Preliminary studies towards the development of an aquaculture system to exploit saline groundwater from salt interception schemes in the Murray Darling Basin

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Project Summary

To combat the rising saline groundwater table in the Waikerie region of the Riverland in South Australia, a salt interception scheme (SIS) has been adopted. Some 93 bores are scattered between the Woolpunda, Waikerie and Qualco SIS's, which intercept saline groundwater that would otherwise enter the River Murray. The intercepted water from the bores in all three SIS's is ultimately combined in a single pipeline and pumped to an arid area 12 kilometres south-west of Waikerie known as the Stockyard Plains Disposal Basin (SPDB). Approximately 30 million litres of water per day enters the SPDB at the "outfall". This saline groundwater has a constant water temperature of 22-24 ^{o}C and a salinity of 16-17 g/L, approximately 50 % of oceanic seawater (35 g/L). The costs associated with pumping the intercepted water to the SPDB are high, therefore it is desirable to identify and establish other industries that can benefit from utilising the intercepted water. The objective of this research project was to commence an assessment of possible commercial aquaculture uses for this resource.

Water from the SPDB 'outfall' was transported to the Cooke Plains Inland Saline Aquaculture Research Centre (CPISARC). At the CPISARC a growth trial was setup comparing the growth of a euryhaline fish, mulloway (*Argyrosomus japonicus*), in water from the SPDB and salinity adjusted oceanic water to match the salinity of the SPDB (water taken from SARDI at West Beach). Six individual recirculating aquaculture systems were assembled to perform the growth experiments that were located within a polytunnel (plastic lined greenhouse) that housed a 66 KL sedimentation pond as part of an integrated aquaculture system. Thirty mulloway were

placed into each tank, that were taken from ponds inside the fish polytunnel at the CPISARC, which was in use as part of another project.

In August (2003), the initial average weight of the fish in the West Beach (WB) and SPDB treatments was 32.5 g (SE ± 1.0) and 32.3 g (SE ± 1.0) respectively. The weight check at the start of November 2003 (92 days) indicated that the average monthly weight in the WB treatment was 14.6 % greater (90.5 g, SE ± 3.2) than the mean for the fish in the SPDB treatment (79.0 g, SE ± 2.3). For the remainder of the trial the percent difference in growth remained constant until the trial was terminated on the 30th December 2003 (146 days). At this time the average weights of the fish for the WB and SPDB treatments were 145.2 g (SE ± 5.2) and 127.1 g (SE ± 4.3) respectively. 17 % mortality was recorded for the duration of the experiment due to fish jumping out of the tanks. This survival record suggests that the ionic composition of water from SPDB did not affect survival during the duration of this trial.

The SPDB water was deficient in potassium (K) compared to oceanic water adjusted to match the salinity of the SPDB. Fielder *et al* (2001) found that snapper (*Pagrus auratus*) grown in saline groundwater water (salinity 20 g/L) with a K concentration of 80 mg/L grew significantly slower over 42 days than fish growing in water with a K concentration greater than 120 mg/L. In our experiment, K concentration of SPDB water was 81.6 mg/L and WB was 207 mg/L. In this water mulloway took 92 days before any difference in growth occurred. The average monthly weights at the October 2003 sampling time were similar, even though the food conversion ratio (FCR) was higher in the SPDB treatment compared to the WB. It took 56 days for the FCR in the SPDB treatment to exceed the WB treatment. In comparison Fielder *et al* (2001) found that the FCR of snapper increased to a similar level as the SPDB treatment after 42 days when cultured in fortified water with a similar K concentration.

The water at the outfall of the SPDB contains a K concentration more similar to natural oceanic water compared to other inland saline aquaculture areas investigated in the Murray-Darling Basin. The current water will, however, still require some K supplementation to achieve optimal growth rates and FCR's for mulloway. Further research is required to determine the most economical way K can be supplemented either within the fish feed or to the water so as to maximise fish growth. The outcomes of this research will help determine the best aquaculture production system for use in conjunction with the SPDB.

Introduction

Salt interception schemes (SIS's) provide an engineering approach to intercept saline groundwater that would otherwise enter the River Murray. However, mitigation strategies concentrate on treating the symptoms rather than the causes of the salinity problem (Ghassemi *et al*, 1988). Near Waikerie in the South Australian Riverland, there is a high load of saline groundwater entering the River between river kilometres 374 and 394. This influx of salt is caused mainly by the irrigation activities in the area (Telfer and Watkins, 1991). The Woolpunda (49 bores commissioned in 1990), Qualco (15 bores commissioned in 2001) and Waikerie (17 bores commissioned in 1992 and 12 bores commissioned in 2003) SIS's were constructed to intercept this saline groundwater (pers. com., Peter Forward, SA Water). The intercepted water from the bores in all three SIS's is ultimately combined in a single pipeline and pumped to an arid area 12 km south-west of Waikerie known as the Stockyard Plains Disposal Basin (SPDB). Approximately 30 million litres of water per day enters the SPDB at the "outfall". This saline groundwater has a consistent water temperature of 22-24 ^{o}C and a salinity of 16-17 g/L approximately 50 % of oceanic seawater (about 35 g/L). The objective of this research project was to commence an assessment of possible commercial aquaculture uses for this resource.

Aquaculture has been identified as an industry that can benefit from water associated with dryland salinity (Bolt, 2001). Establishing an aquaculture industry aligned to water from SIS has great potential due to the volume of water being intercepted and the naturally elevated temperature of the water. The establishment of an aquaculture industry in the Riverland has the potential to create jobs and investment that will add to economic development within the region within the framework of environmentally sustainable development (ESD).

