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POTENTIAL FISHERIES YIELD OF A MOOREA FRINGING REEF (FRENCH POLYNESIA) BY THE ANALYSIS OF THREE DOMINANT FISHES

BY

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RESUME

La connaissance du stock exploitable est une donnée indispensable pour toute gestion rationnelle du milieu. Dans les 110 pays possédant des récifs coralliens, les poissons récifaux occupent une place importante dans l'économie de subsistance et de marché local. De récentes estimations font état d'un potentiel de pêche commercialisable dans l'avenir de l'ordre de 6 millions de tonnes (1/10 des pêcheries mondiales), dont seulement 5% seraient actuellement exploités.

Tout polynésien étant un pêcheur qui apporte à sa famille, avec le poisson, une part importante des proteines animales dans l'alimentation; il est très difficile, en Polynésie française, d'obtenir des données fiables sur les statistiques de pêche et donc du stock exploitable. Dans ce travail nous donnons une approximation de ce rendement de pêche prévisionnel pour un récif frangeant de l'île de Moorea, en étudiant la Dynamique des Populations (biologie, reproduction, stock, croissance, biomasse et production) de trois espèces dominantes du lagon de Moorea. Si cette approche s'avère exacte, elle devrait constituer la méthode la plus simple pour estimer les productions ichtyologiques dans les récifs coralliens soumis à des pêcheries de subsistance et d'exploitation commerciale.

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ECOLE PRATIQUE DES HAUTES ETUDES- LABORATOIRE DE BIOLOGIE MARINE ET MALACOLOGIE- 55 RUE DE BUFFON- 75005 PARIS.

and

ANTENNE MUSEUM/EPHE- CENTRE DE L'ENVIRONNEMENT DE MOOREA- BP 1013 MOOREA- POLYNESIE FRANCAISE.

INTRODUCTION

Recent studies have shown that many coral reefs are capable of yielding a total fish catch of 18- 24 $T.Km^{-2}$ (Hill, 1978; Alcala, 1981; Munro, 1987). There are, however, no estimates for the productivity and yield of fishes associated with coral reefs in French Polynesia. This study was designed to determine the fisheries yield from a part of the fringing reef on the island of Moorea, French Polynesia.

This area, however, has a different assemblage of fishes compared to some of the other reefs that have been studied. There are fewer species in French Polynesia due to its isolation in the eastern part of the Indo-Pacific province, and moreover, the assemblage of fishes is dominated by relatively few species (Galzin, 1986a).

In this paper, I have assumed that it may be possible to estimate the biomass and productivity of whole groups of fishes by studying the population dynamics of the dominant species. Because most fish in Polynesia fall into 3 groups viz. herbivores, omnivores and carnivores, I only collected data on three species. They are: 1/ The herbivore Ctenochaetus striatus (Quoy et Gaimard, 1824) "**Maito**". It is common throughout the Indo-Pacific (Springer, 1982), and is the most abundant species of surgeonfish in the lagoons of high islands in French Polynesia (Galzin, 1985). It is not a commercially important species, however, because it is sometimes ciguatoxic. 2/ The omnivore Stegastes nigricans (Lacepède, 1803) "**Atoti**". In French Polynesia, this species does not occur on the outer slope at depths greater than 3m, but it is extremely abundant in all the fringing reefs. **Atoti** is a pugnacious territory holder (Allen, 1975). One of its favorite habitats is dead coral colonized by filamentous algae. 3/ The carnivore Sargocentron microstoma Günther, 1859 "**Araoe**". It is the most abundant of the large nocturnally active fishes in the lagoon of Moorea island.

In this paper I present data on the biology, biomass and growth of these three species. These data are then analyzed to provide an estimate of the productivity of these fishes and, of the fisheries yield from one part of the reef of Moorea island.

MATERIAL AND METHODS

Area and duration of study. This study was carried out on the northwestern part of Moorea Island, 17°30'S; 149°50'W (Fig.1). Further details of this area are given in Galzin and Pointier (1985). All samples were collected between August 1982 and October 1983.

For the feeding habit study of Ctenochaetus striatus and Stegastes nigricans every two hours and for 24 hours, 10 fishes were collected in a neighbouring fringing reef. An emptiness index (number of empty stomachs . 100 number of examined fishes $^{-1}$) gives some indications on the daily rythm of feeding. The Sargocentron microstoma stomach contents were only analyzed with fish captured by rotenone. The occurence index (f) is the percentage of fishes containing a special kind of prey on the number of fishes with full stomachs. Numerical percentages and percentages by weight of each prey were calculated.

The **reproduction** of these 3 fish was only studied by diving observations of the behavior and by the analysis of the monthly change of the Gonadosomatic index (GSI = Weight of the gonad . 100 weight of the fish $^{-1}$). The 1298 Ctenochaetus striatus, 1270 Stegastes nigricans and 202 Sargocentron microstoma, examined were captured by rotenone every month during 15 months.

