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FRESHWATER FISH GROUP & FISH HEALTH UNIT, Centre for Fish & Fisheries Research, Murdoch University

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IMPACT OF THE KENT STREET WEIR ON FISH MIGRATION IN THE CANNING RIVER

Report to: Department of Parks and Wildlife; Swan Canning Riverpark

Freshwater Fish Group &
Fish Health Unit

Centre for Fish & Fisheries Research

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Executive Summary

One of the most significant impacts of instream barriers is the disruption of habitat connectivity for riverine fishes, many of which migrate to fulfill a life cycle requirement.

Kent Street Weir (KSW) was constructed in 1927 on the Lower Canning River to maintain a freshwater weir pool for agriculture, and was identified as having the potential to limit the upstream movement of freshwater and estuarine fish species. However, no study had specifically assessed the impact of KSW on the migration and other ecological requirements of fish species known to reside in the lower and middle reaches of the Canning River.

This study aimed to assess the relative impact of the KSW on upstream and downstream fish populations and in so doing provides the background information for the improvement of fish passage to mitigate its impact. Specific objectives were to:

- establish a fish monitoring program during spring/summer both above and below KSW
- determine and compare the fish population structure and species abundances above and below the KSW
- determine the requirements and timing of migrations of resident fishes
- identify the impacts of the barrier to the movements and ecology of native and feral fish
- develop preliminary recommendations for appropriate fishway designs to facilitate passage of target species.

In order to compare the composition of fish populations above and below the KSW, six fish sampling events were conducted fortnightly (between October 22 and December 30, 2015). Techniques were employed to capture a full suite of species and wide range of life-history stages (i.e., both juveniles and adults) and included a combination of fyke, seine, and gill netting. Basic water quality measurements were made to characterise the overall conditions throughout the water column during each sampling event.

The sampling period coincided with a comparatively dry year; with below average rainfall and lower than expected winter and spring stream discharge. As a consequence, the KSW regulation boards (usually removed during the winter and spring period to allow freshwater flows to flush downstream) were removed for just over one month before being replaced to prevent the upstream incursion of saline water. Upstream water conductivity was always fresh (ranging from 574 – 1136 µS/cm) compared to below, which varied substantially (i.e., 610 – 40900 µS/cm). Dissolved oxygen levels were usually highly variable, with depleted levels (below 20 % saturation) detected in the deeper pools above and below KSW.

A total of 19,294 fish were captured including representatives from two native freshwater species, 10 native estuarine/marine species and four feral fish species. In addition, numerous Oblong Turtles and decapod Crustacea were captured above and below KSW.

The KSW was found to be a major impediment to the migration of several estuarine native fishes, and likely impeded population mixing of other estuarine species and re-colonisation of freshwater native species. A total of 13,291 (92.4%) native fish were caught below KSW (predominately the Swan River Goby, Western Hardyhead, Black Bream and Yellowtail Trumpeter) compared to only 1,086 above KSW (7.6% of all native fish). Species caught

exclusively below KSW include Yellowtail Trumpeter, Bridled Goby, Elongate Hardyhead, Giant Herring, Perth Herring and Western Minnow. In contrast, the majority (80 %) of the introduced fish were caught above KSW, including 78% of the Eastern Gambusia and 88 % of the Pearl Cichlid.

Adults of most native freshwater potamodromous species (i.e. those that undertake a spawning migration within rivers) in the Canning River migrate upstream to some degree during the winter/spring peak flow period. Larvae are known elsewhere to passively drift downstream and juveniles generally seek refuge pools or other permanent sections within the main channel of rivers during late spring and summer. These species were detected in relatively low abundances during the current study, but are known to be more abundant further upstream in the Canning River. During the wetter years these species can be flushed downstream and would therefore require fish passage to enable re-colonisation of the main river channel.

Additional information on the swimming ability of native fishes would be beneficial for the optimisation of fishway design criteria. However, if the swimming performance of Western Pygmy Perch, as one of the least capable swimmers, is incorporated as a maximum velocity target, adequate passage be achieved for the other potamodromous species.

Improved fish passage at KSW should also be designed to allow larger estuarine species such as Black Bream, Yellowtail Trumpeter and Sea mullet to move upstream to find food and refuge, but also importantly, allow their movement back downstream to suitable breeding conditions. Swan River Goby, Western Hardyhead and South-west Goby are likely to move upstream of KSW with increased fish passage.

With further consideration of the known life-cycles of native fish in the Canning River system, the following recommendations have been developed as guidance for the improvement of fish passage at KSW:

- A fishway is highly recommended for the KSW given that it restricts the movement of most native estuarine species and also probably some native freshwater species.
- The fishway should be designed to operate at low flows to enable upstream and downstream movement of native species where possible.
- The fishway should be designed to reduce internal velocity and turbulence during winter and spring and cater for native freshwater fish that are washed downstream and have a requirement to subsequently return upstream prior to salinity increases.
- The fishway must also allow passage of larger estuarine species (both juveniles and adults) in both an upstream and downstream direction.
- The most appropriate design should be developed based on ongoing discussions with experienced fishway designers, managers, and fish ecologists. It is likely that a vertical-slot fishway would be most appropriate fish design to enable consistently suitable performance criteria and the necessary public security.
- In light of major gaps in understanding of the swimming performance of most species in the vicinity of the KSW (no information exists on burst swimming performance of south-western Australian freshwater fishes) that would likely benefit from a fishway, the recommended preliminary hydrological criteria within the fishway should cater for the

Western Pygmy Perch (given information exists on its sprint swimming performance). A conservative maximum velocity within the fishway would be 0.5 m/s.

- Swimming capability (such as sprint speeds) of key species (Nightfish, Freshwater Cobbler, Black Bream, Yellowtail Trumpeter), along with burst performance of all freshwater species, are important knowledge gaps that if addressed would greatly enhance the robustness of the fishway design.
- The fishway should incorporate suitable monitoring infrastructure (such as PIT antenna system) to provide a platform for assessing the fishway effectiveness.
- The fishway could also include additional management equipment such as fish traps to remove feral species.
- In the light of the declining rainfall and stream discharges in the system, the maintenance and protection of refuge pools and connectivity will become an important management goal and needs to be an important consideration for the fishway design at KSW.

Contents

List of Figures

List of Tables

Background

Instream barriers and fishways

Human built instream structures on rivers can restrict fish passage by creating a physical blockage, by acting as a hydrological barrier, or by forming artificial conditions that act as behavioural barriers to fish. One of the most significant impacts of such barriers is the disruption of habitat connectivity. Almost every aspect of the life history of fish involves movement and this can be over scales of a few metres to hundreds of kilometres (Lucas and Baras 2001). Most fish move along streams for feeding, spawning, to seek shelter and refuge, for dispersal of young fish, to counter downstream displacement in high flows, and to recolonise after droughts. These movements can be regular seasonal migrations undertaken by much of the population or they can be less regular and less well defined such as dispersal or re-colonisation movements that may be undertaken by a few individuals (Northcote 1998; Mallen-Cooper 2000).

Interest in mitigating these impacts through fishway construction and barrier removal has gained considerable momentum across the globe at all levels from local communities to inter-governmental collaborations. Fishway construction in Australia has been very successful, particularly over the last 10 years where targeted research has led to innovative and cost-effective designs, and monitoring has enabled designs to be refined. However, like many environmental issues, the scale of this problem vastly outweighs the resources currently being made available to confront it. Therefore, prioritisation of which barriers to mitigate or remove is an area of growing importance.

Barrier prioritisation is generally conducted on a regional or catchment wide basis and includes first identifying all potential instream barriers and then ranking the physical and biological risk, costs and benefits of fishway restoration. Some of the physical data collected would include the type of barrier, structural attributes (e.g. height, width, head loss, crest-tailwater differential), weir pool characteristics, stream/catchment characteristics (e.g. distance to proximal barriers, flow regimes, drownout frequency) and a range of other information (e.g. age of structure, owner, status of use, presence of existing fishway, availability of data from previous environmental studies in the area). Some key biological data is also required on resident fish assemblages, migration requirements of aquatic biota, habitat quality and suitability upstream, as well as other potential ecological information, such as the potential to spread pest species.

Canning River hydrology

The Canning River arises on the Darling Plateau, joins the Swan River downstream of Kent Street Weir (KSW) and has a total length of 110 km and catchment size of 1300 km^2. The reaches of the Canning River in the Darling Scarp are relatively undisturbed, while the remaining catchment from the scarp (and the Canning Dam) to the coastal plains have been large cleared and urbanised (Middelmann et al. 2005). The hydrological record prior to the development of the Canning River indicates a strong variation in seasonal spring/summer and winter flow regimes. The river is now heavily regulated with three public water supply dams (Canning, Churchman Brook and Victoria), two pumpback stations (Araluen and Bickley) and several release points along the river to supply scheme water (during summer) to users living alongside it and to meet the ecological needs of the river (DOW 2012). Moreover, there are numerous other instream barriers that have been constructed for private water use by riparian landholders between KSW and the Canning Dam (approximately 60 km upstream).

Kent Street Weir

Kent Street Weir (KSW) was constructed in 1927 to limit tidal influence and maintain an upstream freshwater weir pool of approximately 5 km in length for agricultural purposes. Historically, the KSW has been manually operated by removing the weir boards when the winter flows are sufficient to prevent estuarine (salt) water moving upstream. This action restores bio-connectivity and with sufficient winter flow is thought to flush the accumulated sediments of the weir pool. Previously the winter flows have been sustained for approximately four months each year, however, within recent years only one to two months of sufficient flows have occurred. Record low rainfall in winter 2010 meant that the KSW boards were not removed. High tides through 2010–11 resulted in significant saltwater inundation (overtopping the weir) and the intrusion of saline water further upstream (Storer et al. 2013). Storer et al. (2013) confirmed that salt tolerant fish species were able to move further upstream than previously recorded, but overall the impact of the intruding saline water was thought to be less ecologically damaging than the long term impacts of sediment, organic matter and contamination accumulation (most notably chlordane, copper, lead, zinc) and resulting deterioration of water quality associated with the weir pool (Storer et al. 2013). A recently constructed oxygen plant and planned upgrades of the existing oxygen plants can guarantee oxygenation of at least 4.5 km of the KSW pool (A. Hams, pers. comm. DPAW, May 2016).

Fish species in the vicinity of the Kent Street Weir

Fish can be classified based on their migratory groups and behavioural patterns for freshwater species (Morgan et al. 2014) and marine and estuarine species (Potter et al. 2015). Fish regularly sampled in estuarine environments are classified according to four main categories (marine, estuarine, diadromous, freshwater), each of which contain two or more guilds associated with the location of spawning, feeding, refuge and migration between estuaries the marine and/or freshwater ecosystems (Potter et al. 2015). The Swan Canning system currently houses only potamodromous (migration and complete life-cycle within freshwater) freshwater native species, which are further delineated in Morgan et al. (2014). It also houses numerous estuarine species; several of which can often move upstream into freshwater environments for significant periods of time, and in some instanced develop self-sustaining populations (e.g. Morgan et al. 2014; Potter et al. 2015).

Most alien fish species in the Swan Canning are currently all considered to be freshwater potamodromous species. Most of these species also have a high tolerance to salinity and can therefore also be often found in estuarine conditions.

KSW is known to prevent movement of some fish species at certain times; restricting habitat availability and resulting in some mortality where individuals become trapped by the weir (e.g. freshwater species trapped below the weir) (Storer et al. 2013). Low abundances of native freshwater fish species including Western Pygmy Perch (*Nannoperca vittata*), Western Minnow

(*Galaxias occidentalis)*, Nightfish (*Bostockia porosa*), and Freshwater Cobbler (*Tandanus bostocki*) have previously been captured upstream of KSW (Storer et al. 2013).

Fish composition in the weir pool upstream of KSW has previously been dominated by Eastern Gambusia (*Gambusia holbrooki)* and Swan River Goby (*Pseudogobius olorum*) and also high abundances of Black Bream (*Acanthopagrus butcheri*) (Storer et al. 2013). Other species captured in the upstream weir pool include Western pygmy perch, Yellowtail Trumpeter (*Amniataba caudavittata*), Western Hardyhead (*Leptatherina wallacei*), Sea Mullet (*Mugil cephalus*), Bridled Goby (*Arenigobius bifrenatus*), Western Striped Grunter (*Pelates octolineatus*) and Goldfish (*Carassius auratus*). As well as Eastern Gambusia and Goldfish, other feral fish species that have been captured in the Canning River in the vicinity of KSW include One-Spot Livebearer (*Phalloceros caudimaculatus* now *P. harpagos*), Koi carp *(Cyprinus carpio*), Spangled Perch (*Leiopotherapon unicolor*) and Pearl Cichlid (*Geophagus brasiliensis*)*.* Other aquatic taxa also collected upstream of KSW include South-west Glass Shrimp (*Palaemonetes australis*), Oval Spider Crab (*Halicarcinus ovatus*), Marron (*Cherax cainii*), Gilgie (*Cherax quinquecarinatus*), Yabbie (*Cherax destructor*), Oblong Turtle (*Chelodina colliei*) and Murray River Turtle (*Emydura macquari*) (Storer et al. 2013).

Downstream of KSW some freshwater fish species have previously been collected including Western Pygmy perch, Western Minnow, Eastern Gambusia and Goldfish. A number of estuarine and marine species have also been collected immediately downstream including Swan River Goby, Western Hardyhead, South-Western Goby (*Afurcagobius suppositus*), Black Bream, Sea Mullet, Yellowtail Trumpeter, Bridled Goby, Western Grunter, Gobbleguts (*Apogon rueppelli*), Elongate Hardyhead (*Atherinosoma elongata*), Perth Herring (*Nematalosa vlaminghi*), Spotted Hardyhead (*Craterocephalus mugiloides*), Yellowspotted Sand Goby (*Favonigobius punctatus*), Banded Toadfish (*Torquigener pleurogramma*), Southern Anchovy (*Engraulis australis*), Yelloweye Mullet (*Aldrichetta forsteri*), Western Trumpeter Whiting (*Sillago burrus*), Yellowtail Flathead (*Platycephalus westraliae*), Southern Eagle Ray (*Myliobatis australis*) and Flathead Sandfish (*Lesueurina platycephala*) (Storer et al. 2013; Hallet and Tweedley 2014). Other aquatic taxa also collected downstream of KSW include South-west Glass Shrimp and Oblong Turtle (Storer et al. 2013).

