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Preliminary investigation into the distribution of Tilapia in the Upper Fitzroy Catchment

June 2015

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REEF CATCHMENTS

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Centre for Sustainable Tropical Fisheries & Aquaculture

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Cover Figure: Grosvenor Creek, Moranbah. Inset – Tilapia sampled during surveys of Grosvenor Creek, conducted in April 2015

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Background

The Isaac River system is located in the Mackenzie River sub-catchment of the larger Fitzroy River Basin in Central Queensland. Grosvenor Creek is a tributary of the Isaac River and runs through the township of Moranbah. Grosvenor Creek encompasses an ephemeral stream channel, smaller feeder creeks as well as a large number of natural and man-made offstream lagoons and dams. In recent years there have been confirmed reports of the presence of the noxious tilapia species *Oreochromus mossambicus* (referred to herein as tilapia) at a number of locations around Moranbah, however, the extent of the species' distribution in this area had yet to be determined.

The current investigation was part of a wider assessment being conducted by Reef Catchments Limited (RCL) and Fitzroy Basin Association (FBA) to determine the current distribution of tilapia in the Fitzroy River Catchment. It is hoped that once this is known, suitable control measures can be implemented to reduce the spread of the species throughout the wider system. To do this RCL and FBA contracted Catchment Solutions and James Cook University to sample 9 sites throughout the Isaac/Grosvenor systems, including both on and offstream waterbodies (Figure 1). An additional site at Pioneer Park in Clermont was also sampled as part of this work (Figure 1). The preliminary component to this assessment was the sampling of several confirmed tilapia sites and a number of potential tilapia sites. Sampling was to provide presence/absence information on tilapia at sampling sites, length distribution and abundance of current tilapia populations, and species lists of fish communities at all sites sampled. Sampling was conducted using electrofishing/seine netting and environmental DNA (eDNA) methods.

Electrofishing is a non-destructive sampling method which uses a boat mounted or a backpack unit to generate an electric current, this current temporarily stuns fish which can be captured for identification and processing. Electrofishing is effective on most fish species, however, in large open sites it can be difficult to capture tilapia particularly when in low abundance (Thuesen et al 2011). Seine netting uses a large net, of small mesh size that is deployed in a semi-circular pattern and drawn towards the shore. Fish are herded to the bank and removed from the water for processing. Seine nets are often used in conjunction with electrofishing to provide additional coverage of a site.

To complement electrofishing/netting, eDNA was used to test for the presence of tilapia DNA in the storage facility. eDNA works by using species specific genetic markers to test for the presence of tilapia DNA in water samples. This technique has proven to be a sensitive method of detection with the ability to identify the presence of tilapia where traditional methods such as electrofishing have not been successful (Power 2014). Water quality data was also collected to aid in the interpretation of fish community data.

