving creel surveys. Likewise, Hartill *et al*. (2016) found use of web cameras at boat ramps showed trends in boat arrivals that matched trends in snapper catch from creel surveys.

One drawback from using the trail cameras to monitor boat arrivals was technical issues with the camera leading to reduced detection rates, or camera failures from battery issues or storm damage. Other researchers have also experienced some data gaps or reduced detection rates from trail cameras due to equipment malfunction or obstruction of sensors due to overgrowing vegetation (Van Poorten *et al*. 2015, Dutterer *et al*. 2020). More frequent monitoring of cameras and downloading of camera data may help to reduce periods where cameras fail to collect data due to faults, low battery power, insufficient available memory or obstruction of sensors by vegetation.

Most seasonal boat arrival data at Cressbrook Dam showed little change between the pre and post-installation periods, suggesting there was little impact from the FAS installation on visitor arrivals. However, mean summer visitation rates dropped significantly in the post-installation period. This result needs to be treated with caution because the dam was only open to fishing for three weeks in December 2020 during the post-installation summer. The Christmas period in 2020 was not open to fishing. The pre-installation summer period included data from both December and January. January is a period when arrivals during the school holiday period, and during the week following New Year's Day and the Australia Day long weekend can be expected to be high. In 2018 the January arrivals exceeded December arrivals in the pre-installation period.

By the post-installation period, low water had caused the boat ramp to become more difficult to use. Some boat arrivals were observed by project staff to approach the boat ramp, then leaving when they saw the state of the lower end of the boat ramp. Some anglers also perceive Cressbrook Dam to be more difficult to fish during low water levels (Peter Taylor pers comm.), so are less likely to visit when water levels are low. Thus, having no significant decline in boat use (despite the low water level) could be considered a positive result. There were many external factors impacting on visitation to the dam, including closures due to blue-green algae blooms, harmful bacteria levels, bushfires and Covid-19. Extended closures can redirect angler attention to other areas, and it can take some time before anglers become aware that the dam has re-opened for fishing. There was a reduction in the variance of travel times from the pre- to the post-installation period. This reflects a reduction in the number anglers from outside the Toowoomba region travelling to Cressbrook Dam to fish. This is probably related to Covid 19 travel restrictions and closures, and to the extended periods over which Cressbrook Dam was closed to anglers. Anglers require confidence a dam will be open before travelling a significant distance to fish it. The boat arrival data seems to conflict with the reported increase in fishing frequency at the dam among interviewed anglers. This may be explained by an increased frequency of visitation by local anglers being offset by decreased visitation from more distant locations.

When the dam refills, making the boat ramp more useable and the waterbody less subject to blue-green algae blooms, it is plausible that an extension campaign regarding the FAS installation and the improvements to fishing could successfully increase visitation rates from outside the Toowoomba region to Cressbrook Dam. The ending of the Covid 19 pandemic will also give interstate travellers and travellers from elsewhere in Queensland more confidence to start visiting Cressbrook Dam.

Conclusion

While the data analysis for the targeted angling surveys suffered from a small sample size and revealed few significant results, the bulk of evidence seems to suggest that catch rates are moving in a positive direction. The trend towards increasing catches at synthetic and timber FAS sites is encouraging, especially in comparison to Control sites where the catches were decreasing. Unfortunately, only two targeted angling surveys were completed post-installation, and it's likely that a few additional surveys would have consolidated the results and helped to identify significant changes in catch rate after the installation of FAS. Nevertheless, the confidence of survey anglers was growing when fishing around FAS sites, with some memorable captures from directly atop installed FAS clusters.

Other studies have shown that non-catch related variables often enhance the fishing experience (Birdsong *et al.* 2012), and even if we weren't able to demonstrate a significant increase in catches on installed FAS by the targeted angling surveys, this discussion has highlighted other factors such as perception and enthusiasm, along with a visual appeal that may help to increase the overall fishing experience at Cressbrook Dam.

The angler creel surveys showed there was an overall trend towards improving angler attitudes to fishing in Cressbrook Dam and the creel surveys demonstrated improvements in fish capture rates, following installation of FAS. This provides evidence that installation of FAS has improved the attractiveness of the fishery in Cressbrook Dam. However, this study was hampered by falling water levels, frequent lengthy dam closures, a major bushfire and a pandemic, which all may have impacted on angler confidence to visit the dam and contributed to reduced sampling power. Further extension work is required to maximise the use and benefits to anglers from the installed FAS.

General Discussion

An initial examination of using FAS in Australian impoundments

This study was one of the first in Australia to examine the potential of installing fish habitat as a management tool for impoundment fisheries. A multi-pronged approach was undertaken due to difficulties reported in previous studies regarding detecting significant responses in fish distributions and angler experience at the whole-of-impoundment scale (e.g., Anderson 2001, Jacobson and Koch 2008, Allen *et al.* 2014). The different monitoring techniques employed demonstrated relatively consistent trends in increased fish abundance and angler catch rates at sites where FAS were installed, despite varying levels of statistical significance. Anglers were also found to have a more positive attitude towards fishing in Cressbrook Dam after FAS had been installed. Collectively the results indicate that installing FAS has potential benefits for Australian Bass and Golden Perch impoundment fisheries, and that FAS are likely to be beneficial for other stocked impoundment fish species. The question of which FAS types were most effective was less clearly answered. Fish were found to utilise all of the FAS types trialled, but the trends observed between the different monitoring techniques were not always consistent.

Confounding factors and limitations of the results

A number of confounding factors are likely to have contributed to the inconsistencies of the some of the results observed between monitoring techniques. Potentially confounding factors included changes to dam hydrology, increases in aquatic vegetation, dam closures, low sportfish abundance, low water clarity, tampering with equipment and monitoring design restrictions.

One of the largest influences on dam ecosystems is water level fluctuations (Zohary and Ostrovsky 2011). During the current study no major rainfall events occurred in the dam catchment and as a result the water level declined by 5.07 m. The historic annual decline in the dam is approximately 2 m per year. However, to ensure adequate town water supply for the region, water was pumped into Cressbrook Dam from nearby Wivenhoe Dam to maintain the water levels above 30% dam capacity. The falling water levels made it difficult to position and monitor the installed FAS. Additionally, the change in hydrology to stabilise the water levels, resulted in a significant increase in the extent of the aquatic vegetation and algae in the dam. These are key drivers behind productivity in impoundments and their increase likely resulted in an abundance of food resources and cover for fish and invertebrate species (Schmude *et al.* 1998, Cheruvelil *et al.* 2002, Conrow *et al.* 2011). Eadie and Keast (1984) found macrophytes also provide habitat complexity, leading to greater species richness and diversity in vegetated areas (Eadie and Keast 1984). Vegetation also provides supplementary foraging habitat when other habitats are lacking (Beauchamp *et al.* 1994).

In impoundments, the abundance of some sportfish can be significantly higher near aquatic vegetation (McDonough and Buchanan 1991, Bettoli *et al.* 1992, Hinch and Collins 1993, Miranda and Pugh 1997, Smith *et al.* 2011). The benefits of installing FAS can be masked when dense vegetation develops (Wilson 1978). Rogers and Bergersen (1999) attributed a decline in the catch of largemouth bass from FAS sites in Lake Ladora, USA, to the commensurate growth of aquatic macrophytes that provided bountiful alternative habitat in the remainder of the basin. The authors suggested managers may wish to reconsider deploying structures in basins that support lush macrophyte populations because fish attractors in these basins may have little utility in aggregating fish when vegetation becomes dense.

Where water levels are stable, aquatic vegetation can be used as a fisheries management tool (Miranda 2017). In the USA aquatic vegetation is being re-established in some impoundments to attract fish to specific areas and where successful, strong improvements in recreational fisheries have been observed (Cooke *et al.* 2005b, Norris 2016). Largemouth bass utilise vegetation when other complex habitat is absent (Sammons *et al.* 2003). Many Australian fish species also utilise aquatic vegetation for feeding and cover (Allen *et al.* 2003) and thus their distribution was likely to have been strongly influenced by the increase in the extent of this habitat type in Cressbrook Dam. The acoustic tracking results found Golden Perch movements became more frequent around a particular area as the submerged aquatic vegetation extent increased. The movements of this species along shorelines also often appeared to correspond to the outer margins of the submerged vegetation and use intensified as the density and extent of the vegetation increased in the latter parts of the tracking period. A similar, though less pronounced response was also detected in the tracked Australian Bass. This temporary increase in attractive habitat is likely to have confounded the response of fish to the installation of the FAS. A stronger and clearer response is likely to have occurred if the vegetation had not become so abundant.

The fluctuations in the water level also had to be taken into consideration when planning the locations of the FAS. At the commencement of the project, dam water levels were 7.5 m below full supply level. FAS had to be placed so that they could be available to fish as water levels fell, but also not too deep when water levels rose. Structures placed below the thermocline are less likely to be utilised during the warmer months when dam waters become stratified (Smith *et al.* 2011). The majority of FAS were also placed in bays to enable monitoring by electrofishing to be undertaken effectively. These locations may not always have been optimal for attracting fish and the deployment sites would have been different if the project objectives were solely to achieve optimal fish attraction. The fluctuating water levels dictated that the FAS be placed deep enough to remain submerged and not overgrown by vegetation for the duration of the monitoring period. However, as water levels stabilised, the extent of the marginal vegetation increased and engulfed a number of the FAS, particularly those set in slightly shallower water. This potentially decreased their attraction value to the sportfish. When water levels increase again, the aquatic vegetation will senesce as light becomes limiting, and the function of the FAS should increase. Providing that no structural damage occurs, becoming overgrown by vegetation and algae could in fact be beneficial for the FAS if periphyton growth has been higher and remains so once the submerged vegetation dies back.

Several issues resulted in closure of the impoundment to anglers at different times throughout the study. Cyanobacteria blooms, bacteria blooms (*Enterococci spp.*), bushfires and Covid all led to dam closures during the project. The dam closures affected the continuity of the creel surveys and the number of anglers that were thus interviewed. Very few surveys could be conducted in autumn when blue-green algal blooms were typically strongest. Additionally, uncertainty over the open status of the dam may have reduced the number of anglers visiting.

The primary cause of lengthy dam closures was freshwater cyanobacteria (blue-green algae) blooms at levels deemed hazardous to public health. These blooms typically occurred during warmer months and resulted in lengthy closure periods. Occurrence of blue-green algae blooms had not been a common problem at Cressbrook Dam and thus was not anticipated. The blooms most likely occurred due to a combination of eutrophication and ongoing low water levels (Anderson *et al.* 2001, Izydorczyk *et al.* 2008, Gagala *et al.* 2013). The toxins in cyanobacteria can lead to behavioural changes in fish, including avoidance (Godlewski *et al.* 2016), but these vary between species and algal densities (Baganz *et al.* 2004, Ernst *et al.* 2007). Electrofishing surveys and the acoustic tracking continued in Cressbrook Dam during periods when the dam was closed to anglers. The blue-green algae blooms may therefore have influenced the distributions and movements of fish, as well as preventing anglers from fishing.

The relatively low level of sportfish in the dam has potentially confounded some of the survey results. Sportfish abundance was known to be low prior to the study commencing, but was anticipated to be higher than what was observed. Catch rates in the electrofishing and targeted angling surveys were very low, leading to zero-biased catch data. Although this was corrected through the use of appropriate distribution selections in the statistical analyses, small changes in the catch rates could have resulted in significant changes. The creel surveys also reported low catch rates amongst visiting anglers. A higher abundance of sportfish may have resulted in a clearer understanding of the relative effectiveness of the different FAS types. Additional research into the relative cost-effectiveness is needed at sites with higher fish abundance to better understand how FAS can best be applied in Australian impoundments.

Several issues occurred with the equipment which limited monitoring results. The water clarity in Cressbrook Dam proved unsuitable for quantitative use of underwater cameras (both static and a mobile underwater drone). Image range and quality was often poor and visual surveys of fish use of FAS and FAS condition could not be undertaken as intended. A limited number of images were captured showing both Australian Bass and Golden Perch using different FAS types, but even these were not of high enough quality for use in major extension activities. The cameras were slightly more successful at providing images of FAS condition and the development of periphyton. However, significant inconsistencies in image quality occurred between sites and even FAS structures within a site. In the USA where the reservoirs are typically clearer, Norris (2016) reported that the general consensus amongst the fisheries biologists, was that visual surveys were ineffective at providing long-term assessments for habitat enhancement. Focus has instead shifted towards hydroacoustic surveys, with newer units capable of providing estimates of fish number, size and biomass. This approach should be considered in future surveys where quantitative data is required.

The acoustic telemetry array provided valuable insights into the movements and distribution of Australian Bass and Golden Perch in Cressbrook Dam. However, the effectiveness of the array was partially constrained by the number of receivers available, the impacts of receiver shadowing, declining water levels, aquatic vegetation and equipment being tampered with. These factors somewhat confounded the telemetry results because fish could not be tracked as effectively in the inner parts of some bays, amongst vegetation or in areas where receivers had been removed. This may have resulted in an under-representation of fish use in marginal habitats and around FAS. Conducting the telemetry trials in a more open basin where these factors can be better mitigated would provide additional insight into the effectiveness of the different FAS types, seasonal trends, and how these vary between species.

The effectiveness of different FAS types

Historically the materials used to construct FAS were primarily chosen for availability and convenience. This trend still occurs in many places today, but a much greater emphasis is now being placed upon materials and designs tailored to benefit specific species. Since Australia does not have a history of FAS use, the focus in Cressbrook Dam was to evaluate the effectiveness of three broad groups of FAS for stocked native fish to determine if one was more effective than the others. The FAS trialled varied in construction material and location within the water column. No clear preferences for a particular FAS group could be identified from the current study. The electrofishing surveys suggested Australian Bass and Golden Perch used FAS constructed from both timber and synthetic materials, with the largest observed increase in use occurring at the timber FAS sites. However, acoustic tracking observed more use of suspended FAS and synthetic FAS, and only limited use of timber structures. As explained above, a number of factors regarding the acoustic telemetry are likely to have influenced this. In the targeted angling, synthetic structures showed an increasing trend in angler catch rate.