The **total number, the biomass** and the behavior of these 3 species are different. So, in order to study the population dynamics of each species, different procedures were used. For Ctenochaetus striatus the accuracy of the diving counts (Harmelin-Vivien et al.,1985) was good enough to use this sampling method for the stock study. The biomass was calculated by multiplying the number of individuals counted by the mean weight obtained after a monthly rotenone sampling on a neighbouring reef. Stegastes nigricans is very difficult to count while diving, so three different methods were used (Galzin, 1985): a direct evaluation by diving counts and two indirect evaluations by rotenone sampling with tagging (Bailey, 1951; Schumacher et Eschmeyer, 1943) and without tagging (De Lury, 1947). Sargocentron microstoma was the least abundant of these 3 species in the fringing reef. In this case, only the monthly rotenone sampling data collected in the neighbouring fringing reef of Papetoai was studied.

The **growth** of these fish was studied with Petersen's method (1896). In 1982, Pauly justified the possibility of using this method in the case of small tropical fish. Different growth models were adjusted to the data of length frequency (linear, logarithm, power, exponential, Von Bertalanffy and Gompertz). The growth curve adopted was that of the minimum Sum of Square Deviation (SSD) between the experimental and calculated points. I estimated the duration of larval life by measuring the laps of time between the greatest spawning episode and the first settlement of postlarvae. In doing so, I assumed that larvae originating from spawnings at Moorea ended up by settling there or that major spawning episodes occured elsewhere in french Polynesia at the same time.

To obtain an evaluation of the **biological productivity** of each population the equations of Ricker (1946) and Allen (1950) were used:

$$P = g \bar{B}$$

with P = Biological production
g = Instant growth coefficient
$\bar{B}$ = Mean biomass between 2 lengths

RESULTS AND DISCUSSION

FEEDING HABITS

Maito are diurnal feeders (Fig.2). Others features of their feeding habits are: 1/ It empties its stomach in less than two hours and its intestine in less than four hours. 2/ It stays at the foot of patchreefs at night but wakes up at 5 a.m. and begins feeding at 7 a.m.. Between 5 a.m. and 7 a.m. individuals establish a feeding territory. 3/ 80% of stomach contents were inorganic materials ingested incidentally during feeding. This material is redistributed on the reef while the fish swims. 4/ 20% of stomach contents were organic materials. 70% of this was represented by diatoms and unidentified organic matter, 29% were cyanophycae (Calothrix and Lyngbia) and only 1% were macroalgae.

Stegastes nigricans was also diurnally active, with two feeding periods each day: 10 a.m. to noon and 4 p.m. to 6 p.m. **Atoti** were omnivorous with a high tendency to being herbivorous (Table 1). Payri (1982) has found that the algal turf protected by Stegastes nigricans is composed of three parts. 1/ Filaments of colonial blue-green algae (Nodularia, Lyngbia, Mycrosystis) and microphytobenthos (< 5mm). 2/ Brown algae (Sphacelaria, Ectocarpus, Giffordia) and red algae (Wurdemania, Herposiphonia, Jania) (5-10mm) and 3/ Ceramiales (Polysiphonia and Lophosiphonia (10-25mm). However, only parts 2 and 3 are activilly eaten (Lobel 1980, Payri 1982).

Araoe is a carnivore that is most active between 5 p.m. and 7 p.m. Crustaceans, mainly Chlorodiella barbata represented 75% of the stomach contents (Table 2). With increasing age, the fish eats a decreasing number of amphipods and isopods.

REPRODUCTION

There is no sexual dimorphism in the external morphology of **Maito**. Spawning of this species was observed and described by Randall (1961), Bagnis (1970) and Robertson (1983). I observed spawning on the innerslope of the barrier reef in Moorea in October 1982, one day after the full moon, at noon. Together with data on the gonadosomic index (Fig. 3), I concluded that at Moorea during 1982, this species was mature between October and February with an intense spawning period during November- December. The new body fat associated with the gonads (Fishelson & al., 1985) was found in all of the 1 745 fish examined.

Sexual dimorphism is also absent in Stegastes nigricans. Sexual maturity occured between October and April with two long spawning seasons at the beginning, and at the end, of this period (Fig. 3). Yamamoto (1979) found that sexual maturity of **Atoti** in the Ryukyus Islands was obtained at an age of two. Stegastes nigricans spawns in couples, the eggs are demersal.

There is little information about reproduction in Holocentridae (Thresher, 1986). The data on GSI show that Sargocentron microstoma spawns from December to January (Fig. 3). This spawning season (ie summer) seems to be the same for the Holocentridae in the Caribbean (Munro et al., 1973; Wyatt, 1976).

STOCK AND BIOMASS

A mean biomass of 25g.m^{-2} for Ctenochaetus striatus was found during spring and summer (from September to March) and a mean biomass of 15 g.m^{-2} from April to August, except in June (Table 3). It should be noted, however, that the biomass of this species is not expected to be constant across microhabitats within the lagoon at Moorea. **Maito** change locations on the reef at different stages of its development. Small fish are found close to the beach and then mean length increases towards the reef (Galzin, 1985). Moreover **Maito** are always more abundant, but have a lower mean weight on the fringing reef than on the barrier reef.