Given the salinity (16-17 g/L) available, the aim of this project was to determine the potential for growing euryhaline fish in water from the outfall at the SPDB. Euryhaline fish that have been considered for commercial aquaculture in Australia and suited to the location in question include black bream (*Acanthopagrus butcheri*) and mulloway (*Argyrosomus japonicus*). Black bream have been shown to produce similar growth and survival at salinities ranging from 0 – 60 g/L (Partridge and Jenkins, 2002), while mulloway have been grown in salinities ranging from 5 – 35 g/L (Fielder and Bardsley, 1999). Mulloway were chosen for this experiment as fish were readily available from another inland saline aquaculture project and they possess a number of features that suggest they may be a good candidate for commercial inland saline aquaculture operations. These include easy hatchery production and good survival, their good growth rates, their acceptance of readily available extruded pellet fish feeds, their hardiness in a range of culture systems and their acceptance in the market place at a reasonable price.

From previous research it was anticipated that ionic composition of saline groundwater could differ from that of seawater and this may impact upon the performance of the species selected. Potassium (K^+), sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-) and sulphate (SO_4^{2-}) ions comprise over 99 % of the minerals in seawater (Forsberg *et al*, 1996), and the balance of these ions differs independently of where the water is sourced (Saoud *et al*, 2003). Analysis of the water entering SPDB shows that it is potassium (K) deficient (Table 1) as compared to natural oceanic waters. Previous research by Fielder *et al* (2001) has shown that snapper (*Pagrus auratus*) growth was restricted in saline groundwater with a K concentration less than 120 mg/L in water with a salinity of 19.6 g/L. Initial research in this project was thus undertaken to assess the ability of mulloway to adapt to the reduced ion concentrations in water from SPDB compared to fish maintained in oceanic water adjusted to the same salinity.

Chapter 1 Experimental Design

1.1 Method

Water from the outfall of the SPDB was transported to the Cooke Plains Inland Saline Aquaculture Research Centre (CPISARC) and held in two 10 KL tanks outside the sedimentation polytunnel (plastic lined greenhouse). Oceanic water was collected from SARDI West Beach (WB) and transported to the CPISARC and held in two 10 KL tanks inside the sedimentation polytunnel. The salinity of the WB water was adjusted to match the SPDB using local mains freshwater and sodium thiosulfate was added to neutralise residual chlorine.

Six individual recirculating aquaculture systems were assembled to perform the growth experiments (Figure 1). These were located within a polytunnel that housed a 66 KL sedimentation pond as part of an integrated aquaculture system. Each of the recirculating aquaculture systems has the same sized essential components required to maintain optimum water quality for the duration of the experiments. These components include: 800 L fibreglass tank, Dacron™ mechanical filter material, biological trickle filter (20 L plastic media), submerged biological filter (20 L plastic media), foam fractionator, 70 L sump with submersible pump (Pondmaster™ 3600, 3200 L/hr) and 2 x 300 watt aquarium heaters. Aeration was provided to each tank with a single airstone supplied from the main blower for the CPISARC system.

Figure 1. Six tanks with their own recirculating biological filters were used to perform the mulloway growth experiments in the sedimentation polytunnel.

Each treatment was allocated three replicates. The six tank recirculation systems were each randomly assigned a replicate from either treatment. Mulloway used in the experiment were obtained from the fish polytunnel at the CPISARC. At the start of the trial (6^{th} August, 2003), 30 fish were randomly selected, individually weighed, measured and placed into an 800 L tank. This was repeated for all six tanks.

For the duration (146 days) of the experiment the fish were fed to satiation daily and dissolved oxygen, water temperature, salinity and food ration was recorded daily. All tanks received a 10 % water exchange daily coinciding with cleaning of the Dacron™ filter material. The daily minimum and maximum water temperature was recorded using a min/max thermometer located in tank 3 only, to give an indication on how the water temperature was fluctuating during a 24 hour period. Total ammonia and pH were recorded weekly in all tanks. Tanks were spot cleaned when necessary.

At the start of each month, all fish from each tank were individually weighed, except in December 2003 when the fish were sampled twice (3^{rd} & 30^{th}). Using fish weights and feed consumption data, specific growth rates (SGR) and food conversion ratios (FCR) were determined monthly for each tank. SGR refers to how much weight the fish are putting on each day (Equation 1), and the FCR was calculated by dividing the feed consumed by the weight gained.

Equation 1:

$$\text{SGR (\%/day)} = [\ \ln (W_f) - \ln (W_i) / (t_2 - t_1)] \times 100$$

where W_i = initial average weight (g) t_1 = initial time (days)

W_f = final average weight (g) t_2 = final time (days)

A water sample was taken from each batch of the salinity adjusted West Beach water (WB) and the SPDB outfall water on arrival at the CPISARC. These samples were sent to the Australian Water Quality Centre (AWQC) for analysis.

1.2 Statistical Analysis

A repeated measures ANOVA was performed on average monthly treatment weights, and a two-way ANOVA was conducted on the mean monthly FCR's from September through to December. Both statistical analyses were performed using Statistix.

Chapter 2 Results

2.1 Experiment Water Quality Analyses

Initial water quality results obtained from the AWQC for the WB and the SPDB samples are provided in table 1 together with results for the Wakool-Tullakool Subsurface Drainage Scheme in New South Wales (NSW) for comparison (Fielder *et al*, 2001).