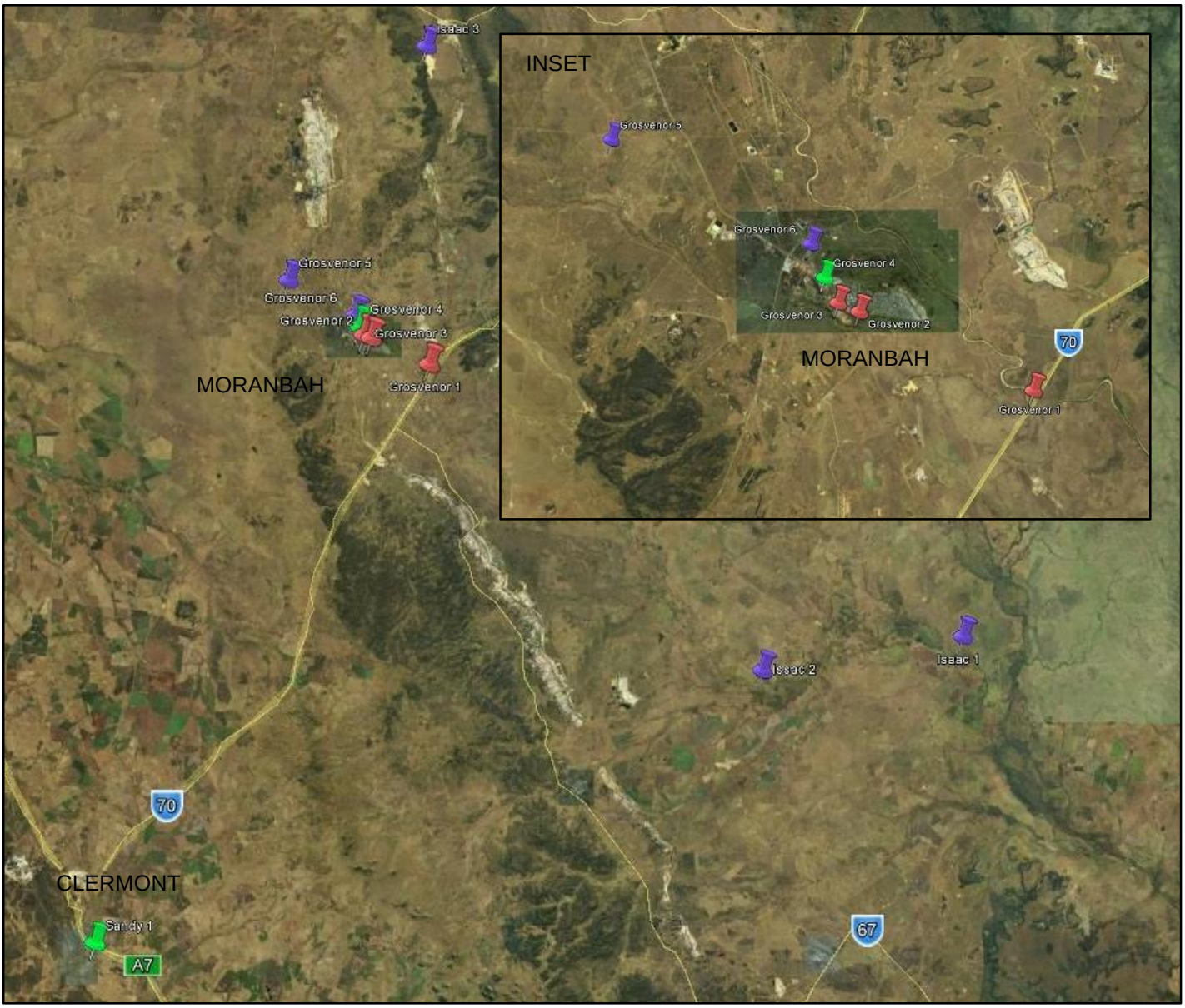

Figure 1. Location of sample sites within the upper Fitzroy Catchment. Green pins indicate sites where tilapia were not identified, red pins where tilapia were captured electrofishing/netting and purple pins where tilapia eDNA was detected using eDNA but not captured electrofishing/netting. Google Earth Base Image.

Methods

Site Selection

A total of 10 sites were chosen throughout the upper Fitzroy system (Figure 1). Three sites had confirmed reports of tilapia and the remaining 7 were potential tilapia sites. The location of confirmed sites was based on documented reports from that site. These sites provided the data on size distribution and abundance required for current tilapia population assessment. The location of potential tilapia sites was based on the connectivity of potential sites with confirmed tilapia sites and their overall location within the upper Fitzroy system. The Clermont site (Sandy Creek 1) was an offstream pool and chosen as a likely hotspot for tilapia incursion due to its close proximity to the urban center. Potential sites were also chosen based on likely habitat features such as waterbody type and size, riparian condition, macrophyte growth etc. to represent a range of different habitat types. Details of habitat features at sites sampled during the investigation are listed in Table 1. Criteria used for habitat descriptions are listed in Appendix 1.

Table 1. Habitat description of sites chosen to sample for the presence of tilapia in the upper Fitzroy Catchment.

Site ID	Water Body Type	Avg. Site Width (m)	Site Length (m)	Flow (m/s)	Avg. Riparian Width (m)	Riparian Condition	Riparian Shade Potential	Aquatic Macrophyte
Isaac River 1	Instream Pool	51	3160	0	10	Low	Very Low	Very Low
Isaac River 2	Instream Pool	20	140	0	10	Low	Moderate	Very Low
Isaac River 3	Instream Pool	10	75	0	20	Moderate	Moderate	Low
Grosvenor Creek 1	Instream Pool	10	125	0	20	Moderate	Moderate	Very Low
Grosvenor Creek 2	Instream Pool	18	800	0	5	Very Low	Low	Moderate
Grosvenor Creek 4	Offstream pool	55	125	0	20	Moderate	Low	Moderate
Grosvenor Creek 3	Instream Pool	16	900	0	10	Low	Moderate	Low
Grosvenor Creek 5	Impoundment Small	45	150	0	5	Very Low	Very Low	Nil
Grosvenor Creek 6	Impoundment Small	170	215	0	Nil	Nil	Nil	Moderate
Sandy Creek 1	Offstream pool	29	900	0	5	Very Low	Very Low	Moderate

Electrofishing/netting

Electrofishing was conducted from the 3.7 m vessel (Electrolyte) operating a Smith-Root 2.5 GPP electrofisher unit, equipped with a single boom arm, 6 dropper anode array and hull cathode. Settings were adjusted based on electrical conductivity of the water on site to maximise the effectiveness of electrofishing operations. A master and single dip-netter were employed during all sampling activities on Electrolyte.

