Preliminary Studies on the Suitability of Catchment Water for Fish Culture

Kevin Hopkins, College of Agriculture, Forestry, and Natural Resource Management, University of Hawaii at Hilo, Hilo, HI 96720-4091

Jeff Million, Department of Environmental Horticulture, University of Florida, Gainesville, FL 32611

Mr. Howard Takata, University of Hawaii Sea Grant College Program

ABSTRACT

Fish farmers on the eastern side of the island of Hawaii commonly complain of difficulties rearing fish in catchment water. The reasons for these problems are assumed to be directly related acid-causing emissions from Kilauea Volcano. Three small studies were conducted to chemically examine catchment waters and to develop and test a simplified method to treat those waters. The preliminary analysis of catchment waters indicates that essentially all catchment waters in the area had pH levels below the minimum sub-lethal level of 6.5. Further, 25% of the samples analyzed for metals had Fe, Zn and/or Mn concentrations in excess of safe levels. A simplified method in which catchment water is placed in contact with crushed oyster shell for increasing periods of time was tested. A 5 minute contact period was adequate to neutralize acidity. The effects on conductivity were also determined.

KEYWORDS: *Aquaculture, Acid rain, Catchment water, Water treatment*

INTRODUCTION

There is a common perception in east Hawaii that fish have difficulty living in catchment water. Anecdotal evidence indicates a correlation between fish kills and the onset of rainfall after dry spells. Also, there are some ponds supplied with catchment water in which fish are unable to survive. As much of Puna , South Hilo and Kau rely on catchment, this is a severe constraint to the development of fish culture in those areas.

The reasons for the unsuitability of the catchment water are not yet identified but the most probable are high acidity and the presence of other contaminants related to emissions by Kilauea Volcano. The current eruption of Kilauea which started in 1983 releases significant amount of gaseous and particulate emissions. Average SO_2 emissions have been estimated to be 1,500 metric tonnes per day (Stokes, 1990 as cited in Morrow et al., 1991) although SO_2 emissions as high as 32,000 tonnes per day were measured during an eruption in 1984 (Casadevall et al., 1987 as cited in Morrow et al., 1991). Rapid oxidation of the SO_2 forms sulfates which are a major component of the haze locally known as "vog". Rain falling through this "vog" can be quite acidic: minimum pH = 4.06 (NADP, 1998). These pH levels are considerably below the minimum desirable level of 6.5 and approach the lethal level of 4.0 Boyd,1990).

But the issue is not as simple as adverse affects from acidity. Tomatoes exposed to rainfall when vog was present had blossom drop, poor fruit set, small fruit and less luxuriant appearance (Kratky et al., 1974). The rainfall was acidic, pH as low as 4.0, and contained 27 detectable organic compounds in the ppb range. The authors noted that cumulative samples of light rainfalls were more acidic than a single heavy rainfall. However, as experimentally increasing the pH did not increase pollen germination, some factors other than pH are suspected of causing poor germination.

The quality of water in a catchment systems is not directly correlated with the quality of rainfall because air-borne particulates which accumulate on roofs between rainfalls can dissolve in the run-off and acidic rainfall can leach materials such as lead and zinc from metal roofs. In a study by the Safe Water Drinking Branch of the Hawaii Department of Health (1989), over 2000 water samples were collected from cisterns on the island of Hawaii. The pH levels ranged between 4.08 and 6.51. In 24% of the samples, lead levels exceeded the Maximum Contaminant Level (MCL) of 20 μg/l proposed by the Environmental Protection Agency and 11% exceeded the existing MCL of 50 μg/l (note: the recommended level for aquatic life is 100 μg/l (Boyd, 1990)). In a study in Malaysia (average pH of rainfall = 5.9), zinc levels approaching 500 μg/l were measured from a catchment system with a galvanized iron roof (Yaziz et al., 1989). The recommended safe level of zinc is also 100 μg/l (Boyd, 1990).

Paradoxically, culturing some species of fish in catchment water can be impossible because the total ion content is so low that osmoregulation becomes too difficult for the fish. Both deionized and distilled water has a conductivity of 1 μS/cm. The conductivity of rainwater can be quite variable but is usually about 10 μS/cm. Streams in granite or other insoluble geologic formations typically have values in the 10 to 50 μS/cm range (Hach 1992) whereas waters influenced by alkalinity or salinity have conductivities of 1000 to 5000 μS/cm (equal to salinities of 0.6 to 3 ppt). Depending upon the fish species and life stage, the effects of very low ion content can range from lethal to highly beneficial.

