

Associative Behavior Of The Arrow Goby,  
Clevelandia ios (Jordan And Gilbert)  
And The Ghost Shrimp,  
Callinassa Californiensis Dana

by

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Clevelandia ios is a small estuarine teleost which inhabits the burrows of the Thallassinid crustacean, Callianassa californiensis, presumably to avoid predation and desiccation at low tides. Field observations and laboratory experiments were undertaken to determine the relationship of Clevelandia ios and Callianassa californiensis, whether it be commensalism, mutualism, or parasitism. C. ios and C. californiensis were found to be negatively associated under field and laboratory conditions. In addition, the arrow gobies were found to inhabit the ghost shrimp burrows only during the spring and summer months. Thus, these two species are facultative associates. Many authors believe these species may be evolving toward an obligate commensal relationship.

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## INTRODUCTION

Some authors define terms such as symbiosis and commensalism in different ways because: 1) They are looking at different features of the association when they define the relationship as a whole. 2) They have fragmentary knowledge of the total biological picture. 3) Such subtle gradations of these associations exist in nature that it becomes almost impossible to draw definitive boundaries (Gotto, 1969).

For example, Allee, et al (1949) cite Van Beneden (1876) who defined commensalism as a living together of two dissimilar organisms where one partner benefits and the other is neither harmed nor benefited by this association. The commensal species are viewed as "messmates" - i. e. the host species provides food for the guest or commensal species. Thus, the original connotation of the commensal association was one of a shared food source. The authors look at this partnership on the level of the individual.

Losey (1972) looked at commensalism from a behavioral view, and he believed commensal or symbiotic associations are suggested when only one member of the association responds to signals in a manner which initiates or maintains the symbiosis. Mutualism is suggested when both



parties respond to signals in this manner.

One type of commensal association is called endoecism. Endoecism is a partnership in which one animal habitually shelters within the tube or burrow of another. Though shelter or protection is the main advantage provided, the endokete may also have a food sharing relationship with its host (Gotto, 1969). Many examples of endoecism exist in nature, particularly in the marine environment. There are many "commensals" which live in the burrows of the ghost shrimp, Callinassa californiensis, including the goby, Clevelandia ios (Ricketts and Calvin, 1968; Mac Ginitie and MacGinitie, 1949; Dales, 1957).

Dales (1957) hypothesized that the origins of many commensal associations were in the crowded conditions of the littoral or sublittoral zone. He argued the food supply is abundant, and the major competition is for space. Therefore, he believed, many associations between species probably have originated by chance. If the commensal species gains some advantage over solitary individuals of that same species, then natural selection may act in favor of the commensal individuals, and any factor which allows the commensal to find or remain with the host will become important. If a species is found with a number of different hosts in the same area, these factors are likely to be of a general nature.

For example, negative phototaxis, rather than a particular chemical attraction to the host, may allow an endokete to find its host's burrow.

Commensal associations may only be inferred in the fossil record. Foerste (1933) reported commensal worms growing in the shells of the cephalopod, Centrocytoceras. Trueman (1942) found spirorbids attached to nonmarine lamellibranchs. Indeed, even the literature of extant species, commensalism is often inferred, rather than proven by quantitative or experimental methods (Forsyth and McCallum, 1978 - insect inquilines of lamellibranchs; Lamberts and Garth, 1977 - langurs and dogs; Paulson, 1978 - Gobiid fish and Alpheid shrimp; Hubbs, 1978 - turtles and ectocommensal invertebrates; Limbaugh, 1961 - cleaner fishes; Davey, Gee, Bayne, and Moore, 1977 - inquiline arthropods and lamellibranchs; Russels, 1977 - Egrets and Roseate Spoonbills; Kushilan, 1978 - Little Blue Herons and White Ibis). There have been some efforts, however, which do try to quantify these associations, notably studies of gobies and Alpheid shrimp (Preston, 1978; Karplus, 1979; Karplus, Szlep, and Tsurnamal, 1972, 1974; Karplus, Tsurnamal, and Szlep, 1972).

Dales (1957) states that we know little about the true nature of most commensal relationships because of the difficulty of applying the experimental method to these problems. The purpose of this thesis is to apply field and laboratory experimental methods to help elucidate the nature of the Clevelandia ios - Callianassa californiensis relationship. All work was performed in Coos Bay, Oregon from August 1979 to September 1980, representing approximately 500 hours of research.

## ANIMALS

Clevelandia ios

The arrow goby, Clevelandia ios (Jordan and Gilbert, 1882) is a small, estuarine teleost which inhabits the burrows of several invertebrate species, including the ghost shrimp, Callinassa californiensis Dana, the mud shrimp, Upogebia pugettensis (Dana), and the fat innkeeper worm, Urechis caupo Fisher and MacGinitie. The goby is said to live commensally in the burrows of these species, and it uses these burrows as a refuge from predators and desiccation during low tides (MacGinitie, 1930, 1934, 1935, 1939; MacGinitie and MacGinitie, 1949; Brothers, 1975). In Coos Bay, Oregon, arrow gobies are reported in localities from the head of the harbor to fifteen miles from the ocean, where salinity ranges from 32‰ to 20‰ (Cummings and Schwartz, 1971).

## History - Synonymy

Clevelandia ios was first named Gobiosoma ios by Jordan and Gilbert in 1882, based on a

female holotype obtained from the stomach of Hexagrammus asper. They placed this Gobiid fish in the genus Gobiosoma because they believed its body was entirely scaleless. Eigenmann and Eigenmann (1888) described it as Clevelandia longipinnis and first named the genus Clevelandia. Jordan and Starks (1895) named it Clevelandia ios. Jordan (1896) described what he thought was a new species, Clevelandia rosae from San Diego. Jordan and Evermann (1898) recognized and described Clevelandia ios and Clevelandia rosae, and believed C. rosae and C. longipinnis were identical species. Jordan, Evermann, and Clark (1930) recognized only Clevelandia ios, and all other names have been reduced to synonyms. Indeed, there is much racial variation in morphometric and meristic characteristics of this species (Prasad, 1948, 1958; Carter, 1965).

#### General Life History

Work has been performed on populations in southern California (Prasad, 1948, 1958) and on populations in Washington state (Carter, 1965). No work has been done on populations in Oregon. Adult C. ios are sexually dimorphic; the males have a dark band on their anal fin during breeding season (Hart, 1973; Brothers, 1975; Carter, 1965). In addition, females have a broad and swollen genital papilla, males have a more pointed papilla. Prasad (1948) found 23% of his sample of female

C. ios were mature at a standard length of 29.0 mm, and all females 34.0 mm standard length and larger were mature. All specimens 19.0 mm and larger may be sexed on the examination of their genital papilla (Prasad, 1948, 1958). In southern California, C. ios spawns mainly during the months of March through June. There is some controversy over whether this species exhibits parental care of its eggs. Prasad (1948) states there is no parental care of its eggs or young, but Brothers (1975) describes in detail the actions of the males brooding eggs in burrows presumably constructed by the gobies. C. ios are believed to have a lifespan of two to three years, though it may be impossible to age this species on the basis of otoliths, opercular bones, or scales (Carter, 1965).

#### Predators

Many species prey on C. ios adults, including rockfish (Sebastes spp.), staghorn sculpins (Leptocottus armatus), whitespot greenlings (Hexagrammus stelleri), terns, Greater Yellow Legs (Totanus melanoleucus), and Short-billed Dowitchers (Limnodromus griseus) (Hart, 1973; Reeder, 1951). Indeed, one wonders why more species do not prey on these small fish when they are presumably out of their hosts' burrows at high tide. Brothers (1975)

has shown weak schooling tendencies of C. ios, particularly among smaller fish (less than 25 mm) as a possible adaptation to reduce predation. Elam, Fuhrman, Kim, and Mosher (1977) isolated a tetrodotoxin-like neurotoxin from C. ios, and they believe this neurotoxin may be used as a predatory protection device for the adults and/or eggs.

Callianassa californiensis

Callianassa californiensis Dana is a Thalassinid crustacean which is found abundantly in estuaries, bays, and sloughs on the west coast of North America. It burrows in mixed sand and mud sediments of the mid to upper intertidal range (MacGinitie, 1934, 1939; MacGinitie and MacGinitie, 1949; Ricketts and Calvin, 1968). Adults may reach a body length of up to 10 centimeters (Kozloff, 1973). C. californiensis has an elongate body which is often bright pink. Adults have a large cheliped, which may be either the right or the left. Females have smaller chelipeds than do males, perhaps because the males use this appendage as a weapon of offense and defense during the mating season (MacGinitie, 1934; MacGinitie and MacGinitie, 1949). C. californiensis is a detritus feeder. It may play an important role in water and oxygen exchange between its burrow and the surrounding sediments through its burrowing and feeding activities (MacGinitie, 1934; Torres, Gluck, and Childress, 1977).

Commensals

Many species are found in the burrows of C. californiensis, including the cyclopoid copepod



"ectocommensals" Clausidium vancouverense and Hemicyclops spp. ; the Polynoid worms, Hesperonoe complanata and Harmothoe spp. ; the Pinnotherid crabs, Pinnixa schmittii, Scleroplax granulata, and Pinnixa franciscana; the shrimp, Betaeus longidactylis; the bivalve, Cryptomya californica; the isopod, Ione spp. ; and the gobies, Gillichthys mirabilis and Clevelandia ios (MacGinitie, 1934; Dales, 1957; Light and Hartman, 1936; Wells, 1928, 1940; Stevens, 1928; Pearce, 1966; Gonor, Strehlow, and Johnson, 1979). Several of these species are also found in the burrows of Upogebia pugettensis and Urechis caupo (Dales, 1957; MacGinitie, 1934).

