Biology of *Icerya purchasi* and Its Natural Enemies in Hawaii[1,2]

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Introduction

The cottony-cushion scale, *Icerya purchasi* Maskell, belongs to the order Homoptera; superfamily, Coccoidea; family, Margarodidae and tribe, Iceryini.

Very little is known about the early history of *I. purchasi* in the Hawaiian Islands. The earliest records on the occurrence of this scale in Hawaii are those by Riley (1891) and Silvestri (1909). According to extracts from correspondence between A. Jaeger and D. W. Coquillett (Riley, 1891) and a translation of Silvestri's 1909 paper in the Hawaiian Forester and Agriculturest, *I. purchasi* became established in Hawaii in the spring or summer of 1889. Subsequently, *I. purchasi* has been reported from various islands by other workers. Today it is known to occur on the islands of Oahu, Hawaii, Kauai, Maui and Molokai. It may occur on Lanai and Niihau although there are no published records.

After discovery of *I. purchasi* in Honolulu, the vedalia, *Rodolia cardinalis* (Mulsant), was introduced into Hawaii in 1890 from California by Koebele (Perkins, 1897), two years after the introduction of this predator into California from Australia by Koebele. According to Perkins (1897), Zimmerman (1948) and others, *R. cardinalis* was successful in suppressing *I. purchasi* in Hawaii.

In 1966 the first specimen of *Cryptochaetum iceryae* (Williston) (Diptera: Agromyzidae) a parasite of *I. purchasi* was collected by Beardsley (1967) in an ultraviolet light trap. Since that time, it has been found to be well established on the Island of Oahu.

Economic Importance: *I. purchasi* became one of the most economically important insect pests of citrus soon after its discovery in the United States on *Acacia* at Menlo Park, California in 1868 or 1869 (Ebeling, 1950). Since then, *I. purchasi* has been recorded as a pest of citrus and ornamentals in over 80 countries, and appears to be most abundant in tropical and semitropical regions of the world.

Damage due to *I. purchasi* was first noticed on Oahu in April, 1890

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by Jaeger (Silvestri, 1909). However, Perkins (1925) reported that the Reverend T. Blackburn, "an expert entomologist in Honolulu, wrote in 1876 'the fruit trees were afflicted with an incurable blight'". Perkins suggested that the Reverend Blackburn was apparently referring to an infestation of *I. purchasi*.

Populations of *I. purchasi* have been suppressed by *R. cardinalis* except for a few short periodic outbreaks in Hawaii for over 75 years. In recent years heavy populations of *I. purchasi* have been observed causing damage to fields of *Desmodium sandwicense* E. Meyer and to hedges of *Casuarina equisetifolia* L.

DISTRIBUTION IN HAWAII: The distribution of *I. purchasi* on the Island of Oahu was observed at Honolulu, Perarl City, Ewa, Kaena Point, Kawela, Laie, Kailua, Lanikai, and Waimanalo. Heavy infestations of scales were observed at Waimanalo, Laie, and Lanikai.

A survey for *I. purchasi* was conducted during 1968 on the islands of Hawaii, Maui, Kauai, Molokai, and Lanai. Scales were observed on all the neighbor islands except Lanai. The locations on each island where *I. purchasi* was collected during this survey are: Hawaii—Kealakekua, MacKenzie Park, Hilo; Maui—along highway 30 near Kapalua Beach; Kauai—Makaweli, Kapaa, Eleele, and Lihue; Molokai—Halawa, Hoolehua, and on the trail leading down to Kalaupapa from the Palaau State Park. Most infestations were light, but heavy infestations were found at MacKenzie Park and Palaau State Park.

Populations of *I. purchasi* were usually observed at low elevations near coastal areas. In one case *I. purchasi* was collected between 400 and 500 meters at the Kalaupapa Lookout on Molokai.

HOST PLANTS

Besides being cosmopolitan, *I. purchasi* is euryphagous. There are many plants of economic importance included in the host list for this scale. One of the most complete host plant records for *I. purchasi* is that of Riddick (1955) where 128 species were recorded in Florida. Some other workers giving host plant species records are Baker and Essig (1912), Japan; Janini (1923), Spain; Poutiers (1930), France; Leonard (1932), Puerto Rico; Zimmerman (1948), Hawaii; Bodenheimer (1951), Palestine and Egypt; and Bennett (1959), Bermuda. Although there are many different host plant species of *I. purchasi*, *Citrus* spp. (lemon, lime, grapefruit and orange), *Acacia* spp., *Casuarina* sp., *Pittosporum* sp., and *Rosa* sp. seem to be the most frequently observed hosts.

The host plants of *I. purchasi* in Hawaii were first reported in excerpts from correspondence between Jaeger and Coquillett (Riley, 1891). Jaeger gave the following common names as host plants of *I. purchasi:* "all the citrus family, semang, causarina, mesquite, banyan, breadfruit, mango, vi: various

