NOTES ON THE BIOLOGY AND COMPARATIVE BEHAVIOR OF *EVIOTA ZONURA* AND *EVIOTA SMARAGDUS* (PISCES: GOBIIDAE)

by

HELEN K. LARSON

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TO THE GRADUATE SCHOOL:

The members of the Committee approve the thesis of Helen K. Larson presented December 1973.

Robert S. Jones, Biosciences, Chairman

James A. Marsh Jr.

James A. Marsh Jr., Biosciences

Lynn Raulerson

Lynn Raulerson, Biosciences

Benjamin F. Bast for Peter Pratt

Peter Pratt, Psychology

ACCEPTED:

Benjamin F. Bast for James A. McDonough

James A. McDonough
Dean of the Graduate School

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Approved: ______________________________
Robert S. Jones, Chairman, Thesis Committee

Eviota zonura and *Eviota smaragdus* are sympatric gobies inhabiting the fringing reef platform of Guam. They are ecologically separated by habitat preference. *Eviota zonura* prefers the cut benches and rimmed terraced pools of the windward reef margins. *Eviota smaragdus* is abundant on both windward and leeward sides of the island. Its preferred habitats are elevated outer reef flats that are usually protected by an algal ridge, and parts of the inner reef flat.

Both species are carnivorous and feed on essentially the same items. *Eviota* are probably not, themselves, important prey species for reef flat dwelling predators. Reproduction may occur year round for both species. There is possibly a peak in breeding from June to August for *Eviota zonura* and from November to January for *Eviota smaragdus*.

Observations on behavior as an isolating mechanism were made in the field and laboratory. Both species are aggressive and display ritualised fighting behavior with several species-specific action patterns. Only breeding males show territoriality in the field.

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CHAPTER I

INTRODUCTION

The genus *Eviota* comprises a large group of small, widely distributed tropical gobies. They are often placed in the family Eleotridae rather than the family Gobiidae because of their pelvic fin structure. The pelvic fins deviate from the typical fused cup characteristic of many gobies in that there is very little membrane connecting the rays. The taxonomy of *Eviota* is confused, there may be from 30 to 50 species in the genus and many are thought to be localised in distribution (Hoese, per. comm.). Nine species are presently known from Guam.

Most Guam species occur on the reef front and in other subtidal regions. These subtidal species are cryptic, living in coral crevices and holes, and are difficult to observe. Three species do, however, occur on the intertidal shallow reef flats around the island and are relatively easy to collect and observe. They are *Eviota afelei* Jordan and Seale, *Eviota smaragdus* Jordan and Seale and *Eviota zonura* Jordan and Seale.

Nothing is known of the biology of these fishes. Related species of *Eviota* (*E. distigma* Jordan and Seale and *E. gymnocephalus* Weber) are discussed in Tyler's (1971) paper on coral-associated fishes. Gosline (1955) investigated the osteology of *E. epiphanes*, an Hawaiian species similar to *E. zonura*. Other small gobiids have been studied from a number of viewpoints, especially reproduction (Tavolga, 1954; Hoese, 1966; Valenti, 1972), but knowledge of most tropical reef gobies is lacking in general.

The outer reef flat is often narrow on Guam, so that these three *Eviota* species may occur quite close together and frequently overlap. Possible competition could arise between the populations of these closely-related fishes. If there is no competition among them, then there must be some differences in their ecology, for example: microhabitat preference, behavior, feeding selectivity, tolerances to environmental factors, differences in breeding season or other factors. *Eviota zonura* and *E. smaragdus* were the fishes selected for study, because their populations overlapped considerably at some localities. *E. afelei's* preferred habitat, the outer edge of the reef margin, is inaccessible much of the time due to wave attack.

Many studies have been done on ecological competition among a variety of organisms, and have invoked Gause's principle of competitive exclusion as the reason why two species can never occupy the same niche (Klopfer's review, 1969). Few such studies have been done on tropical marine fishes. Strasburg (1953) and Stephens et.al. (1970) compared the ecology of various marine blennies, which occupy a similar habitat to *Eviota*. Hoese (1966) showed habitat preference among two sympatric species of *Gobiosoma*, a small eastern Pacific goby; and Gosline (1965) discussed zonation of Hawaiian species. Little else has been done on Indo-Pacific gobies.

This study was done from November 1972 to August 1973. Because of a previous study, an additional six months of data are available for *E. zonura* from May 1972 onward. Field work was carried out on both sides of the island, with most of it done at the northern end of Pago Bay where the University of Guam Marine Laboratory is located. The study was greatly influenced by the occurrence of the lowest tides in Guam's recorded tidal history in August to October 1972. These tides occurred in the daytime and were accompanied by very calm seas. The reef margins and outer reef flats were almost continually exposed to the sun's heat. This resulted in catastrophic kills of marine organisms. Populations of Eviota zonura, then being studied, and those of E. smaragdus which were to be investigated later, were severely reduced, as were populations of all other organisms occupying the fringing reef platform. It is suspected that several changes in distribution of Eviota species came about as a result.

Aspects studied were habitat preference, which involved observations of reef physiography and organisms present; behavior, especially in the areas of territoriality, social order, aggressiveness and courtship; breeding season; feeding habits and other aspects of the biology of these fishes that came to light.

CHAPTER II

DESCRIPTION OF SPECIES

Both species were originally described by Jordan and Seale (1905: 386-389). Figures 1 and 2 show E. smaragdus and E. zonura respectively. E. zonura is morphologically very similar to the other reef margin species, E. afelei, differing from it only in color pattern and shape of the male genital papilla. E. smaragdus differs from both these species in pelvic fin structure, and in possessing a short lateral canal and pore (part of the lateral line system of the head). It is a more slender fish than the stocky E. zonura (Figs. 1,2). Both are abundant, active fishes, but until recently, research on the genus has been limited. Gosline (1955) discusses osteological relationships of the Hawaiian species, E. epiphanes, which is similar to E. zonura.

Eviota smaragdus has the dorsal VI, 1,9; anal i, 8; pectoral 16-17; pelvics i, 4, i and 23 to 25 lateral line scales. The head is 3.75 in standard length, the body depth 4.5 in standard length (Jordan and Seale, 1905). The pelvic rays are terminally branched, and connected by membranes, although both pelvics are themselves separated (inset in Fig. 1). The basic color ranges from a yellowish-white to a light, clear, grass-green (influenced by substratum). The most distinctive color markings are the round purplish black spots on either side of the nape and the two or three rectangular purplish blocks of color on the peritoneum which show through the body wall. Similar black spots are present atop the head and nape.

There are silvery irridescent patches above the eyes and on the snout and cheeks. The rest of the body is marked with short vertical lines (one line per scale), which form short orange-brown bars across the back and faint orange-brown bars down the sides. The latter are usually broken up into "checkered" rectangular blotches. The paired fins are clear, though the pelvics have a dusting of white speckles. Both dorsals are light with a dusky brownish margin, and the anal has two orange streaks across it. The caudal fin is light with orange speckles forming bars across it.

When aroused in aggression or courtship, E. smaragdus may change colour considerably. The unpaired fins turn pink or purplish, with all fin markings darkening. The body colors intensify, while the entire body changes from its normal translucent appearance to opaque. The two nape spots expand and turn black, while the interorbital, snout and tips of both jaws turn purplish-black, and all orange head markings brighten.

E. zonura has the dorsal VI, I, 10; anal i, 8; pectoral 16-17; pelvics 1, 4; lateral line scales 22 to 24. The head is 3.5 in standard length, the body depth 4.5 in standard length (Jordan and Seale, 1905). The pelvic rays are stiffened and side branched many times, with no connecting membrane present but for a reduced one between the bases of the spine and first ray (inset in Fig. 2). This species varies less in color than does E. smaragdus, though fish captured over a light substratum tend to be lighter than those from

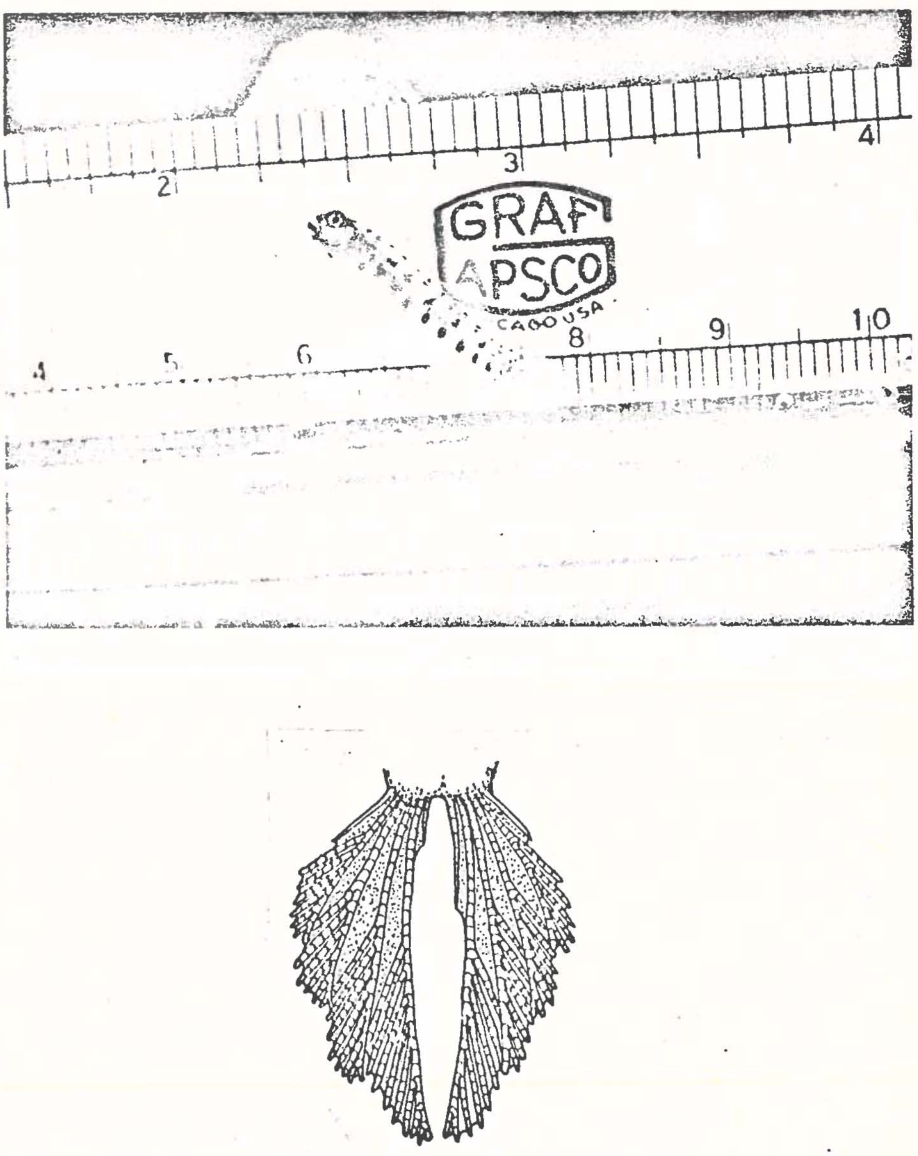


Fig. 1. Eviota smaragdus (twice natural size). Inset shows pelvic fin structure.

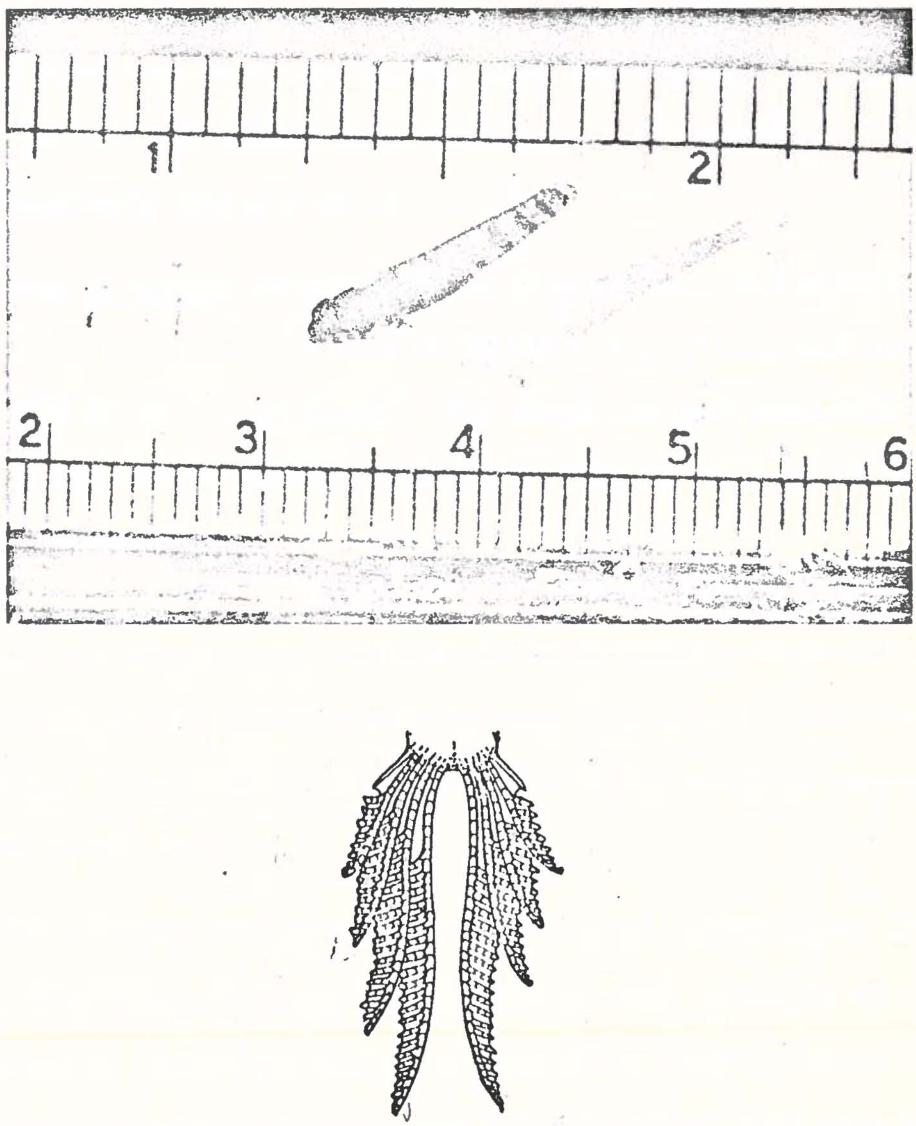


Fig. 2. Eviota zonura (four times enlarged). Inset shows pelvic fin structure.

a very dark substratum. It is generally a clear emerald green fish, with six dark bars across the sides. The bars range in color from a deep green to red-brown or red, and the posteriormost bar has its centre intensified as a black spot. The head is marked with reddish spots, and these are developed into oblong blotches which run across the cheek below the eye. As with E. smaragdus, there are silvery blotches above the eyes, and on the snout and opercle. The paired fins are clear, the caudal light with fine dusky speckling. Both dorsals and anal fins are faint pinkish.

When E. zonura is aroused, the dorsals, anal and caudal turn a deep dusky pink, and the bars on the body slowly fade and dissipate as the body itself turns opaque. The branchiostegal membranes are spread in aggressive display, showing the lighter blue-green of the underside of the head.

CHAPTER III

ENVIRONMENT

For many fishes, habitat preference has been shown to be important in reducing possible competition between species. (Stephens et al. 1970; Hoese, 1966). From preliminary observations, it appeared that there may be habitat preferences in the two *Eviota*. Their preferred habitat, the reef flat, is composed of several distinct communities that may comprise different niches for the two *Eviota*.

The fringing reefs around Guam are diverse in structure, width, height above mean sea-level and associated communities (Emery, 1962; Tracey et al. 1964). They therefore present many different habitat types. There are two basic types of habitat preferred by the *Eviota* studied: the shallow fringing reef platform extending from the shore to the reef margin, and the cut bench which juts from a cliff face and is usually above mean sea-level (Fig. 3a-c). The bench is not a reef feature in the true sense, but is an erosional surface (Tracey et al. 1964).

The fringing reef platform is divided into three zones (Fig. 3a-c), consisting of an inner reef flat or moat, which is covered with water at low tide; the outer reef flat, which is partially or completely exposed at low tide and often dissected into many water retaining pools; and the reef margin, which is awash at low tide except during very calm seas. The margin may be raised into an algal ridge or a series of rimmed terraces (Fig. 3a, b).

To determine distribution of each species, I used random 30cm square quadrat samples at the localities indicated in Figure 4. The quadrat itself was divided into 5cm squares by clear nylon line, to facilitate recording. The quadrat was placed randomly on the substrate. After placement of the quadrat, 30 to 60 seconds were allowed to elapse before recording the position of each fish in the quadrat. After five minutes, the position of each original fish and of any additional fish was recorded again. A brief description of the substrate, the species and relative amount of benthic algae present, as well as conspicuous invertebrates were also recorded. The total number of each species per reef zone was obtained from the quadrat data. The Student's T-test was used to determine any significant difference between the number of each species, in each reef zone.

Cut Bench Habitat

Best developed benches are on the northern half of the island where the coast is composed largely of limestone cliffs. From Haputo Point on the leeward side to Taogam Point on the windward side of the island (Fig. 4), cut benches are present except for an occasional narrow reef flat. Benches are also present on limestone headlands in other parts of the island, for example: Tagachan Point, Cabras Island, and at Inajaran (Fig. 4).

The benches are rather uniform physically and biologically when compared to the reef flats. They may be wide with large,

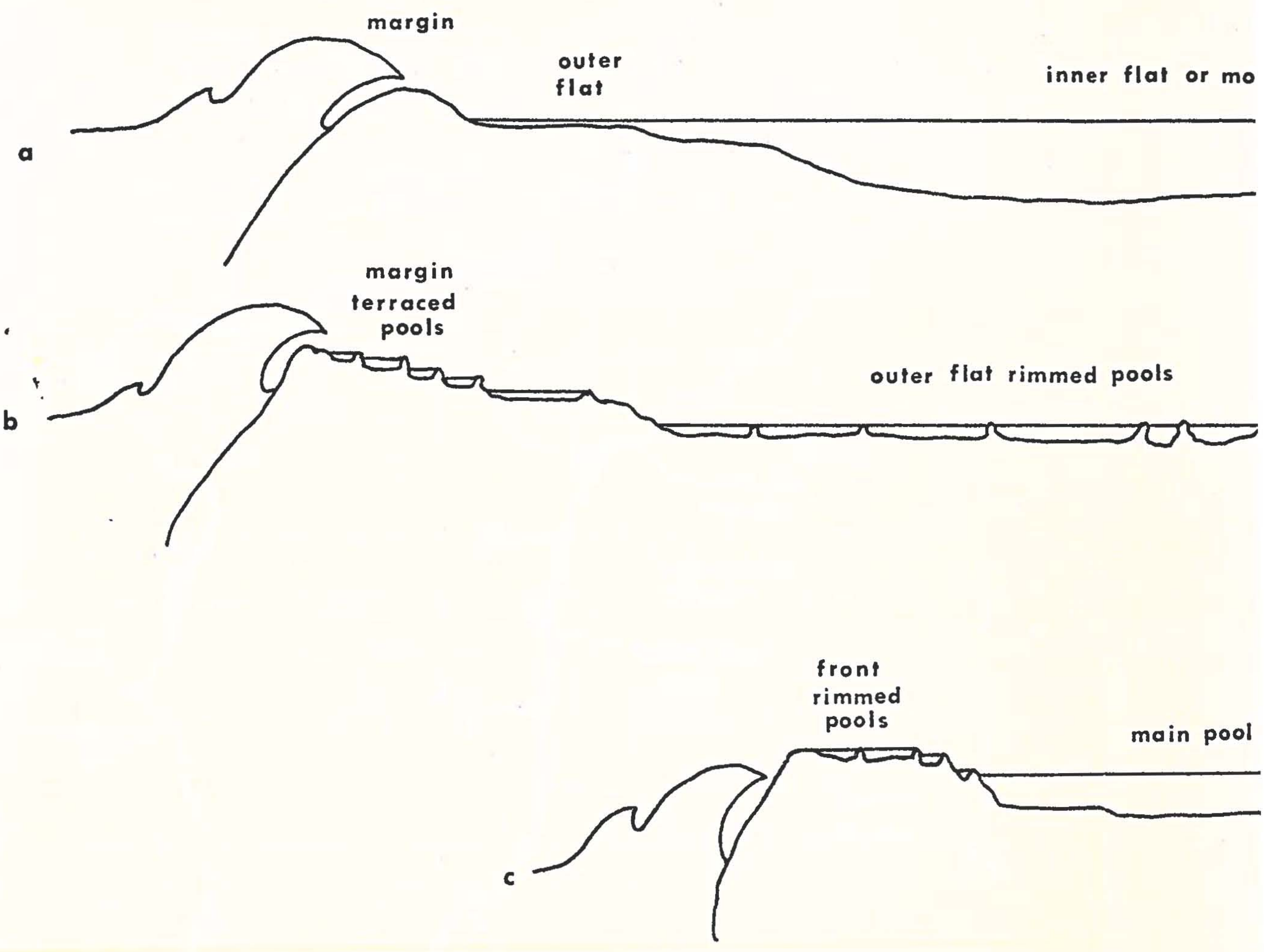


Table 3. Diagram of Eviota habitats

a. Typical moat-dominated reef flat platform at mean low tide.

b. Reef flat platform of the type on which Eviota may be found, at mean low tide.

c. Cut bench (note height above sea-level), at mean low tide.