The mean biomass obtained with the three methods that were used to census the Stegastes nigricans, varied between 58 and 97 g.m^{-2} (Table 4). The lowest biomass was obtained by diving counts. This can be explained by the difficulty I had in counting the juveniles holding inside coral formations. Biomass of this species was greatest at the edge of the fringing reef adjacent to the channel. In this area, I counted a mean of 12 individuals.m^{-2} with a maximum of biomass of 151 g.m^{-2}. Is seems that the population of Stegastes nigricans is relatively stable. Between 1976 and 1983, there were no significant changes in the abundance of this species on the fringing reef (Galzin, 1986b).

For Sargocentron microstoma, the nocturnal species, maximum abundance (0.16 ind.m^{-2}) was found on the barrier reef at dusk (6 p.m.). During the 15 months, the mean biomass was 3.5 g.m^{-2} with a range between 0.9 and 9.5 g.m^{-2}. The maximum density and biomass was found during winter (April to August).

GROWTH AND BIOLOGICAL PRODUCTIVITY

The major spawning episode of **Maito** was recorded on the 18th of October 1982 inside the channel of Tiahura. The first juveniles (total length of 35 mm) were seen on 26th December 1982. This gives a larval life of 70 days which is quite similar to that of 75 days for Acanthurus triostegus (Randall, 1961) and 84 days for the Naso of the Great Barrier Reef (Brothers & al., 1983). The best growth curves (SSD = 0.63) were obtained with the Von Bertalanffy equation (Figure 4, Table 5). Biological productivity was calculated from the rotenone sampling data obtained during the year. The mean productivity for Ctenochaetus striatus in the fringing reef of Moorea was estimated to be 16.1 g.m^{-2}. year^{-1}, range 8 - 32 g.m^{-2}.year^{-1}(Table 5).

The two spawning periods gave rise to two main periods of larval settlement for **Atoti**. The same observation was made by Yamamoto (1979) in Japan. The best growth curves (SSD = 0.52) was obtained with the Gompertz equation (Figure 4, Table 5). Juvenile Stegastes nigricans settled on the fringing reef of Moorea one month after spawning. The first spawning took place in April with settlement of juveniles in May, and the second spawning occured in October with settlement of juveniles in November. My observations are in line with those of Brothers & al. (1983). They found that 14 pomacentrids from the Great Barrier Reef had larval lives of between 21 and 24 days. The mean biological productivity observed for this species was 55.6 $g.m^{-2}.year^{-1}$ (Table 5).

The present observations indicate that **Araoe** has a larval life of 60 days with spawning in December and settlement of juveniles in February at a minimum size of 25 mm. The best growth curves (SSD = 0.54) were obtained with the Von Bertalanffy equation (Figure 4, Table 5). The mean biological productivity of Sargocentron microstoma was estimated to be 2.6 $g.m^{-2}.year^{-1}$(Table 5).

FISHERIES YIELD

The three species that were studied made up 64% of the total number of fishes and 74% of total fish biomass on the fringing reef (Galzin, 1985). Together, these 3 species have a biological productivity of 74 $g.m^{-2}$ $year^{-1}$ and a biomass of 103 $g.m^{-2}$. A simple extrapolation gives a biomass for the total fish community of 140 $g.m^{-2}$.

This biomass is similar to that found in other coral reef areas (Table 6). For example Goldman & Talbot (1976) thought that 200 $g.m^{-2}$ was the maximum biomass that a coral reef could produce. Biomass from natural coral reefs, however, are lower than those from artificial reefs, which can reach 1 500 to 1 700 $g.m^{-2}$ (Russel, 1975; Randall, 1963).

Using the empirical equation given by Gulland (1983) I estimated the maximum sustainable fisheries yield for the fringing reef of Moorea as:

$$Y_{MAX} = X\,(Y + M\bar{B})$$ Gulland, 1983

with:

Y_{MAX}	= Greatest possible yield	Gulland, 1983
X	= Arbitrary factor set at 0.3	Gulland, 1983
Y	= Current annual catch = 10 $T.km^{-2}$	Munro, 1987
$\bar{B}$	= Mean biomass	

with also:

F	= Fishing mortality = $Y/\bar{B}$	Munro, 1987
Z	= Total mortality = $M + F = P/\bar{B}$	Munro, 1987
P	= Biological production	

with my data:

$$Z = P/\bar{B} = 74.2/103.4 = 0.72$$
$$F = Y/\bar{B} = 10/103.4 = 0.09$$
$$M = Z - F = 0.72 - 0.09 = 0.63$$

then:

$$Y_{MAX} = 0.3\ (10 + (0.63 \times 103.4)) = 23$$

$$Y_{MAX} = 23\ T.km^{-2}.year^{-1}$$

$$Y_{MAX} = 23\ g.m^{-2}.year^{-1}$$

This result is in agreement with those obtained from other coral reefs in the Indo-Pacific province (Table 7).

