THE FOOD AND FEEDING HABITS OF THE WHITE INDIAN PRAWN, PENAEUS (FENNEROPENAEUS) INDICUS H. MILNE EDWARDS, 1837

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DAVID CAMERON ORR, H.B.Sc.

THE FOOD AND FEEDING HABITS OF THE WHITE INDIAN PRAWN, PENAEUS (FENNEROPENAEUS) INDICUS H. MILNE EDWARDS, 1837

BY

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A thesis submitted to the School of Graduate
Studies in partial fulfillment of the
requirements for the degree of
Master of Science

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ISBN 0-315-68277-9

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Abstract

There is disagreement within the literature as to whether Penaeus indicus feeds selectively. Few studies deal with the dietary importance of the various items that this prawn ingests. A comprehensive study of the potential food items was made then electivity indices and indices of relative importance were estimated. The indices indicate that P. indicus become more carnivorous as they grow and that members of the family Nereidae (Polychaeta) and Mesopodopsis orientalis (Crustacea: Mysidacea) were selected. In terms of ingested volume and frequency of occurrence, detritus was the most important food item. Examination of faecal pellets indicated that diatom frustules, long strands of Oscillatoria spp., woody plant tissue and harpacticoid copepod exoskeletons were difficult to digest. Plant matter and micro-crustaceans may therefore be of limited nutritional value to P. indicus.

Acknowledgements

I wish to thank the staff of the Kenyan Department of Fisheries and the Food and Agriculture Organization for allowing me to conduct this study at the Ngomeni Lagoon Aquaculture Station; Dr. P. Polk of the Belgium-Kenyan Co-operative Project for providing helpful suggestions and encouragement; and the staff of the Kenyan Marine Fisheries Research Institute in Mombasa, Kenya, for allowing me to use a laboratory and equipment. The Biology Department of the University of Nairobi granted me external student status, making it possible to conduct research in Kenya. I am indebted to Mrs. Mwangi of the Office of the President of Kenya, for assisting in the procurement of various research clearances. This project was funded by a Canadian International Development Agency Scholarship.

I would like to thank my supervisory committee, Drs. D.H. Steele, V.J. Steele, G. Gardner and A. Whittick. Their suggestions and encouragement were invaluable.

I would not have been able to complete this project without the moral support of my parents and my wife. Their patience and understanding were very much appreciated.

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1.0 Introduction

The white Indian prawn (Penaeus (Fenneropenaeus) indicus H. Milne Edwards, 1837) is an economically important species of the Indo-Pacific Region (George 1962, George et al. 1968, Jones 1969, Mohamed 1970, Manisseri and Manimaran 1981). Its range extends from South Africa (Day and Morgan 1956, Emmerson and Andrews 1981) along the east coast of Africa (Brusher 1972), including Madagascar (Crosnier 1965, Hughes 1966, Le Reste 1978) and the Red Sea (Branford 1981), to India (Mohamed 1970). P. indicus has been noted as far east as the waters off the coasts of Malaysia (Hall 1962), southern China, the Philippines (Holthius 1980) and northern Australia (Grey 1982). At Cochin, India, the 1957-1963 catches of P. indicus averaged 116 metric tonnes annually (George et al. 1968). Even though this represented less than fifty percent of the prawn landings, P. indicus brought the highest profits because of its large size. During 1978, approximately 341 metric tonnes of P. indicus were landed at Tamil Nadu (Manisseri and Manimaran 1981). It is the second most important prawn species in the ricefield cultures of the Kerala coast of south western India (Holthuis 1980).

Due to an increasing domestic and international demand for prawns there is a need to improve resource management and prawn culture methods, as well as methods used in locating concentrations of large prawns (George 1962, Jones 1969, George 1975, Chandra et al. 1976, Das et al. 1982, Devi 1986). It is important to understand the interactions of this animal with the environment if the resource is to be maintained on a sustainable yield basis. This study investigates the food and feeding habits of P. indicus.

To understand the breadth of the food resource it is essential to understand food selection, ingestion and digestion (Taghorn 1986). There is some disagreement as to whether P. indicus feeds selectively. As a result of finding a variety of plant and animal material, as well as detritus within the proventriculi of P. indicus, Gopalakrishnan (1952) described the species as opportunistically omnivorous. Later, Hall (1962) and George (1970) compared the stomach contents of various prawn species from pond cultures and concluded that P. indicus selects large crustaceans. Hill and Wassenberg (1987) noted that further research is necessary to determine the degree to which prawns exhibit food selectivity.

To assess selectivity, one must compare the number of potential food items with the number of ingested food items. If potential food items are rare but are often chosen by the animal being studied, those items are said to be selected.

A preferred item may nevertheless form a negligible part of the diet, if only small volumes, or low numbers, of that item are ingested. Das et al. (1982) estimated the percent by volume of items ingested by P. indicus. In descending order, the items were: diatoms, plant parts and crustacean parts. This list may have been biased if a few prawns ingested a large quantity of any of these items. Thomas (1973), Wassenberg and Hill (1987) and Robertson (1988) combined percent volumes and percent frequency of occurrence into unbiased indices of relative importance; however, they studied congeners of P. indicus. Their indices provide important information about what was ingested, but they do not provide knowledge concerning digestion or assimilation.

The digestive enzymes of prawns can break down several types of carbohydrate and protein (Green 1961, New 1976, Karunakaran and Dhage 1977, Lee et al. 1980). Many of these enzymes are secreted by the hepatopancreas and released into the anterior chamber of the proventriculus. Hood and Meyers (1973) isolated microbial species that produce extracellular proteolytic, amylolytic, lipolytic and chitinolytic enzymes within the digestive tract of P. setiferous. Lee et al. (1980) showed equal activity levels of proteases and amylases, suggesting that prawns are omnivorous. However, they concluded that the extent of digestion and assimilation is determined by the amount of time that food remains within the area of enzyme secretion.

Penaeid prawns typically exhibit rapid digestion. The anterior chamber of the foregut may be cleared of up to 53% of all contents within the first hour after feeding (Dall 1968, Marte 1980). Particles small enough to pass through the setose filter press may be digested within the hepatopancreas or pass directly into the midgut. Nutrients are absorbed by epithelial cells that line the midgut, and by vacuoles that line tubules within the hepatopancreas (Green 1961). Defaecation occurs shortly after feeding begins and usually peaks 4-6hrs after feeding ends (Dall 1968). Animals that exhibit such high rates of food passage are unlikely to digest a wide variety of ingested items completely.

Immunological (Hunter and Feller 1987), C^{14} (Adams and Angelovic 1970, and Moriarty 1976) and mass spectrophotometric (Harrigan 1986) methods have shown that particulate organic matter, microfauna and meiofauna are assimilated with varying efficiencies. Moriarty (1976) demonstrated that blue green algae could be digested by

Metapenaeus bennettae; however, the assimilation efficiencies for algae were lower and were more variable than for bacteria. Adams and Angelovic (1970) showed that Palaemonetes pugio could digest and assimilate bacteria and detritus but not eel grass (Zostera marina).

Despite several studies addressing the problem of food and feeding habits among penaeid prawns, there is no clear evidence that P. indicus feeds selectively. Few studies have compared potential food items with ingested items. Those that discuss relative proportions of ingested food make use of indices that may be biased, or deal with other species of Penaeus. Attempts have been made to determine which foods the congeners are able to assimilate; however, few attempts have been made to determine which foods may be digested by P. indicus.

In this study, I compare the quantities of zooplankton, macrobenthos and meiobenthos in Penaeus indicus diets with their availabilities in the prawn habitat. Previous observations of prey selection and capture are both confirmed and elaborated by aquarium and field observations. The study estimates the availability of zooplankton, macrobenthos and meiobenthos. I then determine whether Penaeus indicus feeds selectively upon these items. Percent volume and percent frequency of occurrence of major components of the diet, are estimated. These estimates are then combined into an index of relative importance. Finally, the ease with which ingested items may be digested is determined.

Growth and morphometric comparisons are made between this study and data from the literature. These comparisons are made to assess the condition of the study animals.

2.0 Materials and Methods

2.1 The Study Site

The study was conducted at the Ngomeni Lagoon Aquaculture Station, Ngomeni, Kenya (Fig 2.1). The station is located in a man-made clearing within a mangrove swamp on Ngomeni Peninsula (Kenya). It is bordered to the north by a creek and to the west by a creek and Fundisa Bay. The swamp was dominated by the following mangrove species: Rhizophora mucronata, Bruguiera gymnorrhiza, Ceriops tagal and Avicenia marina. The facility is managed by staff of the Food and Agriculture Organization (FAO) of the United Nations and the Kenya Department of Fisheries.

The facility comprises ten ponds of varying sizes and shapes (Fig 2.2) with varied stocking and harvesting schedules. Some ponds received nutrient enrichments while others did not. Some ponds were treated with lime prior to being stocked. Any attempts at comparing the results from different ponds would have been confounded by the varied treatments; therefore, a single pond was used in the study. Pond 9 was chosen as it was the first to be stocked after the research clearance was granted. Appendix A summarizes the edaphic data for this pond.

Between March 26 (day 0) and April 3 (day 9), 1986, the staff of the Kenyan Department of Fisheries stocked pond 9 with approximately 77,000 prawns. This gave a stocking

Figure 2.1 The location of the Ngomeni Lagoon Aquaculture Station.

LEGEND

- aquaculture station A
- dry weather road
- indefinite water course
- mangrove swamp
- thicket
- scrub
- sand or mud
- rock outcrop

Figure 2.2 A sketch map of the Ngomeni Lagoon Aquaculture Station.

River to Fundisa Bay
River to Fundisa Bay
P11
P9
P8
P7
NP
P5
P6
P1
P2
P3
P4
LEGEND
dry weather road
pond designation P1
nursery pond NP
berm
gate
mangrove swamp
sand or mud
N
Ngomeni
Malindi

density of 4.5 prawns/m^2. Penaeus indicus, P. monodon and P. semisulcatus were the numerically and economically important prawns. Incidental species included members of the families Palaemonidae and Alpheidae.

2.1 Qualitative Observations of Feeding Behaviour

A glass aquarium (60cm X 30cm X 45cm) was constructed for the laboratory observations. On April 4 (day 10), ten P. indicus were seine netted from the pond. A shovel was used to skim enough mud from the pond to provide the aquarium with a substrate that was a few centimeters deep. Twenty litres of pond water were also collected. The water and substrate were added to the aquarium and once the water cleared, the prawns were put into the aquarium. A Hartz Mountain electrical air pump, with a capacity of 1,300cc/min, was used to aerate the water.

The prawns were observed daily between 1000 and 1400hrs, for a one week period. The observations were qualitative because the water became very turbid as soon as the prawns were introduced into the aquarium. The water remained turbid throughout the duration of this portion of the study. The prawns were continually swimming into and out of view; therefore, it was impossible to time their activities. This procedure was repeated two more times, with new prawns, water and sediment.

Qualitative in situ observations were conducted once a week between April 17 (day 22) and May 8 (day 44). The observations were carried out, between 1400 and 1600hrs, by lying on an air mattress and viewing the prawns through a diving mask. The qualitative observations provided

information that was necessary before quantitative sampling strategies could developed.

2.2 Benthic Collections and Analyses

A divider incompletely split the pond thereby affecting the movement of water, the prawns, and their potential food items. Beyond the western tip of the barrier, the bottom sloped more gently toward the shore than it did at any other part of the pond (Fig A-1.1). Thus the pond appeared to be divided into three distinct areas (Fig 2.3).

At least once a month, between March 26 and June 10, triply replicated benthic samples were taken from five sites, with a 5cm diameter corer. The benthic sampling sites were chosen from a grid map of the pond (Fig 2.4) using stratified random techniques. Since areas one and three were larger than area two, two sites were chosen from the former areas and one was chosen from the latter. Only the top 1cm of the core was sampled since the laboratory and in situ observations indicated that only the top 1cm of mud was being utilized by the prawns. The core samples were stored in pond water, in a dark bag, at 5°C. They were processed within 48hrs of being sampled.

A pipette was drawn across the settled sample and 1ml of sample was removed. The subsample was poured into a Sedgewick-Rafter Counting Cell and viewed at 100X (modified from Hulings and Gray 1971). All organisms were identified to class wherever possible and all except filamentous algae were counted. Relative abundances of filamentous algae were

Figure 2.3 The three distinct areas within pond 9.

Section 1
.64ha
Section 2
.25ha
Section 3
.82ha
N
0
40m

Figure 2.4 The grid map used to choose random benthic sampling sites in pond 9.