Project Objectives

This study aims to assess the relative impact of the weir on upstream and downstream fish populations and in so doing provide the background information for the improvement of fish passage to mitigate the impact of the weir. Specific objectives were to:

- establish a fish monitoring program during spring/summer both above and below KSW
- determine and compare the fish population structure and species abundances above and below the KSW
- determine the requirements and timing of migrations of resident fishes
- identify the impacts of the barrier to the movements and ecology of native and feral fish
- develop preliminary recommendations for appropriate fishway designs to facilitate passage of target species

Methods

Sampling and prevailing hydrology

Six fish sampling events were conducted fortnightly from October 22 to December 30, 2015. Daily rainfall data for the Perth airport in 2015 showed that the wettest months were June (100 mm), July (99 mm) and August (103 mm), with a total annual rainfall of 577 mm. Highest daily rainfall events occurred between May and August with peaks of 40 mm on May 18, 37 mm on June 21, 34 mm on July 34 and 25 mm on August 20. Smaller rainfall events occurred from September with peak events of 14 mm on September 5, 13.4 mm on September 12 (as well as 8.6 mm on September 11 and 10 mm on September 15), 15 mm on November 2 and 11 mm on December 6 (Figure 1).

The September 5 and 6 sample event would therefore represent the only sample influenced by increase stream runoff due to rainfall. This increased runoff is shown in the water level recorded upstream of KSW with the increase from 0.55 to 0.64 m AHD. The other minor rainfall event (i.e. 4.6 mm on December 5 and 11 mm on December 6) resulted in an increased water level above KSW from 0.54 to 0.59 m AHD. This occurred after the sampling event on December 4 and 5 (Figure 1).

The KSW boards were removed on August 29 following a relatively high rainfall event in mid-August, however without sufficient follow-up rainfall in September, they were replaced on October 2 to prevent the upstream intrusion of saline tidal water (Figure 1).

Maximum height of water below KSW reflects the tidal influence variability and shows peak heights every 8 to 15 days.

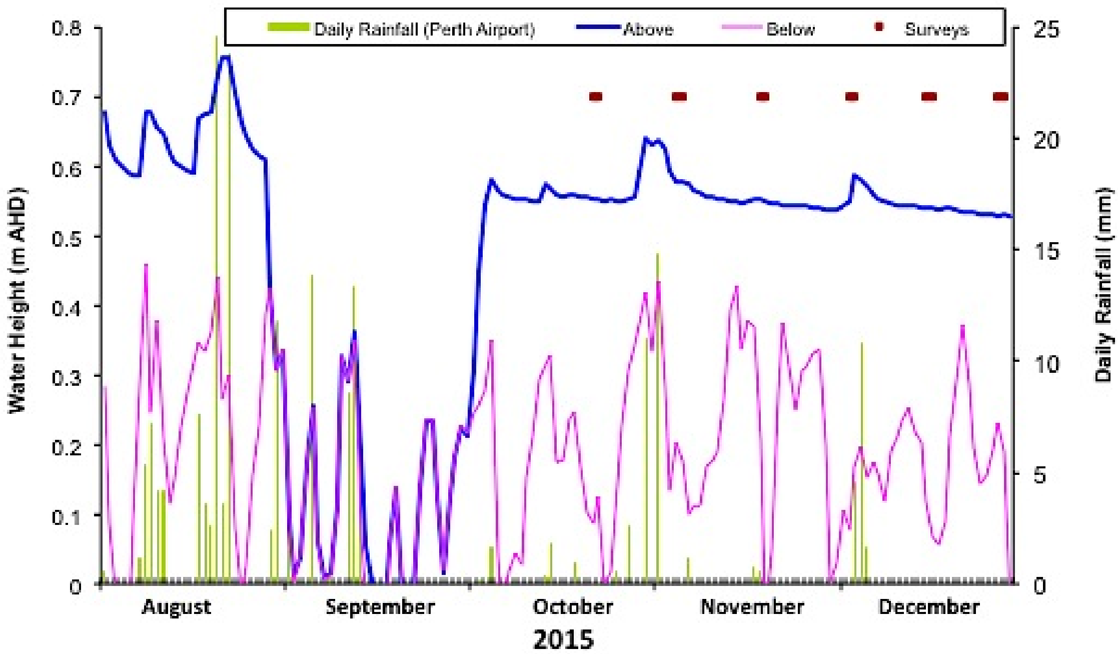


Figure 1: Maximum daily water height (m AHD) above and below KSW, daily rainfall at Perth Airport (mm) and corresponding fish survey dates

Gill nets, seine nets and fyke nets were employed above and below KSW on each sampling occasion. Three gill nets (two 3 inch and one 4 inch stretched mesh) were set for up to two hours in an attempt to capture any large bodied fish present.

Gill netted fish can stress easily and with the capture of large numbers in nets, some fish can be adversely impacted due to the time required for removal and from the impact of entanglement. To minimise this impact, the gills nets below KSW were set for less than1 hour when fish capture rates were comparatively high.

Three seine net (2 mm mesh) pulls were also conducted above and below KSW to sample smaller sized fish present.

Double wing fyke nets (4 mm mesh) were also set overnight above and below KSW. Fyke nets are designed to determine directional movement of fish and each pair were set to capture fish moving in an upstream and downstream direction. Each fyke net had solid plastic mesh with vertical openings of 200 mm high and 60 mm wide in an attempt to exclude large predators such as turtles from entering the net. Each net was also set with two 150 mm polystyrene buoys in the cod end and tied to fixed star pickets at least 200 mm above the high tide mark to ensure that any captured air breathing animals could find the surface to breathe. On most sampling events, two pairs of fyke nets were employed above and below the KSW. However, due to very large fish abundance captured below KSW on November 19, it was decided to use only one pair of fyke nets in subsequent sampling events (i.e. the remaining three). The potential for damaging captured fish increases with increasing fish abundance because fish have less room to move and can damage each other or get pushed up against the net. Halving the number of fyke nets used below KSW mitigated the potential damage to captured fish.

All fish were counted and representative samples of individual fish were measured to the nearest 1 mm total length (TL). Catch-per unit effort for each gill net was calculated using the total capture, divided by the length of each net and time the nets were set. Density of captured fish in seine nets was calculated using the total catch of each species/area of river sampled (m^2) of individuals captured. Catch-per unit effort for each fyke net was calculated using the total capture, divided by the time the nets were set.

All native fish and crayfish were identified using Allen et al. (2002), Morgan et al. (2011) and Gomon et al. (2008), measured to the nearest mm, and then returned to the water as soon as possible. Other captured animals, including turtles and frogs, were counted and returned to the water as soon as possible. Feral fish species were euthanised and disposed of according to the Murdoch University Ethics protocols.

Water quality measurements were made at two locations above (100 m and 500 m upstream) and below (100 m and 500 m downstream) of KSW during each sampling occasion. To obtain physicochemical variables an YSI™ Professional Plus multimeter (YSI Inc., Yellow Springs, Ohio 45387, USA) was used. Water quality variables included temperature, pH, electrical conductivity (µS/cm), salinity (ppt), dissolved oxygen (% saturation and ppm) and oxidation reduction potential (ORP). Water quality parameters were recorded at increments 0.5 m from the surface to the bottom in an attempt to detect any potential differences throughout the water column.

Results

Summary of total captures

The six sampling events captured a total of 19,294 fish including representatives from two native freshwater species, 10 native estuarine/marine vagrant species and four introduced fish species. In addition 68 turtles, 262 tadpoles, and 7,911 decapod crustaceans were captured (Table 1).

The most common native fish species caught were the Western Hardyhead (5,862 in total = 30.4% of all captures), Swan River Goby (4,658 = 24.4%), Black Bream (2,206 = 19.8%), Yellowtail Trumpeter (1,371 = 11.4%), Sea Mullet (219 = 1.1%) and only 22 freshwater fish (including 13 Western Pygmy Perch and 9 Western Minnow). Eastern Gambusia was the most abundant feral fish species (3,829 = 19.8%), followed by Pearl Cichlid (986 = 5.1%), Goldfish (n = 99) and Koi Carp (n = 2).

A total of 1,086 native fish were caught above KSW (7.6% of all native fish), compared to 13,291 (92.4%) caught below. Species caught exclusively below KSW include Yellowtail Trumpeter, Bridled Goby, Elongate Hardyhead, Giant Herring, Perth Herring and Western Minnow. In contrast, the majority (80 %) of the feral fish were caught above KSW, including 78% of the Eastern Gambusia and 88 % of the Pearl Cichlid (Table 1).

Additional aquatic species captured included 66 Oblong Turtle, two Murray River Turtles, 262 Western Bell Frog (*Litoria moorei*) tadpoles and 7,811 South-west Glass Shrimp.

Table 1: Capture summaries from all methods above and below KSW during for each sampling event

>100	High
31-100	Moderate
11-30	Low
1-10	Rare

		22/OCT/15		05/NOV/15		19/NOV/15		04/DEC/15		17/DEC/15		29/DEC/15	
		Above	Below	Above	Below	Above	Below	Above	Below	Above	Below	Above	Below
Estuarine	Black Bream	1	9	3	9		1499		406		269		10
	Yellowtail Trumpeter		36		3		107		647		332		246
	Southwestern Goby					2	4		1				
	Swan River Goby	92	567	164	1548	67	1494	101	159	166	125	63	112
	Bridled Goby		2				13		2		3		1
	Western Hardyhead	58	1706	109	815	124	2595	39	77	19	267	8	45
	Elongate Hardyhead												7
	Giant Herring												1
	Perth Herring										1		3
	Sea Mullet	13	9		5	3	31	6	68	40			44
Fresh	Western Pygmy Perch	3			1	1	3			4		1	
	Western Minnow				9								
Introduced	Goldfish			33	3	37	12	5		5		4	
	Koi Carp	1				1							
	Pearl Cichlid	6	1	10	18	95	73	166	12	372	9	220	4
	Eastern Gambusia	112	21	31	11	1222	58	430	528	441	33	762	180

Figure 2: Photos of some of the aquatic species captured during the survey.

Clockwise from top left: Adult male Pearl Cichlid, Adult Male Western Pygmy perch, Gilgie, Sea Mullet, Bridled Goby, Western Minnow, female Yellowtail Trumpeter, dip net full of juvenile Black Bream, female Western Hardyhead (running ripe), adult Black Bream and Murray River Turtle (center)

Spatial and temporal patterns of species

Of the native freshwater fishes, nine Western Pygmy Perch were caught above and four below the KSW, and the nine Western Minnow were caught below KSW. Most of the Western Pygmy Perch were larger adults (39 - 55 mm), however four juvenile fish were captured above KSW on December 18 and 30. Western Minnows were all caught during one sampling event on November 5 and were between 43 and 59 mm TL (Table 1).

Western Hardyhead

The majority (5,505 - 94%) of the Western Hardyhead were consistently captured below KSW over the sampling period. Larger abundances were captured earlier in the sampling period from October 22 to November 19 (Table 1, Appendix A, Appendix B). The deployment of one pair of fyke nets below KSW from December 4 onwards would have influenced this overall result; however the fyke net catch per hour also demonstrates a decline in the catch rate of Western Hardyhead below KSW for December 4 and 17 and a relative increase in catch rate on December 29 (Appendix B). Consistent juvenile recruitment was evident below KSW from October 22 (30 mm or less) up to the last sample on December 29, when no smaller juveniles were captured in fyke or seine nets (Appendix A, Appendix B, Figure 3).

Above KSW there was also evidence of juvenile recruitment of the Western Hardyhead on October 22 and November 5, but this was not observed in the subsequent four sampling events. This result highlights the likelihood of juvenile recruitment when the boards were removed in August and September.

The majority of Western Hardyhead caught below KSW were juveniles and of the adults captured, few were observed to be in spawning condition. In comparison the Western Hardyhead above the KSW consisted of more adult fish with a greater proportion in spawning condition throughout the sampling period, peaking on December 4. The assessment of spawning condition provides a further explanation for the difference in the recruitment of juveniles above and below KSW (see Appendix D).

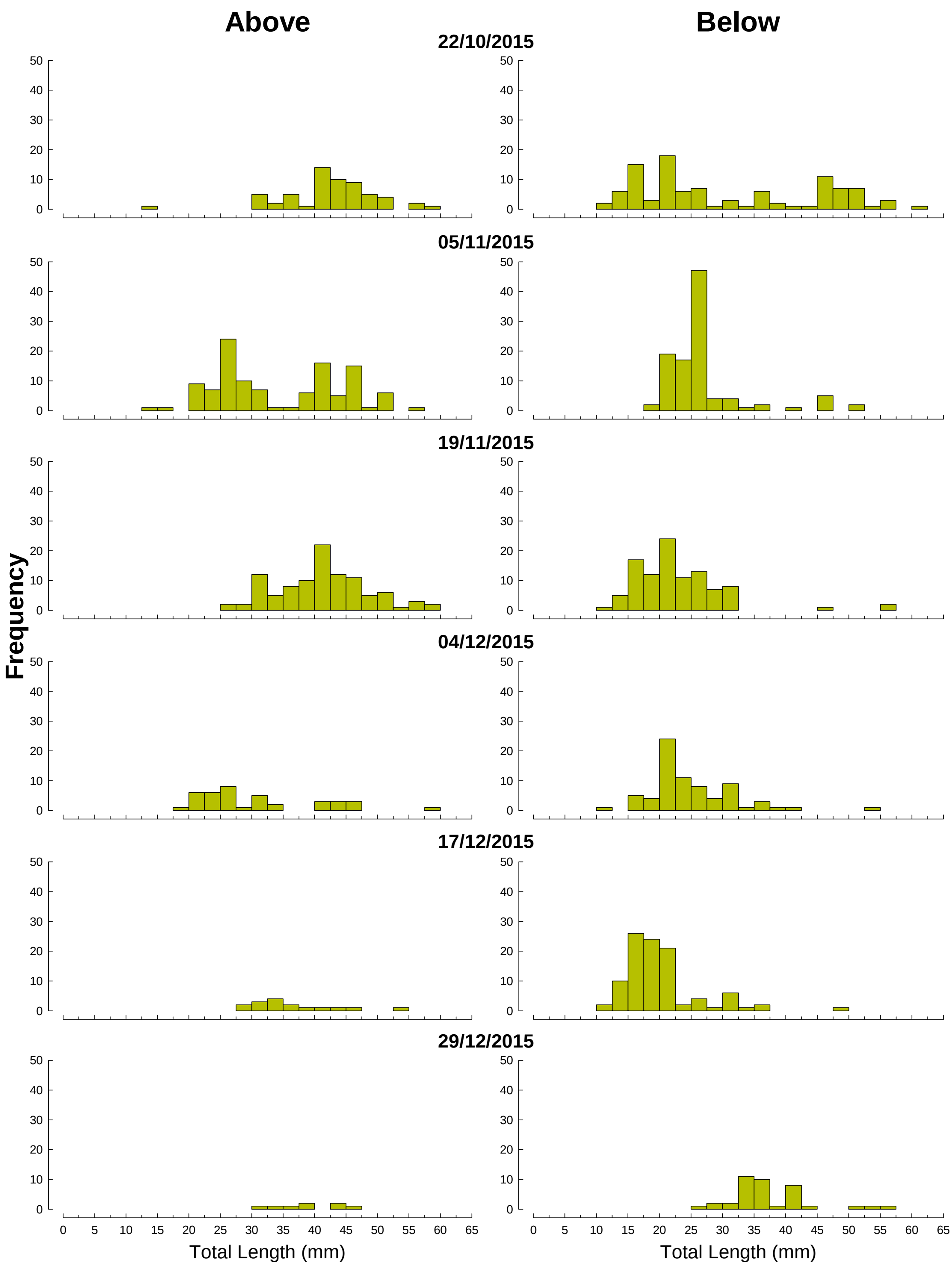


Figure 3: Length-frequencies of the Western Hardyhead above and below KSW during for each sampling event

Swan River Goby

Abundance and distribution of Swan River Goby was similar to Western Hardyhead. The majority (4,005 - 86%) of the Swan River Goby were captured below KSW . Larger abundances were captured earlier in the sampling period from October 22 to November 19 (Table 1, Appendix A, Appendix B), with corresponding decline in the seine net capture density and fyke net capture rate in the subsequent 3 sampling events. Juvenile recruitment was evident below KSW from October 22 (30 mm or less) but declined towards the end of the sampling period

(Appendix A, Appendix B, Figure 4). Most of the Swan River Goby caught below KSW were juveniles throughout most of the sampling period, except for the last event on December 29 when a high proportion of adults in spawning condition was noted (Appendix D).