CONCLUSION

I have demonstrated in this paper that the estimated yield of fishes from a fringing reef in French Polynesia, based on the population dynamics of three dominant species, is similar to that recorded from other coral reefs. This estimate of 23 $T.Km^{-2}.year^{-1}$ is likely to be lower than the actual value, however, because it is based on the biological production of species that constituted only 74% of total biomass. Further research is needed to confirm that estimates of total yield based on dominant species represent the actual yield. This will be hard to achieve in French Polynesia because most Tahitians fish in a subsistance manner and so collection of fisheries statistics is impractical. The only place where it may be practical to make such a comparison is Tikehau Atoll. There, the total catch from the atoll is marketed in Papeete. I encourage verification of my method at the earliest opportunity because, if it proves reliable, it may be the simplest way to estimate the fisheries production of coral reefs subject to subsistence and artesenal fisheries.

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TABLE 1 : Qualitative study of the stomach contents of *Stegastes nigricans*.

	8 Hours			10 Hours			18 Hours			TOTAL		
	Weight of prey $mg.10^{-1}$	Weight %	f	Weight of prey $mg.10^{-1}$	Weight %	f	Weight of prey $mg.10^{-1}$	Weight %	f	Weight of prey $mg.10^{-1}$	Weight %	f
Algae	799	54.1	80%	1124	44.8	90%	300	59.8	100%	2223	49.5	90%
Sponges				60	2.4	10%	29	5.8	10%	89	2	7%
Polychaeta	97	6.6	50%	66	2.6	20%	131	26.1	10%	294	6.5	27%
Sipuncula	30	2.0	20%							30	0.7	7%
Brachyura	550	37.3	60%	533	21.2	50%	19	3.8	10%	1102	24.6	40%
Galatheidae				19	0.8	10%				19	0.4	3%
Harpactacoida				2	0.1	20%				2	0.1	7%
Gasteropoda				106	4.2	10%				106	2.4	3%
Fish eggs				600	23.9	20%				600	13.4	7%
Others							23	4.6	10%	23	0.5	3%
Total	**1476**			**2510**			**502**			**4488**		

TABLE 2 : Qualitative study of the stomach contents of *Sargocentron microstoma* fished on the northwestern fringing reef of Moorea island.

	Number of stomachs with prey	f	Number of prey	Number %	Weight of prey (g)	Weight %
Algae	12	10.6			0.127	0.4
Polychaeta	10	8.8	10	1.6	0.274	0.9
Sipuncula	5	4.4	5	0.8	0.025	0.1
Gasteropoda	23	20.4	32	5.2	0.639	2.0
Opisthobranchs	37	32.7	39	6.4	1.041	3.3
Polyplacophora	30	26.5	37	6.0	1.635	5.2
Stomatopoda	1	0.9	1	0.2	0.062	0.2
Isopoda	5	4.4	7	1.1	0.017	0.1
Amphipoda	15	13.3	25	4.1	0.025	0.1
Shrimps	20	17.7	26	4.2	0.495	1.6
Alphaeidae	18	15.9	22	3.6	4.036	12.9
Paguridae	15	13.3	27	4.4	0.524	1.7
Galatheidae	35	31.0	57	9.3	1.382	4.4
Brachyura	104	92.0	308	50.2	17.535	56.2
Fish	14	12.4	17	2.8	3.192	10.2
Others	1	0.9			0.178	0.6
Total			613		31.187	

TABLE 3 : Mean weight, abundance and biomass of <u>Ctenochaetus striatus</u> inside a 100 m^2 quadrat of the fringing reef of Tiahura at Moorea.

	1982					1983						
Fringing reef	AUG. 08	SEPT. 09	OCT. 10	NOV. 11	DEC. 12	JAN. 01	FEV. 02	MARCH 03	APRIL 04	MAY 05	JUNE 06	JULY 07
Mean Weight	26.5	66.55	51.83	57.04	52.09	56.11	42.99	73.07	30.04	37.17	61.59	32.87
Number of fish measured	42	82	34	34	49	52	133	54	75	37	15	23
Number of fish counted	53	40	46	49	46	50	47	46	47	47	54	48
Biomass ($g.m^{-2}$)	14.05	26.62	23.84	27.95	23.96	28.05	20.21	33.61	14.12	17.47	33.26	15.78

TABLE 4 : Four different ways of estimating the biomass of Stegastes nigricans in the fringing reef of Moorea.