1 2 3 4 5 6
7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
22 23 24 25 26 27 28 29 30 31 32 33 34 35 36
37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52
53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68
69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84
N
0 10 20 30 40 m

noted.

Occasionally the corer landed on a stick. When this happened the stick was put in a jar with pond water and was kept as a sample. An additional substrate sample was then taken at the site.

The stick samples were stored under the same conditions as core samples. Three subsamples were pipetted from along the stick while it was immersed in pond water. The subsamples were then processed as described above.

After June 10, the sampling design was modified to minimize disturbances of the substrate. It was suspected that aerating the anaerobic layers reduces pH conditions (Appendix A). Sampling followed a stratified random design; however, it was restricted to areas that could be reached from shore and eight areas that were cleared for prawn collections. The grids along the shoreline as well as grids 20, 23, 31, 32, 35, 38, 55, 60, 61, and 63 were accessible. The prawn collection sites are described under section 2.4.

On December 11, five random grids were chosen. Three grids were along the shoreline and two were in deep water. Triply replicated cores were taken from each site. The samples were processed as indicated above. A Mann-Whitney U test was conducted for each major taxon to determine whether their rank sums of abundance differed significantly between deep and shallow sites.

Due to transportation and sample storage problems, it was impossible to process all of the samples that were collected. Therefore, the data included as Appendix B do not

indicate that 15 samples were collected on each sampling date.

The aggregation of each major taxon was assessed by the slope within the logarithmically transformed Taylor Power equation. The Taylor Power Law states that the variance of a population is proportional to a fractional power of the arithmetic mean:

$$\sigma^2 = au^b, \text{ therefore, } \log \sigma^2 = \log a + b \log u.$$

where: a = a constant that is dependent upon the size of the sampling unit; and

b = an index of dispersion.

The index of dispersion varies from 0 for a uniform distribution to for a highly contiguous distribution. If the distribution is random, a=b=1 (Elliot 1971).

2.4 Drift Collection and Analysis

Abundances of drift were estimated through the use of a net that was set at the time of full moon spring tides during March, May, July, August, September and December. The net was made of 100um mesh, had a 25cm diameter opening and was set outside the gate that led to Pond 9. It was set at the water's surface during the daytime and the night time, as well as during water inflow and outflow.

The sampling duration was controlled by the period during which the gate was open and by whether the net was becoming filled with debris. Every fifteen minutes the cod end of the net was squeezed to determine the degree of fullness. When the cod end was full, the debris was removed, the sample bottle was emptied and sampling began again.

Samples were stored in 5% formalin in seawater. The fauna were identified to at least Class and individuals of each taxon were counted. Abundance estimates per $1000m^3$ were made for each taxon.

A flow meter was not available and the rate of water flow through the net was estimated by determining the speed at which a stick (30cm X 0.8cm X 0.8cm) moved on the surface of the water. The volume of water that flowed through the net was determined by the following equations:

$$a = \pi r^2 L / b$$

$$c_n = 300a$$

$$d = c_1 + c_2 + c_3 + \ldots\ldots\ldots + c_n$$

where:

- a = the amount of water that flowed through the net per second;
- r = radius of the net opening;
- L = 3.7m which was the distance over which the stick moved;
- b = time in seconds that the stick took to travel 3.7m;
- c_n = volume of water that flowed through the net in 5 minutes; and
- d = the total volume of water that flowed through the net.

After four drift net sessions (each 1 hr or less), the capture efficiency of the net was determined by collecting 100 L of water as it flowed over slats that were left in the gate, into or out of the pond. This 100 L sample was poured through the net. The animals collected in each 100 L sample were counted and the result was expressed as the total number of animals per $1000m^3$. This number was then divided by the total number of animals per $1000m^3$ as estimated from the

drift net sample. The quotient was an estimate of capture efficiency; the mean of all such quotients was used to correct the abundance estimates. The mean efficiency was 0.52 (s.d.= 0.35). This estimate was later corroborated by freshwater studies that C. Campbell (pers. comm.) conducted in Newfoundland. She made use of a similar net, but a different methodology, when she estimated an efficiency of 0.50.

The abundances of numerically important animals that entered the pond and those that left the pond were compared using Mann-Whitney U tests. Mann-Whitney U tests were also conducted to determine whether the rank sums of the abundances of major taxa differed significantly between day and night samples.

2.5 Proventriculi Collections and Analyses

The perimeter of the pond was divided into 12m lengths. Three lengths were chosen at random in each of areas one and three, while only two were chosen in area two (Fig 2.5). The area along each of these lengths and extending 6m into the pond was cleared of stakes and debris. Each of these areas was a site that was used when collecting prawns.

Each week between April 4 (day 9) and June 10 (day 77) a random numbers table was used to chose a sampling site. Prawns were seined from this site during the late afternoon and during the night (Table 2.1). Regardless of the time of day, the cumulative number of different items within the proventriculi did not usually increase after the first three proventriculi were processed. Consequently only five prawns

Figure 2.5 Prawn collection areas in pond 9.

1
2
3
4
5
6
7
8
0
10
20
30
40 m
N

Table 2.1 A summary of the times, dates and number of *P. indicus* that were collected from pond 9 for proventriculi analyses.

day	sampling time (hrs)	sampling method	sample size
8	0400	seine net	5
15	0030	seine net	5
21	2200	seine net	5
29	0150	seine net	5
35	2200	seine net	5
42	2245	seine net	5
49	1645	seine net	5
49	2200	seine net	5
64	1600	seine net	5
64	2300	seine net	5
77	1630	seine net	5
77	2342	seine net	5
93	1030	cast net	6
111	1000	cast net	5
126	1000	cast net	6
140	1100	cast net	6
177	1100	cast net	5
177	2000- 2100	trap net	9
182	1100- 1200	trap net	4
259	1825- 1925	trap net	7
260	0115- 0215	trap net	6
		total	114

were sampled during each session.

After June 10, the prawns were no longer seined because seining was suspected as a cause of low pH within the pond (Appendix A). Prawns were then collected by cast net, or by trap net. Cast net samples were taken as subsamples of FAO collections. The FAO collections were made during the late morning at the sites that were used for seine net collections. Prawns were removed from a single randomly chosen sampling site, on each sampling date (Table 2.1). A trap net was used during the night. The trap net was a rectangular box with a steel frame and had a nylon mesh (3mm stretched mesh) covering (Fig. 2.6). The trap net was always set in the deep water, near the gate. It was not baited and was set for one hour.

Once captured, the P. indicus were sexed, their carapace lengths were measured and their proventriculi were removed and preserved in 5% formalin in seawater.

In the laboratory, the proventriculi contents were spread on microscope slides to a uniform thickness (0.18mm ± 0.30mm) (Hellawell and Abel 1971). The images were enlarged using a microprojector and the fauna were identified and counted.

Figure 2.6 A scale drawing of the trap net.

side view

end view

Data obtained from proventriculi and drift net collections were used when determining Vanderploeg and Scavia (1979) electivity indices. The Vanderploeg and Scavia electivity index is defined as follows:

$$W_i = (r_i/p_i)/\Sigma(r_i/p_i) \text{ and}$$

$$E^*_i = [W_i-(1/n)]/[W_i+(1/n)]$$

where: W_i= the Vanderploeg and Scavia selectivity coefficient which corresponds to the probability that the ith item will be eaten;

r_i= the proportion of the ith item in the diet;

p_i= the proportion of the ith item in the environment;

E^*_i= the Vanderploeg and Scavia electivity index, and

n= number of kinds of potential food items.

The value of the index ranges from -1 to +1 where -1 indicates maximum avoidance, 0 indicates random selection and 1 indicates maximum selection (Vanderploeg and Scavia 1979).

The outlines of all images were traced onto paper and the area of each was estimated using a digitizer (s.e.=0.002mm^2). These data were then used in determining indices of preponderance (Natarajan and Jhingran 1962).

Indices of preponderance are defined as follows:

$$I_i = v_i o_i/\Sigma(v_i o_i)$$

where: I_i= index of preponderance for the ith item in diet;

v_i= percent volume of ith item in diet;

o_i= percentage of proventriculi that contain the ith item (modified from Natarajan and Jhingran 1962). In the original equations, the variable o_i

referred to the frequence of occurence of the ith item, however, it was modified because much of the ingested matter consisted of lab-lab which is material from the surface of the substrate and consists of detritus, meiofauna, microfauna and microflora.

Indices of preponderance between prawns of different size classes, caught by the same method, were compared by Spearman rank correlation tests. A series of runs tests indicated that the order of prawn capture was not affected by their size class ($P>0.05$). Indices of preponderance were used in conjunction with faecal pellet analyses when determining the relative importance of each category of ingested matter.

2.6 Faecal Pellet Collections and Analyses

Faecal pellets were collected and analyzed to determine which ingested items were being digested by *P. indicus*. Prior to this work, it was necessary to determine gut voidance times. On April 1 (day 6), 9 prawns were seined during the nighttime. Each prawn was placed into a 500ml beaker filled with pond water which had been filtered through 200um mesh. The floor of the beaker had a chicken wire platform which allowed the faecal pellets to fall to the bottom but made it difficult for prawns to reach the pellets. A screen covered each beaker. Three prawns were removed after 5hrs. Their proventriculi, midguts and hindguts were removed and stored in 5% formalin in seawater. This procedure was repeated after 6 and 7hrs. The samples were dissected and the percent fullness of each was determined. These data indicated that 6hrs was an appropriate amount of time to allow for gut voidance. This experiment was repeated

on May 1 (day 37) with similar results.

Between April 4 and June 10, faecal pellets were collected from 81 prawns (Table 2.2). Periodically, prawns were dissected after the 6hr period and the degree of voidance was determined. Gut fullness was never greater than 5%.

Permanent mounts of faecal pellets were made on microscope slides. The slides were scanned at 100X, and apparent differences between organisms collected in pond samples and those found in faecal pellets were recorded.

2.7 *Penaeus indicus* Growth and Morphometry

Once each week between April 4 (day 8) and June 10 (day 77), prawns were seined from all of the cleared areas. Seine-netting was along the shore and began at 2200hrs. The *P. indicus* were placed into a large bucket containing pond water and individuals were removed for measurement of carapace length (to ± 0.5mm), sexing and release.

Between March 26 and December 11, 121 *P. indicus* were collected by seine net, trap net or cast net and preserved in 5% formalin in seawater for between one and two weeks. Then their carapace lengths were measured and when possible they were sexed. They were dried at 60°C for 24hrs and allowed to cool for 1hr in a sealed desiccator with anhydrous calcium chloride. They were weighed to ± 0.01mg, and dry weight versus carapace length relationships were determined.

Table 2.2 Faecal pellet collection data, including the times at which white Indian prawns were placed in beakers, and the number of prawns that produced faecal pellets.

day	sample time (hrs)	sample size
8	0400	1
15	0030	4
21	2200	7
29	2030	10
35	2000	8
49	1545	9
49	2200	9
64	1600	9
64	2315	8
77	2342	6
	total	81

On December 11, the pond was harvested and the prawns were put into two large tubs of icewater. The contents of each tub were stirred. A large colander was used to remove three samples of prawns from each tub. The animals were identified and counted. White Indian prawns were separated from the other species and sexed, and carapace lengths were determined. The samples of P. indicus were weighed separately from all other species. The total weight of the harvest was determined. The following relationships were used in estimating the total number of P. indicus that survived the 260 day experiment:

$$e/f = g/h$$

where: e = the number of prawns in the sample;
f = the weight of all species in the sample;
g = the estimated number of all prawns that were harvested from pond 9;
h = the weight of all prawn that were harvested;

and $$i/e = j/g$$

where: i = the number of P. indicus in the sample; and
j = the estimated number of P. indicus that were in the harvest.

Male and female carapace lengths were compared using a series of Kruskal-Wallis one way analyses of variance tests. These analyses were conducted on data collected each week between March 26 (day 0) and June 10 (day 77), and on December 11 (day 260). The weekly length frequency histograms were plotted and the program NORMSEP (Tomlinson 1971) was used to separate the distributions into normally distributed components. If n prawn carapace lengths were measured from a mixture of k normally distributed age groups then NORMSEP used maximum likelihood functions and iterative methods to estimate the mean length and a standard deviation

for each age group, and a chi-square test for goodness of fit to a series of normal distributions. The mean value for each age group was used in developing uniform and von Bertalanffy growth models. The von Bertalanffy growth equation is as follows:

$$L_t = L\ (1-e^{-k(day-t_0)})$$

where: L_t = length at age t;

L = the asymptotic length for the prawn;

k = a growth coefficient;

day = growth period in days; and

t_0 = the time at which the length would theoretically have been zero units (Everhart and Youngs 1981).