TABLE 1. *Host plant species of* Icerya purchasi *in Hawaii*

Family	*Genus—Species*	*Common Name*	*Reference*
Araliaceae	*Nothopanax* sp.		Zimmerman (1948)
Casuarinaceae	*Casuarina equisetifolia* L.	Ironwood	Present study
	Casuarina sp.	Ironwood	Zimmerman (1948)
Compositae	*Emilia sonchifolia* (L.) DC.	Floras Paint Brush	Present study
	Sigesbeckia orientalis L.	Sigesbeckia	Present study
Convolvulaceae	*Ipomoea pentaphylla* (L.) Jacq.	Hairy Merremia	Present study
Euphorbiaceae	*Acalypha godseffiana* var. *heterophylla* Hort.	Leafy Branch	Present study
	Euphorbia glomerifera (Millsp.) L. C. Wheeler		Present study
	Euphorbia heterophylla L. var. *cyathophora*	Mexican Fire Plant	Present study
	Jatropha hastrata Jacq.	Rose-flowered Jatropha	Present study
Goodeniaceae	*Scaevola sericea* Vahl	Beach Naupaka	Present study
Leguminosae	*Acacia koaia* Hbd.	Koai'e or koai'a	Davis (1953)
	Acacia melanoxylon R. Br.	Australian Blackwood	Present study
Leguminosae	*Acacia* sp.		Zimmerman (1948)
	Canavalia cathartica Thou.	Mauna-loa	Present study
	Cassia glauca Lam.	Kolomona	Zimmerman (1948)
	Cassia leschenaultiana DC.	Cassia	Present study
	Crotalaria incana L.	Rattlebox	Present study
	Desmodium canum (Gmel.) Schinz and Thellung	Kaimi clover	Zimmerman (1948)
	Desmodium sandwicense E. Mey.	Spanish clover	Present study
	Desmodium tortuosum (SW.) D3.	Florida beggarweed	Present study
	Desmodium uncinatum (Jacq.) DC.	Silverlead desmodium	Zimmerman (1948)
	Desmodium virgatus (L.) Willd.	Slender Mimosa	Zimmerman (1948)
	Mimosa pudica L.	Sensitive plant	Present study
	Samanea saman (Jacq.) Merr.	Monkeypod	Present study
	Sophora chrysophylla (Salisb.) Seem.	Mamane	Zimmerman (1948)
	Ulex europaeus L.	Gorse	Present study
Magnoliaceae	*Nandina domestica* Thumb.	Sacred Bamboo	Present study
Malpighiaceae	*Malpighia punicifolia* L.	Acerola	van Zwaluwenburg (1956)
Malvaceae	*Gossypium tomentosum* Nutt.	Native cotton	Swezey (1935)
Moraceae	*Ficus benghalensis* L.	Banyan	Present study
	Morus nigra L.	Black mulberry	Present study
Myrtaceae	*Psidium guajava* L.	Guava	Present study
Onagaraceae	*Fuchsia* sp.		Present study
Pittosporaceae	*Pittosporum tobira* (Thunb.) Ait.		Present study
Proteaceae	*Macadamia integrifolia* Maiden and Betche	Smooth-shell Macadamia Nut	Present study
Rutaceae	*Citus grandis* (L.) Osbeck	Shaddock	Present study
	Citrus reticulata Blco.	Mandarin orange	Present study
	Citrus sp.		Zimmerman (1948)

shrubs, such as roses, hibiscus, crotons, etc., in fact nearly everything except eucalyptus, palms and sugar cane." Other host plant species were reported by Swezey (1935), Holdaway (1944), Zimmerman (1948), Davis (1953), and van Zwaluwenburg, (1956).

The host plant list shown in Tables I and II indicate that 56 different plant species have been cited as host plants of *I. purchasi* in Hawaii. Of these 56 different host plants, 34 were identified to species, 5 to genus, and 17 by common name. Those host plants identified to genus and species are represented in 16 different families. I believe at least four of the plants reported by common name (banyan, casuarina, citrus family and monkey-pod) may be included in the genus, species host list, and *Casuarina* sp. reported by Zimmerman (1948) may be the same plant as *Casuarina equisetifolia*, identified in the present study. This would reduce the host plant list from 56 to 51. Twenty-six new host plant species were found in the present study. Only plants infested by the sessile stages were considered to be host plant species in this study.

Life History Studies

Early work on the biology of *I. purchasi* has been of a general nature. According to Bodenheimer (1951), the biology of *I. purchasi* was very difficult to study under natural conditions in Palestine. Perhaps the lack of detailed information is due to the inherent difficulty in studying this insect under field conditions.

Males and females of *I. purchasi* have been observed in various temperate parts of the world. However, the presence of males was extremely rare (Bodenheimer, 1951). Female adults were capable of reproducing by self fertilization and are, therefore, in reality hermaphrodites (Hughes-Schrader, 1930). During this study males were not found though a persistent search was made.

The life history, number of instars, and growth rate of *I. purchasi* were studied under laboratory conditions on potted *D. sandwicense* plants covered with organdy cages (Fig. 1). Four-day-old crawlers were seeded on the leaves of potted *Desmodium* plants. After settling, the number of scales was reduced so that only 20 scales remained on each of the two plants. Maps were made identifying the location of each settled scale on the plants. Changes on the maps were made for each scale's resettling location after each molt. Plants were kept outside the laboratory, and only brought into the laboratory briefly each day for critical observation and measurement of the scales under a dissecting microscope. The number of molts, duration for each instar and daily growth rate were recorded. Body length and width were measured with an ocular micrometer with .01 mm divisions.

Temperature and relative humidity conditions outside the laboratory where the caged scales were placed were measured by a hygrothermograph.

