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Quantitative Studies of Copepods in Hawaii with Brief Surveys in Fiji and Tahiti

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INTRODUCTION

The investigations recorded in this paper relating to Hawaii were conducted during the period from September 22, 1931 to September 21, 1932, with the purpose of determining the amount of potential food expressed in numerical quantity of marine free swimming copepods available at certain localities in the shoal waters about Oahu. That the paucity or abundance of copepods might be correlated with insignificant or luxurious growth of other invertebrates which depend largely upon these minute organisms for their subsistence, was also a consideration of the inquiry.

A similar but brief survey was made in Fiji during February 1933 and in Tahiti during April of the same year. These results are presented for comparison with those of Hawaii.

It is generally conceded that marine copepods are an important source of food for many higher animals of the sea, both invertebrate and vertebrate. Ranging in length from a fraction of a millimeter to several millimeters when adult, free swimming copepods are quite universally dispersed in the oceans from the surface to depths of several hundred fathoms. These minute crustaceans exhibit marked tropisms, their response to light having been the subject of much investigation. Copepods are usually repelled by light rays of high intensity but exhibit a positive reaction to weak light. As a result, where depth of water permits, daily vertical migrations may occur, the organisms being less abundant in the upper strata of the ocean

[1] For synopsis of the Hawaiian investigations, see: Hawaiian Acad. Sci., Proc., B. P. Bishop Mus., Spec. Pub. 20, 1932; Fifth Pacific Sci. Congr., Proc., 3:1997-2001, 1934.

during the day than during the night. Diurnal and nocturnal towings from the surface and under surface waters have revealed that species of copepods collected near the surface at night may be taken at depths of from 200 to 400 fathoms during the day. At these lower levels in the ocean, light rays of the midday sun are appreciated but slightly, if at all. Researches have shown, however, that exceptions should be made to the above generalization regarding vertical migrations since the phototropic response of different species of copepods shows considerable variation.

In shoal waters immediately surrounding a land area or under conditions persisting on a fringing reef where the maximum depth of water may not exceed one or two fathoms, the situation is different from that of the open sea. On a shoal reef the rays of the sun are capable of penetrating to the bottom of the water with slightly diminished intensity. It is not possible, therefore, for copepods of near shore waters to escape the influence of light during the day by any extensive vertical migration. If they disappear it must be by reason of lateral migration or through concealment near the bottom during the period of greatest light intensity.

In the shoal waters about Oahu, animals which probably depend largely upon copepods for food include corals, hydroids, sea anemones, medusae, jelly-fishes, and others of the coelenterate group. These tentaculiferous animals are capable of paralyzing small organisms like copepods by means of their stinging cells and drawing them into their digestive tracts. Numerous other animals are probably casual feeders upon copepods. Plankton-feeding fishes, as the mullet, doubtless derive considerable nourishment from ingested copepods.

Nearly all species of shoal water corals and some other coelenterates are hosts of unicellular algae (Zooxanthellae) which they hold within their tissues. This relationship is without doubt a symbiotic one of mutual advantage to both animal and plant. The work of Yonge[2], however, indicates that coelenterates are carnivorous forms, their digestive cavities lacking the enzymes necessary for starch metabolism. The conclusion follows that the algae cannot serve as food for the coelenterate host. This view is in opposition to that held by Boschma[3] who has contended that the Zooxanthellae

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[2] Yonge, C. M. Studies on the physiology of corals II: Digestive enzymes. Great Barrier Reef Exped., **1** (3), 1930.

[3] Boschma, H. On the feeding reactions and digestion in the coral polyp *Astrangia danae,* with notes on its symbiosis with Zooxanthellae. Biol. Bull. **49**:407-439, 1925.

may be utilized by their animal host if the normal source of nutrition is eliminated. My own observation in experimental feeding tests with corals is that while the coelenterates may completely ingest certain plant tissues, in all instances the plant material is regurgitated in an apparently undigested form after periods ranging from a few minutes to several hours.

