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Ecology of *Callianassa filholi* Milne-Edwards 1878 (Crustacea, Thalassinidea)

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Abstract

THE physical features of a sandy beach and their variation throughout the year is described. The variation in population structure of *Callianassa filholi* and its distribution depends on the physical factors, the most important single factor being sand movement. Burrowing behaviour is intimately connected with feeding and respiration, the main food material being a diatom *Chaetocerus armatus*.

INTRODUCTION

Callianassa filholi Milne-Edwards 1878 is a burrowing decapod crustacean inhabiting sandy beaches and also some areas of sandy mud throughout New Zealand (Fig. 1). In this work an outline is given of the physical environment, burrowing, behaviour, population structure, breeding and distribution.

Much of the study was carried out in New Brighton Beach (part of Pegasus Bay, Canterbury) from December, 1961, to January, 1963, and some additional work was done at Otakou in Otago Harbour, Otago, during 1963.

PHYSICAL ENVIRONMENT

1. DESCRIPTION OF PEGASUS BAY

Pegasus Bay has been built up from overlapping sand and shingle fans formed by two large rivers (Fig. 2), the Waimakariri and the Ashley Rivers, and spread by littoral currents.

Scott (1955) has gathered data from offshore surveys and has sampled the sand from various places along the coast, Reed (1951) has analysed offshore sediments, and Garner (1953) has published data on surface salinities and temperatures.

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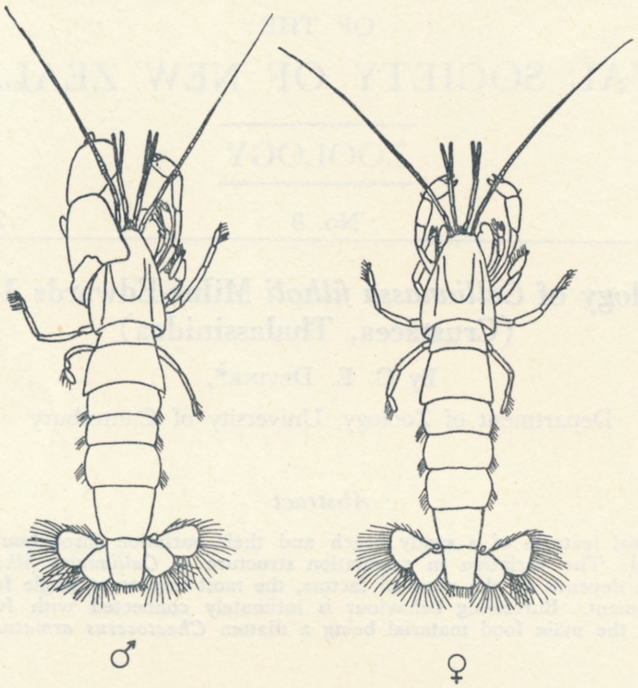

FIG. 1.—Mature male and female *Callianassa filholi* about natural size. Note the large cheliped of the male which is present on one side only.

Dawson (1954) found that the currents in Pegasus Bay are dependent on the local weather conditions. The current off Banks Peninsula is a northwards-moving coastal current. A transient wind-driven surface current moves across Pegasus Bay from the north-east and where it meets the northwards-moving coastal current an eddy is formed.

During northerly and easterly wind conditions, longshore currents move the sedimentary material southwards and build up the beach. With southerly winds, and northwards-moving longshore currents, heavy seas move much material from the beach to beyond the surf zone out of the reach of normal wave action.

2. SAND ANALYSIS AND SAND MOVEMENTS

(a) *Sieve analysis*

Samples of sand were taken at one mile intervals between the New Brighton sandspit and the Waimakariri River, and also at Teviotdale. At low tide level the sand was collected by pushing a 5cm diameter tube into the sand and collecting the top 150cm. The sand samples were analysed using Wentworth grade sieves and the results treated statistically using the Phi notation. When presented graphically (Fig. 3), the various parameters, such as mean grade of sand (Mdϕ), sorting efficiency (slope of curve) and skewness (whether curve is straight or curved between $Q_3\phi$ and $Q_1\phi$) can be found (Inman, 1952; Morgans, 1956). The sand grains were found to be well sorted (Coeff = 0.26); the mean grade of sand varied from 0.13mm at the South Brighton sandspit to 0.25mm both at the Waimakariri River and just north of the Ashley River where the sand suddenly graded into shingle (see Fig. 2). The skewness was zero, indicating that all grades of sand were well sorted. Superimposed on this were variations due to cusp formation and the slope of the beach (Bascom, 1951).

(b) *Film of water retained*

Sand bars and pools of water were often seen on the beach at low tide. During the period the tide was out, the beach became firmer as the water table dropped. Samples of sand about 15cm below the sand surface at low tide level were dried to constant weight. The percentage of water was 22.08%, a figure corresponding to that for many other sand beaches (Reid, 1934).

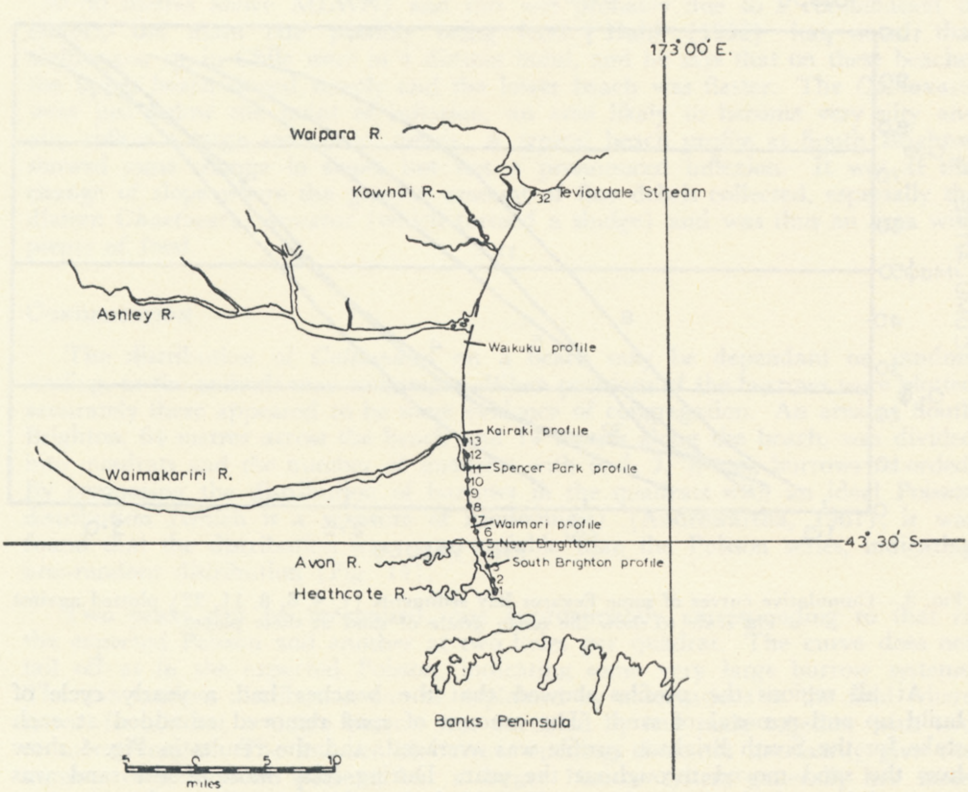

FIG. 2.—Map of Pegasus Bay showing the position of sand profiles and areas where samples of sand were taken.

