CHAPTER 3

RESULTS

3.1 Physical Parameters

The mean physical parameters of pH value and salinity of the three estuaries from the present study are shown in Table 3.1.1.

Table 3.1.1 – Physical Water Characteristics for the Present Study.

Month	Estuary	Tide	Code	pH value				Salinity (ppt.)			
				Mean	Min.	Max.	S.D.	Mean	Min.	Max.	S.D.
4	SSB	Flood	4-SSB_F	7.35	7.30	7.44	0.05	25.30	21.80	32.90	3.52
4	SSB	Ebb	4-SSB_E	7.36	7.16	7.51	0.13	23.33	22.60	23.80	0.46
4	SSK	Flood	4-SSK_F	7.33	7.12	7.70	0.25	25.15	23.10	26.70	1.51
4	SSK	Ebb	4-SSK_E	7.20	6.91	7.45	0.27	26.33	26.20	26.50	0.15
5	SJ	Flood	5-SJ_F	7.30	7.21	7.41	0.05	16.92	15.50	19.20	1.10
5	SJ	Ebb	5-SJ_E	7.79	7.64	7.87	0.05	21.65	17.00	24.30	2.45
5	SSB	Flood	5-SSB_F	7.21	7.10	7.38	0.07	17.89	16.00	19.50	0.98
5	SSB	Ebb	5-SSB_E	7.63	7.36	7.82	0.12	19.68	18.00	21.50	0.90
8	SJ	Flood	8-SJ_F	7.53	7.34	7.84	0.13	19.37	19.00	20.00	0.50
8	SJ	Ebb	8-SJ_E	7.35	7.21	7.57	0.10	20.13	20.00	21.00	0.28
8	SSB	Flood	8-SSB_F	7.98	7.71	8.34	0.13	20.71	17.00	22.00	0.97
8	SSB	Ebb	8-SSB_E	7.96	7.82	8.14	0.08	21.29	19.00	23.00	0.88
8	SSK	Flood	8-SSK_F	7.30	7.23	7.39	0.05	21.20	20.00	22.00	0.70
8	SSK	Ebb	8-SSK_E	7.61	7.40	7.84	0.13	22.60	21.00	23.00	0.63

Note: The unit for salinity is part per thousand (ppt.).

Generally, the mean pH values at the estuaries were higher in August (dry season) than May and April (wet season) (see Figure 3.1.1). The highest mean pH values were recorded in August, during the flood (7.98) and ebb (7.96) tides of SSB while the minimum readings were in May, during the flood tide of SSB (7.21) and in April, during the ebb tide of SSK (7.20).

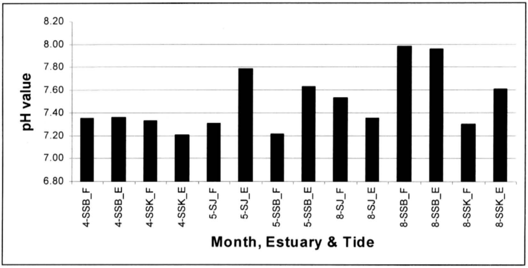


Figure 3.1.1 – Mean pH Value in Relation to Month-Estuary-Tide. Numerics (8, 5 and 4) denote the month (August, May and April). SSB, SJ and SSK denote Sg. Sangga Besar, Sg. Jaha and Sg. Sangga Kecil respectively. F and E denote flood and ebb tides respectively.

Figure 3.1.2 shows that the highest mean salinity recorded during the study was in April during the ebb tide of SSK (26.33 ppt.) while the minimum was in May, during the flood tide of SJ (16.92 ppt.). An ANOVA indicated that the mean salinity was significantly higher ($p<0.05$) during August (20.32 ppt.) than May (18.99 ppt.). Nutrient data for these two months represented complete data sets for analysis of seasonal (dry versus wet) effects.

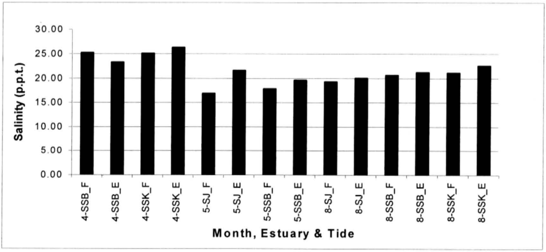


Figure 3.1.2 – Mean Salinity (p.p.t.) in Relation to Month-Estuary-Tide. Numerics (4, 5 and 8) denote the month (August, May and April). SSB, SJ and SSK denote Sg. Sangga Besar, Sg. Jaha and Sg. Sangga Kecil respectively. F and E denote flood and ebb tides respectively.

3.2 Comparison of Background Nutrient and Chlorophyll *a* Concentrations among Estuaries

Detailed results of the 2-factor ANOVA of nutrient and chlorophyll *a* concentrations at 'O' and 'C' stations (non-cage sites) in relation to estuaries (SSB*SJ*SSK) and tides (flood*ebb) for August, 2000 data are given in Appendix A.

a) Ammonia-nitrogen (NH_3-N)

The mean background concentrations of NH_3-N in SSB, SJ and SSK were 1.18 μmol/L, 0.63 μmol/L and 0.53 μmol/L respectively. From the ANOVA, there were no significant differences in the mean NH_3-N concentrations among the three estuaries ($p=0.05$) and between tides ($p=0.93$). In addition, there was no significant interaction effect between estuary and tide ($p=0.35$).

b) Nitrate-nitrogen (NO_3-N)

From the ANOVA, there were significant differences in the background NO_3-N concentrations among the estuaries ($p=0.002$) and between tides ($p=0.005$). In addition, there was significant interaction effect between estuary and tide ($p<<0.001$).

The Student Newman-Keuls test (SNK) indicated that the mean NO_3-N concentrations in SSB (7.44 μmol/L) and SSK (6.79 μmol/L) were significantly higher (p=0.002) than in SJ (4.04 μmol/L). There was no significant difference between SSB and SSK.

The mean NO_3-N concentration for the three estuaries during flood tide (6.98 μmol/L) was significantly higher than during ebb tide (5.01 μmol/L). The ANOVA showed significant interaction effect ($p<<0.001$) between estuary and tide. However, the interaction effect showed that only in SSK was the mean NO_3-N concentrations influenced by tides. There was no significance between the tides for SSB and SJ, while the mean NO_3-N concentration in SSK during ebb tide (4.38 μmol/L) was significantly lower than during flood tide (10.29 μmol/L) (see Figure 3.2.1).

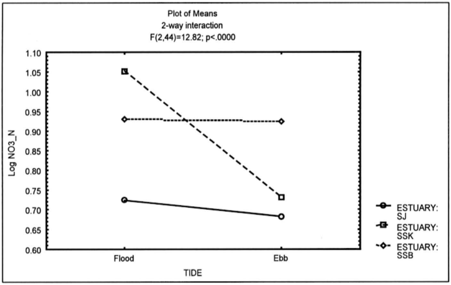


Figure 3.2.1 – Interaction Effects between Estuary and Tide on the Mean NO_3-N (log_{10}) Concentrations (August 2000). SJ, SSK and SSB denote Sg. Jaha, Sg. Sangga Kecil and Sg. Sangga Besar respectively.

c) Nitrite-nitrogen (NO_2-N)

The mean background NO_2-N concentrations in SSB (2.20 μmol/L) and SSK (2.26 μmol/L) were significantly higher ($p<<0.001$) than in SJ (0.82 μmol/L). There was no significant difference between SSB and SSK. The mean NO_2-N concentration for the three estuaries during flood tide (2.07 μmol/L) was significantly higher ($p<<0.001$) than during ebb tide (1.32 μmol/L).

The ANOVA showed significant interaction effect ($p<<0.001$) between estuary and tide. Nevertheless, the interaction effect showed only SSK was influenced by tides. There was no significant difference in the mean NO_2-N concentrations between the tides for SSB and SJ, while in SSK, the mean NO2-N concentration during flood tide (4.14 μmol/L) was significantly higher than during ebb tide (1.07 μmol/L) (see Figure 3.2.2).