It is an observable fact that corals depend primarily upon minute animals for their food, copepods being the chief supply. That copepods are readily captured and devoured by medusae is observed in the feeding habits of species of *Eleutheria* or creeping medusae, which are abundant among *Ulva* and other sea weeds about the shores of Oahu. These minute medusae may be seen ingesting copepods as large as themselves, becoming greatly distorted in the process, and at the same time holding two or three other copepods within the grasp of their tentacles.

Corals and other coelenterates show more active feeding responses at night than during the day. In weak light, the polyps become expanded with the tentacles extended in search of food. They may also become fully expanded during the day when occupying a dark corner or shaded position in the aquarium. There is probably a correlation, in point of time, between the feeding response of coelenterates and the maximum activity of shoal water copepods.

No attempt in these investigations was made to distinguish between genera or species of copepods for the purpose of enumeration. Specific determination of the specimens counted has not yet been made. Probably a dozen species form a majority of the copepods in circulation in the shoal waters of Oahu, and half as many genera, some of which were recognized.

METHODS

In collecting copepods for quantitative work the pouring method was used. A galvanized pail having a capacity of 11 liters served as a container for picking up samples of water from the surface, this quantity being the standard from which all surface counts were made and upon which all bottom counts were estimated. The contents of the pail were poured through a No. 25 silk bolting cloth net with a six ounce bottle attached in which the copepods were concentrated. After adding a few drops of 40 percent formaldehyde the contents of the bottle were permitted to settle for a few hours.

The water was then partially decanted and the residue poured into a test tube and again decanted after the deposition of the suspended matter was complete. The concentrate was then transferred to a watch glass and from there to the counting plate by a pipette.

The counting plate consisted of a narrow trough with three sides of moulding wax on a three by four inch glass plate. The trough, three inches long, one fourth inch wide and one sixteenth inch deep was open at one end to facilitate emptying. Rapid counting of copepods was made possible by moving the counting plate along on the stage of a binocular microscope.

Where large numbers of copepods were present, estimates of the total were made by actual counts of about one fourth the quantity. Parallel counts indicated that the error was not great.

A water bottle with a capacity of one and one fifth liters was devised for taking samples under the surface up to depths of a few fathoms. It was used with considerable success in water from two to eight fathoms deep.

Samples of water were taken during a period of one year, from September 22, 1931 to September 21, 1932 inclusive. At Station A, Waikiki Reef, counts were made on an average of 2.4 times daily throughout the year; at other stations samples were taken at irregular intervals.

STATIONS ABOUT OAHU

The base station, Station A on Waikiki Reef, was the primary one from which collections were made. It was at the end of a stone pier extending 100 feet into the water from the wall at the rear of the Marine Biological Laboratory. At extreme high tide, the water was about one fathom in depth at the end of the pier. Station A was selected for its convenience as it is the only point of vantage in the vicinity from which off shore samples of water may be quickly picked up. The station is within 50 feet of living colonies of coral and far enough from the shore to avoid dilution of water by fresh water outlets in the immediate locality. Although the station was a convenient one from which to work it also had its disadvantages. The shallow depth resulted in considerable turbidity with an incoming tide which doubtless affected the distribution of copepods. While the station is within the innermost coral zone of that section of the reef the nearby colonies of corals are stunted in their growth, having the appearance of being starved, although this condition may not be attributed wholly to lack of food.

Although Station A may not be considered the most favorable locality from which to obtain data regarding the circulation of copepods on Waikiki Reef the records which follow indicate the maximum single count of all samples taken on the reef to be from this station.

In addition to Station A, seven other stations were established on Waikiki Reef from which samples were taken at infrequent intervals. The bottom of this section of the reef is well covered with fragmented dead coral blocks and debris. A luxuriant growth of marine algae is found here and about 20 species of corals are represented by small and scattered colonies.

