



**MAURITIUS RESEARCH COUNCIL**  
INNOVATION FOR TECHNOLOGY

# **GROWTH AND REPRODUCTIVE BIOLOGY OF Lethrinus Mahsena**

**Final Report**

*July 2003*

**MAURITIUS RESEARCH COUNCIL**

*Address:*

Level 6, Ebène Heights,  
34, Cybercity,  
Ebène 72201,  
Mauritius.

**Telephone:** (230) 465 1235

**Fax:** (230) 465 1239

**Email:** [mrc@intnet.mu](mailto:mrc@intnet.mu)

**Website:** [www.mrc.org.mu](http://www.mrc.org.mu)

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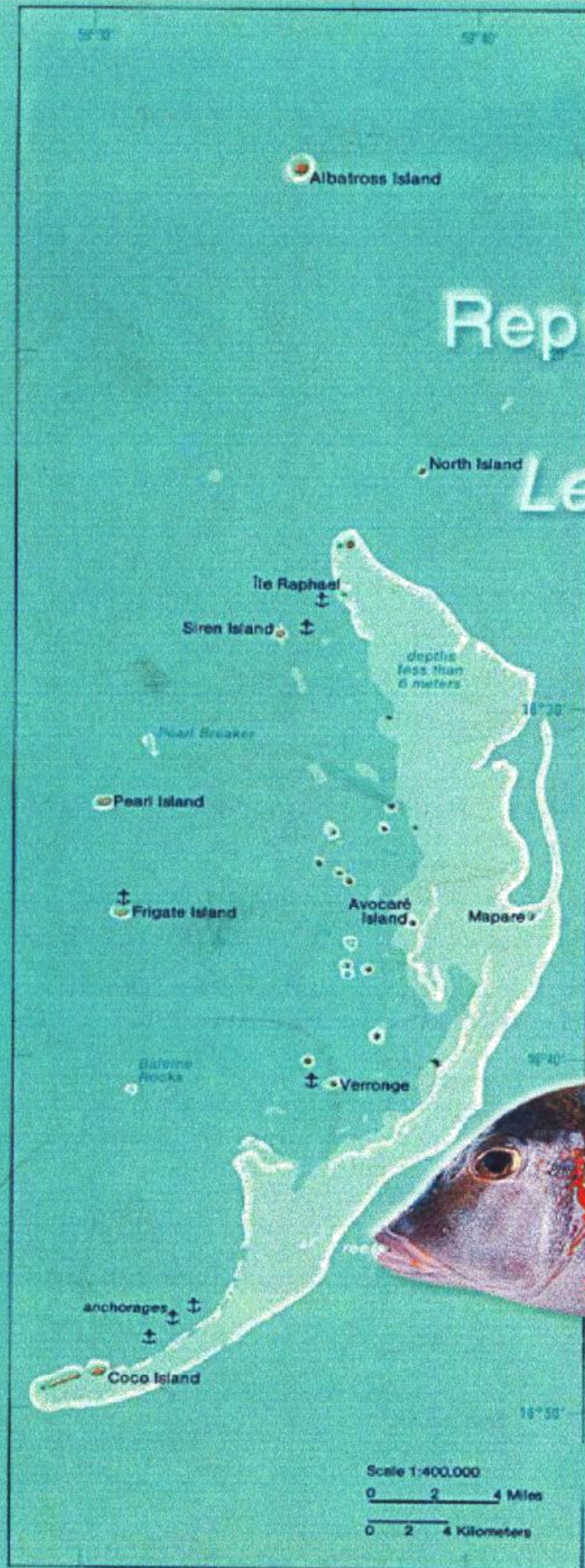


# Growth and Reproductive Biology of

*Lethrinus mahsena*

from the  
St. Brandon Stock

Dr. M. Bhikajee



Mauritius Research Council  
University of Mauritius  
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Dr. Mitrasen Bhikajee