#### Burrows

The burrows of C. californiensis consist of at least two openings to the surface. The entrance has a mound or volcano like appearance, due to the surface deposition of sediments by the organism. There are often fecal pellets deposited at the entrance. There are many turn-around chambers and branches of the burrows, and the animals rarely burrow deeper than 50 to 75 cm (Moore, 1932; Ricketts and Calvin, 1968; MacGinitie, 1934; MacGinitie and MacGinitie, 1949; Frey and Howard, 1969; Shinn, 1969; Peterson, 1977).

Burrows of Callianassa californiensis and those of other Thalassinids are common in the fossil record, and may be used by geologists to indicate ancient sea levels of the paleoenvironment (Frey and Howard, 1969; Shinn, 1968; Pohl, 1936; Weimer and Hoyt, 1964; DeVine, 1966; DeWindt, 1974; Enos and Perkins, 1977). Hayakasaka (1935) recognized the geological importance of crab burrows as trace fossil evidence of species, environments, and sea levels. Thalassinid burrows are similarly important.

Woodward (1876) believed all Thalassinidae were fossorial. Pilsbry (1901) described Callianassa from Cretaceous beds of New Jersey. Only the chelae were preserved as fossils, indicating fossil forms were similar to living, soft bodied Recent species.

Rice and Chapman (1971) suggest the burrowing behavior of the lobster, Nephrops norvegicus was adopted early in the geologic history of this order. The burrows seem to function as refuges. The burrowing habits of Thalassinids may also have served the function of a refuge in the early history of this tribe. Callianassa species are rarely observed leaving their burrows (MacGinitie, 1934; Pohl, 1936), and they are believed to have few, if any, natural predators. However, man may be an important predator of Callianassa as these species are a common bait item (Tollefson and Marriage, 1949; Peterson, 1977).

## THE STUDY AREA

Clevelandia ios and Callianassa californiensis were obtained from the south end of the mudflat at Jordan Cove (43° 26' N. Latitude, 124° 14' W. Longitude) (Map 1). The substrate is thixotrophic, and consists of sandy mud sediments. There are many anaerobic purple bacteria in this environment during the summer. In the winter, an estimated 8 inches of sand are deposited on the mudflats in the mid to high intertidal region (personal observations).

The highest intertidal regions are characterized by a salt marsh zonation of plants. Salicornia is present in the lower levels of this region. Vaucheria lives a little further down than Salicornia.

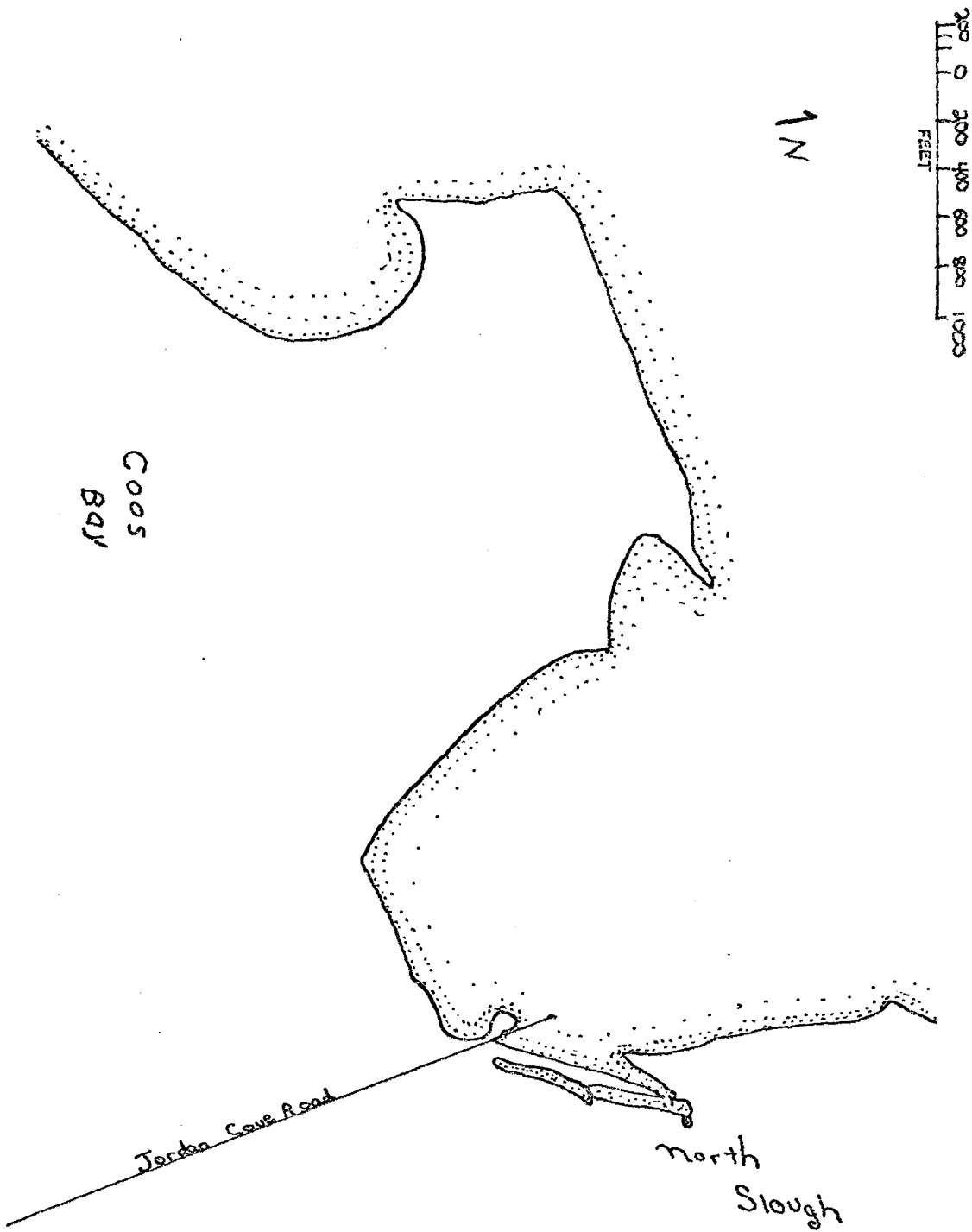
The mid intertidal regions are characterized by the presence of Corophium salmonis, Clevelandia ios (in summer), Callianassa californiensis, Cryptomya californica, Macoma balthica, Hesperonoe complanata, Pinnixa littoralis, Macoma nasuta, unidentified annelids, and, seasonally, Enteromorpha.

The lower intertidal is characterized by the presence of Ulva and Zostera. Some C. ios are found here seasonally. There also a few C. californiensis and associated species. Fish captured in this area by seining methods include juvenile lingcod

(Ophiodon elongatus), staghorn sculpins, (Leptocottus armatus), bay pipefish (Syngnathus griseolineatus), shiner perch (Cymatogaster aggregata), juvenile sand sole (Psettichthys melanostictus), and juvenile coho salmon (Onchorhynchus kisutch). There are also cockle beds (Clinocardium nuttallii) in this area. Gulls and crows were observed feeding here during the low tides.

During the late spring and the summer, Clevelandia ios were found in shallow channel and pool areas with less than three centimeters of water, as well as in occupied and unoccupied C. californiensis burrows. Clevelandia ios were found lower intertidally in the spring, higher intertidally in the summer, and were not found intertidally in the fall and winter. Juvenile C. ios would sometimes hide in Enteromorpha. Salinity measurements taken in the late summer showed the channel water salinity to be 30‰, and the interstitial (burrow) water salinity to range from 28‰ to 30‰ at a depth of approximately 10 cm. Many people were observed in this area, digging up Callinassa californiensis for bait.

Map 1. Jordan Cove, Oregon ( $43^{\circ} 26'$  N. Latitude,  
 $124^{\circ} 14'$  W. Longitude)



## METHODS

Field Studies

Clevelandia ios were obtained from Callianassa californiensis burrows at low tide with the aid of a suction device known as a shrimp gun. This method works better than the traditional methods of obtaining fish, e. g. trawls and seines, as the gobies are very small and will retreat into invertebrate burrows when traditional methods are used (Grossman, 1979). The burrows were chosen at random.

For each burrow dug, the approximate tidal height, the number of Clevelandia ios, the number of Callianassa californiensis, the presence or absence of Enteromorpha alga cover, and the presence or absence of other invertebrate species (e. g. Cryptomya californica) were recorded. Chi-square analyses and coefficients of interspecific association (Cole, 1949) were determined for the species pairs 1) C. californiensis - C. ios. 2) Enteromorpha - C. ios. 3) Enteromorpha - C. californiensis.

Standard lengths of Clevelandia ios were estimated to the nearest millimeter. Length - frequency histograms were plotted for C. ios collected in June and August, 1980.

The body length of Callianassa californiensis, i. e. the length of the body from the rostrum to the telson was measured to the nearest millimeter, and a length - frequency histogram for this species was plotted.