		Time period	Reef area	Sampled area in m^2	Method	Number of Atoti	Number of $Atoti.m^{-2}$	Biomass ($g.m^{-2}$)
Direct estimation	Diving observation	From August 82 to July 1983	Edge of the fringing reef near the channel at 240 m from the beach	100	Diving Counts	93<120<138	1.2	34.5<58<76.4
Indirect estimation	With tagging	From August to September 1975		550	BAILEY (1951)	1856<4122<6389	7.5	43.9<97<151.0
		March 1976	Middle of the fringing reef at 170 m from the beach	40	SCHUMACHER et ESCHMEYER (1943)	130<223<777	5.6	38.7<66<231.3
		June 1976		40		61<175<199	4.4	29.0<83<94.8
		July 1976		20		37<47<65	2.4	56.0<71<98.4
	Without tagging	July 1983		70	DE LURY (1947)	144	2.1	83

	Ctenochaetus striatus (Quoy et Gaimard, 1824)	Stegastes nigricans (Lacepède, 1803)	Sargocentron microstoma Günther, 1859	TOTAL FOR THE 3 SPECIES
Tahitian name	Maito	Atoti	Araoe	
Feeding habits	Diurnal herbivore (grazer) 3.15g dry food day^{-1}	Diurnal omnivore 0.39g dry food day^{-1}	Nocturnal carnivore	
Gonad development	5 months from October to February	7 months from October to April	6 months from October to March	
Spawning peaks	One in November-December	Two in October and April	One in December-January	
Eggs	Planctonic	Demersal	Benthic	
Length range of fish in mm	42 to 246	10 to 156	63 to 183	
Weight range of fish in g	1.12 to 257.79	0.02 to 97.07	3.6 to 84.7	
Length-weight relation ship	$W = 0.0111\ L^{3.10}$	$W = 0.0195\ L^{3.07}$	$W = 0.0129\ L^{3.01}$	
Growth equation (cm)	$L_t = 61.95\left[1-e^{-0.0065(t+9.17)}\right]$	$L_t = 17.54 . 0.07^{0.93^{(t+0.5)}}$	$L_t = 37.28\left[1-e^{-0.0085(t+19.86)}\right]$	
Growth equation (g)	$W_t = 3986.6\left[1-e^{0.0065(t+9.17)}\right]^{3.1}$	$W_t = 128.89\ 0.07^{3.07\ 0.93^{(t+0.5)}}$	$W_t = 692.94\left[1-e^{-0.0085(t+19.86)}\right]^{3.01}$	
Minimum longevity	6 years	4 years	5 years	
% total number of individuals	18.0%	45.7%	0.3%	64.0%
% total fish biomass	9.3%	63.1%	1.8%	74.0%
Mean biomass (B) in $g.m^{-2}$	23.2	76.7	3.5	103.4
Biomass range in $g.m^{-2}$	14.0 to 33.6	29.0 to 231.3	0.7 to 14.2	43.7 to 279.1
Biological production (P) in $g.m^{-2}.year^{-1}$	16.1	55.6	2.6	74.2
Production range in $g.m^{-2}.year^{-1}$	8.2 to 32.0	21.0 to 167.0	1.6 to 28.5	30.8 to 227.5
P/B	0.69	0.72	0.74	

TABLE 5 - Summary of the principal results obtained on the population dynamic and the biology of three dominant fish of the northwestern fringing reef of Moorea island.

TABLE 6 : Ichtyological biomass obtained in different coral reef areas.

AUTHORS	COUNTRY	METHOD	REEF AREA	WET BIOMASS ($g.m^{-2}$)
BROCK (1954)	HAWAII	DIVING COUNTS	FRINGING REEF	4<185<211
ODUM & ODUM (1955)	ENEWETAK Atoll	DIVING COUNTS and ROTENONE STATIONS	REEF FLAT	1<42<200
BARDACH (1959)	BERMUDA	DIVING COUNTS	PATCH REEF	49
CLARK & al. (1962)	RED SEA	DIVING COUNTS and ROTENONE STATIONS	FRINGING REEF	35
RANDALL (1963)	VIRGIN ISLANDS	ROTENONE STATIONS	FRINGING REEF	16
TALBOT & GOLDMAN (1972)	ONE TREE ISLAND (GBR)	EXPLOSIVES	OUTER REEF	43< <390
GOLDMAN & TALBOT (1976)	ONE TREE ISLAND (GBR)	DIVING COUNTS and EXPLOSIVES	OUTER REEF	17<87<195
GALZIN (1985)	MOOREA FRENCH POLYNESIA	DIVING COUNTS TAGGING ROTENONE STATIONS	FRINGING REEF	59<140<377

TABLE 7 : Coastal tropical water fisheries yield in the Indo-Pacific area.

