WATER QUALITY OF TWO CLOSED RECIRCULATING SOFT SHELL CRAB SHEDDING FACILITIES

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by
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ACKNOWLEDGMENTS

The authors wish to thank Mr. James Holland of Brunswick, Georgia for his cooperation and assistance and for the use of his two recirculating soft shell crab shedding systems. The technical assistance of Mr. Tom Shierling, Ms. Lura Relihan, and Ms. Carole Greene was greatly appreciated.

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ABSTRACT

The water quality of two Georgia commercial recirculating soft shell blue crab shedding systems was monitored chemically and microbiologically. A biological filter of crushed coral maintained water quality in system one, while an oyster-shell filter and protein skimmer combination supported system two (Osterling, 1984). The following parameters were determined for each system stocked with crabs at high and low densities: total crabs, total shed crabs, total dead crabs, total added crabs, temperature, salinity, pH, carbon dioxide, MPN total coliforms, MPN *E. coli*, marine agar plate counts, dissolved oxygen, percent oxygen saturation, biological oxygen demand, ammonium, ammonia, nitrate, nitrite, calcium, and alkalinity. Nitrate, nitrite, and ammonium concentrations remained below toxic limits for molting blue crabs in both filter systems. A significant negative correlation was established between nitrate concentrations and the number of crabs shed in the protein-skimmer system. Dissolved carbon dioxide levels correlated significantly with total number of crabs in the protein-skimmer system. Salinity had a significant negative correlation (range 13 to 16 ppt) with the number of crabs shed in the protein-skimmer system. Ammonium, ammonia, and nitrite levels were generally greater in the protein-skimmer system than in the biological-filter system.

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INTRODUCTION

Georgia has not been immune to the heightened interest in shedding blue crabs that has developed along the southeast and Gulf coasts in the last few years. The small initial capital investment attracted crabbers, fishermen, and other small businessmen. Potential shedders, particularly those interested in closed recirculating seawater shedding systems, requested assistance from The University of Georgia Marine Extension Service. The following study was initiated to develop baseline water quality data for closed, recirculating soft shell crab shedding systems.

The Marine Extension Service Analytical Services Laboratory began a project in May 1983 to monitor chemical and microbiological water quality of two commercial soft shell crab shedding systems operated by a south Georgia crabber. The first recirculating seawater system consisted of two 4 ft. x 8 ft. x 1 ft. fiberglass-coated plywood tanks, a 4 ft. x 4 ft. x 2 ft. sump, and a 4 ft. x 4 ft. x 1 ft. biological filter holding 200 pounds (90.7 kg) of crushed Florida coral that was produced by Carib Sea, Inc. (Miami, Florida). The owner completed a second closed, recirculating system in July 1984. It incorporated a 10 ft. x 8 in. cylindrical PVC protein skimmer, four 8 ft. x 3 ft. x 1 ft. fiberglass shedding tanks, and a 4 ft. x 4 ft. x 5 ft. combination biological filter and sump that held 24 bushels (0.8 m^3) of old oyster shells (Osterling, 1984). Water was circulated in both systems by 3/4 hp electric motors driving 1-1/4 in. pumps. Two inlet pipes with venturi tubes for aeration circulated water in each holding tank. The biological-filter system and the protein-skimmer system held approximately 440 gallons (1,666 liters) and 610 gallons (2,309 liters) of seawater, respectively.

METHODS

The operator maintained control of the shedding systems. Crabs were added and sheds removed as determined by peeler supplies and market conditions. The owner kept records of total crabs, sheds, and mortality. All additional data was collected by the laboratory staff.

Water samples for chemical and microbiological analyses were collected at the outlet of the biological-filter system from May 4, 1983, through August 1, 1983. Water samples were taken from the inlet and the outlet of the protein-skimmer system from July 11, 1984, through August 28, 1984. Inlets and outlets in both

systems were sampled between September 25, 1984, and October 6, 1984. Sample collections were specified by Julian dates running consecutively for two years, numbering 1-730.

The following physical and chemical parameters were measured for single samples: temperature, salinity (American Optical hand-held refractometer), pH (American Public Health Association, 1981), carbon dioxide (Hach Chemical Company, 1983), MPN total coliforms (American Public Health Association, 1981), and MPN E. coli (American Public Health Association, 1981). The following were determined in duplicate: dissolved oxygen (American Public Health Association, 1981); percent oxygen saturation (Strickland and Parsons, 1968); biological oxygen demand (American Public Health Association, 1981); ammonium (Martin, 1972); ammonia (Bower and Bidwell, 1978); nitrate (Mullin and Riley, 1955); nitrite (American Public Health Association, 1981); total alkalinity (U. S. Environmental Protection Agency, 1979); calcium (U. S. Environmental Protection Agency, 1979); and marine agar plate counts (Schleper, 1972). Total alkalinity, calcium, and carbon dioxide levels were not determined for 1983 biological-filter samples.

The operator documented the total number of crabs, total sheds, and total mortality for the protein-skimmer system during July and August, 1984. Although complete records were not available for the three remaining operating conditions, the following categories were defined:

(1) Biological Filter Stocked at High Densities, >50 crabs per system per day, (May-June, 1983)

(2) Protein Skimmer Stocked at High Densities, >50 crabs per system per day, (July-August, 1984).

(3) Biological Filter Stocked at Low Densities, <50 crabs per system per day, (September-October, 1984)

(4) Protein Skimmer Stocked at Low Densities, <50 crabs per system per day, (September-October, 1984)

The General Linear Regression Model of the Statistical Analytical System (SAS) (Ray, 1982) was used to perform correlation procedures on protein-skimmer data generated when the system was densely stocked. Four variables - crabs added, crabs shed, total crabs, and dead crabs - were compared with all chemical and physical parameters determined during that portion of the study. A SAS GLM ANOVA procedure compared inlet and outlet samples for all monitored parameters in each system (Ray, 1982).

In the remainder of the paper, "significant" will refer to statistical results with $p < 0.05$.

RESULTS

Biological Filter

Figure 1 details changes in pH, temperature (°C), and salinity (ppt) for biological-filter outlet samples collected from May-July, 1983 (high-density stocking) and Figure 2 does the same for inlet and outlet samples collected during September and October, 1984 (low-density stocking). Water temperatures increased during the summer and decreased in the fall. Salinity levels gradually increased from 11 ppt (day 124) to 27 ppt (day 205) for high-density stocking of the biological-filter system. Salinity concentrations for low-density stocking varied randomly and ranged from 17.5 to 20.5 ppt. Dissolved oxygen (O_2 mg/l) and biological oxygen demand (BOD mg/l) levels determined for dense crab populations are presented in Figure 3. Carbon dioxide (mg/l), O_2 (mg/l), BOD (mg/l), calcium (mg/l), and alkalinity (mg $CaCO_3$/l) concentrations determined for low crab densities are shown in Figures 4 and 5. BOD levels were greater for high crab populations than for low populations. Dissolved oxygen levels were depressed from Julian dates 146 to 180 (Figure 3). Oxygen saturations were consistent at both stocking densities (Figures 6 and 7).

Figures 8, 9, and 10 show nitrogen compound levels for the biological filter operating under dense and sparse crab populations. No consistent differences or concentration patterns were noted for ammonium (NH_4) or ammonia (NH_3) levels. Nitrate (NO_3) concentrations increased rapidly when the system was stocked at low densities, ranging between 189 µg/l and 3.95×10^4 µg/l (Figures 7 and 8). High density NO_3 levels increased from 1.22×10^4 µg/l (day 133) to a maximum of 1.62×10^5 µg/l (day 197) and returned to 1.50×10^5 µg/l (day 208) (Figure 6). Nitrite levels decreased for dense crab populations and demonstrated an inverse relationship to nitrate levels on all occasions. Nitrite concentrations peaked at 1.97×10^3 µg/l for high-density samples and at 17 µg/l for low-density samples (Figures 8, 9, and 10).

Microbiological populations determined by marine agar plate counts ranged between 2.2×10^4 organisms/ml and 1.0×10^8 organisms/ml for densely stocked samples and between 8.5×10^3 organisms/ml and 1.2×10^5 organisms/ml for the sparsely stocked trial (Figures 11 and 12). Coliform and *E. coli* levels showed no

consistent patterns (Figures 13 and 14). No significant differences were determined between inlet and outlet values for all monitored chemical, physical, and microbiological parameters.

Protein Skimmer

Temperature (°C) and pH data presented in Figures 15 and 16 for the protein-skimmer system exhibited no major trends during sparse and dense stocking. Temperatures were within expected seasonal variations. Salinity levels gradually increased from 13 ppt (day 557) to 16 ppt (day 574) during high-density stocking of the protein-skimmer system (Figure 15). Salinity concentrations varied randomly for low-density stocking and ranged from 17 to 19 ppt (Figure 16). Oxygen levels remained between 6 mg/l and 8 mg/l during the summer (Figures 17 and 18) and increased to a maximum concentration of 9.4 mg/l in the fall (day 642) (Figures 19 and 20). Alkalinity levels rapidly fell from an initial value of 125 mg $CaCO_3$/l (day 557) (Figure 17) and leveled off at approximately 70 mg $CaCO_3$/l for the rest of the study (Figures 17, 18, 19, and 20). Calcium levels decreased from an initial mean inlet and outlet level of 101 mg/l (day 557) for high-density stocking to a minimum value of 80 mg/l (day 559) then continued to increase for the remainder of the study, reaching a maximum mean concentration of 240 mg/l (day 643) during low-density stocking (Figures 17, 18, 19, and 20). BOD levels ranged between 0.69 mg/l and 6.33 mg/l, but no consistent pattern was observed (Figures 17, 18, 19, and 20). Oxygen saturation ranged between 78.4% and 100.0% for inlet and outlet samples (Figures 20 and 22). Saturation values increased between days 635 and 644 when the system was stocked at low densities (Figures 21 and 22).

Recorded ammonium concentrations ranged between 31 µg/l and 686 µg/l. No trends were discernible (Figures 23, 24, 25 and 26). Ammonia concentrations peaked at 23 µg/l (day 557). The lowest value, 0.3 µg/l, was recorded on day 641. Nitrates accumulated in the protein-skimmer system over time, regardless of stocking densities (Figures 23, 24, 25, and 26). Nitrite levels ranged between 100 µg/l and 810 µg/l for dense crab populations. Nitrite levels determined for the sparsely stocked system decreased rapidly from 338 µg/l (day 633) to 10 µg/l (day 639) and stayed below 20 µg/l for the remaining samples (Figures 23, 24, 25 and 26).

Marine agar plate count populations ranged between 10^4 organisms/ml and 10^6 organisms/ml for both stocking levels (Figures 27 and 28). MPN total coliform organisms showed no consistent pattern, ranging from 68 organisms/100 ml to 16,000 organisms/100 ml (Figures 29 and 30). MPN *E. coli* levels ranged between none detected and 490 organisms/100 ml (Figures 29 and

30). No significant differences were determined between inlet and outlet values for all monitored chemical, physical, and microbiological parameters.

Figure 31 presents the number of added, shed, dead, and total crabs in the protein-skimmer system stocked at high densities. Total crab populations ranged from 50 to 165 during 16 days of operation. The percentage of successful sheds registered between 15.9% and 97.1% (Figure 32). Mortality figures were low, ranging from 1.5% to 8.1%.

Protein Skimmer Versus Biological Filter (High Density)

The protein skimmer and biological filter systems had similar responses to temperature (°C), salinity (ppt), pH, oxygen concentrations (mg/l), percent oxygen saturation, and BOD levels (mg/l) (Figures 1, 3, 6, 15, 17, 18, and 22). Biological filter ammonium levels (NH_4) fell from 5.12×10^3 µg/l (day 124) to 31 µg/l (day 133). Biological-filter ammonium levels were less than protein-skimmer concentrations for all but the initial sample. Protein-skimmer ammonium levels ranged from 126 µg/l to 686 µg/l for the densely stocked system. Ammonia (NH_3) levels followed a similar pattern with biological-filter concentrations decreasing rapidly from 287 µg/l (day 124) to 2 µg/l (day 138). The minimum recorded ammonia level was 0.5 µg/l (day 187). Protein-skimmer levels ranged between 2.6 µg/l and 23 µg/l (Figures 8, 23, and 24).

Nitrate levels were high in both systems, with peaks exceeding 1×10^5 µg/l. Nitrite concentrations decreased with time in the biological system (1.97×10^3 µg/l to 49 µg/l), while nitrate levels increased. Protein-skimmer nitrite values varied randomly and ranged from 100 µg/l to 810 µg/l.

Biological-filter marine agar plate counts ranged from 8.80×10^3 organisms/ml to 1.00×10^8 organisms/ml, while protein-skimmer populations ranged from 6.85×10^4 organisms/ml to 3.73×10^6 organisms/ml (Figures 11, 27, and 28). No pattern was observed for coliform or *E. coli* populations in either system (Figures 13 and 29).

Protein Skimmer Versus Biological Filter (Low Density)

There were no consistent differences in pH, temperature (°C), salinity (ppt), carbon dioxide (mg/l), or BOD (mg/l) levels between both systems stocked at low densities (Figures 2, 4, 5, 16, 19, and 20). Biological-filter calcium levels were consistently lower (range - 103 mg/l to 132 mg/l) than protein-skimmer concentrations (range - 201 mg/l to 240 mg/l). Alkalinity

values were reversed with protein-skimmer concentrations falling between 67 mg $CaCO_3$/l and 86 mg $CaCO_3$/l, while biological levels ranged between 106 mg $CaCO_3$/l and 131 mg $CaCO_3$/l (Figures 4, 5, 19, and 20). Dissolved oxygen levels were similar in both systems except for a minimum value of 3.75 mg/l for the biological filter on day 634 following a pump failure (Figures 4, 5, 19, and 20). Oxygen-saturation values exhibited the same pattern (Figures 7, 21, and 22).

Both systems' ammonium (NH_4) concentrations were similar. Protein-skimmer ammonia (NH_3) concentrations were lower (range - 0.3 µg/l to 3.5 µg/l) than biological-filter levels (range - 0.4 µg/l to 15 µg/l) (Figures 9, 10, 25, and 26). Biological nitrate levels increased with time (range - 1.84×10^3 µg/l to 3.95×10^4 µg/l), but remained much lower than protein-skimmer concentrations (range - 2.20×10^5 µg/l to 2.49×10^5 µg/l). Biological nitrite concentrations (range - 6 µg/l to 17 µg/l) were less than protein-skimmer levels (range - 10.5 µg/l to 1.92×10^3 µg/l) (Figures 9, 10, 25, and 26). Marine agar plate count populations decreased with time for both systems, but biological-filter populations (range - 8.5×10^3 organisms/ml to 1.22×10^5 organisms/ml) were less than protein-skimmer populations (1.64×10^4 organisms/ml to 3.31×10^6 organisms/ml) (Figures 12 and 28). No trends or differences were noted for total coliform or E. coli levels (Figures 14 and 30).

Protein-Skimmer High-Density Crab Correlations

The only complete record of total crabs, shed crabs, added crabs, and crab mortality was available for the protein-skimmer system stocked at high densities. Crab population levels are presented in Figure 31 (days 557-574). Correlations determined for total crabs, added crabs, shed crabs, and dead crabs and the monitored physical, chemical, and microbiological parameters are presented in Tables 1 and 2 (Ray, 1982). Although not significant at the 0.05 level, two parameters exhibited strong negative and positive correlations between crabs added to and shed in the system, respectively. Ammonia concentrations correlated negatively ($p = 0.059$) with crabs added to the system while alkalinity showed a positive correlation ($p = 0.056$) with crabs shed (Tables 1 and 2). All correlations referred to in the remainder of the paragraph were significant, $p < 0.05$. A positive correlation was determined between total crabs and the carbon dioxide content of the water (Table 1). Negative correlations with crab sheds were determined for salinity and nitrate levels (Tables 1 and 2).

DISCUSSION

Both filters maintained dissolved oxygen levels that exceeded the minimum 4 mg/l needed to support crab and filter metabolisms on all but one occasion (Osterling, 1984). The biological-filter system fell to 3.7 mg O_2/l following a pump failure. However, recent work by Manthe et al. (1984) suggests that acceptable dissolved oxygen levels in the shedding tanks (5.6 mg/l) provided only 2.0 mg/l dissolved oxygen to the biological filter. Low oxygen levels act as the limiting factor for biological oxidation of nitrogen compounds. Additional filter oxygenation could increase efficiency.