Sex, carapace length, total length, fresh total weight, tail length and fresh tail weight data were collected from 146 P. indicus on December 11. Total length was measured from the tip of the rostrum to the tip of the telson. Animals were discarded if a piece of either the rostrum or the telson were damaged. The tail was removed from the cephalothorax by twisting and pulling the abdomen away from the cephalothorax. Tail length was measured from the leading edge of the tergum of the first abdominal segment, to the tip of the telson. The carapace lengths ranged between 9.5 and 25.5mm. The total lengths ranged between 58.5 and 122.0mm.

Weight and length relationships were developed to describe the morphometry of both nonsexable and sexable P. indicus. The slopes of linear relationships for non sexable and sexable animals were compared using a series of t-tests. The growth and morphometric models were then compared with models that are described in the primary literature.

All statistical tests were conducted using SPSS-X (SPSS

Inc. 1986).

3.0 Results

3.1 Prawn Feeding Behaviour

3.1.1 *In situ* and Laboratory Observations

Penaeus indicus were active throughout the daytime. While the prawns were on the bottom, they moved their chelate peraeopods rapidly over the substrate. Periodically these peraeopods would pick up particles and direct them toward the mouth. At these times, the maxillipeds beat rapidly and the proventriculi could be seen churning. Sticks, stones, clumps of algae and faecal pellets were often picked up, but were usually dropped when they touched the oral appendages. Sticks were occasionally torn apart by the mouthparts. At other times, sticks or stones were held by a pair of chelate peraeopods while other chela were closed upon and then drawn along them. Scraping was periodically interrupted and the chela moved to the mouthparts.

Similarly, prawns often scraped their antennae, eyes, carapaces and abdomens. They would stop scraping their bodies and would move their chela to their mouths, their proventriculi would churn, and then they would continue scraping.

Disabled prawns were eaten on only three occasions. On one occasion, a prawn was attacked after it fell to one side. The other animals were attacked while they were moulting. Usually, an aggressive prawn seized the disabled animal by the anterior portion of its thorax, held it and quickly swam

away. The pair was then chased by prawns of varying sizes until the dead one was dropped. Once an animal dropped the carrion, it no longer showed interest in the remains. The cycle of grabbing the carrion, feeding on it, being chased and then dropping the animal was repeated until the remains were completely eaten. In this way, four or five prawns fed upon the dead one.

Small prawns often ran toward concentrations of copepods that were scattered along the glass. However, the copepods were always able to avoid the prawns.

Penaeus indicus spent a great deal of time swimming. During slow swimming, the ischial segments of the first three peraeopods were held forward at 30° to their bodies while the distal segments were crossed and loosely folded backward. The fourth and fifth peraeopods were directed downward (Fig 3.1 a and b). They often swam through groups of copepods while holding their peraeopods in this manner. On at least one occasion, a prawn captured a copepod between its legs. The copepod fell to the bottom where it was eaten by another prawn.

3.2 Benthic Collections and Analyses

Benthic collection dates, sites and the quantities of benthos that were obtained from each site are summarized in Appendix B. This appendix indicates that thirteen categories of benthic organisms were identified during the study. Pennate and centric diatoms, Protista and Nematoda were the most abundant organisms (Figs 3.2 and 3.3). The benthic organisms were clumped (Table 3.1); however, their distribution patterns were not significantly ($P>0.05$)

Figure 3.1 a) Front view of a prawn swimming with its peraeopods held loosely. (3X)
b) Side view of a prawn swimming with its peraeopods held loosely. (3X)

Figure 3.1 a

Figure 3.1 b

Figure 3.2 Temporal variation in mean abundances of benthic flora per 100 ml of substrate. Note that the vertical axis is log scaled and that all raw values were incremented by 1 to accommodate zeroes in the data.

mean number of benthic flora (+1)/ 100 ml
100000
50000
10000
5000
1000
500
100
50
10
5
1
.5
-20
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
time in days
Legend
pennate diatoms
centric diatoms
colonial diatoms
dinoflagellate cysts

Figure 3.3 Temporal variation in mean abundances of benthic fauna per 100 ml of substrate. Note that the vertical axis is log scaled and that all raw values were incremented by 1 to accommodate zeroes in the data.

mean number of benthic fauna (+1)/ 100 ml
50000
10000
5000
1000
500
100
50
10
5
1
.5
-20
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
time in days
Legend
Protista
Nematoda
Harpacticoida
other

Table 3.1 The degree of aggregation among numerically important groups of benthic organisms. Ninety-five percent confidence limits of the slope within logarithmically transformed Taylor Power relationships ($\log\sigma^2 = \log a + b \times \log u$) were used as the index of aggregation. The means and variances were incremented by 1 to accommodate zeroes in the data.

Taxon	sample size	r	a	b(± S.E.)	t
pennate diatoms	9	0.97	0.38	1.93(±0.12)	16.10**
centric diatoms	9	0.93	0.13	1.97(±0.20)	10.01**
Protista	9	0.96	0.08	1.86(±0.14)	13.84**
colonial diatoms	9	1.00	0.00	1.54(±0.04)	41.43**
dinoflagellate cyst	9	0.45	0.12	1.39(±0.58)	2.38*
Nematoda	9	0.97	0.10	1.96(±0.16)	12.45**
Harpacticoida	9	0.96	-0.03	2.14(±0.17)	12.94**
nauplii	9	0.98	-0.02	2.58(±0.13)	20.42**

r = the correlation coefficient of the logarithmically transformed Taylor Power relationship;
a = a constant;
b = the regression coefficient within the logarithmically transformed relationship;
t = t-test score for the regression line;
* $0.01<P<0.05$; and
** $P<0.01$

affected by water depths (Table 3.2).

3.3 Drift Analyses

Appendix C summarizes drift net collection data. Copepoda, Mesopodopsis orientalis, brachyuran crab zoea, Polychaeta and various nauplii commonly occurred within the drift samples. Their rank sums of abundances were not significantly affected by whether water was flowing into or out of pond 9 (Table 3.3), or by time of day (Table 3.4). Figures 3.4 and 3.5 are time-series charts which indicate weighted mean abundances of the major drift taxa.

3.4 Proventriculi Analyses

Vanderploeg-Scavia relativized electivity indices were estimated for Mesopodopsis orientalis, Nereidae, Natantia and Penaeus sp. Indices from nighttime proventriculi suggest that Mesopodopsis orientalis and Nereidae were strongly selected for, while Penaeus sp. and other Natantia were usually avoided (Table 3.5). Polychaete jaws and acicular rods were the only recognizable animal parts that were found within the proventriculi of prawns that were collected during the morning.

Diets varied significantly depending upon the size class of the prawns (Tables 3.6 and 3.7). As prawns increased in size, the relative importance of lab-lab decreased while the relative importance of Crustacea increased.

Table 3.2 Comparison between rank-order sums of abundances of shoreline and non shoreline core samples collected on day 259 (n_1=6; n_2=10; P>0.05).

Taxon	U
pennate diatoms	0.978
centric diatoms	1.684
dinoflagellate cyst	1.789
Protista	0.957
Nematoda	0.218
Harpacticoida	1.291

U = Mann-Whitney U test score corrected for ties

Table 3.3 Rank sum comparisons between abundances of inflowing and outflowing drift animals. Polychaeta, M. orientalis, Brachyuran crab zoea, nauplii, Calanoida, Harpacticoida and Cyclopoida were included in the analyses.

day	inflow net #	outflow net #	U
0	1	2	0.0639
0 & 1	1	3	0.7028
59 & 59	4	5	0.8964
120	7	6	0.4655
120 & 121	7	8	0.4655
149	11	9	0.5117
149	11	10	0.4477
149	11	12	0.3194
176 & 179	15	13	0.1938
178 & 179	15	14	0.5775
179	15	16	0.9801 *
259	18	17	0.9626
259 & 260	18	19	0.5814

U = Mann-Whitney U test score corrected for ties
* $P<0.05$

Table 3.4 Comparisons between rank sums of numerically important drift animals collected during the day and those collected at night (P>0.05). Polychaeta, M. orientalis, Brachyuran crab zoea, nauplii, Calanoida, Harpacticoida, and Cyclopoida were included in the analyses.

day	daytime net #	nighttime net #	U
0 & 1	1	2	0.0639
1	3	2	0.4822
59 & 59	4	5	0.8964
120 & 121	6	8	0.1938
120 & 121	7	8	0.4655
149	9	12	1.0861
149	10	12	1.2152
149	11	12	0.3194
176 & 179	16	13	0.5565
178 & 179	16	14	1.5504
178 & 179	16	15	0.9801
259	17	18	0.9626
259 & 260	17	19	0.5775

U = Mann-Whitney U test score corrected for ties

Figure 3.4 Time related changes in weighted mean abundances of Copepoda per $1000m^3$ of pond 9 water. Weighting was by volume of water that passed through each net. Note that the vertical axis is log scaled and that abundances were incremented by 1 to accommodate zeroes in the data.

mean number of Copepoda (+1)/ 1000 cu m
50000
10000
5000
1000
500
100
50
10
5
1
.5
-20
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
time in days
Legend
Calanoida
Cyclopoida
Harpacticoida
Nauplii

Figure 3.5 Time related changes in weighted mean abundances of non-copepod fauna per $1000m^3$ of pond 9 water. Weighting was by volume of water that passed through each net. Note that the vertical axis was log scaled and that abundances were incremented by 1 to accommodate zeroes in the data.

mean number of non-copepod zooplankters (+1)/ 1000 cu m
5000
1000
500
100
50
10
5
1
.5
-20
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
time in days
Legend
M. orientalis
Brachyuran crab zoea
Polychaeta
other

Table 3.5 Vanderploeg-Scavia electivity indices for macrofauna ingested by *P. indicus*.

day	sampling time (hrs)	number of proventriculi analyzed	ingested invertebrates	Vanderploeg-Scavia electivity index
7	04:00	4	Nereidae	0.928
48	16:45	5	*M. orientalis*	0.923
48	22:00	5		
63	16:00	5	*M. orientalis*	0.923
63	23:00	3	*M. orientalis*	0.923
			Penaeus spp.	-0.999
72	16:00	5	*M. orientalis*	0.923
			Natantia	-0.990
72	23:42	4	*M. orientalis*	0.923
97	10:30	6	Nereidae	0.909
110	10:00	4		
125	10:00	5		
139	11:00	5		
173	11:00	2		
174	20:00-21:00	7	*M. orientalis*	0.933
			Natantia	0.598
260	15:25-16:25	7	Natantia	0.909
260	01:15-02:15	4	*M. orientalis*	0.909

Table 3.6 Indices of preponderance (I) for items ingested by three length classes of *P. indicus* captured by siene net at night in April/May 1986. Paired runs tests indicate that the order of prawn capture was not dependent upon their size.

	Carapace length classes (n)		
	A	B	C
sample size	8.0-11.0mm (11)	11.5-15.0mm (9)	15.5-20.0mm (11)
item	I	I	I
lab-lab	0.908	0.799	0.698
woody veg.	0.027	0.121	0.067
algae	0.001	0.024	0.057
diatoms	0.002	+	+
Nematoda	0.000	+	0.000
Polychaeta	0.002	+	0.000
Harpacticoida	0.000	0.001	+
M. orientalis	0.000	0.001	0.076
Natantia	0.000	0.000	+
Crustacea	0.011	0.046	0.097
other	+	+	0.002
sand grains	0.049	0.005	0.001
total	1.000	0.997	0.998

Spearman rank correlation results

B versus A	number of common items = 10	r_s=0.644 *
B versus C	number of common items = 8	r_s=0.659
A versus C	number of common items = 9	r_s=0.253

Paired runs test results

test	$\|Z\|$
A with B	1.58
B with C	1.11
A with C	1.53

\+ 0.000<I<0.001
* P<0.05

Table 3.7 Indices of preponderance (I) for items ingested by two length classes of *P. indicus* captured by cast net in the daytime between July and September, 1986.

	Carapace length classes (n)	
	D	E
	11.5-15.0mm (12)	15.5-20.0mm (10)
item	I	I
lab-lab	0.894	0.829
woody veg.	0.029	0.065
algae	+	+
diatoms	+	+
M. orientalis	+	0.000
Crustacea	0.001	0.089
other	0.001	0.001
sand grains	0.073	0.013
total	0.998	0.997

Spearman rank correlation test results

E versus D number of common items = 5 $r_s = 0.462$

+ 0.000<I<0.001

3.5 Faecal Pellet Analyses

The faecal pellet analyses indicated whether apparent changes to structures occurred as a result of having passed through the digestive tract of Penaeus indicus. Oscillatoria spp., diatom frustules, other plant matter, harpacticoid copepods (plate 3.1a), and polychaete jaws and setae (plate 3.1b) were found within the faecal pellets.