Sampling was conducted at various depths and encompassed all types of instream habitats within the waterbody. The electrofishing methodology used was a combination of power on, power off for the duration of the sampling effort. The sampling effort consisted of a series of 300 second ‘shots’ where the boat was maneuvered in and out from the shoreline as well as parallel to the shore in deeper water. The effective electric field of this unit was approximately 3 m radius (centered on the anode) to a depth of 3 m. Fish positively identified during operations but not captured were also recorded and contributed abundance and assemblage data in this report.

At sites not accessible with the boat, a combination of backpack electrofishing and seine netting was used to collect fish community data. The backpack unit utilised was a Smith-Root Model-LR24 Backpack Electrofisher operating a 300-500 volt pulsed-DC current and a standard pulse setting (1ms). An operator and single dip-netter were employed during all backpacking operations. Sampling effort was the same used for boat mounted operations and was limited to a wading depth of 1.2 m. Seine netting utilised a 30 m net with a mesh size of 10 mm and a drop length of 2 m. Sampling effort consisted of a series of 'shots' where the seine was deployed in a semi-circular pattern then each end was drawn up the bank. Fish were herded to the shore where they were scooped from the water and processed. Seine netting was limited to a wading depth of 1.2 m in areas free of snags.

All tilapia captured during surveys were counted and measured to the nearest millimeter (total length). Tilapia and other non-native fish species were euthanised as per Fisheries Queensland legislation and ANZCCART procedures, and retained for gonadal development inspection or buried on site above the high water level. Native fish captured for identification purposes were processed and released within the reach or waterbody they were captured from.

Environmental eDNA (eDNA) – Extracted from supporting document *Environmental eDNA Survey of Tilapia Infestations in the Moranbah/Isaac Region (Jerry et al. 2015)*.

eDNA sample consisted of five independent 2 L water samples and one negative control sample of distilled water. All samples were filtered within 24 hr of collection. Water samples (2 L) were vacuum filtered through a 20 µm nylon net filter (Merck NY2004700) and stored in the freezer until further processing.

To ensure quality control of the eDNA survey, all filtration equipment was sterilised with 10% bleach solution before use. Prior to filtration of every sample, 500 ml of deionised water was filtered through the filtration apparatus and the filter paper stored and kept for further analysis. This is called the equipment control and is used to test for equipment contamination for corresponding samples.

eDNA on the filter papers was extracted using the Bioline ISOLATE II Genomic eDNA kit (BIO-52067) following the manufacturers standard protocol. A three phase quantitative PCR (qPCR) analysis was then carried out for each sample. The qPCR protocol consists of a 40 cycle quantitation analysis followed by a melt analysis. The quantitation analysis identifies whether a sample has amplified or not and the melt analysis is used to confirm the PCR product formed is from tilapia eDNA. For each run of qPCR, positive (tilapia eDNA) and negative PCR controls were run to ensure quality control.

Phase 1 of the qPCR analysis tests each sample for PCR inhibition from contaminants in the water using an internal positive control (Qiagen RT2 qPCR Primer geDNA control, cat. no. 330011). Samples that displayed signs of PCR inhibition (e.g. failed to amplify the spiked control eDNA) were further treated using an eDNA clean up column (Bioline ISOLATE Fecal eDNA kit, BIO52082). In total, 10 samples collected from the Moranbah area required further treatment due to PCR inhibition.

Next, during phase 2, all samples were analysed for presence or absence of tilapia eDNA by conducting a qPCR using tilapine species-specific eDNA primers. Each water sample was analysed using five replicate qPCR reactions. Positive reactions were identified for tilapia eDNA when there was the presence of an amplification curve in the quantitation analysis, as well as a distinct peak of the right size compared with positive controls of known tilapia eDNA in the melt analysis. For all water samples which tested positive for tilapia eDNA the corresponding equipment control was then analysed to test for contamination (phase 3). If the equipment control was clear of contamination as well as the site negative control sample the water sample was then classified as positive for tilapia eDNA. Failure to meet any of these quality control measures resulted in the sample being classified as "status uncertain" due to eDNA contamination.