Nitrate levels were high in both systems, with the biological filter peaking at 1.93×10^5 µg/l and the protein skimmer peaking at 2.49×10^5 µg/l. Neither system reached the 3.6×10^5 µg/l level that Manthe et al. (1984) proposed as an approximate upper safety limit for shedding blue crabs; however, a significant negative correlation was determined between nitrate concentrations and the number of crabs shed when the protein-skimmer system was stocked at high densities. Both nitrate levels were within the same orders of magnitude (ranging from 2.14×10^5 µg/l to 3.50 µg/l) reported for closed systems monitored by Malone et al. (1984). Protein-skimmer nitrite levels were generally greater (ranges: high density - 100 µg/l to 810 µg/l; low density - 10.5 µg/l to 1.92×10^3 µg/l) than the biological-filter concentrations (ranges: high density - 49 µg/l to 1.97×10^3 µg/l; low density - 6 µg/l to 17 µg/l), although biological-filter nitrite peaks exceeded protein-skimmer levels on occasion. The peak biological-filter nitrite concentration of 1.97×10^3 µg/l occurred on the first day of sampling, prior to complete conditioning of the filter. The level was less than the 2.0×10^5 µg/l nitrite concentration reported by Malone et al. (1984) for an overstocked and failing closed, recirculating shedding system. Nitrite levels decreased rapidly after the first day and remained below protein-skimmer concentrations. Neither system exceeded the 2.0×10^3 µg/l toxic nitrite limit for molting crabs or the 2.0×10^4 µg/l toxic limit for intermolt crabs (Manthe et al. 1984). Protein-skimmer ammonium (NH_4) and ammonia (NH_3) levels stabilized above biological-filter concentrations, but neither system reached 7×10^3 µg NH_3/l, the concentration toxic to peeler crabs (Osterling, 1984). Maximum recorded ammonia concentrations for the biological-filter system and protein-skimmer system, respectively, 3.5 µg/l and 14.6 µg/l, were much less than the 5.00×10^3 µg/l reported by Malone et al. (1984).

The biological filter maintained lower calcium concentrations (range - 103 mg/l to 132 mg/l) than the protein skimmer (range -

201 mg/l to 240 mg/l) when stocked at low densities. Alkalinity levels showed the opposite effect, with biological-filter values ranging from 106 mg $CaCO_3$/l to 131 mg $CaCO_3$/l and protein-skimmer levels ranging from 67 mg $CaCO_3$/l to 86 mg $CaCO_3$/l. Both oyster-shell (protein-skimmer) and coral (biological) filters maintained greater alkalinity levels than those reported by Malone et al. (1984), 70 mg $CaCO_3$/l to 30 mg $CaCO_3$/l, for a clam shell, dolomite, and activated carbon filter. Although not significant, the number of crabs shed had a strong positive correlation with alkalinity levels (Table 1).

Two significant negative correlations were determined between crabs shed and salinity and nitrate levels when the protein skimmer operated at high densities. Salinity levels ranged between 13 and 16 ppt. Nitrate levels ranged from 672 µg/l to 1.51×10^5 µg/l and were below concentrations reported toxic to intermolt and molting crabs. Positive correlations between total crabs and carbon dioxide levels were indicative of system stress resulting from increased crab populations and their waste metabolites.

CONCLUSIONS

Nitrate, nitrite, and ammonium concentrations remained below accepted toxic limits for molting blue crabs in both the protein-skimmer and biological-filter systems. However, a significant negative correlation was established between nitrate concentrations and the number of crabs shed in the protein-skimmer system. Ammonium, ammonia, and nitrite levels were generally greater in the protein-skimmer system than in the biological-filter system.

The oyster-shell filter of the protein-skimmer system produced calcium levels that exceeded and alkalinity levels which were less than those determined for the crushed-coral medium of the biological-filter system. The efficiency of the crushed-coral biological filter increased with time and conditioning as evidenced by decreasing nitrite levels.

FIGURES

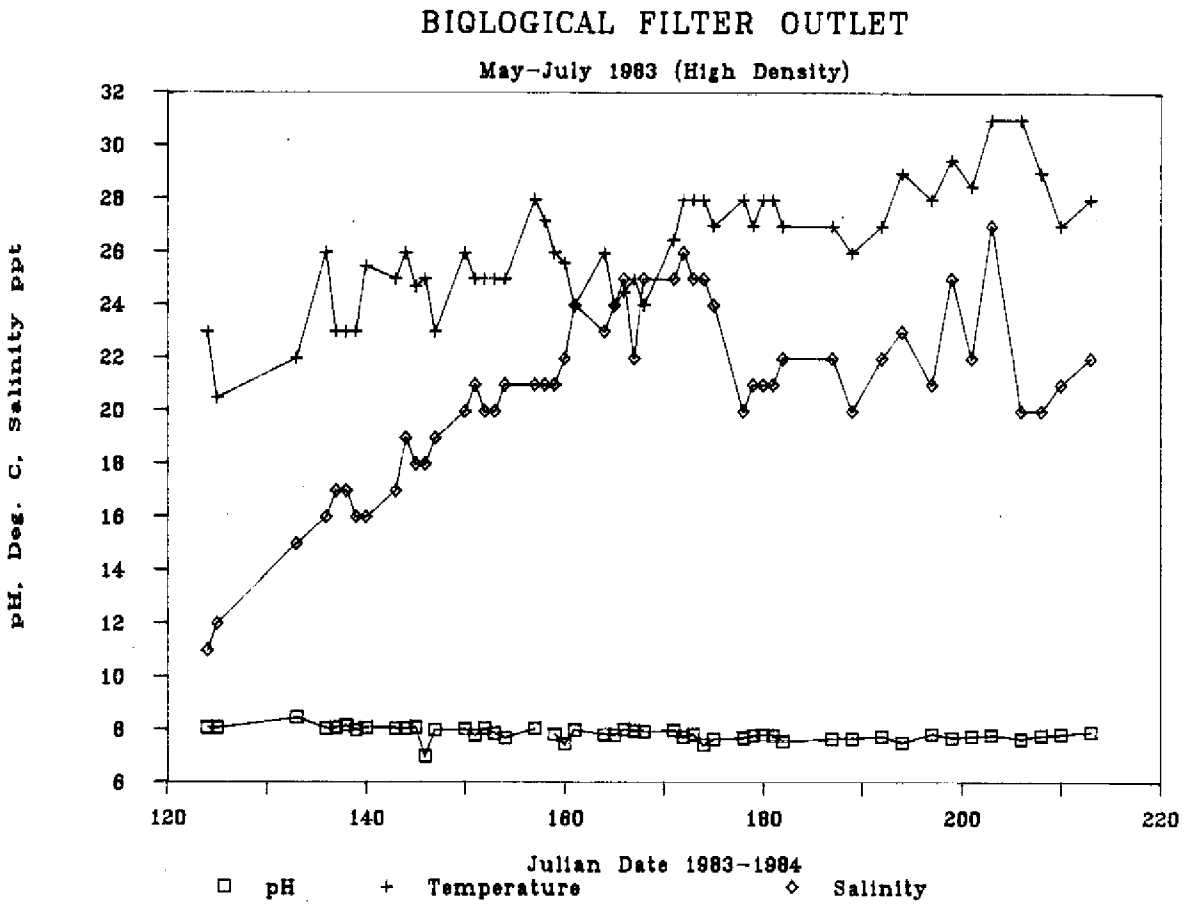

Figure 1. Outlet pH, temperature (°C), and salinity (ppt) levels for the biological filter stocked at high densities (May-July, 1983)

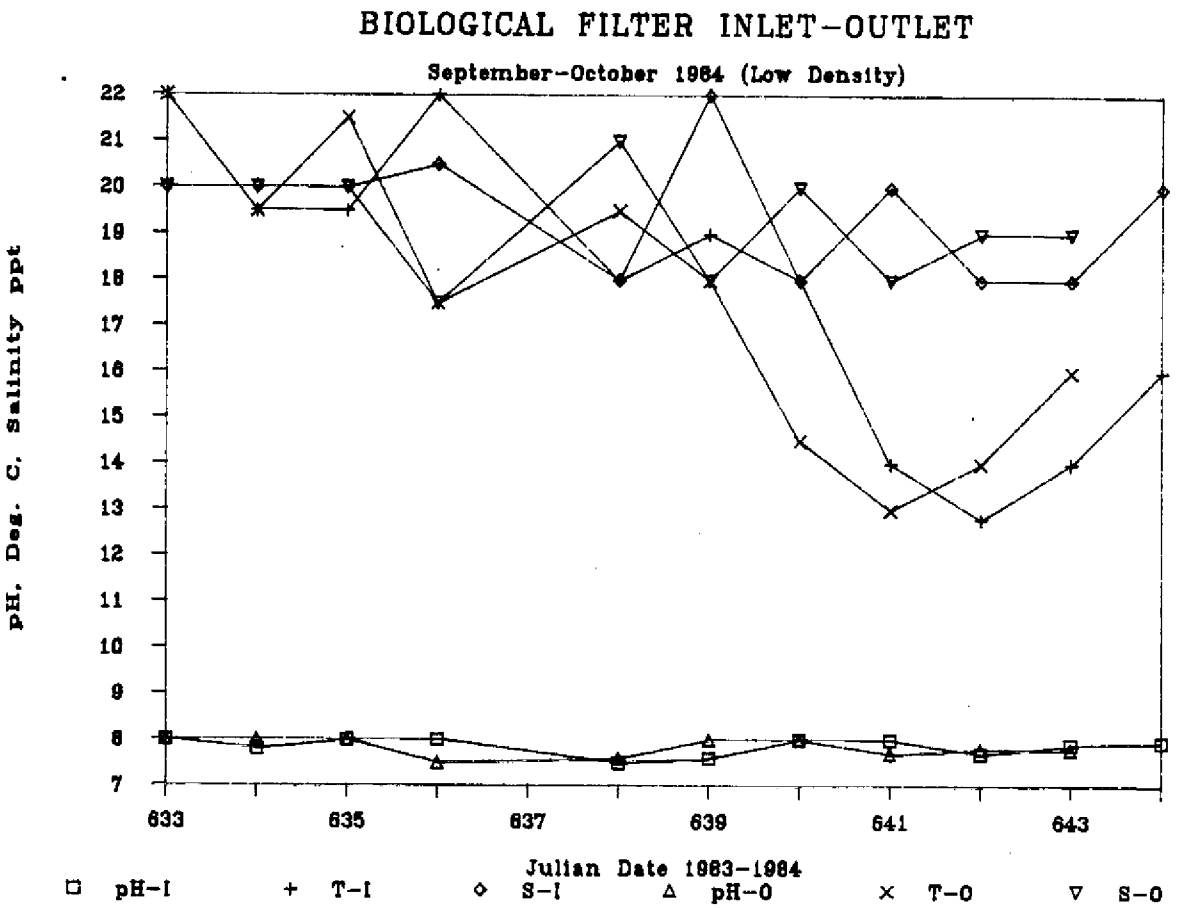

Figure 2. Inlet and outlet pH, temperature (°C), and salinity (ppt) levels for the biological filter stocked at low densities (September-October, 1984)

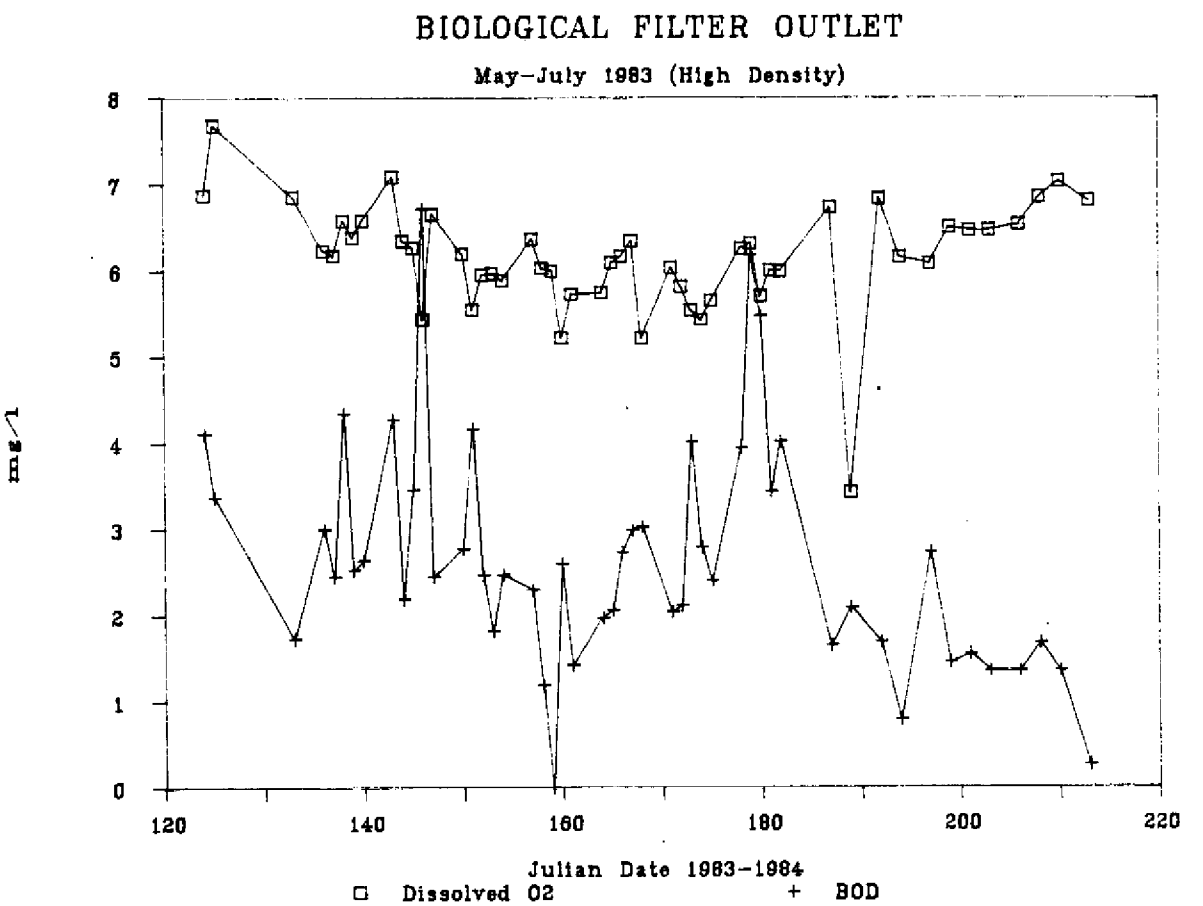

Figure 3. Outlet dissolved oxygen and BOD levels for the biological filter stocked at high densities (May-July, 1983)

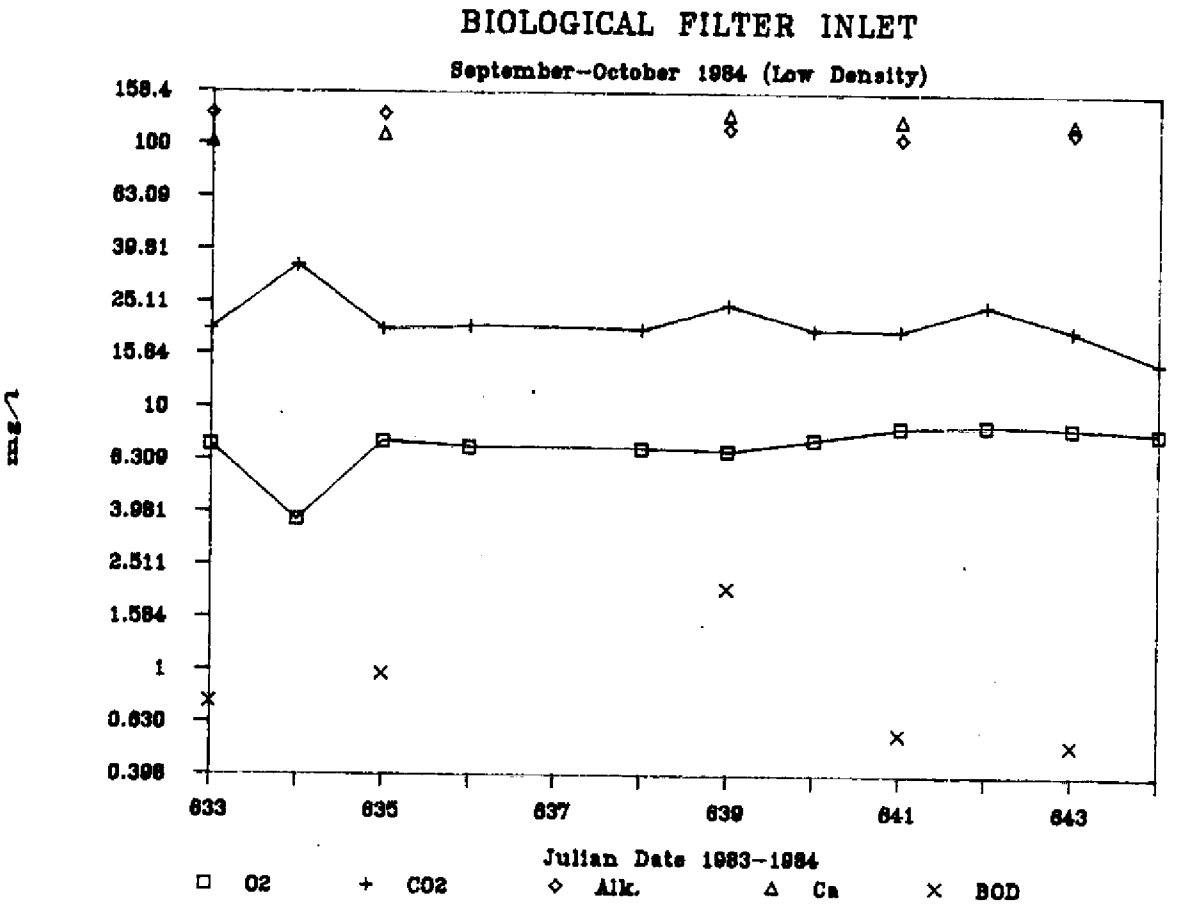

Figure 4. Mean inlet dissolved O_2, dissolved CO_2, alkalinity, calcium, and BOD levels for the biological filter stocked at low densities (September-October, 1984)