The salinity of the SPDB water was 16 ppt and the pH 7. The salinity of the WB water was 17 ppt and the pH 7.8. Potassium is the most obvious ion that is low in the SPDB water (81.6 mg/L) as compared to the salinity adjusted WB water (207 mg/L). Other ions were also present in higher concentrations in the WB water than the SPDB water, these including sulphate, chloride and magnesium. The concentration of the bicarbonate, fluoride and calcium were all greater in

Table 1. Ionic composition of salinity adjusted West Beach water and outfall water from the SPDB, when the samples first arrived at the CPISARC (analyses performed by the Australian Water Quality Centre). Water sample from the Wakool-Tullakool Subsurface Drainage Scheme in New South Wales (Fielder et al, 2001).

	Adjusted Salinity WB	**SPDB Outfall**	**Difference +/- (%)**	**Wakool**
pH	*8.3*	7	-15.7	7.9
Total hardness (mg/L as $CaCO_3$)	*3,488*	2,676	-23.3	N/A
Total dissolved solids (mg/L)	*17,000*	16,000	- 5.9	19600
Conductivity (uS/cm)	*28,600*	26,900	- 6.0	N/A
Dissolved solids by calculation (mg/L)	*18,500*	17,400	- 6.0	N/A
Calcium (mg/L)	*220*	347	+57.7	504
Magnesium (mg/L)	*713*	439	-48.4	820
Potassium (mg/L)	*207*	81.6	-60.6	9.2
Sodium (mg/L)	*5,200*	5,240	0	4,210
Bicarbonate (mg/L)	*112*	532	+475	N/A
Chloride (mg/L)	*10,600*	9,410	-11.2	11,000
Sulphate (mg/L)	*2,920*	1,600	-45.3	1,100

the SPDB water than the WB water. Total alkalinity was higher in water from the SPDB than the water from WB, while total hardness was lower in SPDB water than WB water.

2.2 Mulloway Growth

2.2.1 Average Monthly Growth

In August, September and October 2003 (0, 28 and 56 days) there was no significant difference in the average monthly weights between the two treatments (Figure 2). The fish grown in the WB treatment had mean monthly weights of 32.5 g (SE ± 1.0) in August, 36.2 g (SE ± 1.1) in September and 55.3 g (SE ± 1.7) in October. In the SPDB treatment the mean monthly weights for the corresponding months were 32.3 g (SE ± 1.0), 36.3 g (SE ± 1.0) and 55.2 g (SE ± 1.5).

The weight check at the start of November 2003 (92 days) revealed that the average monthly weight in the WB treatment was 14.6% greater (90.5 g, SE ± 3.2) than the mean for the fish in the SPDB treatment (79.0 g, SE ± 2.3). For the remainder of the trial the percentage difference in growth remained constant until the trial was terminated at the end of December 2003 (146 days). On 3rd December 2003 (119 days) the weight of fish in the WB treatment was

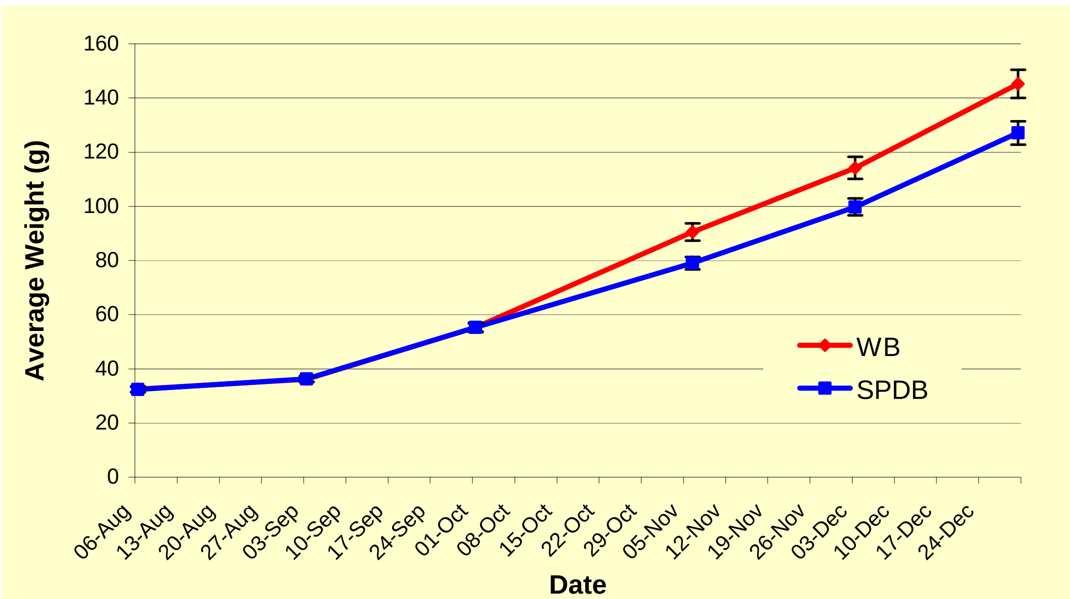

Figure 2. Average monthly weights (± SE) for mulloway in SPDB water and salinity adjusted West Beach water (2003).

14.4 % greater with a mean wet weight of 114.2 g (SE ± 4.1), compared to 99.8 g (SE ± 3.1) for fish in the SPDB treatment. When the experiment was terminated on the 30th December the weight of fish in the WB treatment was14.2 % greater with a mean wet weight of 145.2 g (SE ± 5.2) compared to 127.1 g (SE ± 4.3) for fish in the SPDB treatment ($P<0.05$).