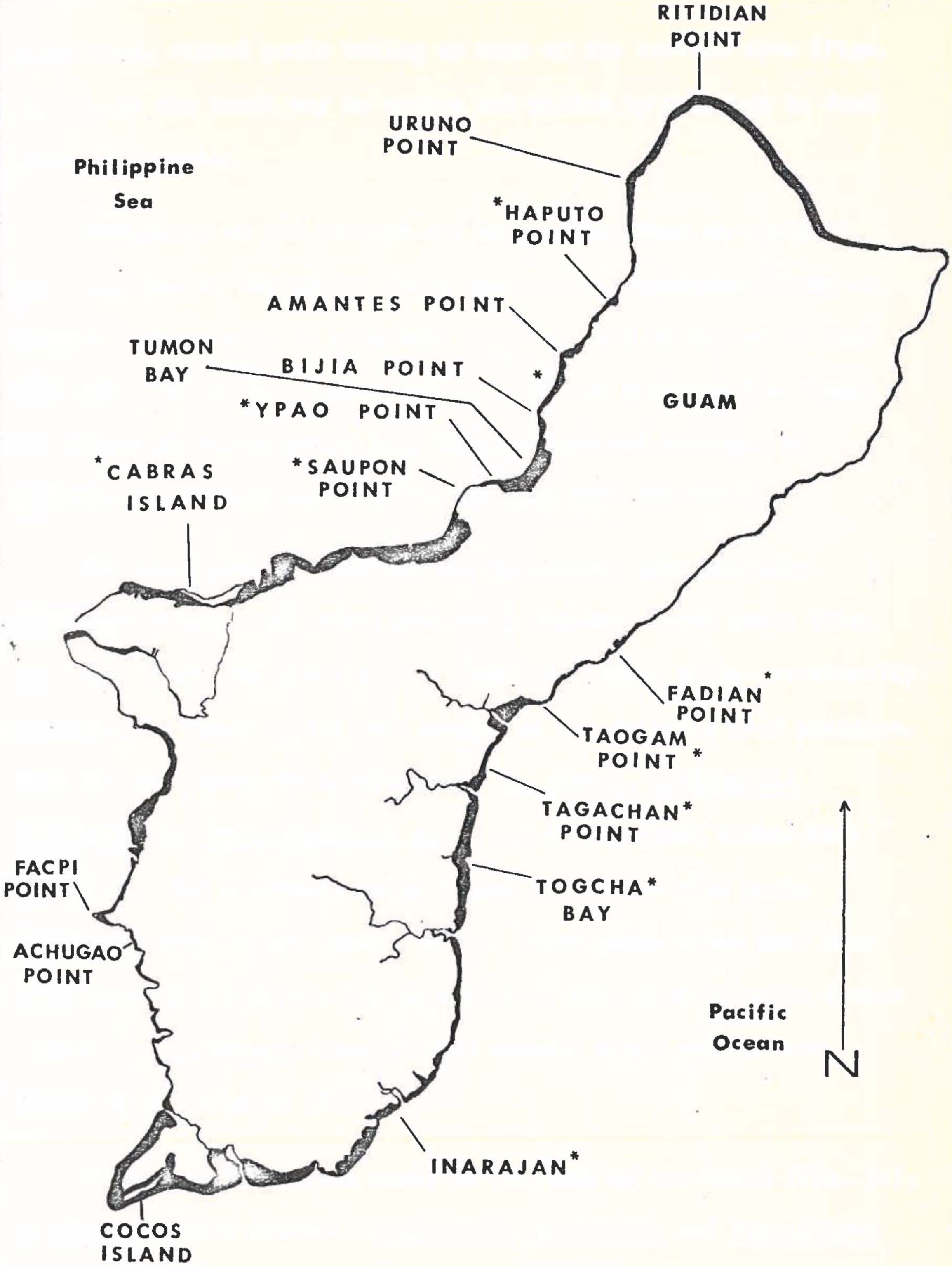


Fig. 4. Map of Guam showing collecting and quadrat sites (marked with an asterisk). Dark areas indicate fringing reefs (after Emery, 1962).

often deep, rimmed pools taking up much of the surface area (Figs. 3c, 5), or the bench may be narrow and pitted by solution to form many small pools.

Conditions on cut benches are more severe than on the reef platform, due to the height above sea-level. Organisms living on benches must be able to withstand pounding surf or splash at high tide and partial or complete drying up of the pools at low tides. The chance of encountering high temperatures and extremes of salinity is greater here than on the reef flat platform.

The bench pools themselves can be divided into slightly different types: the front, mid-bench and back bench pools (Fig. 3c). The front pools are small, step-like rimmed pools structurally analogous to those of the reef margin on the fringing reef platform. They are not always well-developed. *E. zonura*, *Kelloggella cardinalis* and *Rhabdoblennius snowi* are the dominant fishes here (Table 1). The mid-bench pools (Figs. 3c, 5) are wide pools comprising most of the bench's area. These pools often have deep holes providing habitats for juveniles of many reef platform fishes (Table 1). *E. zonura*, blennies and several algal species are common in these pools (Table 1).

In the small solution pools at the back of the bench (Fig. 3c), *E. zonura* is less common. *Kelloggella cardinalis* and *Praealticus natalis* are often the only fishes found here.

I do not consider *E. smaragdus* to be a typical bench species,

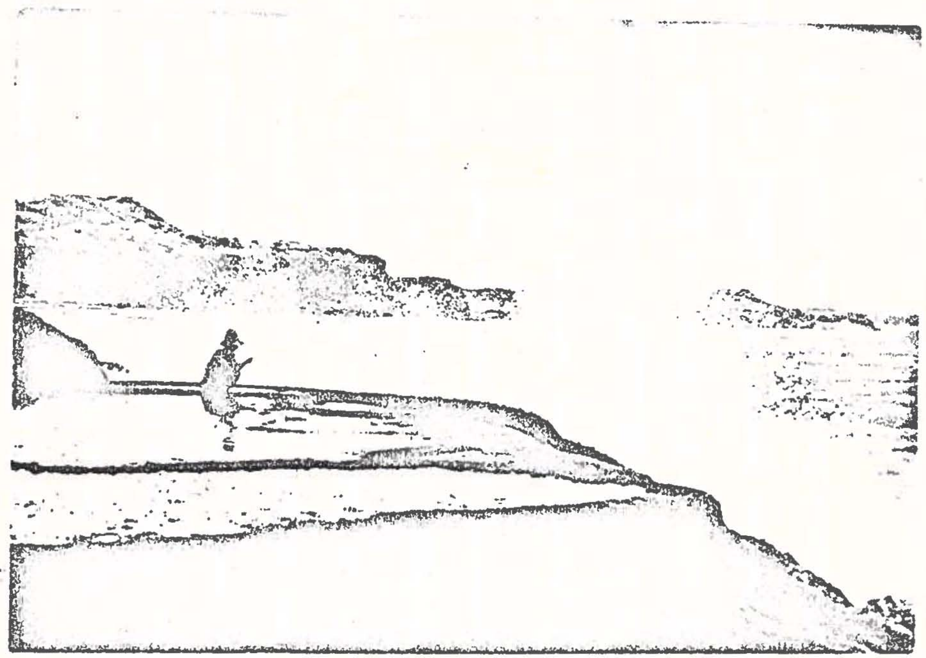


Fig. 5. Cut bench, showing main pools, at Tagachan Point.

although it has been observed on benches in some cases. When the outer reef flat platform grades smoothly into the cut bench (as at Taogam, Tagachan and Ypao Points) both E. smaragdus and E. zonura can be found together. E. smaragdus was also found among bench communities that were severely disturbed by the extreme low tides of October 1972 and had not re-established normal species composition. E. smaragdus does occur on the single basalt bench studied at Achugao Point (Fig. 4). The bench there sustains a depauperate community composed of species common on cut benches, the reef platform and brackish water communities. There are many small creeks running into the bay near Achugao Point which is probably why brackish water gobiids occur on the bench. At Pagan Island in the northern Marianas, E. smaragdus is as abundant as E. zonura both on basalt and limestone pavement pools near the shore.

Eighty-two quadrats were taken on benches; 44 contained E. zonura, while 12 held E. smaragdus (Fig. 6). Neither species was in 30 quadrats. A total of 84 individual E. zonura and 22 E. smaragdus were counted. The mean number of E. zonura on the bench was significantly different from the mean number of E. smaragdus on the bench ($P \leq 0.05$).

Reef Flat Platform Habitats

Reef Margin: The margin is usually awash at low tide and may or may not have an algal ridge developed (Fig. 3a, b). Eviota is rarely found on reef margins without an algal ridge. The ridge may

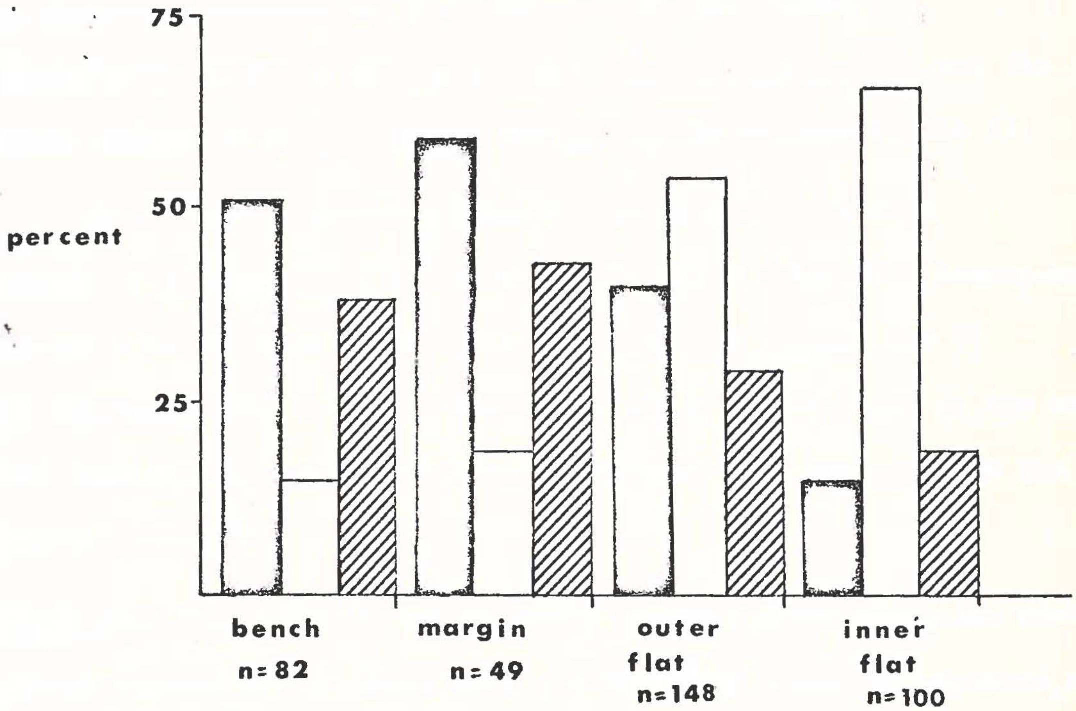


Fig. 6. Number of Eviota per reef zone, expressed as a percentage of total number of quadrats taken per zone (n).

= Percentage of quadrats containing E. zonura.

= Percentage of quadrats containing E. smaragdus.

= Percentage of quadrats containing neither species.

be low and rounded or developed into a series of rimmed terraced pools like those of the cut bench (Figs. 3b, c and 7).

Rimmed terraced pools occur only on the windward side of the island. The pools are very similar to those of the cut bench. The floor of these pools is usually covered with the encrusting alga *Porolithon onkodes* and the rims are built up by vermetid molluscs. *E. zonura* is dominant in this zone, as are the fishes *Rhabdoblennius snowi*, *Eviota afelei*, *Entomacrodus sealei*, and the algae *Sargassum cristae-folium* and *Gelidiella acerosa* (Table 1).

Out of the 49 quadrats taken at the margin, only nine contained *E. smaragdus*, while 29 had *E. zonura* (Fig. 6). Twenty-one quadrats had neither species. A total of 52 *E. zonura* and 14 *E. smaragdus* were counted. The number of *E. zonura* found on the margin was significantly different from the number of *E. smaragdus* on the margin ($P \leq 0.05$).

Outer Reef Flat: *Eviota* may be found on outer flats which are always partly exposed at low tide, have a rather flat limestone pavement, and lie behind a margin with at least a low algal ridge. Many outer reef flats around Guam are structured differently and have no *Eviota*. Shallow, wide-rimmed pools are often present (Figs. 3a, 8), and may form regular terraces, especially near the margin. Sand, rubble and detritus usually cover the pavement. This type of outer flat may be extremely wide, from 50 to 300m. A turf dominated by one species of algae (often *Cladophoropsis* or *Jania*) may be present (Table 1).

Fig. 7. Rimmed terraced pools of the reef margin, at Tagachan Beach.

Eviota smaragdus and Bathygobius fuscus are the dominant fish species. Other abundant fishes include Istiblennius lineatus and I. edentulus (Table 1). E. smaragdus were present in 79 of the 148 quadrats taken on the outer flat, while E. zonura were present in 59 (Fig. 6). Neither species was in 43 of the quadrats. A total of 179 E. smaragdus and 134 E. zonura were counted. The number of E. smaragdus on the outer flat did not differ significantly from the number of E. zonura on the outer flat ($P \leq 0.05$). The data obtained were biased because most of the outer reef flat quadrats were taken at Taogam Point (see below).

The outer flat at Taogam Point (Fig. 4), where more than half of the outer reef flat quadrat samples were taken, had very few rimmed pools and little to distinguish the margin from the outer flat. The margin is low and grades into a narrow, solid pavement reef flat (Fig. 9) backed by a limestone cliff. Fish and algal species resemble those found on the margin. Both species of Eviota occur here in nearly equal numbers, as is reflected in the quadrat data. The large number of E. zonura found on outer reef flats (Fig. 6) is largely a consequence of the fact that much of the sampling was done at Taogam Point. E. zonura is found exclusively on the bench immediately east of the flat, while E. smaragdus is found more often on the wider part of the reef flat towards Pago Bay (which has a 700m wide reef flat, Fig. 4). E. smaragdus has not been able to colonise the cut bench, possibly because of a deep surge groove separating the bench from the reef flat platform.

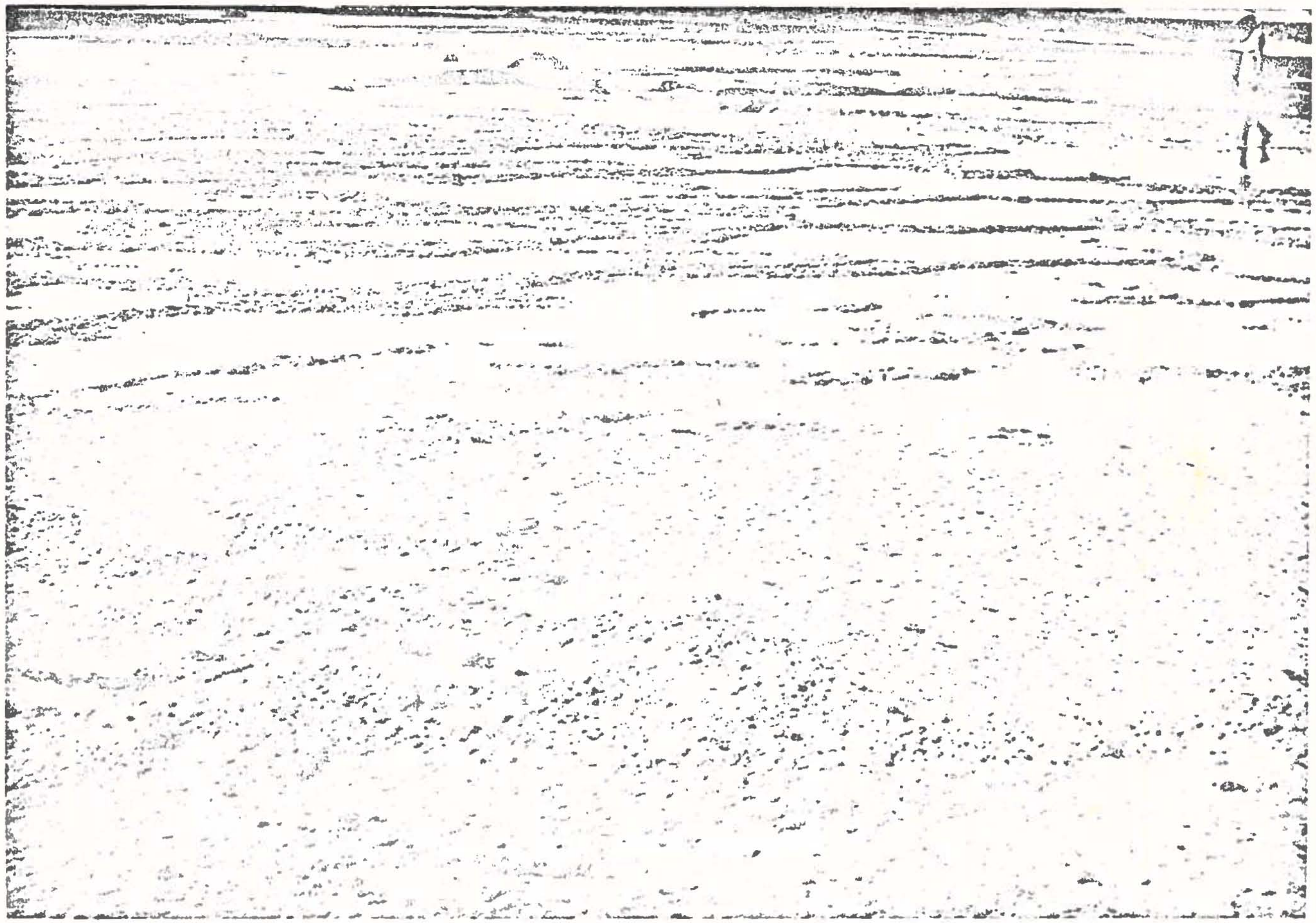


Fig. 8. Rimmed pools of the outer reef flat platform at Tagachan Beach.

Fig. 9. Outer reef flat platform at Taogam Point (at high tide). Reef margin is where surf breaks.

Inner Reef Flat or Moat: Most reef flats on Guam have a moat or inner reef flat (Fig. 3a, b). *Eviota* are found only in moat pools on narrow reef flats, usually backed by limestone cliffs, or in pools in fossil limestone remnants (Fig. 10) in moats such as that between Bijia and Amantes Points (Fig. 4). The moat pools in which both species are found are usually deep (but less than 1m at mean low tide), and have sand over the pavement substrate. A great variety of fishes may be present, especially if the pool is large. Typical "tidepool" forms such as *Kuhlia*, *Canthigaster solandri*, atherinids, juvenile acanthurids, pomacentrids and wrasses may be abundant (Table 1). Algal cover is varied, but often includes *Enteromorpha* and *Cladophoropsis*.