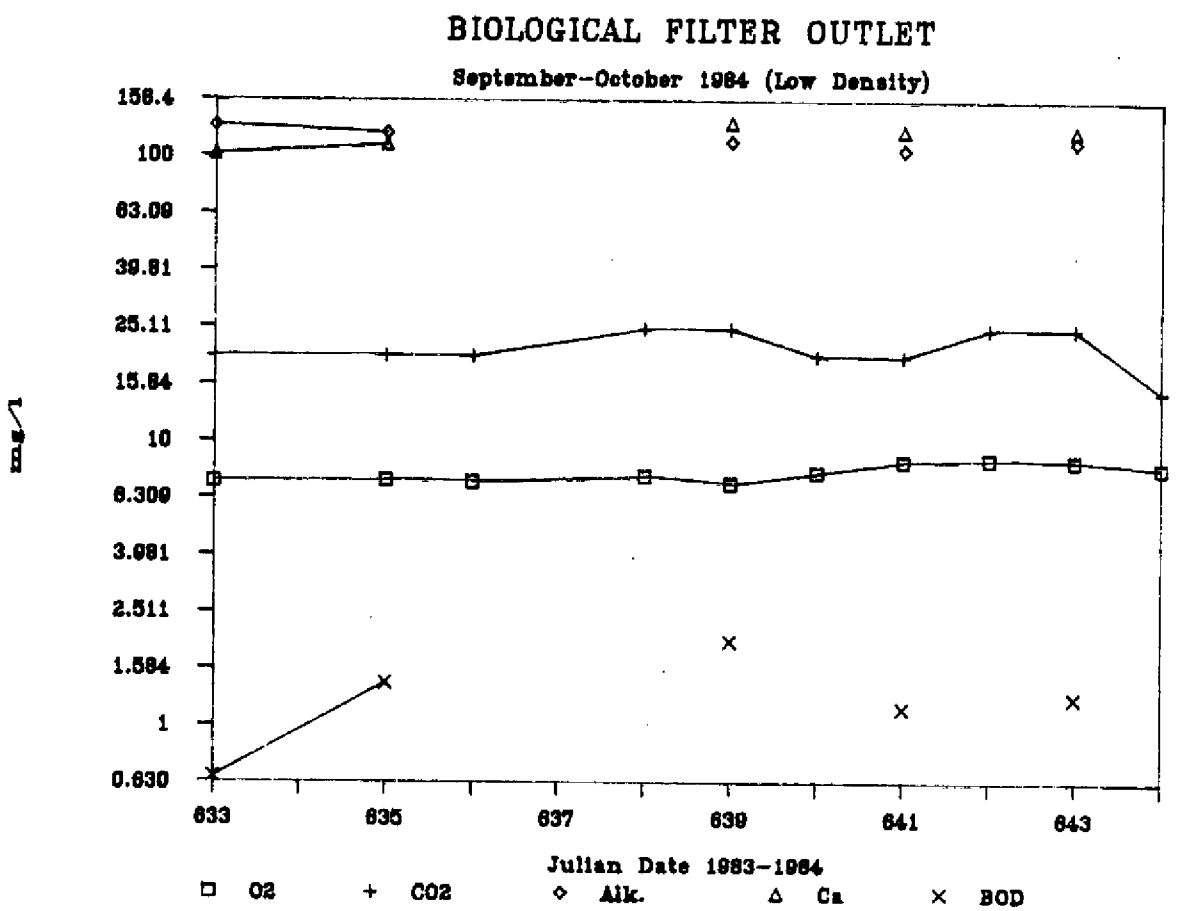

Figure 5. Mean outlet dissolved O_2, dissolved CO_2, alkalinity, calcium, and BOD levels for the biological filter stocked at low densities (September-October, 1984)

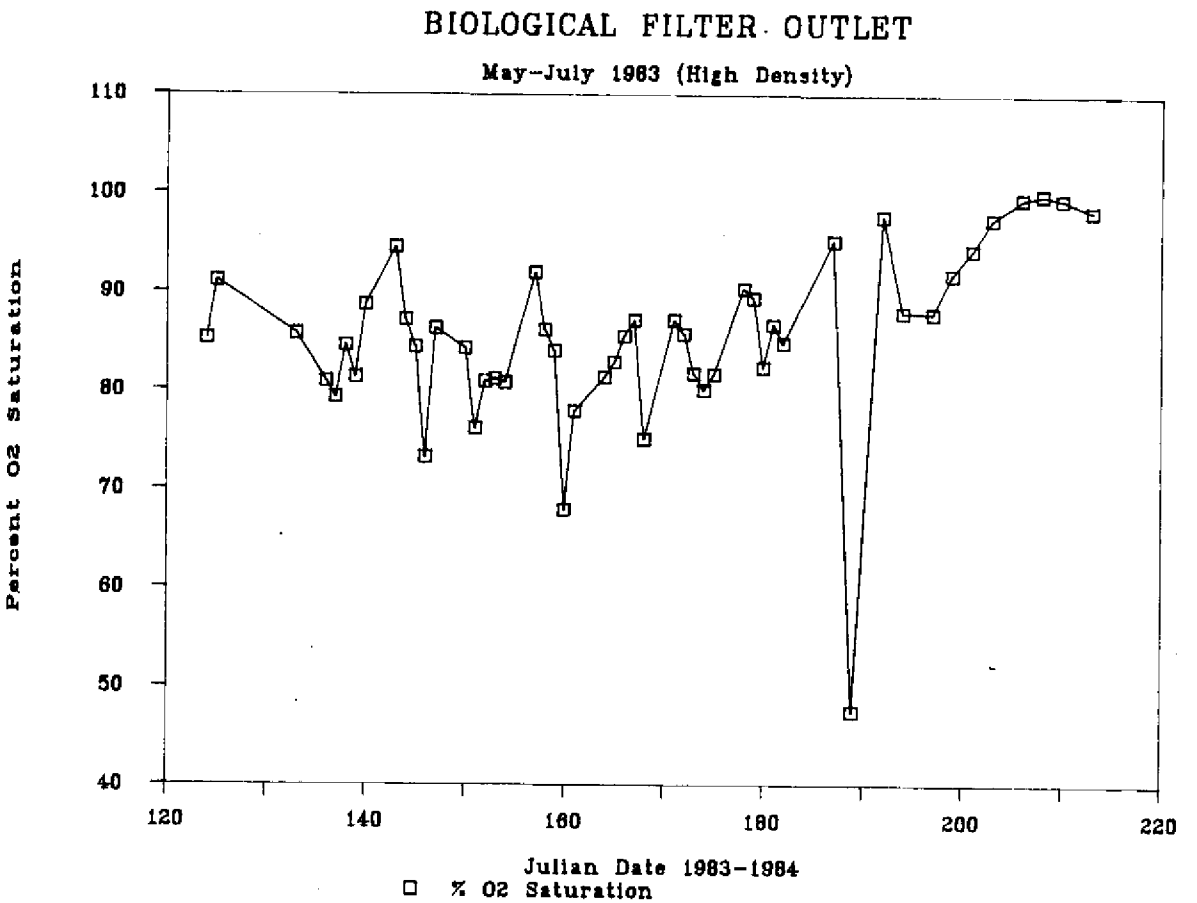

Figure 6. Mean outlet oxygen-saturation levels for the biological filter stocked at high densities (May-July, 1983)

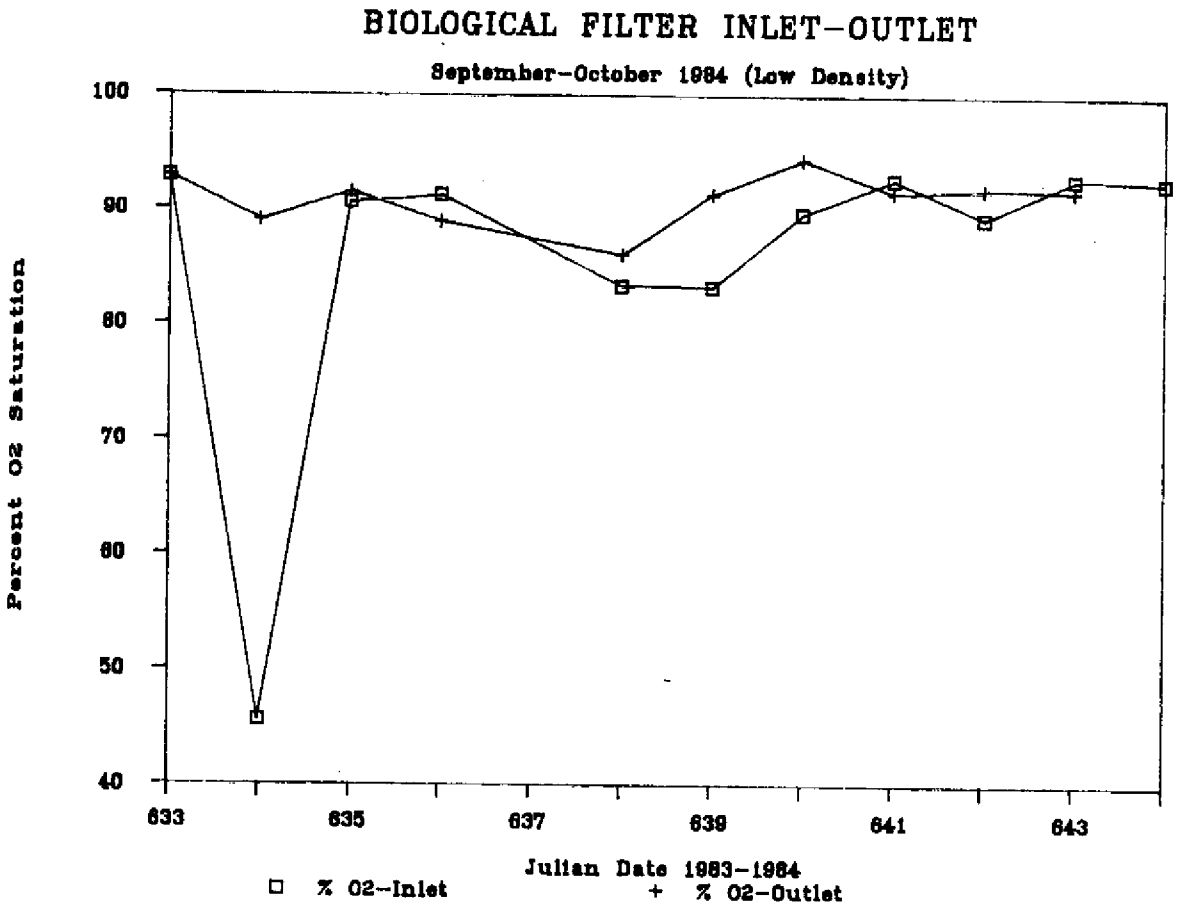

Figure 7. Mean inlet and outlet oxygen-saturation levels for the biological filter stocked at low densities (September-October, 1984)

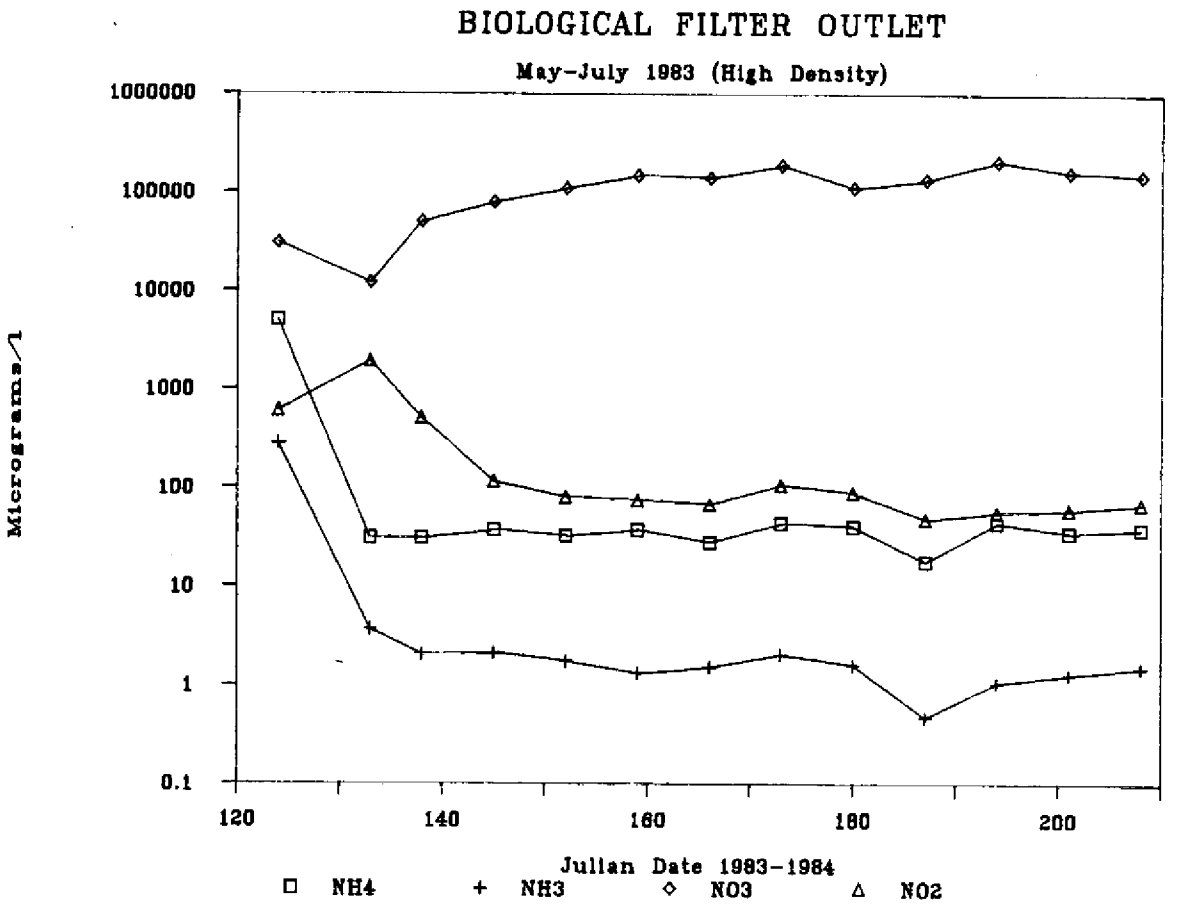

Figure 8. Mean outlet ammonium (NH_4), ammonia (NH_3), nitrate (NO_3), and nitrite (NO_2) levels for the biological filter stocked at high densities (May-July, 1983)

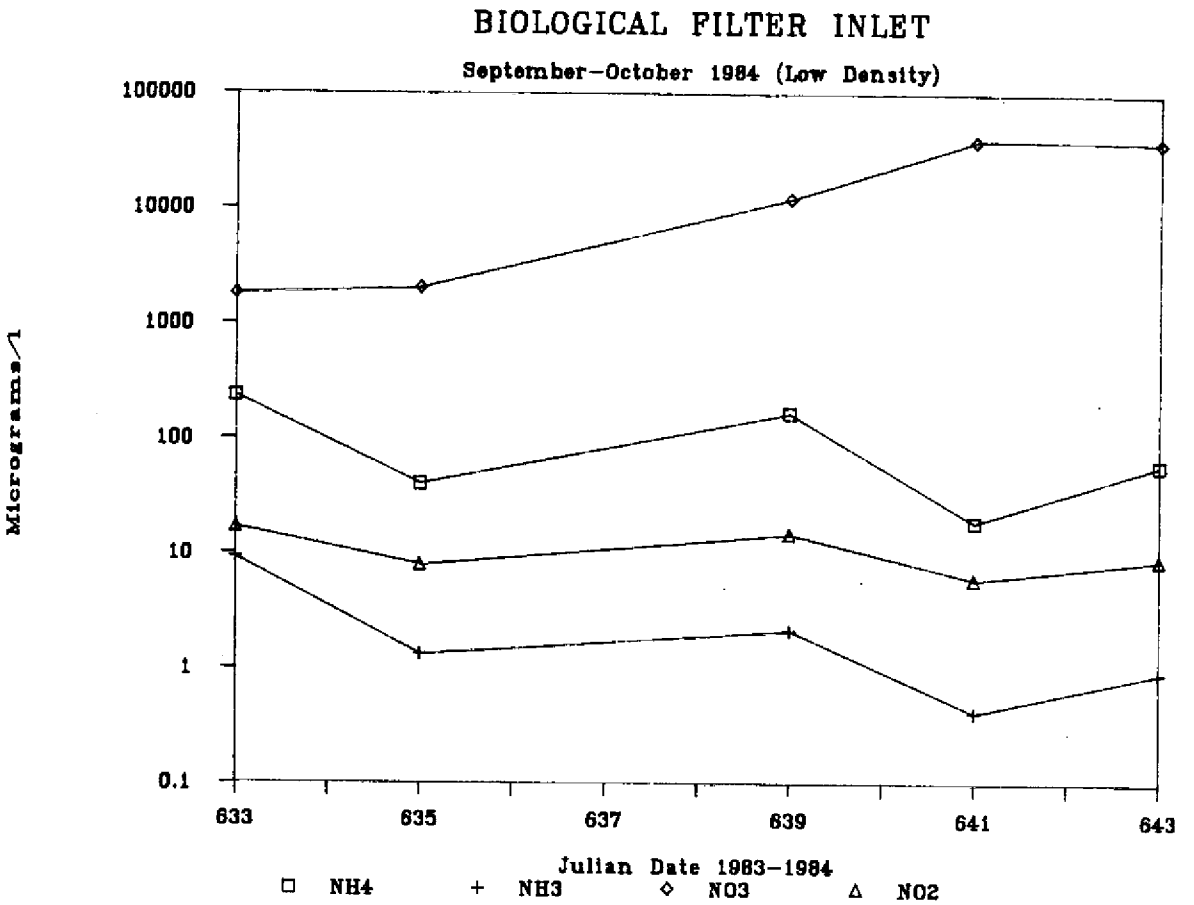

Figure 9. Mean inlet ammonium (NH_4), ammonia (NH_3), nitrate (NO_3), and nitrite (NO_2) levels for the biological filter stocked at low densities (September-October, 1984)