This project was proposed to conduct preliminary studies to identify factors causing the poor water quality and to test inexpensive means of treating the water to make it suitable for fish culture.

CHARACTERIZATION OF WATER SUPPLIES

Water in catchment systems in east Hawaii has two main sources: rainfall directly into storage tanks/ponds and the runoff from roofs used as collectors. Thus it was important to evaluate the suitability of both rainfall and run-off for fish culture. As the National Atmosphere Deposition Program operates a station in Hilo which monitors the composition of rainfall, readily available data from that program was summarized instead of spending funds to duplicate their samples and analyses. Over a 4-year period, 1987 to 1991, the average pH of rainfall was 4.54 while the average conductivity was only 12 μS/cm (Table 1). But fish react to instantaneous conditions, not average conditions. In this case, minimum values are of much more importance than average values. The minimum pH of the rainfall was only 4.06 which would be lethal to most fish and minimum conductivity dropped as low as 2 μS/cm, only slightly higher than the conductivity of deionized water.

Water in catchment systems may have a significantly different composition from rainfall because of leaching. Thus, samples were collected from 20 catchment systems in Puna and South Hilo (Figure 1) and analyzed. The samples were preserved by refrigeration for a few hours after which pH was measured. Each remaining sample was then acidified with nitric acid and stored for subsequent analysis of metals using atomic absorption spectrophotometry. Three of the four initial samples and all 16 of the other samples had pH levels below optimum (Tables 2 and 3). Seventy five percent of the initial samples had conductivities of approximately 30 or less. Twenty five percent of the samples analyzed for metals had concentrations in excess of safe levels: 2 samples had high Fe levels, 1 had high Zn, and another sample had high levels of Fe, Mn and Zn. In all of the samples with high metals concentrations, the pH was 5.3 or lower. However, there was also one sample with low pH that did not have high concentrations of metals.

As the samples were collected from catchment tanks which had collected water over a period of time, the concentrations should be considered as average, not instantaneous, values. Instantaneous values can vary considerably from average values. For example, a single instantaneous pH reading of run-off from a roof in Hilo taken after an extended dry period was only slightly higher than 3.

Treatment of Catchment Water - Experiment 1

Two sets of experiments were conducted to develop simple, inexpensive methods for adjusting pH and increasing alkalinity. In the first experiment, 350 ml of a pH 3 solution made from H_2SO_4 and deionized water was poured into a funnel containing 350 ml of cleaned crushed oyster shell. The oyster shell was prepared by rinsing commercial crushed oyster shell on a 50-mesh screen until all of the fines were removed. The fines composed approximately 25% of the bagged material. The acid solution was allowed to stay in the funnel for periods ranging from 5 seconds to 30 minutes after which it was drained and the pH measured. The data was then plotted and regression fitted using quasi-linear regression.

Almost instantly upon contact with the oyster shell, the pH increases. Within 5 seconds, the pH rises from 3 to about 5.8 . In order to increase the pH to 6.5 which is sufficient for fish to live, 5 to 10 minutes of contact with the oyster shell is required (Figure 2).

The following logarithmic equation was fitted to the data:

$$y = 3.96 + 1.12*\mathrm{LOG}(x)$$
$$R^2 = 0.82$$

where y = the pH after the exposure time, x = the exposure time in seconds + 1 (required for logarithmic transformation of data containing 0), and R^2 is the coefficient determination. The line fit fairly well at the mid and upper portions of the exposure time but is not very accurate at the lower levels. However, this discrepancy is not of major importance because the fish can only live at the higher pH values which require the longer exposure times.

Treatment of Catchment Water - Experiment 2

The second experiment was designed to determine the four different water treatment regimes on alkalinity and conductivity within 36-liter (10 gallon) aquaria stocked with red tilapia fingerlings. The treatments, conducted in triplicate were no oyster shell; 5 minute contact with oyster shell (based on the results of experiment 1); oyster shell in the tanks; and 5 minute contact with oyster shell plus the addition of sodium chloride (NaCl).