Only *E. smaragdus* occurs in the pools of the remnant limestone ridge between Bijia and Amantes Points (Figs. 4, 10). The ridge is dissected and pitted with solution holes, with blue-green algae and *Enteromorpha* forming a turf. *E. smaragdus*, *Bathygobius fuscus* and *Praealticus natalis* are among the few fishes found here. Out of 100 quadrats taken in various moat areas, 60 contain *E. smaragdus* and 14 contained *E. zonura* (Fig. 6). Neither species was in 17 quadrats. A total of 214 individual *E. smaragdus* and 37 *E. zonura* were counted. The number of *E. zonura* in the moat is significantly different from the number of *E. smaragdus* in the moat ($P \leq 0.05$).

Preferred Habitat of Each Species

For either species to be present, the reef flat must be shallow, not much over one meter deep at mean high tide, with a hard,

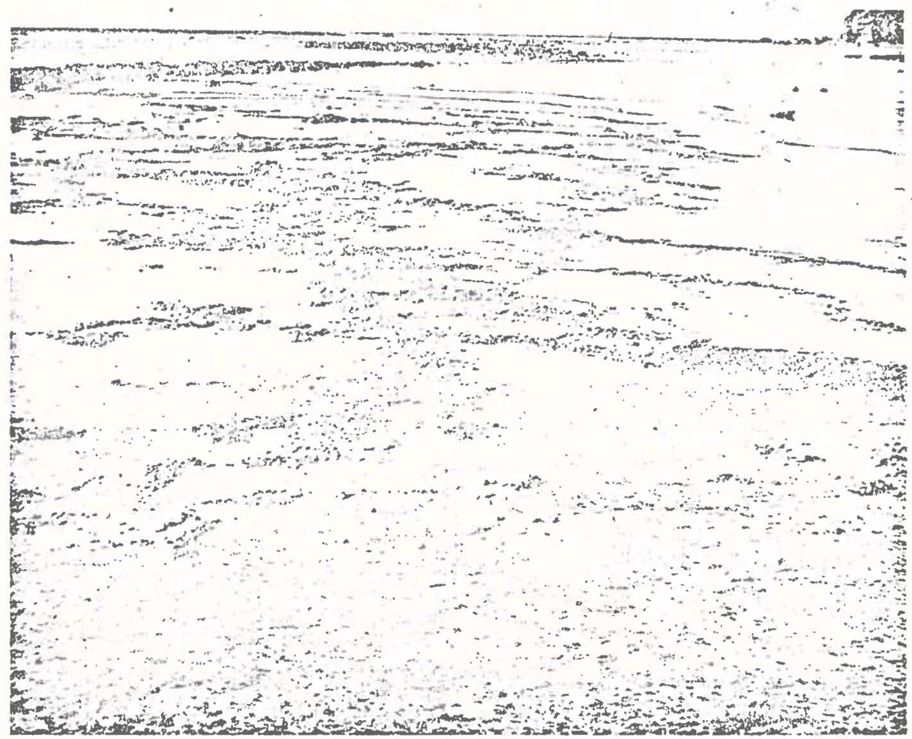


Fig. 10. Fossil limestone remnant and associated raised pools in moat between Bijia and Amantes Points.

TABLE 1. Dominant organisms typical of each reef zone, based on quadrat data and notes taken from May 1972 to August 1973. D = dominant, P = present, C = common.

ALGAE	BENCH	MARGIN	OUTER	INNER
Amphiroa fragilissima	P	P	D	-
Caulerpa racemosa	-	C	P	C
Centroceras clavulatum	-	P	C	P
Cladophoropsis membranacea	P	-	D	D
Enteromorpha compressa	P	-	P	C
Feldmannia indica	P	P	P	P
Gelidiella acerosa	D	D	-	-
Gelidium pusillum	-	-	P	C
Gracilaria salicornia	P	P	-	C
Hydroclathrus clathratus	-	-	P	P
Hypnea pannosa	-	C	C	-
Jania capillacea	P	C	P	-
Microcoleus lyngbyaceus	P	P	-	P
Padina tenuis	P	-	D	C
Porolithon onkodes	D	D	P	-
Sargassum cristae-folium	C	D	P	-
CONSPICUOUS INVERTEBRATES				
Grapsus tenuicrustatus	C	-	-	C
Micippa sp.	P	P	C	C
xanthid crabs (many spp.)	C	C	C	C
portunid crabs (many spp.)	-	-	P	C
Calcinus sp.	P	-	P	C
alpheid shrimp	P	P	P	-
paleomonid shrimp	P	P	C	P
Haptosquilla sp.	P	P	P	-
Holothuria atra	-	-	-	C
Actinopyga spp.	-	P	P	-
Ophiocoma sp.	P	-	C	C
Porites lutea	-	-	-	P
gastropods (many spp.)	P	P	P	P
vermetid molluscs	D	C	-	-
FISHES				
Abudefduf glaucus	P	P	P	C
A. leucozona	P	C	P	P
A. septemfasciatus	-	-	-	C
Acanthurus triostegus	P	-	P	C
Acentrogobius ornatus	-	-	-	P
Alticus saliens	P	-	-	P
atherinids	P	-	-	P
Bathygobius fuscus	C	P	D	C
Canthigaster solandri	P	-	P	C
Entomacrodus decussatus	P	P	-	-

TABLE 1. (continued)

	BENCH	MARGIN	OUTER	INNER
E. sealei	C	D	P	-
E. striatus	C	C	P	-
E. stellifer	-	P	-	-
Eviota afelei	-	D	P	-
E. smaragdus	-	-	D	C
E. zonura	D	D	P	-
Grammistes sexlineatus	P	-	P	P
Istiblennius edentulus	P	-	P	D
I. lineatus	P	P	P	C
Kelloggella cardinalis	D	C	-	-
Kuhlia taeniura	P	-	-	C
Plesiops corallicola	P	P	P	P
Praealticus natalis	C	-	C	C
Rhabdoblennius snowi	D	D	P	-
Stethojulis axillaris	P	-	P	P

consolidated limestone pavement. A thin layer of sand or rubble may cover the substrate. Algal cover is usually thick. The reef will be exposed partly at low tide, with reef organisms restricted to small pools or in water contained in crevices below the reef payment surface. When the sun heats the reef and its contained water, both Eviota will be subjected to temperatures higher than those of the reef margin and subtidal habitats.

E. zonura is always found on limestone cut benches which may occur on both windward and leeward sides of the island. It is more abundant in the front and central pools of the benches (where wave action is most consistent). E. zonura is abundant in the rimmed terraced pools of the reef margin, which are restricted to the windward side of the island. It may occasionally be found in the smaller margin pools on the leeward side of Guam. This species also occurs on narrow (less than 20m wide), elevated reef flats that are backed by limestone cliffs. In these areas, E. zonura is found in the inner flat or moat pools close to the cliff, or it may occur on the outer reef flat itself. This species is generally more abundant on the windward side of the island.

E. smaragdus is common on both sides of the island, where the outer flat is shallow and forms rimmed pools (mostly on the windward side). When the outer flat is narrow and backed by limestone cliffs, this species occurs on the outer flat as well as the moat pools next to the cliff. It also occurs on cut benches if the bench immediately adjoins the outer flat. It is the only Eviota found on the basalt benches south of Facpi Point. E. smaragdus is also abundant in pools in fossil limestone remnants that may be found in the inner reef flat.

Relative density of each species can be determined. A total of 378 quadrats were taken, and 410 E. smaragdus and 312 E. zonura were counted. Therefore the average density of E. smaragdus is 1.08 per quadrat and of E. zonura is 0.83 per quadrat. However, the preferred habitats of E. zonura are rich in algal growth, providing abundant hiding places. It is possible that the determined density of E. zonura is an underestimate.

The two species show the most overlap at localities where each fish's preferred habitat intergrades with that of the other's. In such areas of overlap, both species are usually abundant (Fig. 6), as at Taogam Point. For the most part, however, the two species are distinctly separated by habitat preference.

TEMPERATURE, TIDE AND CHEMICAL FACTORS

Temperature, salinity, dissolved oxygen and tidal fluctuations can be important factors for organisms living in an often unstable habitat such as a reef flat or bench. Extremes of any of the above may be detrimental to reef flat organisms, including Eviota. Most animals living in such a habitat appear to have fairly wide tolerance limits. However, there may be species-specific difference in tolerance to important factors such as temperature and salinity. A difference in tolerance to any factor may be linked to habitat preference.

Field Observations

Temperature and salinity were sampled in conjunction with quadrat sampling, using a hand-held American Optical refractometer and mercury in glass thermometer. Dissolved oxygen was sampled periodically, using a YSI oxygen probe and the Winkler technique. Sampling was usually done in broad daylight during low tide, with a few early morning and midnight sample taken. This was because quadrats were taken only when the water on the reef was calm enough to see the fish on the substrate. Tides were usually low or the seas calm, so temperature data obtained may be above average for reef flats.

Normal oceanic water around Guam (sampled from the reef margin) ranges from 25.6 to 29.4°C, with a mean of 27.6°C, while reef flat temperatures range from 27.2 to 33.9°C, with a mean of 29.2°C (Jones and Randall, 1973). There is seasonal variation in temperature (about 3°C), with May to November being the warmer months and December to April the cooler. Reef flat temperatures are raised by solar heating at low tides in the daytime. Table 2 gives the temperatures taken during this study. For the most part, the data agree with those of Jones and Randall (1973). However, the values for the margin and outer flat taken in August 1972 are extremely high, because the temperatures were taken in early afternoon during a noon time low spring tide. This is also true for the inner flat values for June 1972 and July 1973.

Reef margin salinity averages 34.31‰ with a range of 33.8 to 34.6‰ (Jones and Randall, 1973). Salinity on the reef flat may be modified by evaporation during low tides, or by seepage of fresh water from the Ghyben-Herzburg lens system of the island. Salinities recorded during this study ranged from 15.5 to 37.5‰. The lowest readings were obtained from inner flat areas where seepage from the lens system has its greatest effect. *E. smaragdus* is more often found in areas of low salinity than is *E. zonura*.

Few oxygen samples were taken, as oxygen bubbles could be seen rising from the surface of the reef flat algae on every sunny day, indicating saturation. The values obtain ranged from 6.9 to 11.9mg/1 with a mean of 7.2mg/1 (n=16). This indicates a high level of dissolved oxygen, even at water temperatures as high as 35°C. No oxygen samples were taken at night.

TABLE 2. Mean temperatures per reef zone, arranged seasonally. Total number of samples is given in parentheses unless only one sample was taken.

MONTH	BENCH	MARGIN	OUTER FLAT	INNER FLAT
January	28	-	29 (2)	-
February	28.5	-	29.5	32.4 (10)
March	-	28.7 (10)	28.5 (27)	31.8 (13)
April	29.9 (14)	29.5	-	35 (12)
May	33 (13)	30.7 (56)	32.6 (36)	34.4 (18)
June	32.8 (48)	33.6 (10)	33.4 (24)	37.1 (8)
July	-	31.7 (3)	33.2 (39)	36.3 (2)
August	28.7	38.9 (8)	36.5 (5)	-
September	32.9 (2)	-	35 (3)	-
October	-	30.5 (2)	29.5 (3)	30.5 (7)
November	-	-	28.8 (16)	27.8 (8)
December	30.8 (11)	29.5 (2)	29.7 (6)	29.5 (9)

Low tides and calm seas, especially during clear sunny days, are conditions which can lead to stress and death of reef flat organisms. Low spring tides in the mid-afternoon may occur from March to August. Solar heating can rapidly raise the water temperature, until at about 37°C, invertebrates such as shrimp and crabs show stress behavior. Activity is increased and normally cryptic species appear from crevices and move randomly over the substrate. All species of fishes tend to increase their activity as the temperature rises, and they may seek shelter in holes and crevices. Blenniids and *Kelloggella cardinalis* (a goby closely related to *Eviota*) may actually leave the pools of water to crawl into water-filled holes in the nearby rocks. If the high temperatures persist, both species of *Eviota* congregate around the margins of the reef flat pools. Here the water temperature may be as much as two degrees cooler than that of the centre of the pool. This behavior, along with a complete cessation of aggressive actions, may enable both species to survive pool margin temperatures of 38°C, possibly for the duration of the low tide period (about four hours, but possibly up to six hours under extreme conditions). The centre of the pools may reach 41°C. Dead polychaetes, stomatopods and crabs have been seen in pools rimmed with fairly alert active *Eviota*. Both species have been collected dead in pools of 40 to 41°C. It was not known how long the pools had been at this temperature. Of all the reef flat organisms, the gobiid fishes consistently show this "crowding along the margin" behavior which enables them to survive. Blenniids sometimes behave similarly, but more often retreat into holes or hop from pool to pool.

As mentioned in the introduction, a series of low spring tides from August to October 1972, turned out to be the lowest tides ever recorded in Guam, falling to a lowest level of -2.3 instead of the predicted -0.7 feet. Seas were very calm, the days clear and hot, so that organisms of the outer reef flats, cut benches and parts of the inner flats of the island were almost completely eliminated. Outer flats were practically dry, with rotting algae and animals fouling the remaining pools, in which both species of *Eviota* were often found living. Temperatures in the pools did not exceed 38°C. Water exchange, even at high tide, was limited. Animals were dying due to lack of oxygen and water. By the end of October, few fishes were to be seen on the reef flat at Taogam Point. At least 40 species of dead fish were collected, including numerous specimens of both species of *Eviota*. Those species whose populations were not completely eliminated included *Eviota zonura*, *Eviota smaragdus*, *Bathygobius fuscus*, *Rhabdoblennius snowi*, *Istiblennius lineatus*, *Praealticus natalis*, and *Alticus saliens*. All these species spend nearly their entire life cycle on the reef platform and are apparently adapted to withstand high temperatures. Many other species only use the reef flat as a "nursery" for juveniles (e.g., acanthurids, chaetodonts, siganids, labrids). These species are less well-adapted to such extreme conditions. However, other groups, such as the ophichthids, syngnathids and pseudochromids, which also spend most of their adult life on the reef flat, were apparently killed by the high temperatures or lack of oxygen. These reef flat and other organisms recolonised over the succeeding months, but it was not until September 1973, that the reef flat communities appeared to be re-established. It is suspected that *E. smaragdus* extended its distribution somewhat as a result of the tides.

Laboratory Observations

As temperature appeared to be the major environmental factor capable of causing stress or death in *Eviota*, it was of interest to determine tolerance limits. *E. zonura* is more abundant on the wave-washed margin and on the cut bench, where temperatures in the central pools may not be as high as frequently as those on the outer flats. *E. zonura* may therefore be less tolerant to high temperatures than *E. smaragdus*. The latter species is probably exposed to high temperatures longer and more often. *E. smaragdus* may also be more tolerant of low salinities than is *E. zonura*, because *E. smaragdus* is more often found in areas of reduced salinity (moat).

Two sets of experiments were conducted, one subjecting fish to high temperatures (38°C and above) and one subjecting them to low salinities (4‰ and less). Results were tested for significance by the Student's T-test. Preliminary field observations indicated that both species can survive at temperatures up to 36°C (in normal seawater) and salinities greater than 5‰ (at ambient temperature). Other gobiids have great tolerances to low salinity. *Bathygobius fuscus*, which occurs with *E. smaragdus*, is often exposed to low salinities influenced by the Ghyben-Herzburg lens. An adult Kelloggella cardinalis was observed over a nine month period living in a small pool that fluctuated from 1-4‰, but was usually about 5‰. This individual also survived the phenomenally low tides of October 1972.

Temperature: Four aquaria were used, with a fifth as a control. Each was aerated by a sub-sand filter which provided a strong current and flow of oxygen throughout. Immersion heaters and thermostats provided temperature control and were set at 28°C before putting in the fish. Dissolved oxygen was checked before and during each test with an oxygen probe. Temperature was raised gradually over at least three hours. Fish were tested at 38°C and 40°C. These temperatures were chosen because 40°C was known to be lethal from field observations (after some time) and 38°C was the temperature at which all fish displayed "crowding along the margin" behavior in reef flat pools. The fish were exposed to 38°C for six hours, a greater time period than they would normally be exposed to this temperature in the field. No fish were expected to survive more than two hours at 40°C. Two lots of 12 fish each were tested.

At 38°C, there is a significant difference ($P \leq 0.05$) between the total number of E. zonura surviving both tests and the total number of E. smaragdus surviving both tests (Table 3a). Although fishes have been observed in 38°C pools in the field for over an hour, it is not known exactly how long they are actually exposed to 38°C. Temperatures of the reef platform fluctuated according to intensity of solar radiation and time of day. It is unlikely that fish would be exposed to a constant temperature of 38°C. There appear to be some individual differences in resistance (Table 3a).

All fish died at 40°C. Time of death varied from six to 67 minutes (Table 3b). Two _E. smaragdus_ and one _E. zonura_ died at 39°C, before the test temperature was reached. No further attempt was made to bracket the lethal temperature.

Stress behavior during both the experiments was very similar to that observed in the field. Rapid searching movements and attempts to jump up the walls of the tanks were followed by an increasing reluctance to move. The fish would sit very close together in one corner of the tank or under a rock. They may die without moving or may first dart up into the water column and swim in a rapid spiral before expiring. Oxygen content varied from 6.4 mg/1 before the tests began and decreased to a minimum of 5.6mg/1, at the conclusion of the tests.

Salinity: The same aquaria from the above experiments were used. Fish were held for two days before testing and fed daily. The water was at room temperature (24 to 26°C). The salinity was changed gradually over a two-day period, using tap water that had sat overnight to lose excess chlorine. The fish were held at the test salinity for seven days and fed daily, with any deaths or unusual behavior noted. They were subjected to salinities of 4‰, 2‰ and 1‰. Two lots of 10 fish each were tested, except at 4‰ (See Table 4).

TABLE 3. Results of temperature tolerance experiments.

a. Number of *Eviota* surviving 38°C for six hours. (12 fish run for each test)

	No. of *E.s.* surviving Test 1	Test 2	No. of *E.z.* surviving Test 1	Test 2
After 1 hr	12	12	12	12
After 2 hr	12	12	12	11
After 3 hr	12	10	9	9
After 4 hr	12	10	5	9
After 5 hr	12	9	3	8
After 6 hr	10	9	3	5
Total	10	9	3	5

b. Number of *Eviota* surviving 40°C. (12 fish run for each test)

	No. of *E.s.* surviving Test 1	Test 2	No. of *E.z.* surviving Test 1	Test 2
After 30 min	6	3	7	4
After 60 min	0	0	0	2
After 90 min	0	0	0	0
Total	0	0	0	0

Both species survived 4‰ and showed little stress, eating well and actively moving about (Table 4). At 2‰, all the E. smaragdus survived. There was no significant difference between the total number of E. zonura surviving 2‰ and the total number of E. smaragdus surviving 2‰ ($P \leq 0.05$). At 1‰ there was a significant difference between the total number of E. zonura surviving and the total number of E. smaragdus surviving ($P \leq 0.05$) (Table 4). Both species displayed some stress after one or two days of such low salinities, indicated by lack of activity and lack of interest in food (E. zonura especially).

Both species show considerable tolerance to reduced salinity. Further experimentation may show E. smaragdus to be more tolerant than E. zonura during prolonged exposure.

TABLE 4. Results of reduced salinity experiment: the number of individuals of each species surviving after seven days. Ten individuals were used for each test but for the 4‰ test (number tested in parentheses).

Salinity	*E. smaragdus*		*E. zonura*	
4‰	2 (2)		17 (17)	
2‰	Test 1	Test 2	Test 1	Test 2
	10	10	3	7
1‰	Test 1	Test 2	Test 1	Test 2
	7	7	1	0

CHAPTER IV

REPRODUCTION

Reproductive behavior and breeding seasons have been noted for many species of gobies, chiefly temperate forms (see review by Breder and Rosen, 1966). Breeding is seasonal in most gobies from temperate and warm-temperate regions (Tavolga, 1954; Springer and McErlean, 1961), but occurs all year round for the few tropical forms studied (Breder and Rosen, 1966).