(c) *Shape and structure of the grains*

The sand grains were described by Reed (1951) as "sub angular, quartz, feldspars and composite rock grains or fragments". The assemblage of minerals showed that the sediments were derived from greywackes from the Waimakariri and Ashley Rivers. Negligible amounts were derived from the volcanic rocks of the Port Hills.

(d) *Instability of the beach*

It is well known that beaches are notoriously unstable but it was not known exactly how variable the beach profiles of Pegasus Bay beaches were and how much they change throughout the year.

Profiles were determined by stakes set up at various regions in Pegasus Bay (Fig. 2). Each profile was derived from six stakes each 2.12m long placed down the beach in a straight line with 0.90m projecting above the surface. They were painted and washers welded at regular intervals for more permanent marks and the stakes related to each other by means of a Quickset level. Records of sand movement relative to the first reading of the stakes were taken weekly from May (26.5.62) to January (13.1.63). The slope of the beach was 0° 36′ at low tide level and 2° 18′ at high tide level for the South Brighton profile.

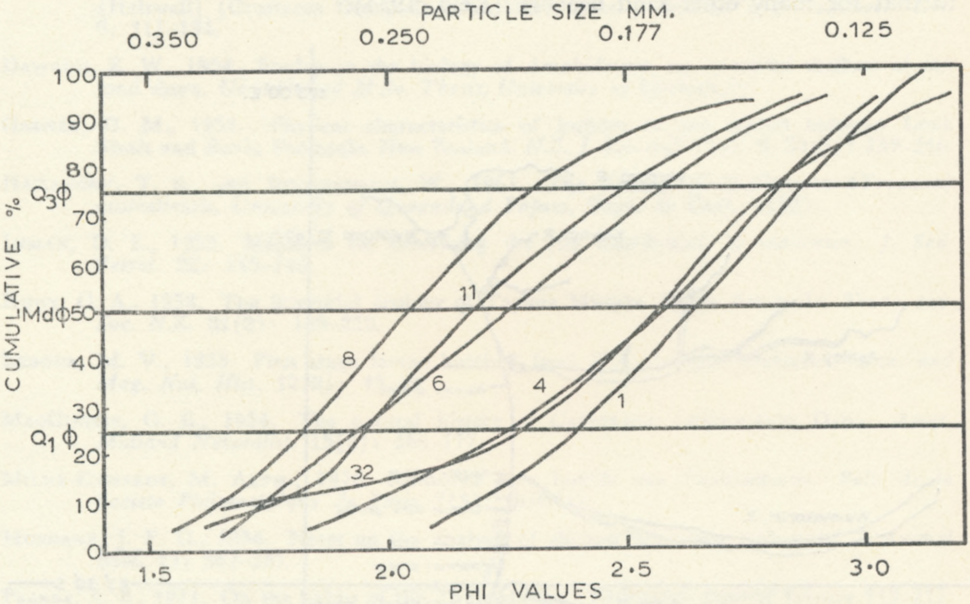

FIG. 3.—Cumulative curves of some Pegasus Bay sediments (1, 4, 6, 8, 11, 32) plotted against a Phi scale to show the mean grade of sand at these places.

At all regions the profiles showed that the beaches had a yearly cycle of build up and removal of sand. The amount of sand removed or added at each stake for the South Brighton profile was averaged, and the results in Fig. 4 show how the sand moved throughout the year. During May most of the sand was removed in a single storm, but at Kairaki during the same storm there was no sand removed at all. The overall effect in Pegasus Bay for the whole year has been a build up of sand.

(e) *Organic content*

The organic content of six samples of surface sand and six samples of sand at 60cm depth were determined by a method described by Morgans (1956). Instead of 1gm samples however, 500gm samples were shaken with water and the fine material in suspension was poured off and allowed to settle out, and the water decanted. The sediment which had settled was oven dried at 120°C. The organic content of the surface sand was higher (0.94%) than the sand at 60cm (0.58%). In the sands where the organic content was determined, there was no black sulphide layer and care was taken to ensure that there were no large particles of organic matter or animals which would have affected the results considerably.

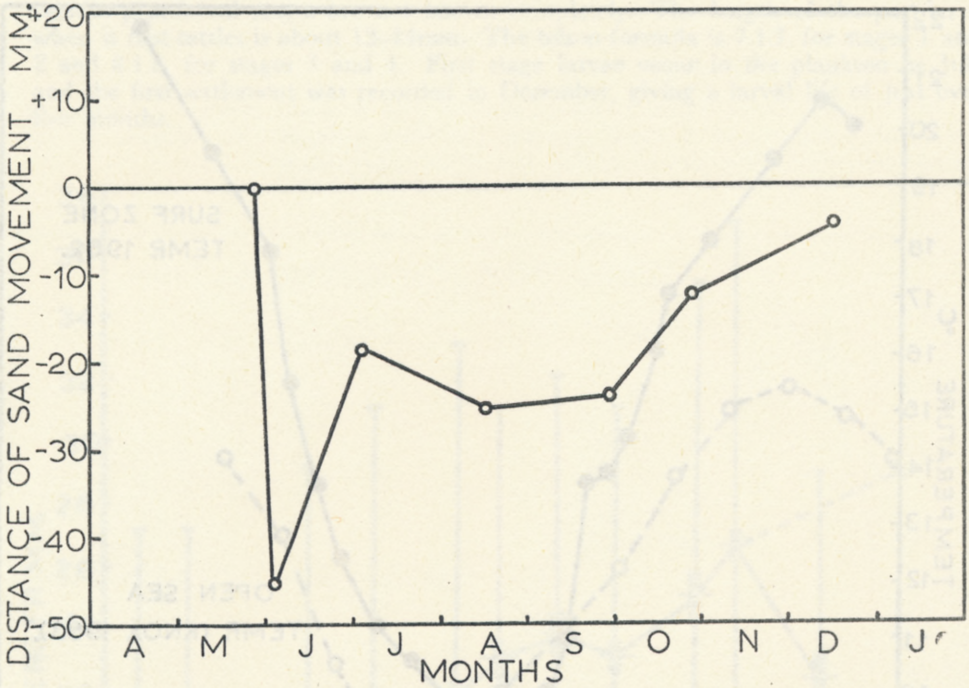

Fig. 4.—The average relative rise and fall of sand from all stakes at the South Brighton profile from March 1962-January 1963.

3. Temperature

Every two weeks readings of sea temperatures with a mercury thermometer to the nearest half degree C. were taken throughout the year at South Brighton beach, and they showed that the maximum and minimum on the sandy beach were more extreme than the open seas off Taylors Mistake (Knox, 1953) (Fig. 5). The maximum temperature measured in the surf zone was about 22.50°C., and the minimum was 8.50°C., giving a yearly range of 14.00°C. The temperature of sand at about 60cm depth would follow that of the open sea (Bruce, 1928), although surface sand temperatures would be influenced by the surrounding air.

4. Salinity

Garner (1953) has shown that the southern parts of the bay were less saline than the northern parts varying about 32.30°/oo–33.00°/oo. At the mouth of the Waimakariri River during the present study there was a lowering of salinity to 18.55°/oo. This would be reduced further by river floods.