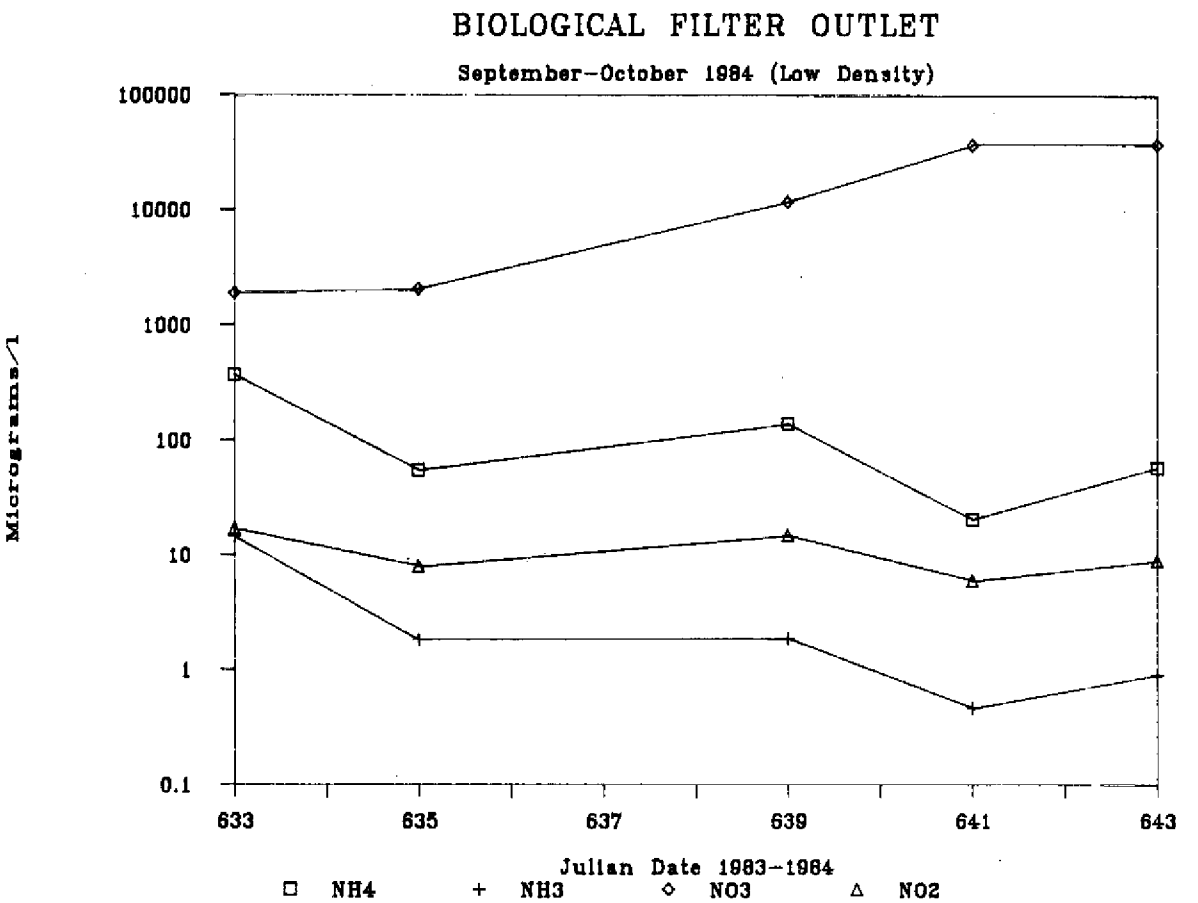

Figure 10. Mean outlet ammonium (NH_4), ammonia (NH_3), nitrate (NO_3), and nitrite (NO_2) levels for the biological filter stocked at low densities (September-October, 1984)

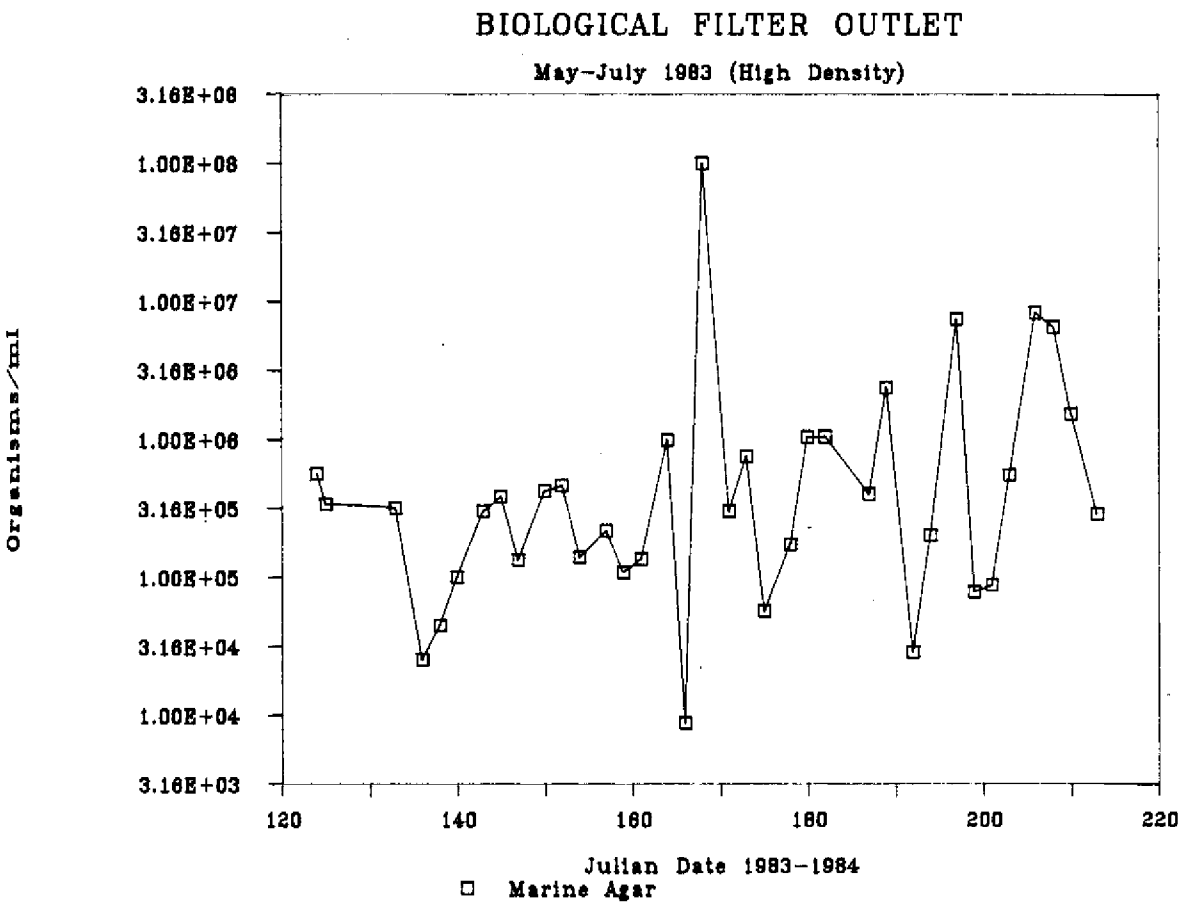

Figure 11. Mean outlet marine agar plate counts for the biological filter stocked at high densities (May-July, 1983)

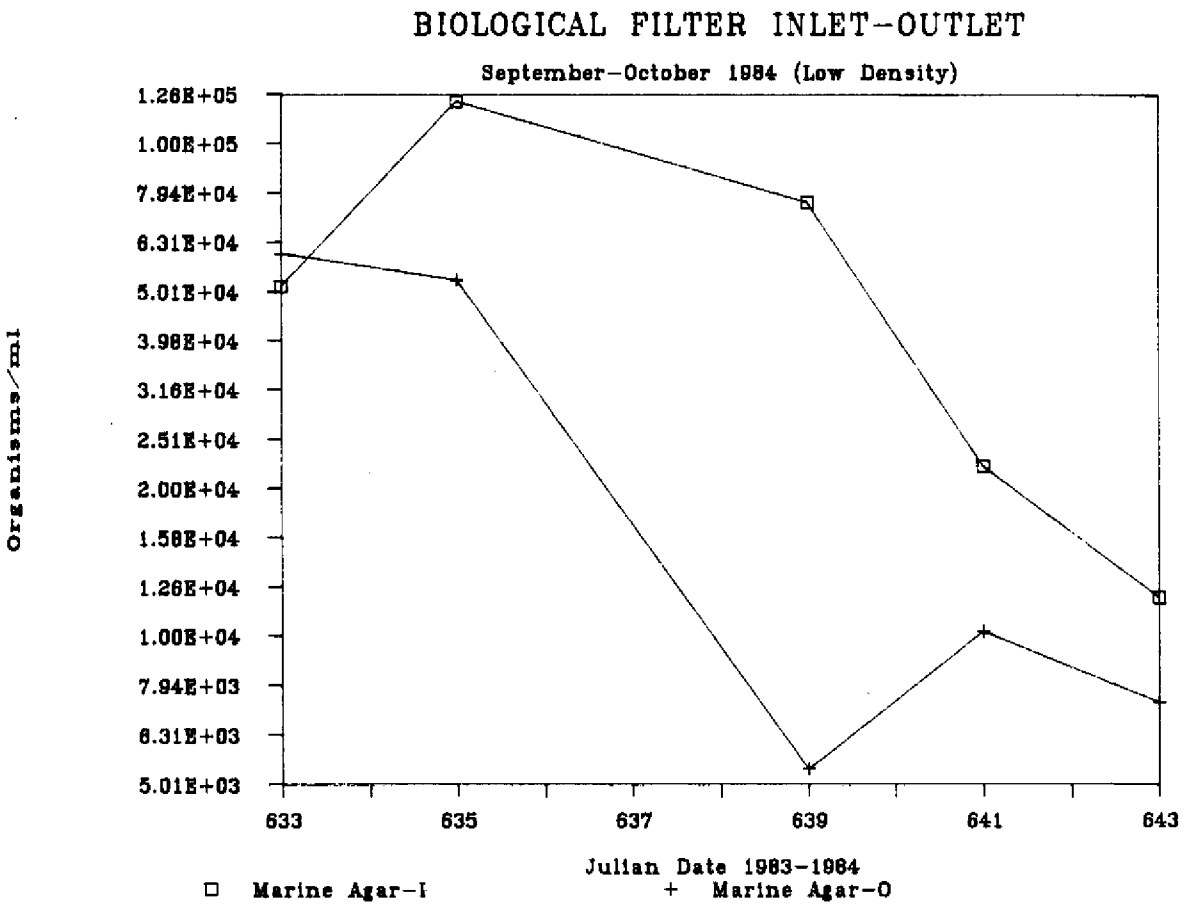

Figure 12. Mean inlet and outlet marine agar plate counts for the biological filter stocked at low densities (September-October, 1984)

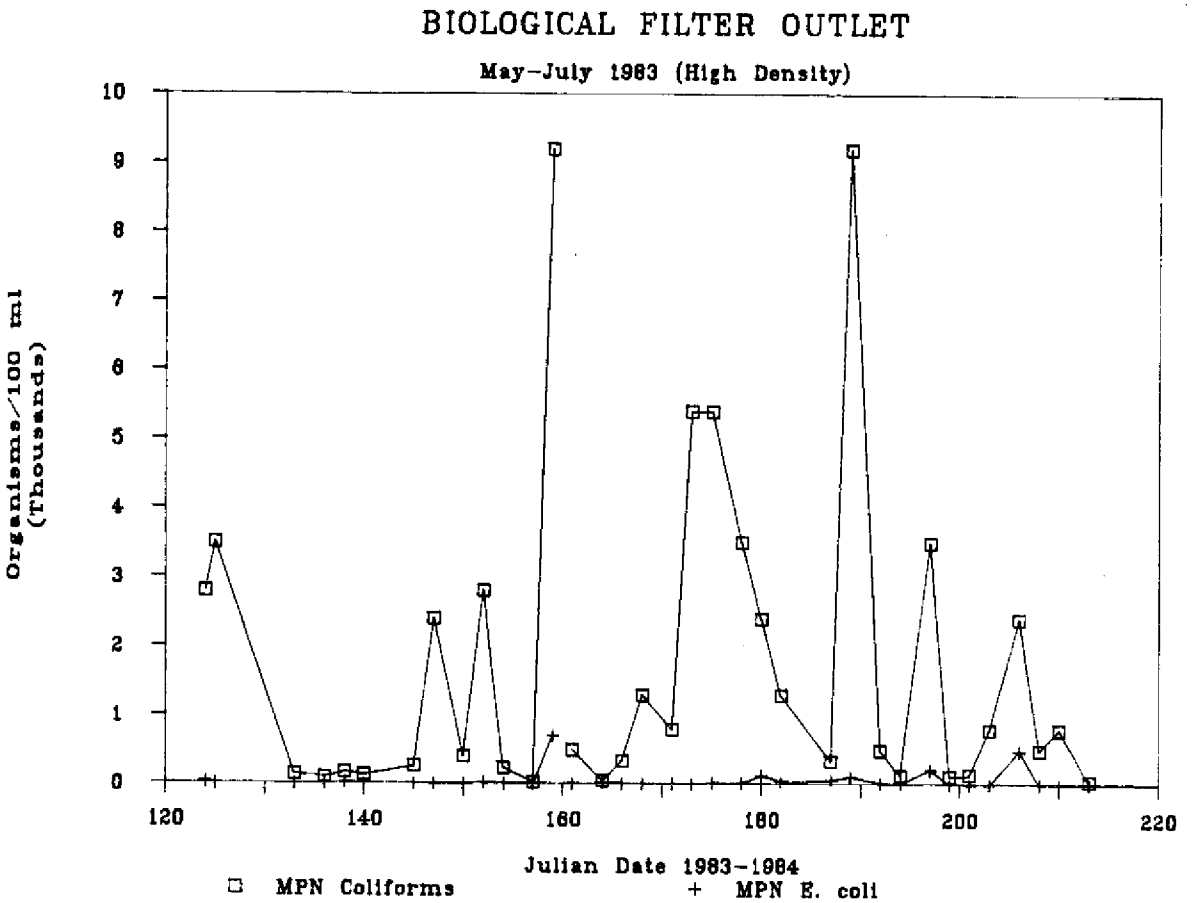

Figure 13. MPN total coliform and MPN E. coli outlet populations for the biological filter stocked at high densities (May-July, 1983)