The experiment was conducted at the UHH Aquaculture Laboratory in Panaewa. Twelve glass aquaria were filled with water of the appropriate quality. The apparatus used to provide the five minute contact period with oyster shell was a 6 foot tall U made out of 3 inch PVC piping. It was filled with oyster shells and then rinsed for several days. The water capacity of the apparatus with the oyster shells was 9 liters. The flow rate was 1 liter per 37 sec. This gave a retention time of 5.5 minutes. In the treatment with NaCl, 1.8 g NaCl was added to each tank.

Twenty red tilapia fingerlings were stocked into each tank. After the fish were stocked, the water pH and conductivity were taken. The pH was taken with a Fisher mini pH meter model 955. The conductivity was taken with a Fisher Conductivity Meter model 152. The temperature was also taken. The fish were fed 3% of their body weight daily. The feed was powdered Purina Trout Chow. After two weeks, the water was changed. The pH and conductivity were taken before and after the water change.

The results of the experiment were analyzed with simple averages. As pH is a logarithmic scale, it was converted to H^+ concentration before averaging. The average H^+ concentration was then reconverted into average pH.

The initial pH and conductivity were as expected (Table 4): 5.7 in the untreated control and above 7 in the treated water. After two weeks, the pH had increased substantially in all of the tanks but was highest where the oyster shell was placed directly into the tanks. In the tanks with oyster shell, the pH reached the expected equilibrium pH of 8.15 . Another observation made in the tanks with oyster shell was that the shell greatly hindered cleaning of the tanks.

The average conductivity for the control was 27 μS/cm in the beginning of the experiment. Before we changed the water halfway through the experiment, the conductivity had climbed to 85 μS/cm. After the water was changed it again dropped below 30 μS/cm. In the treatment with only 5 minute contact water, the conductivity was somewhat higher than the control while in the other two treatments, the conductivity was much.

CONCLUSIONS/RECOMMENDATIONS

Based on the results of this set of studies, the following recommendations are made for all east Hawaii farmers who will be using catchment water for aquaculture:

1. All catchment water must be treated to increase pH to 7 or above.
2. Five minute contact with oyster shell is adequate to increase pH above neutrality (a pH of 7). The crushed oyster shell available at feed stores is adequate for this purpose.

3. If pH levels of untreated water are 5.3 or below, the water should also be checked for high metals concentrations, particularly iron, manganese and zinc. If the levels are too high. Do not use the water
4. If the fish being cultured need higher levels of ions, salt is an inexpensive and ready source of those ions.

ACKNOWLEDGEMENTS

This research was supported in part by the Department of Research and Development, County of Hawaii and the Aquaculture Development Program, Department of Land and Natural Resources, State of Hawaii.

LITERATURE CITED

Boyd, C.E. 1990. Water Quality in Ponds for Aquaculture. Alabama Agricultural Experiment Station. Auburn, Alabama. 482 pp.

Casadevall, T.J., J.B. Stokes, L.P. Greenland, L.L. Malinconico, J.R. Casadevall and B.T. Furukawa. 1987. SO_2 and CO_2 emissions rates at Kilauea Volcano, 1979-1984. Pages 771-779 in Volcanism in Hawaii, U.S. Geological Survey Professional Paper 1350.

Hach Chemical Company. 1992. Measuring conductivity in surface water. WQMonitor (Winter 1992):4-5.

Kratky, B.A., E.T. Fukunaga, J.W. Hylin and R.T. Nakano. 1974. Volcanic air pollution: deleterious effects on tomatoes. Journal of Environmental Quality 3(2):138-140.

Morrow, J.W., E.J. Morgan and A.N. Furuike. 1991. Characterization of volcanic aerosol in two populated areas on the island of Hawaii: first year findings of a 3-year investigation. 84th Annual Meeting and Exhibition, Vancouver, British Columbia, June 16-21, 1991, Air & Waste Management Association

National Atmospheric Deposition Program (NRSP-3)/National Trends Network. 1998. NADP/NTN Coordination Office, Illinois State Water Survey, 2204 Griffith Drive, Champaign, IL 61820.

Safe Drinking Water Branch. 1989. Lead contamination in water cisterns on the island of Hawaii. Fourth International Conference on Water Cistern Systems, August 2-4, 1989. Makati Metro Manila, Philippines.