Burrowing, Respiration and Feeding

1. Structure and Formation of the Burrows

On the beach, the openings to *Callianassa* burrows are not always clearly visible. Some groups of animals congregated together in a shared burrow system, so each opening seen did not necessarily correspond to an animal. The subsurface layout of the burrows was difficult to determine as any material forced down the

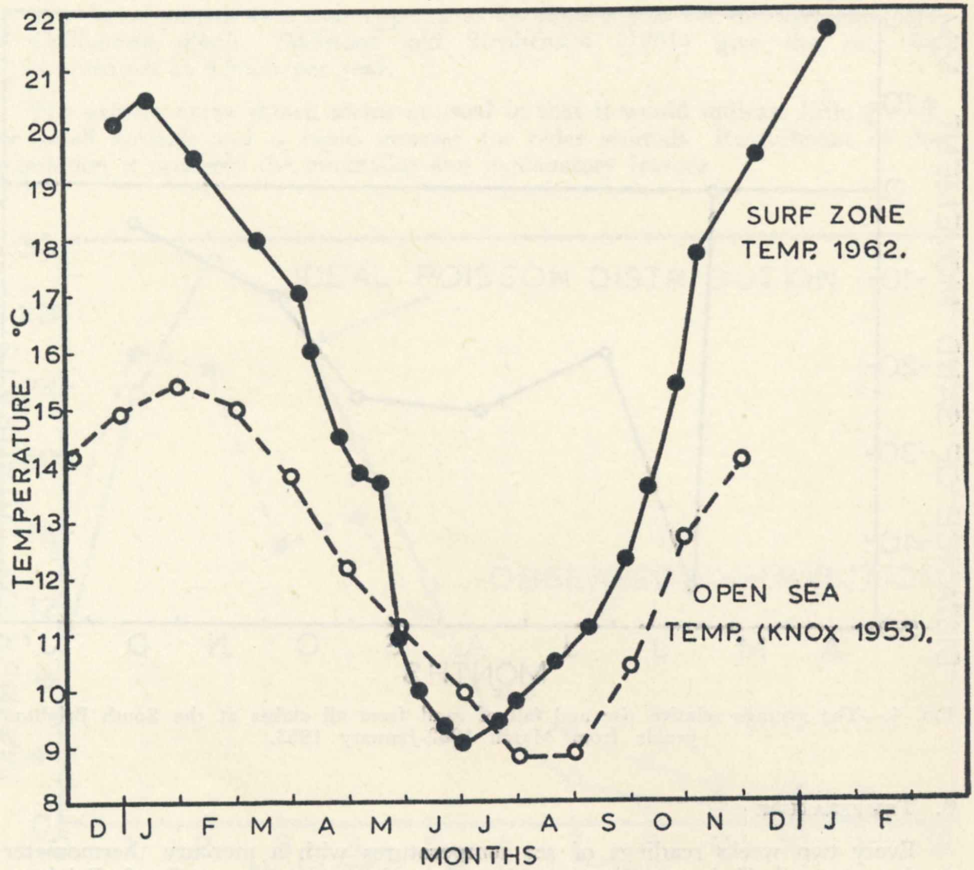

Fig. 5.—Temperature readings taken in the surf zone at South Brighton during 1962-63 compared with the open sea temperatures of Knox (1953).

burrow destroyed the burrow wall causing it to collapse. However, by digging and following the tunnels, and observing the animals burrowing between glass plates in an aquarium, it appeared that the burrows had several vertical openings, each which served as a combination " exit " or " entrance ". When water currents produced by *Callianassa* were forced out of the burrow as the tide was receding " cones " of sand and debris were formed; when water was taken into the burrows bringing sand with it, " erosion craters " were formed. The vertical shaft about 45cm deep leads down to a series of tunnels much wider than the animal's width, which were interconnected at varying depths. At the bottom of the vertical shaft and also at branches in the burrow, turning places were formed. When placed on the sand, *Callianassa* quickly digs itself below the surface as protection against predators. However, on the beach, it is difficult to observe the animals, so more accurate observations were made in the laboratory.

Firstly, using both its chelipeds as a shield to stabilise the sand, *Callianassa* digs into the sand with its second pair of legs. Pushing the sand to one side with its third and fourth legs, it eventually pulls itself below the surface of the sand. Now it proceeds to build a burrow. Digging vertically, using its second legs as a shovel, and its chelipeds to stop sand falling, it transfers the dug sand to the third maxillipeds where a mucous secretion is poured upon it to enable the sand to be used to support the wall of the burrow. It carries sand to the surface in a basket formed by the third maxillipeds, the second and third legs, with the antennules on the top to act as a lid. *Callianassa* slowly burrows down more or less vertically, gathers sand at the bottom, turns around, climbs to the surface and deposits the sand outside the burrow. From this stage, it rarely leaves the burrow.

2. RESPIRATION

In the fairly open branchial chamber, water enters posteriorly and leaves near the antennal peduncle. The *linea thalassinica* on the carapace is a hinge for rapid movements to force water outwards quickly for clearing the gills of debris (Pearse, 1911).

To study the respiratory cycle, apparatus similar to that designed by G. P. Wells (1949) was set up. Basically, it consisted of a glass U tube in a glass container. A division was made in the container making two separate compartments in which the only passage of water between them was through the U tube. An animal placed in the U tube selected one opening as an entrance. It faced the entrance, steadied itself with its legs, and pumped water with its pleopods from one compartment to the other. The water level was raised in one compartment which was recorded by a float attached to a straw beam which traced a line on a smoked drum. The resulting trace gave an indication of how the animal has behaved and consisted of a series of peaks about five minutes apart showing cycles of activity (Fig. 6).

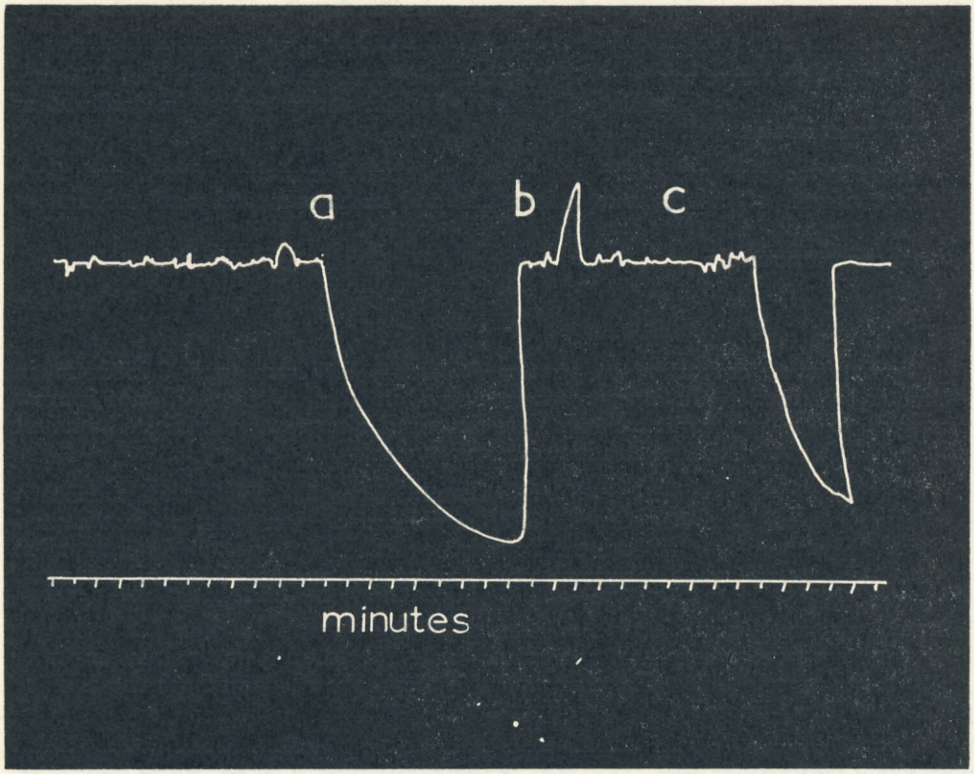

FIG. 6.—Traces on a smoked drum showing behaviour patterns of *Callianassa filholi*. (a) Movements of the pen corresponding to movements of water through the tube (respiratory peak). (b) Backwards movements through the burrow. (c) Spurious movements for cleaning and feeding.