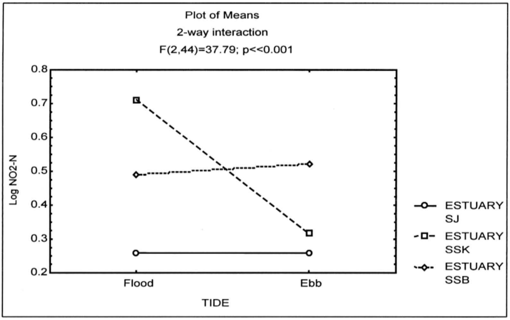


Figure 3.2.2 - Interaction Effect between Estuary and Tide on the Mean NO_2-N (log_{10}) Concentrations (August 2000). SJ, SSK and SSB denote Sg. Jaha, Sg. Sangga Kecil and Sg. Sangga Besar respectively.

d) Reactive Phosphate (PO_4^{3-})

The mean background PO_4^{3-} concentration in SSB (0.69 μmol/L) was significantly higher (p=0.005) than in SJ (0.55 μmol/L) and SSK (0.50 μmol/L). There was no significant difference between SJ and SSK. The mean PO_4^{3-} concentration for the three estuaries during flood tide (0.66 μmol/L) was significantly higher (p=0.033) than during ebb tide (0.58 μmol/L).

The ANOVA showed significant interaction effect (p<<0.001) between estuary and tide. However, the interaction effect showed only SSK was influenced by tides. There was no significant difference in the mean PO_4^{3-} concentrations between the tides for SSB and SJ respectively. The mean PO_4^{3-} concentration in SSK during ebb tide (0.26 μmol/L) was significantly lower than during flood tide (0.78 μmol/L (Figure 3.2.3).

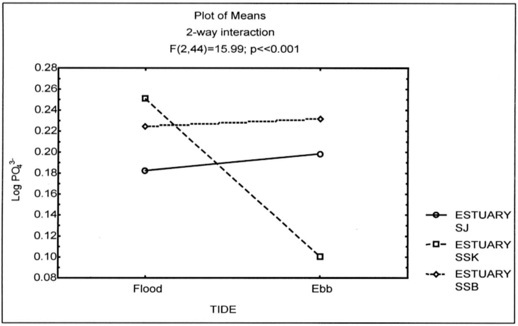


Figure 3.2.3 - Interaction Effect between Estuary and Tide on the Mean PO_4^{3-} (log_{10}) Concentrations (August 2000). SJ, SSK and SSB denote Sg. Jaha, Sg. Sangga Kecil and Sg. Sangga Besar respectively.

e) Chlorophyll *a*

The mean background chlorophyll *a* concentration in SJ (46.51 μg/L) was significantly higher ($p<<0.001$) than in SSB (22.16 μg/L) and SSK (20.49 μg/L). There was no significant difference between the mean chlorophyll *a* concentrations of SSB and SSK. The ANOVA showed no significant difference ($p>0.05$) in the mean chlorophyll *a* concentration with respect to tides for the three estuaries.

The ANOVA showed significant interaction effects ($p<0.021$) between estuary and tide. In SSB, the flood tide chlorophyll *a* concentration (25.76 μg/L) was significantly higher than ebb tide concentration (19.05 μg/L) (see Figure 3.2.4).

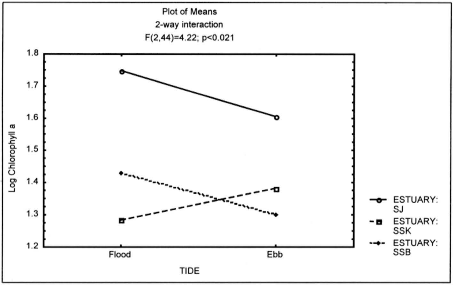


Figure 3.2.4 - Interaction effect between estuary and tide on the mean chlorophyll *a* (log_{10}) concentrations (August 2000). SJ, SSK and SSB denote Sg. Jaha, Sg. Sangga Kecil and Sg. Sangga Besar respectively.

3.3 Comparison of Fish Cage Culture Estuaries in Relation to Seasonal and Tidal Effects

Full results of the four-factor ANOVA of the nutrient and chlorophyll *a* concentrations in relation to seasons (wet*dry), estuaries (SSB*SJ), tides (flood*ebb) and stations (N*I*M*O) are given in Appendix B.

a) Ammonia-nitrogen (NH_3-N)

The ANOVA showed there were no significant differences in the mean NH_3-N concentrations between seasons ($p=0.06$) and between estuaries ($p=0.67$). The mean NH_3-N concentrations during the dry season was 1.26 μmol/L and in the wet season, 0.92 μmol/L. The mean NH_3-N concentrations in SSB and SJ were 1.04 μmol/L and 1.12 μmol/L respectively.

The mean NH_3-N concentration for both estuaries during flood tide (1.71 μmol/L) was significantly higher ($p<<0.001$) than during ebb tide (0.60 μmol/L). The mean NH_3-N concentration from the I stations (2.38 μmol/L) was significantly higher ($p<<0.001$) than those at the N (0.93 μmol/L), M (0.66 μmol/L) and O (0.74 μmol/L) stations. There were no significant differences ($p>0.05$) in the mean NH_3-N concentrations among samples from the N, M and O stations.

Although there were no significant differences ($p>0.05$) in the main effects of seasons and tides, there was significant interaction effect ($p=0.0005$) between season and estuary. The mean NH_3-N concentration in SSB (1.58 μmol/L) was significantly higher than in SJ (0.97 μmol/L) during the dry season. A reverse trend was observed during the wet season and the mean NH_3-N concentration in SJ (1.27 µmol/L) was significantly higher than in SSB (0.62 µmol/L) (Figure 3.3.1).

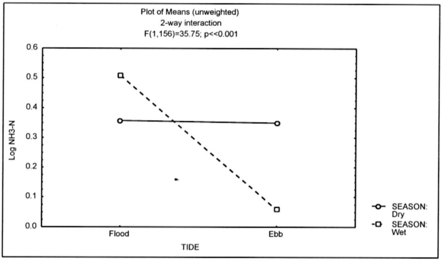


Figure 3.3.1 – Interaction Effect between Season and Estuary on the Mean NH_3-N (log_{10}) Concentration. SJ and SSB denote Sg. Jaha and Sg. Sangga Besar respectively.

There was significant interaction effect between season and tide ($p<<0.001$). The mean NH_3-N concentration in the wet season during ebb tide (0.14 µmol/L) was significantly lower than during flood tide (2.22 µmol/L) but there was no significant difference between the flood (1.28 µmol/L) and ebb (1.23 µmol/L) tides in the dry season (Figure 3.3.2).

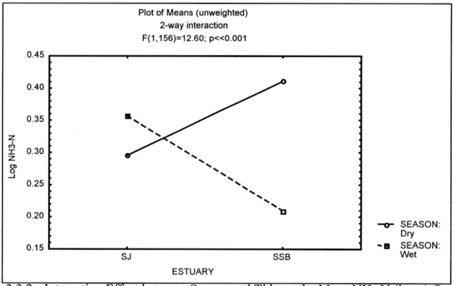


Figure 3.3.2 - Interaction Effect between Season and Tide on the Mean NH_3-N (log_{10}) Concentration.

There was significant interaction effect among season, estuary and tide ($p=0.049$). During the wet season, the mean flood tide NH_3-N concentration in SJ (3.18 μmol/L) was significantly higher ($p=0.001$) than in SSB (1.49 μmol/L). During the dry season, the reverse was true, where the mean flood tide NH_3-N concentration in SSB (1.82 μmol/L) was significantly higher than in SJ (0.84 μmol/L). On the other hand, during the ebb tide, there was no significant difference between the estuaries in the dry (1.28 μmol/L) and wet (1.23 μmol/L) seasons (Figure 3.3.3).