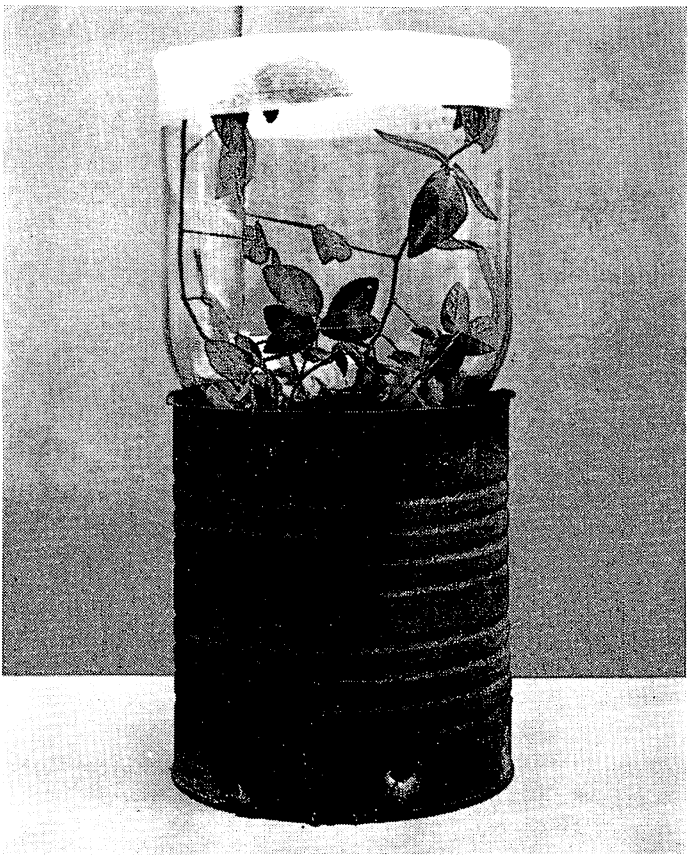

FIG. 1. The type of cage used to study the life history of *Icerya purchasi*

The data are presented in Figure 2. During this study, the temperature and relative humidity ranged from 21–35 °C, and from 42–89%, respectively. To determine whether there were differences in temperature and relative humidity, a "Honeywell" temperature and relative humidity meter was used to take measurements within and outside of the cages. Differences in temperature varied less than 1 °C, and those in relative humidity not more than 5%.

DESCRIPTION OF STAGES: A general description of the life stages of *I. purchasi* follows: Further details or micro descriptions and illustrations of the stages are given by Kuwana (1922) and Bodenheimer (1951). The life stages of *I. purchasi* include the egg, first, second and third instars and the adult. The first instar includes the crawler and the sessile stages.

Egg: Eggs of *I. purchasi* are orange, elongate-oval, and smooth. The mean length was .71 ± .05 mm and the mean width, .31 ± .02 mm.

First instar: Newly hatched crawlers are orange, elongate-oval in

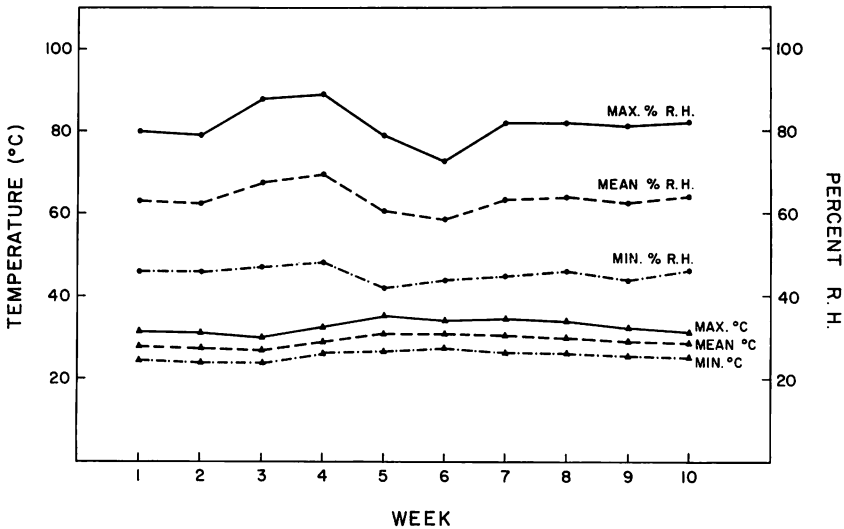

FIG. 2. Weekly temperature and relative humidity data recorded during the life history studies of *Icerya purchasi* outside the laboratory from 25 July to 27 September 1968.

form, flattened dorso-ventrally and slightly convex dorsally, the antennae are 6-segmented. Mean body length was .68 ± .02 mm and the mean width was .34 ± .03 mm.

The sessile, first instar nymphs are identical in shape to the crawlers except they are a little larger in size and the body is covered with a white waxy material. The mean length of the newly settled first instar nymph was .76 ± .05 mm and the width, .41 ± .03 mm. When fully grown and ready for molting, its mean length was 1.51 ± .12 mm and its mean width was .88 ± .05 mm.

Second instar: The second instar nymph differs from the first instar very little in shape and size. The body is rounder and larger and the legs and antennae are much heavier and thicker than the first instar. Their antennae are 6-segmented, but the relative lengths of the corresponding segments differ. The mean body length was 1.44 ± .25 mm and the mean width, .82 mm ± .04 mm. Before molting into the third instar, its mean length was 2.33 ± .11 mm and its mean width, 1.34 ± .12 mm. There was an overlap in size between the fully grown first instar nymph and the newly molted second instar. However, two days after molting the mean dimensions of the second instar were greater than those of the fully grown first instar nymphs. This overlapping was probably due to food intake.

Third instar: The third instar nymphs are reddish in color, oval in shape, and have a considerable amount of waxy-cotton secretion covering the body. Antennae are 9-segmented. Mean body length was 2.44 ±

.46 mm and the mean width, 1.39 ± .29 mm. Prior to molting into the adult, its mean measurements were 3.59 ± .29 mm in length and 2.14 ± .19 mm in width.

Adult: The adults are orange or reddish brown with a thin white powdery wax secretion covering the entire body. The legs and antennae are black. The body is broadly oval, venter flat, and the dorsum strongly convex with two prominent raised areas on the second and third thoraxic segments. The antennae are 11-segmented gradually tapering toward the apex with the distal segment being club shaped. The newly molted adult mean body length was 3.70 ± .41 mm and the mean width, 2.08 ± .25 mm.

The gravid scale has a white cottony ovisac which continues to increase in size with age. The ovisac is dorsally convex and distinctly fluted or grooved with 15 to 16 longitudinal ridges. The largest ovisac measured during this study was 13.8 mm long and 5.0 mm wide.