A difference in breeding season may be important in reducing competition between populations of sympatric species such as the two *Eviota*. Possible competition could arise for space for juveniles or spawning sites, especially in territorial species. Courtship behavior of *Eviota* is described on pages 71 to 74.

METHODS

A monthly collection of at least 20 specimens of each species of *Eviota* was attempted to determine breeding seasonality. The locality sampled (Fig. 4) and actual number of fishes collected each month depended largely upon sea and weather conditions. Systematic collection of *E. smaragdus* did not begin until November 1972, and collection of both species ceased in July 1973. Some *E. smaragdus*, however, were accidentally obtained in early 1972, while I was collecting *E. zonura* for a previous project. No annual cycle is therefore available for *E. smaragdus*.

Upon capture, the fishes were sexed, measured, and the degree of gonad development noted. Fishes could be sexed visually by the shape of the genital papilla. Females of both species have a bulbous papilla reminiscent of a cow's udder, while males have a lobed flap which differs according to species (Fig. 11). Although an attempt was made to check breeding condition of both sexes only females were used in determining breeding seasons, as the criterion for female ripeness was more accurate.

Gonad length, width, and general appearance were used to determine gonad ripeness in males. Ripe males had large, wide testes that were three-quarters the body cavity length, thick and densely white.

In females, egg diameter was the criterion. Both species had identically sized eggs. Ripe ova were 0.6 mm in diameter and were translucent and rounded, with a short pedestal usually present. At this stage the eggs were a pale greenish-blue. Nearly ripe ova were 0.5 mm in diameter, were opaque and whitish-blue and had no pedestal.

RESULTS

Average length at maturity (gonads complete ripe) and average number of ova per female were determined for each species from the monthly collections. Of a total of 557 *Eviota zonura* collected, 271 were female, 265 were male and 21 were juveniles that could not be sexed. Out of 247 *E. smaragdus* collected, 133 were females, 110 were male, and four could not be sexed.

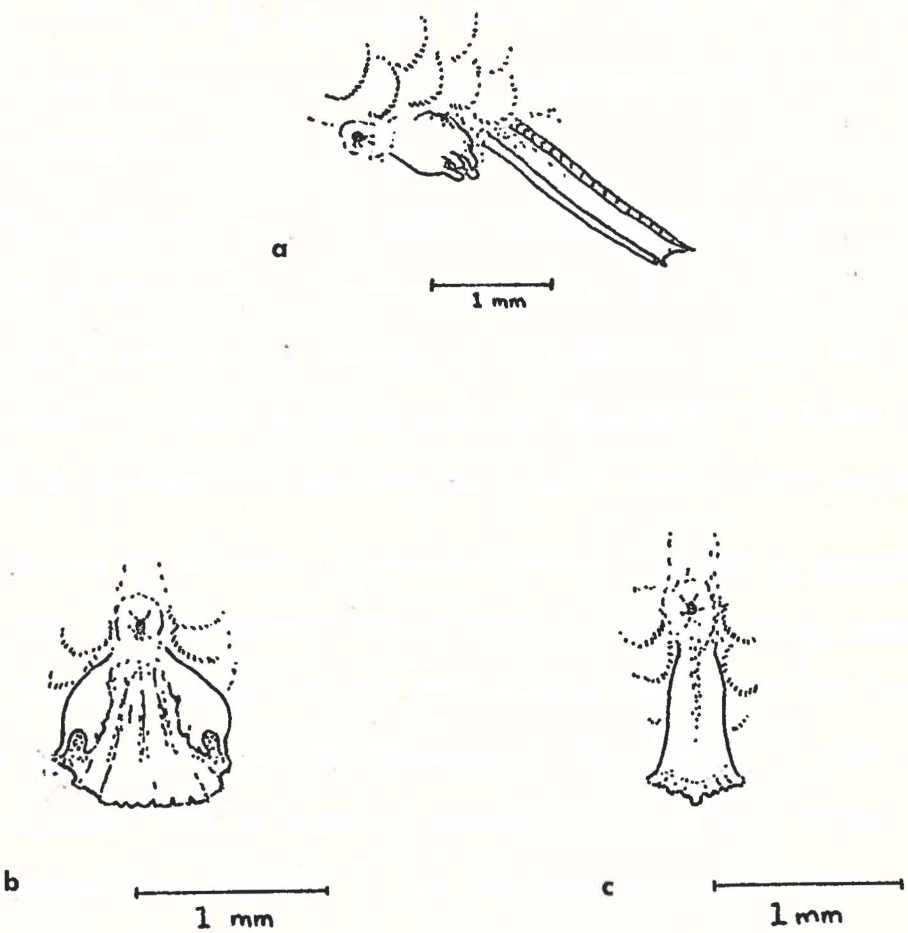


Fig. 11. Genital papillae of

a. females of both species
b. male E. zonura
c. male E. smaragdus

The sex ratio was therefore near 1:1 for both species. The smallest mature female (gonads ripe) E. zonura was 12 mm st.1., with the average length at maturity being 13.3 mm (n=50). The smallest mature E. smaragdus female was 13 mm, with an average length at maturity being 16.8 mm (n=18). Male E. zonura average 15.5 mm at maturity (n=54), while male E. smaragdus average 17.8 mm (n=20) at maturity. The average number of ova in female E. zonura is 126 (n=73), and in E. smaragdus is 166 (n=51).

The number of ripe (or nearly ripe) females per month for each species is presented in Figures 12 and 13. It appears that there are ripe or nearly ripe females of both species present nearly all year round. It must be noted that the abnormally low tides from August to October 1972 may have influenced reproductive activity.

Figure 12 indicates a possible seasonality for E. zonura with most ripe females present during March to August. No E. zonura were obtained during February 1973 because high tides and very rough seas made collecting impossible. The absence of ripe females from November 1972 to possibly February 1973 may be a normal lull in breeding or a response to the low tides in October 1972. In 1973, the number of ripe females is very much less than in 1972. This may be a response to the high mortality brought about by the abnormally low tides in 1972. Juvenile E. zonura were abundant in the field from May through September 1972 and also in May 1973, coinciding with the occurrence of ripe females. Courtship behavior has been noted all year round for this species.

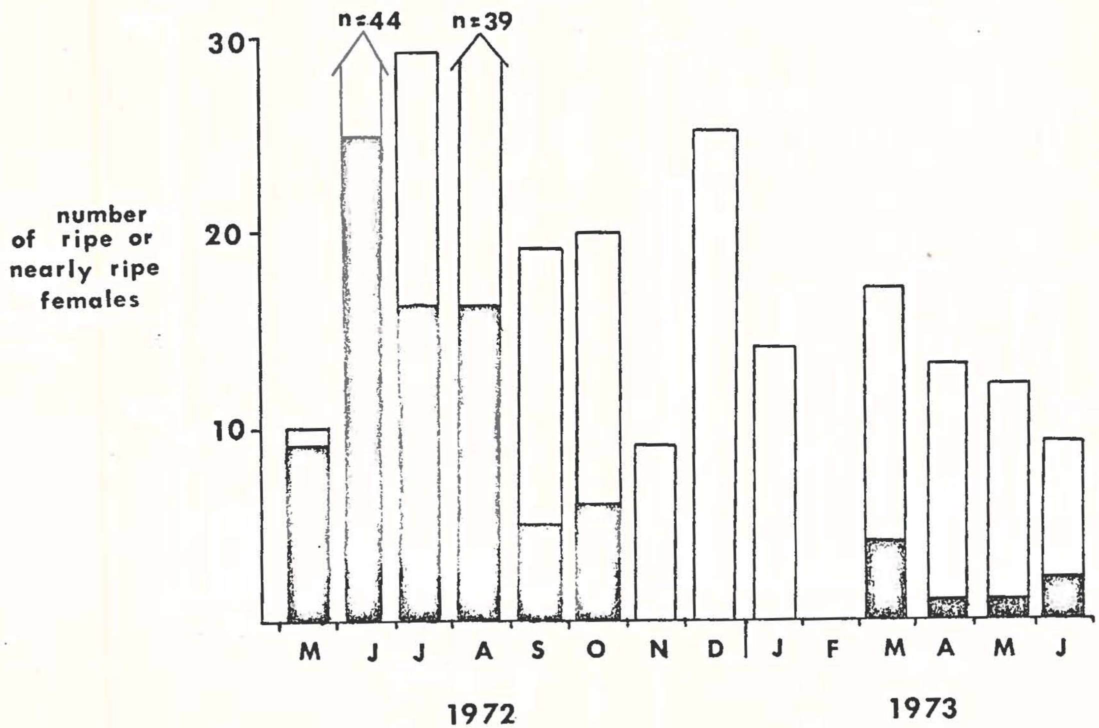


Fig. 12. Number of ripe or nearly ripe female <u>E. zonura</u> per month (solid black). White portion of bar indicates total number of females collected each month.

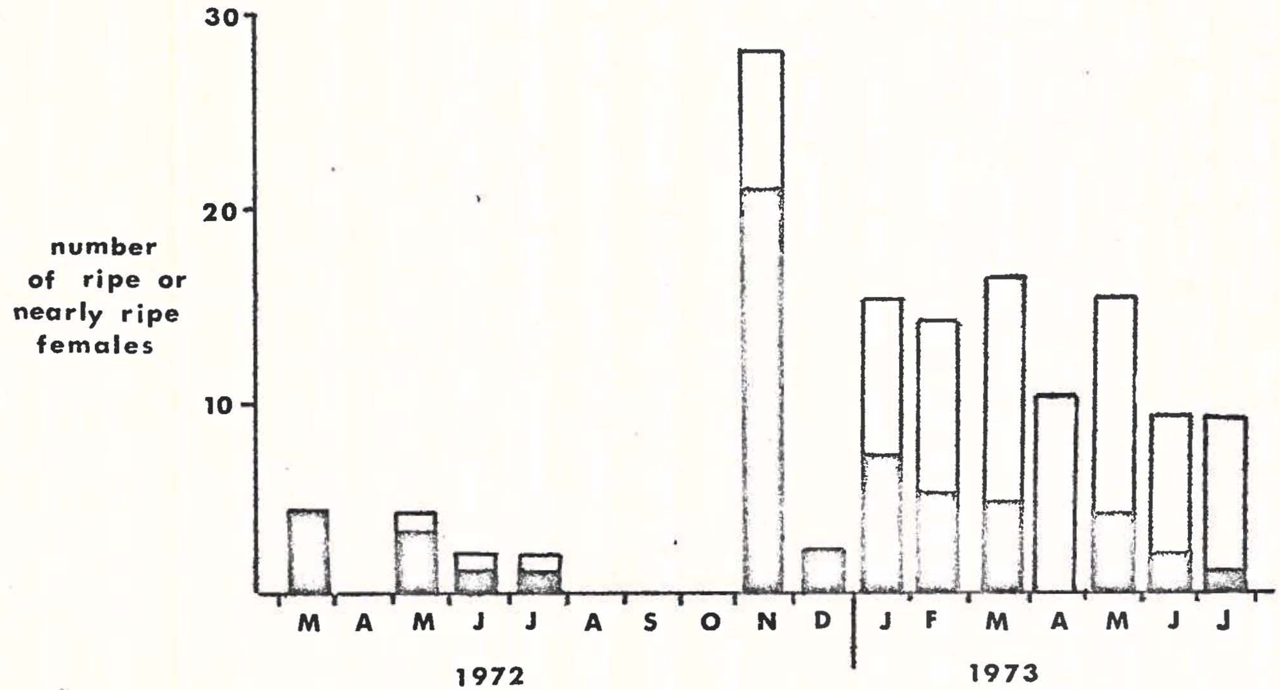


Fig. 13. Number of ripe or nearly ripe female E. smaragdus per month (solid black). White portion of bar indicates total number of females collected each month.

Although an incomplete annual cycle was obtained for *E. smaragdus*, it appears that ripe females were abundant from November 1972 to March 1973. The number of ripe females gradually tapered off after March 1973 (Fig. 13). The absence of ripe females in April 1973 is inexplicable. The few females accidentally collected from March to July 1972, bear out the general pattern present in 1973. There may be a peak in breeding seasonality in November (Fig. 13), unless this is a response to the low tides of the previous month. Juveniles were most abundant from November 1972 to May 1973. These are also the months in which ripe females were common. Courtship has been observed in the field from March to October, in both years.

There does not appear to be a difference in breeding season between the two *Eviota*, a factor which could be important in keeping the two species ecologically separate. However, it would be unwise to assume that there is seasonality in breeding for both species because of possible effects of the destructive tides in 1972.

CHAPTER V

FOOD HABITS

Difference in food habits is often an important factor in ecological separation of sympatric species (Jones, 1968; Stephens et.al. 1970). Gobiids are frequently neglected in fish community food habit studies, although they are very abundant (Randall, 1967). Therefore, an attempt was made to determine food preference and feeding behavior in Eviota.

METHODS

Fishes were collected at localities indicated by an asterisk in Figure 4. The gut contents of all fishes collected were examined. Food items were identified as far as possible. Other genera of small benthic fishes occurring with Eviota were collected and examined periodically, with Kelloggella cardinalis and Bathygobius fuscus sampled most often. The food habits and behavior of these species are more like Eviota than any other species present. It was not known whether intergeneric competition for food occurred.

From observations in the field, it was apparent that both Eviota were picking most of their prey organisms off the benthic algae or substrate. To determine prey organism abundance in the algae, several genera of very common reef flat algae were examined. One sample each of Gelidiella, Centroceras, Cladophoropsis and Hypnea was pried off the substrate and each immediately placed in a plastic bag. Blotted wet weight of the algae was recorded, then the algae and any water from the collecting bag were preserved in formalin. All organisms found in the preserved sample were counted, with the exception of inedible types such as foraminifera.

RESULTS:

Both species have a short gut with the cardiac portion of the stomach being muscular, and the rest of the gut being thin-walled. The teeth are in two irregular rows, and are sharp and curved. At least one canine is found on each side of each jaw. Feeding behavior is described on page 53. The morphology and behavior are both indicative of carnivorous habits.

Food preference is expressed as a percentage frequency of items occurring in all stomachs examined (Table 5). For both species, the major food items are the same; copepods, isopods, ostracods, small gastropods, amphipods, polychaetes, midge larvae and nematodes. The few reef flat dwelling insects, especially the midges and their larvae, are seasonal in occurrence, and possibly breed during low spring tides. Only the larvae of these insects live in the water, with adults living on cliffs near benches and on exposed parts of the reef flat platform such as the rims of the margin's terraced pools. Hence midge larvae are more available to E. zonura (Table 5). The mites are completely marine. Sandgrains, detritus and algal fragments are probably picked up accidentally (see page 53). Detritus is more often found in E. smaragdus (Table 5) stomachs due to a difference in habitat. There is more settled detritus in the outer flat pools than on the margin.

The number of organisms present in the algae is enormous; over 5,000 individuals may occur in a 38g clump of matted algae (Table 6). The kind of organisms found are roughly ranked in order of abundance. The most abundant animals in the algae are also those most often eaten by Eviota. Amphipods and polychaetes are abundant but do not form a large percentage of the diet of either Eviota. These are large (greater than 5mm long) and therefore less frequently eaten. However, it must be considered that the numbers obtained may have been modified by conditions following the phenomenal tides of October 1972, and that there may normally be many more or fewer organisms found in a given weight of algae.

Of the other species of fishes examined randomly for stomach contents, only Bathygobius fuscus was consistently carnivorous. Out of 24 Bathygobius stomachs examined, two contained fish remains, one being bones while the other was an intact Kelloggella. Other food items consumed by Bathygobius were xanthid crabs, amphipods, midge larvae, copepods, small shrimp, polychaetes, gastropods, ostracods and algae. Most of these items were larger than those consumed by Eviota.

Kelloggella cardinalis fed on very similar food items to Eviota, but also consumed large amounts of algae (up to 100% of total gut contents). All blennies examined fed on varying amounts of detritus, sponge, polychaetes, and algae. Rhabdoblennius snowi especially was often observed attempting to tear chelipeds off xanthid crabs.

TABLE 5. Food preference based on monthly collections of both Eviota species. Values are expressed as percentages of total numbers of stomachs of each species. (n=no. of stomachs examined).

ITEMS	Eviota zonura (n=557) Percentage	Eviota smaragdus (n=247) Percentage
Copepods	85.74	93.12
Isopods	44.17	53.85
Midge Larvae & pupae	39.14	7.69
Gastropods, limpets, Chitons	34.11	29.15
Ostracods	29.98	51.82
Amphipods	27.47	10.93
Nematodes	11.31	12.15
Polychaetes	8.26	11.74
Mites	12.39	4.45
Algae and diatoms	10.59	8.10
Detritus	5.57	18.22
Unidentifiable material, Mucus	3.05	16.19
Miscellaneous fragments of worms	5.21	7.29
Adult midges	1.62	0
Sponge spicules	1.80	0.81
Fish eggs	1.62	2.02
Beetles	0	0.40
Other insect larvae	0.54	0
Miscellaneous eggs	0.18	0.81
Sand, foraminfera	3.41	6.81
Small crabs	0.18	0
Empty	1.44	1.22
Loose appendages, zoea larvae, other larvae	3.95	2.02
Fishes, fish scales	0	0.81

TABLE 6. Food Item Abundance in Selected Algal Species.

Species of Algae:	<u>Centroceras clavulatum</u> (from outer flat near margin)	<u>Cladophoropsis membranacea</u> (outer flat)	<u>Gelidiella acerosa</u> (bench)	<u>Hypnea pannosa</u> (outer flat near margin)
Blotted Wet Weight:	42.8 g	38.3 g	17.6 g	62.3 g
Total Number of Organisms:	2855	5833	860	54.83
List of Kinds of Organisms Found: (ranked according to abundance)	copepods isopods amphipods polychaetes nematodes gastropods insect larvae ostracods crab pycnogonid <u>Eviota afelei</u>	copepods ostracods isopods polychaetes gastropods nematodes midge larvae crab megalops amphipods beetle larvae mites	copepods isopods amphipods polychaetes nematodes gastropods midge larvae hydroids ostracods polyclad flat-worms mites red ant crab megalops opisthobranch	copepods amphipods gastropods isopods polychaetes ostracods nematodes sea-anemones midge midge larvae

Stomach contents of many reef fishes had been examined during a survey of Tanguisson Point fishes (Jones and Randall, 1973). Of the 328 predators (chiefly serranids, lutjanids, holocentrids, muraenids, synodontids, gobiids and scorpaenids), most contained an assortment of crustaceans, although a few contained fish bones. Two Bathygobius fuscus contained a fish recognizable as Eviota.

Eviota apparently will prey upon Eviota, as one 15.5mm E. smaragdus was found with a 7mm long partially digested Eviota zonura in its stomach. The fish had been collected from the reef margin rimmed terraces at Tagachan Point, an unlikely place for E. smaragdus to be. Neither species has been observed, in captivity, capturing and eating fishes of any species. However, individuals will pick at a dead Eviota.

CHAPTER VI

COMPARATIVE BEHAVIOR

Many substrate-associated fishes are aggressive and tend to be territorial, especially when breeding (Gibson, 1968; Stephens et al, 1970; Low, 1971). "Territoriality" is the active defense of a specific substrate area. It differs from "individual distance" which is the defense of a "mobile territory" surrounding the fish and is not related to a specific area on the substrate. Many fishes may also occupy a home range, over which they may freely move, but they do not actively defend it. All the above spacing mechanisms, together with a possible size-related dominance order, may serve to reduce competition among the two Eviota.

Both species are aggressive and display many ritualised action patterns. Eviota are easily observed on the reef at low tide. Their accessibility and active nature make them good subjects for ethological study.

FIELD OBSERVATIONS

The reef flat and bench by Taogam Point was the site of most observations. Fishes were observed also on the reef at Tagachan Beach and inner flat of the beach between Bijia and Amantes Points (Fig. 4). I used a small portable taperecorder to record all movements made by a particular fish. Only one fish was observed during a recording session. The sessions lasted from seven to 35 minutes, depending on the tide and number of interruptions (usually dogs or people asking questions). Other notes were taken while in the field collecting as aggressive or courtship behavior was observed. Both Eviota appeared tolerant of the observer and showed apparent habituation in less than five minutes. The observer had to sit in an area inaccessible to the fish observed, because the subject would frequently attempt to use the observer's feet as shelter and feeding sites. Fish were observed only during low tides when the water surface was relatively calm.