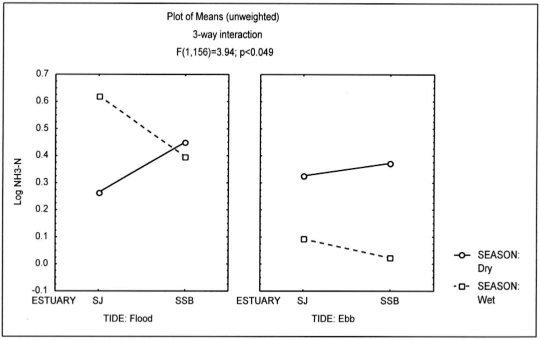


Figure 3.3.3 – Interaction Effect among Season, Estuary and Tide on the Mean NH_3-N (log_{10}) Concentration. SJ and SSB denote Sg. Jaha and Sg. Sangga Besar respectively.

b) Nitrate-nitrogen (NO_3-N)

From the ANOVA, there were no significant differences in the mean NO_3-N concentrations with respect to seasons ($p=0.34$) and stations ($p=0.54$). The mean NO_3-N concentration in SSB (8.69 μmol/L) was significantly higher ($p<<0.001$)

than in SJ (3.45 μmol/L). The mean NO_3-N concentration during flood tide (7.69 μmol/L) was significantly higher ($p<<0.001$) than during ebb tide (3.97 μmol/L).

The ANOVA showed significant interaction effect ($p<0.002$) between season and estuary. Although there was no significant difference in the main effect of season, the interaction effect showed that the mean NO_3-N concentration in SJ during the dry season (3.91μmol/L) was significantly higher than during the wet season (3.04 μmol/L) (see Figure 3.3.4).

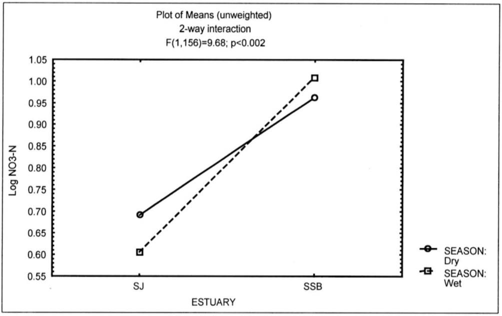


Figure 3.3.4 – Interaction Effect between Season and Estuary on the Mean NO_3-N (log_{10}) Concentration. SJ and SSB denote Sg. Jaha and Sg. Sangga Besar respectively.

With respect to interaction ($p<<0.001$) between season and tide, in the wet season, the mean NO_3-N concentration during flood tide (9.58 μmol/L) was significantly higher than during the ebb tide (2.90 μmol/L). In the dry season, the mean NO_3-N concentration during the flood tide (6.14 μmol/L) was also significantly higher ($p=0.025$) than during the ebb tide (5.33 μmol/L) (Figure 3.3.5).

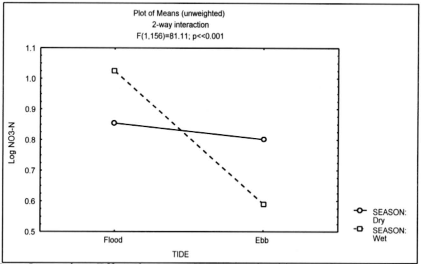


Figure 3.3.5 – Interaction Effect between Season and Tide on the Mean NO_3-N (log_{10}) Concentration.

The ANOVA showed significant interaction effect (p=0.047) among the estuary, tide and station factors. Although there was no significant difference in the main effect of station, the interaction effect showed that the mean NO_3-N concentrations at all the stations in SSB during flood tide were significantly higher than all the stations in SJ. Similar trend was observed during the ebb tide (see Figure 3.3.6).

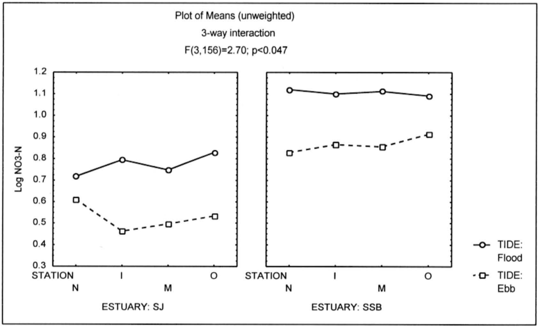


Figure 3.3.6 – Interaction Effect among Estuary, Tide and Station on the Mean NO_3-N (log_{10}) Concentration. SJ and SSB denote Sg. Jaha and Sg. Sangga Besar respectively. N represent station outside cage and at the same side of river bank, I represents station inside cage, M represents station outside cage and at mid river section, O denotes station outside cage and on opposite side of river bank.

c) Nitrite-nitrogen (NO_2-N)

The mean NO_2-N concentration in the wet season (1.85 µmol/L) was significantly higher (p=0.01) than in the dry season (1.54 µmol/L). The mean NO_3-N concentration in SSB (2.82 µmol/L) was significantly higher ($p<<0.001$) than in SJ (0.89 µmol/L). The mean NO_3-N concentration during flood tide (2.47 µmol/L) was significantly higher ($p<<0.001$) than during ebb tide (1.08 µmol/L). There were no significant differences among the stations (p=0.91).

The ANOVA showed significant interaction effect ($p<<0.001$) between season and tide. Although the main effect of tides showed significant difference, the interaction effect showed that in the dry season, there was no significant difference (p=0.85) in the mean NO_2-N concentrations between the flood (1.55 µmol/L) and ebb (1.52 µmol/L) tides. The interaction effect showed only the wet season was influenced by tides (Figure 3.3.7).

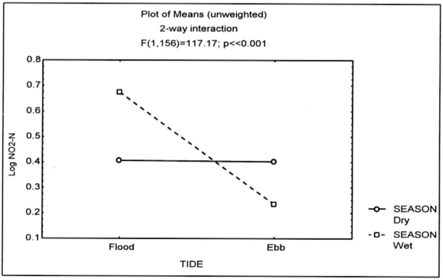


Figure 3.3.7 - Interaction Effect between Season and Tide on the Mean NO_2-N ($\log_{10}$) Concentration.

The ANOVA showed interaction effect (p=0.007) among the season, estuary and tide factors. Although there were significant differences in the main effects of season and estuary, the interaction effect showed that during the dry season, there was no significant difference (p=0.34) in the mean NO_2-N concentrations between samples from SJ during the flood tide (0.88 µmol/L) and from SJ during the ebb tide (0.74 µmol/L) (see Figure 3.3.8).

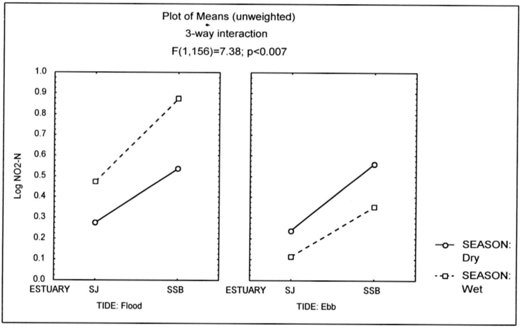


Figure 3.3.8 - Interaction Effect among Season, Estuary and Tide on the Mean NO_2-N ($\log_{10}$) Concentration. SJ and SSB denote Sg. Jaha and Sg. Sangga Besar respectively.

d) Reactive Phosphate (PO_4^{3-})

The ANOVA showed no significant differences in the mean PO_4^{3-} concentration between seasons (p=0.07) and between estuaries (p=0.99). The mean PO_4^{3-} concentrations during the dry season was 0.59 µmol/L and in the wet season, 0.51 µmol/L. Both the mean PO_4^{3-} concentrations in SSB and SJ were 0.55 µmol/L.

The mean PO_4^{3-} concentration during flood tide (0.65 µmol/L) was significantly higher ($p<<0.001$) than during ebb tide (0.46 µmol/L). The mean PO_4^{3-} concentration at the M station (0.44 µmol/L) was significantly lower ($p<0.05$) than those at the I (0.66 µmol/L) and O (0.56 µmol/L) stations respectively. There were no significant differences in the mean PO_4^{3-} concentrations among samples from the N, I and O stations.