### Laboratory Studies

An experimental mudflat aquarium, similar to the one of Grossman and Reed (1980) was constructed in order to observe Callianassa californiensis - Clevelandia ios interactions under simulated burrow conditions. Holes were randomly drilled through the bottom of the tank for the insertion of clear plastic tubing (outer diameter- 1 inch (2.54 cm) inner diameter- 3/4 inch (1.73 cm)) to simulate burrows. This is the correct size tubing to use to simulate burrows of this species (Shinn, personal communication). The tubing was washed with fresh water and placed in the tank. A thin layer of mud from a nearby mudflat covered the bottom of the aquarium. A screen divided the tank in half for a control. Continuous running sea water flowed through the tank. A dark red light was installed for night viewing, and the tank was outdoors, under natural daylight conditions. Tidal height simulation was regulated by a drain tube.

Clevelandia ios and Callianassa californiensis were placed in the tank, and allowed to choose their own burrows. Two days after introduction to the tank, observations of these organisms began. Animals were observed during the morning, afternoon, and evening to minimize effects of diel activity patterns. No attempt was made to analyse differences in behavior or activity levels

during different times of the day, as Hesthagen (1976) states it is difficult to draw field and lab parallels in activity when artificial (night) light conditions are used.

Clevelandia ios and Callianassa californiensis behavior was observed for approximately 200 hours, and ethograms were written for these two species. A behavioral catalogue analysis (Fagen and Goldman, 1977) was conducted for Clevelandia ios. The logarithm of the number of types of acts observed versus the logarithm of the number of acts observed was plotted. This is called a type - token relationship. Focal animal sampling was used to observe behavior of animals in all experiments.

Observations were made to determine whether the number of Clevelandia ios in a burrow was affected by the level of water in the simulated mudflat aquarium. Approximately 40 hours of observations were recorded.

Other experiments were conducted to determine whether the length of a burrow has any relationship to the numbers of either Clevelandia ios or Callianassa californiensis in that burrow. Repeated observations recorded the locations and numbers of each species in each burrow. Since the repeated observations were of the same animals, a two factor analysis of variance was calculated to determine whether the variance in the number of organisms observed in each burrow with respect

to time was a significant variable introduced to this experiment. Observations were from August 12 to August 31, 1980. In addition, a Chi - square analysis of the number of C. ios present in a burrow versus the number of C. californiensis present in the same burrow determined whether the presence of the ghost shrimp has any influence on the presence of the goby in that burrow.

## RESULTS

Field Distribution  
And Abundance

Nineteen Clevelandia ios were collected in June and 124 in August (Figures 1 and 2). The smallest goby collected from a burrow was 12 mm standard length.

There appears to be a peak abundance of Callianassa californiensis at 45 mm body length (Figure 3). There have been no reports on the rates of growth, nor on the longevity of this species, so it is difficult to determine age structure of this population. The peak abundance for C. ios and for C. californiensis occur at about the size for the two species.

Chi-square values and Cole's coefficients of interspecific association (Tables 1 and 2) indicate Clevelandia ios and Callianassa californiensis occur together in burrows less frequently than they would be expected to by chance. The Chi-square value of 20.0 with 8 degrees of freedom ( $P \sim .01$ ) indicating a negative association of these two species. All other species combinations recorded had nonsignificant Chi-square values, indicating associations no more or no less frequent than would be expected by chance.

Figure 1. Length- Frequency Histogram for Clevelandia  
ios collected in June, 1980.

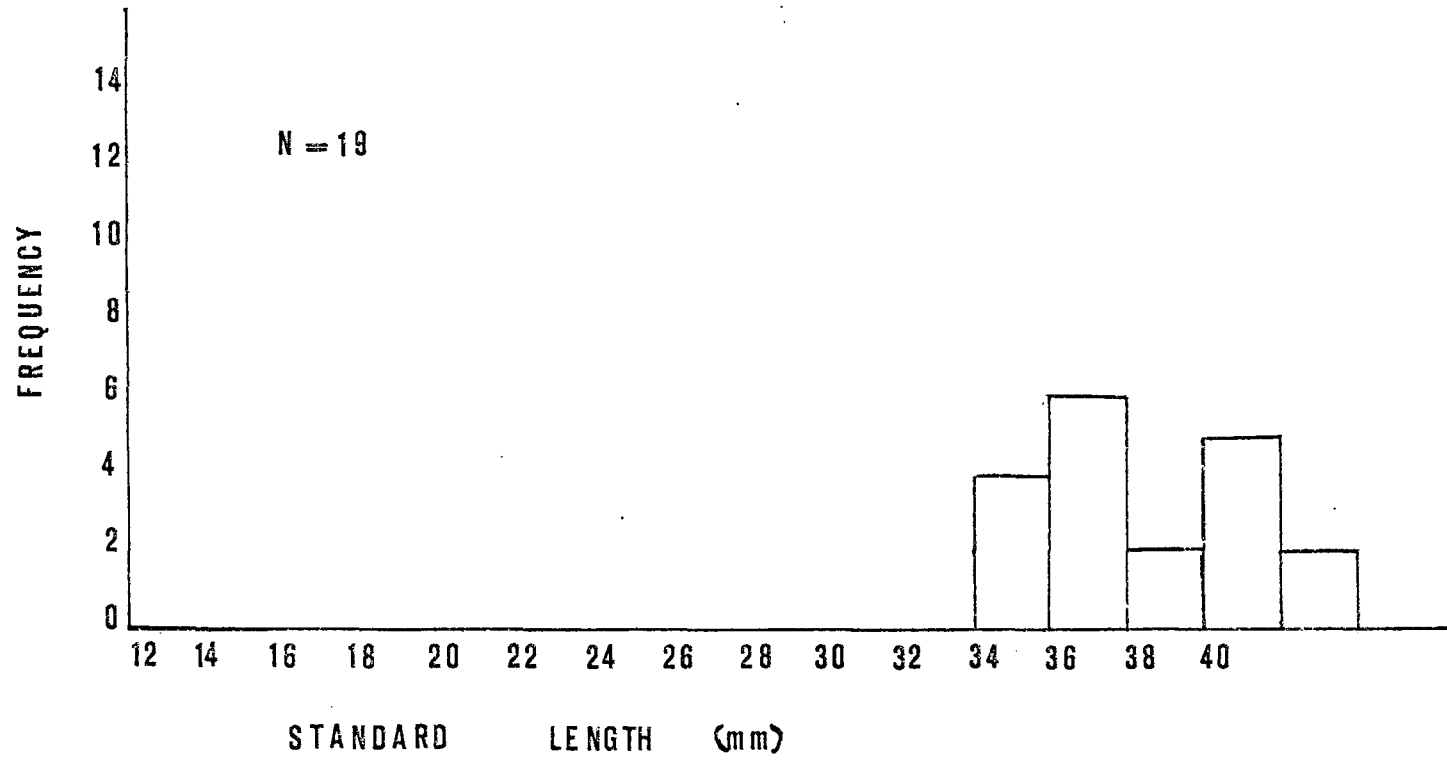


Figure 2. Length-Frequency Histogram for Clevelandia  
ios collected in August, 1980.