Both species are active during daylight hours and also at night if there is a full moon and clear sky. When at rest, the body is partly lifted up anteriorly by the rather stiff pelvics. The dorsals and caudal are partly spread, but are not held taut. Colouring is like that in Figures 1 and 2. Feeding movements and "normal" swimming are the same in both species. The fish usually progress by short hops forward or to one side and they may turn completely around in one movement. The head is often turned to one side or downwards, briefly. Fast swimming is accomplished by a series of swift darts, with a brief pause between each dart, and the body not touching the substrate. Feeding behavior consists of hopping and turning about frequently, moving the head or anterior part of the body toward any movement. Food items are taken up from the substrate or from algal turf and less frequently from the water column. A fish normally averages 20 feeding movements within a 20-minute period, or about one bite per minute. It is impossible to tell if each bite results in capture of a prey organism, as the prey is usually very small.

Territory

Active defense of a specific area (territoriality) was observed only in males guarding a nest-hole. This has been seen three times in the field for *E. smaragdus* and once for *E. zonura*. Occasionally a fish of either species was seen defending an area around an algal clump, but it was not possible to determine if there was a nest-hole present or not. Individual fish have been seen repeatedly in the same area for a number of days, but the same fish could not be found after several weeks. The problem of tagging such small fishes remains to be solved.

Home Range

The term "home range" is used as in Stephens et al.(1970); that of "individuals not wandering at random but confining their movements to limited areas over which they may wander freely." The limited area is the home range. The range covered by an individual in the field was taken as the greatest distance the fish travelled from the starting point at the beginning of the observation period. A fish may possess a territory within the home range. The mean home range for *E. smaragdus* was 39.3cm at greatest diameter (n=11), with extremes of 3 to 105cm diameter. The mean home range, at greatest diameter, for *E. zonura* was 58.9cm (n=14) and the extremes were 12 to 300cm. Males guarding nests usually travelled the least distance, possibly because they are occupied in ensuring that no other males of the same species come near their nests.

Individual Distance

Individual distance is also known as the "fight or flight" distance. It is defined as that distance within which an animal will tolerate another of the same or dissimilar species. An animal coming within that distance will result in either attack or flight. A rough estimate of individual distance was made in the field when possible. Many encounters occurred so quickly it was difficult to say how far apart the fish had been previously. Individual distance is a "mobile territory". Many aggressive encounters may occur in which one fish appears to be defending a specific area when it is actually a rather inactive individual. Therefore other active fish may more frequently overstep its individual distance.

For both species, the individual distance appears to be about 2cm. It may be less for E. zonura, which is a smaller fish than E. smaragdus. Fishes coming closer than 2cm were sometimes tolerated, but more often were chased or threatened. Juveniles were tolerated closer, regardless of species. Small Bathygobius were chased, even though they were slightly larger than the Eviota chasing them. Large adult Bathygobius were avoided. Blennies were tolerated up to several millimeters, even if they were large (100+ mm). Rhabdoblennius snowi was the only blenny which behaved aggressively towards either Eviota species.

Both species showed rather different flight reactions when disturbed by an observer walking over the reef. E. zonura usually darts immediately under cover or into a crevice, to reappear within a minute or so. E. smaragdus generally darts rapidly and erratically from side to side, freezing suddenly after the rapid movements. This confuses the onlooker, who is usually unable to follow the movements. In typical habitat, the colouring of this species has a camouflage effect, blending in with the mottled sandy substrate. E. smaragdus will seek cover when pressed further by attempts at capture.

Intraspecific Agonistic Behavior of E. zonura

Just over seven hours were spent taperecording E. zonura behavior. The action patterns described were seen at least twice, with many of them noted each time E. zonura was observed.

Charging. A quick dart forward toward another fish, with or without elements such as fin-raising, constitutes charging (Fig. 14a). The fish may briefly raise the unpaired fins immediately after charging.

Chasing. Chasing is essentially a charge in which the fish does not halt after the first dart, but continues swimming after the fish it charged (Fig. 14a,b). The swimming action is the same as in normal fast swimming.

Fleeing. This is rapid swimming away from a disturbance, which may be a charging fish or an unfamiliar object introduced into the pool (Fig. 14b). A fish fleeing from another will often halt only a short distance away from the fish that charged it (within 4cm).

Fin-Flagging. This appears to be an intention movement, as it always preceded an aggressive action each time it was seen. Usually, an E. zonura being approached ignores or chases the intruder. On three occasions, however, the fish being approached rapidly vibrated the dorsals up and down (Fig. 14f), remaining still. The fish may perform this action more than once before turning and chasing the fish that had approached it. Fin-flagging is an important part of the fighting behavior of another small reef flat goby, Kelloggella cardinalis.

Fin-spreading. Fin-spreading is the first stereotyped aggressive action displayed in any threat sequence that is not a simple charge-flee sequence. However, a charging fish occasionally finspreads before charging. All unpaired fins are spread widely and held taut, with the first dorsal tipped forward (Fig. 14c). The fins intensify in colour and the head may darken. Fin-spreading often occurs simultaneously with the behavior pattern described next. It is also the only signal displayed for any length of time after a fight and may possibly indicate a high level of aggression in the individual (i.e., the greater period of time the fish displays spread fins, the greater is its aggressive drive).

Puffing. This action may occur with or after fin-spreading. It involves arching the body so as to display the spread fins, raising the head and spreading the branchiostegals wide so as to display the bluish underside of the head (Fig. 14c). The head may be lifted rapidly and smoothly when the body arches, or several small upward jerks may be given. The head has usually darkened in colour, while the bars on the sides of the body begin to fade and dissipate. The degree of fading of these bars appears to vary with the individual and intensity of its aggression. Fish which have undergone the complete colour change go through a full fight sequence more often. The upright "puffed" position of the head is maintained during the entire fight sequence until one fish weakens.

Broadside Display. When neither fish, of a threatening pair, will display its subordination to the other, a broadside display results. The two fish stand head to tail, with fins spread and heads puffed. The arched bodies are curved so as to form a rough circle (Fig. 14d). They may remain still, but usually stamp, swagger or dart in circles, biting. These actions are described below.

Stamping. A fish performing this action maintains its broadside display, with head raised high and fins taut. It then makes a jerky hop upwards, returning to the same position on the substrate (Fig. 14c). The effect is of a fish "stamping its feet". After stamping repeatedly, the fish may be seen to have travelled a short distance sideways or backwards.

Swaggering. A fish may stamp before swaggering and vice versa. When swaggering, the fish undulates the body laterally rather slowly, with the wave of motion beginning at the head. The fish remains stationary while swaggering.

Circling and Biting. These are the actual fight and contact movements, always occurring after a broadside display. The fish spin round in a tight circle, each attempting to bite or grab hold of the other (Fig. 14c). One may dart directly at the other while doing so. Bites are directed toward the posterior part of the body. Fighting individuals frequently lost scales or parts of the caudal or soft dorsal fins. The "winner" of the fight may be determined by one bout of circling and biting, or the fight may be prolonged, with much swaggering and circling before one fish submits.

Submissive Behavior of E. zonura

Submissive behavior is usually expressed by fleeing, or retreating. A fish wishing to submit during a fight will turn away from the other and hop rapidly away (retreating). The dominant fish will often display no reaction, or it may chase the retreating fish.

Rocking. This may be a submissive signal. It has been observed only once. One fish faced the other, lightened its fins, and rocked back and forth on its pelvics, rowing with the pectorals. The fish that rocked was followed by the other for a short distance. The other fish proved to be dominant, as it chased the rocking fish. The subordinate fish turned to face the dominant and rocked at it before it was chased off.

The number of times each action pattern was observed over the total observation period is shown in Table 7. Out of 79 agonistic encounters observed in this species, 10 were actual fights, in which more than a simple charge-flee sequence took place. This is not a large number of fights, but it must be kept in mind that fights

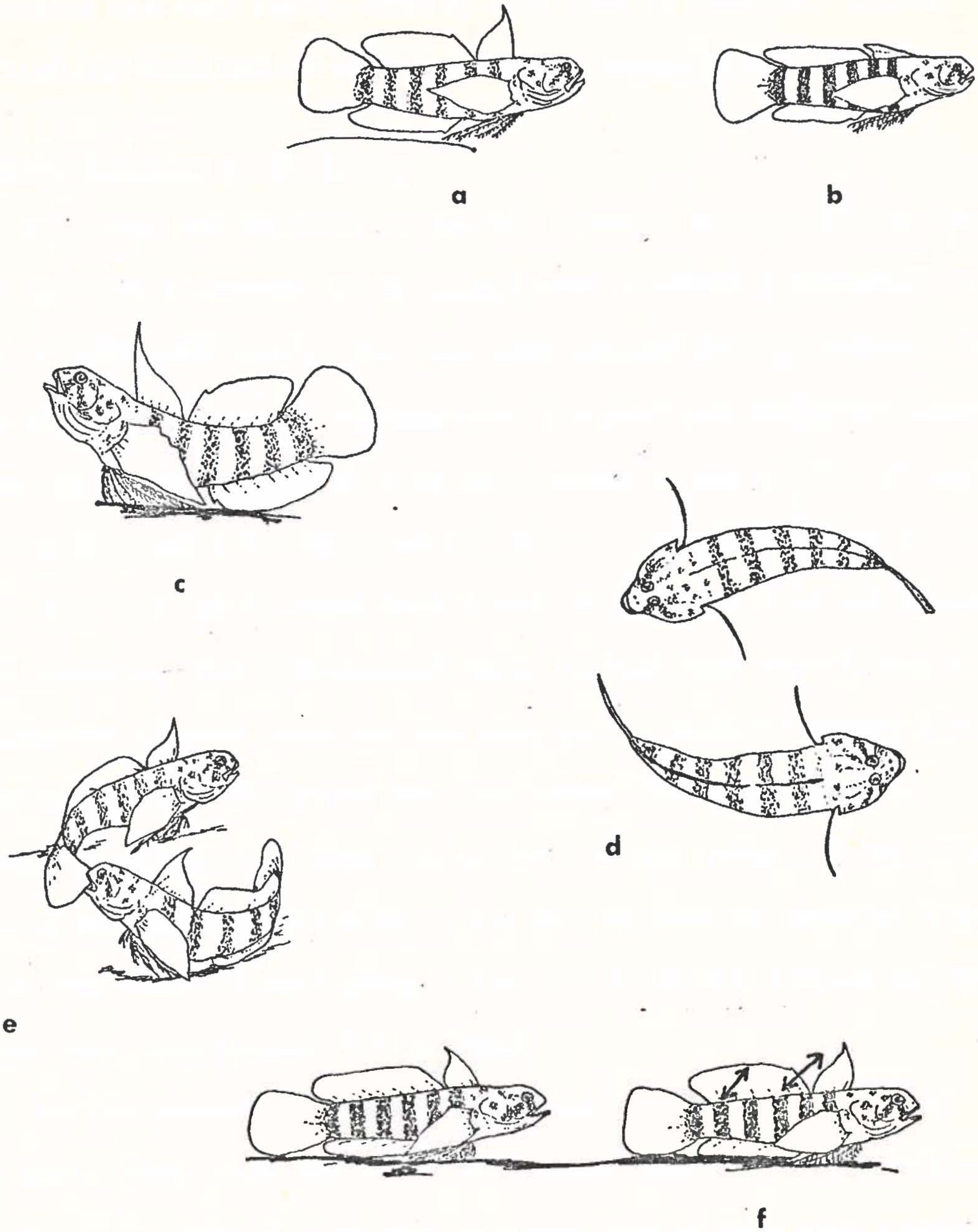


Fig. 14 Agonistic action patterns of E. zonura.

a. charging
b. fleeing
c. puffing (and stamping)
d. broadside display
e. circling and biting
f. fin-flagging

between Eviota are often damaging, not bluff-fights. Most aggressive encounters are very rapid, usually less than 30 seconds. Actual conflict may take one or several minutes, depending on intensity.

Uncommon Behavior of E. zonura

There was one instance of unusual behavior noted. On the Taogam reef flat one afternoon, 10 E. zonura were observed congregated in an area of less than $15cm^2$. The fish were watched for 12 minutes. The tide was beginning to flood back over the reef and the water temperature was normal. These 10 fish were moving around a clump of algae, peering down among its branches and holes. Occasionally one or two would move off and threaten each other, with spread fins and broadside displays. The fish behaved oddly in that they were within a few millimeters of each other for the most part. Normally Eviota will tolerate another within 2cm but fish closer than that releases aggressive behavior. These fish allowed actual contact to be made, butting and nudging each other. The only aggressive behavior took place away from the main group. The fish which did display aggressively were fairly small (10 to 12mm).

One particular hole in the algae was carefully inspected by the fish. They would hop up to it and peer down into it, sometimes hopping right into it. As many as three fish at once were crowded at the hole entrance, one sitting partly on top of the other. While the fish were not looking in the holes, they still would tolerate another fish close by, and would sit touching bodies or heads, but it was difficult to follow the motions of more than one fish for any length of time.

TABLE 7. Number of times each agonistic action pattern was observed in the field, for both species.

Action Pattern	*E. zonura*	*E. smaragdus*
Fin-spread	17	19
Puff	14	11
Gape	0	11
Chase	17	13
Charge	41	23
Flee	21	18
Broadside Display	10	15
Circle, Bite	9	8
Fall	0	11
Stamp	1	9
Swagger	1	6
Butt	0	14
Finflag	1	1
Rock	2	0
Headshake	0	1
Shiver	0	1
Bow	0	1

Intraspecific Agonistic Behavior of E. smaragdus

Five hours of taperecorded behavior were made in the field, with notes on behavior kept while collecting. This species' agonistic behavior patterns are very similar to those of E. zonura. The actions: charge, chase, flee, finspread, broadside display, finflag, stamp, swagger, circle and bite are the same for both species. There are, however, differences in behavior. Three actions used by this species and described below are never performed by E. zonura during aggressive display.

Gaping. In the E. smaragdus aggressive displays, the puffing action may be changed. The head is raised and the branchiostegals are spread (puffing). Then the jaws are opened widely and protruded (Fig. 15a) and the head changes colour as described earlier. This species may often puff without gaping, with the same colour change taking place. Gaping may indicate a higher aggressive drive than if the fish were only puffing.

Butting. This is simply butting with the head, usually directed towards the other fish's head or side (Fig. 15b). It is often used during fights in this species, but is also a courtship action in both species. The action in E. smaragdus appears to be the same in both courtship and aggressive behavior. It may be a recognition gesture, to assure the butting fish of the other fish's sex. Olfactory recognition of females has already been demonstrated in the goby Bathygobius soporator by Tavolga (1955). When one fish butts another, if the other is found to be male, the fight should continue; if it is female, it may warrant different reactions. Butting often precedes the display described next.

Falling. This is the only word that can be used to describe this display, which is performed during fights. The two fish stand head to tail in a broadside display, and may stamp, circle or bite. Then one may draw itself up so that it is perched on its caudal and the tips of its pelvics (Fig. 15c), holding the fins taut and the body stiff. It then smoothly and rapidly lowers itself down, waving the pectorals, coming to rest a little closer to the other fish than it had been. The head colouration is very intense during this display, and gaping usually accompanies it. Both dominant and subordinate fish will perform falling during a fight sequence.

Submissive Behavior of *E. smaragdus*

Fleeing and retreating usually express submissive behavior, as in *E. zonura*. Shivering, headshaking and bowing have been observed only once each in the field, and may also be submissive behavior.

Bowing. The subordinate fish turns and bows quickly to the larger dominant fish, then retreats. Only the head is moved (Fig. 15f).

Shivering. This occurred when a smaller fish was surprised by the dominant. The subordinate darted away a short distance spread fins, gaped, shivered all over, then darted off. It was not threatened directly by the dominant.

Headshaking. A dominant fish was gaping and threatening a smaller fish. The smaller lowered its head to the substrate as though

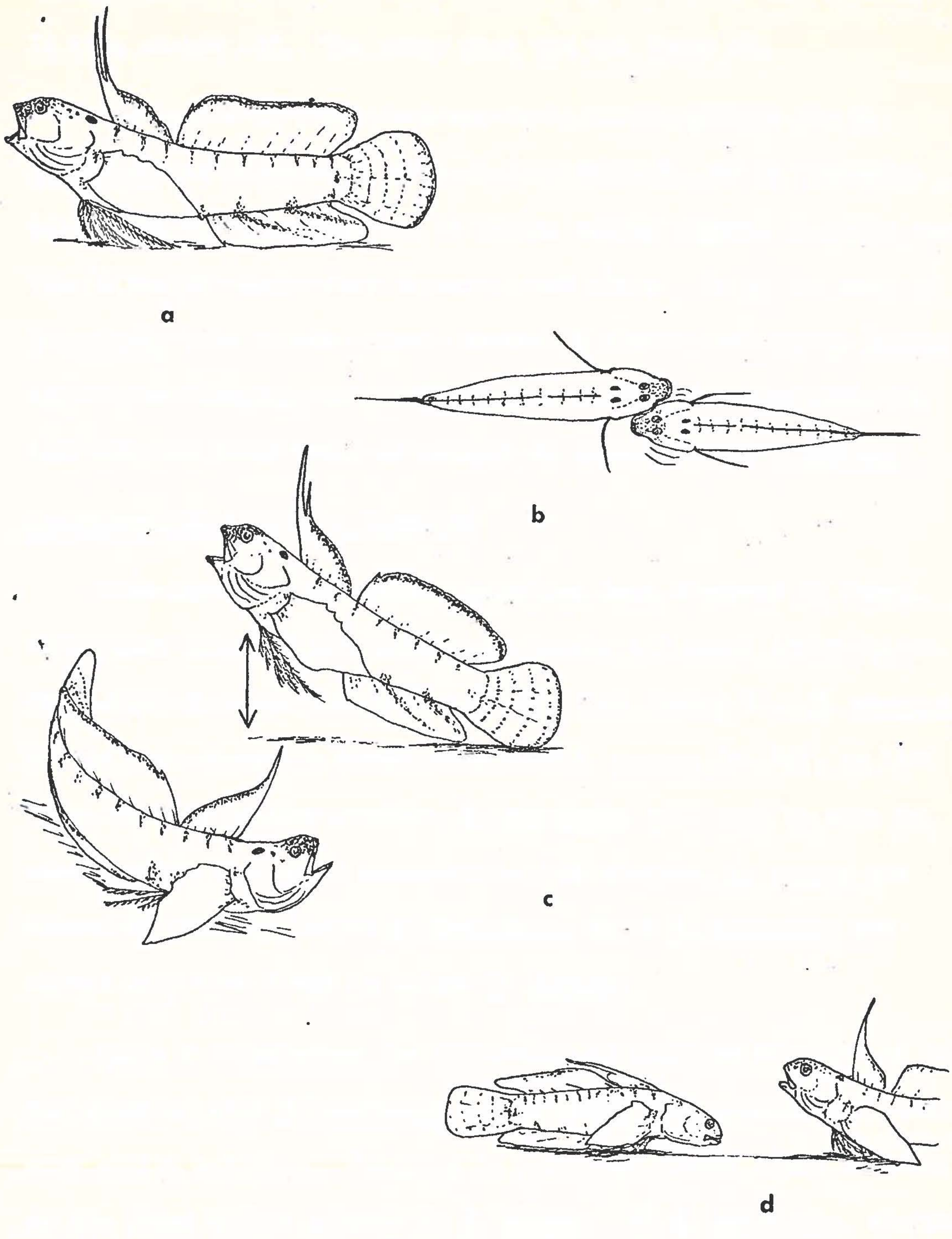


Fig. 15. Agonistic action patterns of E. smaragdus

a. gaping
b. butting
c. falling
d. bowing

bowing and shook it back and forth and up and down, very quickly. It then darted off. The other fish did not chase it.

The number of times each agonistic action pattern for E. smaragdus was observed is indicated in Table 7. Of 65 agonistic encounters for this species, 13 led to actual fights, in which more than a simple charge-flee sequence took place. As in the case of E. zonura, this is not a large number of fights, but again, Eviota fights are damaging, not bluff-fights. Agonistic encounters for this species occur about as quickly as described for E. zonura.