17 % mortality was recorded for both treatments for the duration of the experiment, which occurred due to the occasional fish jumping out of the tanks. All tanks had nets secured to the top on the 26th of August. The similar survival levels between the two treatments suggests that the ionic composition of water from the SPDB did not affect survival during the duration of this trial (146 days). The results from the repeated measures analysis on the growth data indicates that there was no significant difference ($P > 0.05$) in the average weights between the treatments taking into consideration every sampling period.

2.2.2 Specific Growth Rates

The SGR for both treatments (Figure 3) displayed similar results throughout the experiment, except in October-November 2003 when the only major difference in monthly average weight

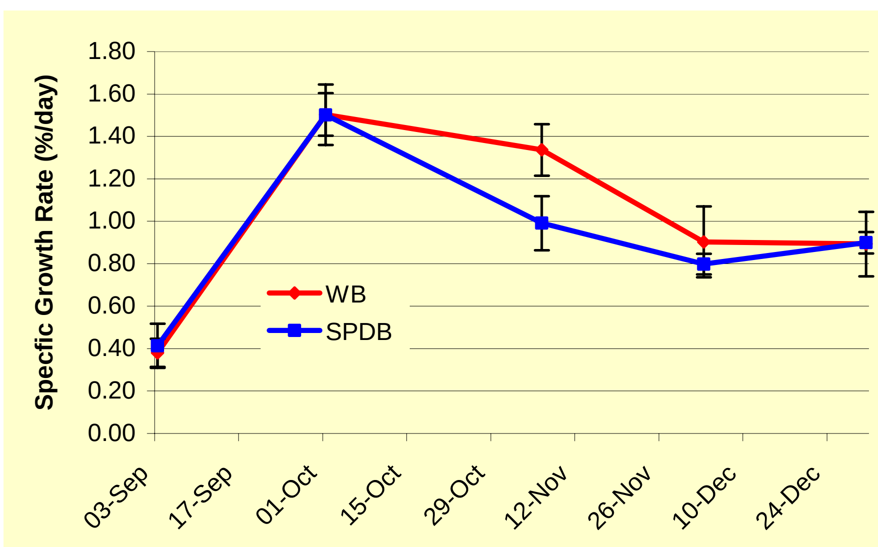

Figure 3. Specific growth rates (± SE) for mulloway in SPDB water and salinity adjusted West Beach water.

was observed. At the start of the trial in August-September 2003 it was noticed that the SGR for the WB and SPDB were 0.38 ± 0.1 %/day and 0.41 ± 0.1 %/day respectively. These were less than anticipated for the average daily water temperatures. The feeding regime was adjusted to three feeds per day for the remainder of the experiment and SGR in both treatments improved to 1.5 ± 0.1%/day during September-October 2003. The SGR for the WB and SPDB treatments in October-November were 1.34 ± 0.1 %/day and 0.99 ± 0.1 %/day respectively. This period was when the separation in average monthly weights occurred between the two treatments. During November-December 2003 and until the end of the trial, both treatments again followed similar SGR performance with the SGR values for the WB treatment being 0.9 ± 0.1 and 0.89 ± 0.1 %/day, and the corresponding values for the SPDB were 0.80 ± 0.1 and 0.9 ± 0.1 %/day.

2.2.3 Food Conversion Ratio (FCR)

In August 2003 the FCR was not calculated as some of the fish had been lost from the tanks, so a true value could not be determined. In September 2003 the mean monthly FCR was 1.13 ± 0.2 and 1.06 ± 0.1 for the WB and SPDB treatment, respectively. In October the FCR of the WB fish increased slightly to 1.35 ± 0.3, but increased to 1.86 ± 0.3 for the SPDB treatment (Figure 4). During November 2003 the FCR for the SPDB tanks remained constant from the previous

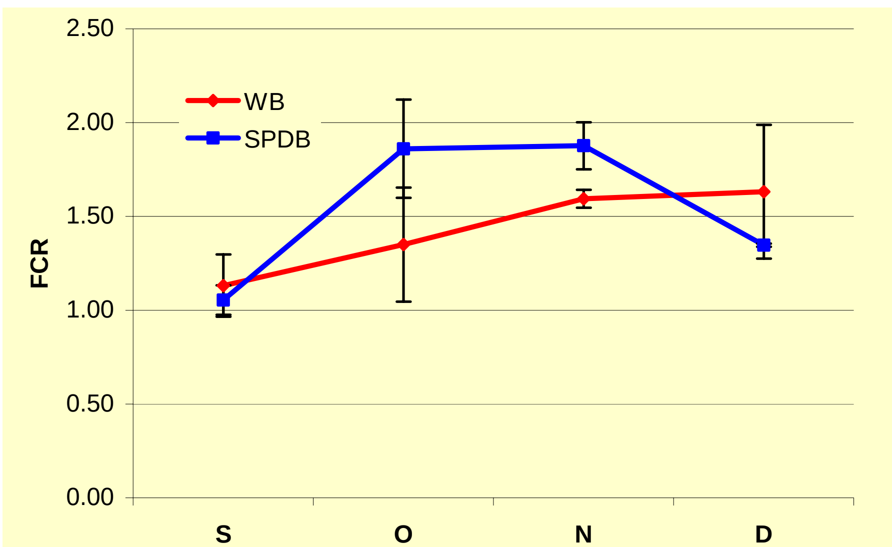

Figure 4. Food conversion ratio (± SE) for mulloway grown in SPDB water and salinity adjusted West Beach water (2003).

month at 1.88 ± 0.1, but the FCR for the WB treatment increased slightly to 1.59 ± 0.1. The FCR for the SPDB fish decreased to 1.35 ± 0.0 in December 2003 while the FCR for the WB fish remained constant (1.63 ± 0.4). The results from the two-way ANOVA indicate that there was no significant difference ($P > 0.05$) between the treatments, but there was a slight significant difference between the months ($P = 0.0464$). A Tukey's test on the monthly data revealed there was a significant difference between the September and November data sets only.