Station B, marked by an iron stake set in the reef, is 100 yards to the west of Station A and slightly farther from shore. The depth of water here is less than at the base station. Stations C and D are in a straight line extending outward from Station B toward the edge of the reef platform. Station D, marked by an iron stake, is about 150 yards from Station B and Station C is half way between the other two. Station 5 is 100 yards east of Station D and is marked by an iron stake. Station 4 is half way between Stations D and 5. Stations 6 and 7 are in a line extending from Station 5 toward the shore, Station 7 being nearer the shore and marked by an iron stake. Station 6 is half way between Stations 5 and 7. Stations B, C, D, 4, 5, 6, and 7 form a rectangle on the reef, Stations D, 4, and 5 being well out on the reef platform in water somewhat more than a fathom in depth at high tide. Here is a maximum growth of coral for this section of the reef.

A station was established at Pier 2 which marks the east boundary of the channel entrance to Honolulu Harbor. Here the water is about eight fathoms in depth and a comparison of surface and bottom distribution of copepods was permitted.

During the year, nearly 100 samples were taken from Pearl Harbor. The Navy Pier in the Middle Loch was considered one of the principal stations for leeward Oahu. Although the water here was less than two fathoms in depth at high tide, some remarkable differences in distribution of copepods between surface and bottom were noted. A few counts were made from samples taken from the surface at a small pier near the railway station of Aiea in the northeastern section of the East Loch.

Because of the muddy character of the bottom of Pearl Harbor in the regions where samples were taken, no corals exist. The principal forms of sessile animals here are oysters, sponges, ascidians, barnacles, hydroids, and bryozoa which thickly cover the submerged portions of piling, floats, and buoys. Medusae, ctenophores, and at times huge jelly fishes abound in the surface waters. Fishes are plentiful.

On the windward side of Oahu, Kaneohe Bay was made the center of investigations. In all, 78 samples were taken during the year from various sections of this large body of water. Series of samples were examined taken from several localities on the southern shore of the bay and along lines converging on Cocoanut Island. A muddy bottom is typical near shore with shoal reefs alternating with deep channels farther out in the bay.

A station was established at the pier of the Territorial Fish and Game Farm in the northeast section of the bay and samples were taken on a north reef of the bay approached from Mokapu Peninsula. In Kaneohe Bay are some of the most luxuriant growths of coral to be seen about Oahu. It was possible to make counts of copepods from water close to actively growing coral colonies, over sand and mud-covered shoals and from the surface and bottom of channels four to six fathoms in depth. In addition to corals a very rich fauna inhabits Kaneohe Bay.

Besides Kaneohe Bay, localities on the north and west sides of the island from which samples were taken include the open reef of Kaaawa, Kawela Bay, and Maile Point. A few collections were also made in Hanauma Bay at the southeastern point of the island.

In all, 1,298 samples of water were examined and counts of copepods made during the year from 21 localities about the island of Oahu, the principal ones being Waikiki, Pearl Harbor, and Kaneohe Bay.

DISCUSSION OF RESULTS

It is obvious from a summary of the investigations on Waikiki Reef that there is a general paucity of copepods circulating in the surface waters of this area. This conclusion seems to be established by counts from 877 samples taken at Station A, as well as by results from seven other stations on the reef. Of the total number of samples from Station A, 253 were taken between the hours of 6 A.M. and 10 A.M. and 119 after 6 P.M., 84 of these being between 6 P.M. and 8 P.M. Of the remaining 505 samples, most of them were collected between the hours of 12 M. and 6 P.M. during which period the greatest amount of heat is accumulated in the upper strata of water. The total number of collections from Station A were, it is believed, sufficiently distributed during the hours of the day to give a fairly accurate enumeration of copepods circulating in the surface waters near shore. (See table 1.)

Table 1.—Number of copepods per 11 liters of water at Station A, Waikiki Reef, from Sept. 22, 1931 to Sept. 21, 1932 inclusive.