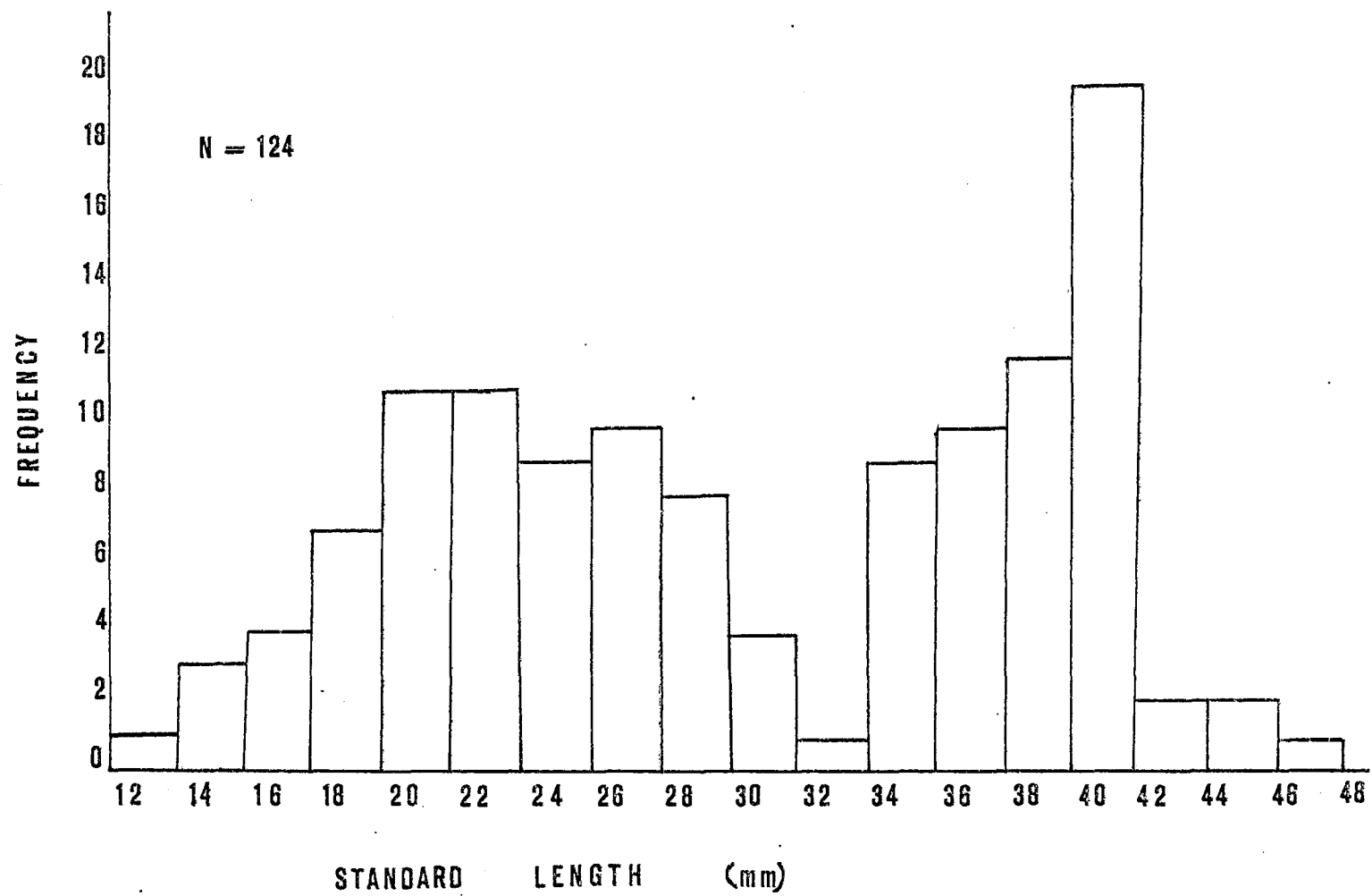




Figure 3. Length-Frequency Histogram for Callianassa  
californiensis collected in August, 1980.

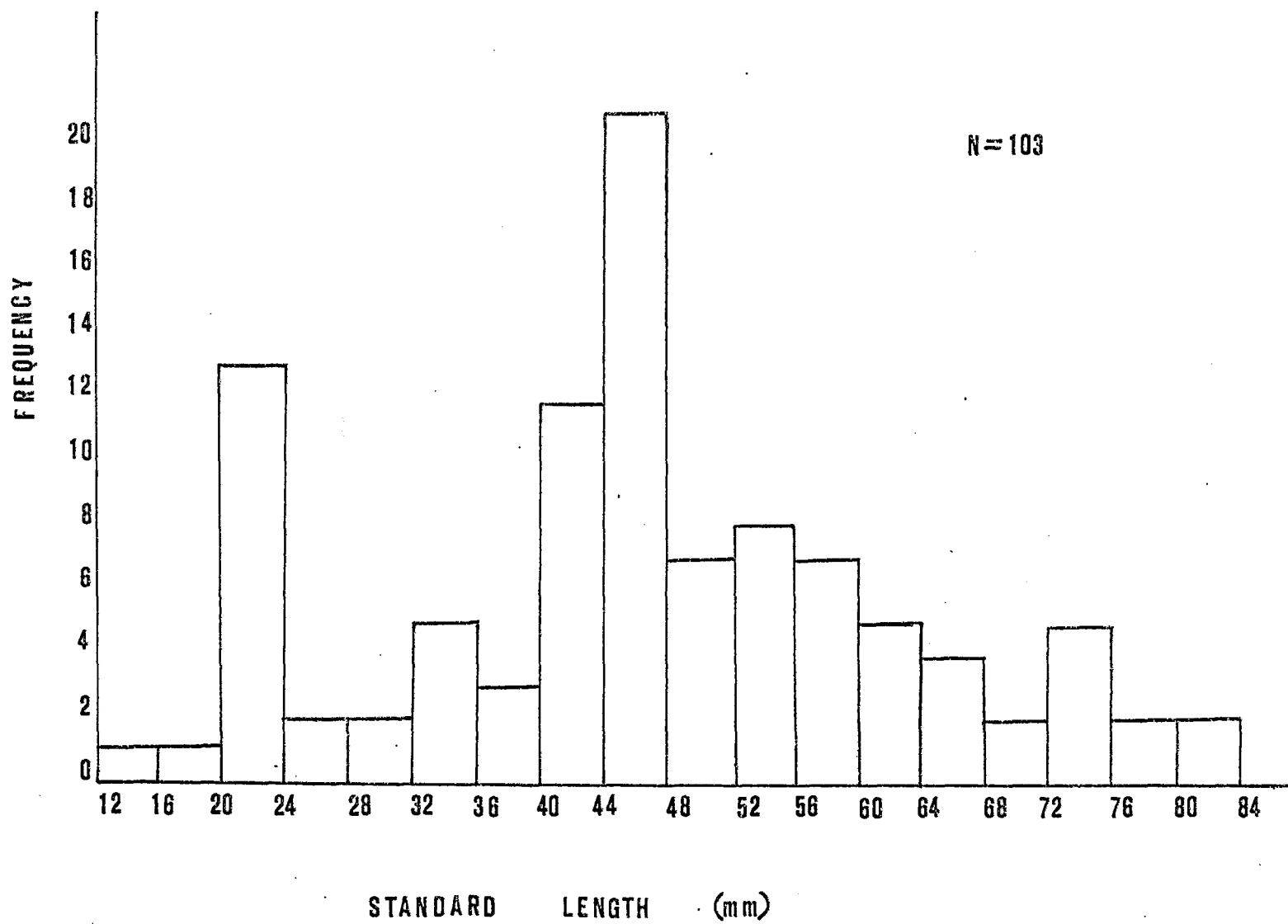


Table 1. Interspecific Association Analyses.

<u>Species Combination</u>	<u>Number of Samples</u>	<u>Coefficient of Association</u>	$\chi^2$ <u>Based on Presence or Absence of Species</u>	<u>Significance Level</u>
<u>C. ios-</u> <u>C. californiensis</u>	254	-.278	5.13	P = .05
<u>Enteromorpha sp. -</u> <u>C. ios</u>	76	-.131	.374	P ~ .5 (nonsignificant)
<u>Enteromorpha sp.-</u> <u>C. californiensis</u>	76	-.131	.134	P ~ .975 (nonsignificant)

Table 2.  $\chi^2$  Analysis of numbers of C. ios versus numbers of C. californiensis found in burrows. Parentheses indicate expected values.  $\chi^2 = 20.0$  2 Degrees of Freedom  $P \sim .01$

		<u>Number of Callianassa californiensis</u>					<u>Row Total</u>
		<u>0</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>3</u>	
<u>Number of C. ios</u>	<u>0</u>	21 (30.7)	50 (43.8)	38 (37.6)	28 (28.8)	22 (18.5)	159
	<u>1</u>	22 (11.8)	12 (16.8)	14 (14.4)	8 (11.0)	5 (7.0)	61
	<u>1</u>	6 (6.6)	8 (9.4)	8 (8.0)	10 (6.2)	2 (3.9)	<u>34</u>
<u>Column Total</u>		49	70	60	49	29	254

### Behavioral Observations

Twenty seven behaviors of C. ios were recorded as well as 12 behaviors of C. californiensis (Tables 4 and 5). A behavioral catalogue analysis was conducted for C. ios (Figure 4). The number of acts observed versus the number of types of acts in this catalogue may be characterized by the equation:

$$Y = .63 X^{.32}$$

where Y = the number of types of acts in this collection;

X = the number of acts with repetitions.

The slope of .32 is in general agreement with May (1975) and Webb (1974). They analysed diversity of species, rather than diversity of behavior, and found regression slopes of about .3 characterize these distributions in all animal species for which these slopes have been calculated. Fagen and Goldman (1977) indicate similar slopes characterize behavioral catalogue analyses.

By the same analogy, a tenfold increase in the total number of acts observed should, on the average, double the number of behavioral types in the catalogue (Fagen and Goldman, 1977). In this example, 11 types of C. ios were observed and 2145 total acts, so theoretically one must look

at 21,450 acts to observe 22 types of behavior, 214,500 acts to observe 44 types of behavior, etc. However, this logarithmic regression procedure does not enable one to make statements about the actual size of the behavioral repertoire, as the theoretical regression line has no finite asymptote (Fagen and Goldman, 1977).

Chi-square values of the number of Clevelandia ios in burrows versus the simulated tidal height of the aquarium are nonsignificant (Tables 6 and 7). This indicates C. ios, whether alone or in the presence of C. californiensis, do not enter the burrows nor leave the burrows more frequently on any one particular simulated tidal height than on any other. C. ios were observed vibrating into the mud, rather than retreating into C. californiensis burrows.

The number of C. californiensis per burrow versus the length of the burrow has no clear linear relationship. The equation for the regression line (Figure 5) is:

$$Y = .506 + .003X$$

Where Y = the number of  
C. californiensis per burrow;  
 X = the burrow length.

An analysis of error (Table 9) reveals the actual slope lies, within 95% confidence limits, between

-.004 and +.110, so one can not state any linear relationship. However, a two - factor analysis of variance (Table 8) reveals no significant variance in numbers of C. californiensis observed with respect to time, yet a significant variance in observations with respect to burrow length. This indicates C. californiensis do show preferences for certain burrows.