Interspecific Agonistic Behavior

Interspecific aggressive encounters were observed 36 times, with three actual fights noted. In nearly all these interactions, the larger fish was the dominant individual (Table 8). E. smaragdus is, on the average, a larger fish than E. zonura (p. 42), so that where the two species coexist, E. smaragdus will tend to have an advantage in aggressive encounters. For example, E. zonura was chased 26 times by larger E. smaragdus, while E. smaragdus was chased only five times by larger E. zonura.

Table 7 illustrates the difference in fighting behavior of the two species, with E. smaragdus fights being more complex and involving more action patterns. Charging is performed almost twice as often as any other action pattern in E. zonura. In E. smaragdus, charging is not as frequent, instead, the other action patterns become more important. A typical sequence of actions for each species (Figs. 16, 17) indicates a possible fight sequence. From the initial approach, up to puffing and gaping, the sequence is rarely changed for both species. It is only when the antagonists are both giving the broadside display that the sequence is varied. The actual fighting movements: circling and biting, stamping, swaggering, and falling, appear in different sequence with each fight. At any time during the fight, the weaker or subordinate fish has the choice of retreating or fleeing. In the three interspecific fights observed, each fish displayed its species-specific behavior patterns. One fight lasted two minutes, while the other two lasted less than one minute.

Courtship Behavior

Notes were kept on courtship behavior any time it was observed in the field. Any observed differences in courtship actions may serve to help keep the two species from hybridizing. Five observations for each species were obtained. _E. smaragdus_ also courted eight times under laboratory conditions, but _E. zonura_ did so only twice. Taken together, these observations are enough to allow adequate descriptions of action patterns used during courtship.

In most gobiod fishes, it is typically the male which selects and cleans out the nest-site (Breder and Rosen, 1966). The courtship dance, if any, is performed to attract a female or a succession of females to the nest-site, where spawning takes place. Fertilization is external. The male guards and aerates the eggs until they hatch. _Eviota_ probably follows this pattern. In the few cases where male _Eviota_ have been seen guarding a specific area, they remained around, or spent much time inside, a specific hole in the reef platform. The holes observed were a little larger than the circumference

TABLE 8. Intra- and interspecific aggressive encounters in the field arranged by size. "Threatening" here includes chasing, charging and displaying threatening postures.

Number of Times Fish Threatened by:	*E. zonura*	*E. smaragdus*
Larger *E. zonura*	51	5
Smaller *E. zonura*	2	3
Larger *E. smaragdus*	26	38
Smaller *E. smaragdus*	0	2

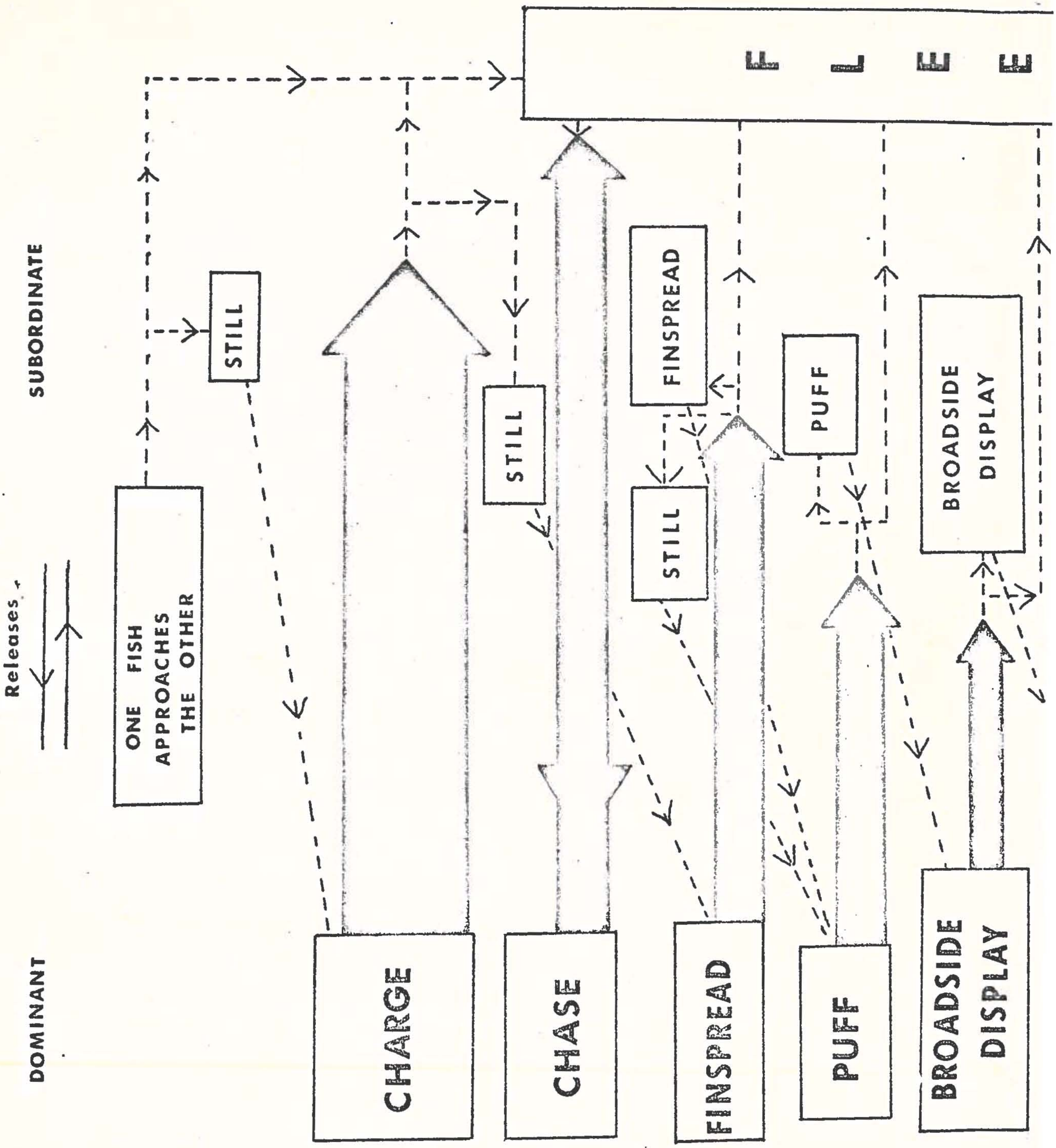
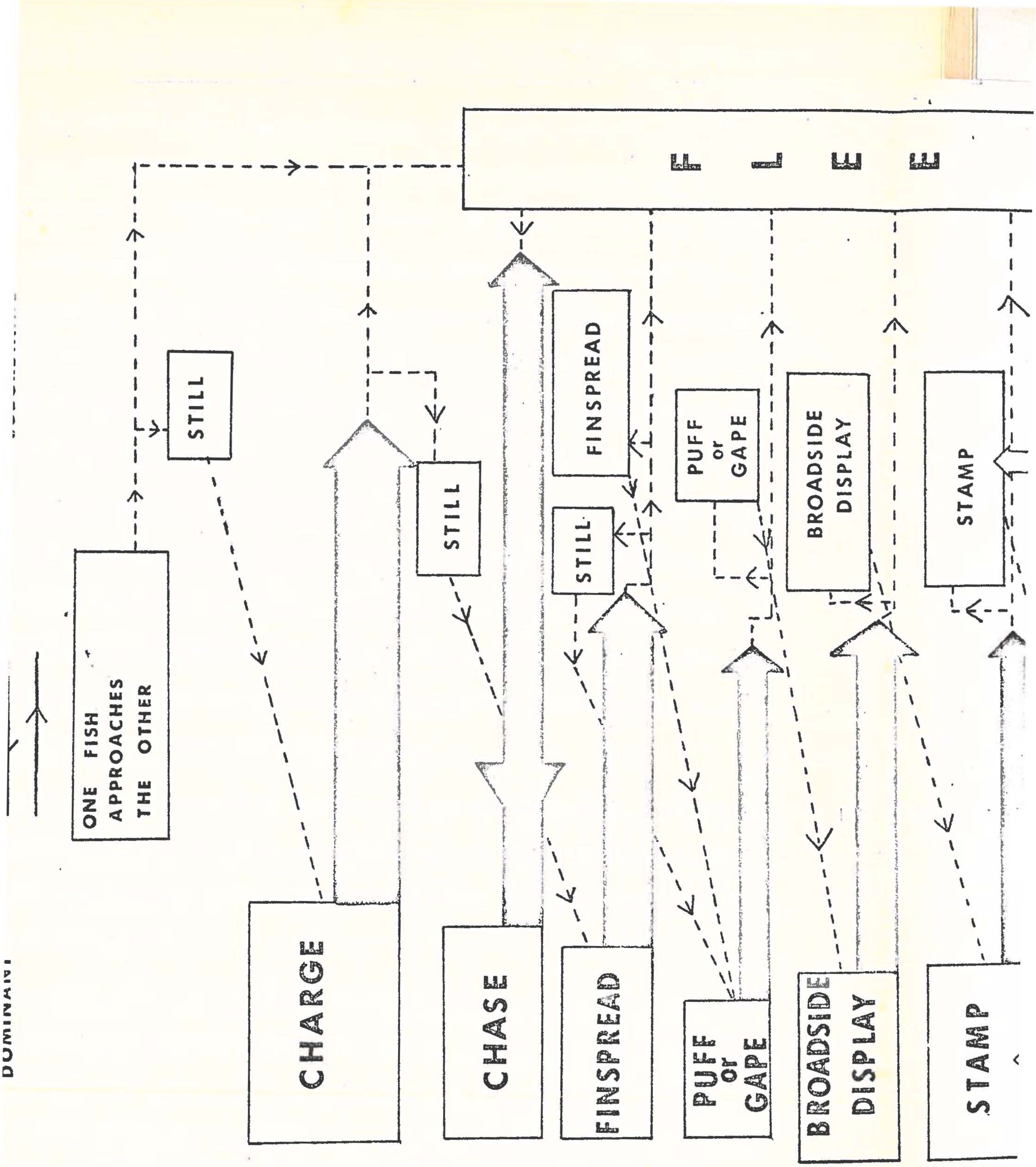


Fig. 16. Sequence of performance of agonistic action patterns for E. zonura. Width of black arrow indicates relative frequency of performance of each action. Dotted lines not based on actual frequency data. White arrows between boxes indicates fish has a choice of performing either action.



g. 17. Sequence of performance of agonistic action patterns for E. smaragdus. Width of black arrow indicates relative frequency of performance of each action. Dotted lines not based on actual frequency data. White arrows between boxes indicates fish has a choice of performing either action.

of the male's body. The male chases off fishes other than females of its own species. Females approaching the nest-hole are courted in an attempt to lead them into the nest. Males are often unsuccessful in that females may follow them for a short distance, then cease responding and move off. A male may court several females successively, presumably until the nest is filled with eggs. Although it has not been observed, it is probable that the male guards and aerates the eggs until they hatch.

Courtship Behavior of *E. zonura*. (1) Body-waggling. This is the basic courtship movement in both species. The anterior half of the body is held still while the posterior half undulates laterally with a rapid, sinuous motion (Fig. 20a). The male may be up to 8cm from the female when he does this. *E. zonura* uses body-waggling more often than any other courtship action.

(2) Fanning. Fanning is a variation of body-waggling in which the male is directly in front of the female, waggling the caudal fin especially rapidly so that it appears to be touching the female's snout (Fig. 20a).

(3) Butting. This is simply butting with the head (Fig. 20b). The male may butt the female once or twice before or after body-waggling. It may be an attention-getting device, as the females are often not very responsive, or it may be a recognition gesture as described earlier.

The courtship dance begins with the male moving away from the nest-hole to approach and butt the female. He will then turn about and body-waggle, then hop forward and continue body-waggling, hopping, turning about and butting, turning about and fanning, hopping, body-waggling and so on until the nest is reached. The female does not perform any actions other than following the male or not responding at all. On reaching the nest, the male immediately enters it. The female may peer into it for several seconds before either entering or moving away. If the female enters the nest, it may be a full minute before either fish reappears. If the female does not enter the nest after a few seconds, the male may come out, butt and fan, then dart back down the nest-hole with an exaggerated swimming motion resembling body-waggling. Usually the female follows. If she does not, but just hops around near the nest entrance, the male will chase her off after reappearing from his nest-hole.

Courtship Behavior of *E. smaragdus*. Body-waggling, butting, and fanning are the same for this species as in *E. zonura*. There are also four additional actions used by *E. smaragdus* during courtship. Three of these are similar to actions used also during agonistic display. Butting, which is solely a courtship action in *E. zonura*, is also an aggressive action for *E. smaragdus*. It may be a recognition gesture, or an expression of conflict behavior. Males guarding a nest may hop close to any fish of its own species and attempt to butt. If the fish being approached is a male, it usually darts away. In one case a nest-guarding male approached a smaller fish and came close enough to nudge it without the other being disturbed. Then he seemed to realize that the smaller fish was a male or immature female that had not reacted typically to the approach of the larger male, and he chased it off.

(1) Darting. This action is performed only by E. smaragdus during courtship, and is a dominant part of the species courtship dance. It is a rapid arching dart through the water column in which the swimming action is very much like swaggering (described next). The male may dart back and forth in front of the female (Fig. 20c) or he may encircle the female in a series of darts (Fig. 20d).

(2) Swaggering. This is very like swaggering in aggressive display, except that the male is moving forward as he swaggers, usually in front of the female (Fig. 20e). The head is not raised much, and the branchiostegals are not spread as they would be in aggressive display. Swaggering is not seen as frequently as darting.

(3) Headstanding. This is very much like swaggering in that it begins as a swaggering motion, with the posterior half of the body slowly rising off the substrate until the fish is moving forward with half his body almost vertical (Fig. 20f). He may swim back and forth in front of the female while headstanding.

(4) Stamping. This has been seen once during an E. smaragdus courtship, and is much the same as in aggressive display. The head is not raised, although the body is held stiffly and a little arched (Fig. 20g). In the single instance this was observed, it was the only action the male used to attract females to his nest-hole.

Courtship behavior of E. smaragdus is very similar to that of E. zonura. However, there are more action patterns that can be used, and more variation in the courtship dance shown by the males observed. In all but one of the courtship dances seen, the courting dart of E. smaragdus is performed very frequently. The dance may begin with the initial nudge or butt. The male may place his head right under that of the female (Fig. 20h). Body-waggling, followed by several darts, then butting, fanning and darting all around the female may take place. Darting is nearly always followed by fanning or body-waggling.

LABORATORY OBSERVATIONS

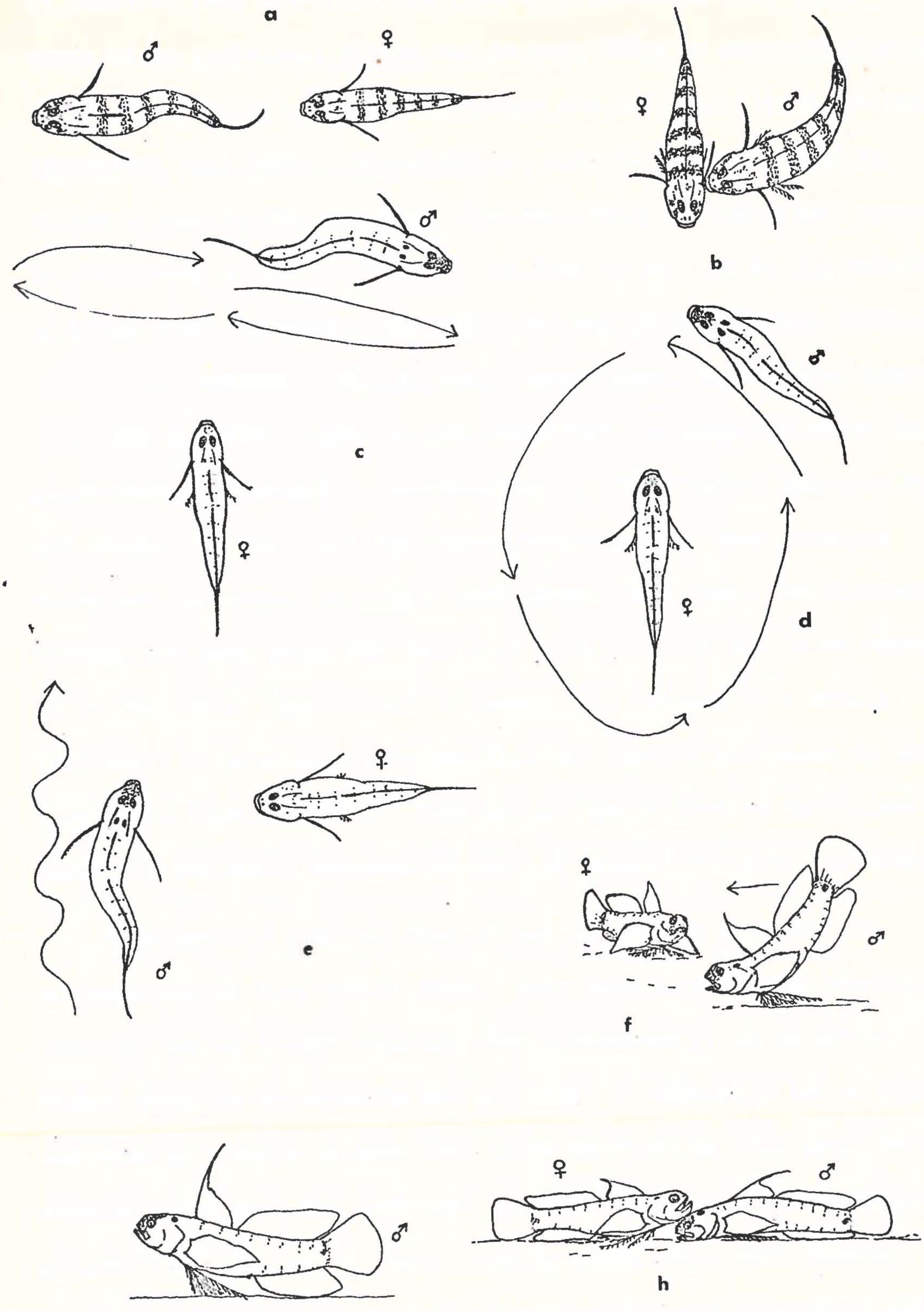
Several experiments were conducted in the laboratory to confirm field observations on size-related dominance, individual distance, home range and courtship behavior. Field observations indicated that territoriality is displayed only when fishes are in breeding condition.

Dominance and territoriality have been studied in the laboratory for many groups of fishes, especially cichlids, pomacentrids and anabantids (Frey and Miller, 1972; Low, 1971). These are active, fairly large fishes with many sterotyped action patterns, particularly in reproductive behavior. Most of these fishes swim well above the substrate, making both field and laboratory observations relatively easy. Secretive, benthic fishes such as blennies and gobies have, in general, been studied to a lesser degree.

It must be kept in mind that organisms rarely behave in the laboratory exactly as they would in their natural habitat (Lorenz, 1963). The laboratory tank exerts a confining effect even on a fish as small as Eviota. Home range and territory are two aspects

Fig. 18. Courtship action patterns

a.	body-waggling
b.	butting
c-d.	darting
e.	swaggering
f.	headstanding
g.	stamping
h.	butting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of behavior that are often modified by confinement. The home range of an individual Eviota can be over 100cm in greatest diameter in the field (p.54). Such home ranges are not possible in the usual laboratory size tanks. Consequently, individuals are forced to divide up the available space. The home range an individual occupies is restricted by the confines of the tank as well as by the behavior of other fishes present. An individual may be forced more often into aggressive encounters than it would under normal conditions, because of crowding. Home range, in the laboratory, is complicated by the appearance of elements of territoriality. Territorial behavior was not evident in the field for these species except when courting males were observed guarding a nest-site. Therefore, the distinction between the home range and territory will probably not be as sharp as in the field. Individual distance (the defense of a mobile territory) is also similarly modified and usually increases in the laboratory (Lorenz, 1963). This may be due to lack of sufficient space for avoidance movement or lack of sufficient cover for hiding.