These inconclusive results are comparable with many previous studies undertaken outside of Australia. Despite more than 50 years of research, identification of the most effective FAS materials and structure designs for attracting sportfish still continues in the USA (Miranda 2017). The specific factors involved in each scenario play a significant role in what works best in a particular dam.

Material availability, structure durability, access to labour and heavy machinery, target species, desired management outcomes, competing water uses and funding can all play a significant role in determining what works best in an impoundment (Norris 2016, Miranda 2017).

The consensus in the USA seems to be that in the absence of other habitat, all fish habitat structures will attract fish, but the relative effectiveness will vary between structure types and fish species (Allen *et al.* 2014, Norris 2016). There is limited data directly comparing the effectiveness of most habitat structure types. Habitat structures are frequently installed in mixed arrays and surveys of the fish response are not at a fine enough scale to identify the contributions of each structure type. A study from North Carolina comparing fish attraction between three synthetic structures (half-barrels, Georgia cubes and Porcupine Balls™) and bundles of evergreen trees found that in the first two years there were no significant differences in the number of fish between the structure types (Baumann *et al.* 2016). However, the authors reported that in the third year all three artificial structures held more fish than the evergreen bundles, which had lost all of their needles and were nothing more than trunks and a few major branches. Of the synthetic structures, the Georgia cubes held the most fish during the third year. Similarly, a study comparing natural brush and synthetic structures in Florida reservoirs found plastic and brush structures concentrated similar numbers of fish, but largemouth bass were more frequently caught angling at the plastic attractors (Thompson 2015). The warm, productive water in Florida quickly broke down the natural brush, necessitating frequent refurbishing. The authors concluded synthetic fish attractors may be a long-term and useful tool for fisheries managers looking to supplement declining/degraded habitat in reservoirs and lakes where natural brush quickly decomposes.

Conversely, other research indicates that natural structure is more effective at attracting the fish species targeted by anglers. Mahnelia *et al.* (2008) compared the fish attracting ability of plastic pipe structures to juniper trees and observed ten times less fish in the plastic structures compared to the juniper trees. A short-term study by Rold *et al.* (1996) found brush fish attractors held more than four times as many sportfish than modular polypropylene fish attractors. The short duration of this study may not have accounted for degradation and the timeframe over which periphyton grows on synthetic structures. The effectiveness has been shown to vary between structure designs even amongst timber materials. Johnson and Lynch (1992) compared fish use of a range of timber habitat structures such as vertical and prone evergreen trees, a brush pile, and stake beds. Evergreens attracted more bluegill, but no differences were observed for white crappie use. However, anglers were most successful for both of these species when fishing at the evergreen trees. The authors concluded that evergreens were the cheapest and most effective structure to install, but stake beds should be avoided because they were expensive to build and yielded poor angler catches. This study did not look into the long-term durability and benefits of each structure type, which may have altered the results as the evergreens degraded.

The design of the suspended FAS used in Cressbrook Dam was relatively novel. The use of suspended structures as fish attractors has only received limited attention in the USA, with small structures typically only suspended beneath piers, wharves and boathouses (Norris 2016). One of the reasons the use of floating reefs and suspended structures has been limited, has been the perception that they pose a navigational hazard (Miranda 2017). In Cressbrook Dam the speed limit for vessels is restricted to 8 knots or less. Additionally, the top of the suspended FAS structure was submerged two metres below the surface and only a large float was present above the water. Together, these factors helped mitigate the risk to boat navigation to a level similar to that of any other marker buoy in the dam. The bottom of the suspended FAS was located at 5 m depth to correspond with the typical depth of the summer-time thermocline. This made the structure available to fish throughout the year, regardless of season or water level.

It was predicted that Australian Bass would display the strongest affinity for the suspended FAS given their semi-pelagic behaviour in impoundments (Smith *et al.* 2011a). They are often discovered in open water following schools of Bony Bream and are frequently targeted by anglers in this situation (pers. observ.). Acoustic telemetry found the mean proximity of Australian Bass to sites where suspended FAS were installed, decreased almost significantly (P = 0.06) after the FAS installation. At one of the open water sites, tight distribution hotspots for Australian Bass occurred around the structures during summer 2020, with radial movement hotspots connecting the fish to the nearby point. An increase in use of suspended FAS sites was also detected in the electrofishing surveys, but again it was not quite significant. The trends observed in these data sets suggest the suspended FAS may be a viable option for Australian Bass and could be a useful FAS design in impoundments with highly fluctuating water levels.

Golden Perch were also predicted to display a positive response to the introduction of the suspended FAS, but this was expected to be greatest at the suspended FAS placed in bays. Golden Perch typically have a high affinity for structure in impoundments (Smith *et al.* 2011a, Koster *et al.* 2020). Attraction of Golden Perch to the suspended FAS appears stronger than that for Australian Bass. A significant increase in the electrofishing catch rates at suspended FAS sites was detected following their installation. The acoustic telemetry revealed distribution hotspots around the deeper suspended FAS, but not as strong a response in the shallower bays. The Golden Perch may have been detecting the suspended FAS in the open water whilst transiting around the impoundment and utilised the structures as resting points before moving on. Alternatively, they may have been attracted to the suspended FAS by the prey species that were associated with the structures. The largest Golden Perch caught electrofishing came from a suspended FAS located off a deep point, and the telemetry data indicated consistent use of these FAS by this species.

The impacts of the materials used to construct fish habitat can also determine where they are suitable for use. For example, managers in reservoirs with hydro-electric power stations often do not allow installation of brush structures because of fears debris may block up the power station turbine intakes (Norris 2016). Similarly, in some reservoirs which are primary sources of potable water for towns, synthetic structures are only used because of concerns over the impacts of brush and timber degradation on water quality. Decomposing organic material can react with the chlorination process for drinking water, creating trihalomethanes (Feger and Spier 2010).

Potential concerns have also been raised over the potential accumulation of pollutants (e.g., organochlorine pesticides, polychlorinated biphenyls and polycyclic aromatic hydrocarbons) absorbed from the surrounding waters into some types of plastics (Zicchardi *et al.* 2016). If the plastics break down over time, these can become hazardous to fish (Tueten *et al.* 2009). Polyethylene is reported to accumulate more contaminants than polypropylene or PVC (Rochman *et al.* 2013), suggesting the latter two materials would be preferable for FAS construction. Much of the research into the risks associated with plastic breakdown and pollutant accumulation has been conducted in marine systems. There is limited information available on how the use of synthetic materials may impact freshwater ecosystems, and the likely scale of their impacts on fish is still largely unknown.

In Cressbrook Dam the FAS constructed from synthetic materials had greater interstitial spacing than the brush and timber structures. As was discussed in Chapter 3, interstitial spacing may influence use by fish. Finer interstitial spacing often attracts a greater size range of fish, but more open structures have been found to be better at attracting the larger sportfish targeted by anglers, although the response varies between fish species (Crook and Robertson 1999). Fine interstitial spacing is possible with both synthetic and natural materials. However, using fine spacing can make angling more difficult. If anglers lose more fishing tackle, they are less likely to enjoy their fishing experience and may not fish around those areas as frequently.

FAS material and design has a large impact on how often anglers get their fishing tackle stuck on structures and thus influences the effective ways to fish a FAS. In Cressbrook Dam, deliberate attention was paid to selecting and constructing relatively snag-less structures to enable the broadest range of fishing techniques to be applied. Brush bundles were by far the most vulnerable structure type for gear entanglement. This may lead to avoidance of fishing around these areas by some anglers. In the USA a number of techniques have evolved to help counter gear loss around brush or sunken trees. When fishing areas with fine complex habitat lures are often rigged in a weedless configuration. This can be achieved by using a flexible section extended over the hook tip or a wire frame to guide the hook around structure (e.g., spinner baits). The hook becomes exposed when a fish strikes at the lure. This approach enables lures to be fished in close proximity to structure, increasing the probability of hooking up whilst decreasing the chance of entanglement. In the synthetic FAS the diameter of the pipe used was greater than the gape size of hooks typically used when targeting Australian Bass and Golden Perch. The round profile and size of the pipe made it unlikely hooks would get stuck and enables anglers to safely fish right in amongst the structure.

The hardness of the materials used in FAS construction also plays a role in the frequency with which hooks get snagged. Harder materials like PVC are difficult for hooks to embed into and thus more snag resistant for anglers. Softer materials like the polyethylene used to create the limbs in the spiders, may be more readily penetrated by hooks and this structure type thus relies on limb flexibility and the pipe diameter for snag resistance. Similarly, the corrugated drainpipe used in the construction of the Georgia cubes is made of polyethylene and relies upon the large diameter to prevent hook penetration and snagging. The hardness of the materials used to make the brush bundles and timber cribs varied. The cribs were constructed from native hardwood which was quite dense and difficult for hooks to penetrate. However, the rough-cut surface and right angles could still trap hooks to some degree. Direct penetration of the hook into the timber was far less likely than if softer timber was used in construction.

A range of other approaches have been used to provide habitat for fish in impoundments to improve recreational fisheries. Rocky reefs and gravel beds have been used to help aggregate fish and also provide spawning habitat (Grove *et al.* 1991, Irwin *et al.* 1997, Creque *et al.* 2006, Houser 2007). Rock structures form natural fish habitat in rivers and impoundments and many fish species utilise the structural complexity and interstitial spaces they create (Allen *et al.* 2003). In impoundments, ongoing sedimentation is often a major issue and can blanket rock habitats making them unavailable to fish (Miranda 2017). Rock riprap is commonly applied to dam walls or areas requiring protection from erosion, creating substantial areas of complex habitat. Unfortunately, these rock walls often correspond to areas where anglers are not permitted to fish. However, rocky reefs can be purposely deployed for use as fish attractors. Construction of dedicated rock fishing jetties can provide twin benefits by increasing angler access and attracting fish to where anglers are located (Hernandez *et al.* 2001).

The installation of rock rubble can be logistically difficult and expensive since heavy machinery is required for transport and deployment (Allen *et al.* 2014, Miranda 2017). The most cost-effective approach is to install rock structures during dam construction or when water levels are low due to seasonal fluctuations or for dam wall maintenance. At low water levels trucks can drive right up to a site and either dump the rocks in a pile/line or for larger boulders have the rocks placed in position by an excavator. Rock reefs are the most durable form of fish habitat enhancement and once in position should provide long-term benefits (Jones *et al.* 2015). A number of studies have demonstrated the effectiveness of rock reefs at attracting fish in impoundments and lakes. Rock reefs have been used since 1980 in the Great Lakes of the USA to attract fish closer to harbours and improve recreational angling (McLean *et al.* 2014). The results of Kelch *et al.* (1999) and Creque *et al.* (2006) demonstrated that sportfish were attracted to installed rock reefs within the Great Lakes. Both studies reported fish began using installed rock reefs quickly (within 6 months) and the abundance of sportfish increased significantly. Mitzner (1984) found the catch rate of sportfish was approximately three-times higher at installed rock ridges when compared to bare control sites. However, not all studies have found rock to reliably attract sportfish. In Table Rock Lake (Missouri), installed rock reefs only intermittently held legal sized black bass species, whilst timber structures more consistently attracted these fish and at greater numbers (Allen *et al.* 2014a).

Concrete has been used as a substitute for rock in creating artificial reefs (McLean *et al.* 2014). Use of concrete has often been opportunistic with building rubble historically used to increase fish habitat (Miranda 2017). In recent times the trend has shifted towards using designed concrete reef modules rather than concrete rubble. The modules provide greater vertical relief and have been widely used in the marine environment (Seaman and Sprague 1991). Concrete modules provide the ability to tailor structural habitat for specific species to achieve the best results. A number of fish attraction projects have installed concrete habitat modules into lakes and reservoirs in the USA, but the results from their installation are yet to be reported.

One of great advantages of rock and concrete is that they are extremely durable. They can be used in impoundments with highly fluctuating water levels because exposure to air will not hasten degradation like it does in timber structures. Linear reefs constructed from rock or concrete extending out from the shoreline have been used to create structures to attract fish across a range of water levels (Allen *et al.* 2014, Norris 2016). This design allows anglers to target fish by casting along the rocks. Allen *et al.* (2014) did note that the use of smaller rocks led to increased abundance of prey species and juvenile sportfish, but few large fish. The authors suggested larger rocks are required to attract larger fish for anglers. The use of this style of structure could provide long-term fish attraction in Australian impoundments which experience drastic water level fluctuations. The initial installation cost would be high, but they would provide extremely durable FAS with no impacts on water quality and their use warrants further investigation. An additional benefit may be the provision of refuge for stocked fish from predators such as cormorants. Lintermans *et al.* (2008) reported avoidance of cormorants by fish was better in complex rock structures than structures made from PVC pipes.

Management of aquatic vegetation has also been used to develop habitat to attract fish. Re-establishment of aquatic vegetation is generally only possible in impoundments with relatively stable water levels. In USA reservoirs where sufficient vegetation has been re-established, significant increases in angler catch rates for sportfish have been observed (Norman and Ott 2014, Webb *et al.* 2014). Other projects have failed to detect any significant increase in catch rates for anglers (Hoyer and Canfield 1996). However, the rehabilitation of aquatic vegetation also provides a broad range of other ecosystem benefits and therefore is always likely to be beneficial (Ratcliff *et al.* 2009).