Above KSW there appeared to be a delay and restriction in juvenile recruitment (17 mm or less) to November 19 and December 4. There was also a larger proportion of adult Swan River Goby above the weir, but there was generally a low number in spawning condition (Figure 4, Appendix A, Appendix B, Appendix D). The majority of Swan River Goby caught below KSW were juveniles. In comparison the Swan River Goby above the KSW consisted of more adult fish with a greater proportion of mature fish throughout the sampling period. During a concurrent study on the Blackadder Creek (Swan River catchment) the spawning period for this species appeared to occur from early September with warmer water conditions, resulting in an abundance of juveniles from early October onwards (Ryan et al. 2015). This spawning pattern confirmed previous observed patterns observed in the Swan River Catchment (Gill et al. 1996).

Black Bream

Four adult Black Bream were caught in gill nets above KSW on October 22 and November 5. No other Black Bream were captured above KSW with any other sampling method in the four subsequent sampling events (Table 1, Figure 5, Appendix C).

Below KSW Black Bream were consistently captured by all three sampling methods. Adult fish were captured using gill nets during all sampling events with a peak capture rate of 0.1 fish/m/hr (Appendix C). Two of the nine adult Black Bream captured in October 22 were still exhibiting signs of spawning condition, however in subsequent sampling events of spawning condition was not detectable. Fyke nets captured mostly juvenile Black Bream from November 5, but had the highest captures in November 19 with catch rates greater than 100 fish per hour (150 ± 44 for downstream moving fish, 101 ± 48 for upstream moving fish) (Appendix B). Seine net captures followed a similar pattern with captures more common from November 19 peaking at a maximum density of 6 (± 7) fish /m on December 4. The strong recruitment of juveniles can be seen in Figure 5 progressing from 20 to 40 mm in length on November 19 to 30 to 70 mm on December 29. The reduced abundance of this cohort by December 29 is likely to be due the movement of these juveniles to other suitable nursery habitats downstream, along with some level of mortality from including predation from birds and larger fish.

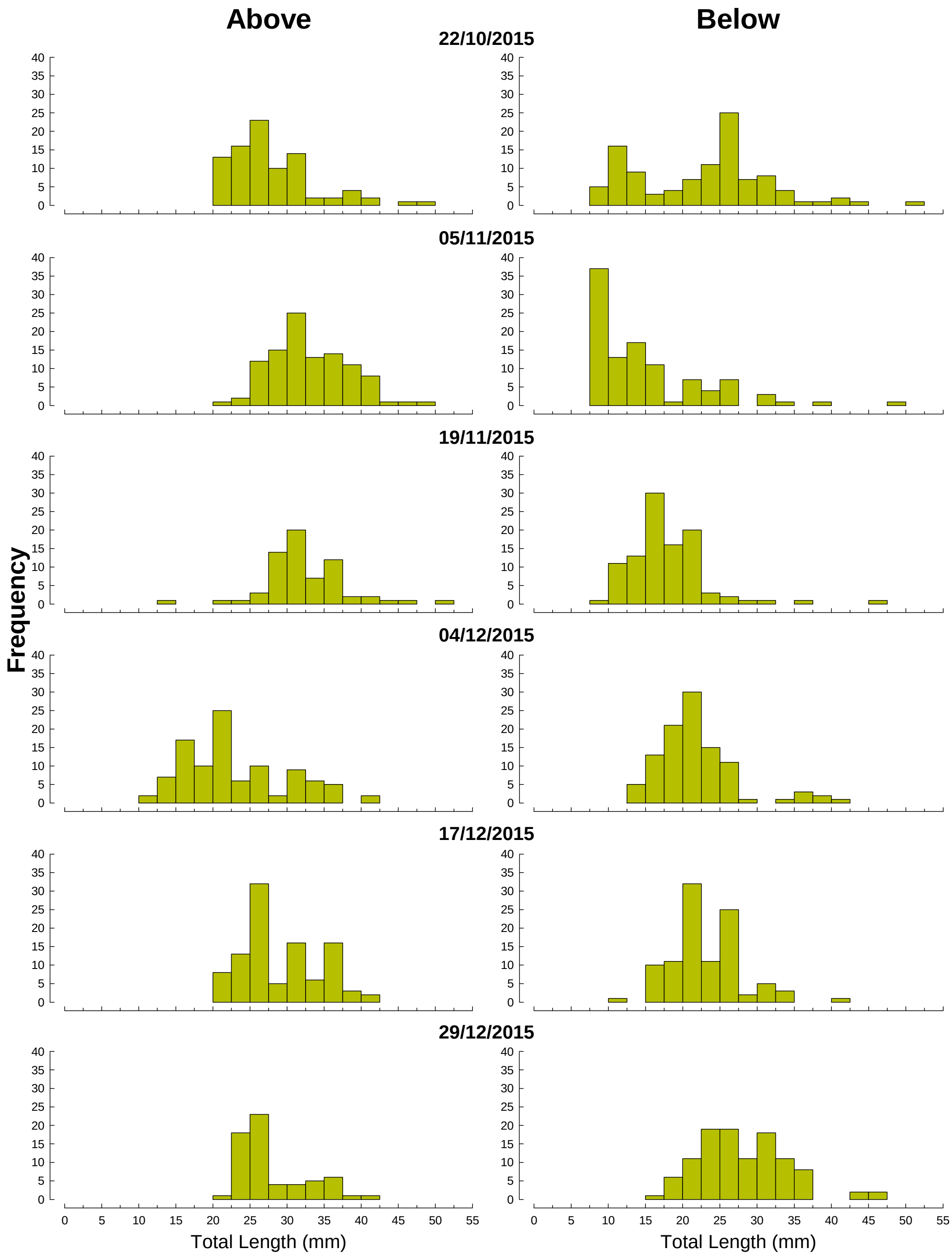


Figure 4: Length-frequencies of the Swan River Goby above and below KSW during for each sampling event

(N.B. Length-frequency plots are derived from a maximum of 100 individuals measured from each sample)

Yellowtail Trumpeter

Yellowtail Trumpeter was also caught below KSW during most sampling events predominately with the use of fyke nets (Table 1: Figure 6). Juvenile recruitment was first detected on November 19 with the influx of smaller fish of 18 to 45 mm with gradually declining abundance during subsequent sampling events. Adults of >140 mm TL were consistently captured downstream of KSW (apart from the small numbers captured on November 5). Large fyke net capture rates of up to 361 individuals/net were made from December 4, justifying the decision to deploy just one fyke net pair to minimise potential harm to captured fish (Appendix B).

Sea Mullet

Sea Mullet were consistently captured above and below KSW predominately in gill nets. Two juvenile Sea Mullet were captured in seine net pulls and three captured in fyke nets on October 22 and December 4 (Table 1, Appendix A, Appendix B). The remaining 214 Sea Mullet captured in gill nets were similar in length above and below KSW and consisted of mostly one size class (280 - 400 mm TL) (Figure 7, Appendix C). It is therefore apparent that this species moves upstream of KSW during winter, while the weir boards were removed, and are able to persist above KSW in freshwater conditions. The lack of Sea Mullet captured above KSW on November 5 and December 29 and below KSW on December 17 is likely to represent small scale movements within the local water bodies away from the capture location.

Other estuarine and marine fish

The Bridled Goby, Elongate Hardyhead, Southwestern Goby, Giant Herring and Perth Herring were not recorded above KSW but were all captured in low abundance and frequency below the weir (Table 1).

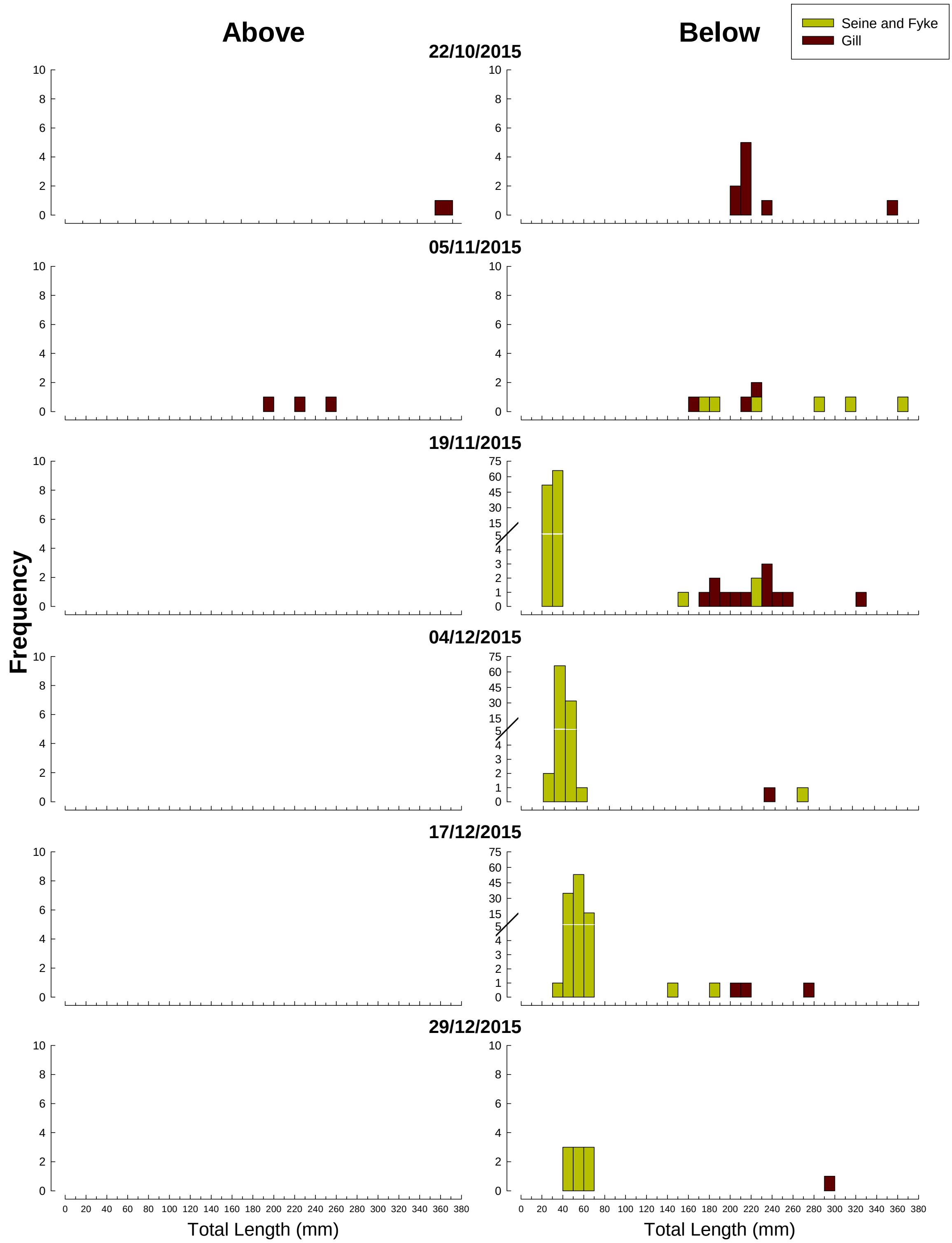


Figure 5: Length-frequencies of Black Bream above and below for each sampling event

(N.B. the clear recruitment of juveniles below the weir detected from November 19)

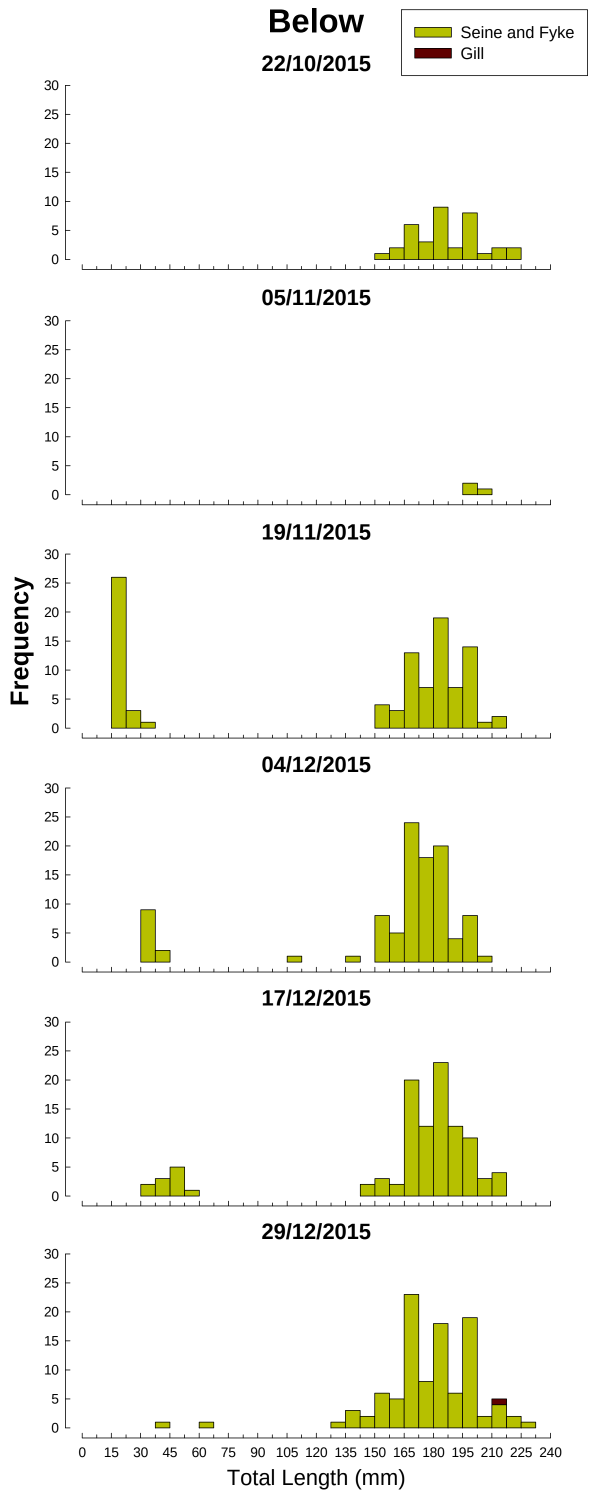


Figure 6: Length-frequencies of Yellowtail Trumpeter below KSW for each sampling event