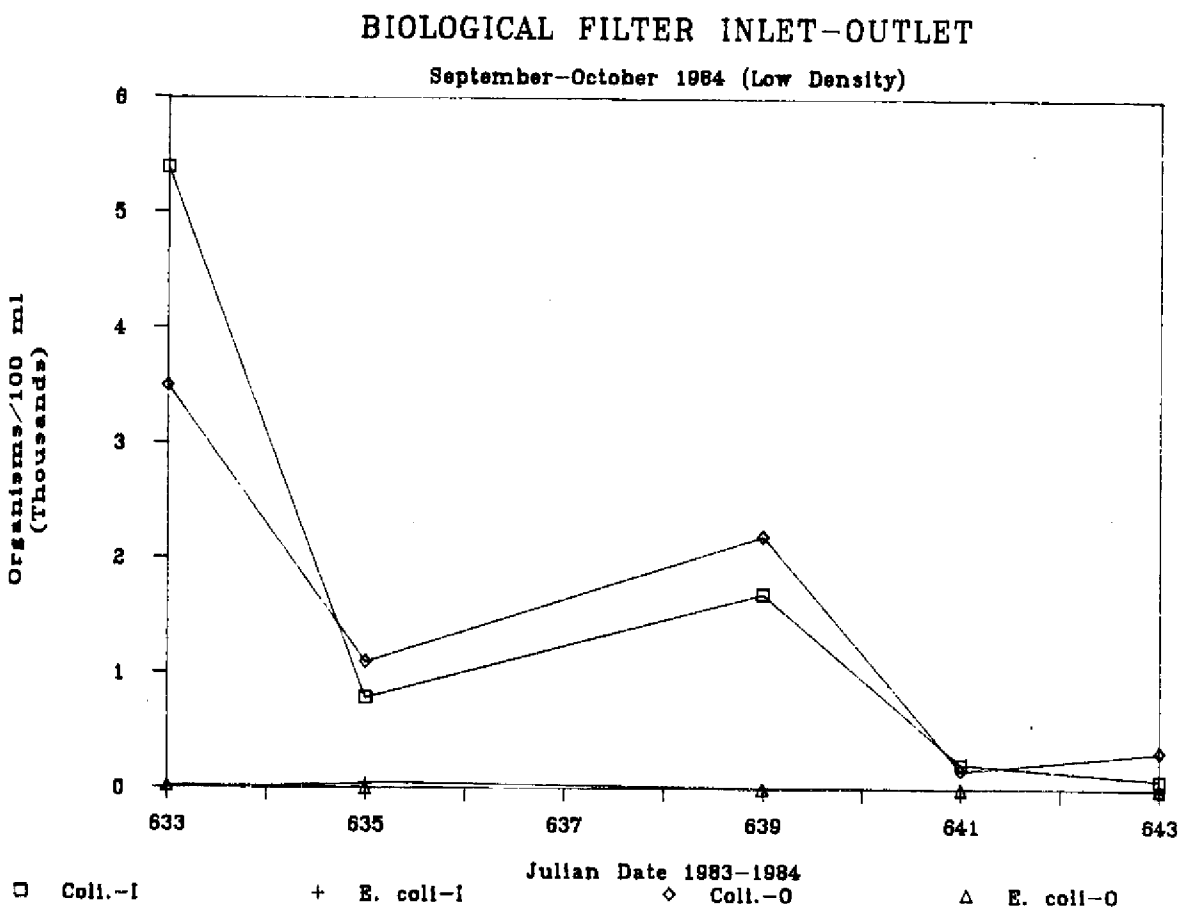

Figure 14. MPN total coliform and MPN E. coli inlet and outlet populations for the biological filter stocked at low densities (September-October, 1984)

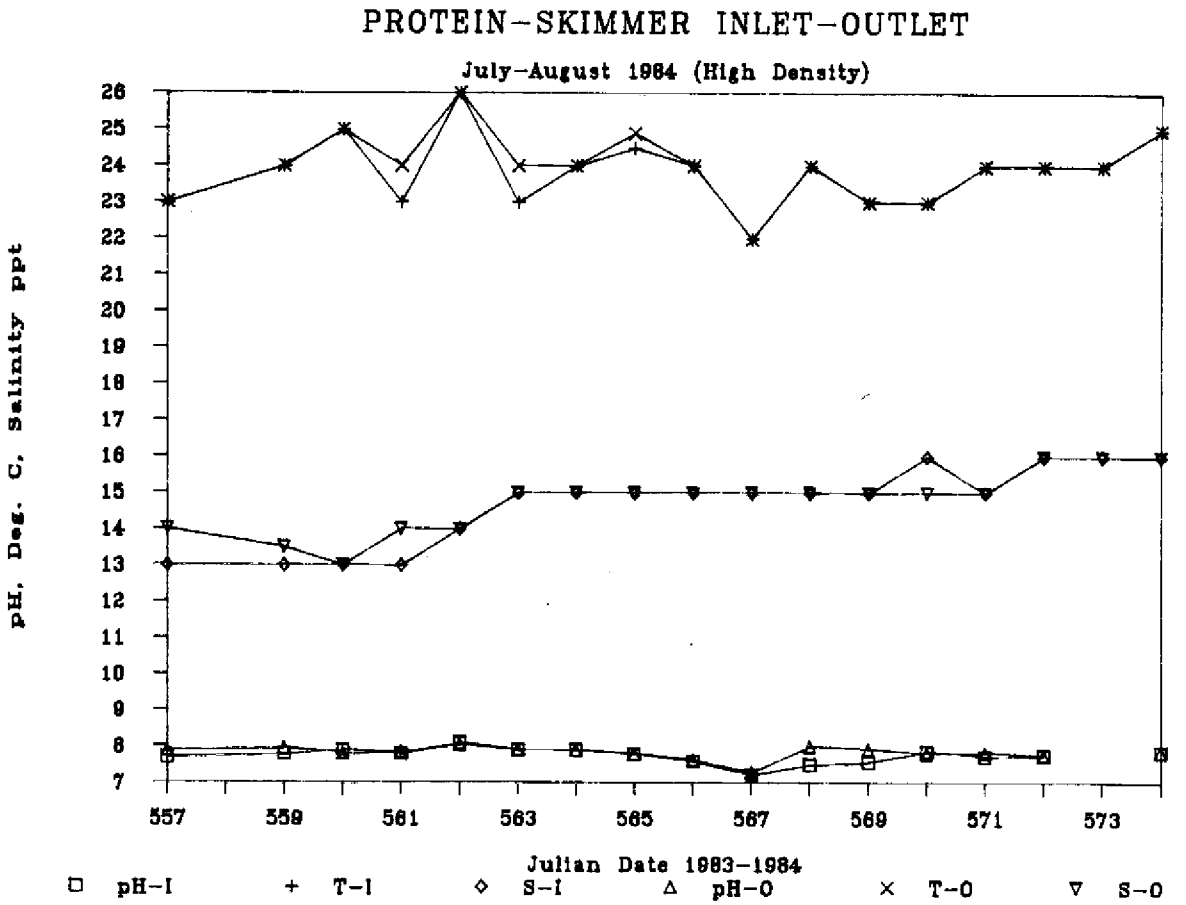

Figure 15. Inlet and outlet pH, temperature (°C), and salinity (ppt) levels for the protein skimmer stocked at high densities (July-August, 1984)

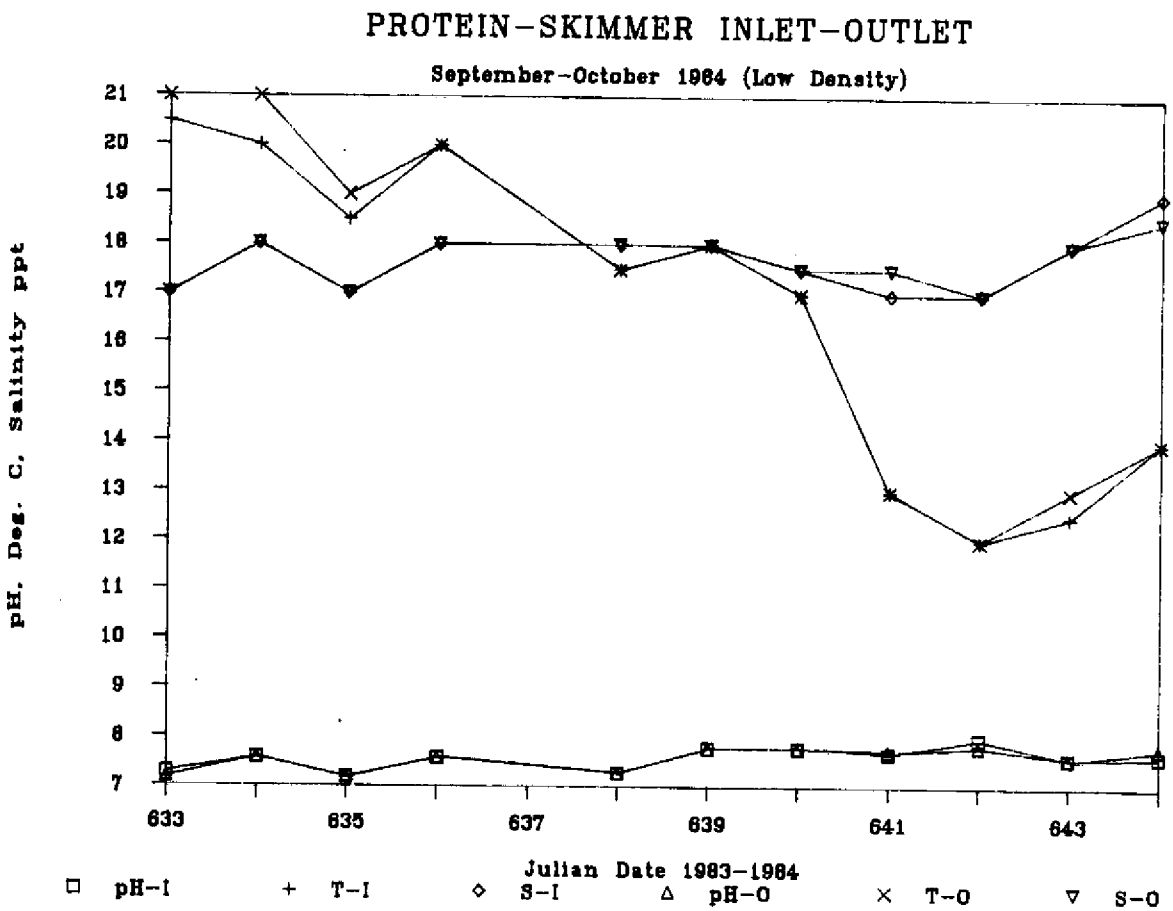

Figure 16. Inlet and outlet pH, temperature (°C), and salinity (ppt) levels for the protein skimmer stocked at low densities (September-October, 1984)

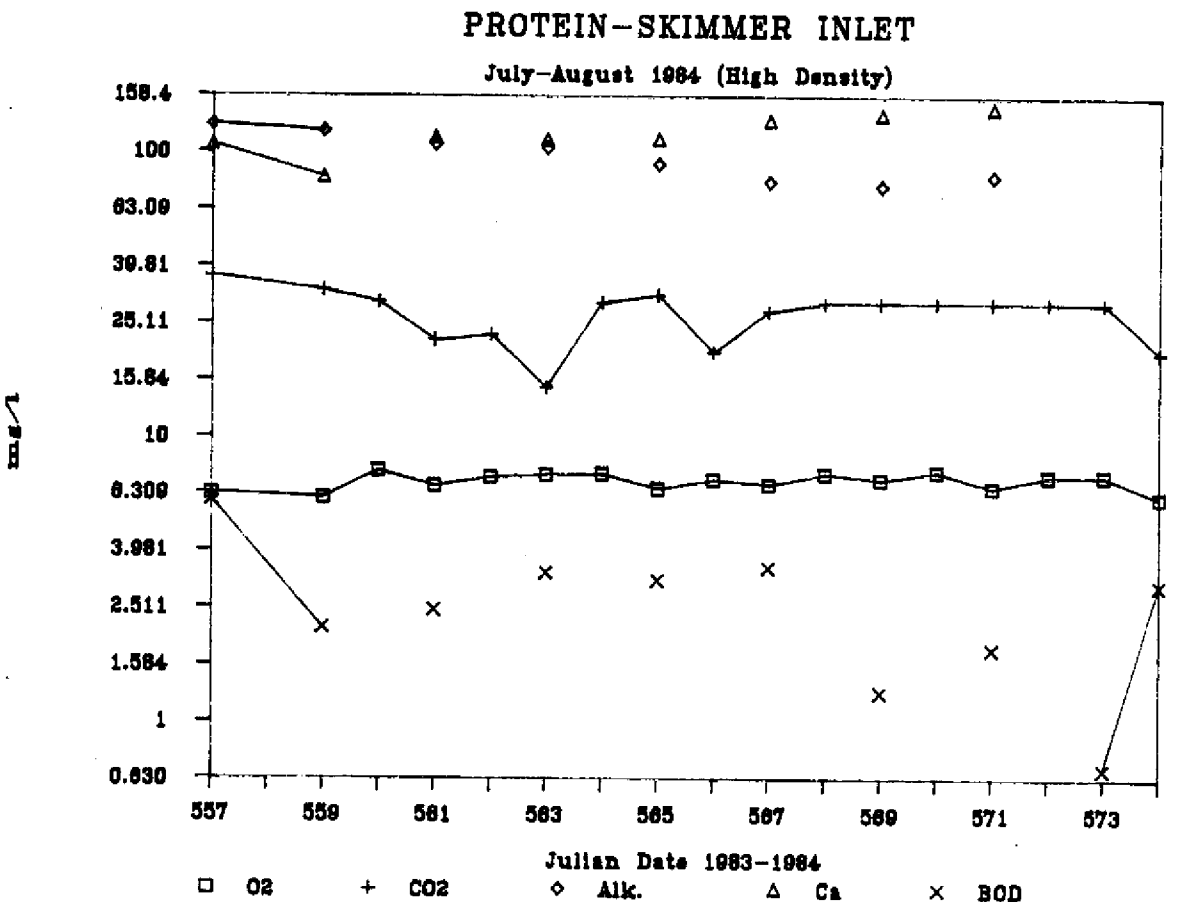

Figure 17. Mean inlet dissolved O_2, dissolved CO_2, alkalinity, calcium, and BOD levels for the protein skimmer stocked at high densities (July-August, 1984)

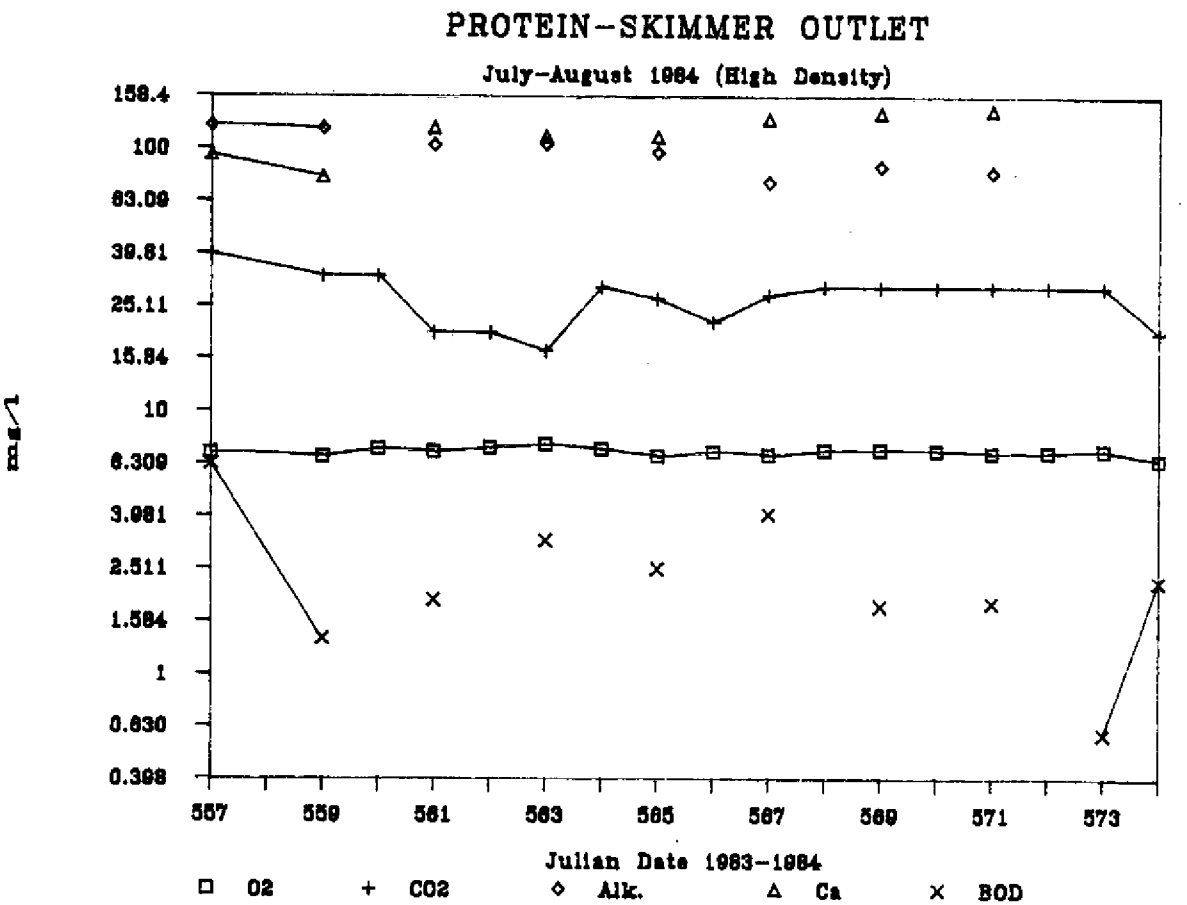

Figure 18. Mean outlet dissolved O_2, dissolved CO_2, alkalinity, calcium, and BOD levels for the protein skimmer stocked at high densities (July-August, 1984)