When C. ios were present in the simulated mudflat without C. californiensis, there were more gobies present in longer burrows (Figure 6, Table 10). The regression equation is:

$$Y = .74 + .035 X$$

Where Y = the number of

C. ios per burrow;

X = the burrow length.

An analysis of error reveals the actual slope to fall, within 95% confidence limits, between the values of +.016 to +.054, indicating a significant positive slope (Table 11). Thus, as the length of the burrow increases, the number of C. ios present in this burrow also increases.

A two-factor analysis of variance (Tables 8, 10, and 12) showed the variance in the number of C. ios and C. californiensis observed with respect to time was not statistically significant.

Therefore, although observations were not independent-  
i. e. the same animals were repeatedly observed,  
there was no significant bias shown by performing  
experiments in this way. Thus, for these experiments,  
I feel justified in analysing results by linear  
regression.

When C. ios were in the presence of C. californien-  
sis, there was a less clear relationship between  
the length of the burrow and the number of C. ios  
present in that burrow (Table 13, Figure 7). The  
equation for the regression line is:

$$Y = 2.89 + .008 X$$

where Y = the number of  
C. ios in the burrow;  
X = the length of  
the burrow.

An analysis of error reveals the actual slope  
to range, within 95% confidence limits, from  
-.057 to +.073. Therefore, the regression is  
insignificant and one can not conclude any  
clear relationship between the number of gobies  
per burrow in the presence of C. californiensis  
and the length of the burrow. Other factors  
may affect this relationship.

The presence of C. californiensis was thought  
to inhibit the presence of C. ios in the burrow,  
as the ghost shrimp were often observed chasing the



gobies out of the burrows. A Chi - square analysis of the number of C. ios present in a burrow versus the number of C. californiensis present in the same burrow (Table 14) indicates C. ios and C. californiensis are negatively associated under laboratory conditions ( $\chi^2 = 7.6$ , 2 d. f. ,  $P \sim .02$ ). When there was more than one C. californiensis per burrow, there were less C. ios present in the burrow with the ghost shrimp than would be expected by chance.

Table 3. Tank Specifications.

Length: 162.5 cm

Width: 129.5 cm

Height: 136.6 cm

Windows:

Two Large Windows:

Length: 71.1 cm

Width: 0.5 cm

Height: 25.4 cm

Four Smaller Windows:

Length: 55.9 cm

Width: 0.5 cm

Height: 25.4 cm

Burrows:

Outer Diameter: 2.5 cm

Inner Diameter: 1.7 cm

Burrow Lengths:

C. ios alone

A) 66cm

B) 86.4 cm

C) 137.2 cm

D) 101.6 cm

E) 73.7 cm

C. ios and

C. californiensis

68.6 cm

83.8 cm

152.4 cm

121.9 cm

63.5 cm

Table 4. Ethogram of Clevelandia ios.Context of BehaviorResting  
(in burrow)

- 1) Holding: The goby is orientated at a 90 degree angle, head upwards or head downwards, and remains motionless in the burrow. It hangs on to the sides of the burrow, and creates a suction by using its pelvic fins. Its pectoral fins are spread outwards from the sides of its body.
- 2) Diagonal Holding: Similar to holding, but the fish is orientated diagonally across the burrow, usually at a 45 degree angle.
- 3) Tail Stand: The goby is orientated at a 90 degree angle, with its head directed upwards, and remains in this position, balancing on the sediments in the burrow by using its tail and pectoral fins.
- 4) Horizontal Holding: The fish rests in a horizontal position in the bottom of the burrow, and creates a suction with its pelvic fins.

Resting  
(out of burrow)

- 5) On Glass: Probably a "misplaced" behavior, the goby is orientated at a 90 degree angle, and remains motionless. It hangs on to the glass windows of the tank by creating a suction with its pelvic fins.

Context of  
Behavior

Resting  
(out of burrows)

- 6) Sediment Resting: The fish remains motionless, lying horizontally over the sediments in the tank.
- 7) Resting Over Burrow: The goby remains motionless, lying over the entrance to a burrow, resting on its pelvic fins, usually with its head directed upwards and tail directed downwards.
- 8) Head Out: The goby sticks its head out of the burrow and remains motionless.

Locomotion  
(in burrow)

- 9) Burrow Swimming: The goby swims either upwards or downwards in the burrow using its body, caudal fin, and to a lesser extent, its pectorals. The dorsal fin remains flattened. This action may be performed while the fish has either its head directed upwards or its head directed downwards. The fish can swim forwards or backwards in the burrow. The goby has been recorded swimming diagonally through the burrow.
- 10) Turn Around: The goby turns around in the burrow, using its entire body. This behavior is usually followed by either a burrow swim or a holding action.

Context of  
BehaviorLocomotion  
(out of burrows)

- 11) Darting: The fish swims in short, jerky motions, close to the bottom sediments in the tank, dorsals flattened, using body, pectorals, and to a lesser extent, caudal fins.

## Maintenance

- 12) Fanning: Observed when the goby is in a hypoxic burrow, the fish waves its pectoral fins up and down to create a small current of water around itself.

## Distress

- 13) Tail Wiggle Dance: Observed when the goby is in a burrow, it wiggles its tail, shakes its entire body in shimmying motion, swims upwards two to three centimeters, turns around, and resumes this pattern.
- 14) Escape Reaction: When the fish is up in the water column, it swims to the top of the tank, turns around, swims downwards, then swims to the top of the tank again.

## Feeding

- 15) Sand Siting: The fish ingests sediments through its mouth, presumably strains particles through its gill rakers, and expels unwanted particles out its opercular region.

Context of  
Behavior

Feeding

- 16) Passive Sinking: Gobies in the water column hover a few inches above the sediments, their bodies at a 45 to 60 degree angle, dorsal fins erect, then they passively sink downwards with their mouths open.
- 17) Surface Feeding: The fish swims upwards at a 60 degree angle, and bites at particles on the surface of the water.
- 18) Burrow Lunging: The fish lunges at dirt particles on the body of a ghost shrimp, or it lunges at particles dropped by the ghost shrimp.

Interspecific  
Agonism

- 19) Nipping: The goby lunges and nips at the ghost shrimp, its mouth open wide. Attack is usually directed at the telson or the cheliped, never at the middle of the ghost shrimp's body, and usually without apparent provocation.

Intraspecific  
Agonism

- 20) Mouth Biting: Two gobies engage in combat by opening their mouths to the fullest extent and trying to bite each others jaws.

Context of  
Behavior

Intraspecific  
Agonism

21) Chasing: The goby chases another goby up or down the burrow by swimming after it with its mouth open.

22) Tail Slapping: While one goby is swimming, and another goby is close to the intended position of the swimmer, the swimmer will slap the other goby with an exaggerated side-to-side movement of its tail.

23) Dropping: An adult goby was observed picking up a dead juvenile in its mouth at an approximately 180 degree angle, and dropping it down to the bottom of the burrow. The adult repeated this action several times.

Beneficial  
Behavior (?)

24) Sliding: The goby swims upwards or downwards in a burrow, sliding over the dorsal surface of a ghost shrimp.

Elimination

25) Defecation: The gobies were observed defecating, usually when they were out of the burrow, swimming.

Context of  
Behavior

Fright or  
Escape

- 26) Vibrate: The fish sticks its head into the sediments and vibrates its body until it is completely covered with mud.
- 27) Retreat: The fish swims into a burrow head first, usually upon being frightened. It slaps its tail over the burrow entrance as it enters the burrow.



Table 5. Ethogram of Callinassa californiensis.Context of Behavior

## Cleaning

- 1) Cleaning: The ghost shrimp uses its 5<sup>th</sup> pair of legs to clean its body. There are fine comb-like hairs on these legs, which it uses to remove sediments. The ghost shrimp have also been observed cleaning each other.

## Locomotion

- 2) Turn Around: The ghost shrimp turns around in the burrow by the use of its telson and pereopods.
- 3) Swimming: Rarely observed. The ghost shrimp swims backwards in the water column when first placed in the aquarium, by using its telson and pleopods.
- 4) Walking: The ghost shrimp use synchronous movements of their pereopods to walk up or down the burrow. They walk with their first cheliped extended.

## Resting

- 5) Resting: In the burrow, Callinassa remain motionless, usually in a curled up position.

Context of  
Behavior

Maintenance

- 6) Dirt Removal: A ghost shrimp removes dirt from the burrow by rolling it into balls with its chelipeds, and walking up the burrow to deposit dirt at the burrow entrance. This activity creates a mound in this area.
- 7) Fanning: Under hypoxic conditions, the ghost shrimp will use its pleopods to create a current around itself.

Defensive

- 8) Roll Up: When out of the burrows and on the sediment surface, the ghost shrimp will frequently curl up into a ball and remain motionless.

Feeding

- 9) Sieving : Callianassa use their first and second pereopods and their maxillipeds to bring mud particles to the mouth, and to sieve out food items.

Interspecific  
Agonism

- 10) Lunging: When the goby gets within a few centimeters of the anterior end of the Callianassa, the ghost shrimp will lunge at the goby, using its first cheliped to try to pinch the fish. This action is usually followed by chasing.

Context of  
Behavior

Interspecific  
Agonism

- 11) Chasing: The ghost shrimp walks up the burrow with its first cheliped extended, lunges at a goby, and chases it up out of the burrow.