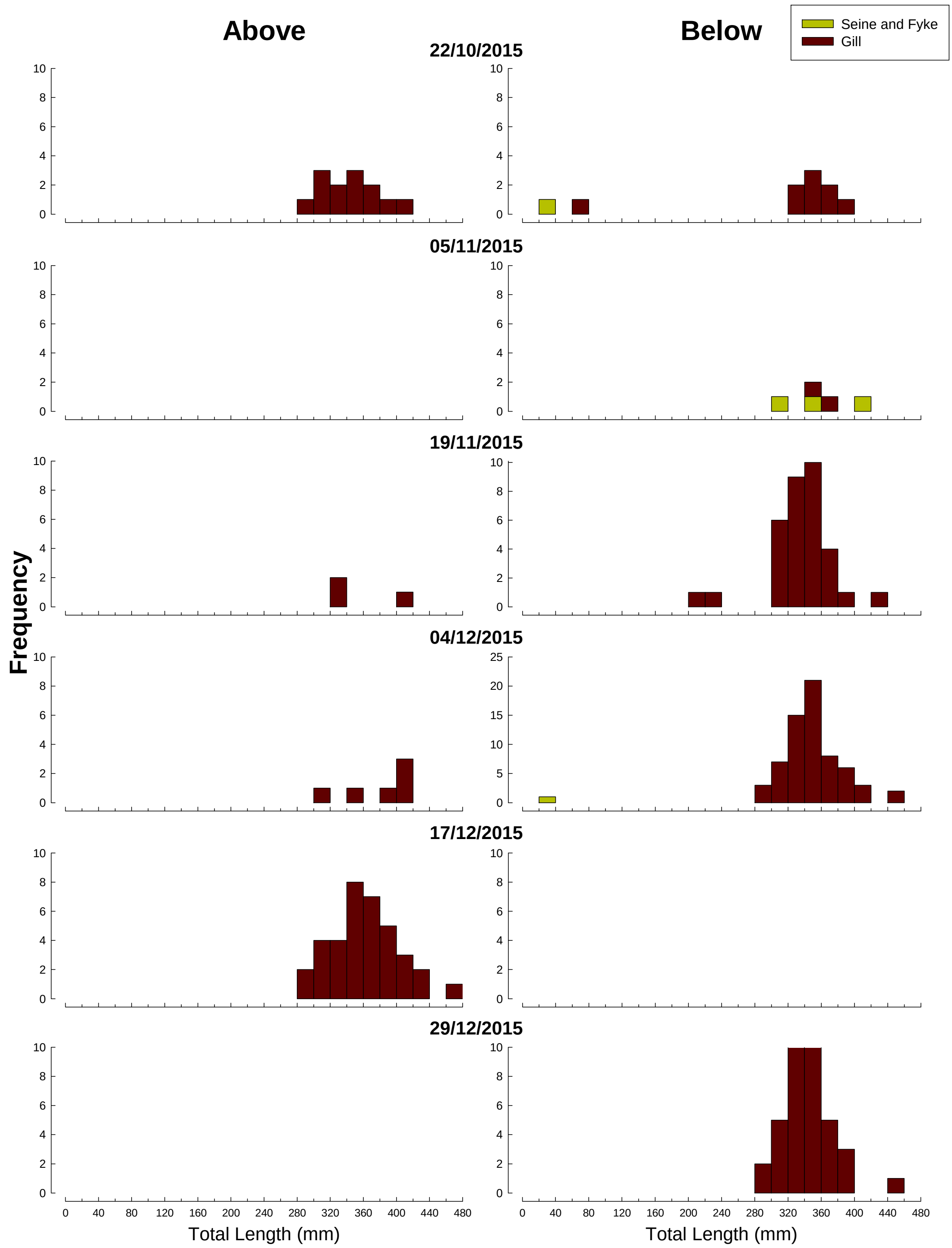


Figure 7: Length-frequencies of Sea Mullet above and below KSW for each sampling event

Feral fish species

Eastern Gambusia was substantially more abundant above KSW than below, with fyke net capture rates generally increasing during the study, peaking at 112 fish/hour on December 30 (Table 1, Appendix A, Appendix B). A successful 2015 breeding season is evident with a number of recruits being continually captured during each sampling event with a peak length cohort from 22.5 to 27.5 mm (Figure 8). Adults were noted to be in breeding condition throughout the survey period which was likely to have commenced in September and would probably continue until early autumn 2016. The comparatively lower abundance of this species below KSW during sampling may be a result of predation by other fishes or unfavourable conditions such as higher salinities.

The Pearl Cichlid was abundant above and below KSW (Table 1). Apart from the capture of two larger individuals in gill nets (Appendix C), most were captured in seine and fyke nets (Appendix A, Appendix B). A strong recruitment of juveniles was captured with a peak cohort at 15 to 30 mm being evident from November 11 below KSW and November 19 above KSW (Figure 9).

Goldfish were captured below and above KSW. Most captures were made using fyke nets, including 14 of the 15 total caught below KSW and 67 of the total 84 caught above KSW. Higher capture rates occurred below the KSW in November 5 and 19. All goldfish captured (above and below) were comparatively small, with lengths ranging from 22 - 46 mm TL.

Only two small Koi Carp were captured during the survey period, however, it should be noted that a number of large adult individuals were observed swimming around the channel margins above the weir on all survey events.

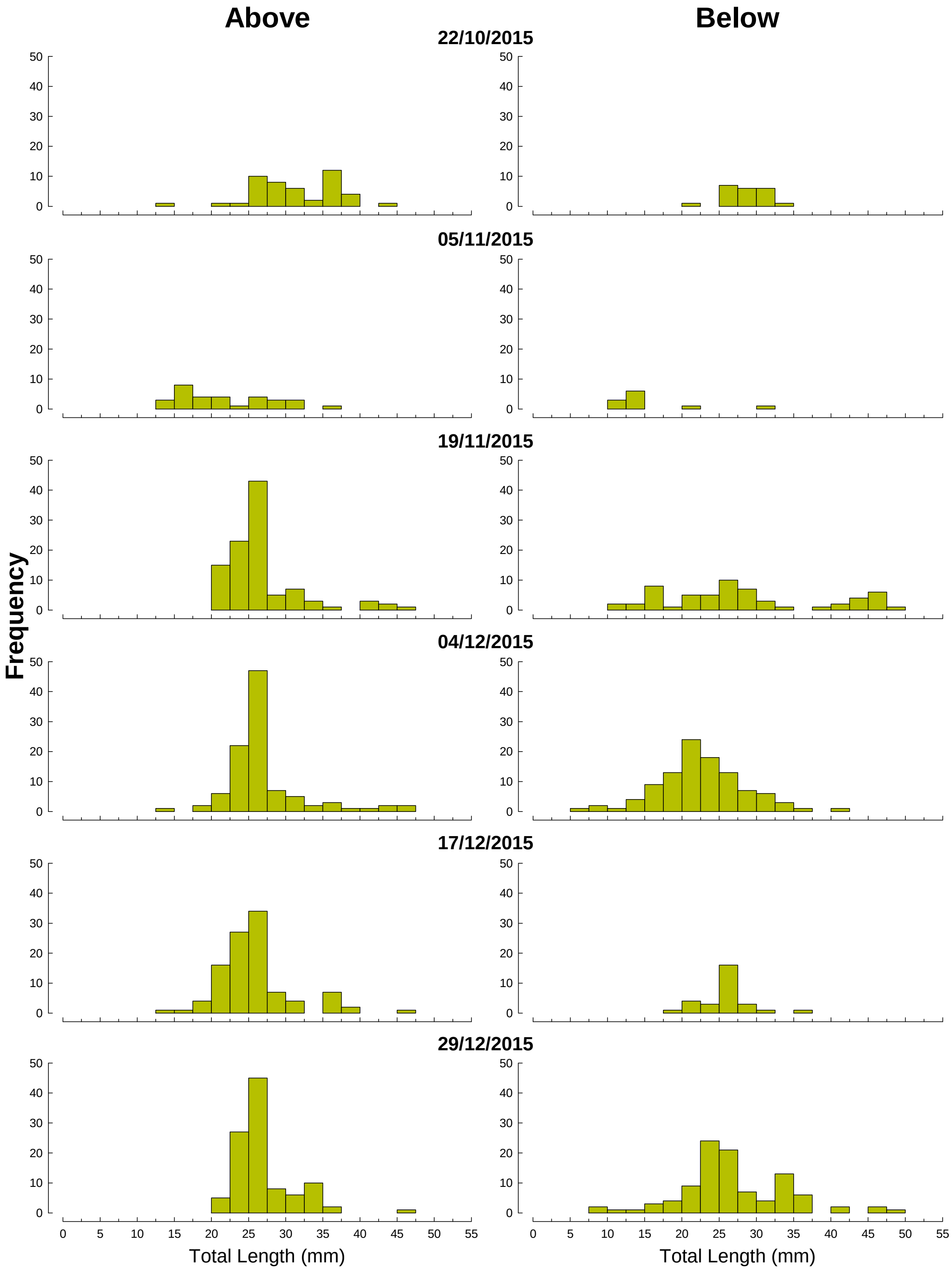


Figure 8: Length-frequencies of Eastern Gambusia above and below KSW for each sampling event

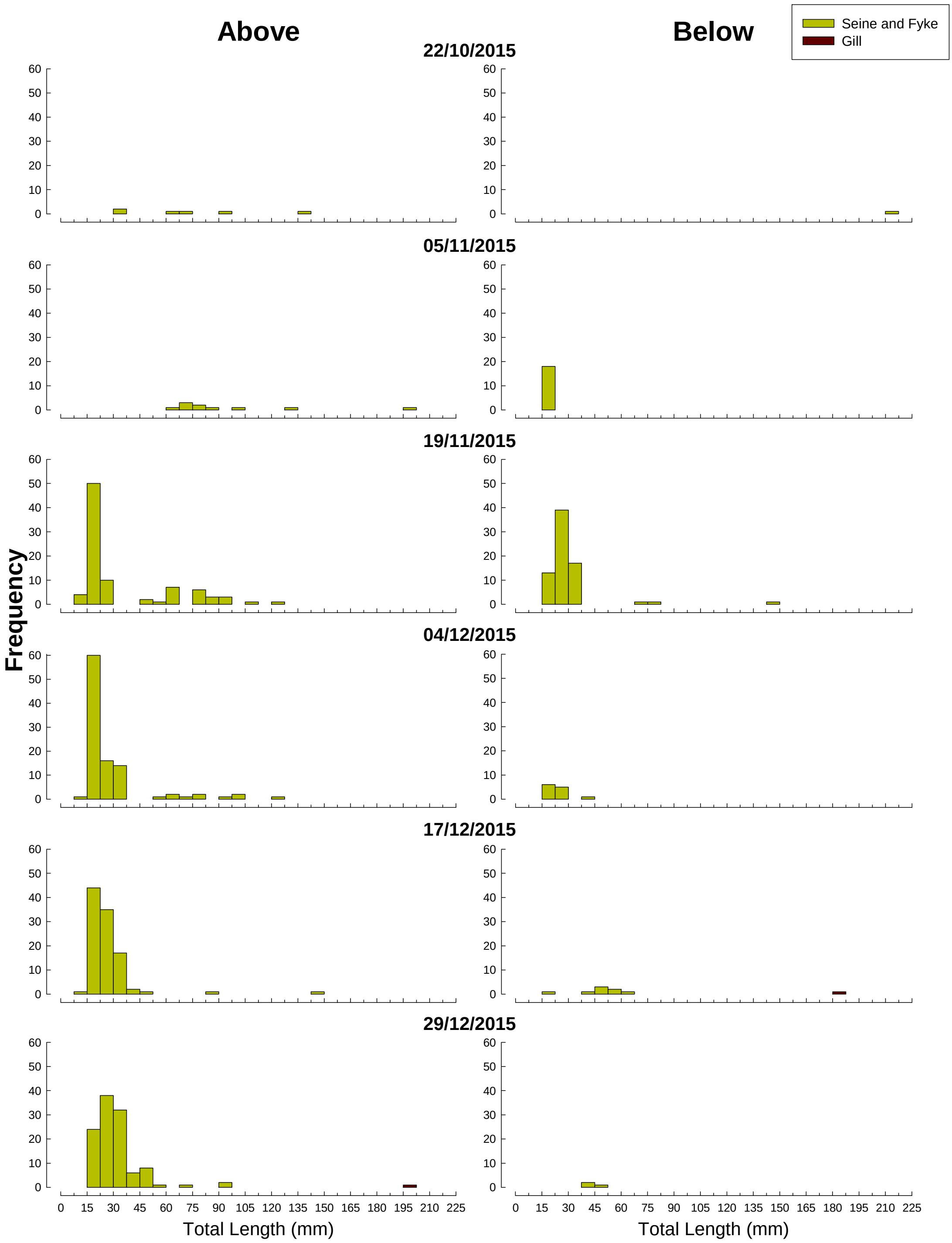


Figure 9: Length-frequencies of Pearl Cichlid above and below KSW for each sampling event

Differences in captures between sampling gear

Gill nets captured 1% of total fish captures, but were important to determine the occurrence of some of the larger fish in the system. They were particularly effective at capturing Black Bream, Sea Mullet and also provided the only records for Perth Herring and Giant Herring (Table 2).

Fyke nets captured 36% of all fish during the study and captured approximately 2.5 times more fish below than above KSW. Fyke nets were a particularly efficient capture method for Black Bream (juveniles), Yellowtail Trumpeter, Swan River Goby, Goldfish, Pearl Cichlid, tadpoles, Longneck Turtles and South-west Glass Shrimp (Table 2, Appendix B). Directionality of fyke net positioning was in the most part inconclusive with relatively even abundances of fish captured moving in an upstream and downstream direction both above and below KSW (Table 2).

Seine net pulls targeted the smaller fish and captured 63% of all fish, including the majority of the Western Hardyhead, Eastern Gambusia and a large proportion of the Swan River Goby captured (Table 2).