The ANOVA showed significant interaction effect ($p<<0.001$) between season and tide. Although the main effect showed no significant difference between the seasons, the interaction effect showed that in the wet season, the mean PO_4^{3-} concentration during flood tide (0.72 µmol/L) was significantly higher ($p<<0.001$) than during the ebb (0.33 µmol/L) tide. There was no significant difference in the mean PO_4^{3-} concentration between flood and ebb tides in the dry season (Figure 3.3.9).

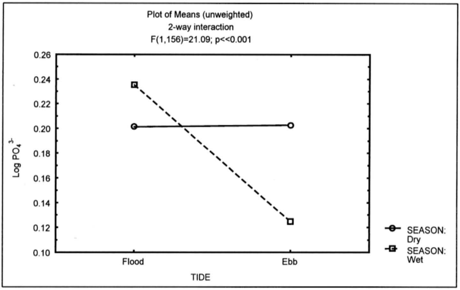


Figure 3.3.9 - Interaction Effect between Season and Tide on the Mean PO_4^{3-} ($\log_{10}$) Concentration.

The ANOVA showed significant interaction effect ($p=0.017$) between estuary and station. Although the main effect showed significant difference among the stations, the interaction effect showed that there were no significant differences ($p>0.05$) in the mean PO_4^{3-} concentrations among the stations in SSB (Figure 3.3.10).

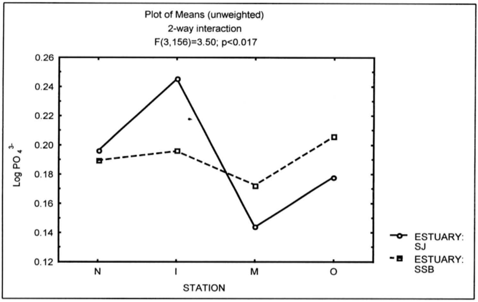


Figure 3.3.10 - Interaction Effect between Estuary and Station on the Mean PO_4^{3-} (log_{10}) Concentration. SJ and SSB denote Sg. Jaha and Sg. Sangga Besar respectively. N represent station outside cage and at the same side of river bank, I represents station inside cage, M represents station outside cage and at mid river section, O denotes station outside cage and on opposite side of river bank.

e) Chlorophyll *a*

The mean chlorophyll *a* concentration in the dry season (31.42 μg/L) was significantly higher ($p<<0.001$) than in the wet season (19.87 μg/L). The mean chlorophyll *a* concentration in SJ (27.80 μg/L) was significantly higher ($p<0.010$) than in SSB (22.48 μg/L). The mean chlorophyll *a* concentration during ebb tide (26.99 μg/L) was significantly higher ($p=0.02$) than during flood tide (23.16 μg/L). There was no significant difference in the mean chlorophyll *a* concentrations among stations ($p=0.55$).

The ANOVA showed significant interaction effect ($p<<0.001$) between season and estuary. The mean chlorophyll *a* concentration in SJ during the wet season (16.72 μg/L) was significantly lower ($p<<0.001$) than during the dry season (45.82 μg/L) but there was no significant difference between the samples from the wet and dry seasons in SSB (Figure 3.3.11).

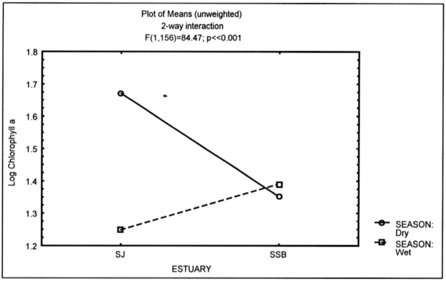


Figure 3.3.11 - Interaction Effect between Season and Estuary on the Mean Chlorophyll *a* ($\log_{10}$) Concentration. SJ and SSB denote Sg. Jaha and Sg. Sangga Besar respectively.

The ANOVA showed significant interaction effect ($p<0.024$) between season and tide. The mean chlorophyll *a* concentration in the wet season during ebb tide (23.00 μg/L) was significantly higher ($p<<0.001$) than during flood tide (17.15 μg/L). However, there was no significant difference between the samples from the flood (31.18 μg/L) and ebb (31.66 μg/L) tides in the dry season (Figure 3.3.12).

The ANOVA also showed significant interaction effect ($p<<0.001$) between estuary and tide. The mean chlorophyll *a* concentration in SSB during ebb tide (28.14 μg/L) was significantly higher ($p<<0.001$) than during flood tide (17.93 μg/L). However, there was no significant difference between the samples from SJ during the flood (29.85 μg/L) and ebb (25.90 μg/L) tides in the dry season (Figure 3.3.13).

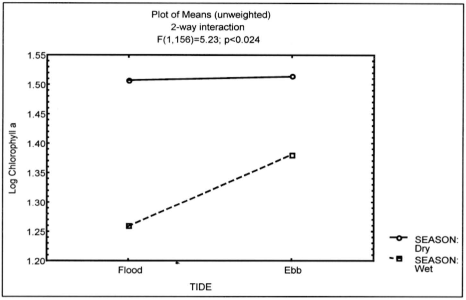


Figure 3.3.12 - Interaction Effect between Season and Tide on the Mean Chlorophyll *a* (log_{10}) Concentration.

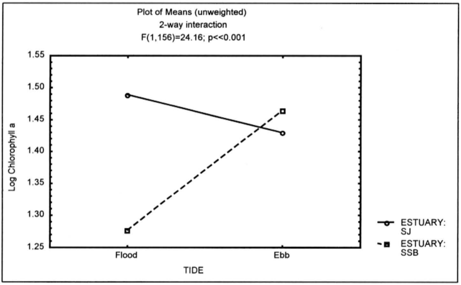


Figure 3.3.13 - Interaction Effect between Estuary and Tide on the Chlorophyll *a* (log_{10}) Concentration. SJ and SSB denote Sg. Jaha and Sg. Sangga Besar respectively.

The ANOVA showed significant interaction effect ($p<<0.001$) among the season, estuary and tide factors. Although the main effect showed significant differences between seasons, between estuaries and between tides, the interaction effect showed that at SSB during the dry season, there was no significant difference ($p=0.65$) in the chlorophyll *a* concentration during flood tide (20.93 μg/L) and during ebb tide

(21.97 μg/L) (Figure 3.3.14). The interaction effect also showed that during the wet season, the ebb tide chlorophyll *a* concentration in SSB (35.96 μg/L) was significantly higher ($p<<0.001$) than in SJ (14.58 μg/L).

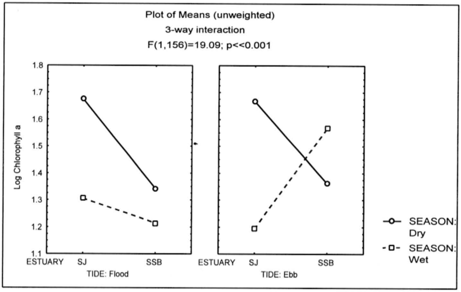


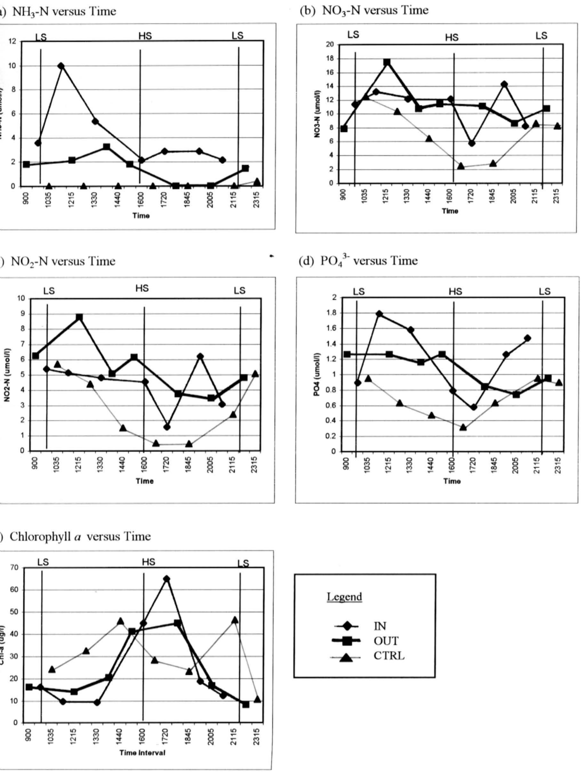
Figure 3.3.14 - Interaction Effect among Season, Estuary and Tide on the Chlorophyll *a* (log_{10}) Concentration. SJ and SSB denote Sg. Jaha and Sg. Sangga Besar respectively.