2.2.4 Length Weight Relationship

In August and September 2003, a random 10 fish from each sample had their length recorded. For the remaining sampling periods all the fish had their lengths recorded. The length-weight relationship for mulloway sampled on 30th December 2003 shows a power relationship with an R^2 of 0.7214. Some of the values do not fit on the line due to the fish competing for food, which has resulted in varying growth rates.

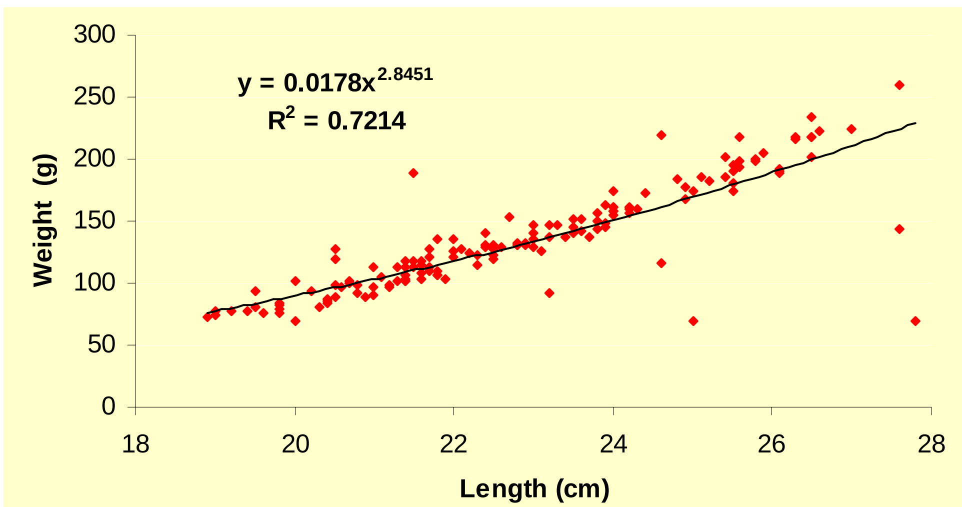

Figure 5. Length-weight for mulloway sampled on 30th December 2003.

2.3 Water Quality

The daily water quality remained within acceptable levels for the duration of the project (Appendix 1). The salinity marginally increased in both treatments due to evaporation. At the start of the experiment the dissolved oxygen levels in the WB and SPDB were both the same level at 7.3 mg/L (SE ± 0.1). By the end of the experiment the oxygen levels had decreased to 5.4 mg/L (SE ± 0.1) in the WB treatment and 5.1 mg/L (SE ± 0.1) in the SPDB treatment. Average monthly ammonia levels never exceeded 1.5 mg/L during the experiment. The pH levels in the SPDB treatments remained constant during the experiment, compared to the pH in the WB treatment that decreased from 7.6 (SE ± 0.1) to 6.7 (SE ± 0.1).

Appendix 2 shows the daily maximum and minimum water temperatures recorded in the WB treatment for replicate tank number three. Water temperatures on some days exceeded 27 ^{o}C, and at the beginning of the experiment minimum water temperatures of 19 ^{o}C were recorded. On the 8th August a second 300 watt heater was connected to each tank within the trial. This improved the water temperature in each tank to maintain the desired 22-24 ^{o}C water temperature range during the coldest period of the trial.

2.4 Internal Organ Analysis

In December 2003, three mulloway from each treatment were sampled to determine if any internal abnormalities could be seen within the fish as a result of the K deficiency in the SPDB water. These fish were dissected by Dr Colin Johnston from the PIRSA Fish Health Unit and had their gills, kidney, liver, gall bladder and intestine fixed in 10 % formalin. Upon dissection, gross pathology indicated no visible changes, so histology of the organs was then undertaken by Dr Colin Johnston.

Histology results indicated that there were no abnormal changes in any of the major organs.

Chapter 3 Discussion

3.1 Fish Growth

Sodium, potassium and chloride are amongst the most common inorganic elements found in fish and are extremely common in freshwater and seawater environments to satisfy the physiological needs of fish (De Silva and Anderson, 1995). Fish absorb these ions through the gills in freshwater and through the gut in seawater, and their concentrations are controlled via osmoregulation (Lovell, 1989). Sodium and potassium are the major extracellular and intracellular cations respectively, chloride is the major extracellular anion, and all are involved in osmoregulation (Lovell, 1989). These ions are required for proper functioning of cells, particularly in maintaining ion gradients between the inside and outside of cells, and for maintaining nerve function (De Silva and Anderson, 1995; Lovell, 1989).

