CULTURING SNAPPER IN DUMBLEYUNG – A CASE STUDY FOR DETERMINING THE POTENTIAL FOR INLAND SALINE GROUNDWATER TO GROW MARINE FISH IN WESTERN AUSTRALIA.

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INTRODUCTION

Western Australia has the largest area of dryland salinity in Australia and the highest risk of increased salinity over the next 50 years (NLWRA 2002). It is estimated that 16% (4.3 million hectares) of the southwest region has a high potential of developing salinity from shallow watertables, with this figure predicted to double by 2050. Of the 4.3 million hectares currently at high risk, 81% is agricultural land. In addition, it has been predicted that Western Australia contains 95% of the nations 'at-risk' native vegetation, with a further 67% of the road network and 30% of built infrastructure (towns) also under threat (NLWRA, 2000)

In 1997 the Department of Agriculture, Western Australia, initiated the Rural Towns Program (RTP) under the State Salinity Action Plan. One of the methods in which the RTP is assisting rural towns is through the implementation of a groundwater pumping program, which aims to reduce the impact of rising groundwater tables on rural infrastructure. This is being achieved by pumping saline water from beneath threatened towns and diverting it into evaporation basins.

Pumping seawater and the high cost of coastal land, are the most significant costs for a typical pump-ashore, marine aquaculture operation. Locating such operations on salt degraded land and utilising saline groundwater from diversionary programs such as the Rural Towns pumping program will significantly reduce these costs. Additional benefits of locating aquaculture operations in rural towns include the existence of infrastructure and population base, and the creation of employment and economic opportunities in areas currently experiencing economic decline.

Although the ionic composition of saline groundwater in the WA wheatbelt generally reflects that of seawater, the exact composition varies between towns and even within towns. This variability relates to the nature and timing of recharge, and the nature of the underlying groundwater systems. For example, groundwater sources based near palaeochannels and related deeper regolith are more likely to be highly saline and geochemically mature. On the other hand, aquifer systems in western or midslope positions are likely to be more modern and therefore composed of a mixture of waters sourced from pre-existing storages and recent recharge from overlying agricultural, peri-urban and urban areas. Due to this variability, it is unlikely that all water sources will have a suitable chemical composition for culturing marine or estuarine fish.

Comparing the growth and survival of marine fish in potential water sources against full-strength seawater and seawater adjusted to an equivalent salinity to that of the groundwater under test is an effective measure of determining suitability. These methods are, however, time consuming and costly to perform. Trials were therefore undertaken to determine if a series of simple laboratory tests could be used as a reliable indicator of the suitability of inland saline water sources for growing marine fish. The four tests included: 1) an assessment of the water's salinity and pH; 2) determination of the ionic composition of the water; 3) bacterial toxicity testing (Microtox®) and 4) pesticide analysis. After these tests were conducted, a series of growth trials using juvenile snapper (*Pagrus auratus*) were then performed to determine if a positive correlation exists between the test results and the results obtained in the growth trials.

Groundwater sources from the Dumbleyung water catchment were used in the case study. Eleven test bores were originally commissioned within the town as a part of a community-based evaluation of salinity risk, with several more bores later drilled as part of the Rural Towns Program (Whitfield, 2001). The bores were established as part of an overall groundwater study to test aquifer properties, measure rates of watertable change over time and observe the impact of salinity management treatments.

If the range of inland saline water sources can be narrowed down to those suitable for aquauculture using a combination of laboratory tests, survival and growth trials can then proceed on a smaller number of potential water sources. By excluding water sources proven to be unsuitable via cost-effective laboratory testing, greater value can be obtained from more costly but essential growth trials.

METHODS

Test 1: Salinity and pH

Salinity and pH were the initial measurements applied to the eleven test bores from the Dumbleyung catchment.

Previous unpublished work conducted at the Aquaculture Development Unit (ADU) has determined that snapper grow well in salinities as low as 12 ppt. This salinity was therefore set as the minimum that would be considered in the Dumbleyung bores. Salinity was measured as normalised electrical conductivity (EC; µS/cm) and converted to parts per thousand (ppt) using the equations given in APHA (1995) and Miller *et al* (1988).