The large downwards movement of the pen corresponded to movements of the pleopods circulating water through the burrow, whilst the animal was holding itself steady in one place (a). After pushing water through the burrow it paused and then moved rapidly backwards through the burrow and gave a peak in opposite direction to the respiratory peak (b). For a while *Callianassa* foraged on the bottom of the tube, (c) gathered detritus and cleaned itself when necessary, and made small peaks on the trace.

At the beach when the tide was coming in and waves trickled over the burrow, water was sucked down the burrow, then after a pause of thirty seconds, water was blown out of the burrow for five to ten seconds after which water was again sucked in for fifteen seconds. The cycle was not regular and was quicker than in the laboratory, where the glass tube was completely covered with water so that the laboratory observations may, in fact, be more indicative of conditions that existed at high tide when the burrows were completely covered.

3. FEEDING

Available food and gut contents

Gut contents were examined from six animals every month. In all cases except the September collection at South Brighton (8.9.62) the diatom *Chaetocerus armatus,* was found in the gut. In the September sample, pinus pollen grains were found. Occasionally another diatom *Nitzschia seriata,* some dinoflagellates, *Ceratium* sp., *Dinophysis* sp., and an unnamed silicoflagellate were found.

Analysis of sand grain size of the gut contents was made using a micrometer eyepiece and the range was from 0–0.03mm with occasional sand grains of 0.10mm. In the substratum, the amount of sand of this size range was so insignificant as to be unmeasurable.

The surface sand from the intertidal zone had the richest fauna and flora which consisted of ciliates, platyhelminthes and nematodes and also the diatom *Chaetocerus armatus.*

The subsurface sand at a depth of 60cm and the surface sand below low tide level had only ciliates and nematodes.

A mixture of carborundum powder 0.275mm, 0.132mm, and 0.0385mm in diameter was made. *Callianassa* when placed on this mixture did not burrow normally, but when the gut contents were examined after two hours a small amount of the 0.0385mm carborundum powder was present.

With all monthly collections of animals, sand from the top 2cm of the beach was taken. In all cases the diatom *Chaetocerus armatus* was present in the sand along with organic detritus and the September sample also contained pinus pollen spores. *Callianassa* must therefore have fed on the surface layer of the sand. The size of the sand grains in the gut indicated that perhaps sorting of food material occurred before it reached the gut of the animal, and the fine grade of carborundum powder ingested confirmed this. *Chaetocerus* was present in large amounts only in the inter-tidal zone and this may have accounted for the absence of *C. filholi* sub-littorally.

Rapsom (1954) found dense quantities of *Chaetocerus armatus* on many North Island beaches. The extremely dense proliferation of diatoms in the open sea during the winter months blew inshore leaving up to 2.5cm on the sand surface as the tide receded. At South Brighton this concentration was never seen but occasionally at Kairaki a 0.5cm layer was seen in a narrow band.

Mechanism of feeding

The sagittal section of *C. filholi* (Fig. 7) shows the medial face of the left appendages. The description of feeding is based on the appendages illustrated together with observations of the animal in a glass U tube into which sand and detritus had been placed.

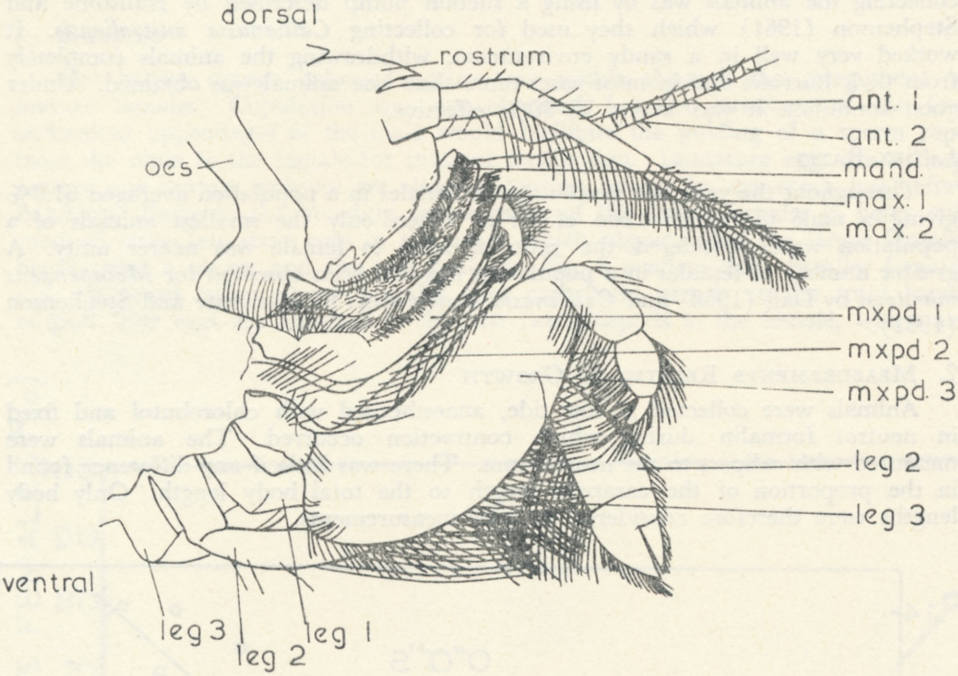

Fig. 7.—Diagram of a medial section through the mouthparts of *Callianassa filholi.* oes, oesophagus; ant. 1, first antenna; ant. 2, second antenna; max. 1, first maxilla; max. 2, second maxilla; mxpd 1, first maxilliped; mxpd 2, second maxilliped; mxpd 3, third maxilliped.

Callianassa scoops sand from the bottom of the U tube with its second leg and flicks it upwards; the shower of falling fine material is sorted by the third maxilliped. The first and second maxillipeds transfer the material to the remaining mouthparts, guided by the end three segments of the modified third maxilliped. This can only happen in relatively still conditions, as water disturbance would disperse the food when it is flicked upwards. The precise functions of the other appendages are not so obvious but the second maxilliped probably traps the food material which is flicked upwards, where it is then combed off by the first maxilliped. A combing action by the second maxilla and first maxilla then takes place, and material is passed on to the fine setae on the mandibles. Food is removed into the mouth by the mandibles and first maxilla.

In a burrow, *Callianassa* collects sand from the face of the tunnel and this sand is worked by the mouth-parts in a similar manner to that just described. It has not been determined whether *Callianassa* feeds on this sand while digging.