Life Cycle: Eggs are laid in a filamentous waxy ovisac which continues to increase in size with age. Oviposition continues to take place after the first eggs hatch. After eclosion the crawlers remain in the ovisac for an unknown period of time before escaping from the ventral portion of the ovisac. The non-feeding crawler stage then moves about and usually settles on the under surface of the leaves near the top of the plant. Experiments conducted by Bodenheimer (1951) showed that the crawlers are positively phototaxic and negatively geotaxic.

Insertion of the stylets into the plant tissues marks the beginning of the sessile or settled stage. After settling the sessile nymph remains attached to the plant by its stylets until ecdysis. A short time after settling, the nymph excretes from the anal opening a long hollow waxy filament on which a droplet of honeydew is frequently present at the distal end. According to Dingler (1930), this filament reached a length of 50 mm in the laboratory, but in nature it does not exceed 5 mm. Observations made in the laboratory during this study showed that the length of the filament did not exceed 21 mm and under field conditions, the length agreed closely to that reported by Dingler.

In the process of ecdysis the second instar emerges through a dorsal longitudinal slit which extends from the head to the thorza. The cast off exuvium remains attached to the plant by the rostralis. After ecdysis the nymph moves about and then settles. It remains sessile, feeding on plant juices, until the next molt. The above process is repeated when the second instar molts into the third instar and the third instar molts into the adult. After a short preoviposition period the ovisac is produced and egg laying begins. As the size of the ovisac increases, the body is pushed up away from the plant surface, and the scale is held in place by the stylets inserted in the plant tissue and possibly by the adhesion of the ovisac to the host.

Duration of Life Stages: The duration of the egg stage was studied

TABLE 2. *Host plants of* Icerya purchasi *in Hawaii cited by common name only*

Common Name	Reference
Banyan	Riley (1891)
Breadfruit	Riley (1891)
Casuarina	Riley (1891)
Citrus (family)	Riley (1891)
Croton	Riley (1891)
Eggplant	Holdaway (1944)
Hibiscus	Riley (1891)
Lime	Zimmerman (1948)
Mango	Riley (1891)
Mesquite	Riley (1891)
Monkeypod	Zimmerman (1948)
Peppermint	Zimmerman (1948)
Rose	Zimmerman (1948)
Sage	Zimmerman (1948)
Samang	Riley (1891)
Silver wattle	Zimmerman (1948)
Soybean	Holdaway (1944)

TABLE 3. *The duration of the various developmental stages of* Icerya purchasi *reared on* Desmodium sandwicense

Stages	*No. observed*	*Duration (Days)*		
		Range	*Mean ± SD**	*Cumulative*
Egg	300**	12–17	15.4 ± .76	—
1st Instar				
Crawler stage	—	Not Known***		—
Sessile stage	27	10–14	12.3 ± 1.16	12.3
2nd Instar	23	9–12	9.9 ± 0.82	22.2
3rd Instar	18	8–13	9.8 ± 1.52	32.0
Adult				
Preoviposition	17	5–14	8.2 ± 2.04	40.2
Oviposition	17	29–57	39.1 ± 8.32	79.3

*SD = Standard Deviation

**Duration based on 275 eggs that hatched.

***Crawlers survived up to 11 days at 75 per cent humidity. Settling occurred with crawlers of known ages from 2 to 9 days old, with settling rates of 4 and 5 day old crawlers being significantly higher than those of other ages.

in the laboratoty at a mean temperature of 25 °C. Since the data for two randomly collected samples of 50 eggs each laid on three different days showed no significant difference the data were pooled (Table III). The duration of the successive stages were studied under laboratory conditions on potted *Desmodium* plants covered with organdy cages.

The data shown in Table III showed that the duration for each stage was: egg, 15.4 ± .76 days; sessile stage of the first instar, 12.3 ± 1.16 days; second instar, 9.9 ± .82 days; third instar, 9.8 ± 1.52 days; preovipositional

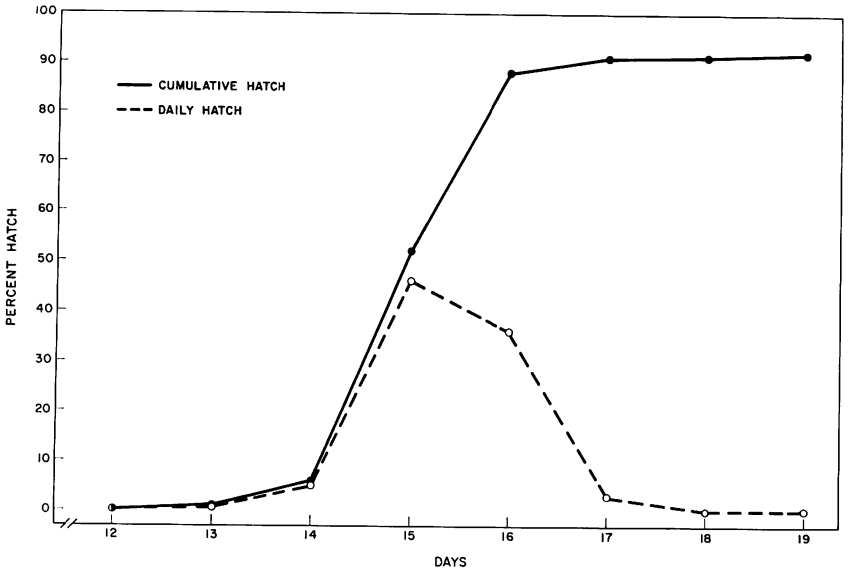

FIG. 3. Cumulative and daily per cent of eggs hatched of *Icerya purchasi* in the laboratory.

period, 8.2 ± 2.04 days, and the ovipositional period, 39.1 ± 8.32 days. The mean development from the sessile stage of the first instar to egg laying was 40.2 ± 2.78 days. The cumulative duration from the beginning of the sessile stage of the first instar to the death of the adult was 79.3 days.