Groundwater sources in the wheatbelt vary both regionally and locally in pH, but are typically acidic. The reason for the low pH of many of these groundwater sources is still being researched, however it appears that they are subject to ferrolysis, and in localized areas, sulfide oxidization. If the pH of a groundwater source is only 1-2 units below an acceptable level for fish culture, aeration may increase the pH to an acceptable level, most probably by the liberation of carbon dioxide from carbonic acid.

The pH of the saline groundwater sources were measured immediately after pumping, then again after 10-15 minutes of vigorous aeration. Those water sources with pH that increased to between 7.2 and 8.5 after aeration were considered for further testing.

Based on the two criteria above, four of the twelve Dumbleyung test bores were selected for further testing. The salinity and pre- and post-aeration pH values of these four bores are shown in Table 1.

Test 2: Ionic Composition

Seawater contains a number of ions essential for the survival and growth of marine fish. The concentration of these ions varies between saline groundwater sources and is likely to be a major factor in determining the suitability of these sources for growing marine fish. Water from the four test bores was therefore analysed for 27 common ions found in seawater using inductively coupled plasma atomic emission spectroscopy (ICPAES). The concentration of chloride ions was determined via a silver-chloride titration. These parameters were compared against those measured in full strength seawater (32 ppt) and seawater diluted to 16 ppt.

Table 1 shows the concentration of the major ions (defined as having a concentration greater than 1 mg/litre (Spotte, 1992)). With the exception of calcium and potassium, the concentration of all other ions in the bore water samples was similar to those in the diluted seawater samples. The range of calcium and potassium for the bore water sources was 16 to 220 ppm and 110 to 130 ppm, respectively, compared to values of 230 and 250 ppm, respectively in diluted seawater.

None of the water samples tested contained toxic levels of heavy metals.

Test 3: Microtox® Toxicity Testing

Microtox® testing relies on the use of the luminescent bacteria, *Vibrio fischeri,* to measure the toxicity of water samples. These bacteria produce light as a by-product of respiration. The presence of toxins in the water inhibits the cellular activity of the bacteria, resulting in a decreased rate of respiration and hence a corresponding decrease in the rate of luminescence.

Water samples from the four test bores were collected immediately after pumping and stored on ice until analysis.

The results of the Microtox® tests are shown in Table 1. Bores 2 and 3 were found to be toxic, whereas bores 1 and 4 were non-toxic.

Test 4: Pesticide Analysis

Thirteen pesticides and herbicides were identified as having been used in the Dumbleyung agricultural region over the last 30 years. Water samples were taken from the four test bores and analysed for these chemicals using gas chromatography. This analysis revealed no detectable levels of any of these pesticides or herbicides (<0.001 mg/L).

	Bore 1	*Bore 2*	*Bore 3*	*Bore 4*	*16 ppt (50% seawater)*	*32 ppt (seawater)*
Salinity (ppt)	16.5	14	15	22	16	32
Pre-aeration pH	5.9	5.8	5.4	6.7	-	-
Post-aeration pH	8.0	8.1	8.0	8.2	-	-
Na (ppm)	5,500	5,000	5,400	5,200	5,600	11,000
Cl (ppm)	9,600	7,800	8,500	13,000	9,600	19,000
Ca (ppm)	88	59	16	220	230	440
Mg (ppm)	640	440	390	1,100	620	1,200
K (ppm)	120	110	130	130	250	490
S (ppm)	450	580	440	620	430	850
B	1.5	2.2	2.9	1.8	2.2	4.2
Sr	1.3	1.2	0.55	2.0	3.9	7.3
Toxicity (EC_{50} %v/v)	Non-toxic	29	50	Non-toxic	-	-

Table 1: Chemical properties of four bore water sources from the Dumbleyung water catchment and seawater (full-strength and diluted).

Growth Trials

During three separate growth trials, the performance of juvenile snapper in raw and modified bore water sources was compared against two controls (full-strength seawater (32 ppt) and seawater diluted to 16 ppt). The treatments compared during each trial are shown in Table 2. In trials 2 & 3, bore water sources were supplemented with $CaCl_2$ and KCl to obtain Ca and K levels equivalent to those in seawater diluted to 16 ppt.