Feeding in *C. californiensis* (MacGinitie, 1934) is similar to that of *C. filholi* except that MacGinitie makes no mention of flicking movements.

Such a feeding method allows the use of fine suspended organic matter in the turbid surf zone. The organic matter carried into the burrow by respiratory currents slowly settles on the floor of the burrow.

BREEDING ACTIVITY, AGE, SETTLEMENT AND GROWTH

To study the population structure of *Callianassa filholi* it was necessary to have a reasonably non-biased sample of the population. The best method for collecting the animals was by using a suction pump described by Hailstone and Stephenson (1961) which they used for collecting *Callianassa australiensis.* It worked very well in a sandy environment, withdrawing the animals completely from their burrows and in most cases more than one animal was obtained. Under good conditions it was about 70–80% effective.

1. SEX RATIO

Throughout the year, the percentage of females in a population averaged 61.3% giving a male to female ratio of 1 : 2. When only the smallest animals of a population were considered the ratio of male to female was nearer unity. A greater number of females in a population has also been observed for *Metapenaeus marstersi* by Dall (1958) and *Callianassa australiensis* by Hailstone and Stephenson (1961).

2. MEASUREMENTS RELATED TO GROWTH

Animals were collected at low tide, anaesthetised with chlorobutol and fixed in neutral formalin during which contraction occurred. The animals were measured with calipers to the nearest mm. There was little if any difference found in the proportion of the carapace length to the total body length. Only body lengths were therefore considered in later measurements.

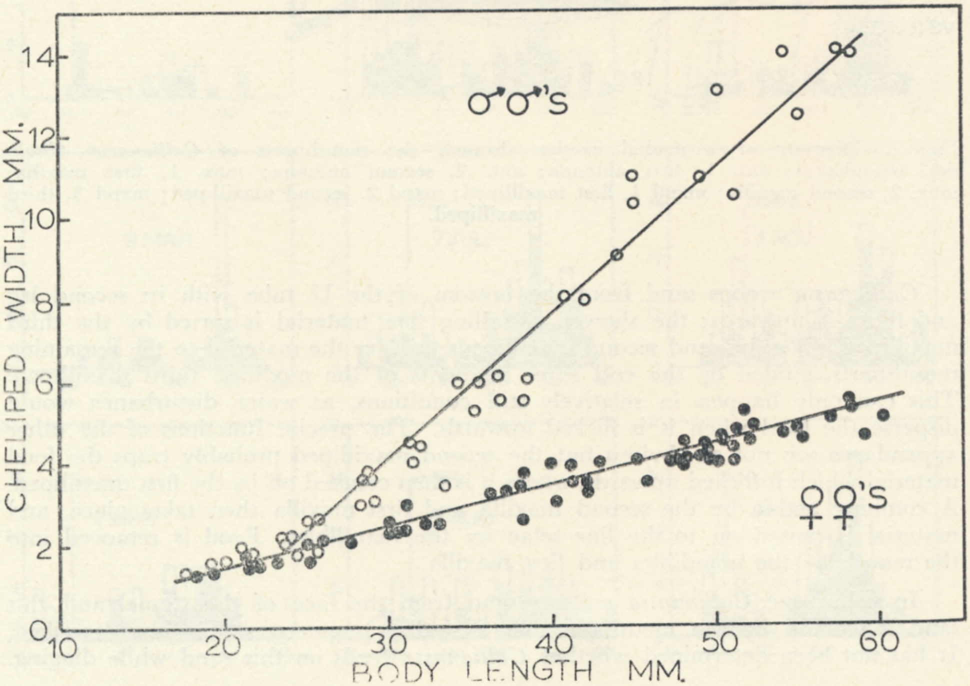

FIG. 8.—Graph of the widths of chelipeds plotted against body length of *Callianassa filholi* to show increase of size of the cheliped in the males during growth.

The curves (Fig. 8) show a differentiation between males and females due to the difference in widths of the propodus of the chelipeds, a secondary sexual characteristic which is shown by males when reaching about 22mm in length. The function of the large cheliped is unknown, but it may be used in fighting. Sexual maturity appears some time after the animals have reached this length and the first egg laying is accomplished at 33mm. *Callianassa australiensis* shows similar sexual dimorphism (Hailstone and Stephenson, 1961).

3. BREEDING

The bright orange coloured ovary was visible through the integument in mature females. Copulation was not observed, but the structure of the first abdominal appendages of the male would facilitate the guiding of a sperm rope from the male to the female for internal fertilisation. Immature eggs are a deep orange, and mature embryos are almost colourless, except for eye spots, just before hatching. Early in the breeding season, most of the larger females in berry still retained some late stage eggs in the ovary which suggests that the larger females breed twice a season and the two peaks in Fig. 9 confirm this. Smaller females did not breed twice a year nor did they contribute greatly to the total larval output. The eggs are attached to the first two pleopods in the female, which are

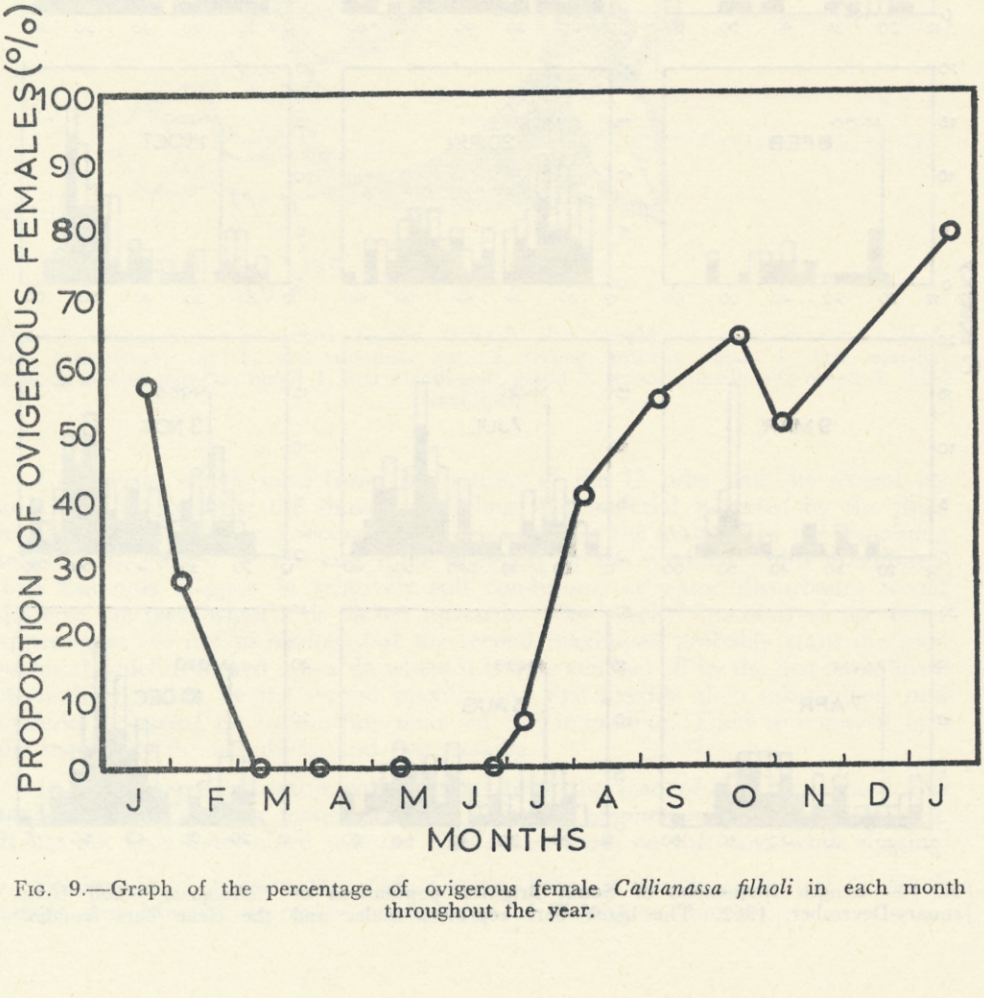

FIG. 9.—Graph of the percentage of ovigerous female *Callianassa filholi* in each month throughout the year.

modified for this purpose, but often the remaining pleopods carry some eggs in the larger females. Egg numbers ranged from 660 for a 37mm female to about 1,500 for a 54mm female.