HATCHING FREQUENCY: The hatching frequency of *I. purchasi* eggs were studied in the laboratory. The temperature in the laboratory ranged from 23.5 to 28.5 °C with a mean of 25 °C. Eggs for this study were obtained from field collected females on *Desmodium* plants. To insure eggs of a uniform age, the ovisacs containing the eggs were removed and discarded by use of a camel-hair brush. Newly laid eggs were then collected daily for three days from ten scales. The eggs laid each day were kept in separate containers. From the eggs laid on the respective days, samples of 50 eggs each were placed into small glass tubes, 0.95 cm inside diameter and 5 cm long. The ends were covered with organdy to allow free movement of air and to confine newly hatched crawlers. The glass tubes were observed daily and the number of eggs hatched was recorded.

Since there were no significant differences among the data obtained, the data for the three days were pooled. Figure 3 shows the daily and cumulative % of *I. purchasi* eggs hatching. The peak number of eggs hatched occurred on the 15th day with a slight decline during the 16th day of incubation. By interpolation of the cumulative % hatched, the period required for 50 per cent and 90 per cent of the eggs to hatch was 15.0 and 16.7 days, respectively. There were 275 eggs which hatched from the 300 eggs tested for a 91.6 % hatch.

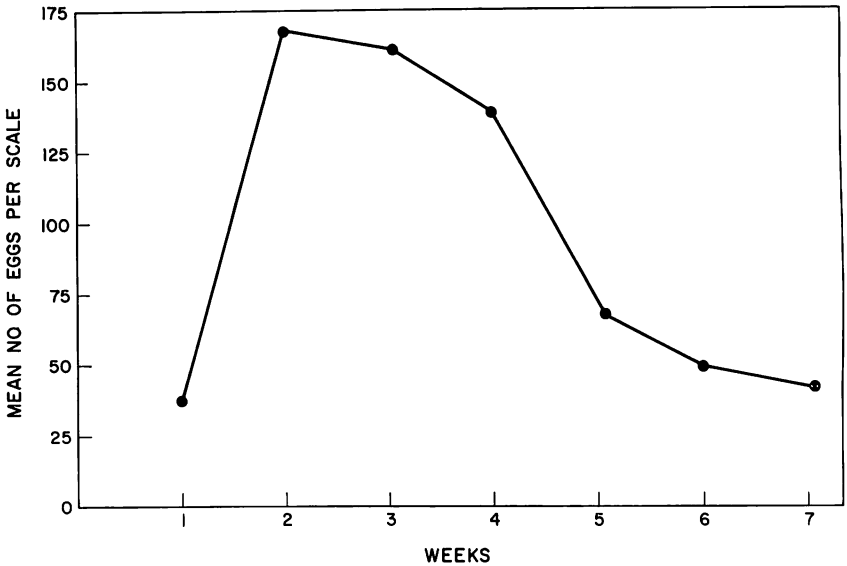

FIG. 4. Mean number of eggs laid per *Icerya purchasi* female per week.

FECUNDITY: The number of eggs laid per female on *Desmodium* was studied. To determine fecundity, 22 young adults without ovisacs were observed and examined daily until the first eggs were oviposited, and there-

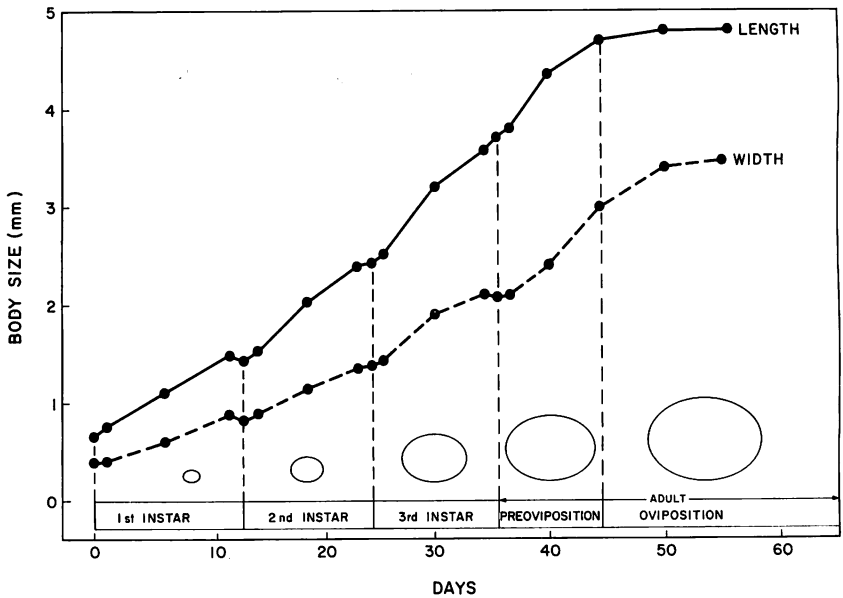

FIG. 5. Growth curve and the relationship in size of the various stages of *Icerya purchasi*

after the scales were examined weekly. All eggs were removed from the ovisacs by the use of a camel-hair brush. Eggs produced weekly by each female were counted under a dissecting microscope and recorded. This procedure was continued until oviposition ceased.

Number of eggs produced, per adult *I. purchasi*, ranged from 337 to 1059 eggs. The mean number of eggs laid during the ovipositional period was 678.6 eggs with a daily mean of 18.3 $\pm$ 8.05 eggs. The weekly mean number of eggs laid per female as shown in Figure 4 is extremely variable. The rate of egg laying increased about five times during the second and third weeks over the number laid during the first week. The third week was followed by a decline, and then a rapid decline occurred between the fourth and fifth weeks and then a trailing off in egg production occurred.