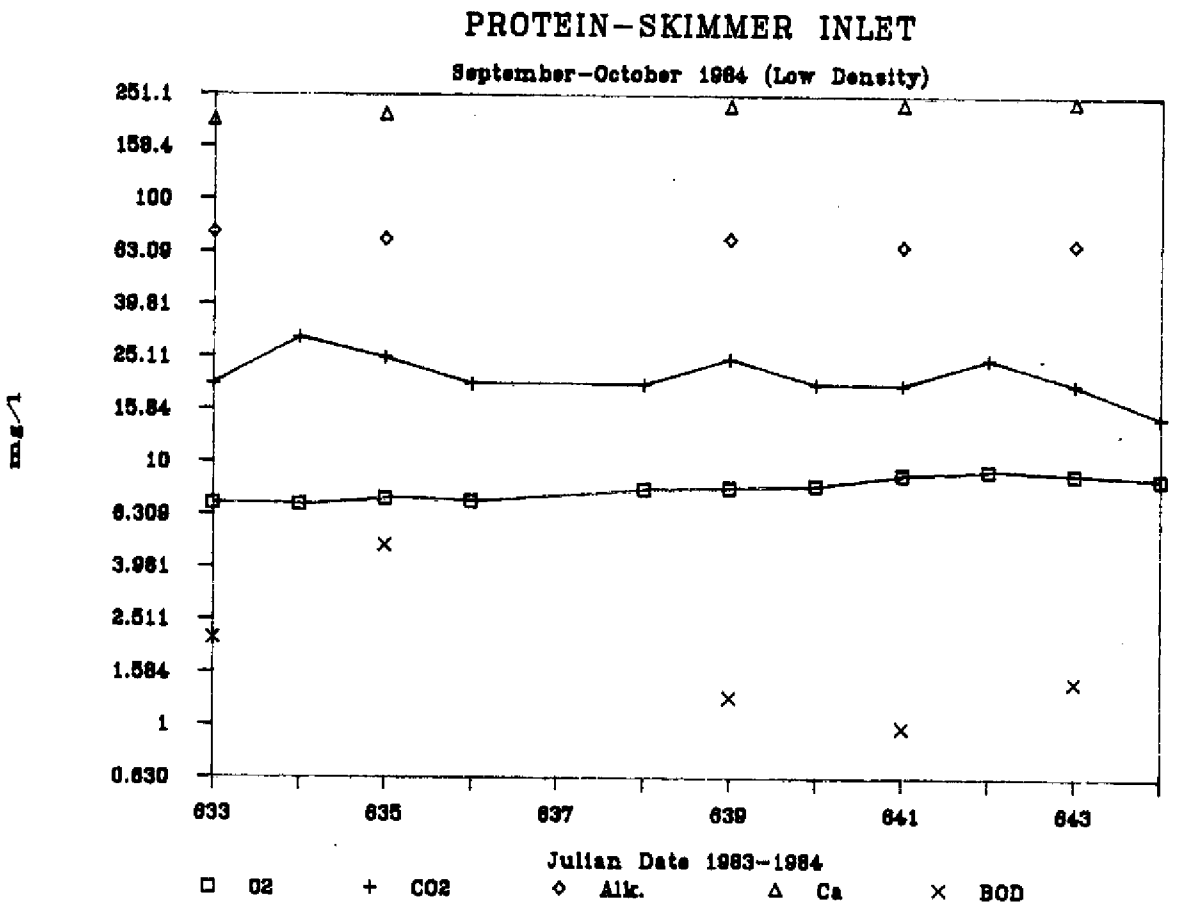

Figure 19. Mean inlet dissolved O_2, dissolved CO_2, alkalinity, calcium, and BOD levels for the protein skimmer stocked at low densities (September-October, 1984)

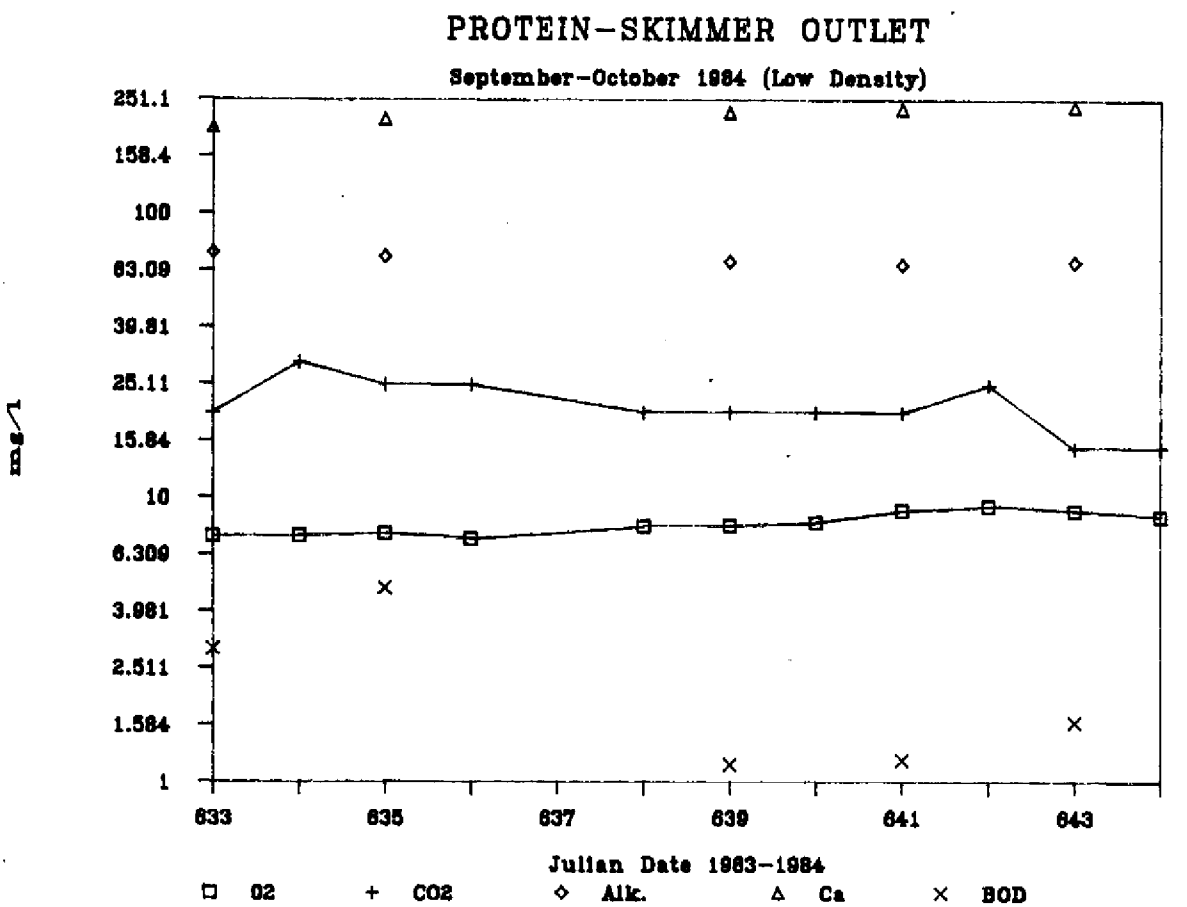

Figure 20. Mean outlet dissolved O_2, dissolved CO_2, alkalinity, calcium, and BOD levels for the protein skimmer stocked at low densities (September-October, 1984)

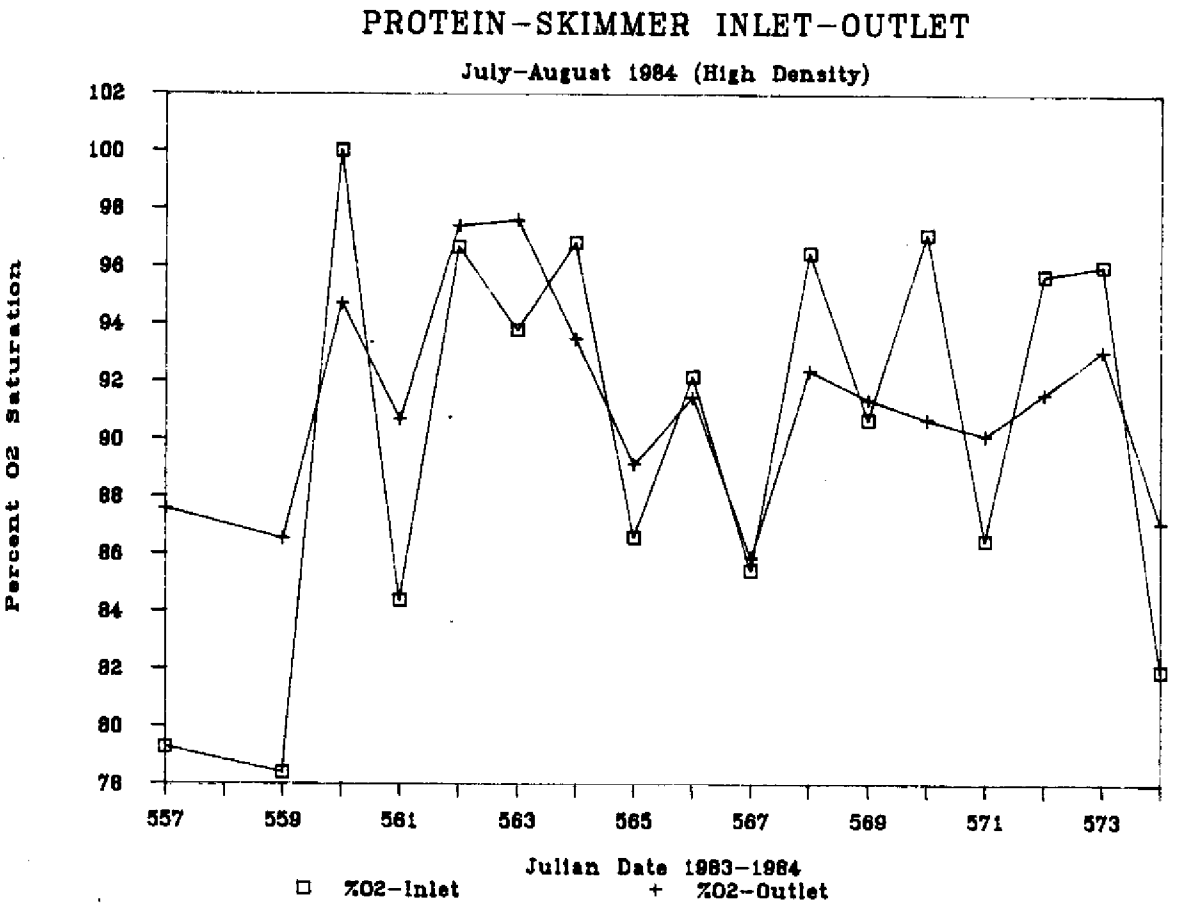

Figure 21. Mean inlet and outlet oxygen-saturation levels for the protein skimmer stocked at high densities (July-August, 1984)

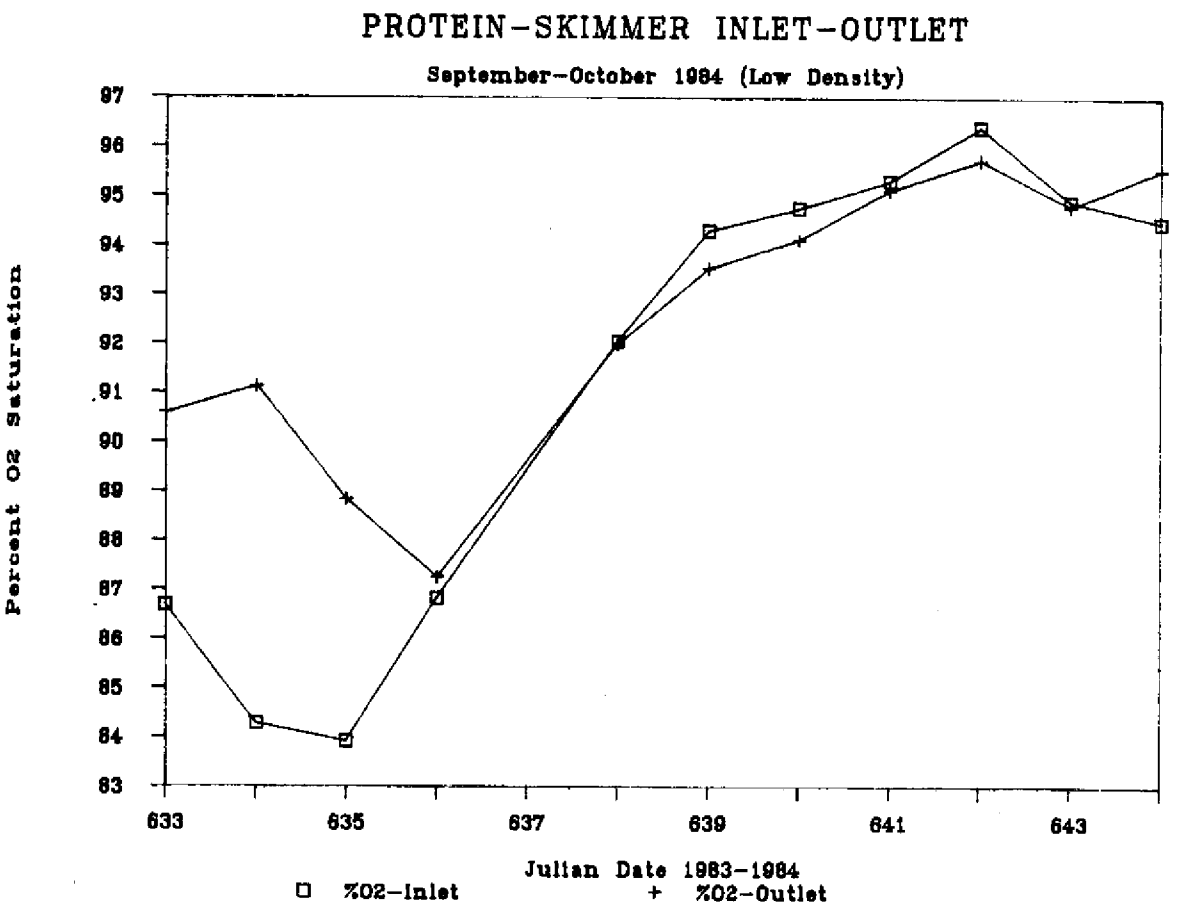

Figure 22. Mean inlet and outlet oxygen-saturation levels for the protein skimmer stocked at low densities (September-October, 1984)

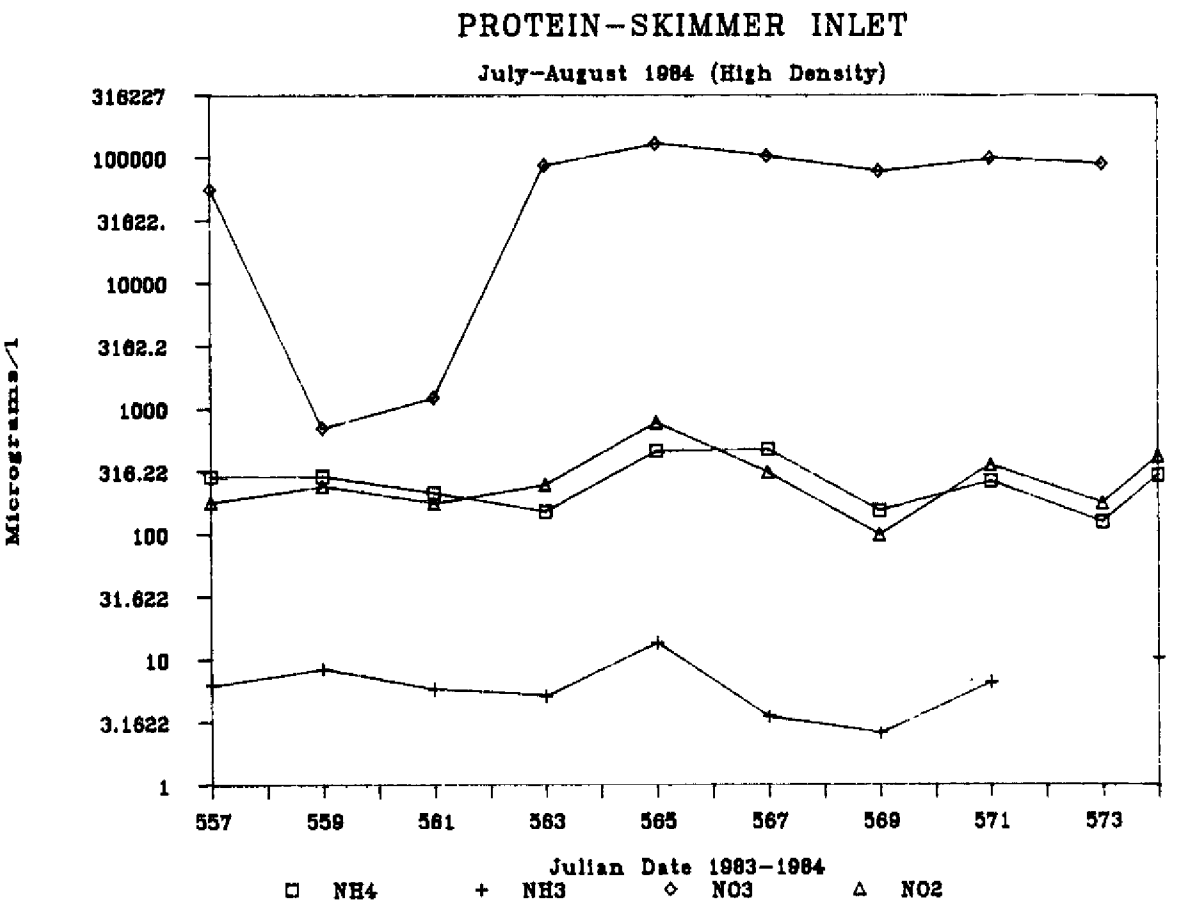

Figure 23. Mean inlet ammonium (NH_4), ammonia (NH_3), nitrate (NO_3), and nitrite (NO_2) levels for the protein skimmer stocked at high densities (July-August, 1984)