Water Quality

Water quality parameters including temperature, pH, dissolved oxygen and conductivity were measured using an Aqua Read AP-2000. The water quality sampling method involved placing the probe into the water at a depth of 0.1 m. After readings had stabilised, values were recorded for each of the water quality parameters. Secchi depths were obtained by lowering a 200 mm secchi disk into the water column until the disk could no longer be seen. The disk was then raised until the contrast between the black and white portions was discernable and the depth value recorded. To account for localised variability, water quality readings and secchi depths were averaged from readings taken at three locations within site.

Results and Discussion

Fish Communities

Pooled counts from all sites in the investigation area identified 19 species — 17 native and two introduced (Table 2). Pest fish were identified using electrofishing/netting methods from Grosvenor Creek 1, Grosvenor Creek 2 and Grosvenor Creek 3, these included tilapia and platyfish (Figure 2). Tilapia DNA was detected by eDNA sampling from a further 5 sites (Table 2). The native fish assemblages present at the detection sites were typical of the communities that occur within each of the habitat types sampled. There was no discernable difference in community composition at sites with similar habitat types regardless of tilapia presence. The greatest variability in community composition appeared to be driven by variations in habitat types and condition between the sites. In general, instream pools recorded greater species diversity than offstream pools and impoundments. Water quality parameters recorded during sampling were also typical of habitat, time of day and season, and were all within acceptable levels for healthy fish communities (Table 3).

Figure 2. Tilapia and platyfish captured during electrofishing operations at Grosvenor Creek, Moranbah.

Table 2. Fish species assemblages recorded during tilapia distribution sampling in the Upper Fitzroy Catchment. ✓ denote species recorded during electrofishing operations, number in brackets denote total number of pest fish identified, * denote positive eDNA indications.

	Common Name	Grosvenor Creek 1	Grosvenor Creek 2	Grosvenor Creek 3	Grosvenor Creek 4	Grosvenor Creek 5	Grosvenor Creek 6	Isaac River 1	Isaac River 2	Isaac River 3	Sandy Creek 1	Species Name
Native Fish	Agassizis glassfish	✓	✓						✓	✓		*Ambassis agassizii*
	Barred grunter							✓	✓			*Amniataba percoides*
	Long-finned eel			✓								*Anguilla reinhardtii*
	Flyspecked hardyhead		✓				✓				✓	*Craterocephalus stercusmuscarum*
	Sooty grunter			✓								*Hephaestis fuliginosous*
	Gudgeon sp_	✓	✓							✓	✓	*Hypseleotris sp.*
	Spangled perch	✓	✓	✓	✓	✓	✓		✓	✓	✓	*Leiopotherapon unicolor*
	Yellowbelly	✓	✓	✓				✓	✓		✓	*Macquaria ambigua*
	Eastern rainbowfish	✓	✓	✓	✓		✓	✓	✓	✓	✓	*Melanotaenia splendida splendida*
	Purple-spot gudgeon			✓								*Mogurnda adspersa*
	Bony bream	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	*Nematalosa erebi*
	Hyrtl's catfish								✓			*Neosilurus hyrtlii*
	Sleepy cod	✓	✓	✓	✓		✓	✓	✓	✓		*Oxyeleotris lineolatus*
	Saratoga							✓				*Scleropages leichardti*
	Leathery grunter	✓	✓	✓					✓			*Scortum hilli*
	Freshwater longtom							✓				*Strongylura krefftii*
	Eel-tailed catfish	✓	✓									*Tandanus tandanus*
Pest Fish	Tilapia	✓* (53)	✓* (83)	✓ (36)		*	*	*	*	*		*Oreochromis mossambicus*
	Platyfish			✓ (2)								*Xiphophorus maculatus*
	Total	10	11	11	4	3	6	8	10	7	6	Total Species: 19

Table 3. Water quality parameters recorded during tilapia detection sampling in the upper Fitzroy Catchment

Site ID	Temperature (°C)	pH	Conductivity (us/cm)	Dissolved Oxygen (%sat)	Secchi depth (m)
Grosvenor Creek 1	21.87	8.19	427.33	110.70	-
Grosvenor Creek 2	21.43	7.37	249.33	50.37	0.36
Grosvenor Creek 3	23.20	7.26	309.67	47.97	0.50
Grosvenor Creek 4	25.33	7.56	187.00	101.53	>0.59
Grosvenor Creek 5	27.37	8.79	148.33	170.53	0.15
Grosvenor Creek 6	24.80	8.88	158.67	103.00	1.34
Isaac River 1	26.07	7.62	78.67	80.53	0.75
Isaac River 2	25.13	7.89	793.33	83.67	-
Isaac River 3	26.07	8.06	1204.33	127.33	-
Sandy Creek 1	23.97	7.34	140.33	68.33	0.61

eDNA – Results extracted from supporting document *Environmental eDNA Survey of Tilapia Infestations in the Moranbah/Isaac Region (Jerry et al. 2015)*.