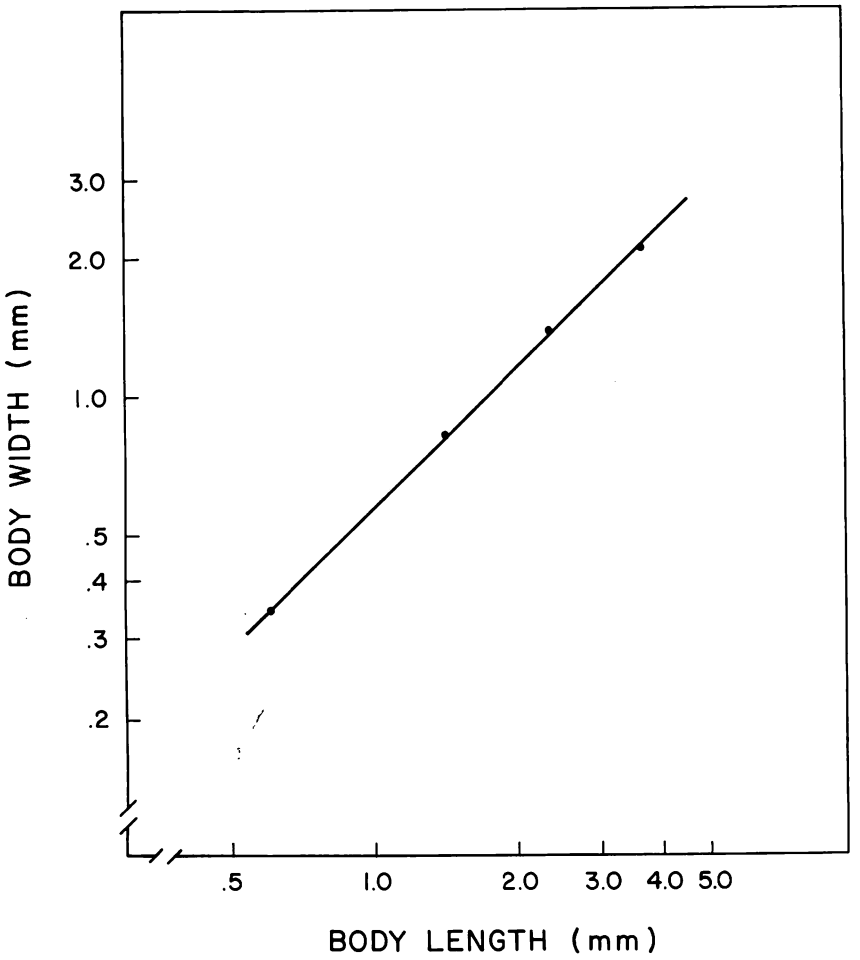

FIG. 6. Relationship between body width and length of the various stages of *Icerya purchasi*

GROWTH RATE: The growth rate of *I. purchasi* was studied by seeding crawlers on potted *Desmodium* plants covered with organdy to exclude predators and parasites. These plants were kept outside and only brought into the laboratory when daily measurements of body width and length were taken by use of an ocular micrometer with .01 mm divisions.

The data are presented in Figure 5. The arithmetic growth curve indicates the possibility of a geometric growth function from the first instar through the preovipositional period. Upon reaching the preovipositional period the increase in size levels off. The continual growth or increase in size of the female scale during the preovipositional period could be due largely to the ovarian development. There was a slight reduction in length and/or width of the immature scales the day after ecdysis., This reduction in volume is undoubtly due to the molting processes. Also, the scale stops feeding during ecdysis and does not commence to feed until after it settles again. It is, therefore, logical that measurements taken during this time reflect changes in volume. Figure 6 shows the correlation between body width and length as plotted on logarithmic paper; it shows a well-fitted rectilinear relationship indicating that growth does occur in a geometrical progression for different stages of *I. purchasi.*

The geometric growth rate between the third instar nymph and the mature female supports the theory that the adult female of *I. purchasi* seems to have been suppressed and that the last immature stage has taken on the reproductive function as a neotenic immature.

The growth rate of *I. purchasi* was similar to results found by Park (1968) for *Ceroplastes rubens* Maskell and the growth rates for other insects which have been subjected to Dyar's law (Dyar, 1931).

NATURAL ENEMIES

The important natural enemies of *I. purchasi* are the vedalia, *R. cardinalis* and *C. iceryae.* Studies were conducted on the life history and biology of *R. cardinalis* and on the biology and spread of *C. iceryae.*

LIFE HISTORY OF R. CARDINALIS IN THE LABORATORY. The classic example of biological control of *I. purchasi* by *R. cardinalis* in California is well known. Since this successful biological control of *I. purchasi*, this predator has been introduced into many different countries.

The duration from egg to adult takes: about 35 days in California (Coquillett, 1889); in Japan from 13 to 20 days during the summer, and from 89 to 168 days during the winter under laboratory conditions (Kuwana, 1922); in South India it takes from 30 to 70 days (Rao and Cherian, 1944); and in Palestine during the summer, the average, development was 21 days and in the winter the average development ranged from 70 to 77 days (Bodenheimer, 1951). The life history of *R. cardinalis* has not been previously studied under Hawaiian conditions.

Life history of *R. cardinalis* was studied during April, 1967 in the laboratory in which the average temperature was 26 ± 3°C. Mated females were placed individually in 5 dram shell vials stoppered with cotton, then mature females of *I. purchasi* with fully developed ovisacs were placed in each vial for a 24 hour period. After *R. cardinalis* had laid eggs on the scales, each eggs was removed and placed singly on an ovisac of *I. purchasi* in separate vials. The larvae that hatched fed on the food provided. Additional scales were provided as needed during the development of *R. cardinalis*.