Both species lost all fear of the laboratory tank and its surroundings in less than a week. They showed no "escape searching" behavior and no flight reaction when approached by an observer. Fishes used for experiments had been held in captivity for at least one week in a large outdoor tank (85cm by 135cm by 25cm deep) with flowing seawater. The tank used for all experiments was of fibre-glassed wood, 35.5cm by 116cm, usually 9.5cm deep, with flowing seawater. The tank was kept in an air-conditioned laboratory and was not screened off in any way. The tank walls were dark blue and the floor marked with one centimeter squares to be used in determining individual distance and area of home range. One half of the tank was white and the other black (Fig. 19a). A preliminary experiment indicated that direction of water flow and background colour did not affect the distribution of fish in the tank. All fish were fed daily with Artemia nauplii. All observations were recorded on a taperecorder, usually following the movements of only one fish at a time. To determine home ranges of the fish, I observed the position of each fish and plotted it continuously on a diagram of the tank.

Intraspecific Behavior in E. smaragdus

Five adult E. smaragdus were introduced into the centre of the test tank simultaneously. Sizes ranged from 13 to 20mm. Cover was provided in the centre of the tank (Fig. 19a). The fish were left for a week so as to lose all fear of the tank and its surroundings. They were observed for 17 days, with three 30-minute observations made per fish. The number and kinds of interactions were recorded, as was the location of each fish during observation periods.

Dominance order is quickly established in any artificial grouping of Eviota. In Table 9a, the fish are ranked according to size, which is very close to the dominance order. Some fish did not interact very often (S3 and S4), as their home ranges did not overlap. If two fish are of similar size, neither fish will readily submit during an agonistic encounter.

A dominance index was determined for each fish, on a scale of a

b

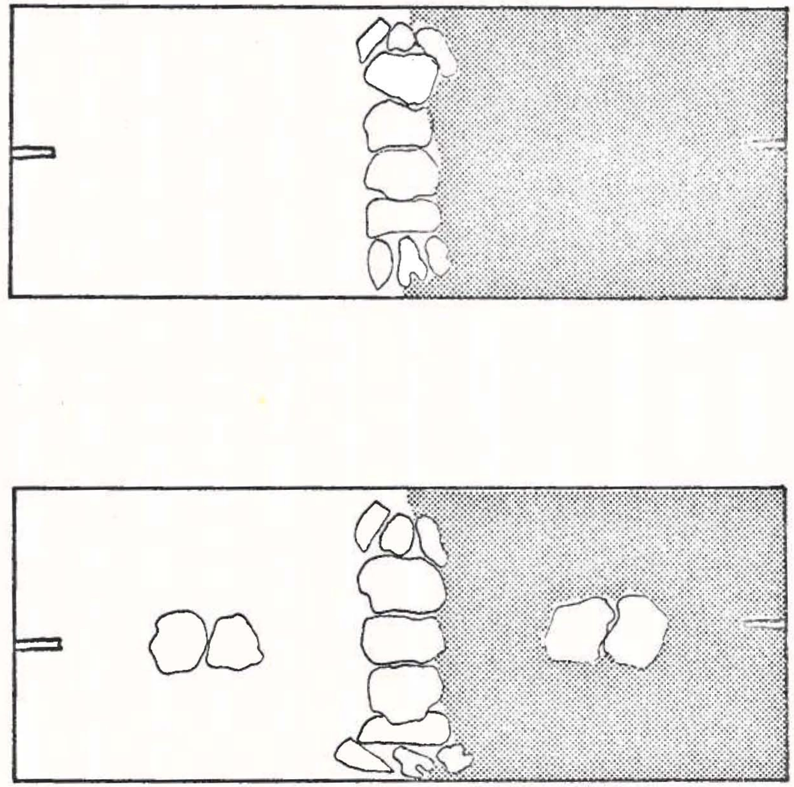

Fig. 19. Tank used for laboratory behavior experiments.

a. arrangement for the first experiment.
b. arrangement for second and third experiments.

0 to 1 (Pratt, pers. comm). The index used is as follows:

$$\text{DOMINANCE INDEX} = \frac{\text{No. of times fish X threatens another.}}{\text{No. of times fish X threatens another. + no. of times fish X is threatened.}}$$

The indices obtained for each fish (Table 9b) can be used to determine possible correlation between size and dominance order. Kendall's tau (a coefficient of rank correlation) was the statistic used (Siegel, 1956). For this experiment, r (tau) was 0.8. There is apparently a distinct correlation between a fish's size and its position in the dominance order. Gibson (1968), while studying the effects of space on agonistic behavior in blennies, found a similar dominance order based on size correlation. Such a relationship is well known in the more aggressive cichlids (Frey and Miller, 1972).

Each individual fish was more or less restricted to a particular part of the tank (Fig. 20). That is, a fish will be found in a particular area (its home range) most of the time, although it may roam, on occasion, to any part of the tank. The size of the home range occupied by each fish was not related to the dominance order; that is, the most dominant fish did not necessarily have the largest home range (Fig. 20, Table 9b). For example, S4 has a much larger home range than the more dominant S2. However, S2 had several rocks in its home range. Similarly, the subordinate fish S3 and S5, although occupying small home ranges, tended to remain close to the wall or rocks. It would therefore appear that adequate cover is required for the well-being of these small benthic fishes.

The average individual distance was 5cm (43 observations). The actual distance from which one fish would come in order to charge another was frequently not recorded due to the rapidity and unexpectedness of some of the attacks. The individual distance was twice that distance observed in the field.

Courtship behavior was observed twice during the course of the experiment, with S2 courting S1 both times. Fish S2 had spent much of its time around and in a particular hole in its home range (Fig. 20), and attacked fish that approached the hole (displayed territoriality). This hole was the nest-hole that S2 led S1 up to, although S1 would not go into it. The courtship dances were essentially the same as in the field.

Intraspecific Behavior in E. zonura.

Because the *E. smaragdus* in the first experiment spent about half their time near the walls or rocks, it was concluded that there may not have been enough cover provided. Therefore two rocks were added to each side (Fig. 19b). Five adult *E. zonura* were introduced simultaneously into the centre of the tank and left for a week. The fish ranged in size from 11 to 16mm. The fish were observed seven days, with one 30-minute observation made per fish. The shorter observation time was used as the previous experiment showed that it was enough to determine dominance and each individual fish's home range. Unfortunately, the smallest, Z5, disappeared on the sixth day of observation, the day on which it was to have been recorded. From notes, it appears to have spent most of its time close to the walls on the right side of the tank, near Z2 (Fig. 21).

In Table 10a, the fish are ranked according to size. A dominance

TABLE 9. Dominance order in E. smaragdus base on

(a) size of fish, indicating number of times each fish threatens another; and

(b) dominance indices.

a.

		THREATENS				
		S1 (20mm)	S2 (17mm)	S3 (16mm)	S4 (15.5mm)	S5 (13mm)
	S1	-	1	0	0	0
F	S2	2	-	0	0	0
L E	S3	18	13	-	2	0
E S	S4	1	13	1	-	0
	S5	23	7	5	1	-

b.

	S1	S2	S4	S3	S5
Size:	20mm	17mm	15.5mm	16mm	13mm
Dominance Index:	.98	.95	.17	.15	0

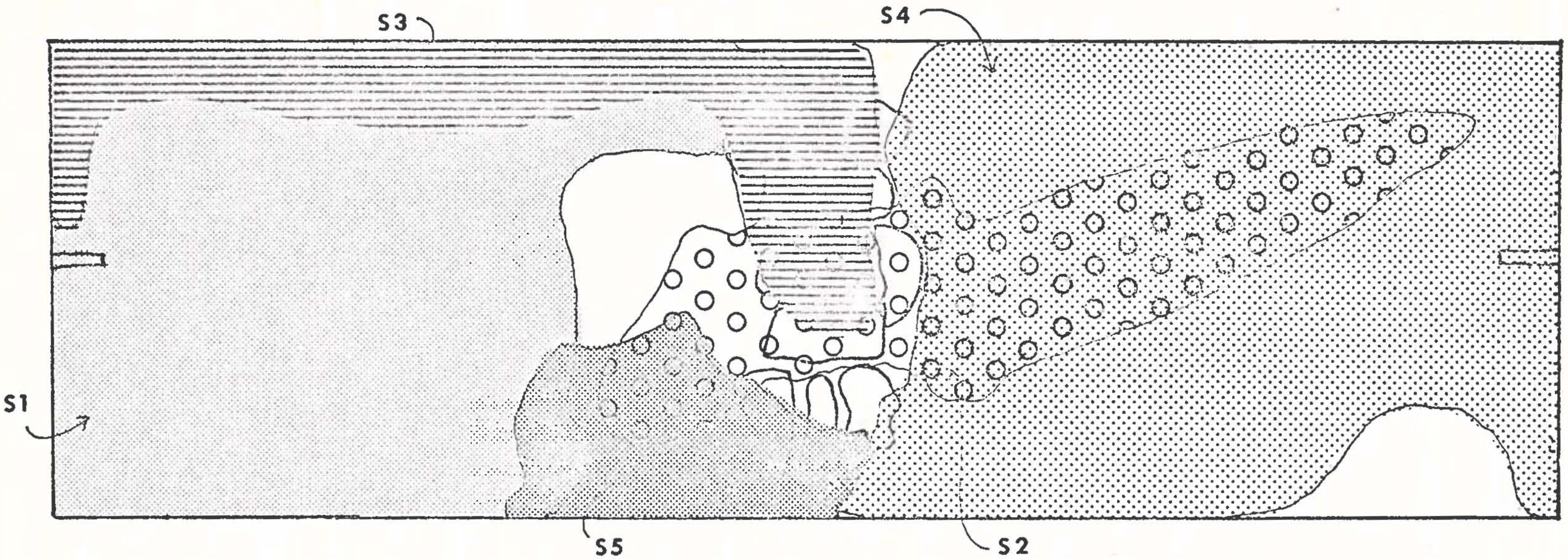

Fig. 20. Areas occupied by each E. smaragdus in first dominance order experiment "X" is nest-hole guarded by S2.

index for each fish was determined (Table 10b). Kendall's tau for this experiment was 1.0, an exact correlation of size with dominance. However, the size order (Table 10a) does not reflect this correlation because of Z4's behavior. Although smaller than Z2 and Z3, Z4 frequently moved out of its home range to attack either of the others. Three complete fights were observed, all initiated by Z4. Fish Z2 succeeded in driving off Z4, but in the two fights Z4 had with Z3, neither fish seemed to have submitted. On the other hand, Z4 was also often threatened by Z1, whose home range overlapped that of Z4. Consequently Z4 appears lower in the dominance order (Table 10b). Again the dominant fish (Z1) did not occupy the largest home range (Fig. 21). Fish Z2 and Z3 had larger ranges than did Z1. However, Z1 had access to all the rocks in the centre.

The mean individual distance in this experiment was 4cm, based on 16 observations. This distance was greater than that observed in the field (2 cm). No courtship behavior was observed during the entire experiment.

Interspecific Interactions.

The tank arrangement remained the same as in the last experiment. Three *E. smaragdus* and three *E. zonura* were introduced simultaneously into the centre of the tank and left for a week before observations began. One of the *E. smaragdus* disappeared during this time and was not replaced. One 30-minute observation per fish was made, with the exception of the largest *E. zonura*, which was inadvertently recorded twice. The fish were observed over five days.

Based on field observations, it was expected that the *E. smaragdus* would be the dominant fish. Although the *E. smaragdus* used were not large specimens of their species, they were both larger than most *E. zonura*. The number of times each fish threatens another is arranged by size (Table 11a). The *E. smaragdus* both appear dominant, although neither of them interacted much with each other. Fish Z1 and Z3 each attacked S1 when it encroached upon their home ranges (again elements of territoriality were shown). The dominance order based on dominance indices is the same as the size order (Table 11b). Fish Z2 and Z3 never interacted, making determination of true dominance difficult. Due to the nature of the dominance index, Z2 has a lower index than has Z3. This is because Z2's home range is surrounded by that of a larger, dominant fish (Fig. 22). As a result Z2 was attacked more often than was Z3 (Table 11a, b). Kendall's tau for this experiment was 1.0, again an exact correlation of size with dominance order.

Fish S1 and S2 occupied the largest home ranges (Fig. 22) and S1 had access to all of the rocks. Fishes Z1 and S2 had access to nearly all the rocks (Fig. 22). The most subordinate fish, Z3, had no rocks in its home range.

The average individual distance was 4cm (20 observations). Although still a greater distance than that seen in the field, it is similar to individual distances recorded from previous experiments. Fish S1, which attacked every fish in the tank at least once, spent much time guarding a nest-hole within its territory. This individual also courted (unsuccessfully) S2 on one occasion.

TABLE 10. Dominance order in E. zonura based on

(a) size of fish, indicating number of times each fish threatens another; and

(b) dominance indices.

a. THREATENS

FLEES		Z1 (16mm)	Z2 (14mm)	Z3 (13mm)	Z4 (12mm)	Z5 (11mm)
	Z1	-	0	0	0	0
	Z2	4	-	0	2	0
	Z3	1	3	-	6	0
	Z4	8	5	6	-	0
	Z5	0	4	1	0	-

b.

Size:	Z1 16mm	Z2 14mm	Z3 13mm	Z4 12mm	Z5 11mm
Dominance Index:	1.00	.67	.41	.30	.0

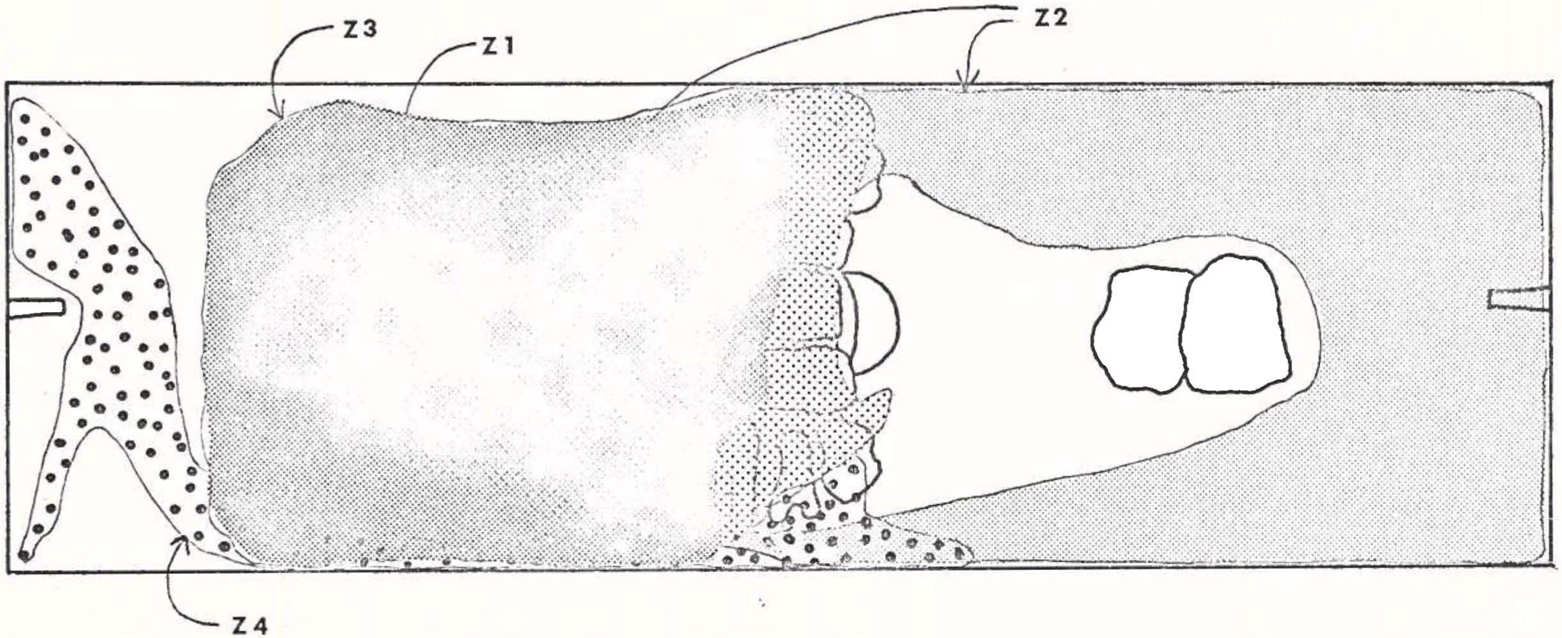

Fig. 21. Areas occupied by each E. zonura in the second dominance order experiment.

TABLE 11. Dominance order in *E. smaragdus* (second experiment) based on

(a) size of fish, indicating number of times each fish threatens another; and

(b) dominance indices.

a. THREATENS

FLEES	S1 (17mm)	S2 (17mm)	Z1 (16mm)	Z2 (14mm)	Z3 (14mm)
S1	-	0	1	0	1
S2	2	-	1	0	0
Z1	1	11	-	1	0
Z2	3	3	11	-	0
Z3	4	0	0	0	-

b.

	S1	S2	Z1	Z3	Z2
Size:	17mm	17mm	16mm	14mm	14mm
Dominance Index:	.83	.82	.50	.25	.06

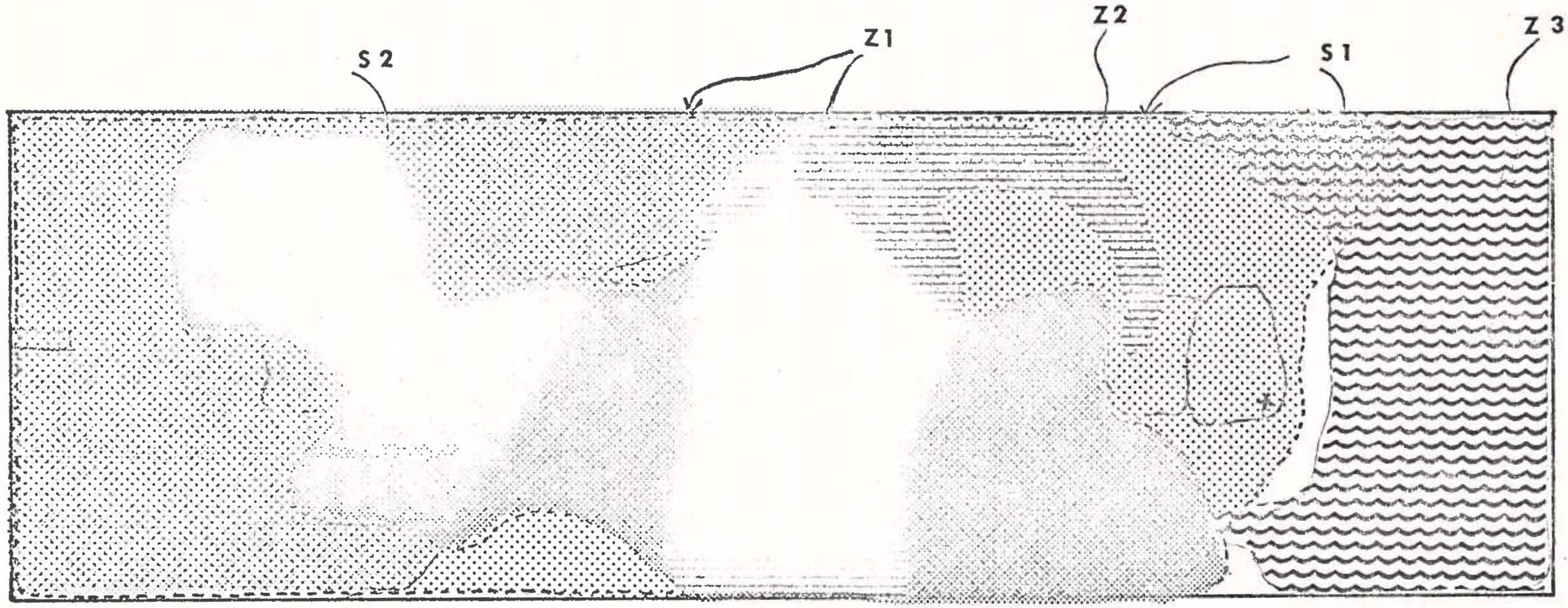

Fig. 22. Areas occupied by each fish in third dominance order experiment "X" marks position of nest-hole guarded by S1.