Of the 10 sites sampled, seven sites resulted in positive detections for tilapia eDNA, the remaining three sites had no detectable eDNA (Table 1). Sites that were positive for tilapia eDNA were, Grosvenor Creek 1, 2, 5 and 6 and Isaac River 1, 2 and 3. The number of positive samples at each site ranged from 2 – 5 and percentage of positive PCR reactions varied from 8 – 88%. All negative control samples and equipment controls of corresponding positive samples were clear of contamination.

Grosvenor Creek 1
Tilapia eDNA was detected in all five water samples collected from this site. The percentage of positive qPCR reactions was 88%. Given the high number of positive reactions for tilapia eDNA, it is likely tilapia are present at this site in high abundance.

Grosvenor Creek 2
Tilapia eDNA was detected in three of the five water samples collected from Grosvenor 2 site with an overall positive detection percentage of 48%. Tilapia are also likely to be present at this site.

Grosvenor Creek 3
Tilapia eDNA was not detected in any of the water samples collected at this site.

Grosvenor Creek 4
Tilapia eDNA was not detected in any of the water samples collected at this site.

Grosvenor Creek 5
Tilapia eDNA was detected in two of the five water samples collected. The two positive water samples consisted of a single positive reaction each resulting in an overall positive detection rate of 8%.

Grosvenor Creek 6
Two water samples tested positive for tilapia eDNA at this site that was made up of four positive qPCR reactions or 16%.

Isaac River 1
Isaac River 1 resulted in a high percentage of positive detections for tilapia eDNA. Four water samples tested positive which consisted of 44% positive qPCR reactions.

Isaac River 2
Tilapia eDNA was found in four of the five water samples collected at this site. Overall, 28% of qPCR reactions tested positive.

Isaac River 3
Tilapia eDNA was found in two water samples collected from Isaac 3 and in total 24% of qPCR reactions were positive.

Sandy Creek 1
Tilapia eDNA was not detected in any of the water samples collected at this site.

Table 4. Results of the eDNA tilapia survey in the Moranbah/Isaac River region, April 2015. Results are presented as both an overall positive or negative assay for tilapia eDNA in each sample (total of five samples per site) and positive or negative for each qPCR reaction (total 25 qPCR reactions per site).

		eDNA Positive/Negative of water Samples			eDNA Positive/Negative of qPCR Reactions		
Site ID	**Date Sampled**	**Number of Samples**	**Number Positive**	**% Positive**	**Number of Reactions**	**Number Positive**	**% Positive**
Grosvenor Creek 1	22/04/2015	5	5	100	25	22	88
Grosvenor Creek 2	21/04/2015	5	3	60	25	12	48
Grosvenor Creek 3	21/04/2015	5	0	0	25	0	0
Grosvenor Creek 4	21/04/2015	5	0	0	25	0	0
Grosvenor Creek 5	21/04/2015	5	2	40	25	2	8
Grosvenor Creek 6	21/04/2015	5	2	40	25	4	16
Isaac River 1	20/04/2014	5	4	80	25	11	44
Isaac River 2	20/04/2014	5	4	80	25	7	28
Isaac River 3	21/04/2015	5	2	40	25	6	24
Sandy Creek 1	22/04/2015	5	0	0	25	0	0

Tilapia eDNA was detected at two of the three sites where tilapia were caught by electrofishing and/or netting. At the third site (Grosvenor Creek 3) it was revealed that eDNA samples were collected approximately 750 m upstream from the electrofishing location (Figure 3), resulting in no cross validation between eDNA and electrofishing/netting at this site. This breakdown in sampling protocols highlights the importance for field staff to carefully coordinate sampling efforts and communicate any changes in site locations.

Tilapia eDNA was also detected from a further 5 sites where electrofishing/netting techniques were unable to identify any tilapia (Table 1). Isaac River 1 and Isaac River 2 were located downstream of the confluence of Grosvenor Creek and Isaac River 3 was upstream of the confluence. Grosvenor Creek 5 and Grosvenor Creek 6 were both small offstream impoundments located within the catchment of Grosvenor Creek.