3.4 Effects of Fish Cage Culture in Relation to Tidal and Diel Effects (12-hour Study)

3.4.1 Graphical Presentation

The mean concentrations of nutrients and chlorophyll *a* were plotted against time to observe the concentrations over time.

The mean NH_3-N concentration (see Figure 3.4.1a) at the IN station (inside cage, SSB) was 3.57 μmol/L at the beginning of sampling (10.10 am). It increased sharply and peaked at 10.00 μmol/L for the first 2 hours, then declined to the lowest level of 2.14 μmol/L during slack high tide (4.00 pm). The mean NH_3-N concentrations were within 2 – 3 μmol/L during the ebb tide. The mean NH_3-N



gure 3.4.1 - Concentrations of Nutrients and Chlorophyll a over Time. IN, OUT and CTRL denote side cage of SSB, Outside cage and on opposite bank of SSB and Cage-free at SSK respectively. S and HS denote slack low tide and slack high tide respectively.

concentrations at the OUT station (outside cage and on opposite bank, SSB) was slightly lower than at the IN station. It experienced a slight increase in NH_3-N concentrations during the first 4 hours and declined subsequently. The mean NH_3-N concentrations at the CTRL station (cage-free as control, SSK) were consistently not detectable during daytime and increased slightly (0.36 μmol/L) during nighttime. Rapid increase of the NH_3-N concentrations in the morning was mainly due to feeding activities at the fish cages, while fluctuations throughout the day may be due to the tidal effect.

The mean NO_3-N concentrations (see Figure 3.4.1b) at the IN station were within 11.43 – 13.21 μmol/L during the flood tide and declined sharply to 5.71 μmol/L two hours after high tide. The mean concentration then peaked two hours later at 14.29 μmol/L before dropping to 8.21 μmol/L during slack low tide. The mean NO_3-N concentrations at the OUT station increased significantly from 7.86 μmol/L to 17.50 μmol/L two hours after the first sampling started, surpassing the NO_3-N concentration at the IN station. Another two hours later, the mean concentration dropped to 10.71 μmol/L and fluctuated slightly towards nighttime. At the CTRL station, the mean NO_3-N concentration (12.50 μmol/L) was slightly higher than the IN and OUT stations during the first sampling (10.35 am). It declined steadily below the levels of the IN and OUT stations during daytime and increased steadily during nighttime. The mean concentration was the lowest during slack high tide and increased to 8.21 μmol/L during the slack low tide in the evening.

The mean NO_2-N concentrations at all three stations showed similar behavior as the mean NO_3-N concentrations (see Figure 3.4.1c).

The mean PO_4^{3-} concentration at the IN station was 0.89 μmol/L at the beginning of sampling (see Figure 3.4.1d). It peaked at 1.79 μmol/L after two hours and declined gradually to the lowest level of 0.58 μmol/L in the late afternoon (5.20 pm). The PO_4^{3-} concentration increased gradually during nighttime. At the OUT station, the PO_4^{3-} concentrations showed similar pattern as at the IN station, but at a lower magnitude of fluctuation. The PO_4^{3-} concentrations at the CTRL station declined steadily from the morning and reached the lowest point during slack high tide at 4.00 pm. The PO_4^{3-} concentrations increased gradually towards the evening. The background PO_4^{3-} concentrations (CTRL station) were found to be consistently lower than inside the cage.

The mean chlorophyll *a* concentrations at the IN station were the lowest among the three stations in the morning and increased rapidly in the afternoon (see Figure 3.4.1e). The highest chlorophyll *a* concentration at the IN station (64.96 μg/L) was recorded at 5.20 pm, the declining trend was observed towards nighttime. The chlorophyll *a* concentrations at the OUT station showed similar trend as at the IN station, but the peak concentration was lower (44.99 μg/L). On the other hand, the chlorophyll *a* concentrations at the CTRL site indicated two peak concentrations at 2.40 pm (46.00 μg/L) and 9.15 pm (46.39 μg/L) respectively. Both peaks occurred at two hours before slack high tide and slack low tide respectively.

3.4.2 ANOVA study

Full results of the two-factor ANOVA on the nutrient and chlorophyll *a* concentrations in relation to stations (IN*OUT*CTRL) and tides (Flood*Ebb), and stations (IN*OUT*CTRL) and diel (day*night) respectively are given in Appendix C and Appendix D.

3.4.2.1 Stations (IN*OUT*CTRL) and Tides (Flood*Ebb)

a) Ammonia-Nitrogen (NH_3-N)

The mean NH_3-N concentration at the IN station (3.97 μmol/L) was significantly higher ($p<<0.001$) than at the OUT station (1.18 μmol/L), while the mean NH_3-N concentration at the OUT station was significantly higher than at the CTRL station (0.04 μmol/L) (see Figure 3.4.2). On the other hand, the mean NH_3-N concentration during flood tide (1.76 μmol/L) was significantly higher ($p=0.033$) than during ebb tide (0.82 μmol/L).

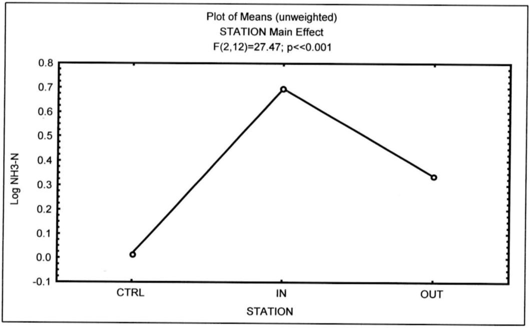


Figure 3.4.2 – Mean NH_3-N Concentrations as influenced by Stations in April 2000.

There was no significant interaction effect between station and tide ($p=0.17$).

b) Nitrate-Nitrogen (NO_3-N)

The mean NO_3-N concentrations at the IN, OUT and CTRL stations were 10.85, 11.07 and 7.53 μmol/L respectively. There were no significant differences in the mean NO_3-N concentrations among the stations ($p=0.26$) and between tides ($p=0.07$). Similarly, there was no significant interaction effect ($p=0.36$) between station and tide.

c) Nitrite-nitrogen (NO_2-N)

The mean NO_2-N concentration during flood tide (5.82 μmol/L) was significantly higher ($p=0.028$) than during ebb tide (3.00 μmol/L).

The ANOVA showed no significant difference in the mean NO_2-N concentrations among stations ($p=0.16$). The mean NO_2-N concentrations at the IN, OUT and CTRL stations were 4.32, 5.77 and 2.95 μmol/L respectively. There was no significant interaction effect between station and tide ($p=0.60$).

d) Reactive Phosphate (PO_4^{3-})

The mean PO_4^{3-} concentrations at the IN, OUT and CTRL stations were 1.09, 1.14 and 0.73 μmol/L respectively. There were no significant differences in the mean PO_4^{3-} concentrations among the stations ($p=0.12$) and between tides ($p=0.19$). The ANOVA showed no significant interaction effect between station and tide ($p=0.89$).

e) Chlorophyll *a*

The mean chlorophyll *a* concentrations at the IN, OUT and CTRL stations were 19.21, 18.62 and 25.96 µg/L respectively. There were no significant differences in the chlorophyll *a* concentrations among the stations ($p=0.66$) and between tides ($p=0.29$). The ANOVA showed no significant interaction effect between station and tide ($p=0.48$).