Egg laying began in early July at New Brighton Beach and continued to the end of February. In Wellington Harbour, first stage larvae were found in the plankton in July (R. Wear, pers. com.) whereas at New Brighton Beach the females were first found to be in early berry in July. Aquarium observations showed that eggs were carried for a period of five and a-half weeks. Hailstone and Stephenson (1961) recorded an incubation period of six weeks for *C. australiensis* which corresponds closely to that for *C. filholi*.

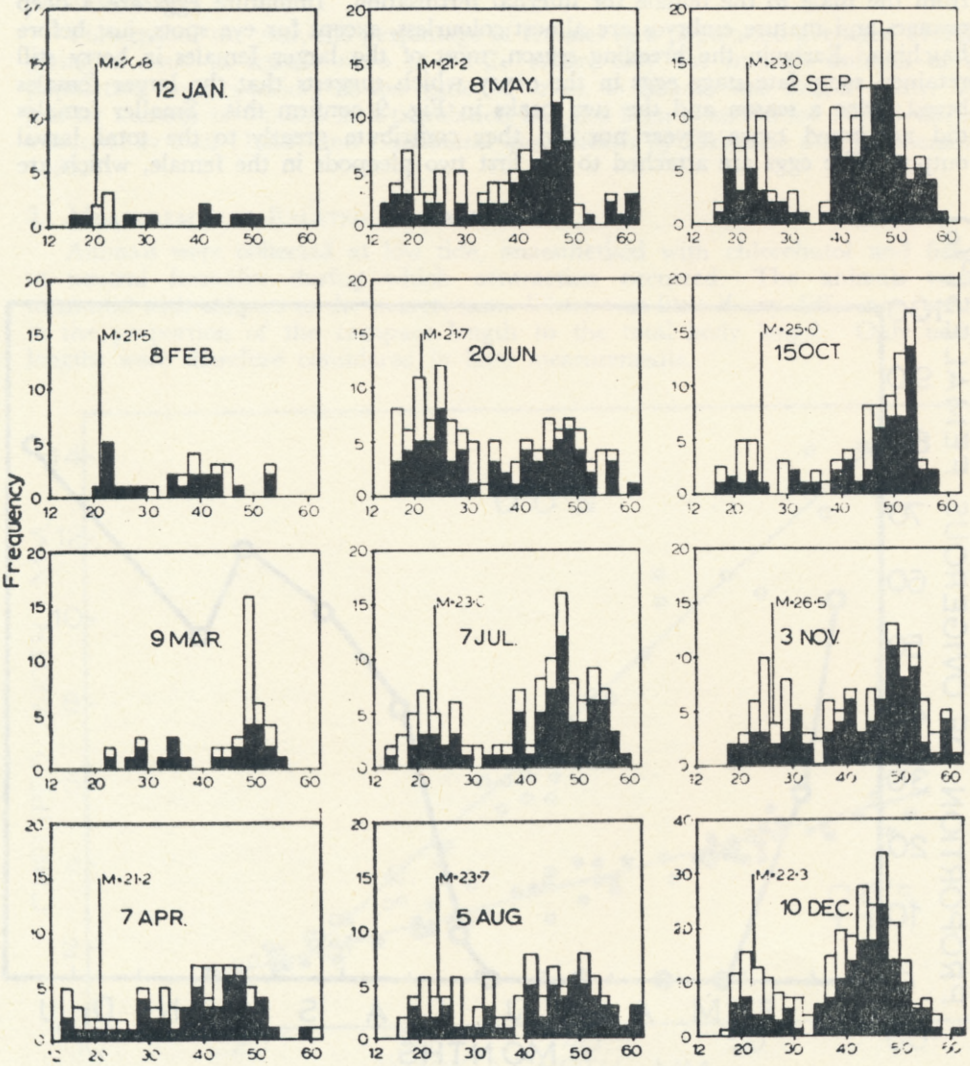

Fig. 10.—Length frequencies of South Brighton populations of *Callianassa filholi* from January-December, 1962. The black bars represent males and the clear bars females.

AGE, SETTLEMENT AND GROWTH

About one hundred animals were collected every month from South Brighton and two samples were compared with two population samples from Kairaki, 11 miles north (Fig. 12). The lengths of *Callianassa* were measured after fixation with calipers to the nearest mm and frequency histograms were plotted using 2mm class intervals (Fig. 10). The curves were also plotted on probability paper using cumulative probabilities (Cassie, 1954) and the means obtained were graphed to show the pattern of growth throughout the year (Fig. 13).

1. *Age determination*

The length frequency histograms for collections made at South Brighton show two distinct year classes for each monthly record. The older peak is larger than the younger one. While sampling bias is present and cannot be avoided it would be unlikely to produce the trend shown. When the July results are expressed as histograms (see Fig. 10) two age groupings are present, but when plotted on probability paper (Cassie, 1954) (Fig. 11) evidence is shown of a third year class which is otherwise obscured. The July population thus has three apparent age classes, a result which can also be shown for all other monthly samples. The first year class ranged from 14mm to 29mm, the second year class from 29mm to 45mm, and the third year class from 45mm to 50mm. Larger animals may belong to a fourth year class, the largest recorded being 65mm.

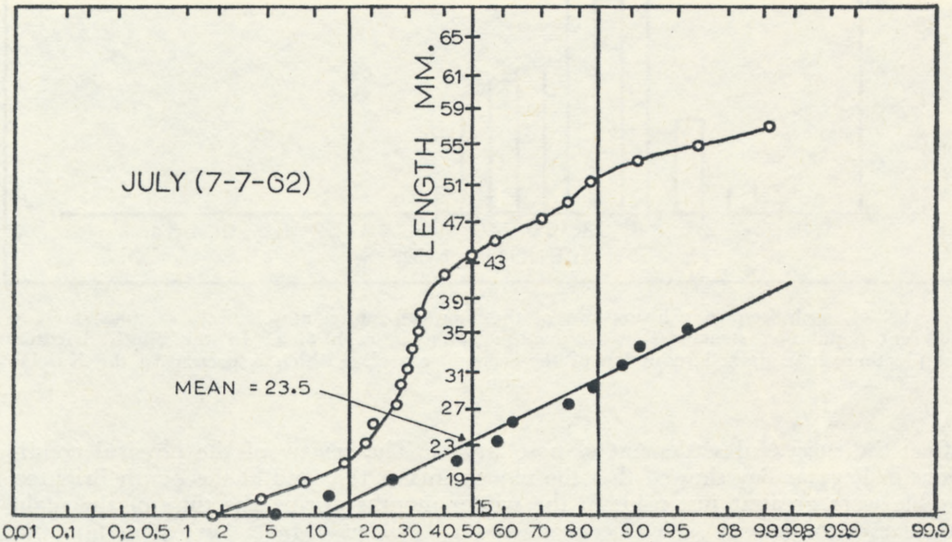

FIG. 11.—Cumulative frequencies per cent versus length of animals for the July collection of *Callianassa filholi,* showing three age classes. An inflexion indicates a separation of one year class from the next. The mean length of the first year class is shown as 23.5mm.