	Trial 1	*Trial 2*	*Trial 3*
Water Sources	16 ppt	16 ppt	Bore 1 + Ca
	32 ppt	32 ppt	Bore 1 + Ca + K
	Bore 1	Bore 1	Bore 1 + K
	Bore 2	Bore 1 + Ca	-
	Bore 3	Bore 1 + Ca + K	-
	-	Bore 4	-
Initial Fish Wt (g)	6.52 ± 0.07	33.20 ± 0.20	71.58 ± 0.94
Fish Number	20	10	9
Trial Duration (wks)	6	6	3

Table 2: Treatments used in the three growth trials. Supplementation of Ca and/or K were made to the equivalent concentration of seawater diluted to 16 ppt.

Each treatment was tested in triplicate in 180 litre tanks. The water in each tank was continuously recirculated through a mechanical and biological air-water-lift filter to remove solid waste and oxidise toxic nitrogenous waste products. The bottom of each tank was vacuumed daily to remove faeces and 10% of the water volume replaced. Temperature, pH and dissolved oxygen were measured daily and total ammonia nitrogen (TAN) measured twice weekly. All of the measured water quality parameters remained within safe limits throughout the trials. Fish were fed to satiety three times daily on sinking aquaculture pellets (Skretting, Australia; 45% protein, 22% lipid). The weight of pellets consumed by fish in each tank was recorded at the end of each day.

RESULTS AND DISCUSSION

Fish in water from bores 2 and 3 died by day 6 and 12, respectively during trial 1. During trial 2, all fish in water from bore 4 died within 9 days. After storing the water from bore 4 for 14 days (with aeration) fish were again added to the trial tanks and subsequently survived for the remaining 14 days of the trial, however, no growth data was collected over this period. Survival of fish in all bore 1 treatments and the two control tanks were 100% in all trials. The survival results obtained in trial 1 correlated well with the initial Microtox® results, which showed bores 2 and 3 to be toxic and bore 1 to be non-toxic. The reason behind the mortality of fish in the water from bore 4 was not apparent and not indicated by the results of the Microtox® testing. The water in which the fish died was, however, not pumped at the same time as the water collected for Microtox® testing and the poor survival may have been the result of a toxin build up in the static bore pipe which was not adequately flushed from the bore line prior to collection. That the fish subsequently survived for a further 14 days after restocking suggests that further analysis of this water source is worthwhile.

Final weights of fish in the remaining three treatments of trial 1 are shown in Figure 1. Fish grown in water from bore 1 were significantly smaller than those grown in both full-strength and diluted seawater at the end of the trial. This lower growth rate in bore 1 was the result of both a significantly lower food intake and higher food conversion ratio compared to both seawater and diluted seawater.

When water from bore 1 was supplemented with both calcium and potassium, there was no significant difference in growth between fish in this water source and those grown in both full-strength and diluted seawater (Figure 2). Supplementation of the water with calcium alone slightly improved the growth performance of fish compared to those grown in raw bore water, but not significantly so. The growth of fish in calcium supplemented bore water was significantly less than fish grown in water at 16 ppt. Results from trial 3 suggest that supplementation of potassium is of greater importance than calcium, as there was no significant difference in growth between fish grown in water supplemented with both potassium and calcium and those grown in water supplemented with potassium only (Figure 3). Those fish grown in water supplemented with calcium only were significantly smaller at the end of the trial than those grown in bore water containing supplemental potassium.