3.4.2.2 Stations (IN*OUT*CTRL) and Diel (Day*Night)

a) Ammonia-nitrogen (NH_3-N)

The mean NH_3-N concentration at the IN station (3.16 µmol/L) was significantly higher ($p=0.009$) than at the OUT station (0.86 µmol/L), while the mean NH_3-N concentration at the OUT station was significantly higher than at the CTRL station (0.08 µmol/L).

There was no significant interaction effect between station and diel ($p=0.55$).

b) Nitrate-nitrogen (NO_3-N)

There were no significant differences in the mean NO_3-N concentrations among the stations ($p=0.31$) and between diel ($p=0.74$). Similarly, there was no significant interaction effect ($p=0.65$) between station and diel.

c) Nitrite-nitrogen (NO_2-N)

There were no significant differences in the mean NO_2-N concentrations among the stations (p=0.33) and between diel (p=0.79). Similarly, there was no significant interaction effect (p=0.52) between station and diel.

d) Reactive Phosphate (PO_4^{3-})

There were no significant differences in the mean PO_4^{3-} concentrations among the stations (p=0.15) and between diel (p=0.41). The ANOVA showed no significant interaction effect between station and diel (p=0.18).

e) Chlorophyll *a*

There were no significant differences in the chlorophyll *a* concentrations among the stations (p=0.70) and between diel (p=0.15). The ANOVA showed no significant interaction effect between station and diel (p=0.76).

3.5 Nutrient Leaching Study

3.5.1 Graphical Presentation

The mean concentrations of nutrients and chlorophyll *a* were plotted against time to monitor the concentrations over time.

The mean NH_3-N concentrations at the pellet-fed cages (PELLET) recorded the highest concentration (7.70 μmol/L) shortly after feeding (see Figure 3.5.1a). The mean NH_3-N concentration declined sharply after the first half-hour (3.57 μmol/L) to the background level. The mean NH_3-N concentration at the trash fish-fed cages (TRASH) was slightly lower than the pellet-fed cage (5.08 μmol/L) immediately after feeding. It experienced a slight drop in NH_3-N concentration (4.37 μmol/L) during the first half-hour and increased substantially at the following half-hour, and then declined gradually. The NH_3-N levels at the trash fish fed cage were higher than at the pellet-fed cage 0.5 – 1.5 hours after feeding. The mean NH_3-N concentrations at the control site (CTRL) were consistently lower (2.14 – 3.81 μmol/L) than the other two sites.

The mean NO_3-N concentration at the pellet-fed cages declined steadily from 2.54 μmol/L to 1.90 μmol/L for the first hour and fluctuated slightly after that (see figure 3.5.1b). The mean NO_3-N concentration at the trash fish-fed cages increased slightly from 2.54 to 2.70 μmol/L at the first half hour and then declined sharply to 1.98 μmol/L (close to the background level) at the subsequent half-hour. The mean NO_3-N concentration at the control site (2.78 μmol/L) was higher than the other two sites initially and experienced a sharp drop at the first half-hour (1.90 μmol/L), and then increased slightly after that. The NO_3-N levels at the pellet-fed cages and trash fish fed cages were similar immediately after feeding, but the levels dropped faster at the pellet-fed cages. Nevertheless, the background NO_3-N concentration was naturally high.

The mean NO_2-N concentration at the pellet-fed cages remained high (0.43 μmol/L) for the first hour after feeding and declined to the background level (0.29 μmol/L)

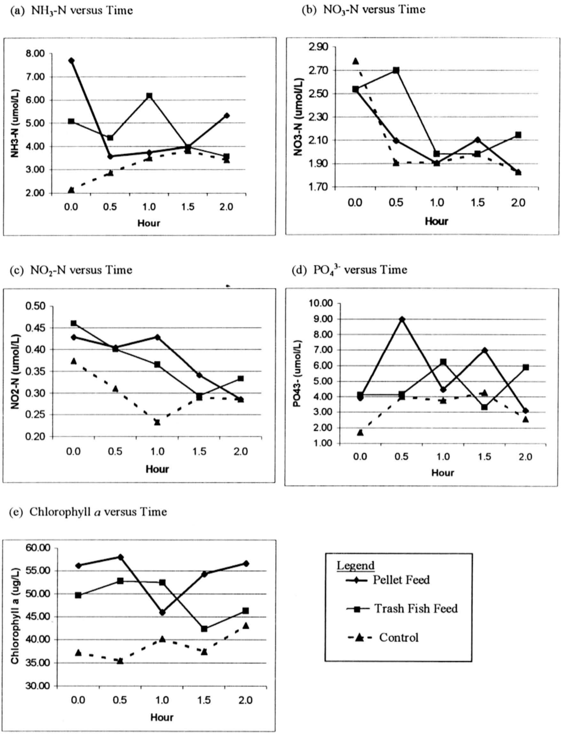


Figure 3.5.1 – Concentrations of Nutrients and Chlorophyll *a* over Time for Nutrient Leaching Study.

only after two hours (see Figure 3.5.1c). The mean NO_2-N concentration at the trash fish-fed cages showed similar trend to the pellet-fed cages. The mean NO_2-N concentration at the control site (0.37 μmol/L) declined steadily for the first hour (0.23 μmol/L), and then increased steadily thereof.

The mean PO_4^{3-} concentration at the pellet-fed cages increased sharply from 3.92 μmol/L to 8.98 μmol/L half an hour after feeding and fluctuated sharply subsequently (see Figure 3.5.1d). The PO_4^{3-} concentration declined to the background level (3.11 μmol/L) two hours after feeding. The mean PO_4^{3-} concentration at the trash fish-fed cages was consistent at the first half an hour (4.13 – 4.15 μmol/L) but fluctuated sharply after that. The PO_4^{3-} level had not stabilized two hours after feeding. At the control site, the initial mean PO_4^{3-} concentration was relatively low (1.69 μmol/L) and increased gradually for the first hour, then declined gradually thereof.

The mean chlorophyll *a* concentration at the pellet-fed cages was relatively high (56.16 – 58.03 μg/L) at the first hour and then experienced a drop half an hour subsequently (46.00 μg/L). The levels increased to 56.68 μg/L thereafter (see Figure 3.5.1e). The chlorophyll *a* concentration at the trash fish-fed cages (49.67 μg/L) was lower than at the pellet-fed cages during the first sampling. It dropped to 42.33 μg/L 1.5 hour after feeding. On the other hand, the mean chlorophyll *a* concentrations at the control site (35.45 – 43.10 μg/L) were relatively lower than the other two sites and fairly stable throughout the experiment.

3.5.2 ANOVA Study

Full results of the two-way ANOVA on the nutrient and chlorophyll *a* concentrations in relation to feed types (pellet*trash fish*control) and time intervals (0.5*1.0*1.5*2.0*2.5 hr) are given in Appendix E.

a) Ammonia-nitrogen (NH_3-N)

From the ANOVA, there was no significant difference in the mean NH_3-N concentrations among the feed types but both sites were significantly higher than the CTRL site (p=0.002). The mean NH_3-N concentrations at the pellet-fed cages (3.98 μmol/L) and trash fish-fed cages (4.14 μmol/L) were significantly higher than at the CTRL site (2.77 μmol/L) (see Figure 3.5.2).

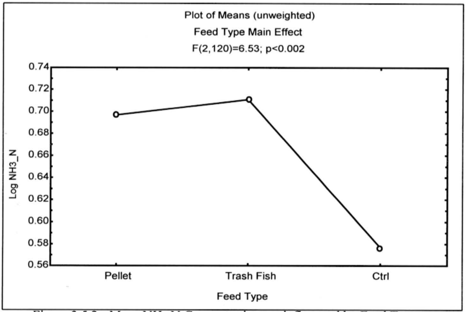


Figure 3.5.2 - Mean NH_3-N Concentrations as influenced by Feed Type.