Beneficial

- 12) Cleaning a Goby: The ghost shrimp will occasionally rub its fifth pair of legs over the body of a goby when the fish is resting under the ventral surface of the ghost shrimp.

Figure 4. Type-Token relationship for the behavioral catalogue of Clevelandia ios.

$\beta = .31$  to  $.33$

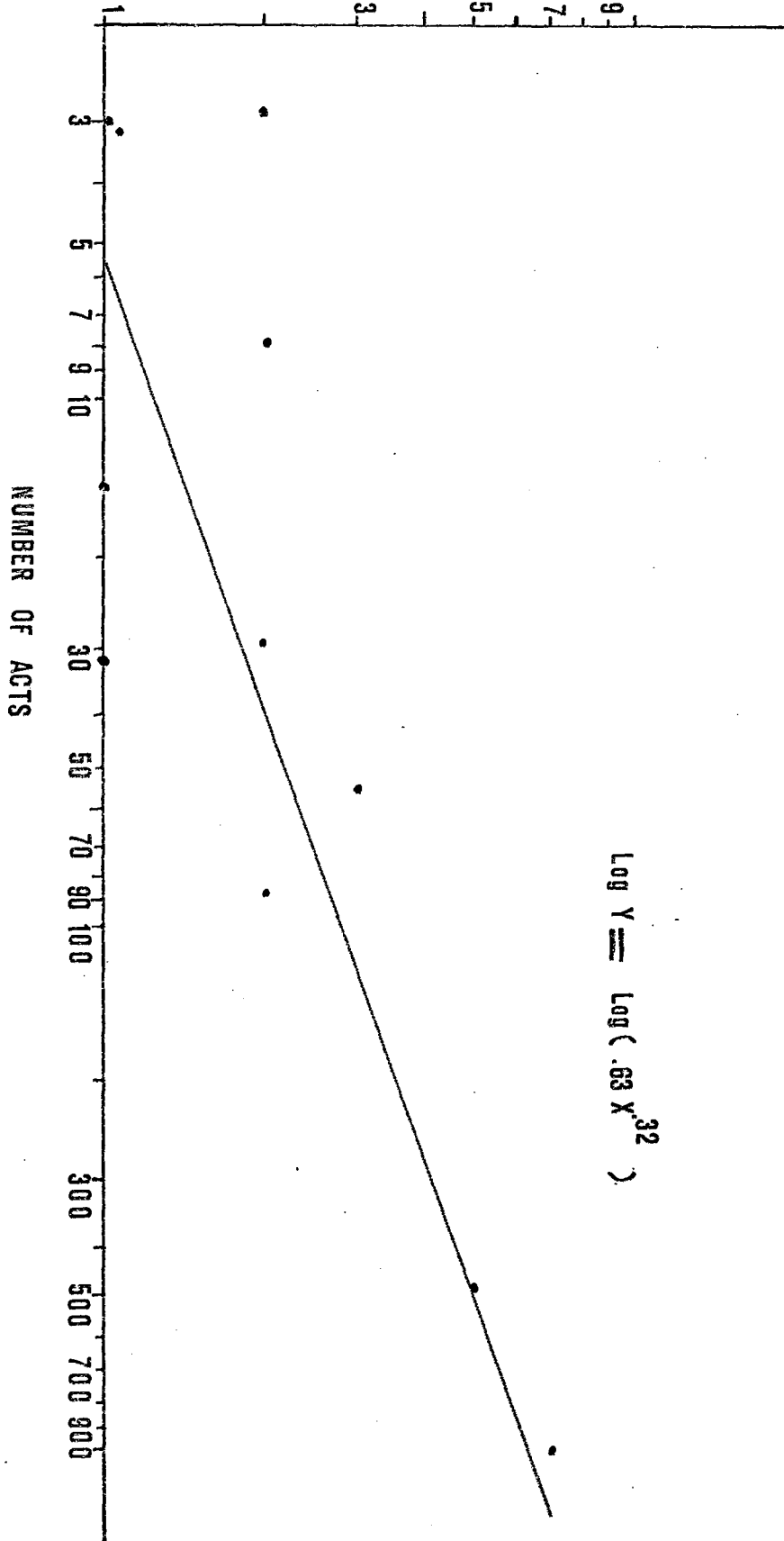


Table 6.  $\chi^2$  Analysis of the number of C. ios present in a burrow versus the simulated tidal height. C. ios alone. Parentheses indicate expected values. N= 420 observations of 35 C. ios.

<u>C. ios</u>	Low	Tank Level		High	Row Total
			$\frac{1}{2}$ Full		
In Burrows	86 (88)	96 (88)		82 (88)	264
Out of Burrows	<u>54</u> (52)	<u>44</u> (52)		<u>58</u> (52)	<u>156</u>
Column Total	140	140		140	420

$$\chi^2 = 3.19$$

2 degrees of freedom

$$.30 < p < .20$$

(nonsignificant)

Table 7.  $\chi^2$  Analysis of the number of C. ios present in a burrow versus the simulated tidal height. C. ios with C. californiensis. N=420 observations of 35 C. ios.

<u>C. ios</u>	Low	Tank Level		Row Total
		$\frac{1}{2}$ Full	High	
In Burrows	60 (69.3)	71 (69.3)	77 (69.3)	208
Out of Burrows	<u>80 (70.7)</u>	<u>69 (70.7)</u>	<u>63 (70.7)</u>	<u>212</u>
Column Total	140	140	140	420

$$\chi^2 = 4.25$$

2 Degrees of Freedom

$$.20 < P < .10$$

(nonsignificant)

Figure 5. Relationship of the number of C. californiensis found in a burrow and the length of the burrow.

N= 117 observations.



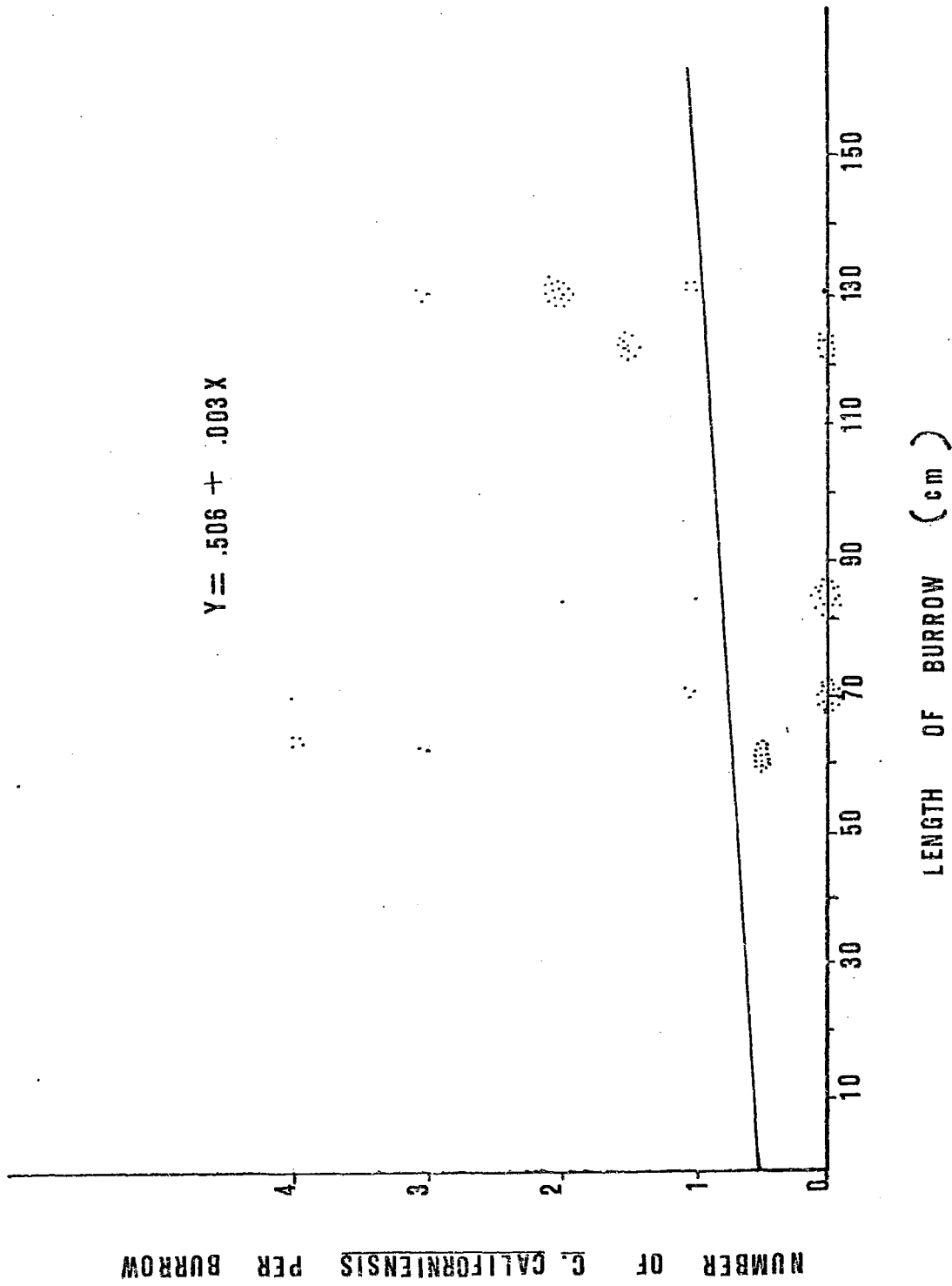


Table 8. Two-factor analysis of variance.