Groundwater can typically be K deficient and has been shown to limit the growth of fish (Fielder *et al*, 2001; Forsberg *et al,* 1996) and prawns (McGraw and Scarpa, 2003; Saoud *et al*, 2003). Growth of fish in K deficient water is reduced due to anorexia and reduced feed conversion (Shearer, 1988). This trial revealed that saline groundwater from the SPDB is deficient in K compared to oceanic water adjusted to match the salinity of the SPDB.

Fielder *et al* (2001) found that snapper (*Pagrus auratus*) grown in saline groundwater water (salinity 20 g/L) with a K concentration of 80 mg/L grew significantly slower over 42 days than fish growing in water with a K concentration greater than 120 mg/L. In our experiment K concentration of SPDB water was 81.6 mg/L. In this water mulloway took 92 days before any difference in growth occurred. During this time the average monthly weights remained the same for both treatments. The average monthly weights at the October 2003 sampling time were similar, even though the FCR was higher in the SPDB treatment compared to the WB. It took 56 days for the FCR in the SPDB treatment to exceed the WB treatment. In comparison Fielder *et al* (2001) found that the FCR of snapper increased to a similar level between treatments after 42 days at a similar K concentration. Figure 4 indicates that the SPDB water may have had a negative impact on the FCR in the first 117 days of the experiment, but it is recommended that the experiment should be repeated with additional replicates to determine a more accurate result.

The results of this experiment suggest that mulloway are able to tolerate K deficiencies longer than oceanic fish such as snapper. Some euryhaline fish such as juvenile turbot (*Scophthalmus maximus*) grown at 22 ^{o}C with a salinity of 15 g/L have been found to have a 14 % higher growth rate than fish grown at the same temperature in 33.5 g/L saline water (Imsland *et al*, 2001) but it is unclear whether this growth persists over time. Sampaio and Bianchini (2002) found that flounder (*Paralichthys orbignyanus*) grown at 22 ^{o}C displayed higher growth rates in 30 g/L seawater than in 0 g/L freshwater. Handeland *et al* (1998) found that only temperature (4 and 8 ^{o}C) affected the growth of Atlantic salmon (*Salmo salar* L.) smolts in seawater with salinities of 28 g/L and 34 g/L during the first two months of a three month growth study. However, between days 64 and 90 higher growth rates were found in the brackish (28 g/L) water at 4 ^{o}C. These results indicate that a reduction in oceanic salinity may improve long term growth of euryhaline fish.

Near the end of the experiment, mulloway were sampled from both treatments to determine if any abnormalities could be seen in the gills, kidney, liver, gall bladder and intestine as a result of the K deficiency in the SPDB water. The results of the histology indicated that no abnormalities were observed, which agrees with Shearer (1988) who examined the gills, livers and kidneys of juvenile chinook salmon fry fed diets containing 88 and 11,908 ppm (0.088 and 11.9 g/L) concentrations of K.

Excess K in the water can adversely affect fish growth. Dersjant-Li *et al* (2001) found that excess K in the water resulted due in a decreasing Na/K ratio for juvenile African catfish which in turn suppressed fish growth (*Clarias gariepinus*).

3.2 Water Chemistry

Water from the SPDB has a K concentration of 81.6 mg/L. This study has been shown that growth in mulloway is reduced by 14 % compared to fish grown in salinity adjusted oceanic water. Saline water can be supplemented with analytical grade potassium chloride (KCl) or agricultural fertiliser such as potash to achieve optimal levels of K suitable for fish production (Fielder *et al*, 2001), as fish can obtain the majority of their K requirement from the water (Sakamoto and Yone, 1978, as cited in Shearer, 1988). One of the main problems with dosing water is the cost. If commercial sized flow-through aquaculture production systems are to be established, it may not be feasible to cost effectively dose the influent water. Alternative production systems such as recirculation aquaculture systems, which operate on minimal water exchange, may require further investigation and be a viable option.

Supplementing K by adding it to fish feeds could be a more viable option to combat K deficiency in the groundwater at the SPDB and should be investigated. Shearer (1988) found that by measuring the whole body K concentrations of juvenile chinook salmon indicated that a dietary K level between 0.62 and 1.20 % is required to maintain a normal level. However, Shearer concluded that a more accurate determination of the K requirement was necessary using graded levels of K between 0.62 and 1.20 % of the diet. Wilson and El Naggar (1992) recommended a K requirement value of 0.26 % for channel catfish (*Ictalurus punctatus*) using a linear regression analysis of the dietary K levels as compared to whole body K balances. They also found that *I. punctatus* have a requirement that can be met by either dietary K or K in the rearing water, and that they could regulate their total body K via unidirectional movement of ions across the gills.

The calcium concentration (Ca) in the SPDB water is 158 % greater than in the WB water. Hossain and Furuichi (2000) found that redlip mullet (*Liza haematocheila*) grown in 32-34 g/L saline water began to decrease in body weight after seven weeks when fed a low Ca diet (200 mg kg^{-1} dry matter). These results indicated that redlip mullet cannot solely rely on Ca uptake from seawater, and Ca must be supplemented in their diet. Extra Ca in the SPDB water precipitated out of solution and deposited on the heaters within the tanks. These heaters required cleaning and acid rinsing everyday.

Magnesium (Mg) and sulphate (SO_4) concentrations have been found to not have a critical effect on the short-term survival of Pacific white shrimp (*Litopenaeus vannamei*) in freshwater (< 1000 ppm TDS) (McGraw and Scarpa, 2003). Over a 10 week period, tilapia (*Oreochromis niloticus*) grown in freshwater experienced higher weight gains with increasing Mg concentrations towards 1.0 g kg^{-1} Mg in the diet (Dabrowska *et al*, 1989). Mg and SO_4 levels in the SPDB water are 62 % and 55 % lower than salinity adjusted seawater respectively.