There was no significant difference in the mean NH_3-N concentrations among time intervals (p=0.83). There was also no interaction effect between feed type and time (p=0.15).

b) Nitrate-nitrogen (NO_3-N)

There were no significant differences in the mean NO_3-N concentrations among the feed types ($p=0.32$) and among time intervals ($p=0.06$). Similarly, there was no significant interaction effect ($p=0.96$) between feed type and time.

c) Nitrite-nitrogen (NO_2-N)

There were no significant differences in the mean NO_2-N concentrations among the feed types ($p=0.06$) and among time intervals ($p=0.12$). Similarly, there was no significant interaction effect ($p=0.84$) between feed type and time.

d) Reactive Phosphate (PO_4^{3-})

There were no significant differences in the mean PO_4^{3-} concentrations among the feed types ($p=0.15$) and among time interval ($p=0.13$). The ANOVA showed no significant interaction effect between the feed type and time ($p=0.51$).

e) Chlorophyll *a*

The mean chlorophyll *a* concentrations at the pellet-fed cages (42.48 μg/L) and trash fish-fed cages (44.28 μg/L) were significantly higher ($p=0.039$) than at the CTRL site (30.91 μg/L) (see Figure 3.5.3). There were no significant differences between the pellet-fed cages and trash fish fed cages.

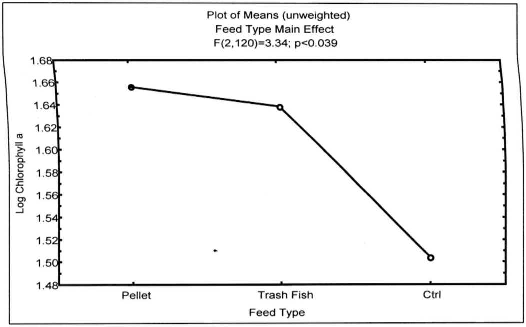


Figure 3.5.3 - Mean Chlorophyll *a* Concentrations as influenced by Feed Type.

There was no significant difference among the time ($p=0.83$). There was also no interaction effect between the feed type and time ($p=0.94$).

3.6 Synthesis of ANOVA Results

Table 3.6.1 summarizes the results of all the ANOVA performed for the nutrients and chlorophyll *a* concentration study.

Full results of the water parameters measured in this study are given in Appendix F.

Table 3.6.1 - Summary Table of ANOVA Results for Nutrients and Chlorophyll *a* Study.

(a) Comparison of Background Nutrients and Chlorophyll *a* Concentrations among Estuaries

Parameter	Estuary (1)	Tide (2)	1 x 2
NH_3-N	NS	NS	NS
NO_3-N	*	*	*
$N0_2$-N	*	*	*
PO_4^{3-}	*	*	*
Chl. *a*	*	NS	*

(b) Comparison of Fish cage Culture Estuaries in Relation to Seasonal and Tidal Effects

Parameter	Season (1)	Estuary (2)	Tide (3)	Station (4)	1 x 2	1 x 3	2 x 3	2 x 4	1 x 2 x 3	2 x 3 x4
NH_3-N	NS	NS	NS	*	*	*	NS	NS	*	NS
NO_3-N	NS	*	*	NS	*	*	NS	NS	NS	*
$N0_2$-N	*	*	*	NS	NS	*	NS	NS	*	NS
PO_4^{3-}	NS	NS	NS	*	NS	*	NS	*	NS	NS
Chl. *a*	*	*	*	NS	*	*	*	NS	*	NS

(c) 12-hour Study – Effects of Fish Cage Culture in Relation to Tidal Effects

Parameter	Station (1)	Tide (2)	1 x 2
NH_3-N	*	*	NS
NO_3-N	NS	NS	NS
$N0_2$-N	NS	*	NS
PO_4^{3-}	NS	NS	NS
Chl. *a*	NS	NS	NS

(d) 12-hour Study – Effects of Fish Cage Culture in Relation to Diel Effects

Parameter	Station (1)	Diel (2)	1 x 2
NH_3-N	*	NS	NS
NO_3-N	NS	NS	NS
$N0_2$-N	NS	NS	NS
PO_4^{3-}	NS	NS	NS
Chl. *a*	NS	NS	NS

(e) Nutrient Leaching Study

Parameter	Feed Type (1)	Time (2)	1 x 2
NH_3-N	*	NS	NS
NO_3-N	NS	NS	NS
$N0_2$-N	NS	NS	NS
PO_4^{3-}	NS	NS	NS
Chl. *a*	*	NS	NS

Note:

* denotes significantly different at $p<0.05$.
NS denotes not significant.

3.7 Principal Components Analysis (PCA)

From the PCA, four composite or principal components (hereafter called PC_1, PC_2, PC_3 and PC_4) were derived as shown in Table 3.7.1. The eigenvalues indicated that

PC_1 is the most important in representing the variation in the water quality as it constituted 45.2% of the total percentage of variance, while PC_2, PC_3 and PC_4 represented only 18.2%, 16.5 and 12.1% respectively. The four principal components accounted for 91.9% of the total variance of the variables used. On this basis, the other components (fifth, etc) may reasonably be ignored.

Table 3.7.1 – Eigenvalues derived from Principal Components Analysis.

Principal Component	Eigenvalue	% Total Variance	Cumulative Eigenvalue	Cumulative %
1	2.714874	45.2479	2.714874	45.2479
2	1.089579	18.15965	3.804453	63.40755
3	0.987775	16.46292	4.792228	79.87047
4	0.723178	12.05297	5.515406	91.92344
5	0.425916	7.098595	5.941322	99.02203

Table 3.7.2 shows the four principal components and their corresponding factor loadings for the variables in the analysis. Factor loadings are the correlations between the original variables and the principal components. PC_1 had high positive factor loadings for the NO_3-N and NO_2-N variables while PC_2 had high positive factor loadings for the NH_4-N and PO_4^{3-} variables. PC_3 had high positive factor loading for the pH variable while PC_4 had high negative factor loading for the chlorophyll *a* variable. The factor loadings of PC1 were plotted against those of PC_2 in Figure 3.7.1.

Table 3.7.2 – Factor Loadings for the Principal Components.

Parameter	Factor 1	Factor 2	Factor 3	Factor 4
NH_3-N	0.139128	***0.889219***	0.127108	0.075416
NO_3-N	***0.960088***	0.18954	-0.06649	0.103848
NO_2-N	***0.934357***	0.150396	-0.15965	0.219343
PO_4^{3-}	0.178797	***0.808404***	-0.30357	0.06732
Chlorophyll *a*	-0.21581	-0.10023	0.011616	***-0.97094***
PH value	-0.13918	-0.06654	***0.967357***	-0.01062
Expl.Var	1.912065	1.517245	1.074137	1.01196
Prp.Totl	0.318677	0.252874	0.179023	0.16866

Note: numbers in bold and italic indicate factor loading with high correlation with respective principal component (or factor).

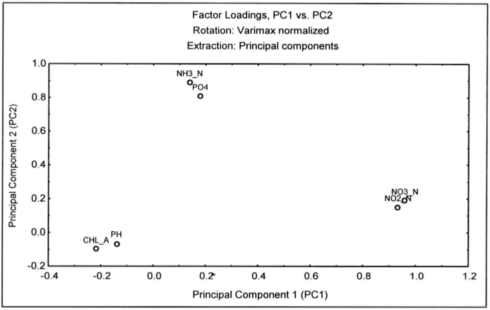


Figure 3.7.1 – Scatterplot of Factor Loadings: Principal Component 1 versus Principal Component 2.

Results of the PCA analysis of water samples taken from SSB, SSK and SJ show essentially five clusters on the scatterplot of PC_1 versus PC_2 (Figure 3.7.2). The characteristics of each cluster of samples are based on their factor loadings on a relative basis, are summarized in Table 3.7.3.

From Table 3.7.3, relatively higher concentrations of NO_3-N and NO_2-N were mainly observed at the non-cage areas of SSB and the non-aquaculture estuary of SSK. Higher NH_3-N and PO_4^{3-} levels were observed at the cages of SSB and SJ while high chlorophyll *a* concentrations were observed inside the cages of SJ. SSK was characterized by moderately high NO_3-N, NO_2-N and chlorophyll *a*, and low NH_3-N and PO_4^{3-}.