3.6 Penaeus indicus Growth and Morphometry

No significant differences were noted between carapace lengths of male and female prawns for the data collected between days 35 and 77 (Table 3.8). The length frequency distribution for one sex completely overlaps that of the other prawns (Fig 3.6). Conversely, on day 260, female prawns were significantly longer than male prawns (Table 3.8, Fig 3.7).

Figures 3.6 and 3.7 show that many of these distributions are polymodal. Each mode is thought to be related to an age grouping which will be referred to as a cohort. When these distributions are presented as a time series chart (Fig 3.8), two cohorts may be followed between days 14 and 77. A third cohort is also evident on days 14 and 70. The combination of carapace lengths for all cohorts deviates from normality ($P<0.05$) on three occasions (Table 3.9). The mean carapace lengths for cohorts one and two were used to develop the following linear growth models for the

Plate 3.1a A harpacticoid copepod found within a *Penaeus indicus* faecal pellet. (70X)

Plate 3.1b A polychaete jaw and acicular rods found with a faecal pellet. (130X)

Plate 3.1 a

Plate 3.1 b

Table 3.8 Weekly comparisons between male and female *P. indicus* carapace length rank order sums.

day	number of sexable prawns males: females		mean carapace length in mm(S. D.) males: females		/Z/	
14	2	:0	-	:-	-	
21	0	:0	-	:-	-	
28	0	:0	-	:-	-	
35	14	:42	17.5(0.140)	:17.5(0.194)	0.08	
42	4	:27	18.5(0.096)	:18.5(0.196)	0.36	
49	40	:56	17.5(0.120)	:18.0(0.149)	0.59	
56	27	:37	18.0(0.166)	:18.5(0.176)	0.63	
63	43	:34	18.5(0.215)	:18.0(0.214)	0.66	
70	91	:108	19.5(0.230)	:18.5(0.236)	2.50	*
77	141	:126	18.5(0.205)	:18.5(0.248)	1.08	
260	481	:413	21.0(0.165)	:23.0(0.204)	18.61	**

/Z/ = absolute normal approximations for Mann-Whitney U test scores corrected for ties

* 0.01<P<0.05

** P<0.01

Figure 3.6 Male and female *Penaeus indicus* carapace length frequencies at selected times during the study. Please note changes within the scales.

Day 35
male
female
22.5
5.0
8
0
8
Day 42
male
female
23.0
9.0
6
0
8
Day 49
male
female
23.5
10.0
18
0
16
Day 56
male
female
22.5
10.5
12
0
12
Day 63
male
female
23.5
13.0
0
10
Day 70
male
female
27.0
13.5
0
Day 77
male
female
30.0
12.0
26
0
25
carapace length in mm
number of prawns

Figure 3.7 Male and female *Penaeus indicus* carapace length frequencies at the completion of the study.

Day 260
male
female
29.5
100
130
0
130
carapace length in mm
number of prawns

Figure 3.8 *Penaeus indicus* length frequency distributions between days 14 and 77. The numbers 1, 2 or 3 refer to the approximate location of the mode within cohorts 1, 2 and 3.

90
0
1
2
3
day 14
day 21
day 28
day 35
day 42
day 49
day 56
day 63
day 70
day 77
number of prawns
25
carapace length in mm

Table 3.9 Summary statistics that were derived by the program NORMSEP for each cohort of *P. indicus*. The X^2 goodness of fit test indicates whether the combined cohorts fit a series of normally distributed frequencies. The prawns were seined at pond 9 between days 14 and 77.

days	cohort	n	mean carapace length in mm (S. D.)	X^2 goodness of fit
14+	1	48	3.5 (0.629)	-
+	2	19	11.0 (1.273)	
+	3	4	16.0 (0.816)	
21+	1	81	4.5 (0.621)-	
+	2	11	11.0 (1.179)	
28+	1	51	6.0 (1.038)	-
+	2	11	12.5 (2.787)	
35	1	102	10.0 (1.805)	5.806
	2	120	17.3 (1.981)	
42	1	81	11.5 (1.056)	18.319**
	2	228	16.5 (2.449)	
49	1	75	13.0 (1.018)	6.938
	2	265	17.0 (1.978)	
56	1	82	15.5 (1.405)	17.493**
	2	71	19.5 (1.360)	
63	1	63	16.0 (1.028)	1.956
	2	62	20.0 (1.515)	
70	1	127	16.0 (1.063)	16.424**
	2	196	19.5 (2.508)	
+	3	5	26.5 (0.707)	
77	1	148	16.0 (0.997)	12.881*
	2	255	18.5 (2.367)	

\+ length frequency components do not overlap
* $0.01<P<0.05$
** $P<0.01$

period between April 8 and June 10, 1986:

Cohort 1: $CL = 3.5 + 0.23$ day and

Cohort 2: $CL = 11.0 + 0.15$ day

where CL = mean carapace length in mm and day = time in days.

Upon converting the mean carapace lengths to mean total lengths the following equations were derived:

Cohort 1: $TL = 42.0 + 1.05$ day and

Cohort 2: $TL = 70.5 + 0.50$ day

where TL = mean total length in mm.

The linear growth rates that were determined within the present study are of the same order of magnitude as those described in the literature (Tables 3.10, 3.11).

Figure 3.9 presents a Walford plot of mean carapace length data. The data and first approximations for the predicted asymptotic mean carapace lengths for each cohort are presented on this figure. The following are von Bertalanffy growth formulae that were derived from each data set:

cohort 1: $CL = 21.0(1-\exp^{-0.02(day+5.5)})$ (k has a standard error of $\pm$ 0.02) and

cohort 2: $CL = 19.0(1-\exp^{-0.05(day+16.5)})$ (k has a standard error of $\pm$ 0.05). The linear and von Bertalanffy models for growth in terms of mean carapace length are presented in Figures 3.10 and 3.11. At least 90% of the variance in the data is accounted for by both models. The von Bertalanffy relationships predict asymptotic mean carapace lengths of 21.0 and 20.0mm for cohorts 1 and 2 respectively. These asymptotic lengths are within the range of carapace length modes at the time of harvest (Fig 3.7).

Table 3.10

A summary of reported carapace length growth rates for *Penaeus indicus*

Linear growth model

Locality	Period during which rate applies	Growth rate (mm/day)	Initial size of prawns (mm)	Final size of prawns (mm)	Sex	Remarks	Source
Singapore	Jan-May 1954	0.102	not available	not available	both	prawn pond	Hall (1962)
Ngomeni Lagoon,	April-June 1986	0.226	3.5*	16.0*	both	prawn pond Stocking density	this study
Kenya		0.148	11.0*	18.5*	both	4.5 prawns/m^2 without supplementary feeding but pond was enriched with inorganic fertilizers and cow dung	

* mean length

Table 3.11

A summary of reported total length growth rates for *Penaeus indicus*

Linear growth model

Approximate Location	Period during which rate applies	Growth rate (mm/day)	Initial size of prawns (mm)	Final size of prawns (mm)	Sex	Remarks	Source
Cochin, India	Sept 1956-Feb 1957	0.06	161-165	166-170	male	offshore commercial catches	George et al. 1968
		0.06	171-175	181-185	female		
	Feb-May 1957	0.48	126-130	146-150	male		
		0.64	141-145	156-160	female		
Ennur Estuary, India	May-Oct 1967	0.50	60.6*	132.4*	both	closed brackish water pond	Subahmanyam (1968)
Adyar Estuary, India	May-July 1967	0.70	41.24*	84.22*	both	open estuary	
Cochin, India	Feb-May 1964	0.50	51-55 & 86-90	not available	both	paddy field cultures	George (1975)
	Jan-May 1965	0.50	71-75; 91-95 & 111-115	not available	both		
	Dec-May 1966	0.50	61-55; 76-80 & 111-115	not available	both		

* mean length

Table 3.11 (Continued)

Linear growth model
Measurement: Total length

Approximate Location	Period during which rate applies	Growth rate (mm/day)	Initial size of prawns (mm)	Final size of prawns (mm)	Sex	Remarks		Source
Ambalapuzha, India	Jan-May 1972	0.24	123**	153**	male	offshore commercial catch data		Kurup & Rao (1975)
	Jan-April 1972	0.38	103**	138**	male			
	Mar-Oct 1972	0.28	98**	158**	male			
	Nov 1972-May 1973	0.32	103**	163**	male			
	Feb-May 1973	0.38	108**	143**	male			
	Oct-Jan 1973	0.27	133**	158**	male			
	Jan-May 1972	0.20	128**	153**	female			
	Feb-Oct 1972	0.20	108**	158**	female			
	Apr 1972-Feb 1973	0.24	98**	173**	female			
	Oct 1972-Apr 1973	0.26	98**	148**	female			
Madras, India	30 days	1.58	12-16	61-65	both	prawn ponds fed ground and boiled *Tilapia*		Chandra & Venkatswamy (1976)
						Stocking density	Survival	
						30 prawns/m^2	27.6%	
	30 days	1.08	12-16	45.6-49.6	both	40 prawns/m^2	28.7%	
	30 days	1.16	12-16	48.2-52.2	both	50 prawns/m^2	7.3%	

** Mode length

Table 3.11 (Continued)

Linear growth model
Measurement: Total length

Approximate Location	Period during which rate applies	Growth rate (mm/day)	Initial size of prawns (mm)	Final size of prawns (mm)	Sex	Remarks		Source
Madras, India						prawns cultures without supplementary food		Chandra & Venkatswamy (1976)
						Stocking density	Survival	
	30 days	1.34	12-16	53.6-57.6	both	30 prawns/m^2	32.8%	
	30 days	0.89	12-16	39.7-43.7	both	40 prawns/m^2	33.3%	
	30 days	1.12	12-16	46.7-50.7	both	50 prawns/m^2	3.0%	
						prawn ponds fed fish meal, rice bran, tapioca flour, algal powder, and shell-grit powder		
						Stocking density	Survival	
	3 months	0.56	30-45	81.9-96.9	both	7 prawns/m^2	80.9%	
	3 months	0.53	30-45	78.4-93.4	both	9 prawns/m^2	91.7%	
						prawn cultures without supplementary food		
						Stocking density	Survival	
	3 months	0.54	30-45	79.7-94.7	both	7 prawns/m^2	61.8%	
	3 months	0.47	30-45	73.2-88.2	both	9 prawns/m^2	71.0%	

Table 3.11 (Continued)

Linear growth model
Measurement: Total length

Approximate Location	Period during which rate applies	Growth rate (mm/day)	Initial size of prawns (mm)	Final size of prawns (mm)	Sex	Remarks	Source
Needakora, India						prawn ponds Stocking density	Nair et al. (1982)
	July-Oct 1978	0.60	18.2*	not available	both	7 prawns/m^2	
	July-Oct 1978	0.86	18.2*	not available	both	5.1 prawns/m^2	
	Jan-June 1979	0.42	18.9*	not available	both	11.0 prawns/m^2	
	Jan-June 1979	0.63	18.9*	not available	both	12.3 prawns/m^2	
Mandapam Camp, India						prawn ponds fed clam meat and trash fish Stocking density	Nandakumar (1982)
	Apr-June 1978 (78 days)	0.78	23.01*	84.2*	both	5 prawns/m^2	
						no supplementary food but fertilizers Stocking density	
	Apr-June 1978 (78 days)	0.64	27.51*	77.3*	both	5 prawns/m^2	
						fed pelletted artificial food Stocking density	
	Apr-June 1978 (78 days)	0.62	32.81*	80.5*	both	3 prawns/m^2	

* mean length

Table 3.11 (Continued)

Linear growth model
Measurement: Total length

Approximate Location	Period during which rate applies	Growth rate (mm/day)	Initial size of prawns (mm)	Final size of prawns (mm)	Sex	Remarks	Source
Kakinada, India	throughout 1979-1980 in periods of up to 3 months	0.81-0.97	41.5-71.5**	not available	female	estuary	Devi (1986)
		1.03	51.5-81.5**	not available	male		
	throughout 1979-1980 in periods of up to 5 months	0.64	81.5-121.5	not available	female	offshore commercial catch data	
		0.40	126.5-151.5	not available	female		
		0.32	156.5-176.5	not available	female		
		0.16	181.5-191.5	not available	female		
		0.64	86.5-126.5	not available	male		
		0.48	126.5-156.5	not available	male		
		0.40	146.5-171.5	not available	male		
Ngomeni, Kenya	Apr-June 1986 (63 days)	1.05	42.0+	89.5+	both	prawn pond no supplementary food but pond enriched with inorganic fertilizers and cow dung Stocking density: 4.5 prawns/m^2 Survival: 72.5%	this study
	Apr-June 1986 (63 days)	0.57	70.5+	99.0+	both		

** mode length
+ mean lengths determined from total length estimates that were determined using the formula $T = 28.631 + 3.803C$ where T equals total length in mm. and C equals carapace length in mm. $r = 0.963$.