Table 2: Summary of total capture by each method

>100	High
31-100	Moderate
11-30	Low
1-10	Rare

		Above Weir			Below Weir		
		Fyke	Gill	Seine	Fyke	Gill	Seine
Estuarine	Black Bream		4		1668	32	502
	Yellowtail Trumpeter				1346	1	24
	Southwestern Goby	2			1		4
	Swan River Goby	475		178	1148		2857
	Bridled Goby				12		9
	Western Hardyhead	256		101	531		4974
	Elongate Hardyhead				7		
	Giant Herring					1	
	Perth Herring					4	
	Sea Mullet		62		3	152	2
Fresh	Western Pygmy Perch	9			4		
	Western Minnow				1		8
Introduced	Goldfish	67		17	14		1
	Koi Carp			2			
	Pearl Cichlid	560	1	308	82	1	34
	Eastern Gambusia	616		2382	104		727
Other Native Biota	Tadpole	233		29			
	Longneck turtle	38			28		
	Murray River Turtle				1	1	
	Gilgie	1					
	SW Glass Shrimp	5346		242	2221		102

Physicochemical variables

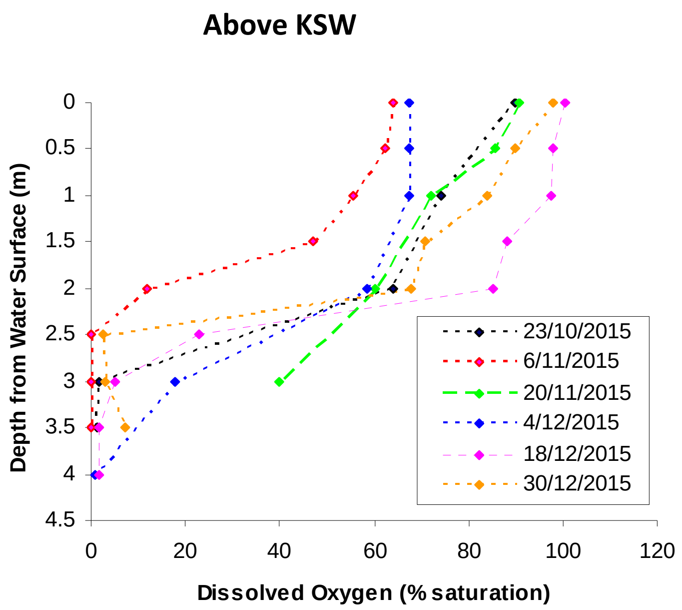
Water quality of the Canning River above and below KSW at the times of sampling (Table 3) was mostly within the range known to be tolerable to the native fish species of the region based on the field threshold analysis of south-western Australian freshwater fishes (see Beatty et al. 2013a). All pH values fell within the recommended suitable range for the protection of aquatic biota for South-Western Australian waterways of 6.5 - 8.0 for lowland rivers (ANZECC 2000) (above KSW), however on December 3 and 29 the pH below KSW was elevated and greater than the 7.5 – 8.5 recommended for estuaries (ANZECC 2000).

Dissolved oxygen concentrations had a similar pattern to the pH and were mostly within the suitable range for the protection of aquatic biota for South-Western Australian waterways of 80 - 120 % saturation for lowland streams and 90 – 110 % saturation for estuaries (ANZECC 2000). Dissolved oxygen conditions did vary outside this range during two sampling occasions in December, when super-saturated dissolved oxygen levels were measured below the KSW in the upper 1.5 m of the water column.

These two events highlighted the lack of mixing of saline water below KSW in December and coincided with comparatively higher temperature and water conductivity. Without the KSW restricting tidal movement, these potentially unfavourable conditions would be likely to progress further upstream.

Table 3: Surface environmental variables taken in the Canning River above and below KSW for each sampling event

Date	Site	Temperature (ºC)	Dissolved Oxygen (% saturation)	Dissolved Oxygen (mg/L)	Conductivity µS/cm	Salinity (ppT)	TDS (mg/L)	pH	ORP
22/10/2015	Below	23.7	71.6	6.1	10427	6.1		7.63	60.4
23/10/2015	Above	21.0	90.0	7.9	1006	0.5		7.68	170.5
5/11/2015	Below	24.3	82.7	6.9	610	0.3	403	7.72	-134.0
6/11/2015	Above	22.5	62.3	5.4	574	0.3	390	7.48	-38.0
19/11/2015	Below	26.7	90.1	7.2	3480	1.8	2190	7.83	-112.0
20/11/2015	Above	24.8	85.7	7.7	993	0.5	650	7.60	40.7
3/12/2015	Below	31.3	164.7	11.1	24174	12.8	13829	8.63	47.2
4/12/2015	Above	24.7	65.8	5.4	1136	0.6	744	7.70	30.2
17/12/2015	Below	30.8	103.8	7.5	11000	5.5	6422	8.20	-57.0
18/12/2015	Above	26.5	95.1	7.6	1025	0.5	647	7.80	24.0
29/12/2015	Below	33.7	217.0	13.4	40900	22.0	22948	8.80	9.0
30/12/2015	Above	27.0	87.5	7.0	1077	0.5	676	8.00	25.3



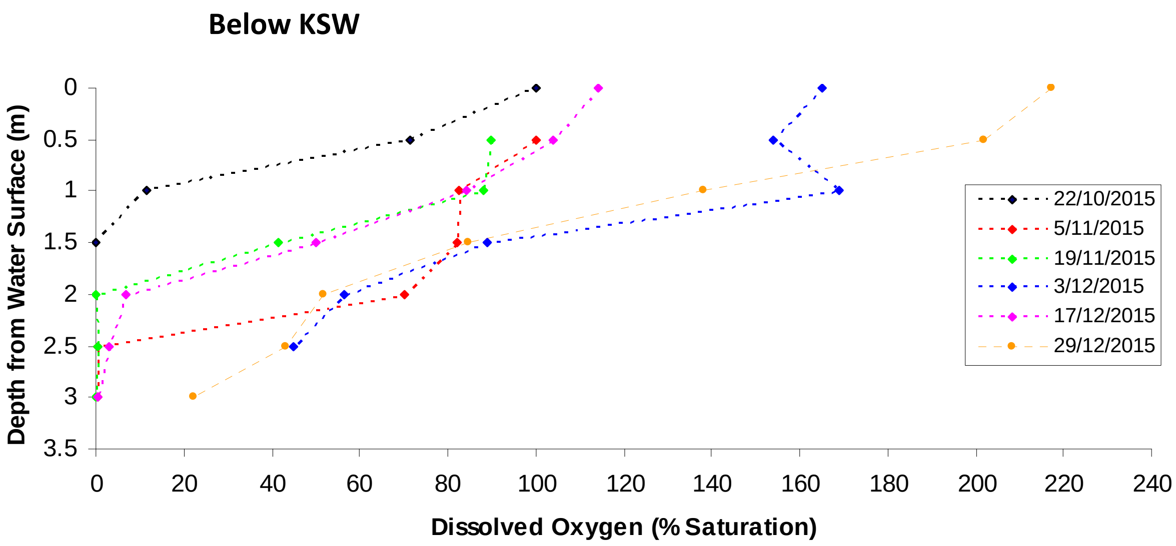


Figure 10: Depth profile of dissolved oxygen above and below KSW for each sampling event

Discussion

Impact of the KSW on fish migrations and implications for fishway design

One of the prerequisites for determining the need for a fishway is to characterise the distribution, abundance, diversity and life stages of fish attempting to move past KSW to infer its potential biological impacts. The current study, together with Morgan and Beatty (2016) and Storer et al. (2013), represent a considerable body of information on the distribution, relative abundance, size composition and movement attempts of fish in the vicinity of KSW. Based on this information and other studies in southwest WA, below we are able to develop expected seasonal migration patterns and assess the implications of the KSW as a barrier to fish movement.

Potamodromous native freshwater fish

Western Minnow

The Western Minnow is widely distributed in the Canning River system in main channel and tributaries from below KSW to as far upstream as below Canning Dam (River Bend Pool) (Morgan and Beatty 2016) (Figure 11). A concurrent survey on Blackadder Creek on the Swan Estuary collected numerous Western Minnow at a weir with a peak in juveniles (< 20mm) being recorded in early September (Ryan et al. 2015). A similar peak in Western Minnow migration below KSW may have occurred prior to the current survey as it commenced in late October. Peak spawning period for Western Minnow is thought to occur in winter and early spring, as water temperature begins to rise and potentially on the tail end of peak flow events (Pen et. al. 1991, Beatty et al. 2014a). Adults migrate upstream into tributaries, and to a degree within the main channels, and juveniles generally recruit back into the main channels as flows subside in late spring (Pen et al. 1991, Beatty et al. 2014a) (Figure 12). It has a good swimming ability of at least 97 cm/sec (Beatty et al. 2014a), is estimated to be able to leap ~0.5m (Beatty and Morgan, pers. obs.), and is therefore capable of ascending most existing fishways in the region and some small instream barriers.

Western Pygmy Perch

The Western Pygmy Perch is widespread throughout the main channel of the Canning River from the KSW to the base of Canning Dam (Morgan and Beatty 2016) (Figure 11). While only 13 Western Pygmy Perch were captured (9 above and 4 below), both adults and juveniles were represented above and below. Western Pygmy Perch undertake upstream pre-spawning migrations from July to November into upstream river reaches, particularly smaller tributaries with suitable nursery habitat for larvae and juveniles (Pen and Potter 1991; Beatty et al. 2014a, b). Adults and juveniles alike, return back to the main refuge pool in the Canning River in summer. The larvae are passively swept downstream from late spring to early summer (Figure 12). Western Pygmy has a relatively low ‘sprint’ swimming ability of up to 67 cm/sec (Keleher 2011) but is known to be capable of ascending rock-ramp fishway on the tail end of winter-spring peak flows (Beatty et al. 2012, 2014b). Significant instream barriers, such as KSW, would therefore limit the seasonal dispersal of Western Pygmy Perch in the lower Canning River and therefore may impact upstream re-colonisation after peak flow events.

Nightfish
The Nightfish is widespread in the middle and upper Canning River above Roe Highway (Morgan and Beatty 2016) (Figure 11). Like the other potamodromous species in the system, they undertake spawning migrations from the main channel of rivers into perennial and intermittent tributaries during winter and spring (Pen and Potter 1990, Beatty et al. 2014a), before retuning back to the large refuge pools. Larvae are likely to be passively swept downstream by spring rainfall events (Figure 12). Nightfish were not captured during the current study around the weir, however it is likely that this species could be flushed downstream below KSW during peak spring/winter flow events.

Freshwater Cobbler
Although Freshwater Cobbler is known to occur further upstream in the Canning River from Bickley Brook to the Canning Dam (Figure 11), it generally prefers the main channel of rivers but is also occasionally encountered in downstream sections of small tributaries (Beatty et al. 2010). Freshwater Cobbler in the Blackwood River catchment breed from late spring to summer, peaking in October and are known to make short upstream migrations during this period (Beatty et al. 2010) (Figure 12). Adults in the Blackwood catchment were also known to make small scale movements upstream and downstream searching for food, but are generally considered to have high site fidelity. An ongoing radio-tracking study is occurring in the Canning River have confirmed the high site fidelity of adults in the Canning River, but also localised migrations can be impeded by a lack of stream flow and instream barriers (P. Close, pers. comm. UWA).

Summary of migratory implications and requirements
Adults of most potamodromous species in the Canning River migrate upstream to some degree during the winter – spring peak flow period. Juveniles and adults then seek permanent refuge pools within the main channel and larger tributaries of rivers during late spring, summer and autumn. These species were detected in relatively low abundances during the current study. All species are more abundant upstream of KSW, however, it is important to note that high winter-spring flows could flush these species below KSW. During these wetter years fish passage through KSW would be required for adults and juveniles in spring and early summer towards the tails of the peaks flows to enable re-colonisation of the main river channel.

Additional information on the swimming ability of Nightfish and Freshwater Cobbler would be beneficial for fishway design criteria (and burst swimming ability of all species is unknown). However, if the swimming performance of Western Pygmy Perch, as one of the least capable swimmers, is incorporated as a maximum velocity target, adequate passage be achieved for the other potamodromous species.

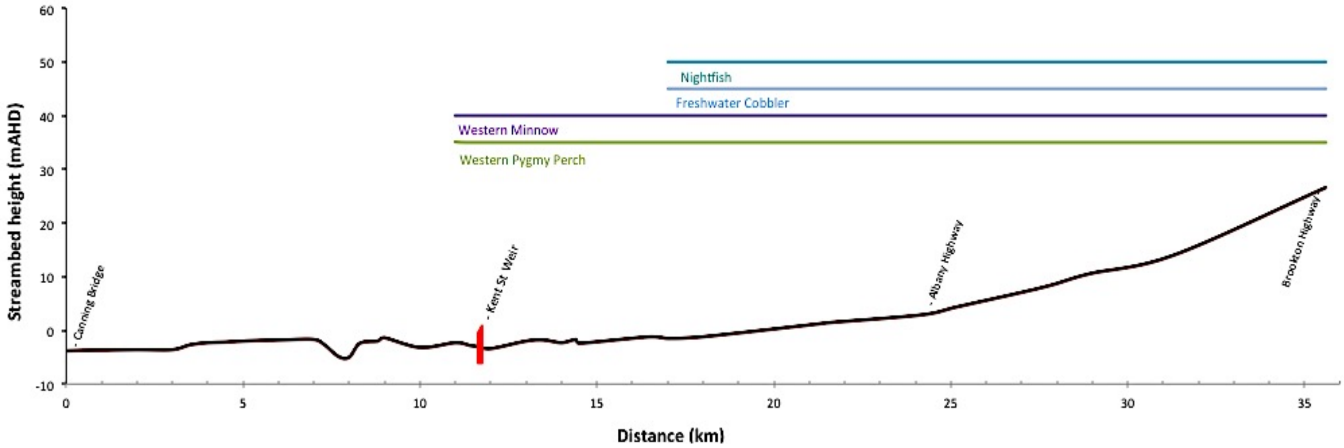


Figure 11: Current distribution of potamodromous native freshwater fish in the Canning River