It has been demonstrated that eDNA originating from upstream sources can be detected downstream (Jane et al. 2015). It is possible that the positive detections the Isaac River sites originated from upstream sources. Whether this was the case would depend on how long the eDNA could have persisted in the environment before it degraded to a level below detection limits. A review into degradation rates of eDNA in field and laboratory conditions conducted by Barnes et al. (2014) indicated that persistence of eDNA in the field conditions is greatly reduced by UV light and high levels of microbial activity. Barnes et al. identified that detection rates varied between species, with reported detection probability >5% ranging from <1 – 25 days. At the time of sampling the Isaac River at Deverill gauging station had not detected flow for a period of 63 days (DNR river flow data – accessed June 2015). Although the persistence of tilapia eDNA has not been thoroughly investigated in field conditions, it is reasonable to assume that the eDNA would not persist for >60 days. Therefore it is highly likely that tilapia eDNA detected at the 3 lower Isaac River sites originated from the pools that samples were collected from, indicating the presence of tilapia at these locations. The detection of tilapia DNA at Isaac River 3 provides further evidence of the presence of tilapia in the Isaac River. A short distance above Isaac River 3 is Burton Gorge Dam, the status of tilapia above this structure is currently unknown and warrants further investigation. If waterways above the dam are free of tilapia the structure will provide a total barrier, preventing the natural movement upstream.

Grosvenor Creek 5, an offstream impoundment is likely to have been isolated from Grosvenor Creek for >60 days, indicating a high probability of the presence of tilapia at this location. This site was extremely exposed to UV light, had elevated pH and DO levels (Table 3), which may be an indication of high algal and microbial growth. All these factors would contribute to the rapid degradation of eDNA and may have contributed to the low eDNA detection rate at this site. Conversely, the lack of tilapia captures in electrofishing/netting operations may be an indication that the low detection rate for eDNA was a result of low abundance of tilapia at this site. Situations such as this highlight the importance of considering rate of eDNA degradation if trying to use detection rates as an indication of abundance.

Grosvenor Creek 6 also returned positive indications for tilapia eDNA. Unlike the other offstream waterbodies sampled, this site is completely isolated from the natural river channels but does receive water from locations outside the study area. To determine if tilapia are present at this site or whether the eDNA originated from external sources requires further investigation.

Figure 3. Location Grosvenor Creek 3 eDNA site (yellow pin) and electrofishing site (red pin). Green pins indicate where tilapia were not identified, red pins where tilapia were captured electrofishing/netting. Google Earth Base Image.

Tilapia populations

Abundance

The abundance of tilapia recorded from the three instream Grosvenor Creek sites (Table 2) indicates the presence of established populations. The species diversity of native fish at several of the sites where tilapia were present was greater than tilapia free sites. Although this may be an indication that tilapia are not having as great an impact on diversity as other pressures (e.g. habitat degradation) it is likely that competition with tilapia for resources will have some impact on local fish communities. There is evidence from controlled experiments that this species of tilapia has the potential to significantly reduce the biomass of several native macrophytes (Doupe. et al. 2010). Therefore it is possible that, in high numbers, similar reductions in macrophyte cover may occur at these sites reducing food availability for native fish.

Length distribution and maturity

In Grosvenor Creek tilapia ranged from 30 mm to 164 mm in length, with the majority of fish ranging between 50 mm and 130 mm (Figure 3). These length distributions were relatively small compared to established populations in the lower Fitzroy River Catchment, where fish ranged from 172 mm – 341 mm (Power 2014). Grosvenor Creek 2 recorded the largest average size tilapia at 91 mm, while Grosvenor Creek 1 and Grosvenor Creek 3 recorded similar averages sizes (Figure 4). Russell et al (2012) reported tilapia from the Wet Tropics, North Queensland displayed growth rates between 50 mm to 100 mm for the first 2-3 years after which plateaus to 20 mm to 30 mm per year. With the assumption that tilapia from the Grosvenor Creek sites displayed similar growth rates it was estimated that the current population has been present for 3-4 years.

This species of tilapia is able to reach reproductive maturity from 110 mm for males and 90 mm for females (Russell et al 2012). Inspection of gonadal development of 40 fish retained from the Grosvenor Creek sites identified the presence of mature fish. Several of the female tilapia examined displayed developing and atretic eggs (Figure 5) indicating that these fish have spawned at least once. The identification of mature fish and varied size classes suggests multiple generations are present and provides further evidence of an established population in Grosvenor Creek.