The optimal depths to place FAS remains unclear and becomes even more difficult where water levels fluctuate significantly. At Cressbrook Dam the electrofishing data suggested catch rates were higher in shallower FAS, whilst the acoustic telemetry suggested deeper structures were utilised more readily. These results were both influenced by equipment efficiencies and suggests structures set at all depths are likely to be used by Australian Bass and Golden Perch. If structures are placed too deep and below the thermocline, they might not be utilised by fish in the warmer months (Prince *et al.* 1985, Smith *et al.* 2011a, Harris 2013, Miranda 2017). Australian Bass forage in deeper epibenthic regions during cooler months when impoundments are less stratified and when they form spawning run aggregations (Smith *et al.* 2011a). This foraging and aggregation behaviour is targeted by anglers who detect fish on the sounder. The presence of deep-water FAS may help dictate where these activities occur and assist anglers locate fish. Some of the FAS deployed on the bottom at deep open water sites frequently attracted fish, including Australian Bass. These sites were quite popular with anglers and regularly targeted. A similar result has been observed in Lake Samsonvale (Brisbane) where deeper water FAS have also proven effective at attracting Australian Bass (Noel Frost, pers. comm.). The majority of Golden Perch captured during the current study were taken from shallower water. However, the acoustic telemetry shows this species to move widely around the dam, and frequently utilize deeper areas. Several distribution hotspots were located around FAS in deeper areas or near steep drop-offs. Once all of the FAS had been installed, the acoustic telemetry results for Golden Perch using FAS in deeper waters was more pronounced than that for Australian Bass. It therefore seems FAS set on the substrate in deeper water could be quite effective at attracting stocked impoundment fish, but further investigation into the optimal depths for installation is required.

Dealing with water level fluctuations

One of the key concerns for fisheries managers regarding the use of FAS in Australian impoundments was how they could be effectively used where water levels fluctuated substantially. This was identified as one of the top five priorities for research in Australia in a survey of researchers, managers and other stakeholders (Norris 2016). Many Australian impoundments periodically release large amounts of water for irrigation which can lead to significant fluctuations in water levels. Other impoundments only experience intermittent filling events, and experience declining water levels in between (e.g., Cressbrook Dam). Two main concerns were raised with respect to varying water levels: 1) FAS degradation due to exposure to air and the wetting and drying cycle; and 2) risks to navigation. It should be possible to overcome these potential problems through the appropriate selection of FAS materials, types and deployment sites. This would enable FAS to be more widely used in Australia.

If habitats are placed in waters deep enough to prevent being exposed even during the most extreme drawdown, they may end up in anoxic waters during stratification in warmer months. As mentioned above, the use of reef lines extending from the shoreline into deeper water can provide habitat to attract fish across a range of water levels. Materials used to construct such reefs need to be durable to exposure. Rock and concrete are the most durable, but the ease and cost of installation may prove prohibitive in some scenarios. FAS constructed from hardwood timber or UV resistant PVC could also be used where exposure is expected. These materials will tolerate repeated exposure, but their functional lifespan may be decreased. The type of FAS used would also need to be robust. Broad based FAS structures, such as timber or thick-walled PVC cribs, would be more suitable than synthetic tree or Georgia cube designs. The risk to navigation could be reduced by labelling the shoreward extent of the FAS with a sign and the open water end with a mooring buoy. This would provide waterway users with a visual reference of where the FAS is. If the reef line is very long, intermediate buoys may be required. Identifying the extent of the reef with signs and buoys has the added benefit of informing anglers exactly where the structures are so they know where to cast.

An alternative approach in impoundments with heavily fluctuating water levels is to suspend the FAS from the surface. This has the advantage of ensuring the structure is maintained a set distance below the surface and always above the thermocline. This should ensure year-round access regardless of dam stratification. In the current study a relatively open suspended FAS was designed to minimise drag during inflow events. This design appears to have been effective at attracting fish, but further research is required into the optimal designs for suspension. Incorporation of greater levels of shade may make these structures more attractive, as long as drag can be kept below the level whereby the structures may shift. Placing suspended structures at least a metre or more below the surface reduces the risk of collision. This is particularly important in multi-use dams with water skiers, wake boarders and tube riders.

Influence of FAS configuration size and shape

The deployment configuration and size of the area covered by FAS impact how well fish are attracted to an area. In general, the average number of individuals and species attracted increases with the structural complexity achieved by increasing the volume, size, and surface area of habitat enhancement structures (Graham 1992, Wills *et al.* 2004). Lynch and Johnson (1989) suggested that larger structures may have the greatest potential to support fish and increase angler catch rates. Similarly, Rountree (1989) reported that the average number of individuals attracted to a structure increased with structure size. Lynch and Johnson (1988a) found angler catch rates of bluegills at grouped offshore woody structure sites were over four times greater than catch rates at isolated woody debris sites. Some habitats may support fewer, larger predatory fish, while others may support more numerous, smaller individuals. Daugherty *et al.* (2014) reported largemouth bass exhibited greater occupancy frequencies in larger habitat structures, but their abundance was higher in smaller structures. The authors observed that at large structures often only a solitary above-average sized bass was present. In Lake Erie, twelve 1-2 m high rock piles had negligible impact on fish populations, but when additional larger reefs approximately 250 m long and 2-4 m tall were created, a wide variety of fish species and more anglers were attracted (Kelch *et al.* 1999). The additional structure resulted in 20-50 times more fish at the reef than at control sites.

In Cressbrook Dam the size of each cluster of FAS was kept relatively consistent. Most clusters contained between three and eight FAS, with more FAS installed when smaller structures, like spiders, were used. The suspended FAS were only set singularly because of their comparatively large volume (approx. 21 m^3). The number of clusters at each monitoring site varied with the site's size. Longer and broader bays typically received a greater number of FAS clusters and thus the total area covered by FAS at those sites was greater. The open water sites all received only three FAS clusters each and thus comparison between them should not be biased by total FAS size. It was not possible to draw any clear conclusions about how fish catch rates varied with the number of FAS installed at a site. The influence of different geomorphologies could not be separated from the effect of different FAS numbers. The relationship between the scale of the FAS deployment at a site and how attractive it is to fish is an important management consideration. Further research into the factors affecting the size and abundance of fish attracted to FAS is required to determine the most cost-effective amount of structural habitat to be deployed for different species and different management outcomes.

The pattern of FAS deployment in relation to other FAS and natural structural complexity may also influence the number and size of fish attracted to a site. Previous studies from the USA have observed the number of fish attracted to a site is often higher when FAS are clustered rather than placed in isolation (Lynch and Johnson 1988a, Hummel 2018). For this reason, FAS were always deployed in clusters within Cressbrook Dam, but a variety of configurations were used. FAS were deployed 2 m apart, except for spiders which were grouped closer together. In deeper sites, FAS were configured in groups with an open centre in the middle. In sites closer to the shoreline, FAS were often deployed in a cross pattern or a linear arrangement extending from the shore towards deep water. These more linear configurations were used to enable both shore and boat-based anglers to cast alongside the structures and keep their bait or lure near habitat for longer. No observations were made of the relative effectiveness of the different configurations but the topic warrants further investigation.

The number of fish attracted also can vary between FAS configurations with different degrees of openness. Lynch and Johnson (1988b) reported adult crappies (*Pomoxis spp*.) and largemouth bass to be more abundant at grouped structure sites implemented in rows compared to bundles, and suggested these sites provided continuous habitat used for better orientation and cover. Daugherty *et al.* (2014) reported FAS deployed in a circular pattern to minimise the amount of edge and maximise the amount of interior cover attracted the most bluegill, but the size was smaller than those attracted to a linear design. Bryant (1992) found discrete open-centred structures attracted more smallmouth and largemouth bass than structures placed in a dense-linear, or continuous open-centred arrangements. However, the larger fish preferred the more open configurations. The results from these studies suggest FAS configuration has the potential for fisheries managers to influence the number and size of fish attracted to a site. At sites established to improve family fisheries, FAS deployment configurations utilising discrete open centres (circular or square) could be used to attract more, but smaller fish, whilst more linear configurations could be employed to attract fewer but larger individuals for trophy sites.

Cost effectiveness

The relative cost-effectiveness of a FAS is influenced by multiple factors, including how well they work, construction cost, deployment cost and durability. Unfortunately, there is limited information on the costs associated with construction and deployment available from previous studies which have compared the effectiveness of different FAS types. The cost for materials to construct individual FAS have ranged from $6.90 through to $450 (Table 13). Where these figures have been reported, they are not always directly comparable because materials were donated, the size of structures varied, costs change through time, and the machinery and vessels available for deployment differed. Construction and deployment labour costs also vary depending upon the relative contributions from volunteers, contractors and fisheries agency staff.

Table 13 A summary of the cost of materials for constructing different FAS types in the current study, previous fisheries agency projects in the USA and the price of commercially available fish attractor kits as of June 2021. All cost have been converted to Australian dollars. [1] Baumann et al. 2016, [2] Allen et al. 2014, [3] Feger and Spier 2010. Commercial fish attractors: [5] Porcupine Fish Attractor, [6] Pond King, [7] Mossback, [8] Fish hiding, [9] American fish-tree, [10] Reef ball.

FAS design	Current study	Fisheries agencies	Commercially available
Brush bundles/tree tops	$6.90	$13.60[1]-68.00[2]	
Timber cribs	$132.75		
Spiders	$13.45		$54.40-257.04[6]
Synthetic trees	$70.32		$176.80-480.00[6,7,8,9]
Georgia cubes	$114.98	$94.52	
Suspended FAS	$317.71		
Half-barrel cube		$246.84	
Reef balls			$136.00-612.00[10]
Synthetic horizontal fence			$30.60[3]-224.40[4]
Porcupine balls			$59.81-81.60[5]
Synthetic stumps and shrubs			$81.60-272.00[7,9]

The most inexpensive FAS to construct have generally been those made from recycled pine trees, freshly felled tree tops and brush bundles. These materials are often available locally, minimising transport, and merely require anchor weights to be attached. The materials for some of the PVC fish attractors can also be quite cheap, but the labour involved in construction and assembly is usually higher and increases with structural complexity. A variety of fish attractors are also produced commercially which are typically more expensive to purchase. However, they are designed for easy assembly and installation with minimal tools, and have become commonly used in some USA reservoirs and lakes.

Deployment costs vary significantly amongst different FAS types. In larger projects, FAS are deployed from specially designed habitat barges (Allen *et al.* 2014, Miranda 2017). The cost of these vessels and the vehicles to tow them, has rarely been reported or incorporated into deployment costs. Allen *et al.* (2014) reported installation costs for five types of FAS varied from $216 to $1677.50 (USD). These costs did not include transportation of materials to the deployment staging area. Baumann *et al.* (2016) reported relatively low construction labour costs for four different FAS types ($8.75-52.50 USD), but reported fixed deployment costs of $170 (USD per 3.5 m^3) since all of the structures were of a similar size and ease of handling. In Cressbrook Dam a landing pontoon was used as a barge to ferry FAS out for deployment, substantially improving installation efficiency and safety. The efficiency gained in utilising large barges can outweigh the additional cost of their hire, and should be considered in projects where large numbers of FAS are to be deployed.

Durability plays a significant role in determining the cost-effectiveness of different FAS types. Brush bundles, evergreens and tree tops have been found to degrade within 3-9 years (depending upon the timber) to a point where they require supplementation or replacement to remain functional. Baumann *et al.* (2016) noticed a significant decline in the fish attraction of evergreen tree bundles by the third year of their study, whilst no decline was observed in the attraction levels of the synthetic structures. The authors concluded fish attractors constructed from synthetic materials were much better at attracting and holding fish over a long period of time than structures made of natural materials and did not need replenishment. A similar trend was observed in a warm water reservoir in Florida where natural brush structures quickly broke down and lost their ability to attract fish (Thompson *et al.* 2015). The authors also concluded synthetic fish attractors may be a long-term and useful tool for fisheries managers looking to supplement declining/degraded habitat in reservoirs and lakes where natural brush quickly degraded. In cooler water impoundments, degradation of brush materials is slower and their long-term value for use as fish attractors is greater (Bolding *et al.* 2004). FAS constructed from large timber posts, stumps and trees cost more, but last longer. Mabbott (1991) noted that evergreen trees had a lifespan of 4 to 7 years in Idaho reservoirs, whereas stumps lasted 20 to 25 years. The porcupine cribs constructed from 50 mm x 50 mm rough-cut hemlock or poplar commonly used in the northern USA reservoirs are reportedly expected to last more than 25 years if they remain submerged (Jones *et al.* 2015).

FAS constructed from synthetic materials are typically reported to be highly durable and provide long-term benefits (10-50 years, Bolding *et al.* 2004, Jones *et al.* 2015, Thompson *et al.* 2015, Baumann *et al.* 2016). Combined with their low to intermediate construction cost, they provide long term value if they effectively attract fish. FAS made with concrete and rock have higher installation costs than other material types but are extremely durable and hence may provide long-term value.

In Cressbrook Dam, all FAS groups attracted fish and no clear preferences for a specific material type were detected. Further research is required to better understand the relative attractiveness of FAS made from different materials, but the results suggest that synthetic FAS are likely to be the most cost-effective material to use for FAS in the long term due to their durability and ease of deployment. The suspended FAS were more expensive than FAS situated on the bottom substrate, but they occupied a unique underutilised zone in the dam and their ability to provide habitat accessible to fish year-round is expected to provide ongoing value.

Additional fisheries management applications for FAS

The goals of structural habitat enhancement often include the provision of cover to collectively increase fish recruitment, survival, and growth and to concentrate fish to improve angler catch rates. There has been much debate regarding whether the installation of habitat enhancement structures actually increases fisheries productivity or just aggregates fish. Australian impoundment fisheries are primarily put-take fisheries because many of the fish species targeted by anglers do not breed successfully in dams. Therefore, the focus of the current study was to investigate how effective FAS were at attracting fish. The FAS selected for the investigation were chosen based on their potential ability to attract fish rather than for the potential broader ecosystem services that FAS could provide.

Installation of suitable habitats has been shown to be successful at improving angling by concentrating fish. This strategy is most effective for primarily catch-and-release species (e.g., Australian Bass) where there is limited harvest and additional angling pressure is unlikely to have a large impact on the fishery. However, if the target species are desirable for consumption and the population experiences increased harvest pressure, more caution needs to be exercised to avoid population decline. In put-take fisheries it may be possible to address this issue by increasing stocking rates.