Figure 3.9 A Walford plot of the weekly mean carapace length data for cohorts 1 and 2.

mean carapace length at time t + 1
mean carapace length at time t
2
4
6
8
10
12
14
16
18
20
22
24
Legend
cohort 1
cohort 2

Figure 3.10 The fitting of linear and von Bertalanffy growth models to weekly mean carapace length estimates for the first cohort.

mean carapace length in mm
18
16
14
12
10
8
6
4
2
0
-2
10
20
30
40
50
60
70
80
90
time in days
Legend
Cohort 1
actual data
Uniform model
CL=3.5+0.23Xday
r=0.96
:on Bertalanffy
-002(day+55)
CL=210(1-exp)

Figure 3.11 The fitting of linear and von Bertalanffy growth models to weekly mean carapace length estimates for the second cohort.

mean carapace length in mm
22
20
18
16
14
12
10
8
6
4
2
0
-2
10
20
30
40
50
60
70
80
90
time in days
Legend
* Cohort 2
actual data
Uniform model
CL=11.0+0.15Xday
r=90
:on Bertalanffy
-0.05(day+16.5)
CL=190(1-exp
)

Von Bertalanffy equations which predict growth in terms of mean total lengths are as follows:

cohort 1: $TL = 109.0(1-\exp^{-0.02(day+28.5)})$ and

cohort 2: $TL = 102.0(1-\exp^{-0.04(day+19.0)})$. The asymptotic total lengths for cohorts 1 and 2 are within the range of values that are described in the literature (Table 3.12).

An estimated 55,663 prawns were harvested; therefore 72.4% of the prawns survived the 260 day study. Approximately 52,500 of these prawns were P. indicus.

The slopes of various pond 9 morphometric relationships differ significantly between nonsexable and sexable prawns ($P<0.01$) (Table 3.13). Both sexes were combined in the relationships for sexable prawns. The slopes of the logarithmically transformed weight versus length relationships are higher for nonsexable than for sexable prawns. Conversely, the intercepts for these relationships are higher for sexable than for nonsexable prawns. The linear relationship between total lengths and carapace lengths for sexable prawns has a shallower slope but a higher intercept than does the relationship for nonsexable animals. Conversely, the linear relationship for tail lengths versus total lengths for sexable prawns has a steeper slope and a lower intercept than does the relationship for nonsexable prawns.

The linear relationships between total length and carapace length that Branford (1981) derived for male and female P. indicus are depicted in Figure 3.12. His animals were collected from creeks along the Sudanese Red Sea. The respective carapace length ranges for male and female prawns were 12.0mm to 35.0mm and 12.0mm to 42.0mm. His

Table 3.12

A summary of Von Bertalanffy growth models as determined by various studies

Measurement: Total length

Approximate Location	Period during which rate applies	L (mm)	K	To (mm)	initial size of prawns (mm)	final size of prawns (mm)	Sex	Remarks	Source
Ramanthuruh Island, India	Jan-July 1979	87.7	0.834	0	33.0*	88.1*	both	cage cultures stocking density 5 prawns/m2 time is measured in 14 day periods	Aravindakshan et al. 1982
Kakinada,	throughout 1979-80 in periods of up	218.9	2.0	0.100	81.5-121.5	not available	female	offshore commercial catch data is measured in years	Devi(1986)
	5 months	227.2	1.8	-0.073	86.5-126.5	not available	male		
Ngomeni, Kenya	Apr-June 1986 (63 days)	109	0.02	-18.800	42.0+	89.5+	both	prawn pond no supplementary food but pond enriched with inorganic fertilizers and cow dung	this study
		102	0.04	-28.713	70.5+	99.0+	both	Stocking Density	Survival
								4.5 prawns/m2 time is measured in days	72.4%

* mean length

\+ mean lengths were determined from total lengths which were estimated using the formula $T = 28.631 + 3.803\ 0$ where T equals length in mm. and C equals carapace length in mm. $r = 0.963$.

Table 3.13 Comparisons between slopes of morphometric relationships for sexable and nonsexable *P. indicus*. Fresh weight measurements were in gm, dry in mg, and lengths in mm.

nonsexable	fresh prawns	sexable
9.5-16.5	carapace length ranges in mm	14.5-25.5
58.5-94.5	total length ranges in mm	87.0-122.0
13	sample size	133
	dried prawns	
2.0-17.5	carapace length ranges in mm	13.5-27.5
52	sample size	69

regression models for nonsexable prawns	regression models for sexable prawns	t
	log tail wt/ log carapace lt	
logY=-2.947+2.795logX	logY=-2.046+2.054logX	75.98 (sig.)
	log total wt/ log carapace lt	
logY=-2.911+2.912logX	logY=-2.168+2.303logX	69.62 (sig.)
	log dry wt/ log carapace lt	
logY=-3.582+2.887logX	logY=-3.941+3.178logX	21.74 (sig.)
	total lt/ carapace lt	
Y=3.794+5.522X	Y=38.200+3.338X	32.69 (sig.)
	tail lt/ total lt	
Y=8.606+0.471X	Y=-1.011+0.601X	22.36 (sig.)
	tail wt/ total wt	
Y=0.076+0.642X	Y=0.464+0.558X	3.99 (sig.)

t = t-test score ($P<0.01$)

Figure 3.12 Total length versus carapace length for fresh *P. indicus* harvested from pond 9. The relationship is being compared with similar relationships that are presented in Branford (1981).

total length in cm
14
13
12
11
10
9
8
7
6
5
4
.5
.7
.9
1.1
1.3
1.5
1.7
1.9
2.1
2.3
2.5
2.7
2.9
carapace length in cm
Legend
This study
confid limits
This study
all prawns
TL=2.85+3.80XCL
r=.96
Branford (1981)
female prawns
TL=2.983+3.875XCL
Branford (1981)
male prawns
TL=2.125+4.288XCL

relationships fit within the confidence limits for a similar relationship derived from pond 9 data (Fig 3.12). The logarithmically transformed relationships that Branford (1981) derived for total weight versus carapace length data and tail weight versus carapace length data fall within confidence limits for similar pond 9 relationships. However, in each case, his relationships have lower intercepts and steeper slopes than the pond 9 relationships (Figs 3.13, 3.14).

The regression line for tail length versus total length that Brusher (1972) describes is below the confidence limits for a similar relationship that was derived using the pond 9 data (Fig 3.15). Brusher collected his data from 1,000 prawns from Ungwana Bay, Kenya. His prawns had total lengths that ranged between 62.0mm and 200.0mm.

Figure 3.13 Total weight versus carapace length for fresh *P. indicus* harvested from pond 9. The relationship is being compared with relationships that are presented in Branford (1981).

total weight in gm
20
10
8
6
4
2
1
.8
.8
.9
1
2
3
carapace length in cm
Legend
This study
confid. limits
This study
all prawns
LogW=006+253LogC
r=0.985
Branford (1981)
female prawns
LogW=001+277LogC
Branford (1981)
male prawns
LogW=-003+291LogC

Figure 3.14 Tail weight versus carapace length for fresh *P. indicus*. The relationship is being compared with two relationships that are described in Branford (1981).

tail weight in gm
8
6
4
2
1
.8
.6
.8
.9
1
2
3
carapace length in cm
Legend
This study
confid limits
This study
all prawns
LogW=-008+2 33LogC
r=977
Branford (1981)
female prawns
LogW=-016+2 71LogC
Branford (1981)
male prawns
ogW=-020+2 88LogC

Figure 3.15 Tail length versus total length for fresh *P. indicus*. The relationship is being compared with one that is described in Brusher (1972).

tail length in mm
total length in mm
80
70
60
50
40
30
20
50
60
70
80
90
100
110
120
130
Legend
This study
confid. limits
This study
all prawns
Tail=05+059XTL
r=.98
Brusher (1972)
all prawns
Tail=-4341+0585XTL

4.0 Discussion

This study indicates that Penaeus indicus feeds upon lab-lab, plant matter, Nematoda, Polychaeta, fish and Crustacea. However, the laboratory and in situ observations indicate that they do not feed indiscriminantly. The aggregated distribution of meio- and micro-benthos and observations that prawns methodically probe the bottom suggest that the prawns were searching for patches of food items. The fact that the peraeopods occasionally brought items to the pre-oral cavity and then ingested, or forcefully rejected masses further indicate selection. These observations corroborate earlier findings (Hindley 1975) that particles may first be selected by the chelate appendages and then by the oral appendages.

Even though intensive aquaculture of Penaeus indicus has been conducted throughout its range, comparisons between abundances of potential food items and proventriculi contents were not found in the literature.

The electivity data suggest that this ability to discriminate amongst food items is expressed as a strong preference for certain foods. Nereidae and Mesopodopsis orientalis were clearly selected for by the prawns. Strong preferences for nereids was also noted by Shigueno (1975); however, few, if any of the preference studies included mysids as a food type. New (1976) and Shigueno (1975), however, established that prawns prefer diets with amino-acid compositions similar to their own, and certain mysid species meet this requirement (Table 4.1). Such diets provide relatively low food conversion ratios (FCR). Food conversion ratios are defined as the ratio of total dry weight of food

Table 4.1 Percentage amino acid composition of protein hydrolysates of three mysids and *Penaeus aztecus*.

Amino acids	*Neomysis integer* overigous female (a)	*Mesopodopsis slabberi* (a)	*Mysis relicta* (a)	*Penaeus aztecus* (b)
Cysteic acid	-	-	0.1	-
Taurine	-	-	-	-
Aspartic acid	11.2	11.0	11.7	10.9
Threonine	4.1	4.4	5.4	5.3
Serine	3.8	4.6	6.1	5.0
Glutamic acid	17.2	14.8	14.7	13.4
Proline	3.0	3.2	3.8	3.1
Glycine	3.6	4.0	7.4	5.7
Alanine	5.2	5.8	8.0	5.6
Valine	5.2	5.6	5.5	5.0
Cystine	1.1	1.4	0.8	3.3
Methionine	2.3	2.4	1.7	3.4
Isoleucine	5.3	5.3	4.9	4.4
Tyrosine	4.0	4.3	2.1	2.7
Phenylalinine	5.1	4.6	3.9	5.6
Lysine	10.2	10.4	7.5	6.0
Histidine	3.5	3.6	1.3	3.1
Tryptophan	-	-	-	1.0
Arginine	7.3	6.7	5.7	-
Orithine	0.2	0.2	-	-
Hydroxyproline	-	-	-	0.3
Leucline	7.7	7.8	9.1	9.6

(a) Mauchline (1980)
(b) Shewbart et al. (1972)
\- undetermined

to the total wet weight gain (Capuzzo and Lancaster 1983). The FCR for mysids is 1.5/1; this implies a relatively high growth efficiency (Reddy and Shakuntala 1986). Ogle and Price (1976) note that the growth of mysid-fed Penaeus aztecus was comparable to that of Artemia-fed P. Aztecus. Further studies are required to determine the factors which make M. orientalis a favoured food item.

The present observations corroborate earlier findings (Gopalakrishnan 1952) that only disabled prawns are taken. It should be beneficial to select only disabled animals otherwise, a great deal of time and energy would be expended to chase, attack, or avoid healthy animals. An animal that attacks a strong member of its own species faces a high risk of being killed. However, the benefits from attacking a disabled animal may outweigh the risks. Finally, a species increases its chances of survival by eliminating individuals that may have less advantageous genes.

Electivity indices were not determined for the Harpacticoida, Nematoda or Foraminifera as it is unlikely that prawns sort individual particles (Alexander and Hindley 1985). These taxa were probably picked up with masses of substrate.

Electivity indices do not appear to have been biased by the time lapse between sampling the food resource and sampling the proventriculus of the study animal. Table 3.3 indicates that abundances of drift present within the pond for up to two weeks were similar to abundances within the canal (outflow nets 13 and 17 were set at the beginning of water exchanges and collected abundances of fauna that were similar to collections by inflow nets 15 and 18

respectively). Nereidae and M. orientalis were strongly selected for regardless of the length of time between which drift and proventriculi were sampled. Drift samples were collected on day 59 while electivity indices were determined on days 48, 63 and 72. On all three days, the index for the mysid was 0.923. Drift was collected on days 176 and 260 while indices for M. orientalis were 0.939 and 0.909 on days 174 and 260 repectively. Indices of 0.909 and 0.928 were determined for Nereidae.