	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
No. of samples	27	57	73	61	51	48	49	79	94	88	70	133	47
Average no. of copepods	12.8	11	7	7.7	3.7	8	14	8	13	5.7	8	5.3	3.7
No. of samples 6 A.M.–12 M.	6	12	25	15	9	7	2	22	30	36	34	76	18
Average no. of copepods	15	12	8.4	5.4	3.7	7	24	10.8	18.2	6.9	11.3	6.3	3.8
No. of samples 12 M.–6 P.M.	4	21	39	41	42	40	45	53	56	34	31	24	18
Average no. of copepods	5	7	7.5	9.3	3.6	8	13.7	7.1	10.4	5.4	4.6	3.8	3.9
No. of samples 6-12 P.M.	17	24	9	5	0	1	2	4	8	18	5	33	11
Average no. of copepods	15	14	7	17.6	0	2	7.5	4	13.3	3.9	2.4	3.4	3
Max. no. in one sample	90	44	29	73	11	24	80	60	85	22	38	42	11
Min. A.M. temp. in degrees C.	25.6	24.8	23.5	21	22	21	23.2	22.3	23	24	24.3	25	24.8
Max. P.M. temp. in degrees C.	28.1	29	27	25	26.8	26	27.2	27.1	27.1	28.2	28.4	28.2	28.6

Tabulations by month show, in general (during 8 months) that the maximum count of copepods occurs in the early morning or early evening. Two peaks as a rule, occur during 24 hours, one between 6 A.M. and 8 A.M. and one between 6 P.M. and 9 P.M. Certain exceptions to the general rule, however, were noted. During March, the maximum number of copepods per 11 liters of water occurred at 12 M. on the first day of the month. The day was dark with a heavily overcast sky.

Studies of collections from Station A with observations on the level of the surface of the sea usually indicate a general dearth of copepods in the shoal waters during high tides. Increased turbidity at this time because of suspended material doubtless acts as a repellent to circulating organisms. Some exceptions, however, were noted. The relatively high count of March 1 at 12 M. was made at high tide. During the last week in May a larger number of copepods than usual appeared at Station A regardless of the condition of the tide.

Twice during the year, April 16-17 and August 15-16, the number of copepods per liter of water was determined at Station A hourly, for 24 consecutive hours. A detailed study of these two periods is significant in that it verifies, in general, the results of collections taken throughout the year. High morning and evening peaks were observed and a relatively small number of copepods at high tides. (See figure 1.)

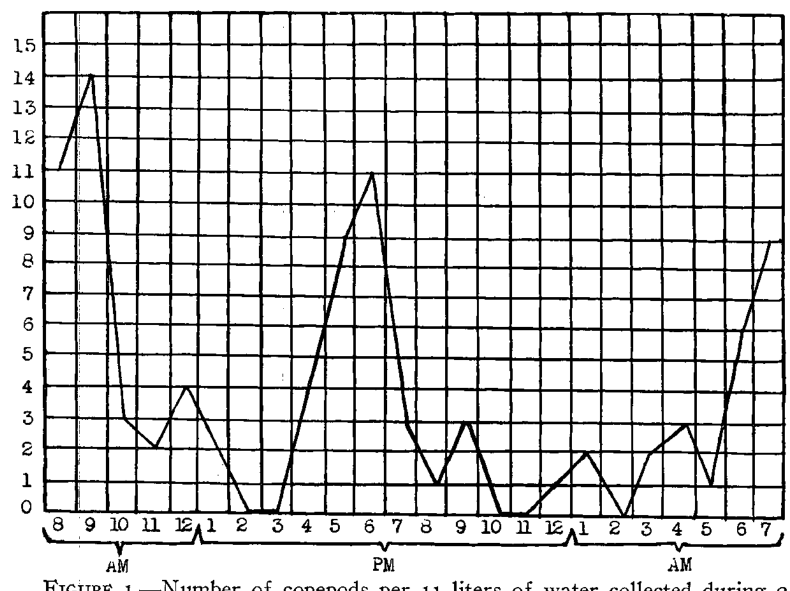

FIGURE 1.—Number of copepods per 11 liters of water collected during 24 consecutive hours at Station A, Waikiki Reef, August 15-16, 1932. Abscissa represents hours; ordinate, number of copepods.