Observations of the different stadia were made twice each day to record any developmental changes. Data on the duration of the stadia, and measurements of the width of the head capsule, and body length after each molt were recorded foreach larva.

Adult: The adult is oval in form and varies greatly in size. The females are usually larger than the males. The color pattern, black markings on a reddish orange, is very pronounced and striking. The dorsum is covered with very minute hairs.

Adults emerge by splitting the pupal case from the anterior end to the middle of the 8th abdominal segment. Mating was observed shortly after emergence and copulation may take place several times. In some cases observed copulating activities lasted for 4 1/2 hours. The observed preovipositional period lasted for approximately two days.

Egg: Eggs are long elliptic or oblong in form; red in color and average .71 mm in length and .34 mm in width. Eggs are laid either singly or in pairs on the ventral aspect of the ovisac of a mature female of the host. As many as ten eggs have been found on the ovisac under laboratory conditions; however, only 3 to 4 eggs are usually observed under field conditions. Eggs hatched in 3.5 to 5.5 days in the laboratory during April.

Larvae: During eclosion the egg shell splits nearly 1/3 of its entire length on the upper side and the larva emerges from this opening. The newly hatched larvae measure .83 ± .05 mm in length and the head capsule is .18 ± .01 mm in width. They are pinkish in color with a dark brown head. The body is somewhat elongate and tappers toward the caudal end. Segments two to eleven each have three dark brown warts on each lateral side. The warts on segments two and three were situated more subdorsally than those on four and eleven.

TABLE 4. *The mean body length and head capsule width of different instars of rodolia cardinalis*

Instar	*Body length (mm) Mean ± SD**	*Head capsule width (mm) Mean ± SD**
First	0.83 ± .05	0.18 ± .01
Second	1.63 ± .24	0.25 ± .05
Third	3.02 ± .32	0.36 ± .05
Fourth	4.86 ± .48	0.51 ± .17

*Standard deviation.

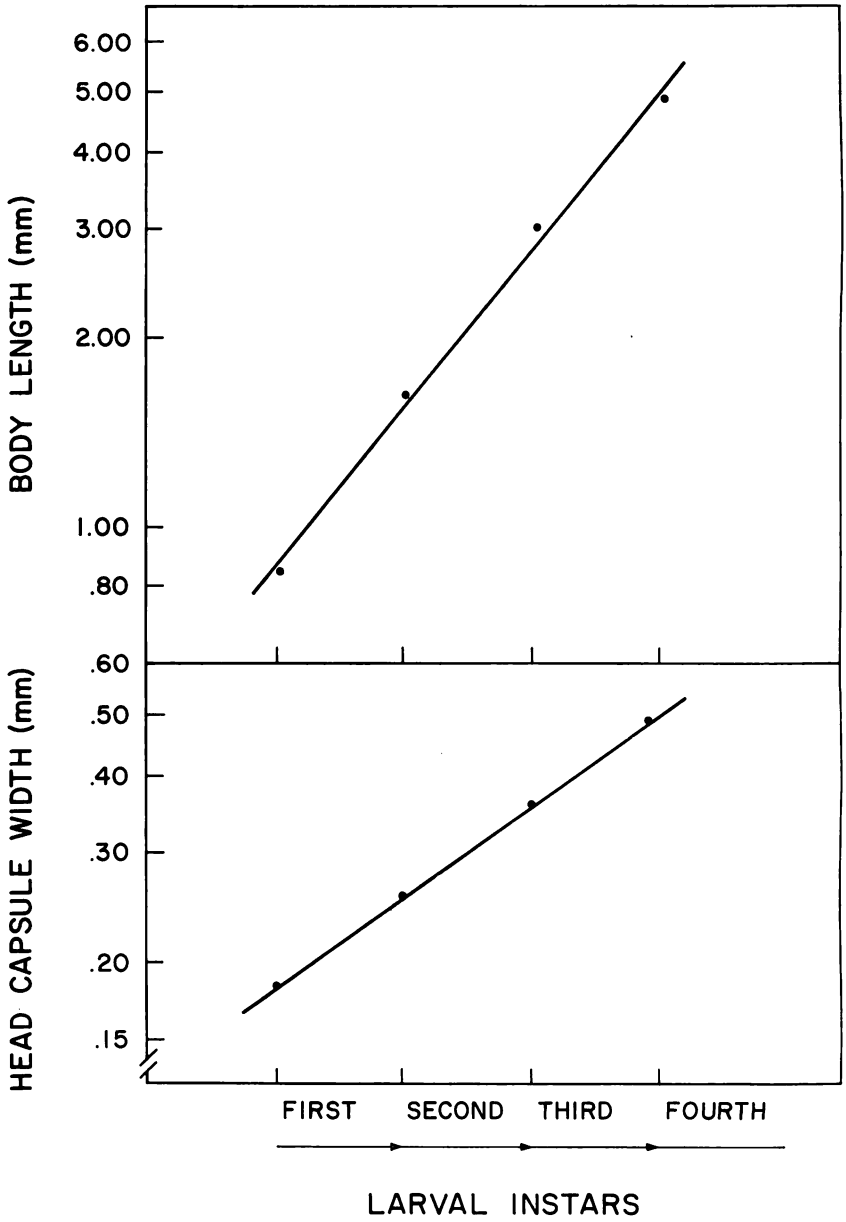

FIG. 7. Mean body length (top) and head capsule width (bottom) of the larval instars of *Rodolia cardinalis*

TABLE 5. *The duration of the different stages of* Rodolia cardinalis

Stage	Number of Observations	Days		
		Mean ± SD*	Cumulative	Range
Egg	20	4.50 ± .38	—	3.5 — 5.5
Instars				
First	12	3.88 ± .52	8.38	3.5 — 4.5
Second	12	3.64 ± .77	12.02	3.5 — 45.
Third	12	2.75 ± .46	14.77	2.5 — 3.0
Fourth**	12	5.64 ± .37	20.41	5.5 — 6.5
Pupa	8	4.63 ± .84	25.04	3.5 — 5.5

*Standard deviation.
**Includes the pre-pupal period.