There is also potential for FAS to help increase survivorship of fingerlings stocked into impoundments devoid of structural habitat. Predation is the large source of mortality in stocked fingerlings

(Buckmeier *et al.* 2005). The provision of suitable complex habitat structure can assist juvenile fish to evade predation (Bohnsack 1989, Conrow *et al.* 1990, Freitas and Petrere 1991). Evidence from the USA has clearly demonstrated that installation of artificial habitats has increased juvenile survival and growth in black bass species, sunfish and crappies (Miranda and Pugh 1997, Klecka and Boukal 2014). Investigation into the most effective habitat types to install to improve survival of stocked Australian species is needed. These structures may also provide a secondary benefit by functioning as FAS and attracting larger fish to the sites for anglers.

Applicability of FAS to other Australian species

The results from the present study suggest FAS could be effective for a broad range of Australian fish species targeted by anglers in impoundments. Australian Bass and Golden Perch are typical examples of the native fish species stocked into impoundments for angling. These species display a preference for complex habitat but still range widely around an impoundment. Many other stocked Australian fish species also show a high affinity for structural habitat and are expected to respond well to FAS installation. Species such as Estuary Perch (*Macquaria colonorum*), Murray Cod (*Maccullochella peelii*), Mary River Cod (*Maccullochella mariensis*), Trout Cod (*Maccullochella macquariensis*), Silver Perch (*Bidyanus bidyanus*), Saratoga (*Scleropages leichardti*), Barramundi (*Lates calcarifer*), Sooty Grunter (*Hephaestus fuliginosus*), Mangrove Jack (*Lutjanus argentimaculatus*) and Sleepy Cod (*Oxyeleotris lineolatus*) are all likely to be attracted to FAS for either the structural complexity or the food resources that accumulate on and around them. The findings of Norris (2016) generated interest amongst fishing groups and managers about how FAS could be used in Queensland. This resulted in establishment of a small number of pilot studies looking at the effectiveness of FAS on a range of fish species and these are summarized below. Despite less rigorous monitoring, the results from these studies support the findings of the current study and validate the potential applicability of using FAS for other stocked species.

Kinchant Dam (Mackay) had little in the way of structural habitat apart from the marginal vegetation and dam infrastructure in areas closed to anglers. There was little structure to aggregate fish, making them difficult for anglers to locate, and fishing was reported to be difficult at times, despite the presence of good numbers of large fish (Norris *et al.* 2020). As part of a collaborative project to improve the angling, a total of 197 FAS were installed at 36 sites around the impoundment. The FAS were all constructed from synthetic materials, with a mixture of designs deployed at each site to maximise habitat complexity and diversity. Survey catch rates for Barramundi were estimated to increase by approximately 2.6 times at sites where FAS were installed (Norris *et al.* 2020). The installation of FAS thus created new fishing hotspots and broadened the potential fishing techniques that could be used to target Barramundi in the impoundment.

A pilot study has also been undertaken in Lake Samsonvale (Brisbane) trialling the use of FAS to primarily concentrate fish in the permitted boating zone and improve angler catch rates. The local fish stocking group led the project and Noel Frost (President, Pine Rivers Fish Management Association (PRFMA)) was interviewed in May 2021 about the project results so far. Baseline surveys were used to develop a detailed habitat enhancement plan. A total of 259 FAS were installed at six sites in the permitted boating zone of the impoundment. Brush and timber were not allowed to be deployed due to concerns for water quality, so the FAS comprised of 124 x 2 m high synthetic trees, 78 x 1 m high synthetic trees and 57 spiders. Most of the material to build the FAS was donated and construction was undertaken entirely by volunteers, keeping project costs down. The FAS have proven to be reasonably durable in the 15-20 months since installation. A few tree limbs have been lost and several synthetic trees have fallen over. Underwater footage showed algae and periphyton growth to begin developing withing weeks and now most structures have a thick coating. The FAS have been very reliable places for anglers to catch fish and anglers using them reported increased catch consistency. Approximately 50% of their total catch now comes from around the structures. Not all anglers are willing to target fish around the structures, but the numbers are improving, especially as the quantity of positive social media reports increases. The FAS have been effective at attracting Australian Bass and Freshwater Catfish, but the best response has been from Golden Perch. The Australian Bass are often caught in the vicinity of the FAS, but not always directly on top. Conversely, Golden Perch are typically captured from right in amongst the structures. On-going monitoring is continuing through a catch-card system to investigate the long-term effectiveness of FAS installation and how angler behaviour changes over time.

A third pilot study commenced at Mt Morgan Dam (Rockhampton), but has been interrupted by extremely low water levels in the dam. The initial results from this project indicate Sleepy Cod have been attracted to synthetic FAS. However, the abundance of other recreational target species in the dam is extremely low and a positive benefit from FAS installation is unlikely until future stocking occurs. Large numbers of Gudgeon and Olive Perchlet have been observed aggregating around installed brush bundles, suggesting FAS may help aggregate prey species.

A larger-scale trial is occurring at Leslie Dam near Warwick. The impoundment is a popular angling spot and well stocked with Murray Cod, Golden Perch and Silver Perch. However, the Murray Cod fishery was underperforming. High-quality rock habitat existed in the impoundment towards the dam wall, but much of this was located in a no access zone. Limited structural habitat was present in the rest of the dam due to clear felling prior to flooding and degradation as the dam aged. An extended period of poor rainfall resulted in extremely low water levels. The Warwick and District Fish Stocking Association (WDFSA) saw the low water levels as an opportunity to improve structural complexity in the dam to increase the Murray Cod carrying capacity and potentially encourage natural recruitment.

Concrete pipe, culverts and railway sleepers, together with a large amount of rock, were installed at 346 sites in the section of the dam upstream of the wall. Timber structures were not permitted to be used due to concerns over water quality. Structures were installed at different levels to ensure fish had access to habitat from 5% to 70% water levels and located in a go-slow zone to minimise potential navigational issues. Initial results from anglers and sonar suggest fish are utilising the structures and social media content on Murray Cod captures has increased. No formal monitoring or assessment has occurred yet.

Conclusion

This project was one of the first to comprehensively examine the potential of using fish attracting structures (FAS) to improve recreational fishing in Australian impoundments. Baseline surveys and stakeholder engagement were used to develop a fish attraction plan for Cressbrook Dam. A total of 576 FAS were installed across 25 sites between February 2019 and January 2020. This was comprised of 182 synthetic spiders, 142 synthetic trees, 130 brush bundles, 44 Georgia cubes, 39 timber cribs, 26 suspended FAS and 13 branch bundles. The FAS were constructed in conjunction with volunteers from the Toowoomba and District Fish Stocking Association and the general community. Set monitoring sites were established in the impoundment to enable comparison of fish attraction and angling catch between three broad groups of FAS: timber, synthetic, and suspended synthetic FAS. A multi-faceted monitoring program was undertaken to overcome the reported difficulties of assessing the response of fish to FAS at the impoundment scale. Surveys of fish distributions and FAS use were complemented by angler creel surveys, investigating changes in catch rates, project knowledge and attitudes towards FAS, as the structures were installed.

The results of this study indicated a range of native Australian fish species responded positively to the installation of FAS. The primary species targeted by anglers in Cressbrook Dam (Golden Perch and Australian Bass) were both observed to use the installed habitat structures. Smaller prey species were also commonly detected around the FAS, but the pre to post-installation trends were less clear due to significant increases in abundance occurring across the entire impoundment.

The monitoring indicated the abundance of Australian Bass and Golden Perch increased around all FAS types following their installation. The observed trends varied between monitoring techniques. Electrofishing surveys detected the greatest increase at sites where timber FAS were installed, but positive trends were also observed around the synthetic and suspended FAS. In contrast, the acoustic tracking data indicated little use of timber structures, but this was confounded by a number of technical factors which limited our ability to effectively track fish within bays where most of the timber FAS were located. The acoustic telemetry data found the mean seasonal proximity of Australian Bass to the synthetic, suspended and mixed FAS sites all decreased following installation, but the response was statistically insignificant. The mean seasonal proximity of Golden Perch did not change with FAS installation. However, the kernel density analysis of detected fish positions clearly indicated localised hotspots for both species around most FAS types and identified consistent use of deep water FAS by both species.

All FAS types retained their structural integrity for the duration of the study, with no degradation evident. Unfortunately, the period of monitoring was insufficient to assess long term durability, but all FAS types tested appear suitable for use in other impoundments. Visual surveys using underwater cameras and an underwater drone provided limited quantitative data due to limited water clarity, but they did provide further evidence of sportfish use of FAS and also showed aggregations of small prey species around some FAS. Sonar surveys provided adequate detail on FAS condition and produced some information on the abundance of prey species and sportfish around the FAS.

Targeted angling surveys suggested that catch rates were moving in a positive direction, but the results were limited by very low catch rates and generally not statistically significant. Catch rates increased at synthetic and timber FAS sites whilst decreases were observed at the Control sites.

Angler creel surveys demonstrated an overall trend of improving angler attitudes, along with increases in fish capture rates following the installation of FAS. This provides evidence that installation of FAS has improved the attractiveness of the fishery in Cressbrook Dam. Further extension work is required to maximise the use and benefits to anglers from the installed FAS.

The results from all aspects of this study support the use of fish attracting structures in Australian impoundments and also corroborate the findings of other pilot studies recently undertaken in

Queensland. The similarities in habitat use between many of the species stocked into Australian impoundments for fishing suggest the technique is likely to have broad applicability. Significant knowledge gaps remain regarding the optimal types and quantities of FAS, deployment depths, configurations and locations, but the concept for FAS use appears sound and likely to be a valid fisheries management tool. To improve knowledge and optimise FAS use, it is recommended that future projects incorporate comprehensive monitoring programs to investigate specific questions or knowledge gaps regarding the use of FAS impoundments.

Implications

Currently, management in Australia focusses on stocking and harvest control (through size and bag limits) to regulate impoundment fisheries. The results from our study indicate that installing fish attracting structures into impoundments may provide an additional tool for fisheries managers to improve the recreational fishing opportunities and the value of these fisheries to local communities.

Fish attractors can entice fish to particular areas making them easier for anglers to locate. This can help increase angler catch and trip success rates, which is likely to encourage greater participation and angler effort. A potential concern raised by some fisheries managers has been that fish attractors may increase angler harvest to unsustainable levels. However, unlike most wild fisheries, impoundment fisheries are typically highly regulated and artificial systems. Fisheries in the majority of impoundments rely upon annual stocking because native fish do not spawn or spawn poorly in impoundments. Recruitment is controlled by the number of fingerlings stocked and they are purposely designed to be put-grow-take systems. Additionally, there has been an increasing trend for anglers to practice catch and release fishing techniques. This reduces harvest pressure on impoundment fish stocks. The risk of overharvest in impoundment fish populations through increased angler catch rates is therefore very low and manageable.

Fish attracting structures also hold the potential to help manage where anglers fish and improve angler access to fisheries resources. Some of the best habitat for fish can be found around dam walls and offtake infrastructure. Unfortunately, these areas are often closed to angler access. FAS could be used to provide additional areas of high fish habitat complexity away from the closed zones. Attracting fish to such sites may reduce the incidence of anglers illegally fishing in closed zones. FAS could also be used to attract fish closer to boat ramps or launch sites. This would help encourage anglers to fish closer to where they launch and potentially reduce the impacts of boat wash erosion and pollution from outboards. The same principle has application for shore angling. Shore-based anglers are often restricted in the places where they can fish, and these sites do not always coincide with prime fish habitat areas. Installing FAS to attract fish to areas where shore angling is allowed could deliver better fishing and encourage anglers to remain within the permitted zones. Mobility limited anglers could especially benefit from this approach if FAS were installed adjacent to parking areas with easy shoreline access.

The use of FAS in impoundments should be broadly applicable to many impoundments across Australia. Like Cressbrook Dam, many impoundments suffer from having limited structural habitat complexity, although the scale of the problem varies greatly. Additionally, many stocked fish species show a high affinity for structural habitat or cover and are expected to respond well to FAS installation. Species such as Estuary Perch, Murray Cod, Mary River Cod, Trout Cod, Silver Perch, Saratoga, Barramundi, Sooty Grunter, Mangrove Jack and Sleepy Cod are all likely to be attracted to FAS for either the structural complexity or the food resources that accumulate on and around them.

The FAS types examined in this study were chosen because they were modular, relatively light-weight, easy to construct and easy to deploy. These criteria were selected because for broad uptake of FAS to occur, construction and installation costs need to be kept low. This ensures FAS could be suitable for construction and installation by community groups, such as fishing and stocking clubs. The associated best practice guidelines produced as part of this project provide a blueprint for these groups on how to plan and undertake FAS projects, including the necessary permits and technical oversight that is required.

With so many potential designs, FAS can be created or selected to address particular scenarios or target particular fish species. Further research into species-specific FAS designs and deployment configurations could enable fisheries managers to tailor fish attraction plans to each impoundment to achieve specific management objectives.

Recommendations and further development

Recommendations

Much of the knowledge on the outcomes of using fish attractors in impoundments comes from overseas. Research is needed to verify that the same principles will deliver similar results for Australian species and conditions. This study has demonstrated that a number of FAS types will work for Australian fish. Further investigation is required to optimize the use and cost-efficiency of FAS efforts in impoundments, but with the knowledge gained to date, significant improvements in angling and fish production can be generated if the method is properly undertaken.

Data is still limited when conducting cost-benefit analyses. Additional detailed costing data is needed for the construction and deployment of different FAS types. Information on the scale-dependent response of FAS installation is also necessary to evaluate their full impact. It is recommended that an economic assessment of the impoundment fishery's value be conducted prior to the commencement of any on-ground works and repeated after the habitat enhancement activities have been completed. The follow-up assessment should be conducted several years after FAS installation to allow an appropriate time for the full biological and social responses to occur. The information from these assessments will provide valuable data on the economic changes to the fishery's value brought about by the FAS and permit estimation of the project cost recovery time. This will enable cost-benefit analyses to accurately identify the most cost-efficient strategies for improving the fishery.