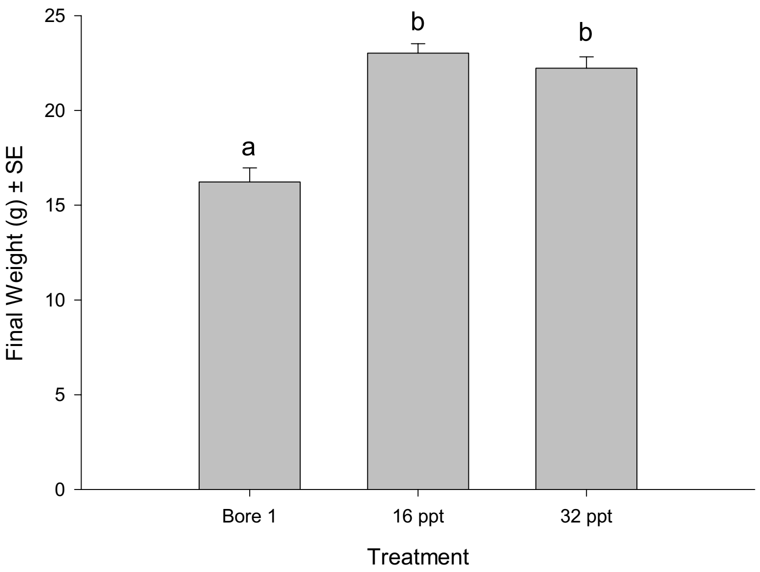

Figure 1: Final weight of juvenile snapper grown in saline groundwater, diluted seawater and full-strength seawater. Columns sharing the same letter are not significantly different (p>0.05).

The importance of ionic composition to the survival and growth of snapper has been shown by Fielder et al (2001). These authors found that raw saline groundwater with potassium levels of 9 ppm resulted in 100% mortality within 3 days. When levels were increased to 130 ppm fish were found to survive and grow at the equivalent rate to those in diluted seawater. Water from bore 1 in the current trials contained a very similar level of potassium to that found by Fielder et al (2001) to support excellent growth. Growth rate in this water source was, however, significantly lower than obtained in seawater of an equivalent salinity. In the current trials, supplementation with potassium to a level equivalent to that of diluted seawater (250 ppm) significantly improved growth.

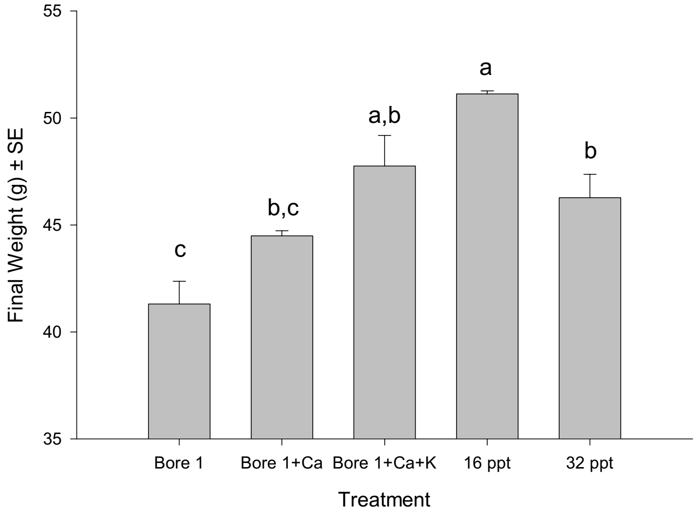

Figure 2: Final weight of juvenile snapper grown in raw and modified saline groundwater, diluted seawater and full-strength seawater. Columns sharing the same letter are not significantly different (p>0.05).