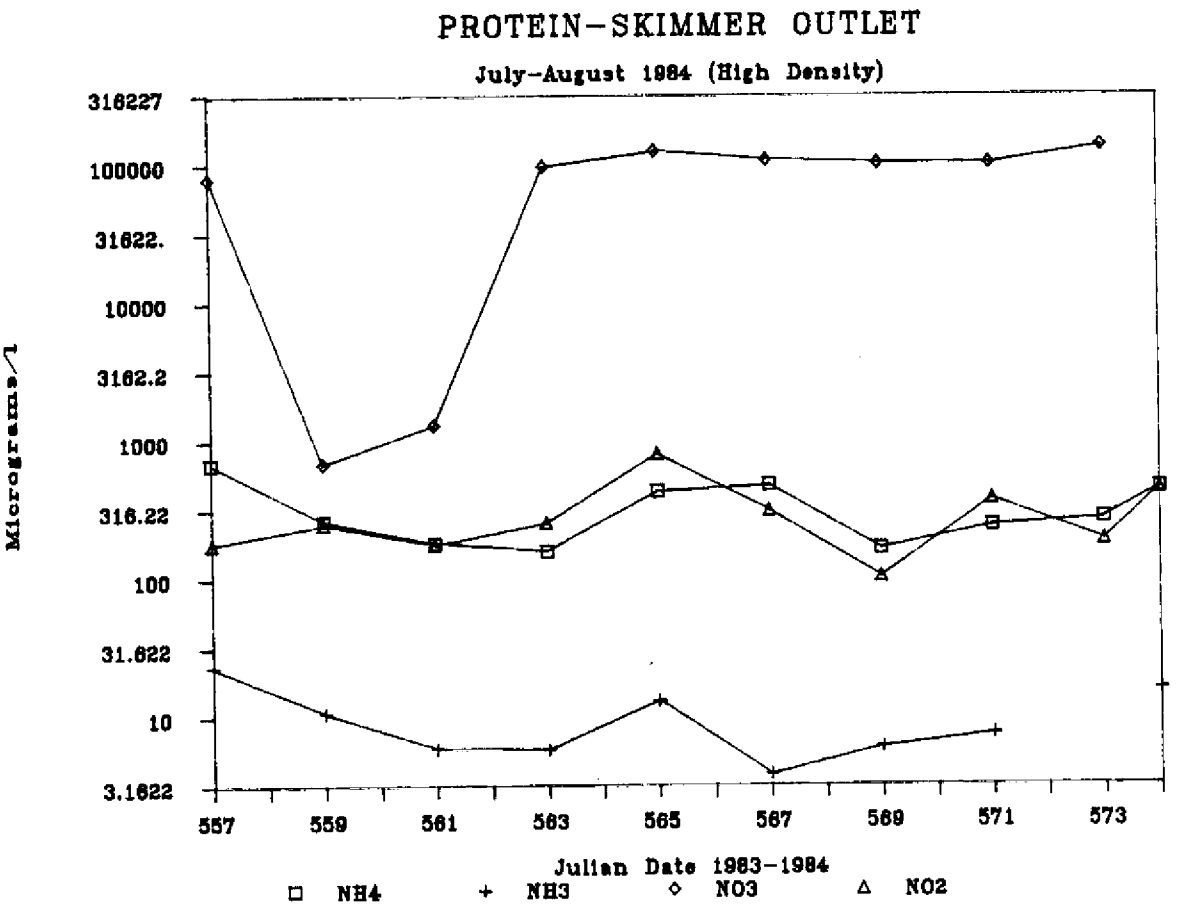

Figure 24. Mean outlet ammonium (NH_4), ammonia (NH_3), nitrate (NO_3), and nitrite (NO_2) levels for the protein skimmer stocked at high densities (July-August, 1984)

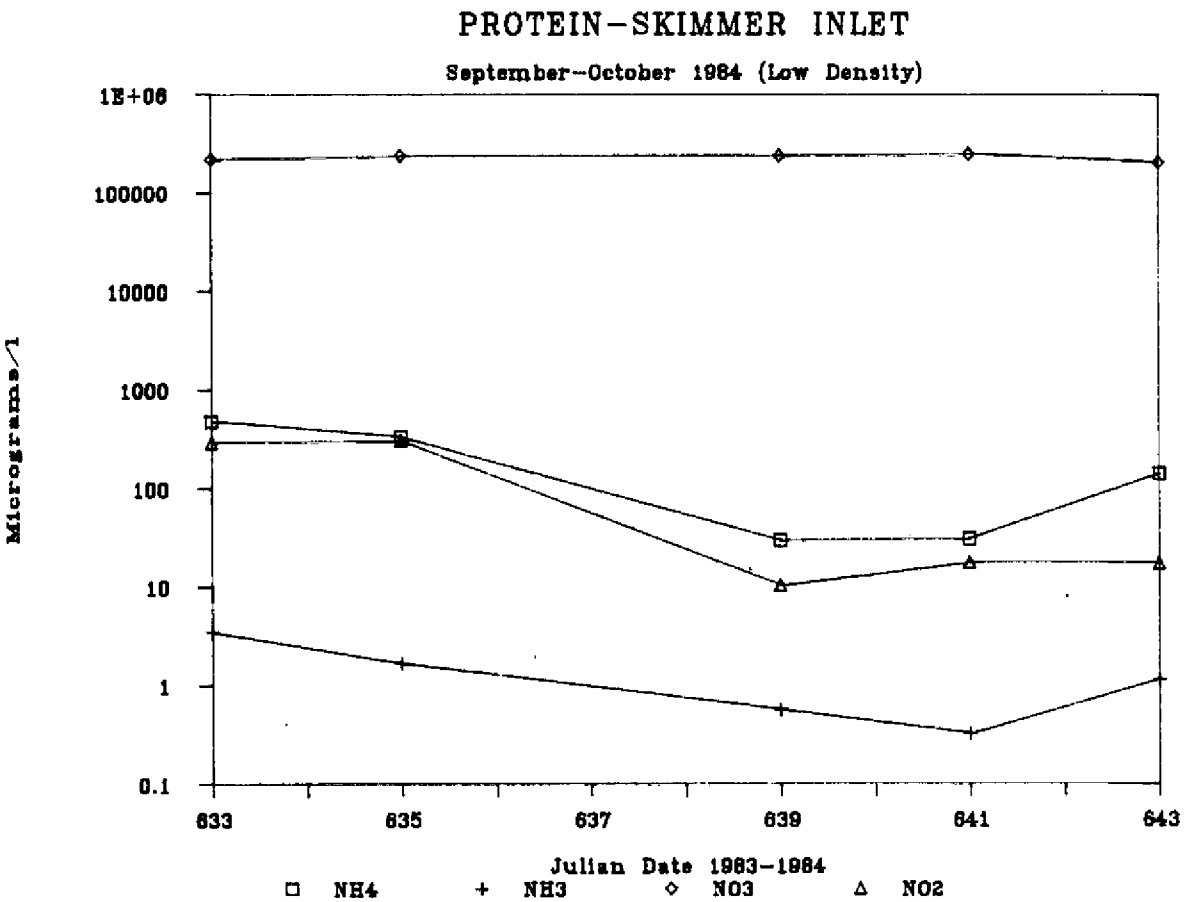

Figure 25. Mean inlet ammonium (NH_4), ammonia (NH_3), nitrate (NO_3), and nitrite (NO_2) levels for the protein skimmer stocked at low densities (September-October, 1984)

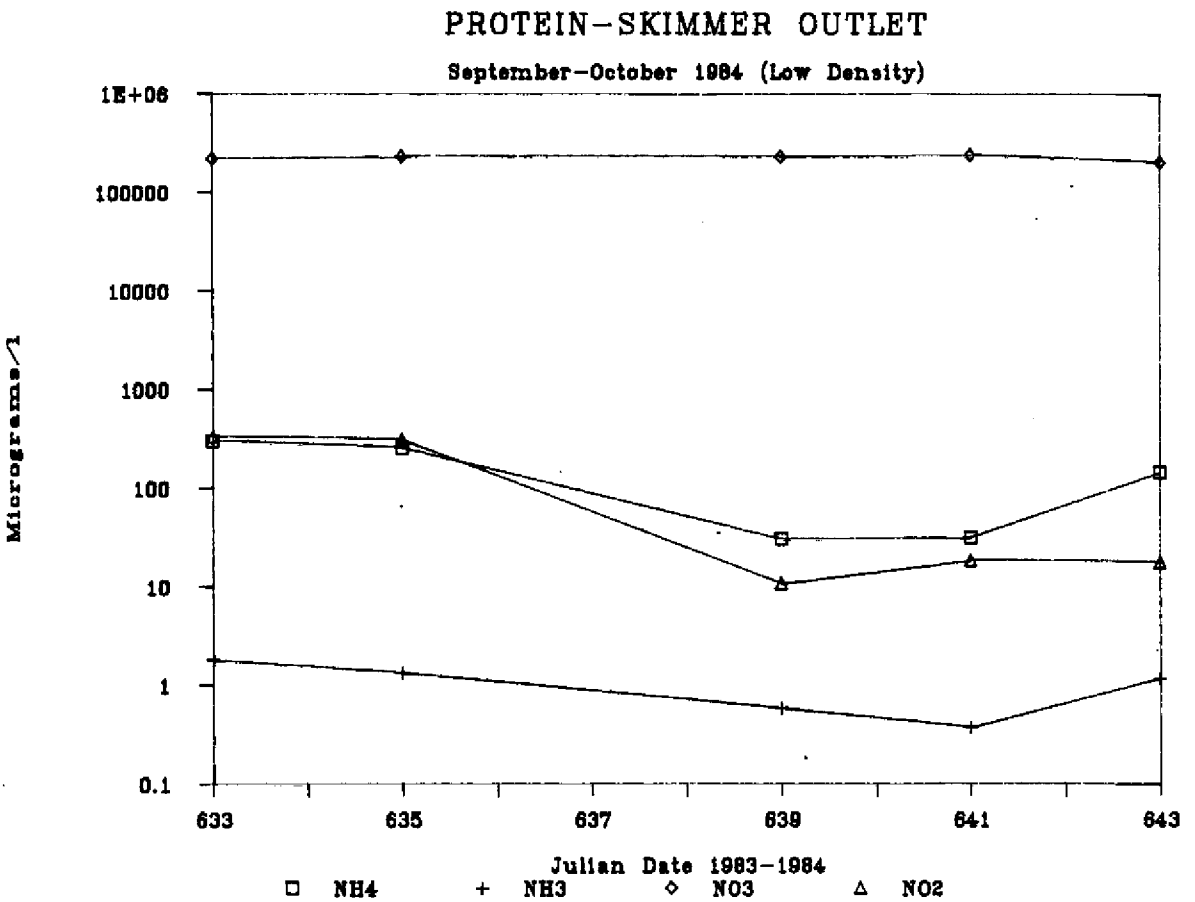

Figure 26. Mean outlet ammonium (NH_4), ammonia (NH_3), nitrate (NO_3), and nitrite (NO_2) levels for the protein skimmer stocked at low densities (September-October, 1984)

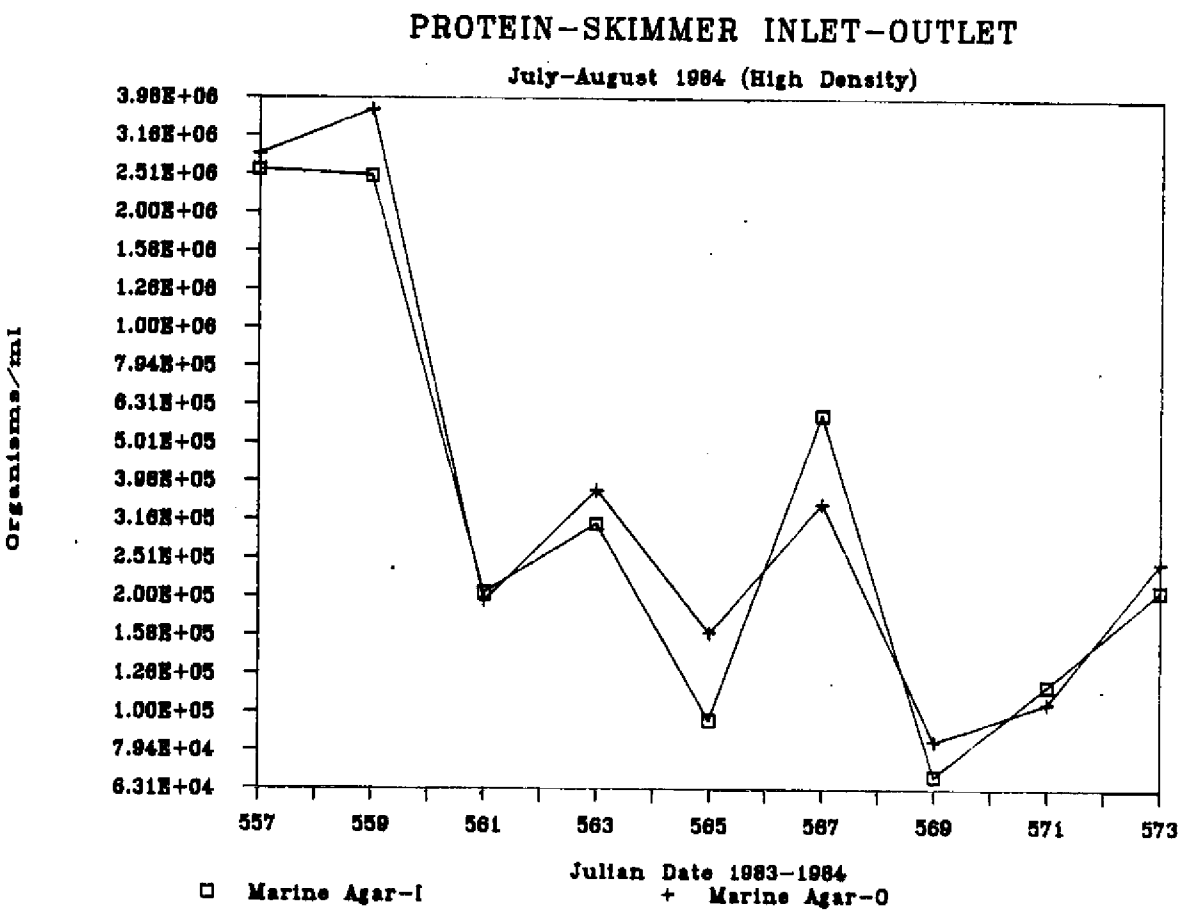

Figure 27. Mean inlet and outlet marine agar plate counts for the protein skimmer stocked at high densities (July-August, 1984)

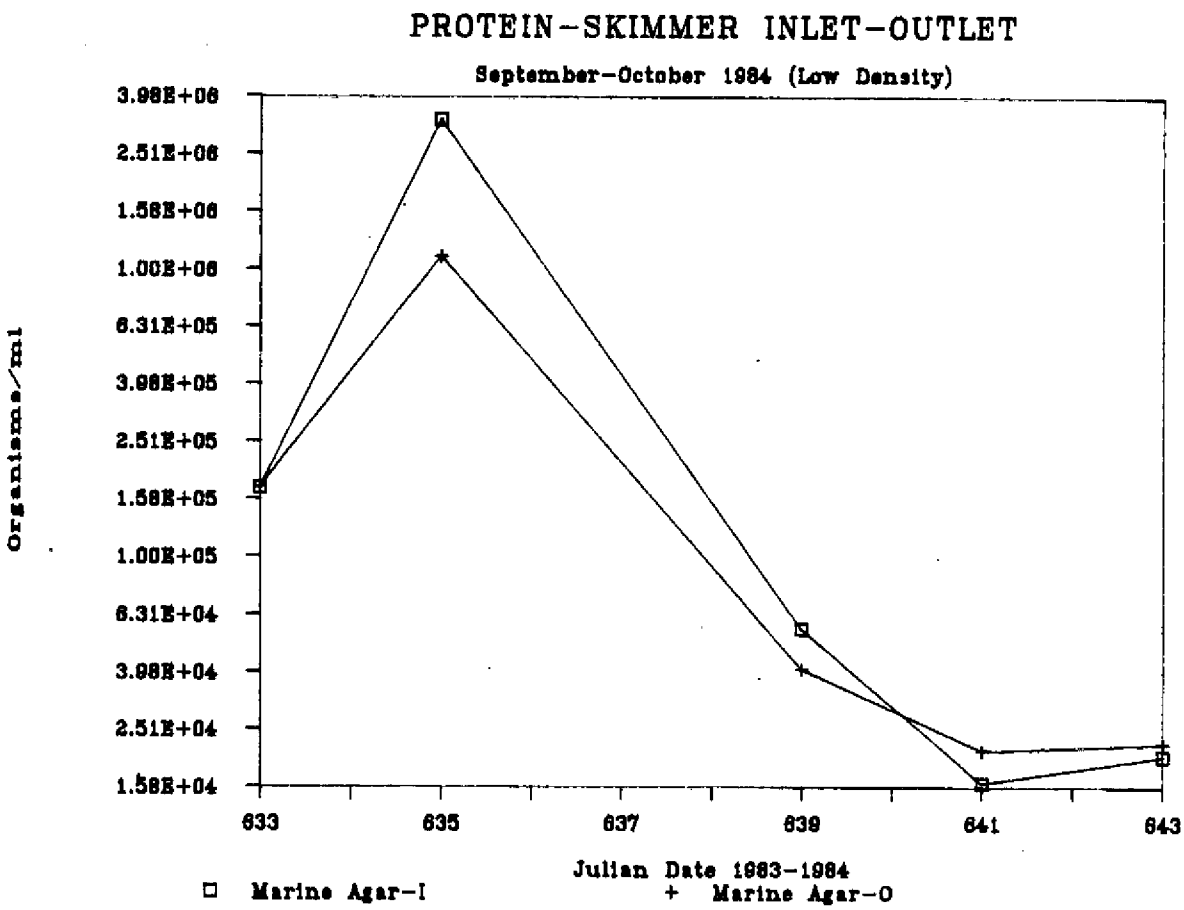

Figure 28. Mean inlet and outlet marine agar plate counts for the protein skimmer stocked at low densities (September-October, 1984)