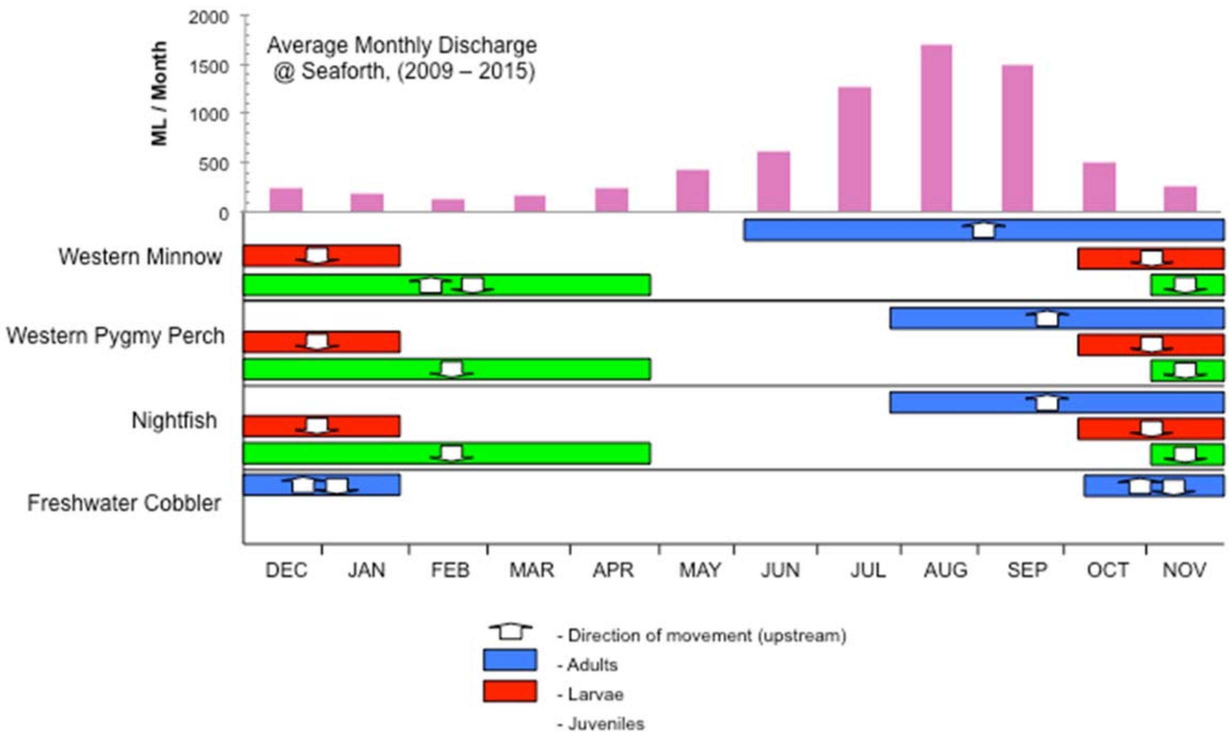


Figure 12: Mean monthly Canning River discharge (at Seaforth, 2009 – 2015) and expected migration pattern of potamodromous native freshwater fish

Native estuarine and marine fish species

Based on the total abundance of marine/estuarine species caught below and above KSW, it appears that most are impacted by reduced fish passage. Species not captured above KSW include Yellowtail Trumpeter, Bridled Goby, Elongated Hardyhead, Giant Herring and Perth Herring (Figure 13). Others were captured in lower abundance above KSW compared to below included Black Bream, Sea Mullet, Southwestern Goby, Swan River Goby and Western Hardyhead and those captured above had presumably moved upstream while the boards were out in winter. Habitats above KSW provide refuge for these species during the summer period.

The Swan River Goby, although generally considered an estuarine species, is known to develop sustaining populations in riverine or lacustrine environments elsewhere in southern Australia (Morgan et al. 1998, 2011). It is widespread throughout the Canning River, having been collected as far upstream as Gosnells in 2010-11 (Storer et al. 2003) (Figure 13). The majority of the Swan River Goby (4,005 - 86%) were captured below KSW, with highest capture rates at the start of the sampling period from October 22 where numerous adults were present along with a strong juvenile recruitment detected. A higher proportion of adult Swan River Goby were in spawning condition towards the end of the sampling period in late December. Above the KSW, Swan River Goby had a lower number of adults in spawning condition and a lower proportion of juveniles. This difference in spawning success between the estuarine and freshwater environments highlights a protracted spawning period for this species in freshwater conditions compared to the estuary (see Gill et al. 1996). It also indicates that this species may utilise a future fishway to migrate downstream in spring and early summer to breed. It is capable of climbing rock ramps aided by the morphological adaptation of fused pelvic fins and is therefore a very capable migrating species, however, even this fish species is unlikely to be capable of scaling the approximately 0.5 m barrier at the KSW.

Western Hardyhead is thought to have an annual life-cycle, with a peak spawning season in spring in the lower catchment (Prince and Potter 1983). It is known to predominately occur in estuarine environments; however it is known to persist and recruit in freshwater sections of rivers and in fresh and saline lakes (Potter and Hyndes 1999, Morgan et al. 2011, Rashnavadi et al. 2014), where it is known to have a more protracted spawning period into summer (Prince and Potter 1983). Previous studies in other streams have found spawning individuals in water of 1 to 2 ppt (~ 1.3 to 2.6 mS/cm) (Rashnavadi et al. 2014). While Western Hardyhead has previously been recorded as far upstream as Odell Street (Thornlie) (Figure 13), the majority (5,505 - 94%) of the Western Hardyhead was consistently captured below KSW between October and December 2015, with peak capture rates between October 22 and November 19. Consistent juvenile recruitment, as indicated by fish of <30 mm TL, was recorded below KSW up to, but not including, the last sample on December 29, while above KSW there was also evidence of juvenile recruitment on October 22 and November 5. A higher proportion of adults in spawning condition above KSW was indicative of the previously observed protracted breeding season in freshwater environments.

Black Bream, a true estuarine species, is known to penetrate upstream into near-freshwater environments. In the Swan Canning Black Bream were first found to mature at the end of the second year of life, at lengths of 174 and 172 mm, for female and males, respectively (Sarre and Potter, 1999, 2000). Subsequently, Cottingham et al. (2014) found that Black Bream in the oxygen stressed reaches of the Swan Canning estuary, captured from 2007 to 2010, first reached maturity at 156 mm for females and 155 mm for males at an age of approximately 2.5 years of age. Adult and sub-adult Black Bream are regular visitors to the lower Canning River and appear to pass through the KSW during the winter flushing period, but the majority of adults and juveniles are blocked when the boards were replaced for remainder of the year (Figure 13). Mature adults would be accessing the system in spring and early summer with spawning being triggered by increasing water temperature and upstream encroachment of the salt wedge interface to breed (Sarre and Potter 1999). Just four adult Black Bream were captured in gill nets above KSW in the first two sampling events (October 22 and November 5. Spawning condition (extruding eggs and milt) of Black Bream declined from approximately 20% October 22, to less than 10% on November 5 to 0% in spawning condition in subsequent sampling events. These observations coincide with the spawning triggers of increasing water temperature and upstream encroachment of salt wedge interface, generally in late spring to early summer (Sarre and Potter 1999). Young-of-the-year fish (20 – 80 mm) were first captured on November 5 but were a dominant component of the captured Black Bream from November 19 onwards. Given the option, these fish may move upstream of the KSW, however, when arriving in the freshwater environment above, it is likely that they would seek to relocate back into the more saline environment, as they are seldom recorded in non-tidal sections of rivers. The proposed fishway would therefore need to accommodate the movement of juvenile (20 – 80 mm) and larger (200 – 450 mm) fish in both an upstream and downstream direction.

Yellowtail Trumpeter is thought to breed in the upper reaches of the Swan – Canning Catchment during late spring and early summer, generally at the tidal interface where water conductivities reach between 12 and 29 mS/cm (Wise et al. 1994). Maturity occurs toward the end of the second year at approximately 150 mm in length and typically adults migrate back to coastal offshore waters (Wise et al. 1994). Storer et al. (2013) caught Yellowtail Trumpeter approximately 3 km upstream at Hester Park (Nicholson Road Bridge) in summer 2011 following the extended period no weir boards. In the current study, Yellowtail Trumpeter was caught below KSW during most sampling events predominately with the use of fyke nets, with a larger influx of fish >140 mm in December. A high proportion of mature fish in breeding condition was noted on October 22 and during December sampling, indicating a protracted breeding season. Juvenile recruitment was first detected on November 19 with the influx of smaller (18 - 45 mm) fish that could be seen progressing through with gradually lowering abundance during subsequent sampling events. As with other estuarine species, both adult and juvenile Yellowtail Trumpeter would be likely to utilise the proposed fishway in an upstream and downstream direction. Breeding adults would presumably move in search of the salt/freshwater interface.

Sea mullet is thought to spawn in deep water off the coast from early autumn to early spring (Chubb et al. 1981) and juveniles utilise estuaries and rivers as a nursery grounds (Orr 2000). Sea Mullet grow rapidly in the productive waters of the Swan – Canning estuary and by the end of their first year of life, can reach lengths of 180–220 mm (Chubb et al. 1981). The similarity in length ranges (280 – 470 mm) above and below KSW indicates that migration for this species occurs during the winter flushing period. A concurrent survey conducted in the upper estuary of the Swan River catchment on Blackadder Creek, however, caught numerous juvenile Sea Mullet (20 – 40 mm) below a weir in September to early October (Ryan et al. 2015). Within the Canning River, it is found predominantly in the main channel of the river downstream from Gosnells (Morgan and Beatty 2016, Storer et al. 2013) (Figure 13). While it is apparent that this species is able to negotiate KWS when the boards were removed and persist in the weir pool for extended periods, thought should also be given to providing passage for the migrating juveniles in spring and early summer. While adult Sea Mullet are thought to be relatively good swimmers (and known to jump out of the water) (Thomson 1963) little is known of the swimming ability of juveniles and therefore the potential upstream movement through a fishway on KSW.

The Bridled Goby is also a ubiquitous species of the Swan Canning system and have been caught in lower abundance predominately below KSW. Bridled Goby is thought to be a predominately estuarine species, completing all life stages in the estuarine environment. However, South-western Goby have previously been captured as far upstream as Gosnells in 2011 (Storer et al. 2013) (Figure 13) and therefore also appears to capable of surviving as a potamodromous population, as they appear to have done in a secondary salinized reach of the Blackwood River (Morgan et al. 2003).

Perth Herring, which is endemic to Western Australia, is the only fish species found in the Swan estuary that spends much of its life feeding in coastal marine waters but then migrates into the low salinity areas in the upper reaches. During this migration adult Perth herring mature and spawn between late spring and the middle of summer (Chubb and Potter 1986). Young-of-the-year fish are therefore dispersed in the upper and middle estuary, while the older individuals move out to sea. Perth Herring reach a length of about 100 mm by the end of its first year of life, does not typically reach maturity until at least 160 mm in length and in the Swan Canning System reaches an age of up to eight years in age (at 350 mm in length) (Chubb and Potter 1986). The four larger fish (231 – 275 mm) captured below KSW were possibly on a spawning migration and may have moved further upstream given an opportunity although they are not recorded in fresh waters.

The Giant Herring, *Elops machnata*, is found in the coastal regions of Indian Ocean and western Pacific Ocean (Adams et al. 2012), generally in tropical regions, but also often along the Perth coast and estuaries. All *Elops* species are thought to spawn offshore and larvae drift in the ocean for several months before drifting into shallow embayments and metamorphose (Beckley 1984). Age 0+ are thought to grow in low salinity estuaries, do not generally enter freshwater, but often can tolerate hypersaline conditions (Bayley 1972; McBride et al. 2001). In estuaries juvenile *Elops* species are thought to be carnivorous with a wide range of potential prey including crustacean, fish and other invertebrates (Hiatt 1947; Smith 1997). Maturity occurs at sizes larger than 500 mm when fish leave the estuary environment (Blake and Blake 1981; McBride et al. 2001). They can live for 4 – 6 years and as adults frequently enter estuaries in search of larger prey items. The juvenile fish (377 mm) caught on December 29, 2015 is likely to have been preying on the accumulated population of smaller fish below KSW.

Summary of migratory implications and requirements

Swan River Goby, Western Hardyhead and South-west Goby are likely to move upstream of KSW with increased fish passage and either maintain an estuarine or potamodromous breeding strategy. It will therefore be essential that these species have upstream and downstream passage most of the year, but particularly in spring and summer for adults in spawning condition attempting to locate suitable upper estuarine conditions and in summer – autumn when juveniles are moving upstream.

Mature Black Bream and Yellowtail Trumpeter are also likely to move upstream through KSW, however they are unlikely to be able to successfully breed in the freshwater conditions. These species may attempt to relocate back into more saline conditions for breeding and as such, a fishway will need to cater to this downstream migration. Black bream is known to spawn at the tidal interface at intermediate salinity conditions and therefore may attempt to spawn in or immediately downstream of the fishway where the upstream freshwater mixes with the saline water downstream.

Sea Mullet are also likely to utilise a fishway and move further upstream as previously detected in 2011 following the extended period of no weir boards. These species need to migrate back to sea to breed and therefore will also require downstream passage.

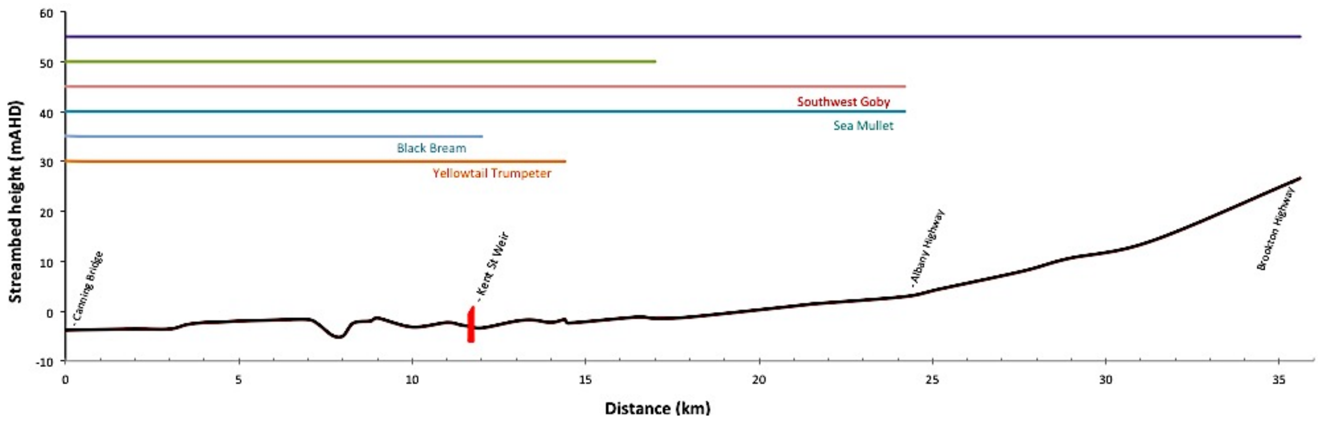


Figure 13: Current distribution of native estuarine fish species in the Canning River

Feral freshwater fish

The Canning River has eight species of feral fish species, which is more than any other system in Western Australia. Some of these species are concentrated further upstream in the Canning River, including Spangled Perch, One-Spot Livebearer, Rainbow Trout (*Onchorhynchus mykiss*) and Redfin Perch (*Perca fluviatilis*). Others including Eastern Gambusia, Goldfish, Koi Carp have been established throughout the system from many years, however, the occurrence of Pearl Cichlid is relatively recent. Storer et al. (2013) did not catch any Pearl Cichlid in 2010 or 2011 in the Canning River, suggesting that this species has been introduced to, or colonized (from the Swan River) this lower reach of the Canning since that time. Pearl Cichlid is now abundant above and below KSW with a strong recruitment of juveniles (15 to 30 mm) being evident. It is also apparent that Pearl Cichlid has been able to negotiate the KSW where they appear to be thriving in slow flowing environment above KSW. The opportunistic omnivorous diet (including fish), prolonged and flexible reproductive strategy, ability to exist in both lenthic and lotic habitats and high salinity tolerance are some of the main attributes that make Pearl Cichlid one of the most invasive species found in the Perth Coast Plains (Beatty et al. 2013b).