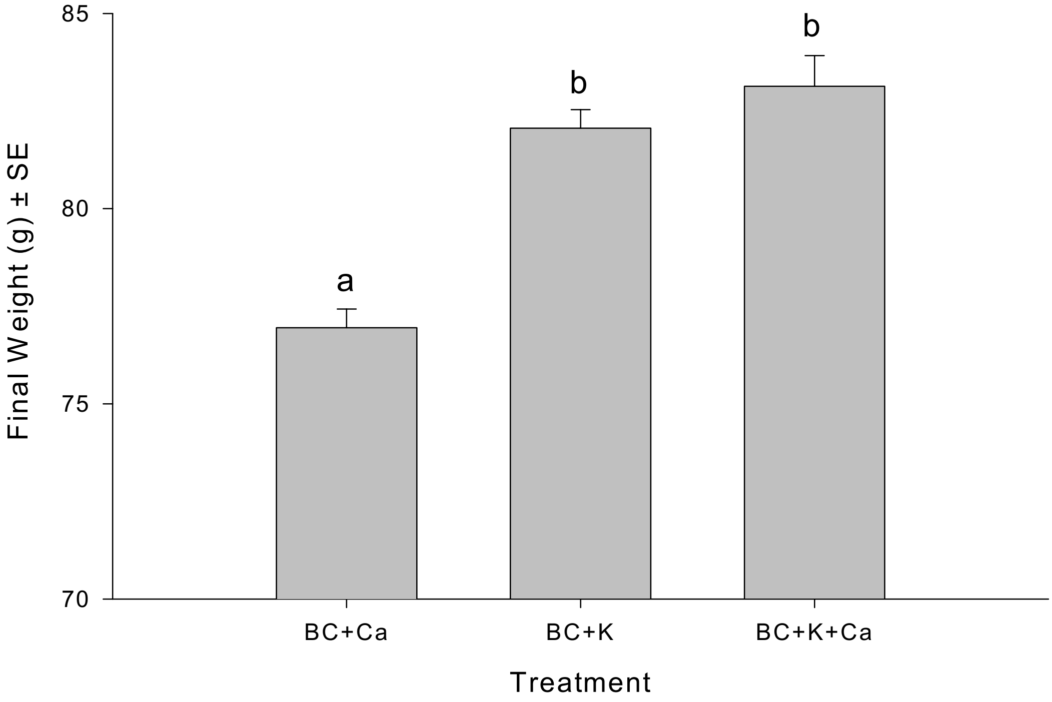

Figure 3: Final weight of juvenile snapper grown in modified saline groundwater. Columns sharing the same letter are not significantly different ($p>0.05$).

CONCLUSIONS

Knowledge of the target species' salinity and pH tolerances enables a broad-brush approach to narrowing down potential water sources. This assessment alone, however, is insufficient to determine suitability.

The importance of ionic composition to marine fish was highlighted in the current trial. Although the required levels of essential ions will vary between species, depending on their physiology, determination of ionic content via ICPAES is still an important step in determining a water source's potential. Not only is such analysis effective in determining the extent of any possible deficiencies in essential ions, it is also important for ensuring safe levels of potentially toxic ions such as heavy metals.

No detectable levels of pesticides were found in the current trial. The specificity of pesticide testing is a disadvantage in that it requires a detailed knowledge of the pesticides for which to test. In locating water sources with potential for aquaculture there is no advantage knowing the exact toxin present; simply knowing that it is toxic to aquatic organisms is sufficient for eliminating a water source.

The benefit of Microtox® testing over pesticide testing is that is cheaper to perform and provides information only on the degree of toxicity, rather than the nature of the toxin. Microtox® testing showed good potential for determining water suitability, as 100% mortality occurred in all water sources that were found to be toxic. Microtox® testing did not, however, forecast the poor survival experienced in bore 4. Further investigation is therefore required to determine the cause of this mortality and whether any further tests are available that could have predicted this result. At this stage it appears that a positive Microtox® test may exclude a water source from further investigations, however a negative test is not a guarantee that fish will survive. Further investigations into Microtox® testing are continuing.

Based on the current findings, it is recommended to firstly narrow down potential water sources using the selected fish's known tolerance of pH and salinity. Physical characteristics of the water supply such as pumping rates and bore depth are also useful parameters for limiting prospective sources. The amount of water required will depend on the production of fish required and the type of system used for their culture (eg recirculating vs flow-through). Bores intersecting a substantial (>5m) thickness of a saturated aquifer are preferable due to their ability to maintain pumping rates over the long term. Deeper bores are more likely to be geochemically mature and less contaminated by toxins. Secondly, Microtox® testing may be performed, with any a positive results eliminating potential water sources. Remaining sources should then be subjected to an analysis of ionic composition to identify limiting and toxic elements. Finally, growth trials should be used confirm or deny a water sources potential by comparing growth and survival rates against those obtained in both full-strength seawater and seawater adjusted to a salinity of that of the water under investigation.

ACKNOWLEDGEMENTS

This study was funded under the Dumbleyung Water Management Strategy; a cooperative project between the Dumbleyung Zone Committee, the Water and Rivers Commission and the Department of Agriculture, WA.

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