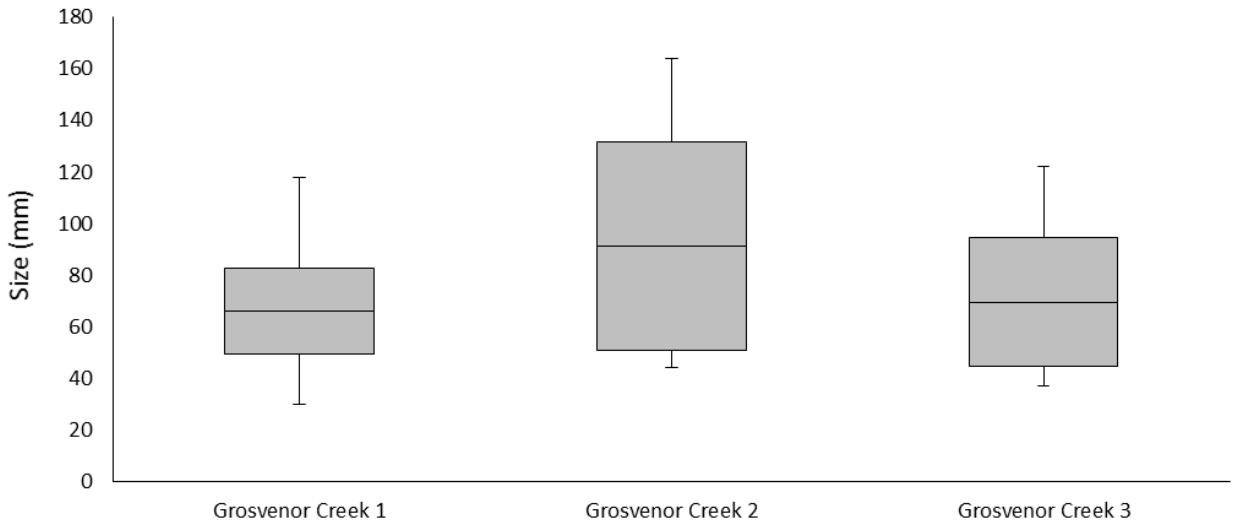

Figure 4. Average size and standard deviation of tilapia captured instream pools at Grosvenor Creek, Moranbah. Error bars indicate minimum and maximum sizes recorded from each site.

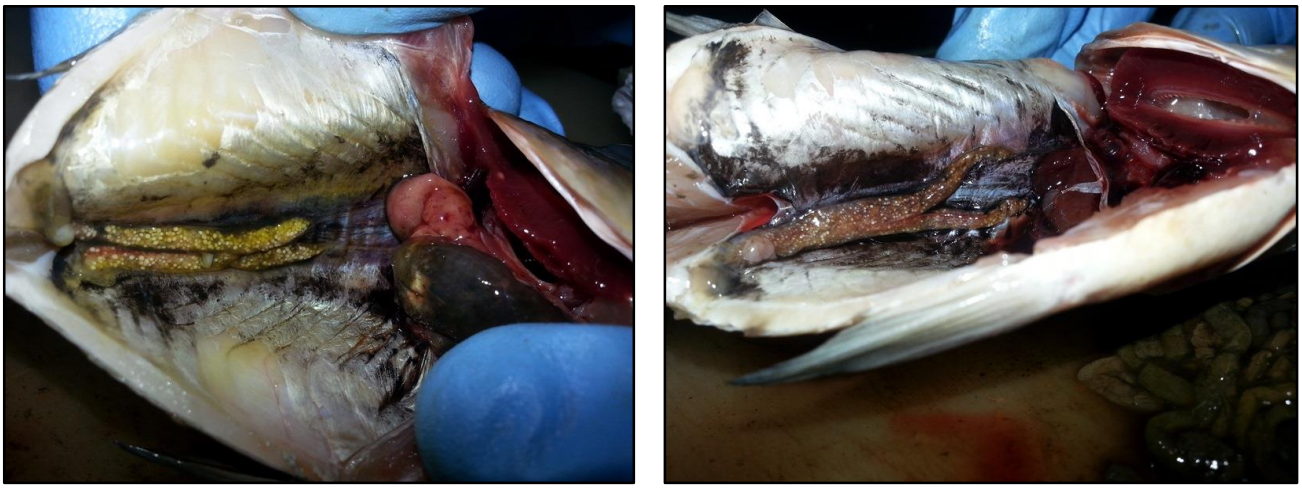

Figure 5. Female tilapia measuring 97 mm (left) and 113 mm (right) captured from Grosvenor Creek, Moranbah in April 2015. Note: gonads contain both developing and atretic eggs.

Conclusion

Based on results of electrofishing/netting and eDNA surveys it appears that tilapia are wide spread through the Grosvenor Creek and Isaac River System and that the population has been present for 3-4 years. It is uncertain whether tilapia have moved into the adjoining Connors and Mackenzie rivers, however given that positive eDNA indications were recorded from Isaac River 3 it is probable that movement further downstream has occurred. Native fish communities did not appear to be adversely affected by the presence of tilapia however this may change as the size and population densities of tilapia increase over time.