Collections made at other stations on Waikiki Reef were too unevenly distributed during the day and too infrequent during the year from which to draw conclusions regarding the relative abundance during morning, afternoon or evening periods. The infrequent counts from Stations B, C, D, and 4 to 7 were at times slightly higher than those from Station A, but the maximum of 90 per 11 liters of water recorded from Station A was not equalled at any other station on the reef.

Although the 33 samples taken at Pier 2, Honolulu Harbor, were too few to be of much significance in a comparative way, they afforded some opportunity of observing vertical migrations in depths of about eight fathoms. On December 14 at 1:30 P.M. there was a considerably larger number of copepods at the bottom than at the surface. This was also true on November 2 at 3:15 P.M. On November 23 at 3:15 P.M. there was an almost equal distribution vertically and on April 4 at 3 P.M. a larger number appeared at the surface than at the bottom.

Seventy-five samples were taken from Pearl Harbor during the year, at a station established at the end of the Navy Pier in the Middle Loch. Sixty-four of the samples were from the surface and 11 from the bottom. The collections were distributed over 11 months, none being taken during February. During most of the year the average number of copepods per 11 liters of water ranged from 1,000 to more than 3,000. The maximum count for the year and for six samples taken from the surface on June 16 at 2 P.M. was 5,000, or 3,000 less than the maximum for Kaneohe Bay. The general average for Pearl Harbor was, however, somewhat higher than for Kaneohe Bay. (See tables 2, 3, 5, and 6.)

Table 2.—Number of copepods per 11 liters of surface water at Navy Pier Station, Pearl Harbor.

	Oct. 9 2 P.M.	Nov. 4 1:30 P.M.	Dec. 5 6 P.M.	Jan. 18 10:30 A.M.	Mar. 4 2:15 P.M.	April 8 2:30 P.M.	May 20 2:30 P.M.	June 16 2 P.M.	July 15 11 A.M.	Aug. 9 3:45 P.M.	Sept. 16 1:15 P.M.
No. of samples	2	6	5	2	3	3	3	6	1	3	5
Average no. of copepods	1,391	2,266	1,060	1,507	8.3	1,369	2,261	3,275		1,510	1,997
Max. no. in 1 sample	1,408	3,000	1,474	1,815	13	1,665	3,086	5,000	1,200	1,800	2,750

Table 3.—Number of copepods per 11 liters of bottom water at Navy Pier Station, Pearl Harbor.

	Nov. 16 2:30 P.M.	Dec. 5 5:45 P.M.	Jan. 9 3 P.M.	Mar. 4 2:15 P.M.	Apr. 8 2:30 P.M.	May 20 2:30 P.M.
No. of samples	1	2	2	2	3	1
Average no. of copepods		1,218	956	2,168	2,672	
Max. no. in 1 sample	1,422	1,552	1,168	2,952	3,264	4,000

Table 4.—Number of copepods per 11 liters of surface water at Aiea Railway Station Pier, East Loch, Pearl Harbor.

	Oct. 9 3 P.M.	Oct. 28 3 P.M.	Mar. 4 3:15 P.M.	Apr. 8 3 P.M.	May 20 2:55 P.M.	July 29 2 P.M.	Sept. 16 2 P.M.
No. of samples	2	1	2	2	1	1	1
Average no. of copepods	277		0	195			
Max. no. in 1 sample	424	150	0	254	400	188	700

Table 5.—Number of copepods per 11 liters of water at stations in Kaneohe Bay.

	Shallow reef Surface		Channel surface bottom		Off shore 400 yds. surface			South shore surface
	Oct. 16 3:30 P.M.	April 28 3:30 P.M.	Oct. 16 4 P.M.	Oct. 16 4:15 P.M.	April 7 9 A.M.	April 21 11 A.M.	Aug. 11 3 P.M.	Nov. 18 1:30 P.M.
No. of samples	4	2	8	1	9	4	4	2
Average no. of copepods	720	361	2,500	....	483	115	52	6.5
Max. no. in 1 sample	910	396	8,083	765	772	182	60	8

Table 6.—Number of copepods per 11 liters of surface water in the northeast and north sections of Kaneohe Bay.