Stokes, J.B. 1990. personal communication, USGS Hawaiian Volcano Observatory, Hawaii.

Yaziz, M.I., H. Gunting, N. Sapari and A.W. Ghazali. 1989. Variation in rainwater quality from roof catchments. Wat. Res. 23(6):761-765

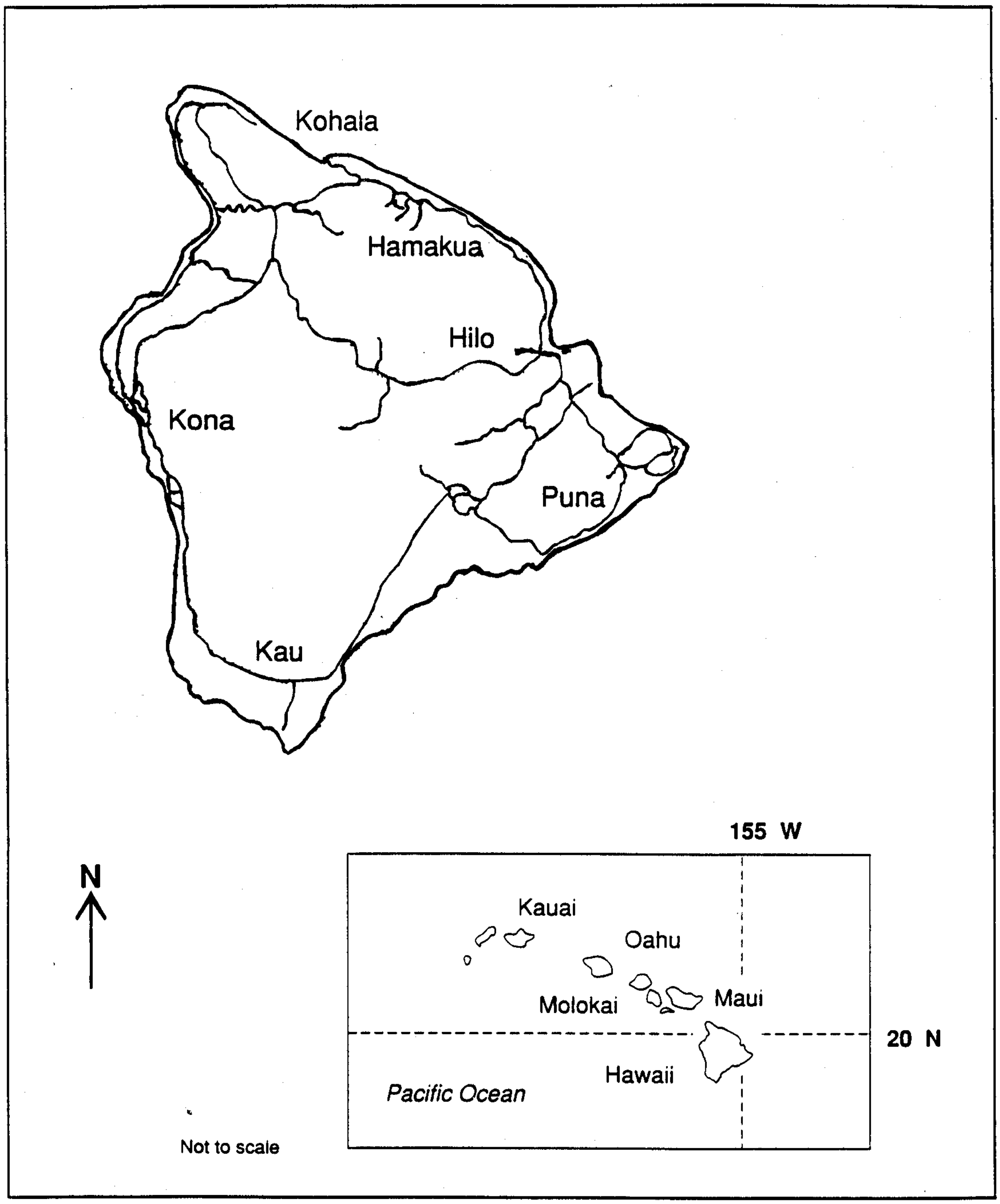

Figure 1. Island of Hawaii – location of main districts

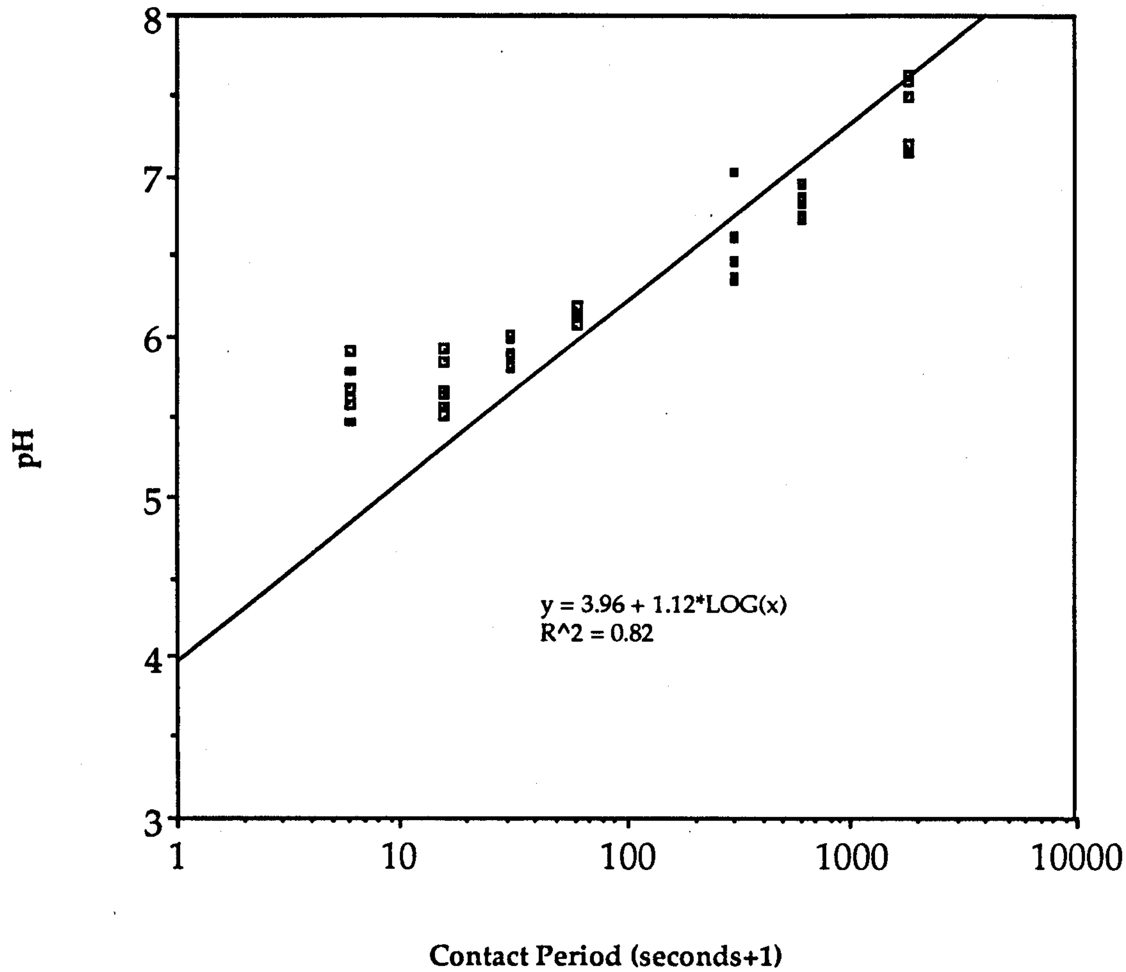

Figure 2. Effects of exposure to oyster shell on pH of acid water

Table 1. Summary of weekly weather data during 1987 through 1991 in Hilo[a]

	p[H]	Conductivity[b]
Number of samples[c]	66	66
Maximum	5.38	34
Minimum	4.06	2
Average	4.54[d]	12

[a] Field data collected by NADP (1998)
[b] Microseimens per centimeter
[c] Validated samples which passed all screening criteria
[d] Average computed using H^+ concentrations

Table 2. Initial samples from catchment tanks

Location	Roof	Tank	p[H]	Conductivity[a]
Kapoho	Fiberglass	Plastic-lined	5.8	32
Kapoho	Enamel on metal	Concrete	7.4	62
Kurtistown	Painted metal	Plastic-lined	5.8	30
Hawaiian paradise Park		Plastic-lined	6.1	29

[a] Microsiemens per centimeter

Table 3. pH and dissolved metal concentration (mg/l) in water from catchment tanks.