Nighttime preponderances for lab-lab, diatoms, Polychaeta and sand grains decreased as the animals grew. The decrease in importance of Polychaeta may have been an artifact since polychaetes were rare within the environment. Conversely, M. orientalis, algae and Crustacea became increasingly important as the animals grew. Comparisons between morning preponderances also showed that the prawns became more carnivorous as they grew. These findings are in agreement with Hall (1962).

The morning proventriculi contained Crustacea which were invariably well digested and only a small piece of mysid was identifiable. This is in contrast to the proventriculi contents of animals that were sampled during the afternoon and night. These proventriculi held easily identifiable animal parts. The differences in digestive states suggest that feeding activities may vary diurnally.

Regardless of the size of prawns, or when they were caught, lab-lab, woody vegetation, algae, Polychaeta and various crustaceans were important in frequency of occurrence and volume. Such a wide variety of food types suggests that P. indicus is omnivorous.

Further research should investigate the relative nutritional importances of the various ingested items. The preponderance for lab-lab was relatively high, however, this should not imply that the nutritional value of lab-lab is correspondingly high.

Fecal pellet analyses determined that diatoms, dinoflagellate cysts, woody tissue, filamentous algae and harpacticoid copepods pass through the digestive tract without apparent change. These substances may be difficult for Penaeus indicus to digest; however, differential digestion has been noted among many prawns. For example, Palaemonetes pugio is capable of digesting the lipids that are contained within the diatom Nitzschia closterium but can not digest the frustules (Johannes and Satomi 1966). P. pugio is able to assimilate bacteria and detritus but is not able to assimilate eel grass (Zostera marina) (Adams and Angelovic 1970). Moriarty (1976) was able to demonstrate that Metapenaeus bennettae may assimilate bacteria more readily than algae. Since a great deal of undigested plant matter was found within the faecal pellets and since the scientific literature suggests that only certain plant matter may be digested by prawns, it is doubtful that plants are important sources of prawn nutrition.

Decomposing plants may, however, be important as an indirect source of nutrition. Such plant matter is a component of detritus. The broad definition of detritus includes particles that range from freshly dead plants and animals to colloidal aggregates. The term also includes bacteria, fungi and Protozoa, as well as the organic and inorganic compounds that are associated with each particle (Odum 1971, Wilcox and Jefferies 1974). Prawns may not be

able to digest all of the plant matter that they ingest; however, the associated decomposers and compounds may be an important food source (Johannes and Satomi 1966, Dall 1968, Odum 1971, Odum and Heald 1972, Wilcox and Jefferies 1974, Moriarty 1976, 1977).

The growth rates and morphometric relationships determined using the pond 9 prawns were within the ranges found in the literature. The rates for the study animals were not confounded by migration since the animals were contained within a pond. One Penaeus indicus was captured in all of the outflow collections (Appendix C net 11); therefore, the effect of emigration was believed to be negligible.

This study corroborates Hall's (1962) findings that the growth rates of juvenile Penaeus indicus were not dependent upon sex. The modes could be separated according to sex only on day 260 when the rank sum of female carapace lengths was greater than it was for males. Therefore, Penaeus indicus may eventually exhibit sexual dimorphism in growth (eg., George et al. 1968).

A broad range of growth rates have been noted within the literature (Tables 3.10-3.12). Carapace length growth rates range from 3.06mm/month (Hall 1962) to 7.0mm/month (the present study), while total length growth rates range from 1.8 mm/month (George et al. 1968) to 47.4 mm/month (Chandra and Venkataswamy 1976). There are many reasons for this disparity. Growth rates decrease as prawns grow (Tables 3.11 and 3.12). Secondly, the only possible means of determining prawn ages is to plot length or weight frequencies and then

separate the modes. In most cases, each mode is considered to be an age cohort. Unfortunately, this is a very subjective method. Some of the subjectivity is removed by programs such as NORMSEP. However, such techniques require input data such as the number of cohorts and an estimate of the mean values for each cohort. These data are subjectively estimated by the researcher. Modal progression over time is used in determining growth rates. The progression of modes is determined subjectively. Growth rates also vary because of differences in prawn density (Edwards 1977), water temperature (Eldred et al. 1961, Kurata 1962), the organic content of the substrate (Edwards 1977), water pH (Saenger et al. 1984) and food abundance (Kurata 1962).

The slopes of the morphometric relationships are dependent upon the size range of the animals being studied (Table 3.13). Because an animal increases in weight exponentially as it grows and since the data at the end points have a relatively high impact on the slope of the line, data covering only a small size range will tend to result in a smaller slope than data from a wide size range. The slopes within the Branford (1981) weight/length relationships are steeper than those for the pond 9 relationships, because slopes are dependent upon the range of the independent variable. The pond 9 carapace lengths range between 9 and 25.5mm while Branford's range between 12 and 42mm. At least 92% of the variance was accounted for by the pond 9 regression equations. Unfortunately, Branford does not include regression coefficients with his relationships. The tail length versus total length relationship that Brusher (1972) derived is parallel but falls below the confidence limits for the pond 9 relationship. This is probably the result of differences in measurement techniques.

In summation, Penaeus indicus ingested a wide variety of potential food items; however, there is strong evidence that Mesopodopsis orientalis and Nereidae are being selected. The prawns appear to become more carnivorous as they grow. Lab-lab is the most important food item in terms of preponderance indices. Further research must be conducted to determine the dietary importance of the various ingested items.

The growth and morphometric relationships determined in this study did not differ significantly from the relationships that were found within the literature; therefore, there is no evidence that the electivity and preponderance indices were constrained by the condition of the study animals.

5.0 Literature Cited

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Appendix A The Environment within Pond 9

Unless otherwise noted, employees of the FAO and the Kenyan Department of Fisheries were responsible for collecting all of the edaphic data.

A-1.1 Physical Characteristics

Pond 9 had a surface area of 1.71ha. The ratio of length to width was approximately 2:1. A 1.2m high berm of mud was built around the pond to prevent flooding at times of high water and a central ridge incompletely divided the pond into a U-shape (Fig A-1.1). The central ridge increased the effective length to width ratio to 8:1. The sides of the pond sloped gently toward a median ditch along each arm. The ditch gently sloped downward in a U-shaped course around the central ridge toward a single outflow gate, thereby allowing water to flow around the central ridge and out of the pond during periods of water exchange and harvest. Figure A-1.2 presents a series of cross sectional views of pond 9.

Water exchange occurred over either two or three consecutive days before, during and after spring tides. The exchange was due to tidal flow along the main canal which led from Fundisa Bay. As indicated below, water quality was maintained through regular exchanges. Potential food items were also exchanged at these times. Between water exchanges, depths were maintained by sealing off the gates with wooden slats and mud.

Figure A-1.1 The bathymetry of pond 9 (mean depth 45cm).

A
B
C
D
E
F
N
0 10 20 30 40 m
depths in cm
Legend
central ridge

Figure A-1.2 Cross-sectional views of pond 9. Each section is labelled according to a transect, as indicated in figure A-1.1.

A
B
0
100
0
70
C
D
0
100
0
80
E
F
0
90
0
10
depth in cm
length in m

A-1.2 Materials and Methods

On March 26, 1986, pond 9 was drained and then refilled to a depth of 15cm. Between March 26 (day 0) and April 3 (day 9), the pond was stocked with approximately 77,000 prawns.

Throughout the study, the water level was maintained at a mean depth of 40cm. Precipitation (indicated by rain gauge), water temperature, salinity, transparency and mean water depth (taken near the gate) were monitored each day between 0900 and 1000hrs. Surface water temperature was determined using a floating mercury thermometer that was placed in situ for five minutes prior to reading. An optical refractometer (American Optical), was used to estimate the salinity of the surface water to $\pm$ 0.5$^{o}/_{oo}$. A secchi disc was used to estimate transparency. Mean water depths were read from a permanent water level gauge. The pH of the water was monitored after heavy rains, when pH decreases were expected (H. Kongekeo, pers. comm.).

Pond 9 was treated with cow dung and diammonium phosphate when the secchi disc readings were high and the bottom of the pond appeared to have little algal growth. Table A-1.1 presents a record of nutrient applications.

A-1.3 Results

Time series charts of edaphic variables are presented in Figure A-1.3. This figure also indicates the periods during which water exchanges took place and the dates during which nutrients were added. The mean water depth increased while temperature and surface water salinity decreased, after heavy

Table A-1.1 The quantities of cow dung and diammonium phosphate that were applied to Pond 9 and the days on which these treatments were made.

Day	Cow Dung (kg)	Diammonium Phosphate (kg)
0	171	17.1
9	171	17.1
52	171	17.1
93	171	17.1
138	87	8.5

(Kenyan Department of Fisheries, unpub. data)

rain storms. These trends were reversed during the dry season. Turbidity generally increased following the addition of cow dung and diammonium phosphate. Transparency and surface salinity increased immediately after water exchanges (Fig A-1.3). Surface pH decreased after heavy rains (Table A-1.2).

A-1.4 Discussion

The time series charts (Fig A-1.3) clearly reflect normal meteorological trends for the study area. The study began while the north-east monsoon of the Indian Ocean was moving southward along the east coast of Africa. The monsoon caused the heavy rainfall that prevailed throughout much of April and May (days 20 to 67). On May 30 (day 66) 115.5mm of rain fell. May was the transition period as the prevailing winds shifted to the south-west.

If the 50mm per month isohyet is used as a demarcation between wet and dry months, the dry season began during June (Griffiths, 1972). The air temperatures cooled until July and August when the coolest temperatures are usually felt. This slight decrease in temperature is evident in the surface water temperature data. During September, the increase in surface water temperatures reflected the increase in ambient air temperatures. The second transitional period began during November, as the winds began to reverse their direction (Fig A-1.4).

The surface area of the pond was 1.71ha and throughout much of the study, the mean depth was held at approximately 45cm. Such a high surface area to depth ratio allowed rapid changes in salinity to occur. During the rainy season, the

Figure A-1.3 Abiotic conditions in pond 9 between March 12 and December 12, 1986. This set of time-series charts also indicates the water exchange schedule and the dates during which cow dung and diammonium phosphate were applied. (Kenyan Department of Fisheries, unpub. data)

Precipitation
mm
Surface Water Temperature
C°
Surface Water Salinity
ppt
Transparency
cm
Mean Water Depth
cm
Water Exchange and Nutrient Addition Dates
Legend
water exchange
nutrients
0
20
40
60
80
100
120
140
160
180
200
220
240
260
days

Table A-1.2 The pH of water within pond 9 and within the canal outside of pond 9 during various mornings between March 26, and December 12, 1986.

Day	Pond 9 (pH)	Canal (pH)
0	8.4	8.4
66	4.5	8.5
157	8.3	8.4
174	7.0	8.5
176	6.7	8.4
202	8.5	8.5

(Kenyan Department of Fisheries, unpub. data)

Figure A-1.4 Percent frequencies of wind directions for Ngomeni Lagoon, Kenya, March-December 1986 (Kenyan Department of Meteorology, unpub. data).

March
0600
1200
April
0600
1200
May
0600
1200
June
0600
1200
July
0600
1200
August
0600
1200
September
0600
1200
October
0600
1200
November
0600
1200
December
0600
200
scale 0% 100%

pond water quickly became diluted with rainwater and with low salinity estuarine water, whereas, during the dry season, there was extensive evaporation due to solar radiation and wind. This resulted in an elevation in salinity. Decreases in salinity usually occurred during water exchanges. This indicates that the water within pond 9 had higher salinity than the water within the estuary. The amounts of water that were exchanged during each water exchange are noted in Table A-1.3. This table indicates variations that existed between the volumes of water at the end of certain water exchanges, and the volumes that were present at the beginning of the next exchange. Rainfall caused increases in volume of up to $2140m^3$ (50.4%); while evaporation caused decreases of up to $2210m^3$ (38.23%). Salinity extremes of 19ppt and 55ppt occurred respectively on May 29 (day 65) and August 6 (day 134).

Peaks in transparency occurred during water exchanges, indicating that inflowing water had lower quantities of particulate and dissolved matter than did outflowing water. Increases in turbidity were usually associated with the timing of nutrient additions (Table A-1.1). The relationship between secchi disc readings, transparency and matter is complicated by many factors. Secchi disc readings are determined subjectively and are affected by surface glare (Beeton 1957), the amount of seston within the water and the colour of the water (Carlson 1977; Edmondson 1980).