The bicarbonate level in the SPDB water is 475 % greater than the salinity adjusted seawater. Carbon dioxide in natural waters reacts with bases (eg. calcite and dolomite) in rocks and soils to form bicarbonate (Boyd, 1996). The high bicarbonate levels in the SPDB water provided buffering within the SPDB treatment tanks to resist changes in pH. This was evident during the experiment where the pH in WB treatment decreased over the experiment duration, whereas in the SPDB treatment the pH only fluctuated slightly.

Water entering the outfall of the SPDB is made up of water from the Woolpunda, Waikerie and Qualco SIS. Appendix 3 displays variations in the ionic composition between all three SIS from sampling over a short period of time. This agrees with results of Saoud *et al* (2003), who discovered that when water samples are taken over a wide area, the ionic composition of the water varies even when the water is part of the same aquifer.

Since the SPDB has been receiving water from the SIS's, very few water quality analyses have been performed. Currently it is unknown whether the water quality varies from the SIS's due to seasonal variation or if it remains constant all the time. Water quality is critical for any aquaculture facility, and it must be suitable all the time. Any major fluctuations in the essential ions in the intercepted groundwater could be detrimental to commercial production levels.

Future Work

The results from this project support that the growth of mulloway in water containing <120 mg/L of potassium at a salinity of 17-18 g/L is reduced. These results suggest that mulloway, a euryhaline fish, has different requirements for potassium compared to oceanic fish such as snapper. Mulloway displayed a 14.6 % reduction in growth after 92 days in SPDB water, compared to snapper grown in similar potassium concentration water that had a reduction in growth within 42 days (Fielder *et al,* 2001). Further research is required to identify the most economical way K can be supplemented either within the fish feed or to the water to maximise fish growth.

If fish growth deficiencies can be overcome using water from the outfall of the SPDB to grow mulloway as seems likely from the literature, then appropriate systems need to be designed that will maximise the use of water aligned to the SIS at Waikerie. Water from SIS's have attributes which support the development of aquaculture facilities such as warm temperature (20-24 ^{o}C) and high volume. Elevated water temperatures provide significant cost savings for aquaculture facilities during cool SA winters and allows high growth rates characteristic of summer months, all year round. Wastewater associated with these systems will require biological treatment before being discharged to evaporation basins and further research is required to identify appropriate technologies that meet with the need for environmentally sustainable development (ESD).

The research carried out in this project has used water from the outfall of the SPDB, which is a combination of all waters from the interception schemes in the Waikerie region. If appropriate production systems can be identified, the volume of water available for aquaculture might support the growth of multiple companies ideally aggregated within an aquaculture technology park (ATP). This would allow co-ordinated planning undertaken by the appropriate authorities and for companies to realise cost savings because of this and shared intake and discharge facilities as well as perhaps a hatchery, workshop, technical and support staff, and research and training facilities. Research needs to be undertaken to address the issues associated with the establishment of an ATP.

Mulloway is an ideal candidate to initially produce using the water from the outfall of the SPDB as this species readily adapted to the SPDB salinity, and is suitable for semi-intensive pond or intensive recirculation culture. However, for this species to be a successful business proposition, appropriate marketing is required to establish the end product sale prices and volumes within the region, nationally and overseas. Elevated SPDB water temperatures will allow consistent production, which in turn provides constant availability to markets. Once mulloway has been fully commercialised, other species should be targeted to diversify products therefore reducing marketing risks. Greenback flounder (*Rhombosolea tapirina*) might be one such suitable species as it is euryhaline like mulloway and is also caught locally in SA. Hatchery and growout techniques for flounder have been researched and similar species are consumed in Asia and Europe, so markets already exist which producers could access. The key research issues need to determine the suitability of this species to SPDB water, the optimal production system to use at this site and the commercial viability of this culture.

Developing ATP's aligned to SIS's in the Riverland region provides a viable option to offset the high operational costs of SIS and increase economic activity in the region. A pilot scale facility is required that utilises water from the outfall of the SPDB, which will enable the initial research and provide demonstrations to encourage potential investors to visit the site to begin commercialisation. Additionally, the pilot scale facility will provide opportunities for local TAFE and indigenous groups to become involved and act as a regional training centre. It is believed that three years will be required to establish a pilot scale facility and develop the technology at the SPDB to a stage where it should be able to be commercialised. After this time the pilot scale facility might be used by the TAFE and indigenous groups for continuing training, or by commercial operators that could use it, for example, for quarantine facilities for new stock introduced to the site or an ongoing research facility.

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Appendices

Appendix 1. Mean monthly water quality parameters recorded for WB and SPDB treatments (±SE).