Location	pH	Fe 248.3 nm	Cu 327.4 nm	Mn 279.5 nm	Zn 213.9 nm	Cd 228.8 nm	Ni 232.0 nm	Pb 217.0 nm
Glenwood	***5.7***	<0.1	<0.05	<0.02	<0.01	<0.02	<0.1	<0.1
Glenwood	***5.4***	<0.1	<0.05	<0.02	<0.01	<0.02	<0.1	<0.1
Mountain View	***6.1***	<0.1	<0.05	<0.02	<0.01	<0.02	<0.1	<0.1
Pahala	***6.0***	<0.1	<0.05	<0.02	<0.01	<0.02	<0.1	<0.1
Keaau	***5.5***	<0.1	<0.05	<0.02	<0.01	<0.02	<0.1	<0.1
Pohoiki	***5.3***	***2.0***	<0.05	<0.02	<0.01	<0.02	<0.1	<0.1
Kapoho	***5.6***	<0.1	<0.05	<0.02	<0.01	<0.02	<0.1	<0.1
Kurtistown	***6.3***	<0.1	<0.05	<0.02	<0.01	<0.02	<0.1	<0.1
Upper Kaiwiki	***5.2***	***0.8***	<0.05	<0.02	<0.01	<0.02	<0.1	<0.1
Hawaiian Beaches	***5.8***	<0.1	<0.05	<0.02	<0.01	<0.02	<0.1	<0.1
Pahoa	***5.7***	6.0	<0.05	<0.02	***0.20***	<0.02	<0.1	<0.1
Volcano	***5.0***	<0.1	<0.05	<0.02	<0.01	<0.02	<0.1	<0.1
Upper Kaiwiki	***6.1***	<0.1	<0.05	<0.02	<0.01	<0.02	<0.1	<0.1
Orchidland Estates	***5.1***	***11.0***	<0.05	***0.40***	***0.10***	<0.02	<0.1	<0.1
Orchidland Estates	***5.6***	<0.1	<0.05	<0.02	<0.01	<0.02	<0.1	<0.1
Keaau	***6.3***	<0.1	<0.05	<0.02	<0.01	<0.02	<0.1	<0.1
Safe level	6.5 to 9.0	0.3	0.025	0.1	0.1	0.01	0.1	0.1
96 hr LC 50	>11 & <5		0.3 to 1.0		1 to 10	0.08 to 0.42		0.3 to 4.0

Notes: Standards from Boyd (1990). Bold face indicates sublethal concentration.

Table 4. pH and conductivity in aquaria under 4 different treatment regimes.

Treatment	Replicate	pH			Conductivity		
		Initial	After 2 wks	After refill	Initial	After 2 wks	After refill
Untreated Catchment Water (Control)	Tank 1	5.75	7.62	6.38	25	83	24
	Tank 2	5.81	7.57	6.46	25	91	23
	Tank 3	5.66	7.58	6.33	30	81	24
	Average	5.74	7.59	6.39	27	85	24
5 minute contact w/ oyster shell	Tank 4	7.10	7.61	7.56	49	100	57
	Tank 5	7.08	7.53	7.44	35	100	59
	Tank 6	7.46	7.44	7.67	55	110	70
	Average	7.18	7.52	7.55	46	103	62
Oyster shell in tank	Tank 7	7.87	8.15	7.76	58	220	110
	Tank 8	7.84	8.15	7.84	61	215	120
	Tank 9	7.95	8.17	7.91	63	230	120
	Average	7.88	8.16	7.83	61	222	117
5 minute contact w/ oyster shell and added NaCl	Tank 10	7.35	7.75	7.32	170	210	180
	Tank 11	7.44	7.62	7.45	160	200	180
	Tank 12	7.44	7.76	7.53	150	170	160
	Average	7.41	7.71	7.42	160	193	173