The use of non-polluting hard plastic and rock structures is recommended where there are concerns on the impact on water quality from the introduction of fish habitat structures. These materials will not degrade and introduce additional nutrients and fine debris into the water. These materials can be most cost-effectively installed during periods of low water levels. At such times the materials can be deployed directly from machinery without the need for specialised vessels. It is recommended that such opportunities are sought out during drought periods when fish may not be stocked or when water levels are lowered for dam infrastructure maintenance. The ideal scenario is to install FAS prior to the dam filling, and it is recommended that this approach be encouraged as part of any new dam construction process.

It is recommended that specialist equipment and heavy machinery be used during larger FAS projects to increase transport and deployment efficiency. In particular, it is recommended that specialized habitat barges be used to transport and deploy FAS. These vessels allow greater numbers and sizes of structures to be deployed more safely and efficiently. It is recommended that the barges remain of trailerable size to enable their use in multiple projects and at multiple sites.

It appears that FAS constructed from both timber and synthetic materials may be effective for Australian fish species. In town water supplies timber and brush may not be permitted for use due to concerns over potential water quality issues. Synthetic materials and rock should be used in these scenarios. It is recommended that discussions with the impoundment operator be undertaken early in the project planning process to define the scope of FAS types suitable for the waterbody.

All habitat enhancement activities need to be based upon the target species' behaviour and habitat requirements. However, most types of FAS structures will attract fish. Where possible, it is recommended that projects make opportunistic use of materials to decrease construction costs, particularly if funding is limited. Recycled or clean waste materials should be used where suitable to keep minimize project costs.

Prior to the commencement of any impoundment fishery improvement project the current status of the fishery and habitat availability must be assessed. This baseline assessment will identify key impediments and deficiencies that need to be addressed in order for the fishery to be improved. The information collected will enable specific and targeted project objectives to be developed and form baseline data against which project progress and success can be measured.

It is recommended that all FAS projects implement a monitoring program to evaluate the effectiveness of their installation for both fish and anglers. The information collected can be used to adaptively manage the project to achieve the best return on investment and help address the knowledge gaps in this field. New information can be used to update the FAS use guidelines and ensure best practice is being employed.

Further development

This project was the first thorough examination of the use of fish attracting structures in Australian impoundments. The objectives of the research were therefore relatively rudimentary: 1) to understand if FAS work for Australian fish; and 2) to compare the effectiveness of three broad groups of FAS types. The project results have confirmed the potential of FAS to attract fish in Australian impoundments, but less clarity was achieved regarding the relative cost-effectiveness of different FAS types.

The project provided the justification for using FAS in Australia, but further research is needed to understand where and how they can be most cost-effectively applied. We recommend further research to address the following key questions:

- How do other key recreational fish species respond to FAS in impoundments?
- What are the optimal FAS deployment densities, patterns and materials and how does this vary between structure types?
- What are the most effective depths to deploy FAS for different species?
- What is the optimal quantity of FAS to install and how does fish attraction vary with scale?
- Can FAS be effective in impoundments with significant levels of existing structural complexity?
- What is the potential for increasing stocked fingerling survival using reefs or other structurally complex habitat at release points?
- How does medium to long-term durability differ between FAS constructed from different materials and using different designs?
- At what scale are FAS capable of increasing impoundment productivity and/or carrying capacity?
- Can some FAS improve recruitment in native fish species which breed in impoundments?
- Are microplastics an issue from the use of synthetic FAS?

Extension and Adoption

Extension

A key component of the project has been engagement of local stakeholders and extension to increase awareness. As part of project development, meetings were held with the two major water providers (Seqwater and Sunwater) in Queensland who managed many of the stocked impoundments to assess their attitudes towards the use of fish attractors in their dams. Favourable consideration on the use of fish attractors in dams they manage has been given, including permission to develop fish attractor trials at several impoundments.

A project steering committee was established to guide project development and extend progress and results to stakeholders. The committee consisted of representatives from key stakeholders, including Fisheries Queensland, Seqwater, Toowoomba Regional Council, Toowoomba and District Fish Stocking Association and Gary Fitzgerald (Somerset and Wivenhoe Fish Stocking Association). The steering committee met four times during the course of the project.

Presentations on the potential opportunities and benefits of using fish attraction structures in impoundments were given to:

- Toowoomba Regional Council
- Brisbane Valley Anglers
- Somerset and Wivenhoe Fish Stocking Association
- Pine Rivers Fish Management Association
- Mackay Area Fish Stocking Association
- Mackay Regional Council
- Rockhampton Regional Council
- Victorian Fisheries Authority, VRFish, stocking groups and anglers at Codfest 2017
- State-wide fish stocking groups at the state-wide fish-stocking workshop, Warwick, 4th November 2018. The presentation at this workshop also outlined the Cressbrook Dam FAS project.

A presentation was also made at the Reservoir Fisheries Habitat Partnership conference held in Kansas City, Missouri, USA. Conference participants were extremely interested in progress in this field in Australia and provided invaluable insight and recommendations. Whilst at the conference a nearby manufacturer producing commercially available fish attractors was visited and discussions had about the suitability of their product for Australian conditions and the Australian market.

Six fish habitat construction working bees have been held since the program's inception (15th September 2018, 1st December 2018, 2nd March 2019, 22nd June 2019, 12th October 2019 and 9th November 2019). At FAS construction working bees, community members learned how to construct the different types of FAS and the reasons why they might be suitable in Australian impoundments. Working bees were also taken as an opportunity to share results of the project to date, including photographs of fish captured from FAS, sonar images of fish around FAS clusters, maps of deployment locations and tables of deployment coordinates.

Anglers fishing Cressbrook Dam were also provided with information about the project after being interviewed for the project's creel survey.

Information boards about acoustically tagged fish were erected at the Cressbrook Dam boat ramp and campground, in various tackle shops in Toowoomba and in the local supermarket in Crows Nest.

To raise awareness in the broader community, four media releases about the project were prepared and released to fishing magazines, newspapers and other media. A podcast (Fish attractors: Dams of dreams) was produced about FAS in Queensland Dams. The podcast is available on the DAF Surf'n'turf podcast site https://www.daf.qld.gov.au/news-media/podcasts/Fishattractors. Additionally, an article on fish attracting structure research in Queensland was published in the Freshwater Fishing Australia magazine in January 2020.

A media day was held in November 2019 to coincide with the deployment of the remaining FAS. Coverage from the event extended to a local TV station, media releases by the DAF and TRC, an article in the FFSAQ monthly newsletter, and an article in Queensland Fishing Monthly magazine. Senior fisheries managers were also invited to the event to provide them with a better understanding of the project and its potential value as a fisheries management tool.

Some of the tourists who visit Cressbrook Dam use boats or kayaks that are not equipped with the best technologies for locating habitat structures. To improve the opportunities for anglers to use the installed habitat structures, clear signs have been installed on the shoreline around the impoundment to identify all bays and points where FAS were installed. For anglers with GPS units, the FAS coordinates will be made available on the Fisheries Queensland website, and links to this information will be located on the Toowoomba Regional Council's information page for Cressbrook Dam and several other recreational fishing information websites. The GPS coordinates will be available in a variety of formats so that anglers can download the points for the FAS straight into their specific GPS unit.

Throughout the project information signs have been installed at the boat ramp to keep anglers up to date regarding the project's progress. These signs were continually updated as additional FAS were installed. Several additional FAS constructed from left over materials are being deployed. Large, permanent sign boards, which include a map showing the location and GPS coordinates of all FAS sites, have been installed at the boat ramp, day-use area and campground. These fish attractor signs provide anglers with a starting point to improve their angling experience. An additional benefit to placing fish attractor signs is to heighten awareness of the project. These signs are highly visible and therefore should increase visitor knowledge of the fish attraction efforts in the impoundment.

A Best Practice Guideline has been produced which details the steps required to use FAS in impoundments and provides examples of the planning materials necessary. This guideline will be released nationally and made publicly available online. The results and best practice guidelines will also be presented to all Queensland fish stocking groups at the biennial Queensland fish stocking workshop in March 2022 (postponed from October 2021 due to Covid)

Additional extension activities are planned beyond the completion of the project. A media release will be published highlighting the study's findings and the best practice guidelines. It is anticipated print, radio and tv coverage will be associated with the release. A presentation will be given to the local angling groups and an article will be prepared for one of the fishing magazines. The final report and copies of the best practice guidelines will be sent to fisheries agencies and the peak state bodies for recreational fishing in each state. Aspects of Chapter 3 (fish response to FAS installation) will be submitted for peer-reviewed publication.

Adoption

Adoption of the results from the current project has been deliberately limited so far. Interest in the concept of using fish attractors in impoundments has led to the development of four additional FAS installation trials in Queensland. These projects are outlined in Chapter 5. Strong interest in the use of FAS has been expressed by numerous other fish stocking groups in Queensland. Policy relating to the use of FAS in Queensland impoundments has not yet been fully developed and will be informed by the results from this project. It is anticipated that the use of FAS in impoundment fisheries will be encouraged following the development of appropriate guidelines and policy.

Project materials developed

A number of products have been developed for the project. These include

- Cressbrook Dam Fish Attraction Plan
- Fishing magazine articles
- Conference abstracts (FFSAQ + RFHP)
- Best practice guidelines on the use of fish attractors in Australian impoundments

We also propose to develop a four-page project factsheet summarising key information for distribution (hard copy and electronically) to active fish stocking groups and fisheries agencies. The factsheet will be available online.

Appendix 1 – Project staff

(in alphabetical order)

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Dr Andrew Kaus, Fisheries Biologist, Fisheries and Aquaculture

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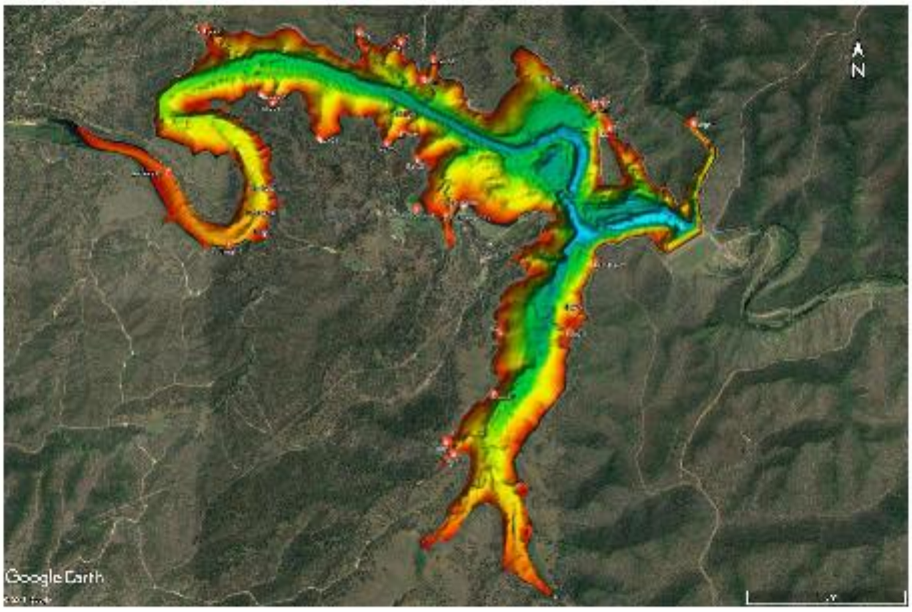
Appendix 3 – Cressbrook Dam Fish Attraction Plan



Cressbrook Dam Fish Attraction Plan 2018-21

Version 2.0 June 2021

Queensland Government

This publication has been compiled by Andrew Norris of Agri-Science Queensland, Department of Agriculture and Fisheries.

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Background

Recreational angling in impoundments is increasing in popularity and generating significant social and economic benefits to regional communities. One of the major limiting factors on the success of an impoundment fishery is the lack of quality fish habitat. Dams with good quality fishing have substantial, high quality fish habitat in common. Since the majority of impoundments are not built or operated with fisheries as a major consideration, structural habitat suitable for fish, is often lacking. Additionally, as impoundments age the remnant habitat degrades over time. Structural habitat is vital to support strong fish communities and angling opportunities.

Strategic installation of fish habitat structures in freshwater impoundments overseas has been found to be capable of significantly improving productivity, carrying capacity, growth rates, spawning and survival of wild and stocked fish (reviewed in Miranda 2016). The installation of habitat to attract fish also helps manage conflicts between waterway user groups and improve fishing for shore-bound or mobility limited anglers.

There is convincing evidence from the USA that strategic habitat enhancement has positively influenced their impoundment fisheries (reviewed in Norris 2016). Habitat enhancement has become a primary tool for fisheries managers in the USA and is used by almost all state fisheries agencies (Tugend *et al.* 2002, Norris 2016). The recreational fishery in many USA dams has been significantly improved, or even completely revitalised through the strategic use of fish habitat enhancement. This has led to significant increases in the number of angling tourists visiting or utilizing these impoundments and resulted in flow-on socio-economic benefits to local communities. These enhancement techniques have yet to be examined for Australian fish species under local environmental conditions.

To date, impoundment fisheries management in Australia has focussed on stocking and bag limits. There has been surprisingly little research or attention on impoundment fish habitat. The introduction of structural habitat for fish has been successfully used in open river systems to support native fish populations and led to localised increases in the abundance of fish species targeted by anglers. Much of this effort has focussed on providing the necessary resources required at various life history stages for fish to enable self-sustaining populations. Most of the impoundment fisheries in Queensland are put-grow-take and thus sustained by stocking. Many native fish species will not spawn in impounded waters. The focus of habitat installation in these impoundments is therefore on providing habitat to aggregate fish to improve the angling experience. A secondary benefit may be to improve survival of stocked fish where juvenile habitat is limited or of poor quality.

Cressbrook Dam, located near Toowoomba, has been stocked with significant numbers of fish through the ongoing efforts of the Toowoomba and District Fish Stocking Association (TDFSA) and the Stocked Impoundment Permit Scheme (SIPS). Despite the stocking efforts, the dam is generally regarded at times as difficult to fish and of having limited structure to aggregate fish. It therefore has the potential to benefit from the strategic introduction of fish habitat structures, and also provides an ideal setting to investigate the relative effectiveness of different fish attractor types.