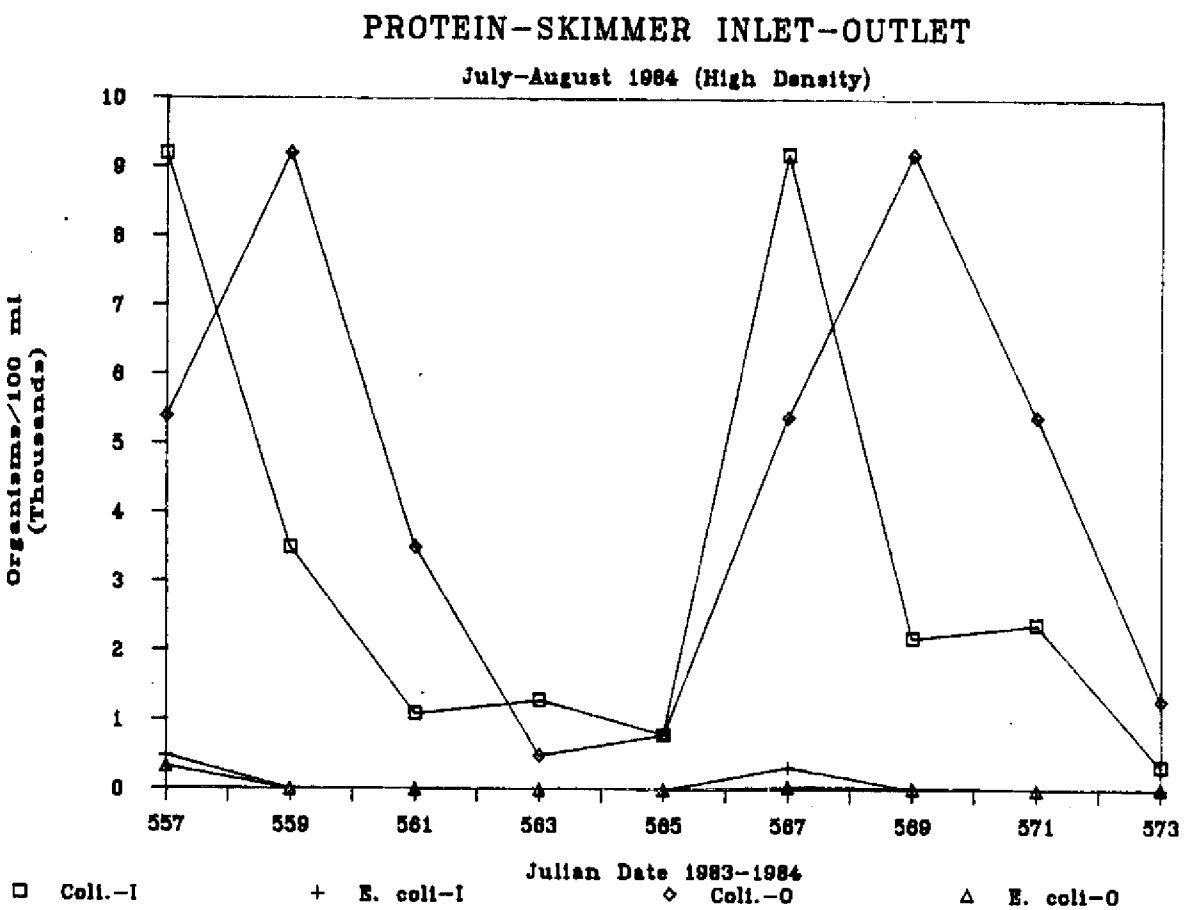

Figure 29. MPN total coliform and MPN E. coli inlet and outlet populations for the protein skimmer stocked at high densities (July-August, 1984)

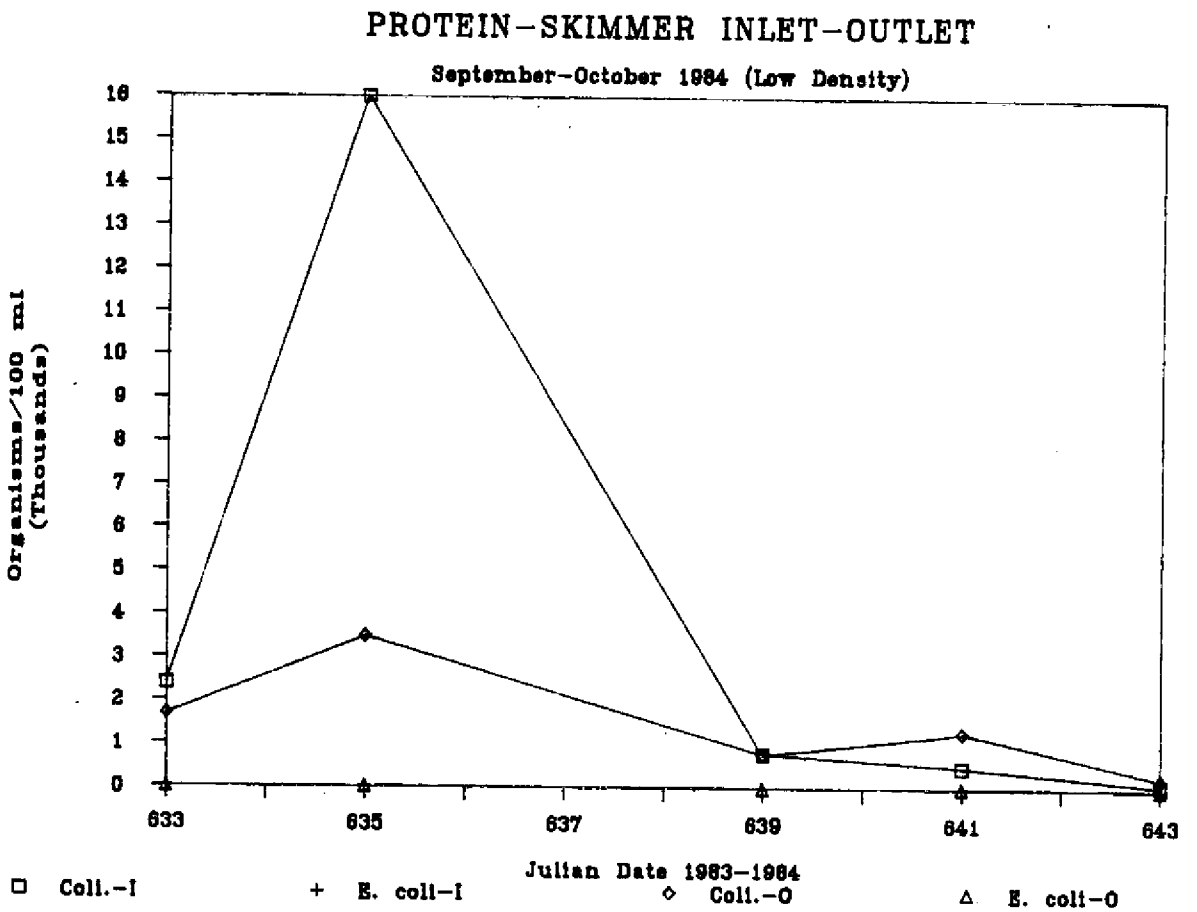

Figure 30. MPN total coliform and MPN E. coli inlet and outlet populations for the protein skimmer stocked at low densities (September-October, 1984)

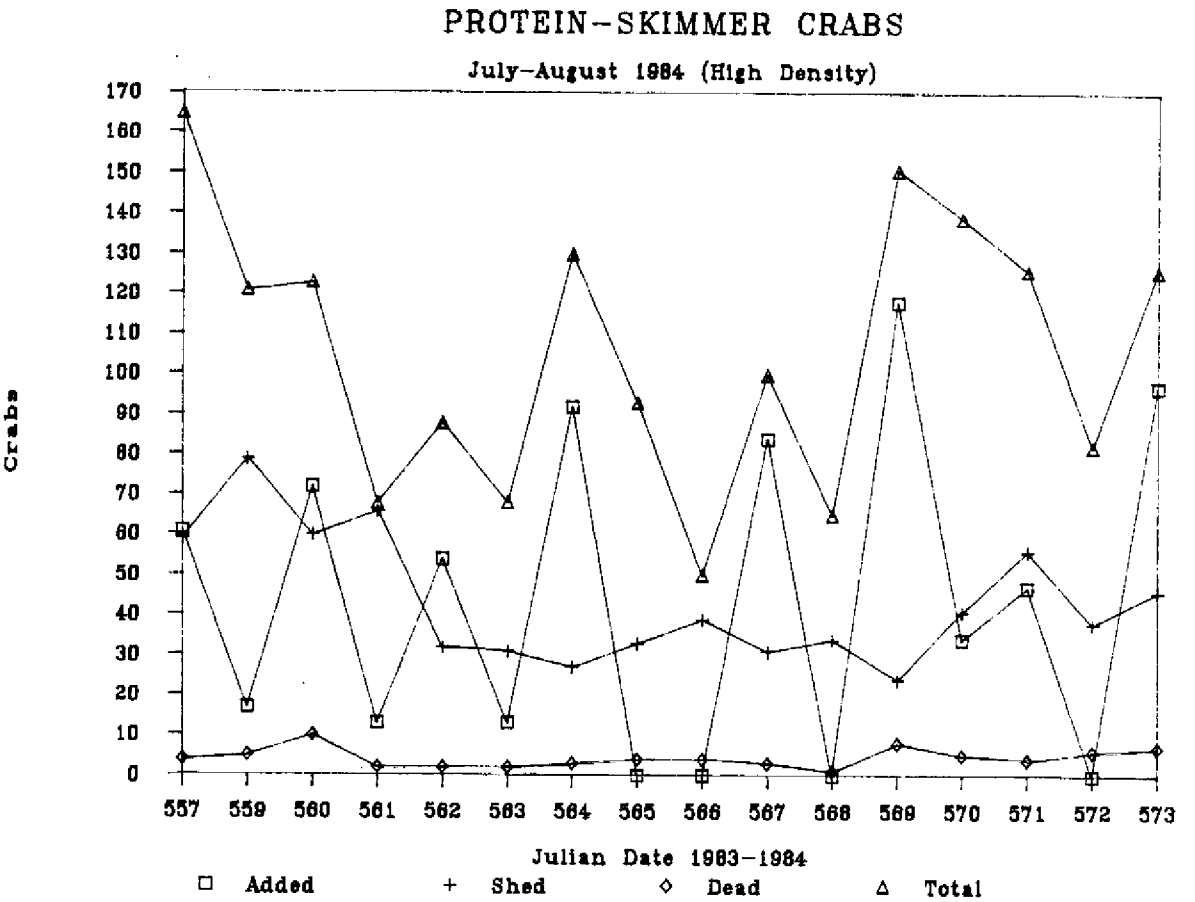

Figure 31. Total crabs, total crabs added, total crabs shed, and total dead crabs for the protein skimmer stocked at high densities (July-August, 1984)

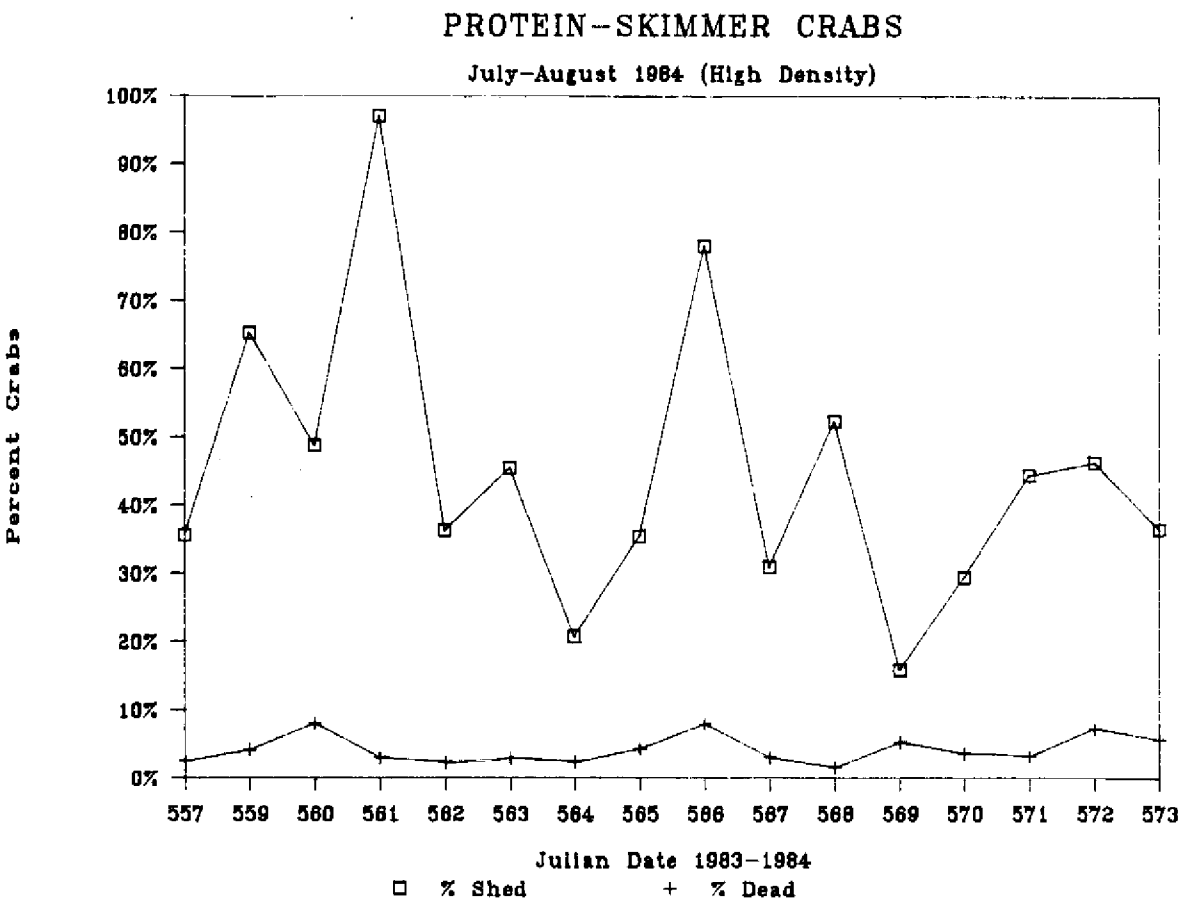

Figure 32. Percent crabs shed and crab mortality for the protein skimmer stocked at high densities (July-August, 1984)

TABLES

PARAMETER	TOTAL CRABS IN SYSTEM	CRABS ADDED TO SYSTEM	CRABS SHED IN SYSTEM	DEAD CRABS IN SYSTEM
pH	-0.12904	-0.56517	0.39741	0.10666
Temperature	0.11087	-0.21601	0.31999	0.57113
Salinity	-0.31582	0.14335	-0.74350*	0.01407
Dissolved Oxygen	-0.34044	0.18158	-0.45876	0.35894
Dissolved Carbon Dioxide	0.75709*	0.28657	0.27222	0.50144
Alkalinity	0.17417	-0.50389	0.69399	-0.30473
Calcium	0.00933	0.58488	-0.57670	0.20385
BOD	0.17815	-0.17718	-0.01302	-0.50861
% O_2 Saturation	-0.28728	0.15169	-0.41453	0.46299

* Significant at the 0.05 level

Table 1. Pearson correlation coefficients comparing crab population variables with physical and chemical water quality parameters for the protein-skimmer system stocked at high densities, days 557-574

PARAMETER	TOTAL CRABS IN SYSTEM	CRABS ADDED TO SYSTEM	CRABS SHED IN SYSTEM	DEAD CRABS IN SYSTEM
Ammonium (NH_4)	-0.09128	-0.21898	-0.09264	-0.26643
Ammonia (NH_3)	-0.13563	-0.68851	0.22128	-0.09309
Nitrate (NO_3)	-0.07879	0.26317	-0.77176*	0.04501
Nitrite (NO_2)	-0.32347	-0.49071	-0.21245	-0.23364
Marine Agar Plate Counts	0.60826	-0.05841	0.57525	-0.05280
MPN Coliforms	0.44623	0.29331	0.05411	-0.14074
MPN *E. coli*	0.45725	0.27240	0.01495	-0.15551

* Significant at the 0.05 level

Table 2. Pearson correlation coefficients comparing crab population variables with nitrogen and microbiological quality parameters for the protein-skimmer system stocked at high densities, days 557-574

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