C. californiensis.

SS = Sum of Squares

DF = Degrees of Freedom

MS = Mean Square

Variable	SS	DF	MS
Burrow Length	10.56	4	2.64
Time	0.255	3	0.085
Error	5.285	12	0.440
Total	16.10	19	

MS Burrow/MS Error

F = 6.00 P .01

MS Time/MS Error

F = 0.193

(nonsignificant)

Table 9. Analysis of error in slope  
of regression line. C. californiensis.

Standard Error of Estimate =  $S_{yx}$

$$= \sqrt{\frac{\sum(Y-\bar{Y})^2 - b^2 \sum(X-\bar{X})^2}{N-2}}$$

$$= 1.03$$

$$\begin{aligned} \beta &= b \pm t_{97.5} S_{yx} \sqrt{1/\sum(X-\bar{X})^2} \\ &= .003 \pm (1.98) (1.03) (.0035) \\ &= .003 \pm .007 \\ &= -.004 \text{ to } +.110 \end{aligned}$$

Figure 6. Relationship of the number of gobies per burrow and the length of the burrow. N = 110 observations.

NUMBER OF C. IOS PER BURROW

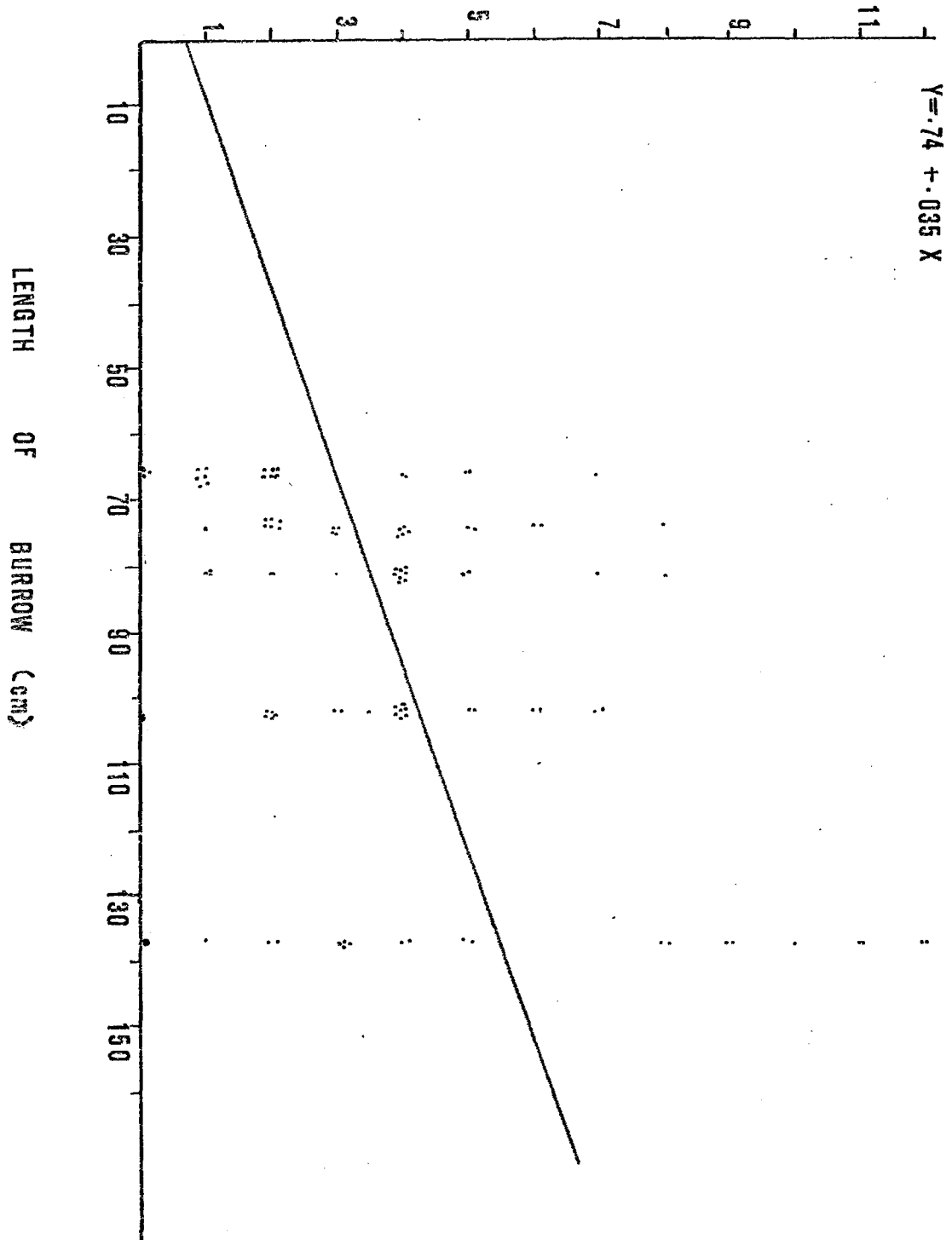


Table 10. Two-factor analysis of variance.

C. ios alone.

SS = Sum of Squares

MS = Mean Square

DF = Degrees of Freedom

Variable	SS	DF	MS
Burrow Length	38.48	4	9.62
Time	4.38	3	1.46
Error	34.83	12	2.90
Total	77.69	19	

MS Burrow/MS Error

F = 3.32 P=.05

MS Time/MS Error

F = .50 (nonsignificant)

Table 11. Analysis of error in slope of regression line. C. ios alone.

Standard Error of Estimate =  $S_{yx}$

$$= \sqrt{\frac{\sum (Y - \bar{Y})^2 - b^2 \sum (X - \bar{X})^2}{N - 2}}$$

$$= 2.54.$$

$$\beta = b \pm t_{97.5} S_{yx} \sqrt{1 / \sum (X - \bar{X})^2}$$

$$= .035 \pm (1.98) (2.54) (.004)$$

$$= .035 \pm .019$$

$$= .016 \text{ to } .054$$

Figure 7. Relationship of the number of gobies per burrow versus the length of the burrow. C. ios and C. californiensis.

N = 111 observations.



## BURROW LENGTH (cm)

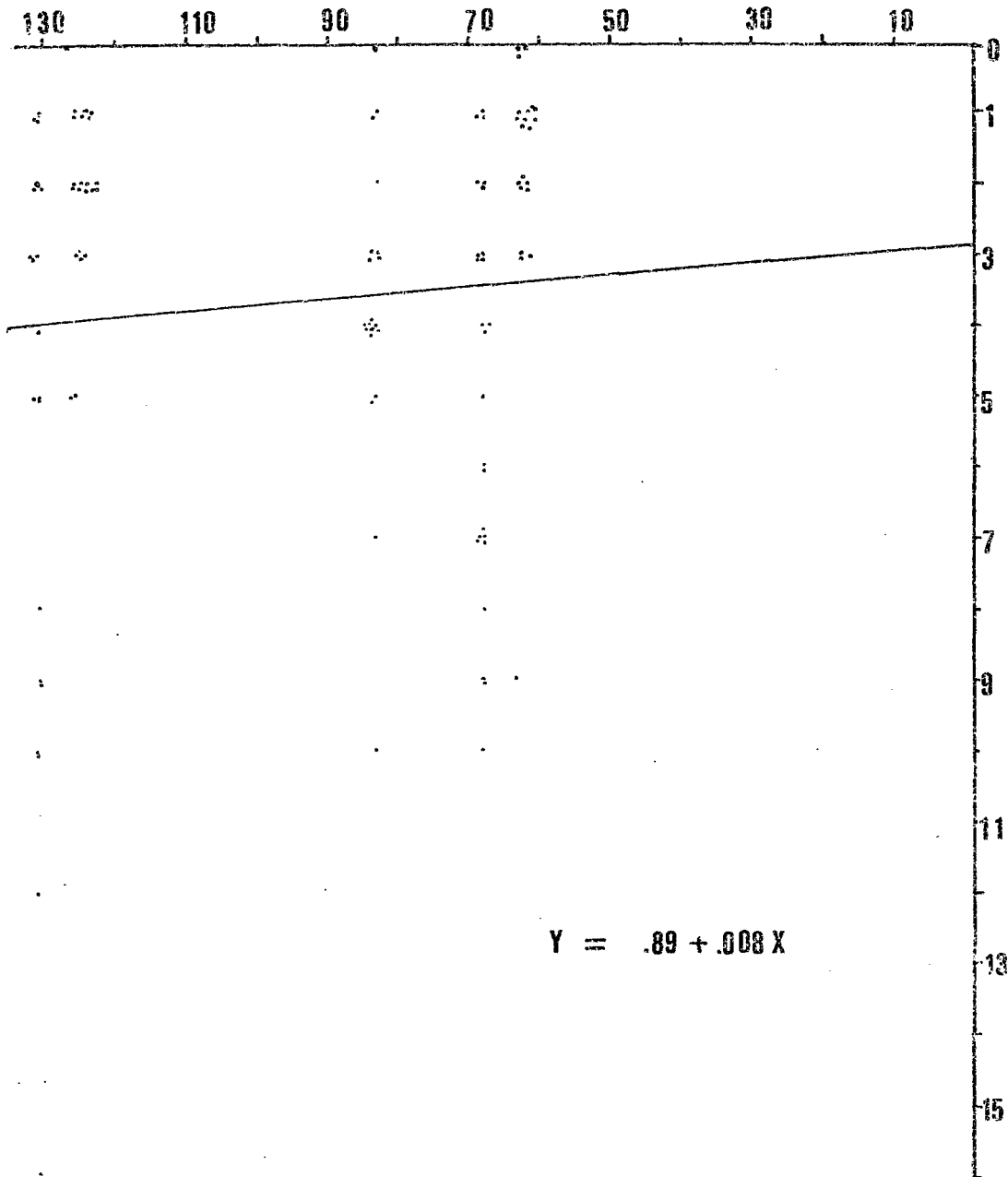


Table 12. Two-factor analysis of variance.  
C. iqs with C. californiensis.