Summary August 2003

Tank	Water Temp (oC)	DO (mg/L)	pH	Salinity (ppt)	Ammonia (mg/L)
WB	21.6 ± 0.2	7.3 ± 0.1	7.6 ± 0.1	18.3 ± 0.2	1.5 ± 0.1
SPDB	22.0 ± 0.4	7.3 ± 0.1	8.5 ± 0.1	18.0 ± 0.1	0.9 ± 0.1

Summary September 2003

Tank	Water Temp (oC)	DO (mg/L)	pH	Salinity (ppt)	Ammonia (mg/L)
WB	23.5 ± 0.1	6.9 ± 0.1	7.8 ± 0.1	17.8 ± 0.0	1.0 ± 0.1
SPDB	23.8 ± 0.1	6.9 ± 0.1	8.2 ± 0.1	18.8 ± 0.0	0.9 ± 0.1

Summary October 2003

Tank	Water Temp (oC)	DO (mg/L)	pH	Salinity (ppt)	Ammonia (mg/L)
WB	24.0 ± 0.1	6.7 ± 0.1	7.2 ± 0.1	18.7 ± 0.0	0.9 ± 0.1
SPDB	24.1 ± 0.1	6.5 ± 0.1	8.0 ± 0.1	19.3 ± 0.0	1.0 ± 0.2

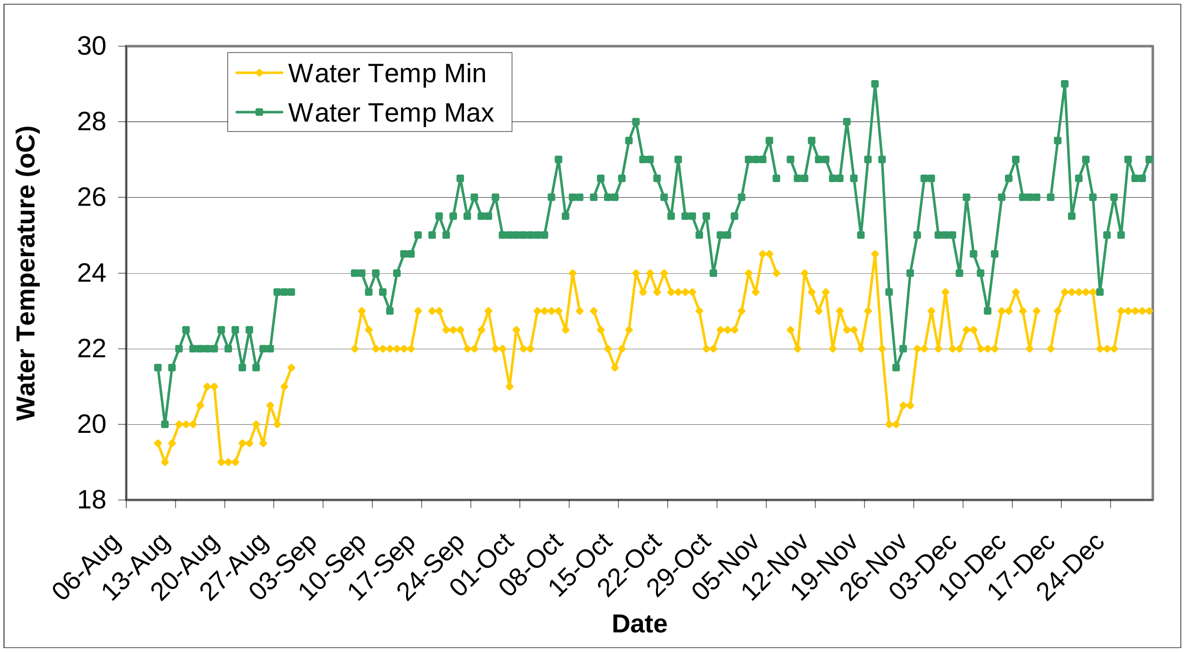
Summary November 2003

Tank	Water Temp (oC)	DO (mg/L)	pH	Salinity (ppt)	Ammonia (mg/L)
WB	24.3 ± 0.2	5.6 ± 0.1	6.9 ± 0.1	19.0 ± 0.0	0.9 ± 0.1
SPDB	24.6 ± 0.2	5.5 ± 0.1	7.7 ± 0.1	19.7 ± 0.0	1.0 ± 0.9

Summary December 2003

Tank	Water Temp (oC)	DO (mg/L)	pH	Salinity (ppt)	Ammonia (mg/L)
WB	24.0 ± 0.1	5.4 ± 0.1	6.7 ± 0.1	19.2 ± 0.0	0.7 ± 0.1
SPDB	24.3 ± 0.1	5.1 ± 0.1	7.8 ± 0.1	21.1 ± 0.0	0.9 ± 0.0

***A*ppendix 2.** Daily maximum and minimum water temperature fluctuations in the WB treatment, replicate number 3 tank.



Appendix 3. Ionic composition of water from all three interception schemes in the Waikerie area diverting water to the SPDB and the SPDB 'Outfall'.

General data		***Woolpunda***[a]	***Waikerie***[a]	***Qualco***[a]	***Outfall A***[a]
	Sampling Date	*24/07/2001*	*24/07/2001*	*24/07/2001*	*04/08/2001*
	PH	6.9	7.2	7	6.9
	Total dissolved solids (by EC)	18,000	16,000	11,000	17,000
	Conductivity (uS/cm)	30,000	25,800	19,200	28,600
	Dissolved solids by calculation (mg/L)	20,300	17,500	14,400	19,800
Cations					
	Calcium (mg/L)	467	235	550	405
	Magnesium (mg/L)	543	391	519	477
	Potassium (mg/L)	71.2	65.4	<100	75.7
	Sodium (mg/L)	6,260	5,560	3,900	5,970
Anions					
	Bicarbonate (mg/L)	472	592	480	485
	Chloride (mg/L)	11,700	9,560	6,130	11,000
	Sulphate (mg/L)	1,070	1,380	2,990	1,600

[a] Analyses provided by Peter Forward from SA Water.