Eastern Gambusia is found from below KSW upstream to Canning Dam. As an aggressive species that severely impacts native fishes, the high density of this species above KSW may be contributing to the lack of native freshwater fishes. Breeding commences in spring with warmer water temperatures with live-bearing in the Swan Canning commencing in September, and possibly continues into autumn. Because of it tolerances to a range of environmental conditions and live-bearing strategy, it is a difficult, if not impossible, fish to completely eliminate (Lowe et. al 2000). Management for the impacts of this species should therefore concentrate on maintaining sufficient instream habitat and cover for smaller natives to help minimise the competitive and aggressive fin nipping impacts of Eastern Gambusia.

Juvenile Goldfish were captured below and above KSW and are likely to be breeding above KSW. Large Koi Carp were also observed and two small juveniles were captured above KSW, which also suggests that they are recruiting, with only limited success.

Summary of migratory implications and requirements
As the Pearl Cichlid has a slower swimming ability in water less than 20 ^{o}C (Kelleher 2011), it likely that limited upstream movement will occur during the higher winter flows when KSW is opened. Alternatively during warmer and slower flowing periods (spring – autumn), it may be possible to install fish traps within the fishway to control these fish moving through the fishway in both directions.

Fishway traps may also be a useful tool for the control of Goldfish and Koi Carp that appear to be concentrated in KSW pool. The use of traps would be complimented by a tracking program that could alert the fishway managers of the aggregation of fish immediately above or below KSW, thereby triggering the installation of the fish traps.

A fishway at KSW is not expected to impact the other four feral fish species found further upstream in the Canning River.

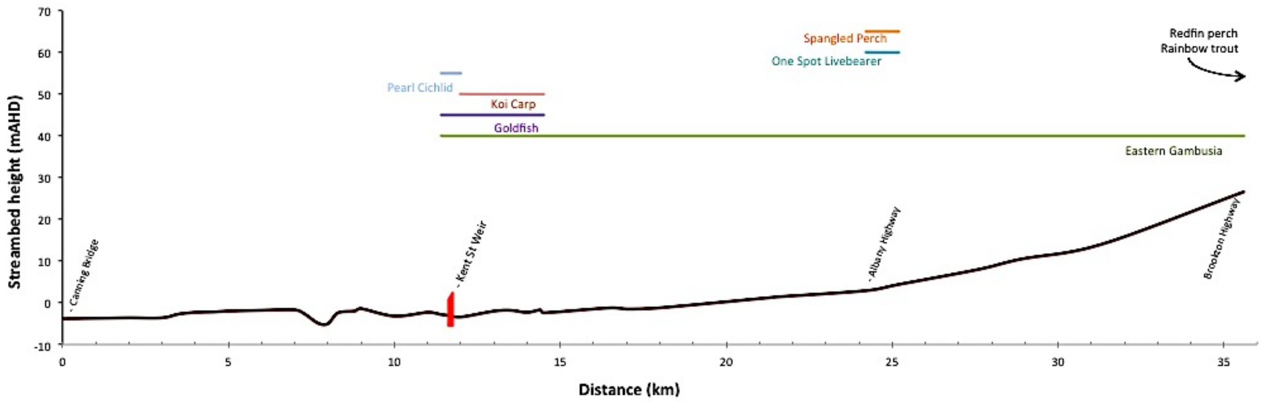


Figure 14: Current distribution of introduced fish species in the Canning River

Other aquatic taxa
Other aquatic taxa may also need to be considered in the construction of a fishway at KSW. The South-west Glass Shrimp is believed to breed during spring and summer and is an important dietary component of many native fish species. It has a limited swimming ability, however it has the ability to climb and could migrate during low to moderate discharge events given sufficient substrate roughness.

A number of decapod Crustacea are also known to occur in the Canning River, mostly upstream of KSW. Storer et al. (2013) captured numerous Gilgies from upstream of KSW to Gosnells, with high abundances at O'Dell Road and Gosnells. Marron had a similar distribution pattern, but at an apparently lower relative abundance. A small number of the feral Yabby (*Cherax destructor*) were recently captured at Gosnells (Storer et al. 2013).

The Oblong Turtle was regularly caught in fyke nets, particularly below the KSW. This species is endemic to the SW Australia and is known to breed in spring and also summer (Cogger 1996, Clay 1981). The relatively large number of Oblong Turtle below KSW is likely to represent a significant predatory pressure on the large number of accumulated native fish. A fishway suitable for oblong turtles would reduce this predatory impact and help the Oblong Turtle migrate more easily within the system.

The Murray River short-necked turtle is native to the Murray-Darling Basin in eastern Australia where it is found in lagoons and the mainstream of rivers. Males grow to about 2.2 kg and females may sometimes exceed 4.0 kg. They are typically olive green or bronze in colour on the carapace and cream underneath. The neck is short relative to the other species. They can often be seen basking on logs, but generally remain in the water, except to nest a short distance from the river edge. Nesting generally occurs from late spring to early summer, often in two clutches of 30 eggs with a 6 to 8 week incubation period. The Murray River short-necked turtle is omnivorous, eating considerable plant material, as well as invertebrates and will scavenge dead animals and fish in the water. One small specimen was previously captured above KSW in 2011 (Storer et al. 2013) and based on the current survey, appears to have expanded its range, with both small and large adults captured below KSW. It is suggested that a control program be implemented for the species.

Summary of Migratory Implications and Requirements

The fishway design should incorporate necessary passage requirements for these taxa, including sufficient surface roughness and unrestricted passage during slower flowing periods that are likely to be more suitable for these species to move.

Fishway prioritisation, construction and operation

The design and construction of fishways requires biological expertise to be successful. Hydraulic and physical performance standards for fishways are mostly derived from information on the swimming ability, size and behaviour of fishes. The broad guiding principles for the design should be based around getting fish moving upstream and downstream through a fishway including attracting fish to the fishway, enabling fish to migrate through a fishway, allowing fish to safely exit a fishway. Hydraulic and physical performance criteria can be classified into a number of categories relevant in particular situations and include water velocity, turbulence, hydraulic gradient, roughness, depth, length of fishway, vectors or flow direction and light.

General criteria for best practice design and operation of fishways include the following:

- catering for whole fish community (all size classes, biomass, life-stages)
- providing year-round passage to operate from low summer flows to high flooding flows
- accommodating both upstream and downstream fish passage
- directing all water releases through the fishway in preference to other outlets, and where possible isolate spillway flows from fishway attraction flows)
- minimising fish injury, mortality, entrapment with suitable spillways, aprons and dissipaters
- locating spillway flows adjacent to fishway to facilitate direct access
- maintaining appropriate light, water height, hydraulic characteristics and resting habitat
- attraction water sourced from high quality surface water
- maintaining accessibility of fish entrance under all flows with adequate hydraulic conditions for all fish sizes
- maintaining suitable hydraulic conditions and depth at fishway exit

- providing adequate "in water" downstream passage including adequate plunge pool depth.

Operational and maintenance schedules are a key component of an efficiently functioning fishway and should be developed where possible. To achieve this process the ownership and key responsibilities of each designated waterway and land manager will need to be clearly defined.

For a well-designed and well-operated fishway to perform consistently, it requires regular maintenance. Build-up of debris, movement of the structure over time, weed encroachment, and sedimentation will impact upon the performance of the fishway. Fishway maintenance should include at least annual de-watering and inspections, quarterly measurement of internal fishway hydraulics and functionality and regular debris and sediment removal.

An efficiently operating fishway should also be regularly monitored to ensure fish passage is proceeding as planned. During construction there may be an opportunity to install additional infrastructure to assist future fish monitoring. Removable traps can be designed for the entrance and/or exit of the fishway and electronic monitoring systems such as PIT tag readers or digital sonar monitoring systems can also provide continuous monitoring options. These options provide the additional advantage of providing the information required to assess effectiveness of fishways to provide passage and a method of controlling feral fish species such as Pearl Cichlid, Koi Carp and Goldfish.

The design and construction of suitable public access to the fishway infrastructure can also provide an opportunity increase community appreciation for the ecological importance of fishways.

Reducing discharge in a changing climate

Climate change will increase the pressure on freshwater fauna in southern Australia (Morrongiello et al. 2011), especially in catchments where natural hydrological regimes have already been heavily modified by instream barriers. In the south-west of Western Australia for example, winter rainfall has decreased substantially since the middle part of last century, a trend that has been particularly evident since the 1970s (Suppiah et al. 2007). Further reductions in rainfall (~8%) and surface water discharge (~25%) are predicted over the next 20 years (Suppiah et al. 2007; Silberstein et al. 2012). The number of no-flow days in some rivers in south-western Australia is also predicted to increase by up to 4 months by 2030 (Barron et al. 2012).

Historically the Canning River catchment received between 700 and 1100 mm of rainfall per annum (Brearley 2005). However, due to changes in climate since 1975, conservative predictions of river flow at Seaforth have included a reduction of flows by 20% winter and 25% in summer (DOW 2012). Further to this, recent re-analysis of climate data have demonstrated a southward shift of the winter storm systems in southern Western Australia and a reduction in rainfall is expected by up to 15% by 2030 and by up to 30 % by 2090 for the Southern and South-Western Flatlands (Hope et al. 2015). Together with the predicted increase in evaporation and reduction in soil moisture (Hope et al. 2015), further reductions in runoff in systems is highly likely. Consequently, the amount of available permanent refuge habitat, connection between refuge pools and the overall carrying capacity of catchments throughout the region are likely to decline. It will therefore become increasing important for fish passage to be maintained up into and down out of the large refuge pool upstream of KSW.

Recommendations

With further consideration of the known life-cycles of native fish in the Canning River system, the following recommendations have been developed as guidance for the improvement of fish passage at KSW:

- A fishway is highly recommended for the KSW given it restricts the movement of numerous native estuarine species and probably some native freshwater species.
- The fishway should be designed to operate year-round to enable upstream and downstream movement of native species where possible.
- The fishway should be designed to reduce internal velocity and turbulence during winter and spring flow period and cater for native freshwater and estuarine fish that get washed downstream and have a requirement to subsequently return upstream.
- The fishway must also allow passage of larger estuarine species (both juveniles and adults) in both an upstream and downstream direction.
- The most appropriate design should be developed based on ongoing discussions with experienced fishway designers, managers, and fish ecologists. It is likely that a vertical-slot fishway would be most appropriate fishway design to enable consistently suitable performance criteria and the necessary public security.
- In light of major gaps in understanding of the swimming performance of most species in the vicinity of the KSW (no information exists on burst swimming performance of south-western Australian freshwater fishes) that would likely benefit from a fishway, the recommended preliminary hydrological criteria within the fishway should cater for the Western Pygmy Perch (given information exists on its sprint swimming performance). A conservative maximum velocity within the fishway would be 0.5 m/s.
- Swimming capability (such as sprint speeds) of key species (Nightfish, Freshwater Cobbler, Black Bream, Yellowtail Trumpeter), along with burst performance of all freshwater species, are important knowledge gaps that if addressed would greatly enhance the robustness of the fishway design.
- The fishway should incorporate suitable monitoring infrastructure (such as PIT antenna system) to more provide a platform accessing the fishway effectiveness.
- The fishway could also include additional management equipment such as fish traps to remove feral species.
- In the light of the declining rainfall and stream discharges in the system, the maintenance and protection of refuge pools and connectivity will become an important management goal and needs to be an important consideration for the fishway design at KSW.