When a length frequency histogram of Kairaki population (18.9.62) is compared with that of a South Brighton population (10.9.62) there is a marked difference. In the Kairaki population, there is a peak where a possible year class is missing in the South Brighton population (Fig. 12). Also the Kairaki population has a poor representation of the first and last year classes. It is unlikely that a population of *Callianassa* would have a mean growth rate of 24mm in one year so it is possible that some variable factors present during different years could

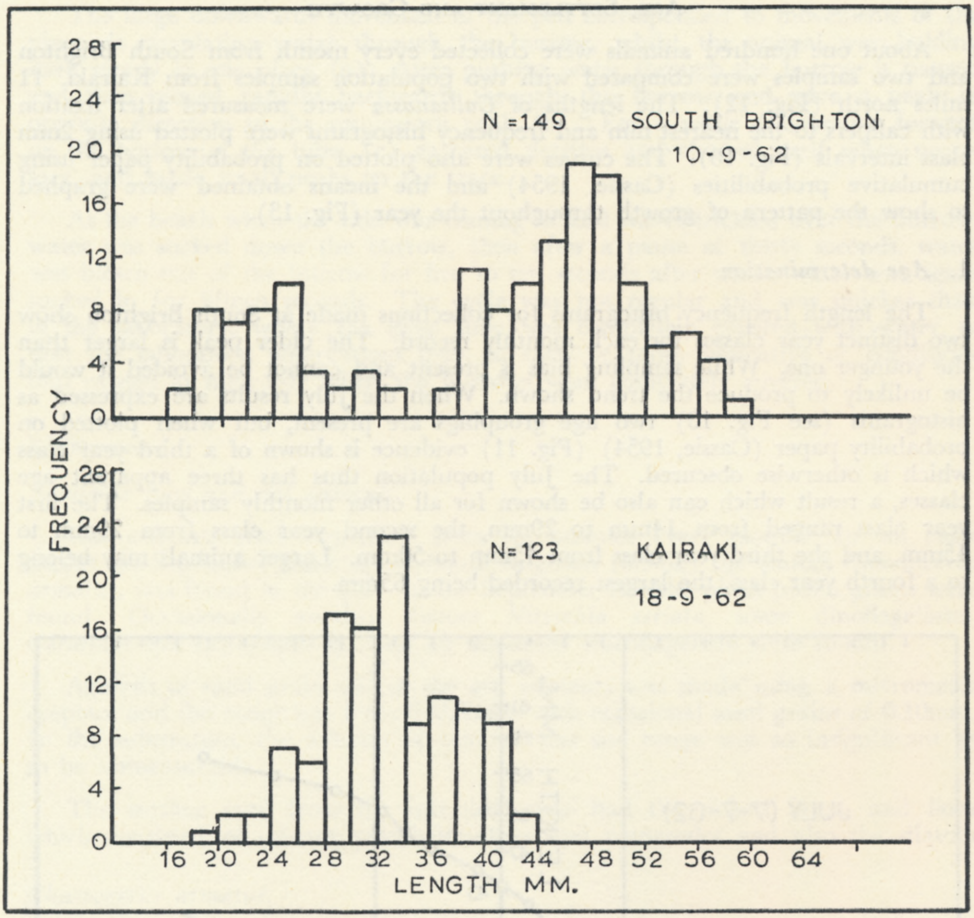

FIG. 12.—Length frequency histograms of the South Brighton and Kairaki samples showing different population structures of *Callianassa filholi* in each area. In the South Brighton sample there is a marked reduction of the second year class which is present in the Kairaki sample.

affect the successful settlement of post larvae. The review of the physical conditions in Pegasus Bay showed that the movements of the sand at the South Brighton profile were greatest just prior to the winter months during the time of the main post-larval settlement, which occurred about April and May. An explanation put forward is that the settling post-larvae were profoundly influenced by sand movements and unfavourable currents during this period. Because conditions were not identical at Kairaki and South Brighton, it is postulated that when sand was removed at South Brighton but not at Kairaki there would only be successful settling at Kairaki. This pattern is not identical every year and this would account for the variation in year classes.

2. *Growth and settlement*

Some twelve hours after hatching the prezoea moults to the first larval stage, 3mm long described by Lebour (1955). The second, third, fourth and fifth larval stages are 4mm, 5mm, 6mm, and 7mm long respectively, but the lengths of the various post-larval stages are not known completely. The length of the post-larva when it first settles is about 12–14mm. The telson formula is 7.1.7. for stages 1 and 2 and 8.1.8. for stages 3 and 4. First stage larvae occur in the plankton in July and the first settlement was recorded in December, giving a larval life of just over five months.