SS = Sum of Squares

DF = Degrees of Freedom

MS = Mean Square

Variable	SS	DF	MS
Burrow Length	44.93	4	11.23
Time	7.45	3	2.48
Error	29.02	12	2.42
Total	81.40	19	

MS Burrow/MS Error

F = 4.64 P = .05

MS Time/MS Error

F = 1.02 (nonsignificant)

Table 13. Analysis of error in slope  
of regression line. C. ios with  
C. californiensis.

Standard Error of Estimate =  $S_{YX}$

$$= \sqrt{\frac{\sum (Y-\bar{Y})^2 - b^2 \sum (X-\bar{X})^2}{N-2}}$$

$$= 2.92$$

$$\beta = b \pm t_{97.5} S_{YX} \sqrt{1/\sum (X-\bar{X})^2}$$

$$= .008 \pm (1.98) (2.92) (.011)$$

$$= .008 \pm .065$$

$$= -.057 \text{ to } +.073$$

Table 14.  $\chi^2$  Analysis of the number of C. ios per burrow versus the number of C. californiensis per burrow in the experimental aquarium. Parentheses indicate expected values.

Number of <u>C. ios</u>	Number of <u>C. californiensis</u>		Row Total
	0 - 1	>1	
0 - 1	23 (26.9)	11 (7.1)	34
2	16 (18.2)	7 (4.8)	23
> 2	<u>56</u> (49.9)	<u>7</u> (13.1)	<u>63</u>
Column Total	95	25	120

$$\chi^2 = 7.6$$

2 degrees of freedom

$$P \approx .02$$

## DISCUSSION

Although the August length - frequency histograms for C. ios appear to indicate a bimodal age class distribution, the frequency of any one size class was usually so low, compared with the total number of fish captured, it is difficult to draw any conclusions regarding the age structure of the population. The same holds true for C. californiensis. However, the results of the August length - frequency histograms may show one age class of the gobies less than 34 mm standard length, and one age class of C. ios whose standard length is greater than this amount. This would be in general agreement with Prasad (1948, 1958) who states all female C. ios are mature at 34 mm standard length. But more data are needed to confirm these results.

C. ios apparently do not retreat into their burrows during the simulated low tide on the experimental mudflat in any greater numbers than during the simulated high tides. This may be due to: 1) a limiting number of gobies present in any particular burrow; 2) An inadequate simulation of tidal height; or 3) The gobies may retreat into the mud or into any potential hiding place, and may only find the invertebrate burrows by chance, or may show no preference for these burrows. A ten - inch

change in the height of the water above the burrows may not be an adequate simulation of tidal height, though conditions such as these may occur in the higher intertidal areas where gobies are found. Alternatively, the C. ios in the field may sense an influx of water to the C. californiensis burrow, which they may interpret as a signal to leave the burrows during high tide. This condition was not simulated in the experimental aquarium. Perhaps there may be a limiting number of C. ios in a burrow to prevent anoxic conditions. Also, since C. ios and C. californiensis were negatively associated under field and lab conditions, the gobies may prefer not to go into the invertebrate burrows, unless, for example, they are frightened.

In the absence of C. californiensis, there are more C. ios present in longer burrows, but further experimentation should be designed for a priori comparisons. C. ios alone, and C. californiensis do seem to have burrow preferences.

In the presence of C. californiensis, C. ios do not show a preference for longer burrows. Instead, there tend to be more C. ios in those burrows with no more than one C. californiensis host. The ghost shrimp were often observed in the experimental mudflat, chasing the gobies out of their burrows. Grossman and Reed (1980) report Upogebia acted aggressively toward the presence of

either C. ios or L. lepidus, and attempted to grab the fish with its chelipeds. Lepidogobius lepidus seemed to be in empty burrows more often than in ones occupied by Upogebia, but they were in Urechis burrows about the same amount as would be expected by chance. In neither case was there a statistical preference for burrows with hosts.

The ethogram of Brothers (1975) C. ios behavior is in general agreement with behaviors I have observed, though I have observed more behaviors, and interspecific behaviors as well. Brothers (1975) and Prasad (1948, 1958) agree C. ios is generally nonaggressive and nonterritorial.

MacGinitie and MacGinitie (1949) have noted up to 15 gobies per ghost shrimp burrow. I have observed up to 5 gobies per burrow in the field, and up to 16 gobies per burrow in the lab. Prasad (1948) states smaller (less than 21 mm) C. ios remain in pools, though I have observed C. ios 12 mm standard length in burrows in the field.

Much has been written in recent years of the associations of Gobiid fishes with pistol shrimps (Karplus and Szlep, 1972; Karplus, Szlep, and Tsurumal, 1972, 1974; Karplus, 1979; Preston, 1978). In this system, visual and tactile communication exists between the shrimp and the goby. The goby obtains the benefit of a shelter and a resting place. The shrimp never leaves the burrow without continual antennal contact with the

goby. The fish provides warning signals to the shrimp when a predator approaches, and they both retreat into the burrow.

This is in contrast to the goby - Thalassinid associations (Brothers, 1975; Grossman and Reed, 1980; MacGinitie, 1934, 1939; MacGinitie and MacGinitie, 1949) which seem to indicate a commensal relationship, in which the goby is provided with a refuge from predators and desiccation and the shrimp presumably derives little or no benefit.

The C. ios may be using the C. californiensis burrows as a refuge, but only during the spring and summer. They may be using the burrows only at those times of the year when they are in reproductive condition (Hart, 1973; Prasad, 1948) either to assure the protection of the eggs, or to assure an increased survival rate of the adults at a time when the fish can contribute to the growth of the population. Alternatively, many shore birds such as Yellow Legs and Dowitchers migrate from the estuaries to the Arctic during their breeding seasons (Robbins, Brunn, and Zim, 1966). Thus, many avian predators may not be found in the estuaries in the summer months, and the gobies may migrate intertidally to obtain a refuge from predatory fish.

C. ios appear to migrate subtidally during the fall and winter months. They have been reported



to be eaten by adult rockfish (Hart, 1973) which are usually found subtidally. In the Gulf of Finland, Gobius microps spend the winter in the deep water, but in May and June they migrate inshore to breed, usually resting under a Mya arenaria shell (Green, 1958). The Japanese goby, Sicyopterus japonicus, as well as some other goby species are reported to be amphidromous (Fukui, 1979; Harden-Jones, 1968). The change in temperature may initiate the migrations of these fish (Grossman, 1979; Hesthagen, 1977).

There is much sand deposited intertidally during the winter at Jordan Cove. Perhaps the C. ios simply can not enter the C. californiensis burrows when the entrances are covered. They may migrate to find new refuges. Callianassa gigas has been reported in Coos Bay (Lynn Rudy, personal communication). C. gigas is a subtidal Thalassinid. Perhaps Clevelandia ios use C. gigas burrows, or any other hiding places they can find, to avoid predators when they are subtidal.

The Callianassa californiensis - Clevelandia ios association may be contrasted with the Callianassa affinis - Typhlogobius californiensis association. Typhlogobius is a blind goby which lives permanently in the burrows of C. affinis on the unprotected rocky coasts of the western United States. The gobies are totally dependent on the "shrimp" for food and shelter, and would

obviously be preyed upon if they left the burrows. The goby may help drive out intruders, eat larvae which enter the burrow, or help keep the burrow clean. However, C. affinis have been reported to live in the absence of T. californiensis under aquarium conditions with no apparent ill effects. Thus, many believe it is the goby who derives the primary advantage of this association (Hubbs, 1927; MacGinitie, 1939; MacGinitie and MacGinitie, 1949).

Hubbs (1927) suggested the fish originally had reduced eyes and favored dark refuges. Gradually, it became adapted to its habitat, lost its sight, and became dependent upon C. affinis. Other gobies such as Gillichthys mirabilis and Clevelandia ios are believed to be developing along similar lines (Hubbs, 1927; MacGinitie and MacGinitie, 1949; Dales, 1957).

Although C. ios and C. californiensis may be an evolving toward an obligate commensal relationship they are presently facultative associates. Indeed, I have shown there is a preference of C. ios for unoccupied burrows, or for those burrows occupied by only one C. californiensis host. Therefore, this relationship may take a long time, chronologically to develop into an obligate association, though this may be a relatively short time on the evolutionary time scale.

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