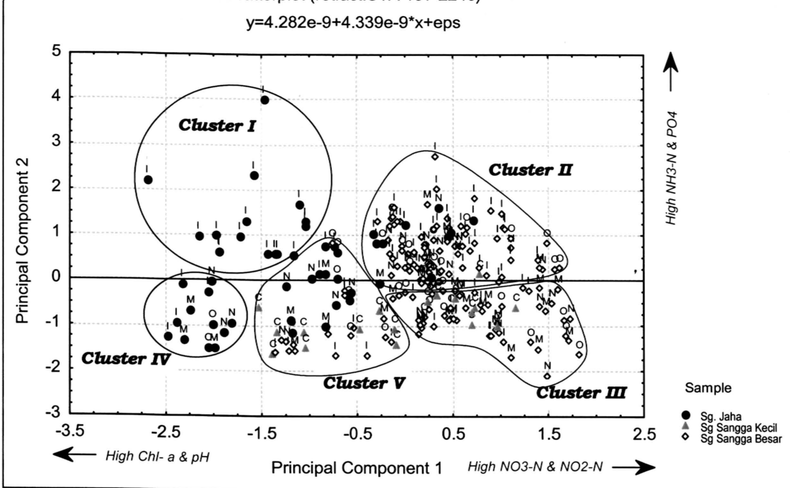


Figure 3.7.2 – Scatterplot of PCA Ordination Showing the Distribution of Site Samples in Relation to Nutrient and Chlorophyll *a* Concentrations. N represent station outside cage and at the same side of river bank, I represents station inside cage, M represents station outside cage and at mid river section, O denotes station outside cage and on opposite side of river bank, C denotes control station (SSK, cage-free).

Table 3.7.3 – Observation on the Cluster Formation from PCA Ordination.

Cluster	Main Characteristics	Observation
I	High NH_3-N & PO_4^{3-} Low NO_3-N & NO_2-N High chlorophyll *a* & pH value	All of the samples are from SJ and inside cages.
II	High NH_3-N & PO_4^{3-} High NO_3-N & NO_2-N Low chlorophyll *a* and pH value	Most samples are from the inside cages of SSB and some samples from the inside cages of SJ.
III	Low NH_3-N & PO_4^{3-} High NO_3-N, NO_2-N Low chlorophyll *a*	Most samples are from outside cages (N, M and O stations) of SSB and some from SSK.
IV	Low NH_3-N & PO_4^{3-} Low NO_3-N & NO_2-N High chlorophyll *a* and pH value	Most of the samples are from outside cages (N, M and O stations) of SJ.
V	Low NH_3-N & PO_4^{3-} Low NO_3-N & NO_2-N Moderately high chlorophyll *a* and pH value	Most samples are from SSK, outside cages (N, M and O stations) of SJ and SSB.

3.8 Spatial Distribution of Nutrient Concentrations

Figure 3.8.1 shows the spatial distribution of the mean NH_3-N concentrations during the dry season and flood tide in SSB. An NH_3-N plume indicating high levels of between 3 – 4 μmol/L was observed inside and around the fish cage farms. Formation of the NH_3-N plume around and near to the fish cages was also observed during the wet season and flood tide in SSB (see Figure 3.8.2). However, no specific trend was observed in SJ.

Figure 3.8.3 shows the spatial distribution of the mean NO_3-N during the wet season and flood tide in SSB. Relatively higher NO_3-N concentrations were observed at river transects with fish farms, though no clear indication of NO_3-N plume formations around the fish cages were observed. The NO_3-N concentrations declined towards the river mouth.

Figure 3.8.4 shows the spatial distribution of the mean PO_4^{3-} concentrations during the wet season and ebb tide in SSB. A band of higher PO_4^{3-} concentrations was observed at river transects with fish farms, although no clear indication of PO_4^{3-} plume formations around the fish cages were observed. The PO_4^{3-} concentrations tapered off at distances away from the fish farms.

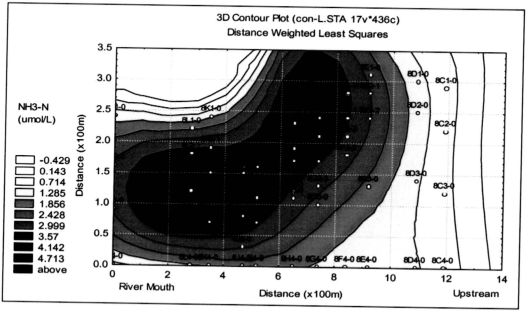


Figure 3.8.1 - Spatial Distribution of Mean NH_3-N Concentrations in the Dry Season and Flood Tide in SSB. Samples from inside cages are 8E2-1, 8E2-2, 8F2-1, 8F2-2, 8G2-1, 8G2-2, 8G2-3, 8H2-1, 8H2-2, 8H2-3, 8I2-1, 8J2-1, 8J2-2, 8K2-1, 8K2-2 and 8L2-1 (see Table 2.3.2 for code number assigned to each station).

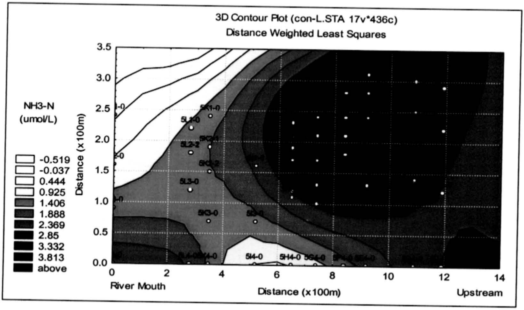


Figure 3.8.2 - Spatial Distribution of Mean NH_3-N Concentrations during Wet Season and Flood Tide in SSB. Samples from inside cages are 5E2-1, 5E2-2, 5F2-1, 5F2-2, 5G2-1, 5G2-2, 5G2-3, 5H2-1, 5H2-2, 5H2-3, 5K2-1, 5K2-2, 5L2-1 and 5L2-2 (see Table 2.3.2 for code number assigned to each station.

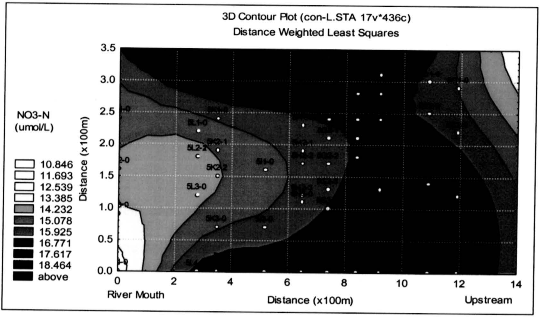


Figure 3.8.3 - Spatial Distribution of Mean NO_3-N Concentrations during Wet Season and Flood Tide in SSB. Samples from inside cages are 5E2-1, 5E2-2, 5F2-1, 5F2-2, 5G2-1, 5G2-2, 5G2-3, 5H2-1, 5H2-2, 5H2-3, 5K2-1, 5K2-2, 5L2-1 and 5L2-2 (see Table 2.3.2 for code number assigned to each station).

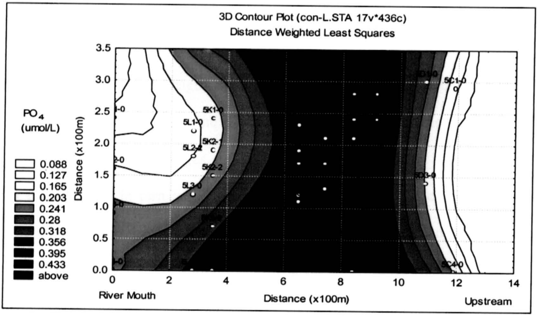


Figure 3.8.4 - Spatial Distribution of Mean PO_4^{3-} Concentrations during Wet Season and Ebb Tide in SSB. Samples from inside cages are 5E2-1, 5E2-2, 5F2-1, 5F2-2, 5G2-1, 5G2-2, 5G2-3, 5H2-1, 5H2-2, 5H2-3, 5K2-1, 5K2-2, 5L2-1 and 5L2-2 (see Table 2.3.2 for code number assigned to each station).