Historically the materials used for fish attracting structures have largely been those that are convenient, economic and readily available (Miranda 2016). As knowledge in the field grows, more specialist fish attracting structures are being created to service specific needs of different species and size classes. Generally a combination of fish attracting structure types is utilized to provide greater diversity of habitats for a wide range of species. Many of the techniques are suitable for construction and deployment by community groups such as angling clubs, and can be cost-effectively implemented.

Objectives

The two main goals of this Fish Attraction Plan (FAP) are

i) to improve recreational angling in Cressbrook Dam by strategically installing fish attracting structures (FAS), and

ii) to provide a platform for evaluating the response of native recreationally important fish species to different FAS types.

In areas with little habitat, fish are often dispersed and thus more difficult for anglers to locate and target. The installation of FAS can aid recreational anglers by aggregating fish into specific areas, increasing the probability that anglers cast their lure or bait in the vicinity or their target species. Fish attracting structures can attract prey species seeking food and refuge, provide refuge for stocked juvenile fish, and provide structure and ambush opportunities for predatory species (Miranda 2016).

Little research has been conducted on the response of Australian fish species to introduced structures in impoundments. This FAP forms part of a scientific project looking to determine the most effective type, location, density and deployment patterns for attracting fish to installed structures in Australian impoundments. A range of different FAS types will be installed and monitored over several years. This information is essential for assessing the cost-benefit ratios for different FAS as well as the overall use of FAS.

Cressbrook Dam

Cressbrook Dam is located on Cressbrook Creek an upper tributary of the Brisbane River, 43km north-east of Toowoomba. The dam is managed by Toowoomba Regional Council (TRC). Cressbrook Creek flows into the Brisbane River downstream of Toogoolawah. The dam was originally built in 1983 for town water supply and consists of a zoned earth fill embankment with a central clay core. The 363 m long wall contains an un-gated overflow spillway controlled by an ogee crest with open channel chute and flip bucket (TRC 2017). At full storage capacity (280 m AHD) the dam holds 81,800 ML and covers 517 ha. The water supply off-take occurs via 51 m high intake tower with multiple-level draw-off. The dam has a catchment area of 326 km^2 consisting of moderately undulating country varying from patches of rain forest to lightly-timbered with some land originally cleared for dairy farming (TRC 2017).

Although constructed for water supply, Cressbrook Dam is now also used for a range of recreational activities. A campground containing 30 sites is also located on the shores of the lake to the west of the day use area and boat ramps. Fishing, boating, canoeing and sailing are all permitted on the dam, but swimming is prohibited. Outboard motors are permitted, however, under Local Law, boat speeds must be confined to 4 knots (7.25kms per hour) inshore and 8 knots (14.5kms per hour) offshore.

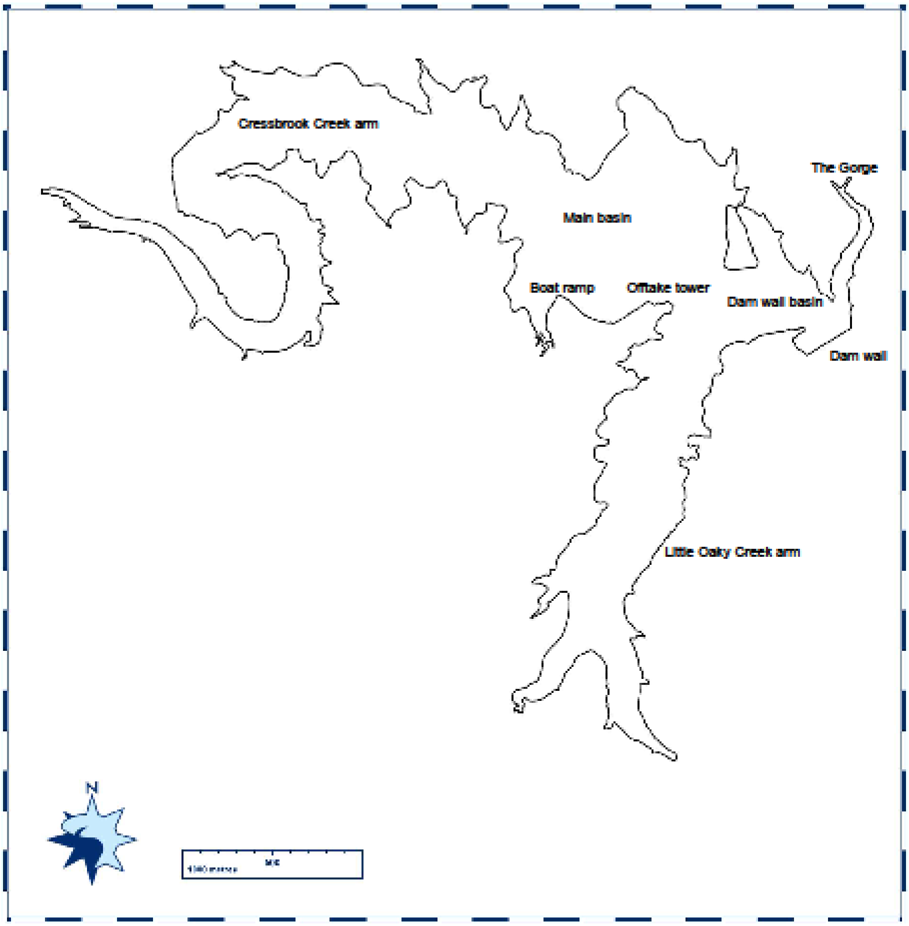

Figure 1. Map of Cressbrook Dam

Existing structure and fish habitat

To aid development of the FAP, a sonar survey was conducted by DAF across Cressbrook Dam to map the bathymetry and existing fish habitat (Figures 2-5). The survey highlighted the limited structure in the dam which could aggregate fish, and the need for the addition of fish attracting structures. The dam's habitat was dominated by silt and gravel flats leading into deep rock ledges along the old creek channels. The dam also had a number of small steep bays containing channels and frequently descending into deep water.

The sonar survey was completed in summer and a thermocline was located between 5-6 m depth across most of the dam, but was shallower (4 m) in the Cressbrook Creek arm.

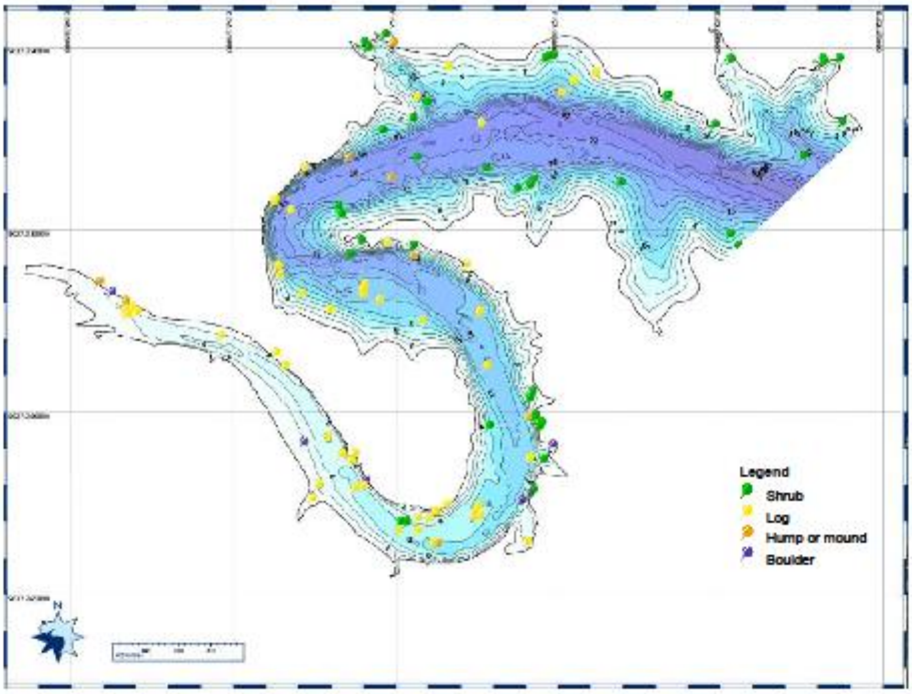

Figure 2. The pre-existing habitat in the northern Cressbrook Creek arm of Cressbrook Dam

Marginal submerged macrophytic growth was dense to around 2 metres depth around much of the dam shoreline, with more scattered vegetation extending to 5 metres depth in parts. Simple tree trunks and logs were present in the vicinity of both major feeder creeks (Little Oaky Creek and Cressbrook Creek, Figures 2 and 5) and appear to have washed down during major flow events. However these logs lacked structural complexity (no branching or apparent root balls) and are likely to offer little habitat for most fish species. Only a few complex branching submerged trees were observed. Small dead shrubs were also present along the margins down to 5 m in several sections of the dam, most notably along the steeper banks and points near the wall. These small shrubs offered some habitat complexity for fish, especially when they were in clusters.

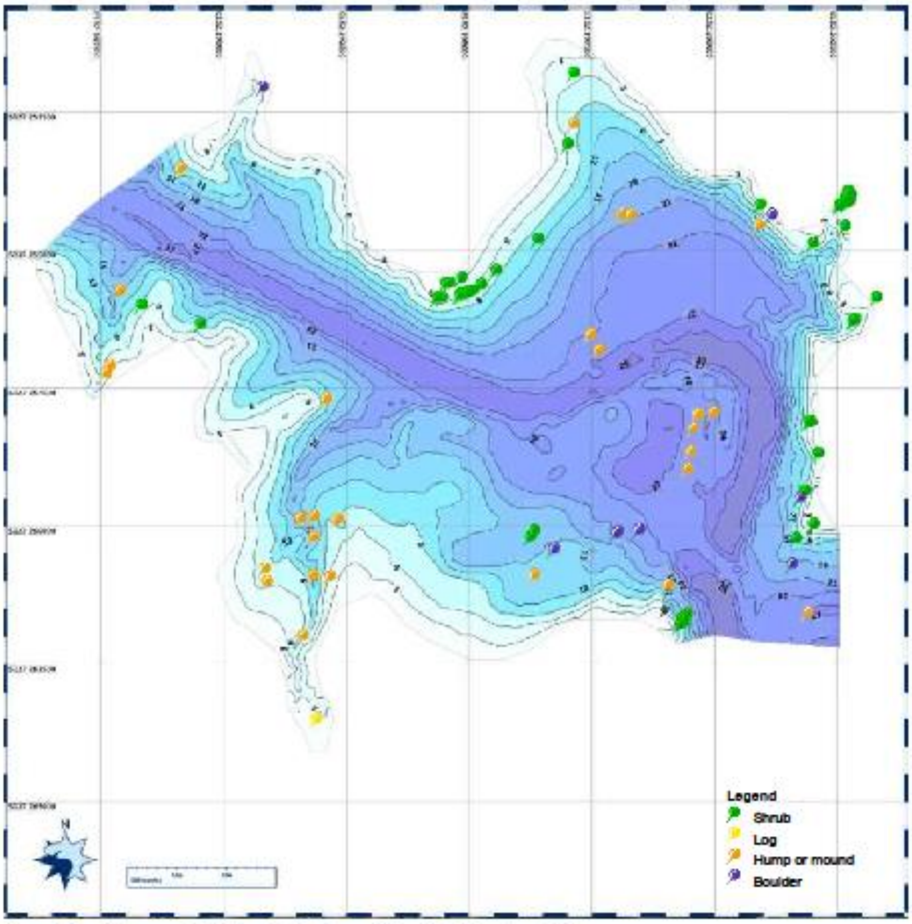

Figure 3. The pre-existing habitat in the main basin of Cressbrook Dam

The best fish habitat occurred in the Gorge to the north of the dam wall (Figure 4). This area is closed to public access. The steep rocky walls here extended into the relatively deep water and a marginal row of dead shrubs occurred along most of the shoreline in 1-3 m depth. There were numerous rocks, large boulders and rock crevices for predatory fish to utilize, as well as several complex fallen trees or large branches. Good quality fish habitat was also found along several steep rock walls and drop-offs in the Cressbrook Creek arm (Figure 2).

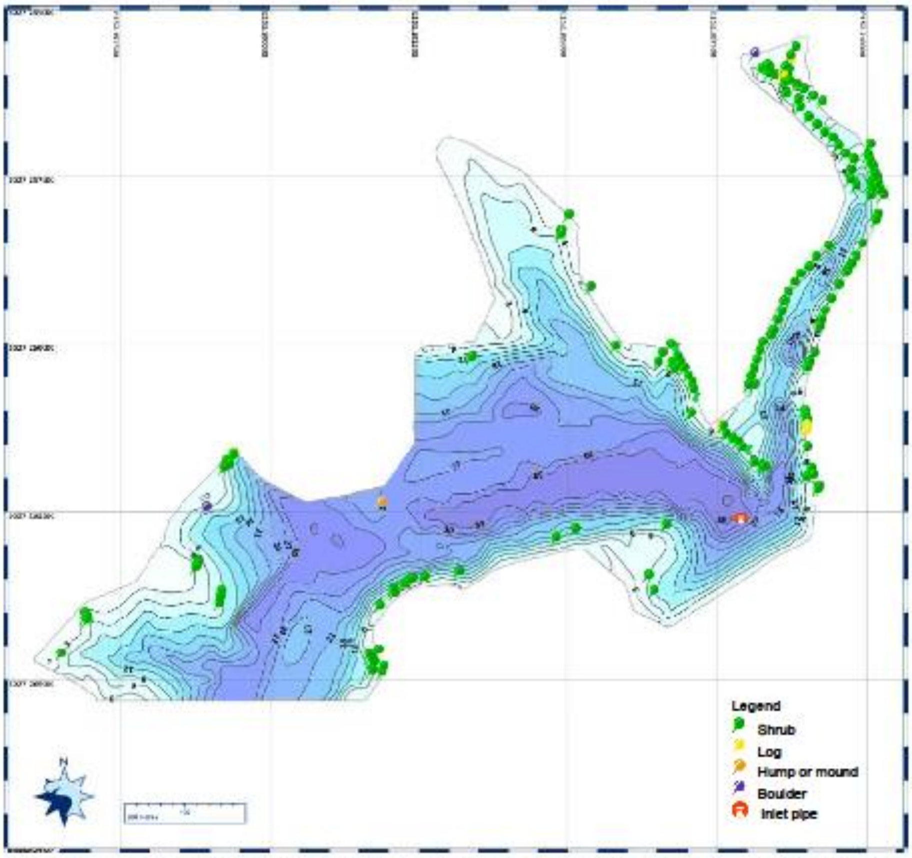

Figure 4. The pre-existing habitat in the basin near the dam wall of Cressbrook Dam. The majority of this area is currently closed to fishing.