Summary of Experiments

The mean correlation coefficient (Kendall's tau) for all of the experiments was 0.74, indicating that size was related to the position of the fish in the dominance order. This is in agreement with field observations (Table 8). The size-dominance relationship may be important on the reef in areas of species overlap; *E. smaragdus* could theoretically be capable of "invading" *E. zonura's* preferred habitat by dominating in any agonistic encounters.

The dominant fish did not necessarily occupy the largest home range in the tank; it may have occupied a very small area. The home range of the dominant fish usually included several rocks. Subordinate fish were left to occupy areas of the tank in which only the walls or corners provided tactile security.

The size-dominance order was sometimes altered in the laboratory by fishes displaying territoriality with courtship. A fish defending a territory may drive off a larger fish (both field and laboratory observations). Most territorial fishes were guarding nest-sites (as in the field) and were presumed to be males. Territoriality during breeding ensures a suitable site for the deposition and development of eggs. Because fishes of both species will defend territories from larger fishes, the normal size dominance order may not affect competition (if any) for nest-sites. However, if good nest-sites are limited (as in the laboratory), the larger, most dominant, fishes will obtain them.

CHAPTER VII

CONCLUSIONS

Eviota zonura and *Eviota smaragdus* are sympatric reef flat dwelling gobies that often overlap in distribution. If the species are to coexist, there must be one or more differences in their ecology. Quadrat data show that *E. zonura* is most likely to be found on the cut bench or in rimmed terraced pools of windward reef flat margins while *E. smaragdus* is most likely to be found in pools of outer reef flats and in most pools on narrow reef flats. Both species may overlap at some localities. This overlap usually occurs if the cut bench intergrades into the outer reef flat, as at Taogam and Tagachan Points. Ecological competition for space, food or breeding sites may occur in such areas.

Both *Eviota* are able to withstand periodic high temperatures that they are exposed to during low tides. Field observations and laboratory experiments indicate that some individuals of each species can withstand a temperature of 38° C for up to six hours while both species are killed within two hours at 40° C (a temperature which may be recorded on cut benches and parts of outer flats during days of low tides and calm seas).

Eviota are also tolerant of reduced salinity caused usually by seepage from the fresh water lens system of the island. *E. smaragdus* is more often found in areas of low salinity (inner reef flat) and may be more tolerant of low salinity than is *E. zonura*. Both species are able to survive seven days in the laboratory at a salinity of 4‰.

At lower salinities, more _E. smaragdus_ individuals survive, than do _E. zonura_. It is unlikely that either species would ever be exposed to 4‰ or less in the field.

Eviota feed chiefly on small benthic crustaceans. There are some habitat related differences in the amount of several prey items, such as midge larvae and ostracods, consumed by each species. There are large numbers of all food items dwelling in the algal turf of the reef flat, so that there can be little interspecific competition for food. Competition from other small benthic reef flat fishes is limited.

Ripe females of both species apparently are present all year round. There may have been a disturbance in the breeding cycle caused by the phenomenally low tides of 1972. This possibility makes it difficult to determine with certainty that the two species have their breeding peak at different times of the year. It appears that there are more ripe _E. zonura_ females from June to August than at any other time of year, and more ripe _E. smaragdus_ females from November to January. If this is the usual cycle, it would be an effective way of reducing competition in reef areas of species overlap. Further work needs to be done on the breeding cycles of most tropical reef fishes.

The possibility of ecologically important differences in behavior led to the compilation of an ethogram for both species. Agonistic and courtship action patterns of both species are quite similar. _E. smaragdus_, in agonistic display, has two action patterns which are not performed by _E. zonura_ at all, and one action pattern which is also performed by both species during courtship. *E. smaragdus* performs several actions during courtship which are also agonistic action patterns used by both species. Intra- and interspecific fighting was observed for both species. All interspecific fights were observed at Taogam Point, where species overlap is very great. Although the displays before each fight are ritualized, the actual conflict results in damage to both antagonists (which is not typical of many other fish). The dominant fish in aggressive encounters is determined mainly by size (this was observed in the field and verified in the laboratory). This is important in areas of species overlap, because *E. smaragdus* is a larger fish than *E. zonura*.

Territoriality may be an effective way of spacing aggressive fishes. However, like many other gobies and blennies, territoriality is displayed by *Eviota* only by males guarding nest sites (in the field). A territorial fish will attack an intruder larger than itself. Fish displaying courtship behavior in the laboratory showed strong territoriality (as in the field).

REFERENCES

Breder, C. M. and D. E. Rosen. 1966. Modes of reproduction in fishes. Am. Mus. Nat. Hist. Press.

Emery, K. O. 1962. Marine geology of Guam. U.S. Geol. Survey Prof. Paper 403B., Dept. Interior.

Frey, D. F. and R. J. Miller. 1972. The establishment of dominance relationships in the Blue Gourami, Trichogaster trichopterus (Pallas). Behavior 42: Parts 1 and 2.

Gibson, R. N. 1968. The agonistic behavior of juvenile Blennius pholis L. (Teleostei). Behavior 30: 192-217.

Gosline, W. A. 1955. The osteology and relationships of certain gobioid fishes, with particular reference to the genera Kraemeria and Microdesmus. Pac. Sci. 9 (April).

______________. 1965. Vertical zonation of inshore fishes in the upper water layers of the Hawaiian Islands. Ecology 46 (6) : 823-831.

Hoese, H. D. 1966. Habitat segregation in aquaria between two sympatric species of Gobiosoma. Pub. Inst. Mar. Sci. (Univ. Texas) 11: 7-11.

Jones, R. S. 1968. Ecological relationships in Hawaiian and Johnston Island Acanthuridae (Surgeonfishes). Micronesica 4.

Jones, R. S. and R. H. Randall. 1973. A study of biological impact caused by natural and man-induced changes on a tropical reef. Interim Report, Contract No. 18080 EUK.

Jordan, D. S. and A. Seale. 1905. The fishes of Samoa. Bull. U.S. Fish. 25: 386-389.

Klopfer, F. H. 1969. Habitats and territories. Basic Books Inc. New York.

Lorenz, K. 1963. On aggression. Harcourt, Brace and World, Inc. New York, pp. 15-22.

Low, R. M. 1971. Interspecific territoriality in a pomacentrid reef fish Pomacentrus flavicauda Whitley. Ecology 52: 648-654.

Randall, J. E. 1967. Food habits of reeffishes of the West Indies. Stud. Trop. Ocean. 5.

Siegel, S. 1956. Nonparametric statistics for the behavioral sciences. McGraw-Hill Book Co., New York.

Springer, V. C. and A. J. McErlean. 1961. Spawning seasons and growth of the code goby, Gobiosoma robustum (Pisces: Gobiidae), in the Tampa Bay area. Tulane Studies in Zool. 9 (2).

Stephens, J. S. Jr., R. K. Johnson, G. S. Key and J. E. McCosker. 1970. The comparative ecology of three sympatric species of California blennies of the genus Hypsoblennius Gill (Teleostomi, Blenniidae). Ecol. Monog. 40 (2): 213-233.

Strasburg, D. S. 1953. Comparative ecology of two salariine blennies. Ph. D. dissertation. Univ. Hawaii.

Tavolga, W. N. 1954. Reproductive behavior in the gobiid fish, Bathygobius soporator. Bull. Amer. Nat. Hist. 104 (5): 427-460.

__________. 1955. Ovarian fluids as stimulus to courtship behavior in the gobiid fish, Bathygobius soporator. (C. and V.) Anat. Rec. Philad. 122 (3).

Tracey, J. I. Jr., S. Q. Schlanger, J. T. Stark, D. B. Doan and H. G. May. 1964. General geology of Guam. U. S. Geol. Surv. Prof. Paper 403A. Dept. Interior.

Tyler, J. C. 1971. Habitat preferences of the fishes that dwell in shrub corals on the Great Barrier Reef. Acad. Nat. Sci. Philad. 123 (1).

Valenti, R. J. 1972. The embryology of the neon goby, Gobiosoma oceanops. Copeia 3.

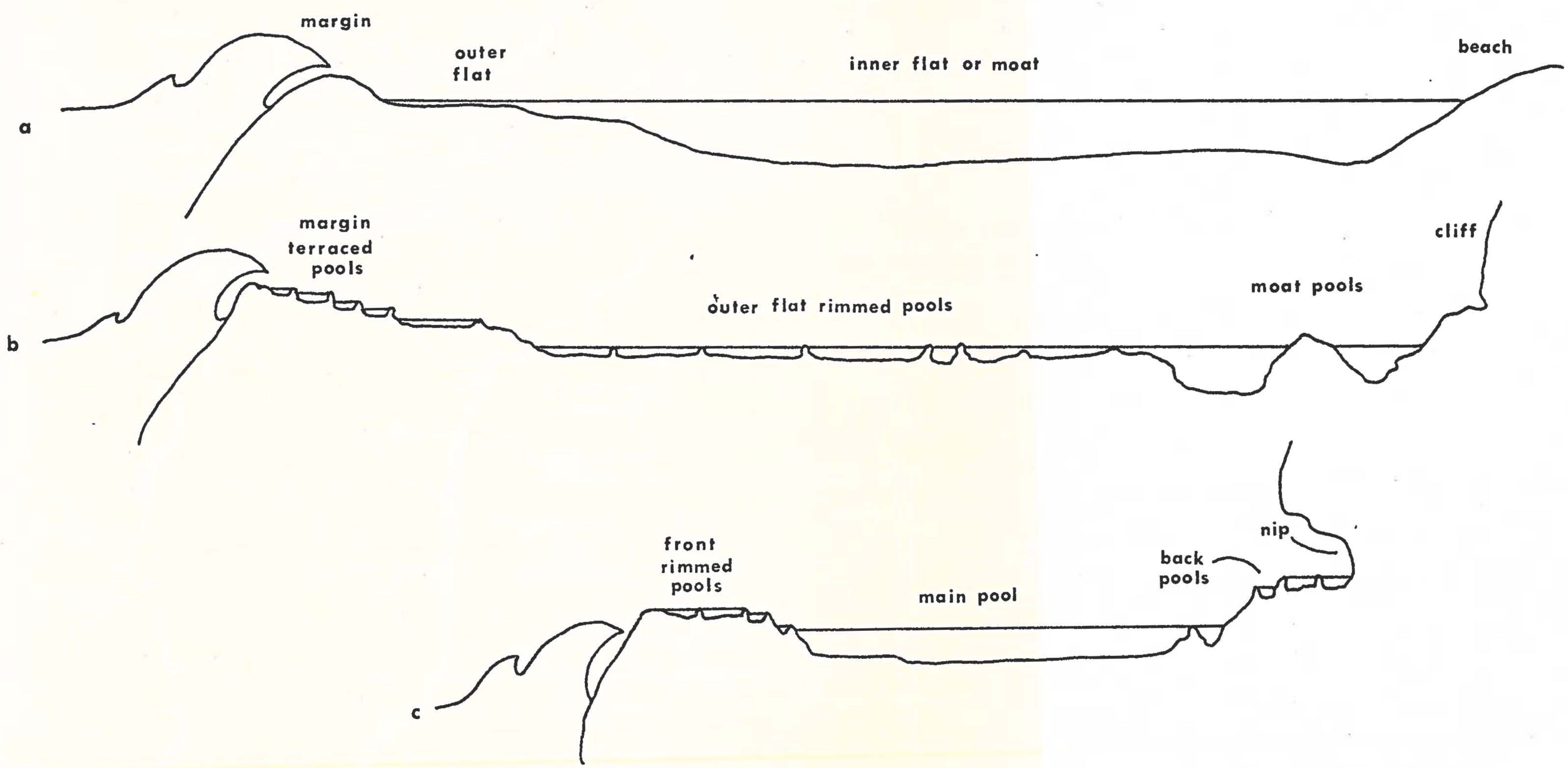

Table 3. Diagram of Eviota habitats
a. Typical moat-dominated reef flat platform at mean low tide.
b. Reef flat platform of the type on which Eviota may be found, at mean low tide.
c. Cut bench (note height above sea-level), at mean low

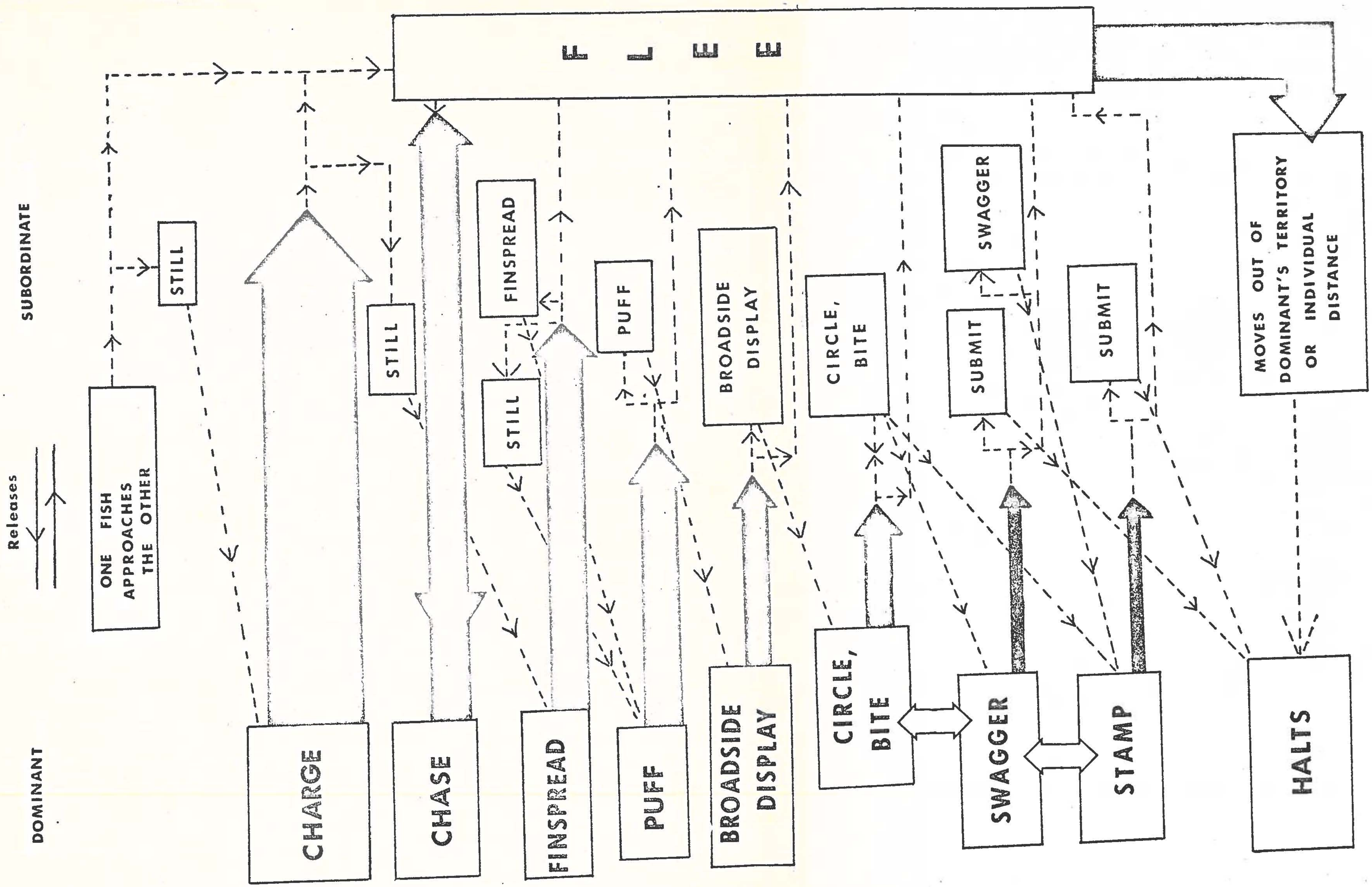

Fig. 16. Sequence of performance of agonistic action patterns for E. zonura. Width of black arrow indicates relative frequency of performance of each action. Dotted lines not based on actual frequency data. White arrows between boxes indicates fish has a choice

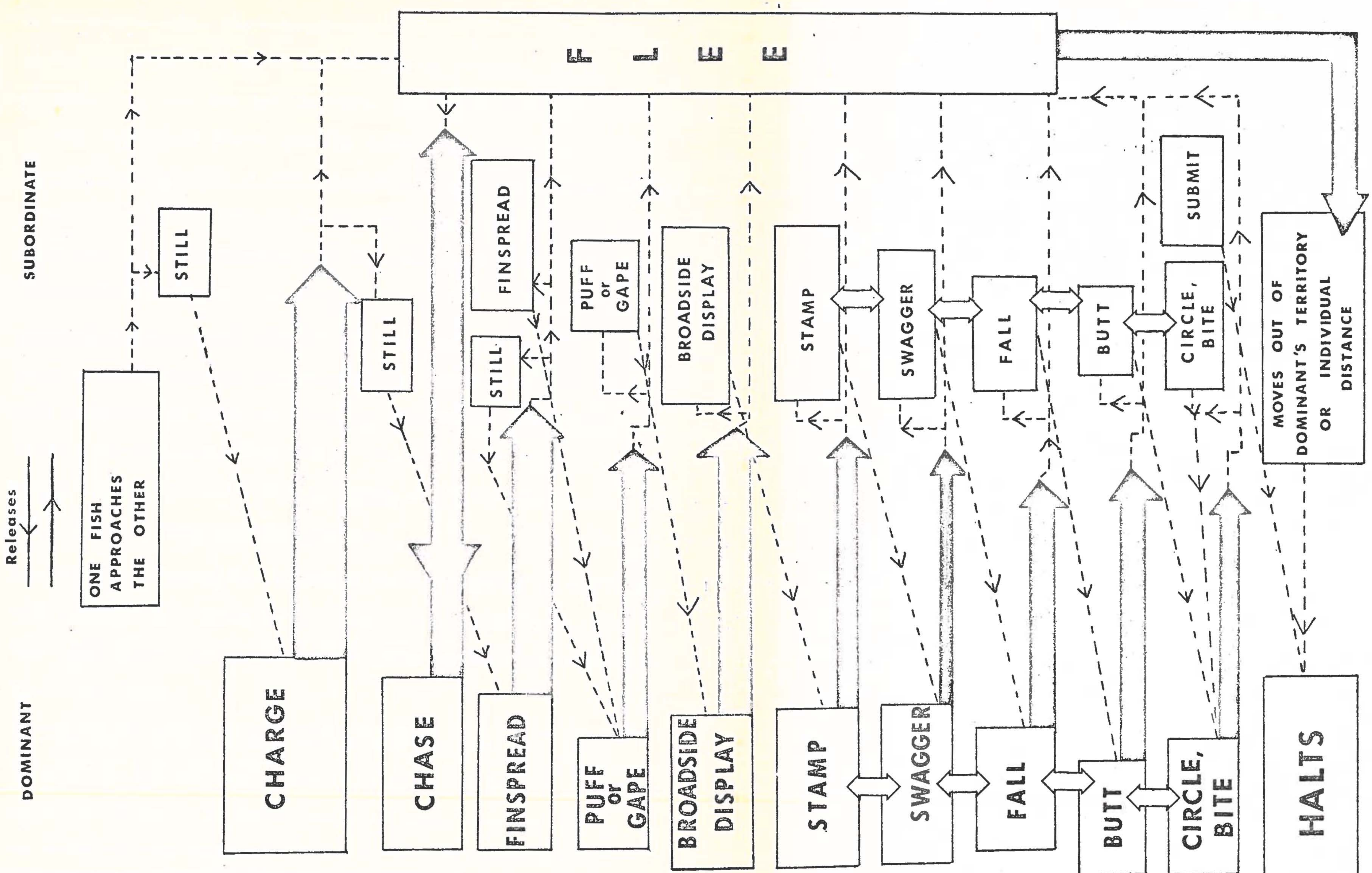

Fig. 17. Sequence of performance of agonistic action patterns for E. smaragdus. Width of black arrow indicates relative frequency of performance of each action. Dotted lines not based on actual frequency data. White arrows between boxes indicates fish has a choice of performing either action.