AUTHORS	COUNTRY, AREA	RESULTS ($T.Km^{-2}.year^{-1}$)	METHOD
HILL (1978)	COASTAL FISHERIES SAMOA	18	FISHERIES STATISTICS
ALCALA (1981)	CORAL REEFS PHILIPPINES	24	FISHERIES STATISTICS
MUNRO (1985)	CORAL REEFS AMERICAN SAMOA	20	FISHERIES STATISTICS
GALZIN (1985)	CORAL REEFS FRENCH POLYNESIA	23	POPULATION DYNAMICS

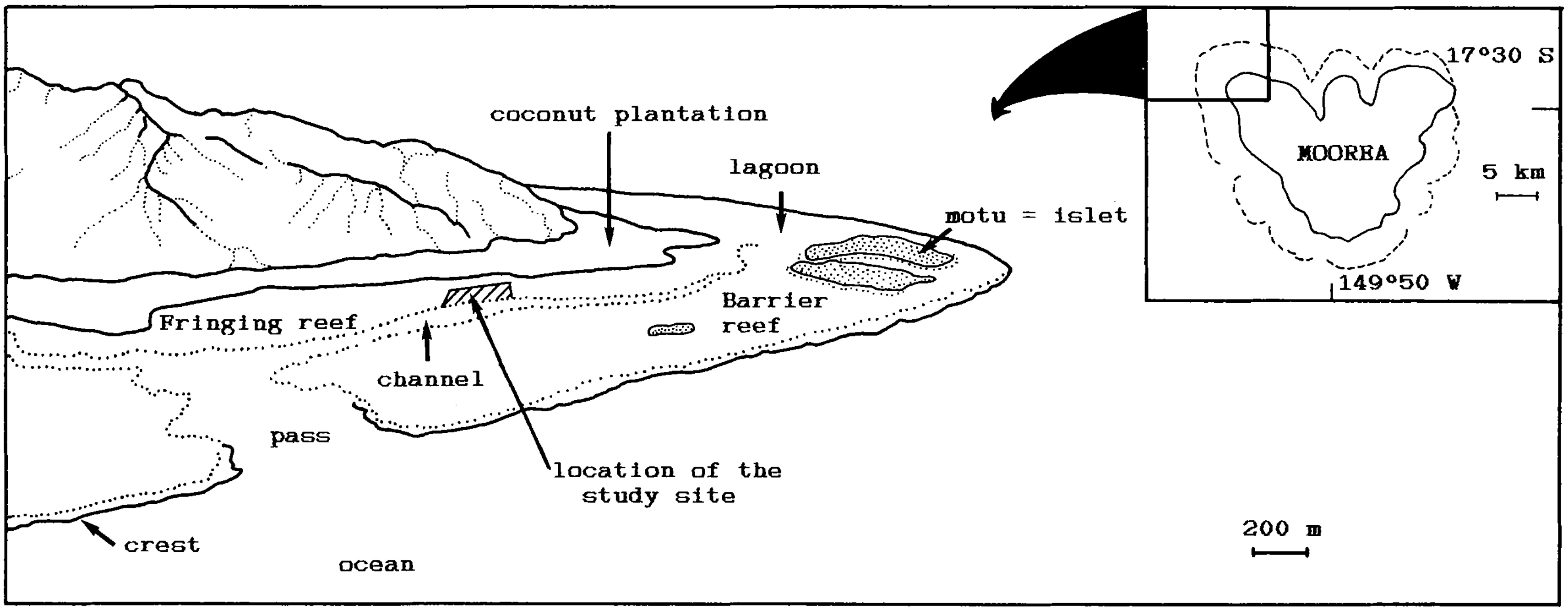

Figure 1 - The aerial view shows the northwestern part of the island of Moorea with the location of the study site on the fringing reef.