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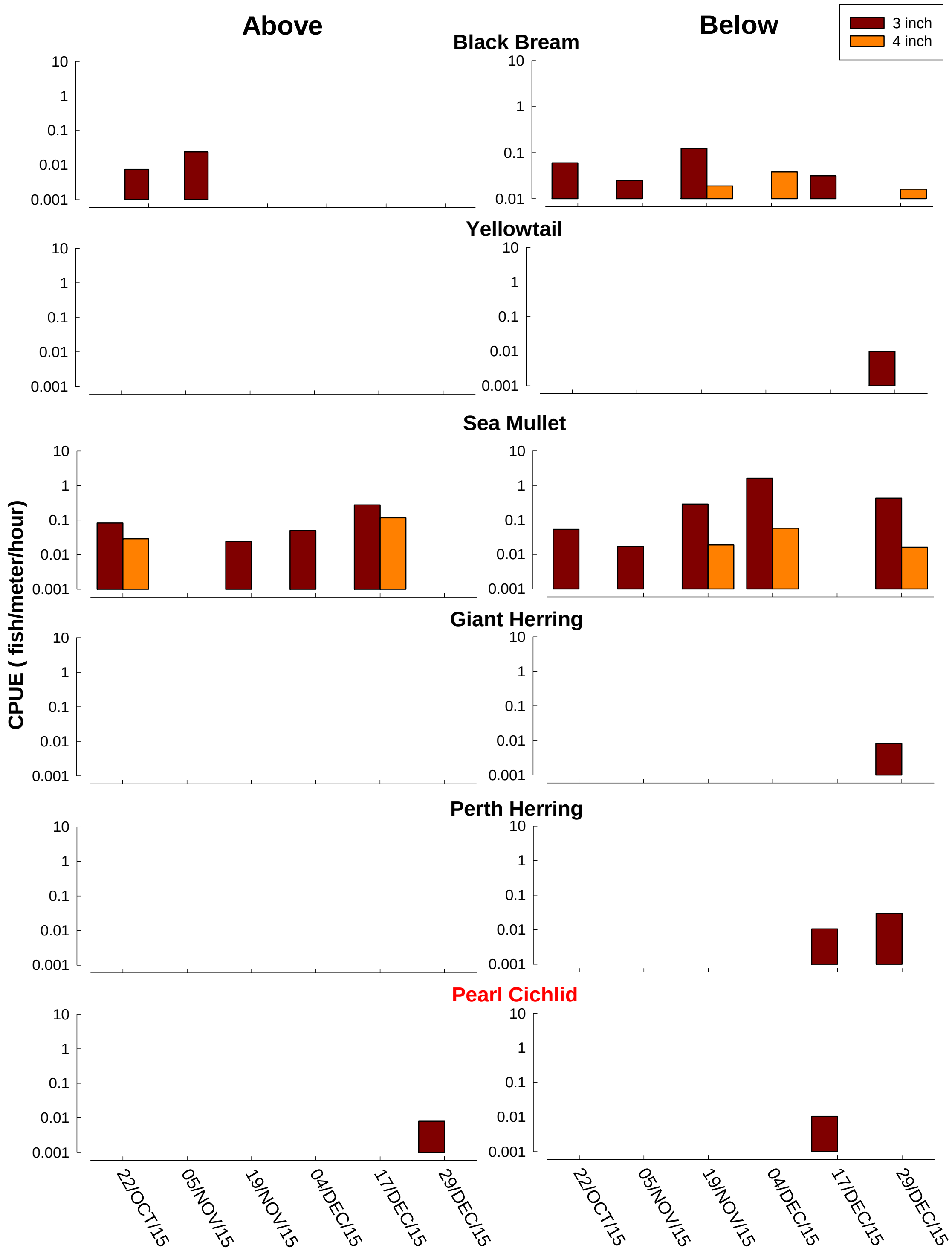
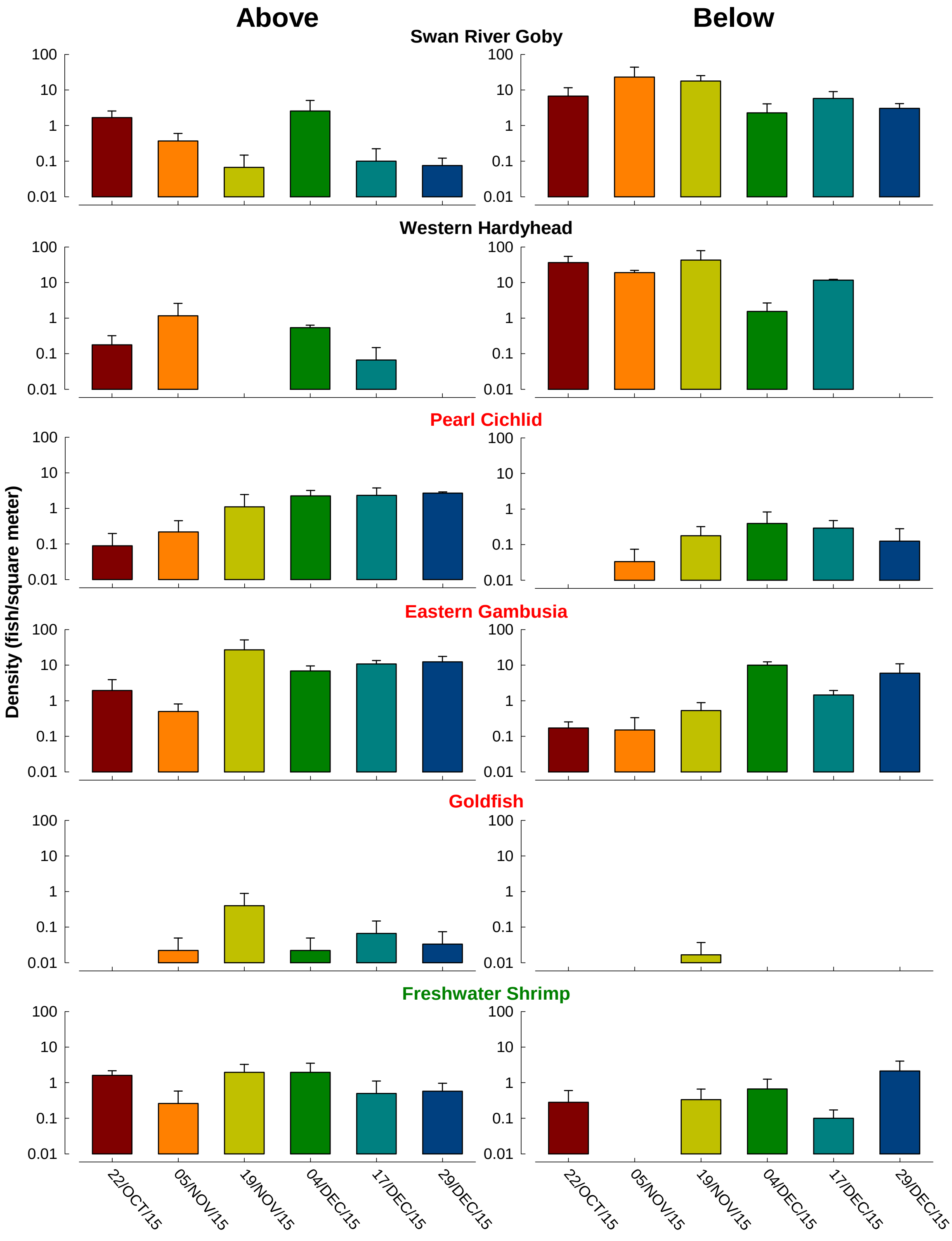
Appendix A: Fish catch rate (fish/meter/hour) using gill nets above and below KSW

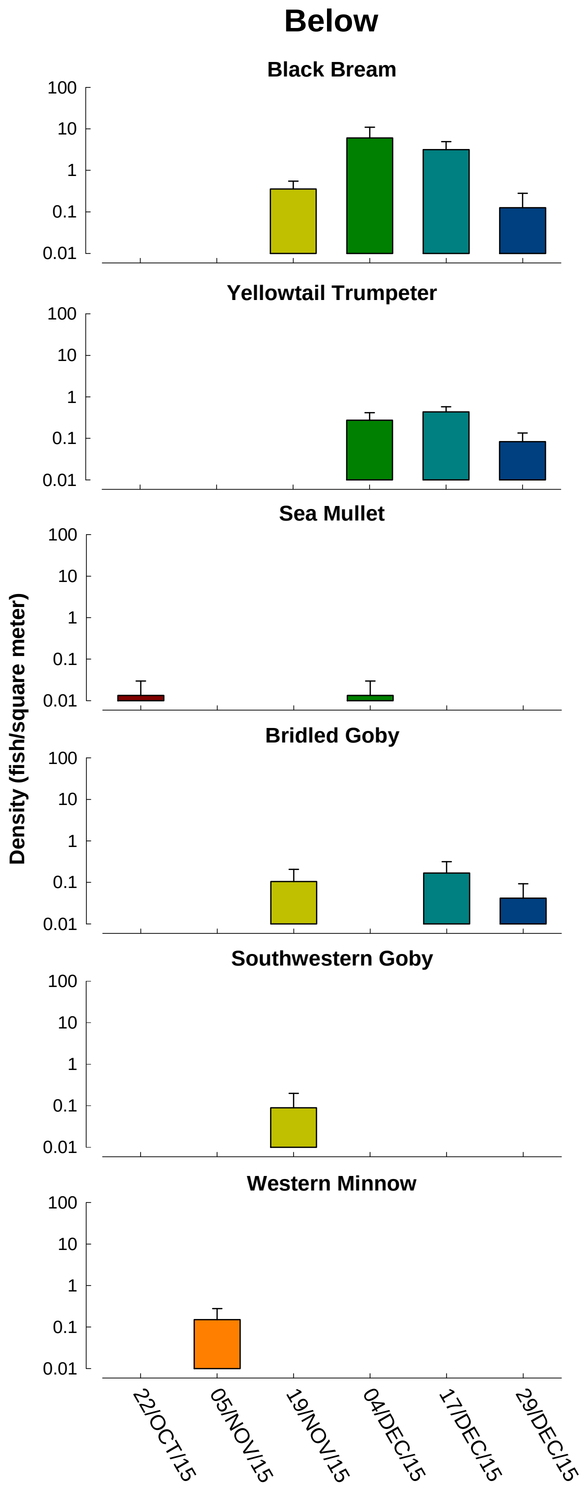


N.B. CPUE is average number of fish per meter of net per hour (±1 S.E.).

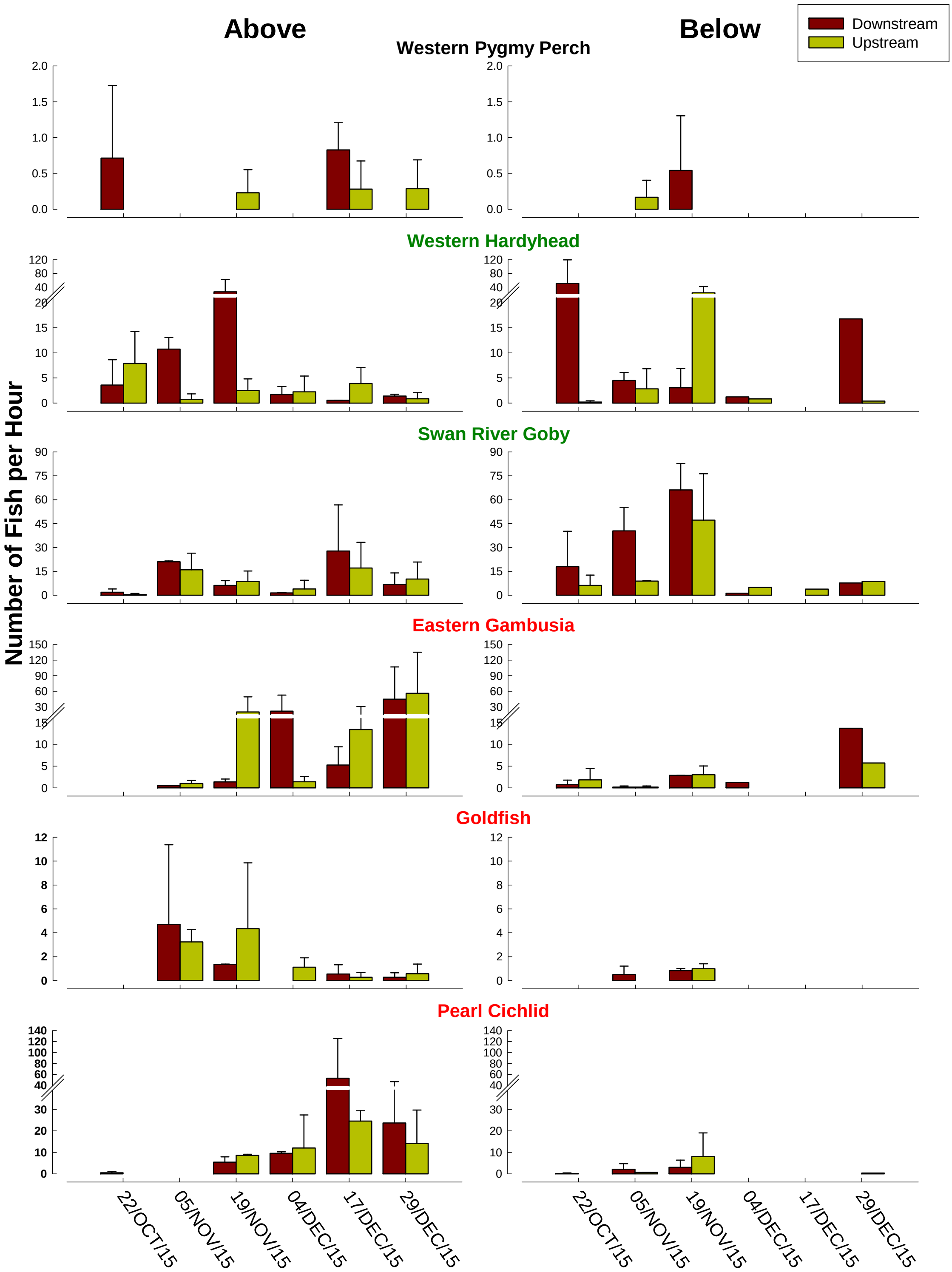
Appendix B: Fish capture density using seine net trawls above and below KSW



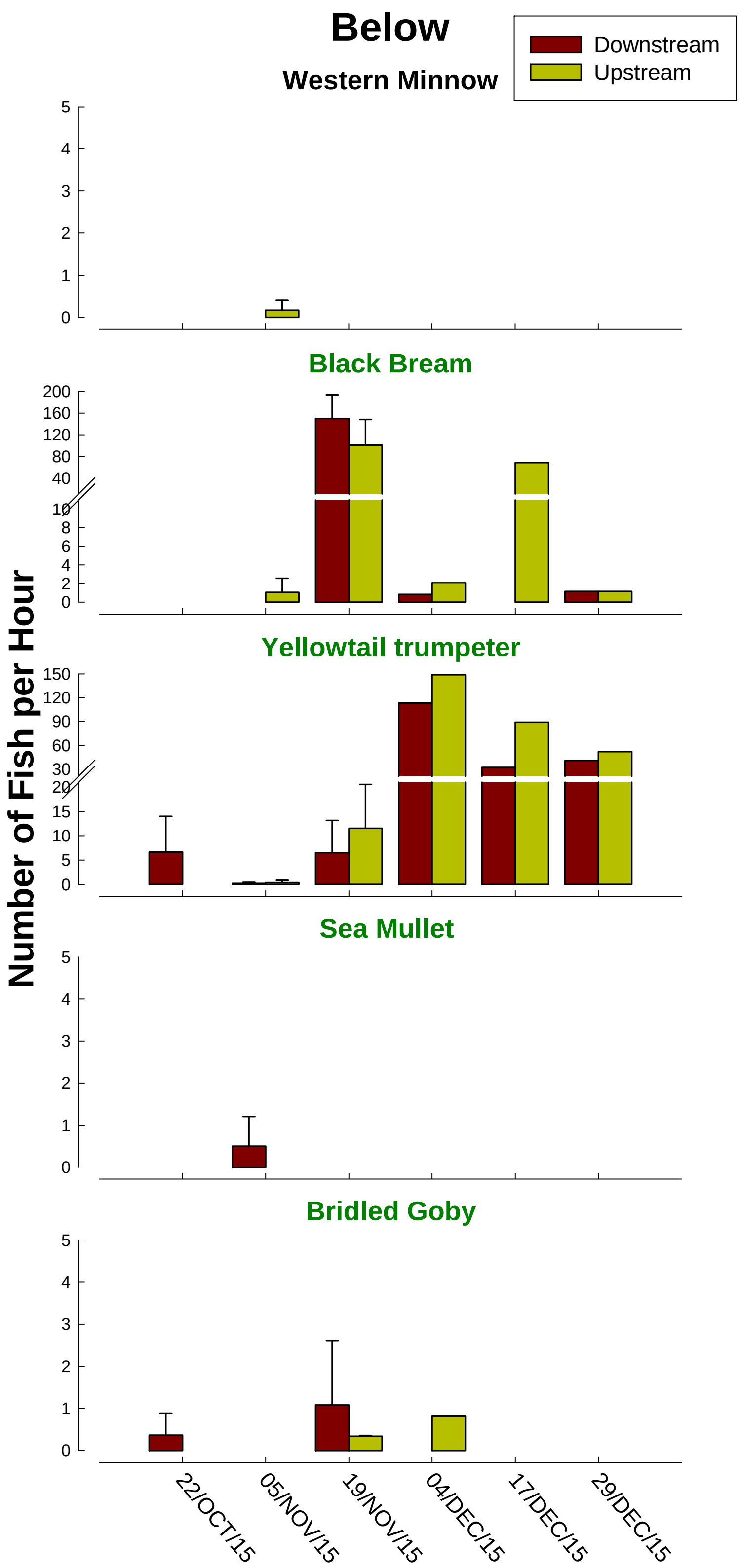
Appendix B: (Cont.)



Appendix C: Fish catch rate (fish/hour) and direction of movement using fyke nets above and below KSW



Appendix C. (Cont.)



Appendix D: Proportion of maturity, and spawning condition of Black Bream, Yellowtail Trumpeter, Western Hardyhead and Swan River Goby above and below KSW