The second, third and fourth instars are similar in appearance to the first except for size and a slight darkening of the warts on segments two and three.

The average body length and width of the capsule are presented in Table IV and shown graphically on log-log, 2 cycle paper (Fig. 7). Measurements of the width of the head capsules were more uniform than the body length in all four instars. However, the body length and width of the head capsule of the first instar larvae were very uniform with little deviation from the mean measurements. Figure 7 shows that the growth is geometric and is in agreement with Dyar's law. The growth rates of the body length and the width of the head capsule are not the same as indicated by the slopes of the curves. The growth rate of the body length was greater than that of the head capsule (Fig. 7).

The duration of egg, larval and pupal development at 79°F is given in Table V. The developmental period of the fourth instar larva includes a pre-pupal stage which lasts about two days where the larva stops feeding and becomes covered with a light gray powder before pupation occurs. The pupa is partially enclosed in the old larval skin which has black spots and a whitish powdery appearance. The exposed part of the pupa is lightly mottled and brownish red with two dorsal black spots. The duration of the pupal stage ranged from 3.5 to 5.5 days with an average of 4.63 days.

The immature stages feed primarily on eggs and crawlers of the *I. purchasi* by sucking out the body contents. However, the adults and fourth instar larvae feed on adult scales. All active stages of *R. cardinalis* are very active and ferocious feeders.

BIOLOGY, ESTABLISHMENT, AND DISPERSAL OF CRYPTOCHAETUM ICERYAE: The biology and post-embryonic development of *C. iceryae* was elucidated by Thorpe (1930) in California. According to Thorpe and from observations made during this study, the eggs of *C. iceryae* are most frequently found in scales which are about half grown (second instar). The eggs are inserted

in the hemocoel of the host where they swell similarly to those of hymenopteriform eggs. The incubation period was 3 to 4 days (Thorpe, 1930), but according to Smith and Compere (1916) it was 4 to 5 days. A high egg mortality was observed by Thorpe (1930). Smith and Compere (1916) estimated that a single female deposits as many as 200 eggs.

There are three molts and four larval instars. The duration of each instar is not known. However, Thorpe (1930) gave the duration of each as follows: first instar, every short being almost certain not to exceed two days; the second instar, probably three days or a little longer; and the third instar, about 10 to 12 days. The durations for the fourth instar and pupal stage were not given. The longevity of the adult fly is not known.

ESTABLISHMENT AND DISPERSAL

There are no records of the introduction of *C. iceryae* into Hawaii. Dr. J. W. Beardsley first reported the presence of this parasite when he caught specimens in an ultraviolet light trap near the Manoa Campus of the University of Hawaii in July, 1966 (Beardsley, 1967).

The establishment of *C. iceryae* was confirmed by rearing several speciment of this parasite from *I. purchasi* collected on *Desmodium* on the Manoa Campus during the latter part of December, 1966 (Hale, 1968).

In order to determine the distribution of *C. iceryae*, monthly surveys were conducted on the Island of Oahu. The parasitization by *C. iceryae* was established by dissecting the immatures of *I. purchasi* collected during this survey. *C. iceryae* was observed during 1967 in the following areas: Waimanalo, 21 April; Lanikai, 14 July; Laie, 25 August; and Pearl Harbor, 30 November, 1967. *C. iceryae* apparently is not established on Hawaii, Kauai, Maui, and Molokai since surveys conducted during August and September of 1968 showed no parasitized scales.

SUMMARY

Icerya purchasi Maskell is widely distributed throughout the tropical and semitropical regions of the world. In Hawaii *I. purchasi* is present on the islands of Hawaii, Kauai, Maui, Molokai and Oahu from sea level up to an elevation of 400 meters. It infests about 51 host plants of which 26 were new host plants found during this study. It was found abundantly on perennial plants such as *Citrus*, *Casuarina*, and *Desmodium*.

Life history studies were conducted under laboratory conditions on potted *Desmodium sandwicense* E. Meyer covered with organdy cages. The average duration of the different stages were: egg stage, 15.4 $\pm$ .76 days; crawler period of the first instar, about 4 or 5 days; sessile period of the first instar, 12.3 $\pm$ 1.16 days; second instar, 9.9 $\pm$ .82 days; third instar, 9.8 $\pm$ 1.52 days; preovipositional period, 8.2 $\pm$ 2.04 days; and the ovipositional period, 39.1 $\pm$ 8.32 days. The developmental period from egg to adult was about 60 days, and the mean longevity from egg to death was about 99 days. The

average fecundity per adult female during her life span was 678.6 eggs.

Studies on the life cycle of *Rodolia cardinalis* (Mulsant), a predator of *I. purchasi*, showed that the average duration of the stages was: egg stage, 4.50 ± .38 days; first larval instar, 3.88 ± .52 days; second larval instar, 3.64 ± .77 days; third larval instar, 2.75 ± .46 days; fourth larval instar (including prepupal stage), 5.64 ± .37 days; pupal stage, 4.63 ± .84 days averaging from egg to adult, 25 days.

Cryptochaetum iceryae (Williston), a parasite of *I. purchasi*, has become established on the Island of Oahu. However, it has not been found on any of the neighbor islands.

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