During November (days 217-248), the prevailing monsoon shifted its direction. It then came from the north-east causing the pond water to be blown toward the gate.

Table A-1.3 The days during which water exchanged at Pond 9, and the estimated volumes in m^3 of water that were exchanged between March 26, 1986 and December 11, 1986.

Day	est. vol. of water at beginning of exchange (m^3)	est. vol. increase due to inflow (m^3)	est. vol. decrease due to outflow (m^3)	net change in vol. (m^3)
13	6460	0	510	-510
13	5950	1190	680	+510
14	6460	2210	2210	0
15	6460	680	1190	-510
16	5950	5270	4760	+510
29	6460	1870	1870	0
30	6460	4590	6800	-2210
32	4250	8500	7820	+680
33	4930	6120	6120	0
34	4930	2720	850	+1870
43	6800	0	2040	-2040
44	4760	1870	2380	-510
45	4250	2210	0	+2210
57	8500*	0	3740	-3740
58	5950	2550	3400	-850
59	5100	5100	2380	+2720
60	7820	4930	6290	-1360
61	6460	5440	5440	0
62	6460	3400	0	+3400
87	7650	0	2550	-2550
88	5100	2550	2890	-340
89	4760	4250	3910	+340
90	5100	5100	6120	-1020
91	5780	2720	0	+2720
116	6290 #	0	1360	-1360
116	4930	2550	2380	+170
117	5100	4080	4080	0
118	5100	5780	3400	+2380

* between days 45 and 57 239.8mm of rain fell, causing the volume of water in pond 9 to increase by $2140m^3$.
# between days 91 and 116 there was a net loss of $2210m^3$.

Table A-1.3 (continued)

Day	est. vol. of water at beginning of exchange (m^3)	est. vol. increase due to inflow (m^3)	est. vol. decrease due to outflow (m^3)	net change in vol. (m^3)
133	5780	0	2040	-2040
134	3740	3570	3570	0
135	3740	3400	1190	+2210
136	5950	1700	1530	+170
147	6290	0	1190	-1190
148	5100	4250	4590	-340
149	4760	5100	5610	-510
150	4250	4930	5100	-170
151	4080	2040	510	+1530
152	5610	4080	2550	+1530
153	7140	510	0	+510
165	8500 ***	0	3400	-3400
166	5100	3230	4590	-1360
167	3740	5950	6292	-340
168	3400	4250	0	+4250
176	6630 ##	0	3230	-3230
176	3400	3400	2040	+1360
177	4760	3740	4930	-1190
178	3570	4760	1530	+3230
192	6800	0	2210	2210
192	4590	3910	3400	+510
193	5100	5440	5780	-310
194	4760	6630	7140	-510
195	4250	6460	5950	+510
196	4760	3910	1020	+2890

*** between days 153 and 165 there was 51.3mm of rainfall, causing the volume of water in pond 9 to increase by $850m^3$.
between days 168 and 176 there was a net loss of $1020m^3$ of water.

Table A-1.3 (continued)

Day	est. vol. of water at beginning of exchange (m^3)	est. vol. increase due to inflow (m^3)	est. vol. decrease due to outflow (m^3)	net change in vol. (m^3)
206	7140 ###	0	2720	-2720
207	4420	2720	2380	+340
208	4760	3740	3740	0
209	4760	4420	4420	0
210	4760	3230	340	+2890
221	8500 ****	0	4760	-4760
221	3740	3570	3230	+340
222	4080	5780	4590	+1190
223	5270	6630	7650	-1020
224	4250	9860	10710	-850
225	3400	6460	0	+6460
235	9860	0	5100	-5100
235	4760	3400	3230	+170
236	4930	2890	1870	+1020
237	5950	1530	0	+1530
252	5270	1870	1190	+680
253	5950	2550	3400	-850
254	5100	2210	3060	-850
255	4250	3740	3400	+340

between days 196 and 206 there was a net loss of 510m^3 of water
**** between days 210 and 221 there was
causing the volume of the water to increase by 850m^3.

(Source: Kenyan Department of Fisheries, unpublished data)

Particles from the bottom were stirred up by the wind and were moved toward the gate resulting in relatively high turbidity readings. For this reason, pre- and post-November transparency readings were not comparable.

Turbidity may have also been caused by the prawns. P. merguiensis typically form dense schools in which they generate intense localized turbidity (Penn 1984). Aquarium experiments demonstrate that P. setiferous (Williams 1958) and P. indicus (D. Orr, unpub. data) may actively cause the water to become muddy.

Small scale trends are evident in the mean depth/time series data. When rains occurred between water exchanges, there were often minor increases in water depth (Table A-1.3).

There are several reasons, for the drastic changes in pH (Table A-1.2). As previously mentioned, the ponds were constructed in a mangrove swamp. As a result of biological processes these soils contribute to the acidification (MacNae 1968; and Boto 1984). Brackish water ponds usually become acidic during rainy seasons, when hydrogen sulphite and pyrite are leached from the berms that surround the ponds. Researchers at Chilean aquaculture stations have noted pH values as low as 4 (Saenger et al. 1984). Low pH values have also been noted in India (Gopinathan et al. 1982; Kurian, 1982; and Nair et al. 1988) and in Thailand (H. Kongekeo pers. comm.).

The pH values within pond 9, dropped below 7.0 on May 30 (day 66) and September 17, 1986 (day 176). Several factors caused these decreases. During May, iron pyrite was leached

from the berms. This was evident by the orangey-red colour of the streams that drained the berms. Also, each time shrimp were sampled for this, FAO, or Kenyan Department of Fisheries studies the substrate layers became mixed. These problems were further compounded, as there was no water exchange between May 26 (day 62), and June 20 (day 87) because high tide during the spring tide on June 7 (day 74) was too low.

The pH of ponds 6 and 8 was also determined on May 30. Their respective values were 5.5 and 6.5.

The above observations indicate that seasonal environmental changes occurred within pond 9. However, there must also have been diurnal variations in such parameters as water temperature and pH. Throughout the daytime, photosynthesis was taking place and the net carbon dioxide concentration would presumably decrease causing the pH of the water to increase. Due to the large surface area to volume ratio of the pond, there was probably a large diurnal range in temperatures.

Appendix B The abundances of benthos per ml. within samples that were obtained from each site, on each date. The sampling sites refer to Figure 2.4.

a = pennate diatoms b = centric diatoms c = colonial diatoms
d = Protista e = Nematoda f = Harpacticoida g = nauplii
h = dinoflagellate cysts i = other (Polychaeta, Turbellaria, Rotifera, Bryozoa, and unidentifed eggs)

Day	Site	Sample	a	b	c	d	e	f	g	h	i
1	35	1	0	0	0	0	0	0	0	0	0
1	35	2	0	0	0	0	0	0	0	0	0
1	35	3	0	0	0	0	0	0	0	0	1
1	25	1	0	0	0	0	0	0	0	0	2
1	25	2	0	0	0	0	0	0	0	0	1
1	25	3	0	0	0	0	0	0	0	0	0
1	68	1	0	0	0	0	0	0	0	0	0
1	68	2	14	0	0	0	2	0	0	0	1
1	68	3	0	0	0	0	0	0	0	0	0
14	46	1	263	14	0	85	203	0	0	0	0
64	76	1	1130	15	0	30	83	7	0	0	10
64	28	1	37	135	0	0	0	0	0	2	1
64	71	1	124	21	0	0	7	1	1	0	0
77	10	1	5	29	0	32	0	1	0	2	1
77	10	2	15	11	0	0	0	0	0	1	0
77	17	1	5	29	0	32	0	1	0	0	1
77	74	1	37	43	0	0	0	0	0	1	0
77	74	2	15	11	0	0	0	0	0	1	0
107	14	1	0	0	0	0	0	0	0	0	0
107	14	2	0	0	0	0	0	0	0	0	0
107	14	3	0	0	0	0	0	0	0	0	0
107	78	1	251	0	0	2	30	4	0	0	0
107	16	1	0	0	0	0	0	0	0	0	0
107	16	2	6	0	0	0	0	0	0	0	0
107	63	1	5	3	0	0	1	0	0	0	1
107	63	2	42	104	0	0	0	0	0	5	0
140	52	1	30	0	0	1	6	1	0	0	0
140	70	1	14	0	0	1	2	0	0	0	0
140	70	2	51	0	0	1	3	1	0	0	0
140	70	3	4	0	0	0	2	0	0	0	0
140	15	1	0	0	0	0	0	0	0	0	0
140	15	2	6	0	0	0	0	0	0	0	0
140	15	3	0	0	0	0	0	0	0	0	0
174	7	1	0	0	0	0	1	0	0	0	0
174	7	2	1	0	0	2	2	0	0	0	0
174	7	3	1	0	0	0	4	0	0	0	0

Appendix B (continued)

a = pennate diatoms b = centric diatoms
c = colonial diatoms d = Protista e = Nematoda
f = Harpacticoida g = nauplii h = dinoflagellate cysts
i = other (Polychaeta, Turbellaria, Rotifera, Bryozoa and unidentified eggs)

Day	Site	Sample	a	b	c	d	e	f	g	h	i
174	60	1	6	0	0	193	59	0	0	0	0
174	60	2	0	0	0	90	77	0	0	0	0
174	60	3	0	0	0	139	75	0	0	0	0
174	16	1	1	0	0	12	6	0	0	0	0
174	16	2	14	0	0	4	4	0	0	0	0
174	16	3	7	0	0	6	5	0	0	0	0
174	55	1	3	0	0	200	14	0	0	0	0
174	55	2	2	0	0	36	14	0	0	0	3
174	55	3	13	0	0	200	28	0	0	0	0
174	77	1*	66	52	0	65	16	0	0	12	4
174	77	2*	7	38	0	3	11	0	0	2	0
174	77	3*	18	29	0	49	21	0	0	0	0
189	14	1	2355	0	0	615	135	7	0	0	0
189	14	2	3955	16	0	298	43	2	16	3	0
189	14	3	2052	25	0	411	46	1	5	4	2
189	78	1	208	42	0	242	69	1	0	4	2
189	61	1	300	300	0	600	300	0	0	0	0
189	61	2	300	300	0	600	300	0	0	0	0
189	61	3	300	300	0	600	300	0	0	0	0
199	84	1	124	34	3	164	0	0	0	2	0
199	84	2	7	16	0	392	15	0	0	0	0
199	84	3	32	24	1	54	0	0	0	3	2
199	11	1*	517	17	0	489	28	0	0	1	7
199	16	1	12	5	0	107	0	0	0	0	0
199	16	2	17	9	0	124	1	0	0	2	0
199	16	3	16	6	0	116	0	0	0	2	1
199	52	1	60	45	0	166	8	0	0	6	6
199	52	2	68	87	2	337	11	0	0	2	0
199	52	3	17	80	1	37	9	0	0	5	2
199	7	1	14	15	0	0	3	0	0	0	0
199	7	2	82	28	0	0	10	0	0	0	1
199	7	3	126	19	0	543	0	0	0	0	0
259	80	1	4	2	0	0	3	0	0	0	0
259	12	1	58	5	0	0	9	0	0	0	0
259	12	2	7	9	0	0	2	0	0	2	8
259	12	3	18	9	0	0	1	0	0	0	0
259	7	1	43	20	0	4	12	0	0	3	6
259	7	2	14	11	0	4	3	0	0	5	6

* refers to a sample that was taken along a stick.