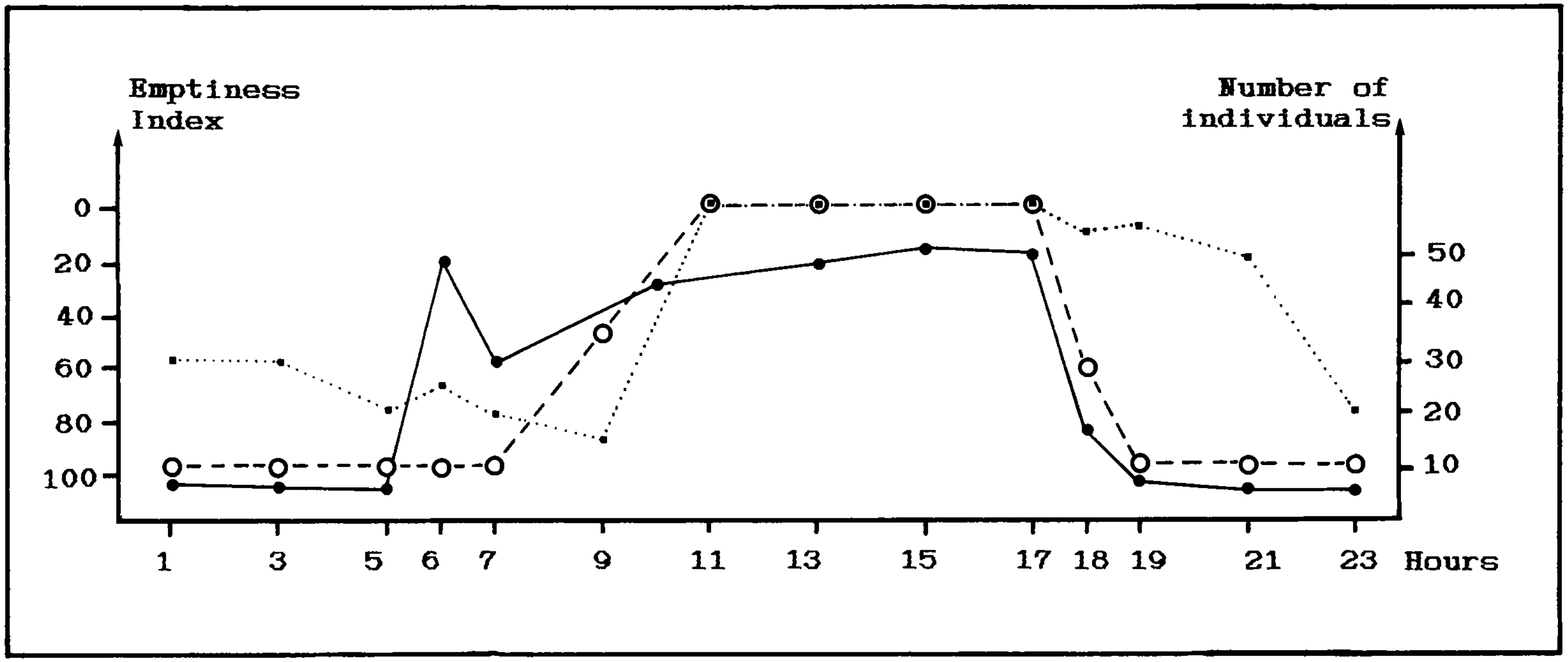

Figure 2 - 24 hours changes for the abundance and emptiness index of <u>Ctenochaetus striatus</u> fished on the fringing reef of Moorea island.

O- - -O emptiness index for stomach studies

▪·······▪ emptiness index for intestine studies

●——● number of individuals.