	Pier, Territorial Fish and Game Farm					North Reef		
	June 17 8:30 A.M.	June 30 6 P.M.	July 1 6 A.M.	Aug. 5 3 P.M.	Sept. 19 2 P.M.	June 30 10 A.M.	July 19 9 A.M.	Aug. 2 9 A.M.
No. of samples	3	3	1	4	5	4	2	4
Average no. of copepods	625	1,583	3,000	1,150	1,150	947	737	825
Max. no. in one sample	800	1,800	3,000	3,400	1,250	1,800	875	1,150

Considerable variation was noted in the number of copepods in the surface waters of Pearl Harbor at intervals of a few days. On July 6 at 10 A.M. one sample yielded but 25 copepods per 11 liters of water. Nine days later at 11 A.M. there were 1,200 copepods in the same quantity of water. At the station the surface waters were practically void of copepods on March 4 at 2:15 P.M., the average for three samples of water being 8.3 per 11 liters of water and the maximum 13. At this time the bottom waters contained an average of 2,168 copepods for two samples of water with a maximum of 2,952. On the warm afternoons of January 9, April 8, and May 20, copepods were much more abundant at the bottom of Pearl Harbor than at the surface, but on the afternoon of November 16, with the sun apparently equally as bright, no such difference was noted. The difference between the temperature of the surface and the bottom at this station, on a warm afternoon, varied from 0.5°C. to 1.0°C. On December 5 at 6 P.M. with darkness approaching, the copepods were evenly distributed from the surface to the bottom. The temperature at the bottom at this time being 0.3°C. lower than at the surface. (See tables 2 and 3.)

The ten samples taken at Aiea, in the northeast arm of the East Loch of Pearl Harbor were too few for a very exact determination of the quantity of copepods in that locality. From the limited record, however, it would seem that fewer copepods frequent this section of the Harbor than the vicinity of Navy Pier. Compared with the open reef at Waikiki, however, the surface waters at Aiea are carrying a much greater potential food supply. (See table 4.)

A summary of the 72 samples collected in Kaneohe Bay, windward Oahu, indicates an increase in the number of copepods from the shore to the deeper parts of the bay. The maximum number was found in the surface waters of the deeper channels rather than on the more shallow adjacent reefs. This is probably explained by phototropic responses of the organisms themselves. The reflected light from the white sand bottoms of the shallow reefs probably serves as a repellent agent to many of the copepods driving them into the nearby channels which are deeper and darker since less light is reflected. The maximum count of copepods for Kaneohe Bay was made from samples taken from the surface waters of a channel about four fathoms deep during the afternoon of October 16. At this time the sky was heavily overcast with clouds. (See table 5.)

In the northeastern section of Kaneohe Bay, surface samples from the station at the end of the pier of the Territorial Fish and Game Farm, with few exceptions, showed relatively high counts of copepods. (See table 6.) Although the pier extends for about one fourth of a mile into the bay, where samples were taken, the depth of the water is not over one fathom at high tide. Here the bottom of the bay is muddy and sandy with no corals in the immediate vicinity. Many sedentary animals, however, find attachment on the piling of the wharf.

The few collections made on a north reef of Kaneohe Bay during July and August gave consistently high counts of copepods (see table 6), although not higher, in general, than those from other sections of the bay. Here the samples were taken directly over actively growing coral colonies.

From a review of the copepod enumeration made from Waikiki Reef, Pearl Harbor, and Kaneohe Bay, it is obvious that the semi-enclosed bodies of water about Oahu support a much larger number of copepods than do the open reefs.

It seems obvious that some correlation exists between the quantity of potential food in the form of free swimming copepods carried in the surface waters and the abundance and condition of other forms of animals which normally derive their sustenance from organisms circulating in the water. The paucity of copepods on Waikiki Reef may, in part at least, be an indicator of the biologic conditions persisting there. Although 20 or more species and varieties of corals are found living on the reef the colonies grow slowly and obviously are starved and stunted. Hydroids, sea anemones, jelly fishes, alcyonarians and other tentaculiferous forms are almost absent. To the careful observer, Waikiki Reef seems to be decadent and unable to maintain a flourishing animal population.