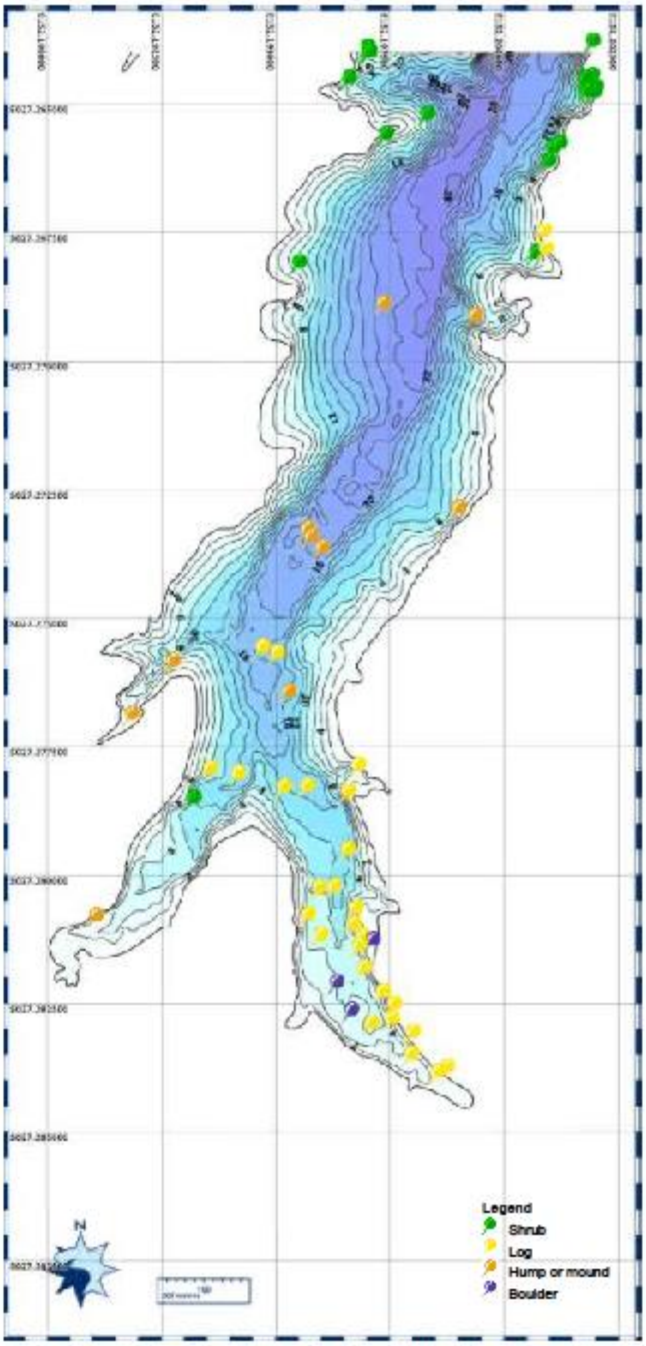

Figure 5. The pre-existing habitat in the southern Little Oaky Creek arm of Cressbrook Dam

Cressbrook Dam Fish Attraction Plan 2018-21 (version 2.0), Department of Agriculture and Fisheries 7

Fish distribution

Cressbrook Dam is stocked by the TDFSA under the SIPS. Fish were first stocked in 1988, but the dam was not opened to fishing until the end of 1994 (Kuhl *et al.* 2003). The species stocked for recreational angling include Australian bass (*Macquaria novemaculeata*), golden perch (*Macquaria ambigua*), Mary River cod (*Maccullochella peelii mariensis*), saratoga (*Scleropages leichardti*) and silver perch (*Bidyanus bidyanus*) (Peter Taylor, TDFSA, personal communication). Eel-tailed catfish (*Tandanus tandanus*) and spangled perch (*Leiopotheropon unicolor*) have naturally occurring, self-sustaining populations in the dam. Snub-nosed garfish (*Arrhamphus sclerolepis*) and bony bream (*Nematalosa erebi*) have been introduced as prey species (Peter Taylor, TDFSA, personal communication). Other native fish observed include fly-specked hardyhead (*Craterocephalus stercusmuscarum*) and olive perchlet (*Ambassis agassizii*). Several introduced non-endemic fish species were present in the dam during the electrofishing survey, including goldfish (*Carrassius auratus*), mosquitofish (*Gambusia holbrooki*) and barred grunter (*Amniataba percoides*), the latter of which has become highly abundant in shallow waters and a nuisance to anglers.

Australian bass and golden perch are the primary targets for most recreational anglers. These two species both utilize different habitats and depth ranges throughout the year. In Cressbrook Dam, the majority of Australian bass are located in more open, deep water areas and habitat during the summer months. At this time they can be found schooling up near the thermocline (5-6 m depth) or beneath bait schools located above the drop-offs and rock ledges lining the old creek channels in deep water. In winter months the Australian bass are located more frequently over the shallow weed beds and near the shoreline of steeper banks. Conversely, golden perch are more likely to be found in the shallower waters of bays and points during summer and in deeper waters during the cooler winter months (Peter Taylor, personal communication).

Dam hydrology

Cressbrook Dam was first pumped in November 1988 when it reached 67% of its full capacity. Since 1988, it has had an average useable storage volume of 71.8% of its full capacity. The dam's lowest storage volume on record was 7.5% in February 2010. The dam experienced prolonged very low water levels during the record drought (2005-2011), but once filled up during the record level floods (2011), remained near capacity for the next 3 years (data provided by Toowoomba Regional Council). This boom or bust cycle means statistics on mean water levels from the last 10 years are unlikely to be relevant. Additional historic data is being sought to determine the best long-term locations for FAS to be installed, regarding suitable water levels.

Dam water levels have been on a slow decline over the past three years. During this time the levels have dropped approximately 5.7 m. If there are no substantial rainfall events and unless there is unusual major water offtake, it is anticipated that the water levels would likely drop by another 6 m over the next three years. During the sonar and fish surveys the dam was at 272.5 m AHD or approximately 54% storage capacity. It is hoped that sufficient rainfall should occur at some stage over the next three years to maintain water levels similar to the present status. Thus, in the absence of additional data, the water level at the time of the sonar surveys will be taken to be representative of the short term scenario and used for the purposes of designing FAS deployment patterns and locations. This will ensure sufficient data can be collected from the monitoring sites during this project. The fish attraction plan will have to be reviewed each year during the project due to the uncertainty of water levels and to ensure the optimal locations for installing the fish attractors are selected.

During substantial rainfall events, significant flow rates are expected in both the Cressbrook Creek and Little Oaky Creek arms of the dam. The accumulation and deposition of large logs in the vicinity of where these two creeks enter the dam provide evidence for this assertion. It is therefore recommended that no fish attractors be deployed in or adjacent to the main channels in these areas to avoid movement of the attractors and minimise the risks to waterway infrastructure.

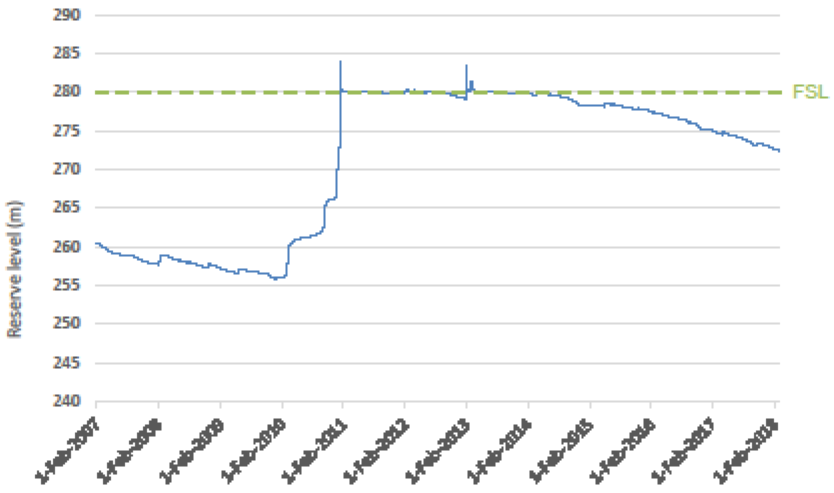

Figure 6. Reserve water levels in Cressbrook Dam between 2007 and 2018. The dashed green line (- - -) indicates the full supply level (FSL). Data provided by Toowoomba Regional Council.

Stakeholder consultation

A broad range of stakeholders have been consulted during the preparation of this fish attraction plan. The primary stakeholders for Cressbrook Dam include Toowoomba Regional Council (co-investors and waterway and campground managers), Toowoomba and District Fish Stocking Association, FRDC (co-investors) and the Department of Agriculture and Fisheries (manage stocking, SIPS and research). The low boat speed restrictions (<8 knots) in the dam mean that water skiing and wakeboarding is not permitted and thus these groups are not key stakeholders. A project steering committee was established to encompass the views of the primary stakeholders as well as other interested parties and to provide an avenue for information dissemination. The committee includes members from FRDC, Fisheries Queensland, TRC, Seqwater, TDSFA and the Wivenhoe and Somerset Stocking Groups.

Fish attraction structures (FAS)

Types

Three broad groups of FAS will be used in Cressbrook Dam. Within each grouping there will also be several structure types to enable fish attractors to be employed at different depths and provide a range of complex habitat types. All materials used to construct the FAS will be organic or inert to ensure there are no detrimental impacts on the aquatic environment. The majority of recommended FAS types are relatively snag-free, meaning anglers can fish right in amongst the habitat with little fear of losing gear. Brush bundles are the exception, but they are relatively cheap and provide excellent structural complexity. All FAS will be suitably weighted and located to ensure that movement is minimal.

Examples of the main FAS types include:

1. Brush and timber
   - Brush bundles

   - Porcupine fish cribs

2. Synthetic materials
   - Spiders

- Georgia cubes


- Synthetic trees


3. Suspended or floating
   - Similar to synthetic trees, but suspended 1 - 5 m below the surface
   - For deeper water use only.


Locations

It was initially proposed to install a total of 733 FAS into Cressbrook Dam. However, due to ongoing low water levels the plan was revised to a total of 576 FAS, consisting of 182 spiders, 142 synthetic trees, 130 brush bundles, 26 suspended FAS, 39 porcupine cribs, 44 Georgia cubes and 13 branch bundles. The FAS will be located around the dam at 26 locations to spread out angler effort and provide accessible habitat for fish throughout the year. Since there is little structural complexity in the dam apart from old creek channels and rock ledges, FAS will primarily be used to develop new fishing hot-spots rather than enhance existing structures. Where remnant habitat is available it has been incorporated into the FAP designs for that area. The goal will be to achieve an appreciable increase in structural complexity through a mix of FAS types suitable for the local conditions and water depths. At sites using spiders, the FAS density will be higher because these structures are smaller and thus individually cover less area. Conversely, suspended FAS cover a much larger area and thus will be placed more sparingly. All FAS sites will be accessible by boat, however three sites near the campground and boat ramp have also been specifically included for shore-based anglers (Shore 1, Shore 2 and Bay 26; see Table 1 and Appendix 1 for more details).

Table 1. The location of proposed fish attracting structure (FAS) sites around Cressbrook Dam.