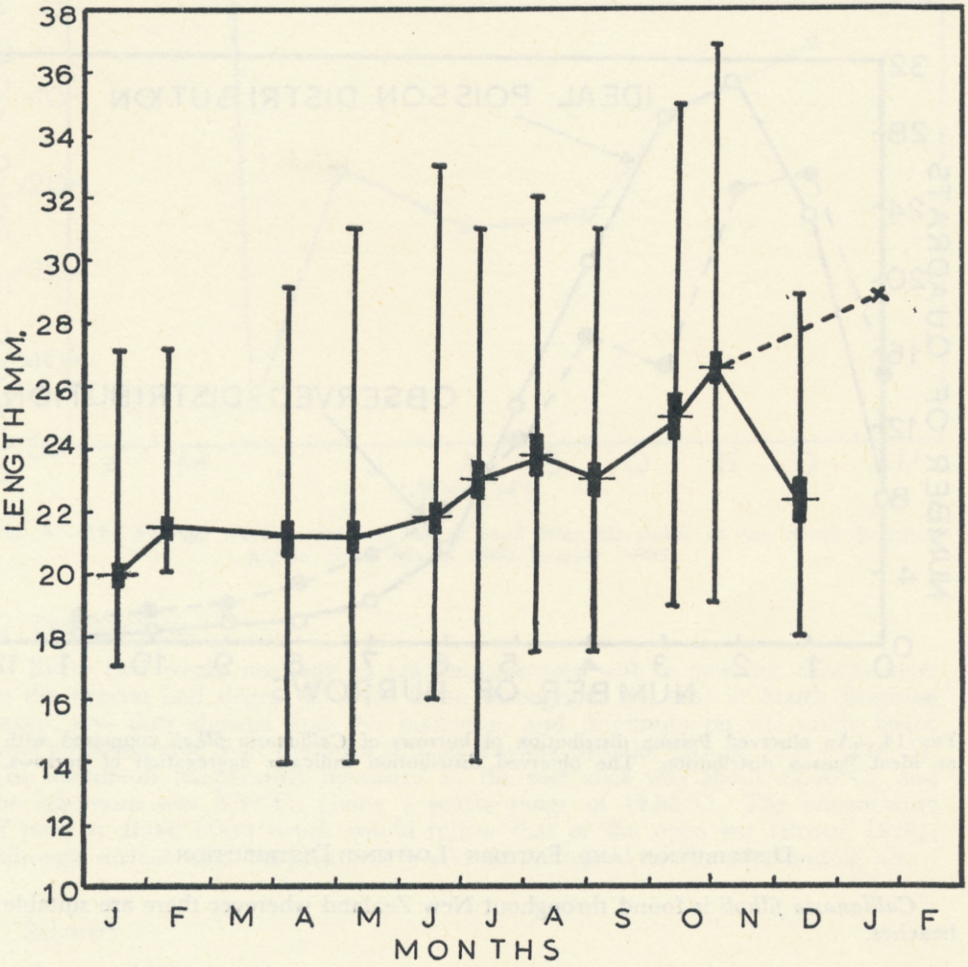

FIG. 13.—A graph of the range, standard deviation and mean lengths of the first year class of *Callianassa filholi* from January 1962-January 1963.

Fig. 13 shows the range, standard deviation and means of the youngest year class of *C. filholi.* The general trend indicated is for a very slow increase in the mean over the period January to July, and then a more rapid increase in later months. The slow progression of the mean was probably due to continued recruitment to the first year class, the more rapid shift of the mean after June occurred when most of the settling had been accomplished. The sharp drop in December was probably due to the influence of the next first year class. In January following, there was an indication of a new year class appearing, and the mean of the now second year class is joined by the dotted line.

The mean growth rate thus appears to be 8mm a year for the first year class of *Callianassa filholi*. Hailstone and Stephenson (1961) give the rate for *C. australiensis* as 9.5mm per year.

The growth curve shown seems unusual in that it would indicate little growth for small animals and a rapid increase for older animals. Recruitment of the population is probably the modifying and explanatory feature.

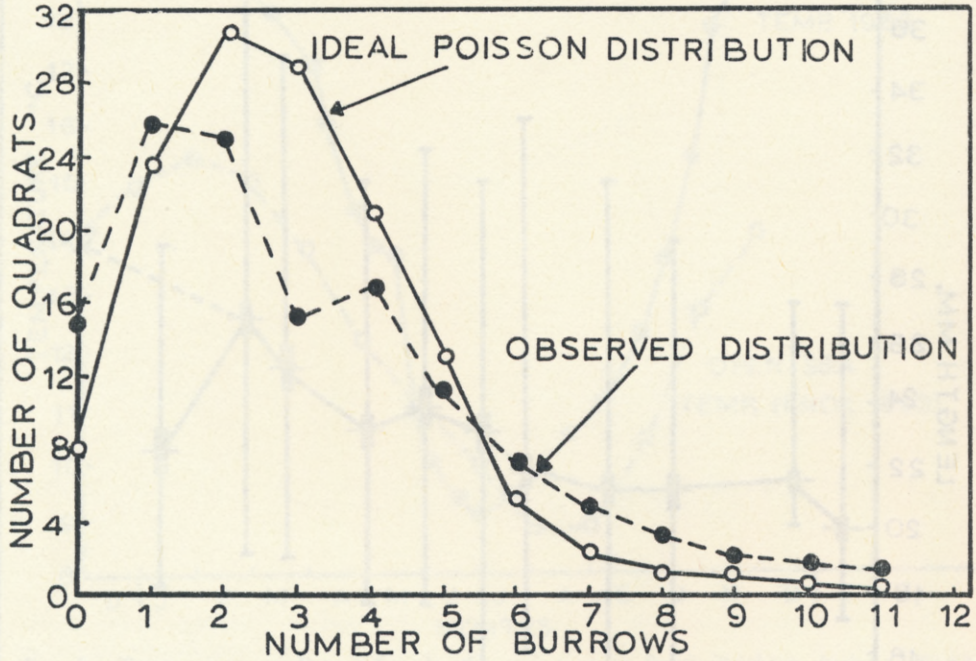

Fig. 14.—An observed Poisson distribution of burrows of *Callianassa filholi* compared with an ideal Poisson distribution. The observed distribution indicates aggregation of burrows.

Distribution and Factors Limiting Distribution

Callianassa filholi is found throughout New Zealand wherever there are suitable beaches.

C. filholi and *C. ceramica,* an Australian species, are possibly very closely related (Chilton, 1906) and *C. filholi* may have been derived from *C. ceramica.*

The profile of a sandy beach is continually changing due to sand movements, thus the broad terms high, medium and low tide are all that are considered necessary.

The presence of *Callianassa filholi* in any area was determined by recognising the openings to the burrows which resembled either cones or craters. In Pegasus Bay, the horizontal distribution was almost continuous except in sand areas adjacent to river mouths and where sand graded into pebbles.

There appeared to be no correlation of numbers of animals with temperature, salinity or grade of sand and *Callianassa* has been found in estuarine areas and extensive mud flats such as Marakopa Estuary (Wood, 1962) and Otago Harbour. The most important limiting factor in the distribution was the instability of the sand with respect to removal by wave action. In an area approximately 500 square metres there were 47 holes at South Brighton and 117 holes at Kairaki.

VERTICAL ZONATION ON A BEACH

When present in sufficient numbers to indicate distribution patterns, *C. filholi* was present from 3 metres below low tide level to just above half tide level. On South Brighton beach, this was a strip of beach about 90 metres wide.

The greatest concentration of animals was in the middle portion of the beach (50–60 metres above MLWN) and this was probably due to a combination of factors, the main one possibly being food. Dahl (1952) has noted that *Callianassa* sp. in Chile were in a distinct band, and he says that on these beaches the upper beach sloped steeply and the lower beach was flatter. The *Callianassa* were just below the point of inflexion, an area likely to become very silty and also collect a large amount of debris. A typical beach profile at South Brighton showed some change in slope, but not a pronounced inflexion. It was at this change of slope where the greatest amount of fine debris collected, especially the diatom *Chaetocerus armatus* (which formed a sludge) and was thus an area with plenty of food.

CONGREGATION

The distribution of *Callianassa* on a beach may be dependant on random settling, or the animals may congregate. When positions of the burrows were plotted accurately there appeared to be some evidence of congregation. An area at South Brighton, 64 metres across the beach and 14 metres along the beach, was divided into quadrats and the number of quadrats with 0, 1, 2, 3, etc., burrows recorded. By comparing the distribution of burrows in the quadrats with an ideal Poisson distribution (which is a measure of randomness) (Andrewartha, 1961), it was found that the distribution was more variable than the Poisson series, indicating non-random distribution (Fig. 14).

Two peaks can be recognised, one approximately corresponding to that of the expected Poisson and another at two holes per quadrat. The curve does not tail off as in the expected Poisson, indicating some very large burrow systems. The non-random distribution can be explained by observations in the field where it was found that a single burrow was occupied by one male together with two or more females. The number of burrow openings does not necessarily give the number of individuals present, but a larger burrow system generally has more animals. When collecting the animals with the suction pump, many more openings became visible as sand was sucked down into the burrow from these other openings.

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