Contrasted with Waikiki Reef both Pearl Harbor and Kaneohe Bay support a luxuriant growth of sessile organisms which normally feed upon copepods. Especially is this true for Kaneohe Bay. Here strong healthy colonies of numerous genera of corals are found on the shallow reefs and flourish to a depth of four or five fathoms. Hydroids, jelly fishes, sea anemones, and other coelenterates are abundant. Sessile organisms of other phyla are numerous as are schools of plankton-feeding fishes. In semi-protected waters such as Pearl Harbor and Kaneohe Bay may be found the richest invertebrate fauna about Oahu. Here also is the greatest abundance of free swimming copepods.

RESPONSE TO EXTREME ECOLOGICAL FACTORS

Resistance to Rising and Falling Temperatures

All of these responses were studied under laboratory conditions. Stender dishes of sea water containing an assorted lot of copepods were placed in warming and cooling chambers and permitted to gradually assume higher and lower temperatures. The behavior of the copepods was observed.

1. Resistance to increasing temperature.

a. With water at 26° C. the temperature was gradually increased reaching 31° C. in 35 minutes. All copepods were active during this period. In one hour and 30 minutes, the temperature reached 33° C. Nearly all copepods were active. After five hours with the temperature at 33.5° C. nearly all copepods were still active, the larger specimens being inactive. At the end of 13 hours with the temperature at 34° C. the stender dish was removed from the warming chamber and the water permitted to return gradually to room temperature. After one hour specimens were examined. Larval and young forms of copepods survived. Adult specimens with the exception of a species of *Peltidium* did not recover.

b. Copepods in water at 26° C. were placed in the warming chamber. After four hours the temperature had advanced to 32° C. All copepods were active.

c. Copepods lived 24 hours at 30° C. without losing activity.

d. A small proportion of copepods survived 31° C. for 48 hours.

e. All specimens died after 16½ hours at 35° C.

2. Resistance to falling temperature.

a. With water at 26° C. this temperature was gradually reduced to 10.5° C. in 20 minutes. Only a few copepods remained active. In 50 minutes the temperature was reduced to 5.5° C. All copepods were now inactive. At the end of 60 minutes, with the temperature at 5° C., the stender dish was removed from the cooling chamber and the water gradually assumed the room temperature. In 15 minutes it had reached 21° C. at which time all copepods revived.

b. Beginning at 26° C. water containing copepods was reduced to 9° C. in 45 minutes. Copepods showing evidence of life were very sluggish. In two hours and 40 minutes, the temperature had reached 6° C. with all copepods inactive. At the end of 10 hours, at 6° C., the stender dish was removed from the cooling chamber and the temperature permitted to rise gradually. After one hour it had reached 24.5° C. In a lot of 100 copepods, about 10 percent had recovered activity.

c. In other tests, four fifths of the copepods survived a temperature of 5° C. for 17 hours. All were dead after 17 hours at 1.5° C.

d. All copepods in water gradually lowered in temperature to 2° C. in a period of 24 hours were dead at the end of that time.

e. A graduated reduction in temperature of four lots of copepods ranged from 4° C. to 10° C. in one hour and 15 minutes. All copepods were inactive. On reversal of temperature, all copepods had recovered activity in 30 minutes.

f. Four lots of copepods, after 18 hours, showed reduced temperatures graduated between 3° C. and 8° C. All copepods were inactive and none recovered when the temperature was reversed and reached normal.

3. Resistance to dilute sea water.

a. Copepods removed to fresh water from normal sea water became quiet in 30 seconds. After one minute they were returned to sea water. There was no recovery.

b. Copepods were subjected to sea water dilution in the following proportions: 3 parts sea water to 1 part fresh water; 2 parts sea water to 1 part fresh water; 1 part sea water to 1 part fresh water; 1 part sea water to 2 parts fresh water; 1 part sea water to 3 parts fresh water. All copepods survived in the above solutions for a period of 48 hours without apparent ill effect.