Name	Latitude	Longitude	FAS types
Bay 3	-27.269119	152.195313	Suspended
Bay 5	-27.275620	152.191772	Brush and timber
Bay 8	-27.269091	152.199936	Synthetic
Bay 9	-27.267694	152.200409	Suspended
Bay 11	-27.256260	152.202957	Synthetic
Bay 12	-27.254650	152.202499	Brush and timber
Bay 14	-27.250019	152.174210	Suspended
Bay 16	-27.250681	152.188217	Synthetic
Bay 17	-27.250120	152.185226	Brush and timber
Bay 22	-27.263241	152.179153	Brush
Bay 23	-27.254299	152.178452	Brush and timber
Bay 25	-27.257139	152.182632	Suspended
Bay 26	-27.257429	152.187408	Synthetic and brush
Bay 27	-27.258459	152.189560	Synthetic
Boat ramp bay	-27.261957	152.191620	Synthetic and brush and timber
Point F	-27.272890	152.194850	Brush and timber
Point K	-27.253229	152.199066	Suspended
Point L	-27.253260	152.189865	Synthetic
Shore 1	-27.255630	152.185630	Synthetic and brush
Shore 2	-27.256763	152.188400	Synthetic and brush
Open water 1	-27.272942	152.197865	Brush and timber
Open water 2	-27.271543	152.198306	Synthetic
Open water 3	-27.269724	152.198758	Suspended
Open water 4	-27.257386	152.192532	Suspended
Open water 5	-27.258543	152.194035	Synthetic
Open water 6	-27.260456	152.194926	Brush and timber

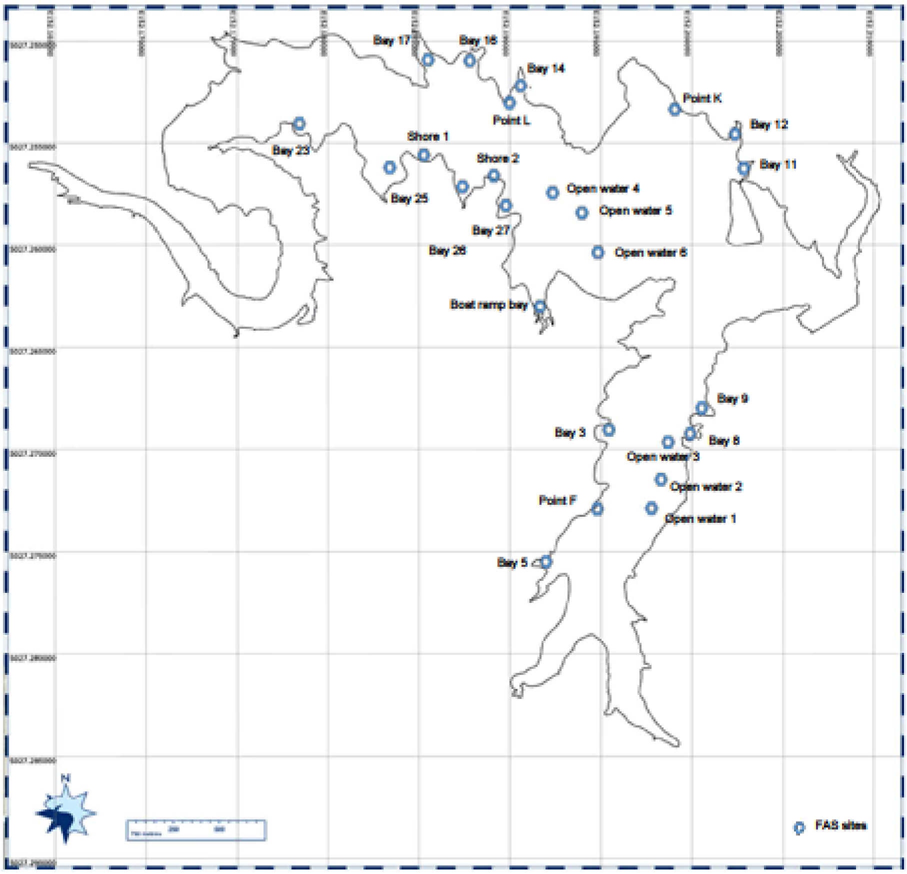

Figure 7. The location of proposed fish attracting structure (FAS) sites around Cressbrook Dam.

In bays and coves, FAS will be deployed from the apex of the bay out into deeper water to provide habitat at a range of water depths and counter fluctuations in water level. Channels formed from incoming surface run-off into bays will be avoided to prevent installed FAS from potentially shifting. In these areas FAS will be deployed along the top of the drop-off instead. Along points, lines of habitat will be run tangential to the shoreline, as well as along depth contours to contour water level fluctuations.

The littoral locations for brush/timber and synthetic FAS will be divided into shallow and deep areas. In water less than 3 m, shallow water structures such as spiders, brush piles and short suspended designs, will be utilised. These will be placed in areas where aquatic macrophyte growth is minimal to ensure they are not overgrown. Shallow water structures will be distributed at each site along or across contour lines in clusters of five, with a gap of 0.3 – 1.0 m between the extremities of each structure.

In deeper littoral water (> 3 m) more substantial structures such as porcupine cribs, vertical brush piles, Georgian cubes, suspended FAS and synthetic trees will be utilised. The goal of these structures will be to provide greater vertical structure, and where possible be at least as tall as half the vertical height of the water column. They will be located in clusters with the extremities of individual clusters separated laterally by 1 – 3 m. Deep water FAS will primarily be installed in 4-7 m of water to ensure they are near or above the thermocline in summer and to allow for sufficient depth should water levels fall.

Several FAS sites have been located in open water to provide structure for fish in deeper waters (Open water sites 1-6, see Table 1 and Appendix 1 for more details). The fish attractors installed will be taller where possible but may still be located below the summer thermocline. Three clumps of attractors will be placed in each open water site, spaced at least 50 m apart.

Detailed descriptions, maps and GPS coordinates for each of the FAS deployment areas can be found in Appendix 1 (Figures 9-34, Tables 3-28).

Details of the type and location of all FAS will be made available to the general public via:

- Numbered markers above the full supply level at bays and points
- Labelled floats for suspended and deep water FAS
- A sign with a map at the boat ramp
- An online PDF map
- Access to downloadable Google Earth map files

Installation priorities

The initial priority for FAS installation will be the deep water sites and monitored points and bays located south of the water offtake tower to take advantage of the acoustic monitoring system. These include Bays 3, 5, 8 and 9, Point F and Open water sites 1-3.

Once FAS installation in these sites has been completed, the focus will shift be to installation of at least half of the FAS into the other monitoring sites.

Installation of FAS at non-monitored sites, whilst important, will be have the lowest priority and is likely to be undertaken in years 2 and 3 of the project.

Monitoring and evaluation

One of the key components of the FAP is deploying FAS in a manner in which the response of recreational fish species and angling catch rates can be evaluated. A multi-faceted approach will be taken using acoustic tracking, targeted angling, electrofishing and creel surveys.

One of the most effective and least invasive methods for studying the behaviour and movements of fish is via acoustic tracking. The department of Agriculture and Fisheries will be using this process to determine the use of the FAS by tagged fish. An acoustic array consisting of 30 acoustic receivers will be established in the Little Oaky Creek arm of the dam, south of the water offtake tower. Thirty Australian bass and 30 golden perch will be captured, surgically implanted with acoustic transmitters and then released into this area. The fine scale movements of the tagged fish will be remotely monitored for 2 years to establish their usage patterns of the different FAS types, habitats and locations.

Appendix 4 – Angler questionnaires

Cressbrook Dam Angler Survey (pre-habitat installation)

Time of day (hh:mm): ______________

Date: Day _________ Month_______________ Year____________

Weather conditions _______________________________________

Fishing frequency

1. **How often do you fish in general?** ________________________________
2. **How often do you fish at Cressbrook Dam**
   a) First time fishing at Cressbrook ☐
   b) If not first time, record the frequency of fishing at Cressbrook ___________________

<u>**Today's fishing activity**</u>

1. **Have you been** a) boat fishing ☐ b) shore fishing ☐ c) both ☐
2. **Have you been** a) lure fishing ☐ b) bait fishing ☐ c) both ☐
3. **How many hours, to nearest ½ hour, have you been fishing?** _________
4. **How many people are fishing in your group today?** ___________
5. **Have you finished fishing today?** Yes ☐ No ☐
6. **Describe your catch today to help complete the catch table.**

Species	Total caught (including released fish)	Number of legal sized fish caught	Number of fish released	Number of legal sized fish kept
Golden Perch				
Australian Bass				
Saratoga				
Silver Perch				
Freshwater Catfish				
Mary River Cod				
Snub-nosed Garfish				
Spangled Perch				

7. **If the angler or group is willing, measure total length of the fish kept. Do not measure Garfish or Spangled Perch. Measure in cm.**

Species	Length	Species	Length

Fishing quality and satisfaction information

1. **How would you rate the quality of fishing at Cressbrook Dam? If you have fished here more than once, then rate the quality in general.**

   1) very poor ☐ 2) poor ☐ 3) average ☐ 4) good ☐ 5) very good ☐

2. **Where have you travelled from to fish at Cressbrook Dam?**

   Town name ______________ State__________________

   International visitors can provide country __________________

3. **How many hours did you travel to fish here?** ______________

4. **Do you plan to fish at Cressbrook Dam again?**

   1) Strongly disagree ☐ 2) Disagree ☐ 3) Neutral ☐ 4) Agree ☐ 5) Strongly agree ☐

5. **Would you recommend others fish at Cressbrook Dam?**

   1) Strongly disagree ☐ 2) Disagree ☐ 3) Neutral ☐ 4) Agree ☐ 5) Strongly agree ☐

6. **How would you rate your satisfaction level with fishing at Cressbrook Dam?**

   1) Strongly disagree ☐ 2) Disagree ☐ 3) Neutral ☐ 4) Agree ☐ 5) Strongly agree ☐

Fish habitat

1. **When you fish in Cressbrook Dam do you seek out bottom structure (timber, rock outcrops etc) to improve your fishing success?**

   1) Strongly disagree ☐ 2) Disagree ☐ 3) Neutral ☐ 4) Agree ☐ 5) Strongly agree ☐

2. **Are you aware of plans to install fish attracting structure in Cressbrook Dam to improve fishing?** a) yes ☐ b) no ☐

3. **Would you fish at Cressbrook Dam more frequently if fish attracting structure was installed?**

   1) Strongly disagree ☐ 2) Disagree ☐ 3) Neutral ☐ 4) Agree ☐ 5) Strongly agree ☐

4. **Would you prefer structure was installed to improve**

   a) boat fishing ☐ b) shore fishing ☐ c) both ☐ d) don't want structure installed ☐

Cressbrook Dam Angler Survey (post-habitat installation)

Time of day (hh:mm): ______________

Date: Day _________ Month_______________ Year____________

Weather conditions ______________________________________

Fishing frequency

1. **How often do you fish in general?** ________________________________
2. **How often do you fish at Cressbrook Dam**
   c) First time fishing at Cressbrook ☐
   d) If not the first time, record the frequency of fishing at Cressbrook ________________

Awareness of fish attracting habitat installation

1. **Are you aware that fish attracting habitat has been installed into Cressbrook Dam?**
   1) Not aware ☐
   2) Aware, but I don't know where it is ☐
   3) Aware I know where it is but am not fishing it ☐
   4) Aware, I know where it is and I target it some of the time ☐
   5) Aware, I know where it is and target it most of the time ☐
2. **Did you come to fish at Cressbrook Dam because of the installed fish attracting habitat?**
   1) Strongly disagree ☐ 2) Disagree ☐ 3) Neutral ☐ 4) Agree ☐ 5) Strongly agree ☐

Today's fishing activity

1. **Have you been** a) boat fishing ☐ b) shore fishing ☐ c) both ☐
2. **Have you been** a) lure fishing ☐ b) bait fishing ☐ c) both ☐
3. **How many hours, to nearest ½ hour, have you been fishing?** _________
4. **How many people are fishing in your group today?** ___________
5. **Have you finished fishing today?** Yes ☐ No ☐
6. **Describe your catch today to help complete the catch table.**

Species	**Total caught (including released fish)**	**Number of legal sized fish caught**	**Number of fish released**	**Number of legal sized fish kept**
Golden Perch				
Australian Bass				
Saratoga				
Silver Perch				
Freshwater Catfish				
Mary River Cod				
Snub-nosed Garfish				
Spangled Perch				

7. **If the angler or group is willing, measure the total length of the fish kept. Do not measure Garfish or Spangled Perch. Measure in cm.**

Species	Length	Species	Length

Fishing quality and satisfaction information

1. **How would you rate the quality of fishing at Cressbrook Dam? If you have fished here more than once, then rate the quality in general.**

   1) very poor ☐ 2) poor ☐ 3) average ☐ 4) good ☐ 5) very good ☐

2. **If you have fished Cressbrook Dam prior to the habitat installation do you agree that the fishing has improved since installation?**

   Haven't fished here before ☐
   1) Strongly disagree ☐ 2) Disagree ☐ 3) Neutral ☐ 4) Agree ☐ 5) Strongly agree ☐

3. **Where have you travelled from to fish at Cressbrook Dam?**

   Town name _______________ State___________________

   International visitors can provide country ___________________

4. **How many hours did you travel to fish here?** _______________

5. **Do you plan to fish at Cressbrook Dam again?**

   1) Strongly disagree ☐ 2) Disagree ☐ 3) Neutral ☐ 4) Agree ☐ 5) Strongly agree ☐

6. **Would you recommend others fish at Cressbrook Dam?**

   1) Strongly disagree ☐ 2) Disagree ☐ 3) Neutral ☐ 4) Agree ☐ 5) Strongly agree ☐

7. **How would you rate your satisfaction level with fishing at Cressbrook Dam?**

   1) Strongly disagree ☐ 2) Disagree ☐ 3) Neutral ☐ 4) Agree ☐ 5) Strongly agree ☐

Fish habitat

5. **When you fish in Cressbrook Dam do you seek out bottom structure (timber, rock outcrops etc) to improve your fishing success?**

   1) Strongly disagree ☐ 2) Disagree ☐ 3) Neutral ☐ 4) Agree ☐ 5) Strongly agree ☐

6. **Did you seek out the installed fish attracting habitat for your fishing trip today?**

   1) Strongly disagree ☐ 2) Disagree ☐ 3) Neutral ☐ 4) Agree ☐ 5) Strongly agree ☐

7. **What structures did you fish (tick one or more)**

   a) None ☐ b) naturally occurring timber or rock ☐ c) Georgian cubes ☐ d) PVC spiders ☐
   e) Suspended FADS ☐ f) wood cribs ☐ g) brush or timber bundles ☐ h) PVC Trees ☐
   i) All types ☐ j) Installed habitat but don't know which type ☐

8. Where did you catch the most fish today

a) Don’t know ☐ b) open water- no structure ☐ c) naturally occurring structure (timber/rock) ☐
d) weed beds ☐ e) Georgian cubes ☐ f) pvc spiders ☐ g) Suspended FADS ☐ h) wood cribs ☐
i) brush or timber bundles ☐ j) Installed habitat but don’t know which type ☐ k) PVC Trees ☐

9. Do you agree with the following statement?
I fish or plan to fish at Cressbrook Dam more frequently since installation of fish attracting habitat

1) Strongly disagree ☐ 2) Disagree ☐ 3) Neutral ☐ 4) Agree ☐ 5) Strongly agree ☐

10. Score the quality of fishing in different habitats in Cressbrook Dam

1 is the poorest fishing and 5 is the best fishing (circle one number for each category)

Don’t know	☐
Open water no structure	1 2 3 4 5
Weed beds/edges of weed beds	1 2 3 4 5
Naturally occurring timber or rock	1 2 3 4 5
Suspended FADS	1 2 3 4 5
Other installed structure	1 2 3 4 5

(Georgian cubes, cribs, spiders, synthetic trees, brush bundles)