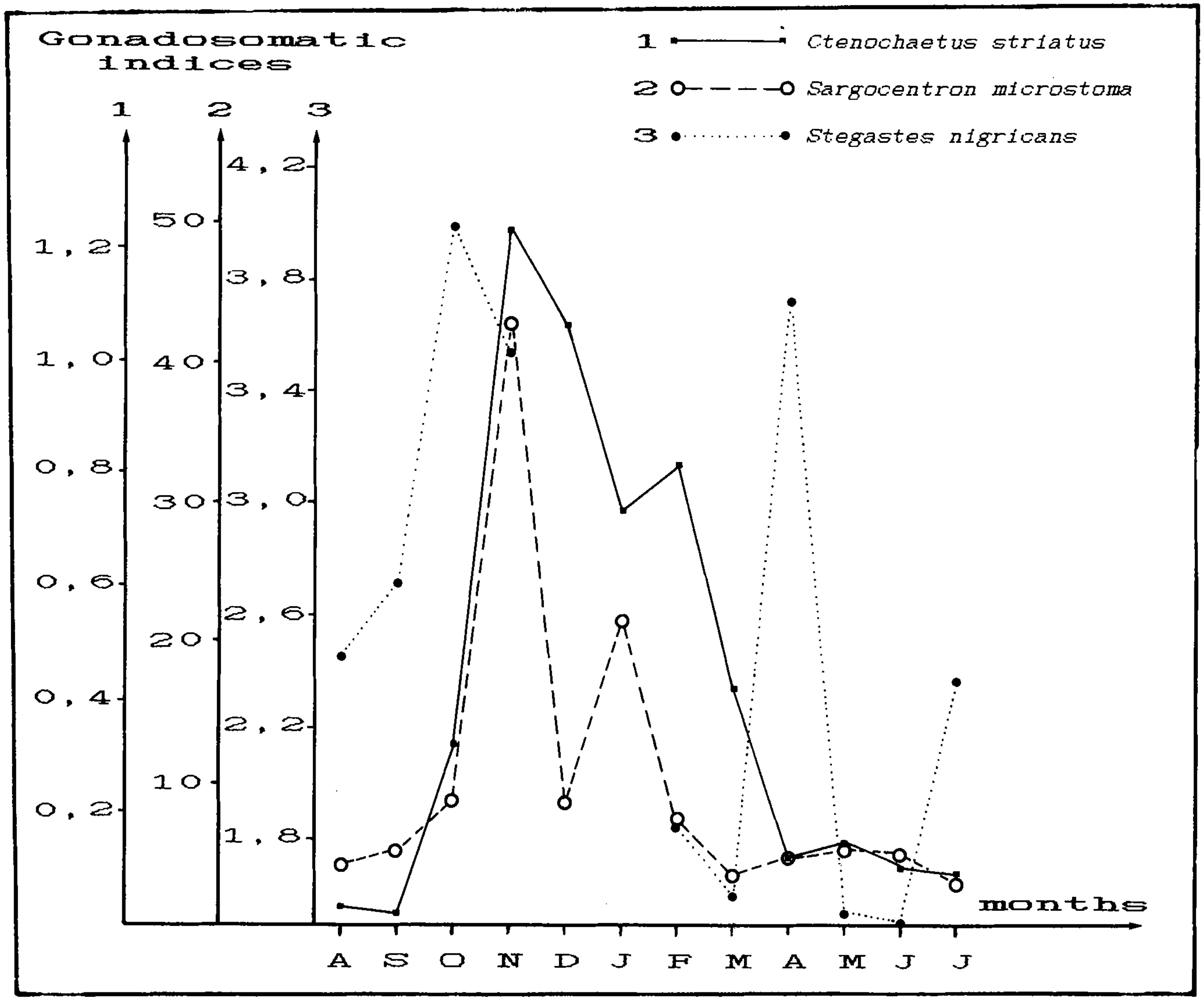

Figure 3 - Seasonal changes for the GSI of the three species fished on the North fringing reef of Moorea island.

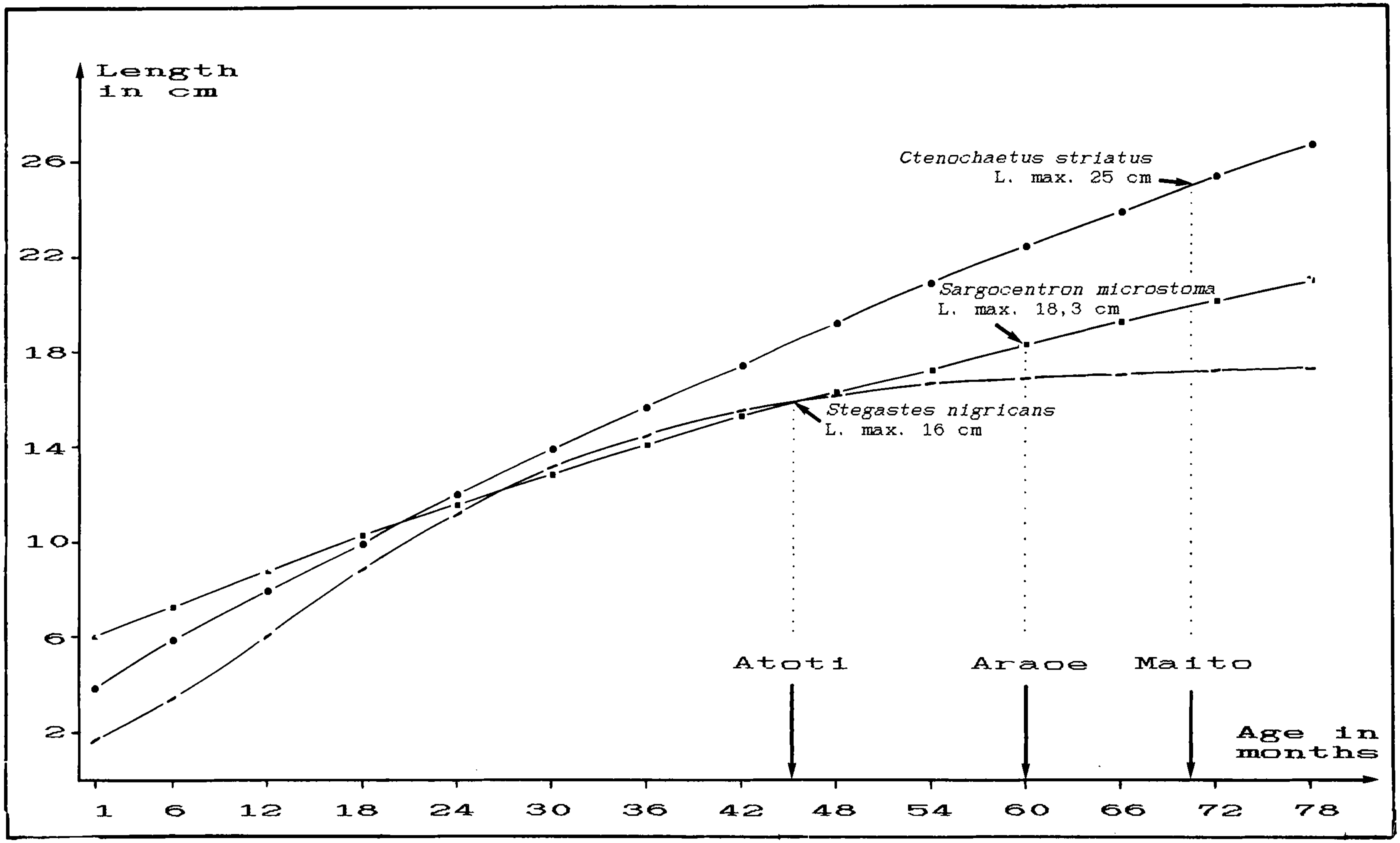

Figure 4 - Comparative length of growth curves for the three species studied on the North fringing reef of Moorea island.