Recommendations

- Given the presence of mature breeding populations of tilapia at several locations in the upper Fitzroy, eradication is not feasible. A concerted effort on public awareness and education conveying the presence of tilapia and the threat this species poses on existing ecosystems will be the most effective control measure to reduce the spread of tilapia in the wider Fitzroy system.

- Further sampling to more thoroughly determine the extent of the tilapia distribution within the upper Fitzroy system. By determining the incursion 'front line', awareness products such as information signs can be placed at strategic sites to help raise public awareness. The use of eDNA may provide a more cost effective method for sampling a large number of sites. After the presence of tilapia is detected further sampling with other methods such as electrofishing or netting can be utilised to determine the structure of these populations and impacts to native fish.

- Investigation into the impact of tilapia on aquatic macrophytes at sites with established populations. This will aid in determining the impact tilapia have on native fish.

- There is little documented information on the impacts of tilapia in native fish in Australia. Ongoing monitoring of native fish communities will help understand the impact of tilapia in Grosvenor Creek and native fish in general. Sampling annually for the next 3 years then every 3-5 years thereafter will provide suitable data to determine the impact of tilapia on existing fish assemblages.

- There are several potential incursion pathways by which pest fish can make it into new catchments, including: translocation by people, natural movement during flood periods and inter-catchment water transfer. The pathway responsible for the tilapia incursion in Grosvenor Creek and Isaac River should be thoroughly investigated by Fisheries Queensland and resource managers. This will aid in updating pest management strategies used by government and industry and will reduce the probability of future incursions occurring.

- Habitat improvement (e.g. riparian restoration) of confirmed tilapia sites to increase resource availability to native fish communities and existing ecosystems and reduce competition with tilapia and other noxious species.

Acknowledgments

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Supporting Document

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Appendix 1

Habitat Description Criteria

Category	Classification criteria	
Flow	Estimated rate of flow; (1) 0 m/sec, (2) <0.1 m/sec, (3) 0.1-0.5 m/sec, (4) 0.51-1.0 m/sec, (5) 1.01-3.0 m/sec, (6) >3.0 m/sec	
Water Body Type	Run	in stream water body with unbroken flowing water >0.1 m/sec
	Riffle	in stream water body with broken flowing water <0.1 m depth
	Rapid	in stream water body with broken flowing water >0.1 m depth
	Weir Pool	water body contained within a stream channel created by an artificial structure
	In stream Pool	in stream water body contained within a stream channel with flow <0.1 m/sec
	Off stream pool	off stream water body that connects to a stream channel during periods of elevated flow
	Impoundment Large	water body >10 hectare that extend beyond stream channel or located off stream created by an artificial structure
	Impoundment Small	water body <10 hectare that extend beyond stream channel or located off stream created by an artificial structure
	Natural Wetland	naturally occurring series of interconnected water bodies that extend beyond a stream channel or located off stream
	Constructed Wetland	artificial series of interconnected water bodies that extend beyond a stream channel or located off stream
Average Site Width	Calculated using spatial software and aerial imagery by averaging ten evenly spaced distance measurements of the water body width along the length of the site	
Site Length	Calculated using spatial software and aerial imagery by measuring the middle stream length of water body sampled, this may be portion of total water body length	
Average Riparian Width	Calculated using spatial software and aerial imagery by averaging ten evenly spaced distance measurements of riparian width along the length of the site, each measurement encompasses both banks	
Riparian Condition	Estimated condition of riparian zone; (1/Very Low) cleared to waters edge - very few trees and shrubs, (2/Low) 1-5 m width - some trees and shrubs,(3/Moderate) 5-30 m width - some trees and shrubs, 5-10 m width - many trees and shrubs (4/High) 10-30 m width - many trees and shrubs, (5/Very High) undisturbed riparian zone	
Riparian Shade Potential	Estimated potential for riparian vegetation to shade water body; (1/Very Low) <10% daylight hours, (2/Low) 10-35% of daylight hours, (3/Moderate) 35-65% daylight hours, (4/High) 75-90% daylight hours, (5/Very High) >90% daylight hours	
Aquatic Macrophyte	Estimated coverage of aquatic macrophytes at a site, includes: submerged, floating and emergent types; (1/Very Low) <10% coverage, (2/Low) 10-35% coverage, (3/Moderate) 35-65% coverage, (4/High) 65-90% coverage, (5/Very High) >90% coverage	

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