4. Resistance to altered pH.

Copepods in stender dishes of sea water of pH 8.6 (without alteration for salinity) were subjected to the following reductions of pH:

a. Reduction to pH 7.6. Copepods were alive at the end of 48 hours but dead at the end of 72 hours.

b. Reduction to pH 6.5. Many copepods were alive at the end of 24 hours. About 20 percent were alive at the end of 48 hours but all were dead at the end of 72 hours.

c. Reduction to pH 5.8. Many copepods were alive at the end of 24 hours. About 20 percent were alive at the end of 48 hours but none survived 72 hours.

ENUMERATION OF COPEPODS NEAR FIJI AND TAHITI

While in Fiji and Tahiti during 1933, I had the opportunity to make brief quantitative comparisons between the copepods of Suva Harbor and Papeete Harbor. The results are presented here for comparison with those of Oahu. Similar methods were employed in each locality. For a summary of the records from Suva and Papeete, see table 7.

During February 1933, the surface waters of Suva Harbor carried a much larger number of copepods than did the near-shore waters of Papeete Harbor during April of the same year. The enumeration of copepods at Suva corresponded closely with that of certain sections of Kaneohe Bay, Oahu, while Papeete Harbor in its paucity of copepods more closely resembled Waikiki Reef. This difference is remarkable inasmuch as during part of February the waters of Suva Harbor were very turbid, carrying much suspended matter, and the bottom in the vicinity of the station was muddy, while the water of Papeete Harbor during April was very clear and the samples were taken directly over living coral colonies.

The mean range of tide at Suva is 2.9 feet while at Papeete it is but 0.8 of a foot, which makes a very insignificant change in water level. Another quite constant ecological feature of Papeete Harbor was the temperature of the surface water which showed a narrow range between 28° C. and 29° C. during 24 days of April. In February the range for the station water at Suva was between 26° C. and 32° C.

Table 7.—Number of copepods per 11 liters of surface water of Suva Harbor, February 1-24, 1933 and Papeete Harbor, April 1-24, 1933.

	Suva Harbor			Papeete Harbor		
	6 A.M.—12 M.	12 M.—6 P.M.	6 P.M.—9 P.M.	6 A.M.—12 M.	12 M.—6 P.M.	6 P.M.—9 P.M.
No. of samples	14	12	5	21	7	8
Average no. of copepods	133.7	260.3	320.4	9.9	10.3	15.5
Max. no. in 1 sample	530	1,750	700	18	16	40

CONCLUSIONS

1. The waters of Waikiki Reef, Oahu, carry an insignificant number of copepods in circulation, the maximum number of 90 per 11 liters of water being sharply in contrast with an enumeration of 5,000 for Pearl Harbor and more than 8,000 for Kaneohe Bay.

2. A correlation is suggested between the biologic conditions of Waikiki Reef and areas such as Pearl Harbor and Kaneohe Bay and the paucity or abundance of copepods in the surface waters. Biologically Waikiki Reef is more decadent than Pearl Harbor or Kaneohe Bay.

3. In the enumeration of copepods on Waikiki Reef two peaks appear daily, one in the early morning and one in the early evening.

4. Shoal water copepods are more resistant to falling temperatures than to rising temperatures. A large proportion of specimens survive 5° C. for 17 hours but all die in 16½ hours at 35° C. Dilute sea water in the proportion of 1 part sea water to 3 parts fresh water has no detrimental effect on copepods during a period of 48 hours. Many copepods survive a reduction in pH from 8.6 to 5.8 for 24 hours, a few for 48 hours, none for 72 hours. Adult specimens are more sensitive than larval forms to altered ecological conditions.

5. Copepod enumeration in Suva Harbor during February 1933 showed a favorable comparison with certain sections of Kaneohe Bay, Oahu. Papeete Harbor, Tahiti, during April 1933, carried about as many copepods in circulation as Station A, Waikiki Reef, Oahu.