Appendix B (continued)

a = pennate diatoms b = centric diatoms
c = colonial diatoms d = Protista e = Nematoda
f = Harpacticoida g = nauplii h = dinoflagellate cysts
i = other (Polychaeta, Turbellaria, Bryozoa, Rotifera and unidentified eggs)

Day	Site	Sample	a	b	c	d	e	f	g	h	i
259	25	3	4	24	0	3	1	0	0	4	7
259	7	3	6	16	0	0	2	0	0	2	7
259	25	1	28	16	0	8	7	0	0	2	4
259	25	2	7	6	0	0	1	0	0	1	5
259	79	1	110	14	0	1	3	0	0	2	3
259	79	2	137	34	0	4	18	0	0	2	6
259	79	3	124	54	0	1	12	0	0	2	6
259	62	1	13	49	0	1	6	0	0	3	0
259	62	2	24	75	0	1	19	2	0	11	4
259	62	3	24	98	0	2	16	0	0	7	4

Appendix C The estimated abundances of fauna per 1000m^3 that flowed into or out of pond 9 at each drift net sampling session.

net	day	time	inflow	outflow	volume filtered (m^3)
1	0	16:30-17:30	*		44.069
2	1	0:30- 4:30		*	33.784
3	1	7:30-11:30		*	50.700

taxon	net 1 abundance	net 2 abundance	net 3 abundance
unidentified eggs	0	0	0
unidentified trochophore	36	16	0
Hydrozoa	12	0	0
Pleurobrachia spp.	0	0	0
Nematoda	0	0	10
micro Turbellaria	12	16	31
Polychaete larvae	333	47	134
Nereidae	12	0	31
Tubificida	12	0	10
Mesopodopsis orientalis	12	544	10
Cumacea	12	16	10
Tanais spp.	12	0	0
Apseudomorpha spp.	0	0	0
Apseudes spp.	0	0	0
Gnathiidae	12	12	12
Munnidae	0	0	0
Flabellifera	0	0	0
unidentified Isopoda	0	0	0
Talitridae	0	31	0
Ostracoda	24	31	52
Brachyuran crab eggs	0	0	0
Brachyuran crab zoea	60	249	300
Brachyuran crab megalopa	0	16	0
Anomuran crab zoea	0	16	0
Jaxea spp. larvae	0	0	0
Palaemoninae larvae	36	0	41
Metapenaeus monoceros	0	0	0
Penaeus indicus	0	0	0
Penaeus spp. larvae	0	0	0
Lucifer spp.	0	0	10
nauplii	512	1398	14657
Calanoida	1345	9661	5547
Harpacticoida	1524	637	2376
Cyclopoida	4310	124	1983

Appendix C (continued)

taxon	net 1 abundance	net 2 abundance	net 3 abundance
Copilia spp.	0	0	0
Cladocera	0	0	10
Chironomid larvae	0	0	0
Heleid larvae	0	0	0
Dipteran pupal case	0	0	10
Entomobryoidea	0	0	0
Acari	0	0	10
Gastropoda	0	0	0
Bryozoa	0	0	0
Sagitta bipunctata	167	155	72
Oikiopleura spp.	0	16	10
Pisces larvae	0	0	0

Appendix C (continued)

net	day	time	inflow	outflow	volume filtered (m3)
4	41	15:45-18:00	*		100.33
5	42	18:30- 3:05		*	661.81

taxon	net 4 abundance	net 5 abundance
unidentified eggs	5	0
unidentified trochophore	0	0
Hydrozoa	0	0
Pleurobrachia spp.	0	0
Nematoda	16	0
micro Turbellaria	16	6
Polychaete larvae	0	1
Nereidae	16	1
Tubificida	5	0
Mesopodopsis orientalis	120	5
Cumacea	5	0
Tanais spp.	0	0
Apseudomorpha spp.	0	0
Apseudes spp.	0	0
Gnathiidae	16	2
Munnidae	0	0
unidentified Isopoda	0	0
Talitridae	5	1
Ostracoda	5	1
Brachyuran crab eggs	0	0
Brachyuran crab zoea	8195	0
Brachyuran crab megalopa	0	0
Anomuran crab zoea	0	0
Jaxea spp. larvae	0	0
Palaemoninae larvae	5	0
Metapenaeus monoceros	0	1
Penaeus indicus	0	0
Penaeus spp. larvae	0	0
Lucifer spp.	0	3
nauplii	0	157
Calanoida	1898	492
Harpacticoida	162	806
Cyclopoida	162	52
Copilia spp.	0	0
Cladocera	0	0
Chironomid larvae	5	0
Heleid larvae	0	0
Dipteran pupal case	0	0
Entomobryoidea	0	0

Appendix C (continued)

taxon	net 4 abundance	net 5 abundance
Acari	0	0
Gastropoda	37	0
Bryozoa	0	0
Sagitta bipunctata	5	1
Oikiopleura spp.	0	6
Pisces larvae	0	0

Appendix C (continued)

net	day	time	inflow	outflow	volume filtered (m^3)
6	120	06:35-13:05		*	770.12
7	120	16:40-17:40	*		26.41
8	120- 121	20:25- 0:25		*	313.15

taxon	net 6 abundance	net 7 abundance	net 8 abundance
unidentified eggs	0	0	2
unidentified trochophore	0	0	0
Hydrozoa	0	0	0
Pleurobrachia spp.	0	0	0
Nematoda	0	0	0
micro Turbellaria	3	0	7
Polychaete larvae	1	0	2
Nereidae	0	0	0
Tubificida	0	0	0
Mesopodopsis orientalis	7	0	5
Cumacea	1	0	2
Tanais spp.	0	0	0
Apseudomorpha spp.	0	0	0
Apseudes spp.	0	0	0
Gnathiidae	3	60	2
Munnidae	0	0	2
Flabellifera	0	0	0
unidentified Isopoda	0	0	0
Talitridae	2	20	5
Ostracoda	1	20	2
Brachyuran crab eggs	0	0	0
Brachyuran crab zoea	0	0	0
Brachyuran crab megalopa	0	0	0
Anomuran crab zoea	0	0	0
Jaxea spp. larvae	0	0	0
Palaemoninae larvae	2	0	5
Metapenaeus monoceros	0	0	0
Penaeus indicus	0	0	0
Penaeus spp. larvae	0	0	0
Lucifer spp.	2	0	0
nauplii	1212	755	968
Calanoida	839	2484	1431
Harpacticoida	127	536	369
Cyclopoida	0	0	0
Copilia spp.	0	0	0
Cladocera	0	0	0
Chironomid larvae	0	0	0

Appendix C (continued)

taxon	net 6 abundance	net 7 abundance	net 8 abundance
Heleid larvae	0	0	0
Dipteran pupal case	0	0	0
Entomobryoidea	0	0	0
Acari	0	0	0
Gastropoda	0	40	3
Bryozoa	0	0	2
Sagitta bipunctata	6	238	10
Oikiopleura spp.	0	99	0
Pisces larvae	2	0	0

Appendix C (continued)

net	day	time	inflow	outflow	volume filtered (m^3)
9	149	06:55-08:55		*	213.29
10	149	10:23-11:23		*	203.81
11	149	16:15-17:15	*		43.61
12	149	20:40-21:40		*	99.60

taxon	net 9 abundance	net 10 abundance	net 11 abundance	net 12 abundance
unidentified eggs	5	0	0	10
unidentified trochophore	0	0	0	0
Hydrozoa	0	0	0	0
Pleurobrachia spp.	0	0	0	0
Nematoda	12	0	24	0
micro Turbellaria	7	13	48	37
Polychaete larvae	0	5	24	10
Nereidae	0	0	0	0
Tubificida	0	0	12	35
Mesopodopsis orientalis	20	5	0	163
Cumacea	0	8	24	60
Tanais spp.	0	0	0	5
Apseudomorpha spp.	0	0	0	0
Apseudes spp.	0	0	0	0
Gnathiidae	2	5	84	79
Munnidae	0	0	0	5
Flabellifera	0	0	0	0
unidentified Isopoda	0	0	0	0
Talitridae	2	3	24	37
Ostracoda	0	15	0	0
Brachyuran crab eggs	0	0	0	0
Brachyuran crab zoea	344	2330	168	1370
Brachyuran crab megalopa	0	0	12	0
Anomuran crab zoea	0	0	0	0
Jaxea spp. larvae	0	3	0	0
Palaemoninae larvae	0	3	0	5
Metapenaeus monoceros	0	0	0	0
Penaeus indicus	0	0	0	0
Penaeus spp. larvae	0	0	12	0
Lucifer spp. larvae	0	3	0	5
nauplii	2691	3321	5101	10504
Calanoida	5351	3527	14739	15710
Harpacticoida	197	255	565	3098
Cyclopoida	1528	971	11333	3530
Copilia spp.	2	0	0	16
Cladocera	0	0	0	0

Appendix C (continued)

taxon	net 9	net 10	net 11	net 12
Chironomid larvae	0	0	0	0
Heleid larvae	0	0	0	0
Dipteran pupal case	0	0	0	0
Entomobryoidea	0	0	0	0
Acari	0	0	0	0
Gastropoda	0	3	0	248
Bryozoa	0	0	0	0
Sagitta bipunctata	2	5	156	42
Oikiopleura spp.	5	0	156	0
Pisces larvae	2	0	12	16

Appendix C (continued)

net	day	time	inflow	outflow	volume filtered (m^3)
13	176	21:50-22:40		*	150.92
14	178	21:15-22:15		*	142.43
15	179	04:20-05:20	*		27.40
16	179	10:25-11:25		*	180.16

taxon	net 13 abundance	net 14 abundance	net 15 abundance	net 16 abundance
unidentified eggs	10	33	0	0
unidentified trochophore	0	0	0	0
Hydrozoa	0	0	0	0
Pleurobrachia spp.	0	0	19	0
Nematoda	14	7	0	0
micro Turbellaria	52	29	77	215
Polychaete larvae	0	4	77	0
Nereidae	0	0	77	0
Tubificida	0	15	0	6
Mesopodopsis orientalis	949	1706	0	0
Cumacea	3	4	19	3
Tanais spp.	0	0	0	3
Apseudomorpha spp.	0	0	19	3
Apseudes spp.	0	0	0	0
Gnathiidae	0	18	134	3
Munnidae	0	0	0	0
Flabellifera	0	4	0	0
unidentified Isopoda	0	0	0	0
Talitridae	45	30	57	3
Ostracoda	14	0	0	0
Brachyuran crab eggs	0	0	0	0
Brachyuran crab zoea	97	4196	3198	4083
Brachyuran crab megalopa	0	0	19	0
Anomuran crab zoea	0	0	0	0
Jaxea spp. larvae	0	0	0	0
Palaemoninae larvae	0	11	172	0
Metapenaeus monoceros	0	0	0	0
Penaeus indicus	0	8	0	0
Penaeus spp. larvae	0	0	19	0
Lucifer spp.	0	0	19	0
nauplii	17161	38306	1283	970
Calanoida	63452	51580	40065	446
Harpacticoida	233	880	2260	108
Cyclopoida	0	0	0	0
Copilia spp.	0	0	0	0
Cladocera	0	0	19	0

Appendix C (continued)

taxon	net 13	net 14	net 15	net 16
Chironomid larvae	3	0	0	0
Heleid larvae	0	0	19	0
Dipteran pupal case	0	4	0	0
Entomobryoidea	0	0	0	0
Acari	0	0	0	0
Gastropoda	0	52	555	0
Bryozoa	0	4	0	0
Sagitta bipunctata	4	40	249	29
Oikiopleura spp.	0	37	172	0
Pisces larvae	0	0	0	0

Appendix C (continued)

net	day	time	inflow	outflow	volume filtered (m^3)
17	259	17:33-18:05		*	150.92
18	259	22:50-23:50	*		11.014
19	260	03:25-04:25		*	70.52

taxon	net 17 abundance	net 18 abundance	net 19 abundance
unidentified eggs	0	0	0
unidentified trochophore	0	0	0
Hydrozoa	0	0	0
Pleurobrachia spp.	0	0	0
Nematoda	10	0	15
micro Turbellaria	146	0	82
Polychaete larvae	0	0	0
Nereidae	3	0	0
Tubificida	7	0	7
Mesopodopsis orientalis	309	11243	953
Cumacea	0	0	7
Tanais spp.	0	0	0
Apseudomorpha spp.	0	0	7
Apseudes spp.	0	0	22
Gnathiidae	0	762	37
Munnidae	0	0	0
Flabellifera	0	0	0
unidentified Isopoda	0	0	7
Talitridae	0	0	0
Ostracoda	3	333	22
Brachyuran crab eggs	0	0	37
Brachyuran crab zoea	0	0	0
Brachyuran crab megalopa	0	0	0
Anomuran crab zoea	0	0	0
Jaxea spp. larvae	0	0	0
Palaemoninae larvae	0	0	0
Metapenaeus monoceros	0	0	0
Penaeus indicus	0	0	0
Penaeus spp. larvae	0	0	0
Lucifer spp.	0	0	0
nauplii	29546	64887	29598
Calanoida	4468	308810	88465
Harpacticoida	59	2858	417
Cyclopoida	671	14292	4062
Copilia spp.	0	0	0
Cladocera	0	0	0
Chironomid larvae	0	0	0

Appendix C (continued)

taxon	net 17	net 18	net 19
Heleid larvae	0	0	0
Dipteran pupal case	0	0	0
Entomobryoidea	0	48	0
Acari	0	0	0
Gastropoda	0	0	0
Bryozoa	0	0	0
Sagitta bipunctata	0	0	74
Oikiopleura spp.	0	0	0
Pisces larvae	0	48	15