MAURITIUS RESEARCH COUNCIL - UNIVERSITY OF MAURITIUS

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## TABLE OF CONTENTS

|  |     |
|--|-----|
| LIST OF FIGURES .....                                      | iii |
| LIST OF TABLES.....  | iv  |
| ACKNOWLEDGEMENT.....                                       | v   |
| Abstract.....  | 1   |
| 1.0 Aims of project .....                                  | 4   |
| 1.1 OBJECTIVES.....  | 4   |
| 2.0 INTRODUCTION .....                                     | 5   |
| 3.0 LITERATURE REVIEW .....                                | 6   |
| 3.1 MAURITIAN FISHERY .....                                | 6   |
| 3.2 CURRENT MANAGEMENT REGIME .....                        | 10  |
| 3.3 LETHRINIDS.....  | 13  |
| 3.4 FAO IDENTIFICATION .....                               | 14  |
| 3.5 THE MECHANICS OF LENGTH SAMPLING .....                 | 15  |
| 3.6 WHY STOCK ASSESSMENT? .....                            | 15  |
| 3.6.1 Basic Concepts of Fisheries Science .....            | 18  |
| 3.7 REPRODUCTIVE BIOLOGY OF THE FISH .....                 | 18  |
| 3.8 ASSESSMENT OF AGE AND GROWTH .....                     | 18  |
| 3.8.1 Anatomical methods .....                             | 21  |
| 3.8.2 Biochemical Methods .....                            | 27  |
| 3.8.3 Length Frequency Analysis .....                      | 27  |
| 3.9 PARAMETRIC METHODS .....                               | 29  |
| 3.10 NON-PARAMETRIC METHODS .....                          | 30  |
| 3.10.1 Shepherd' s length composition analysis (SLCA)..... | 31  |
| 3.10.2 Projection matrix method (PROJMAT) .....            | 31  |
| 3.10.3 Electronic length frequency analysis (ELEFAN) ..... | 32  |
| 3.10.4 About FiSAT .....                                   | 32  |
| 3.11 ESTIMATION OF GROWTH IN TROPICAL SPECIES.....         | 33  |
| 3.12 THE EFFECTS OF FISHING ON POPULATIONS.....            | 34  |
| 3.13 EFFECTS ON SIZE AND AGE STRUCTURE .....               | 36  |
| 3.14 EFFECT ON THE SPAWNING STOCK .....                    | 37  |
| 3.15 EFFECTS ON GROWTH .....                               | 38  |
| 4.0 MATERIALS AND METHOD.....                              | 42  |
| 4.1 DEFINING AND DESIGNING OF A SAMPLING STRATEGY.....     | 42  |
| 4.2 FIELD AND LABORATORY WORKS .....                       | 42  |
| 4.3 FISH FOR THE STUDY.....                                | 43  |
| 4.4 LABORATORY WORKS .....                                 | 43  |
| 4.5 DATA ANALYSIS .....                                    | 44  |
| 4.5.1 Powell-Wetherall Plot.....                           | 44  |
| 4.5.2 Pauly's M empirical Equation .....                   | 45  |
| 4.5.3 Length-converted catch curve .....                   | 46  |
| 4.5.4 Modal progression analysis (MPA) .....               | 48  |
| 4.5.4.1 <i>Bhattacharya's method</i> .....                 | 48  |
| 5.0 RESULTS.....   | 50  |

|  |    |
|--|----|
| 6.0 DISCUSSION.....  | 58 |
| 6.1 LENGTH-WEIGHT RELATIONSHIP AND FULTON'S CONDITION<br>INDEX (K) ..... | 58 |
| 6.1.1 Length/Weight Relationship.....                                    | 59 |
| 6.1.2 Condition Factor, CF .....   | 60 |
| 6.2 GONADO-SOMATIC INDEX AND HEPATO-SOMATIC INDEX.....                   | 61 |
| 6.2.1 Gonado-Somatic Index (GSI).....                                    | 61 |
| 6.2.2 Hepato-Somatic Index (HSI).....                                    | 61 |
| 6.2.3 Relationship between GSI and HSI .....                             | 62 |
| 6.3 LENGTH FREQUENCY ANALYSIS .....                                      | 62 |
| 6.4 MORTALITY .....  | 65 |
| 6.4.1 Natural Mortality .....  | 66 |
| 6.5 SPAWNING TIME / FREQUENCY .....                                      | 67 |
| 6.6 LC50 AND LM50 .....  | 68 |
| 7.0 CONCLUSION .....   | 69 |
| 7.1 MANAGEMENT MEASURES .....  | 69 |
| 7.2 DATA COLLECTION .....  | 69 |
| 7.3 OTHER TECHNIQUES TO DETERMINE GROWTH PARAMETERS .....                | 69 |
| 9.0 BIBLIOGRAPHY .....   | 70 |

## LIST OF FIGURES

|  | Page |
|--|------|
| <b>Figure 1</b> Map of Cargados Carajos (St-Brandon) | 7    |
| <b>Figure 2</b> <i>Lethrinus mahsena</i>             | 14   |
| <b>Figure 3</b> Length frequency data (Sample 1-16)  | 50   |
| <b>Figure 4</b> Modal Progression Analysis (FiSAT)   | 51   |
| <b>Figure 5</b> Length Weight relationship           | 52   |
| <b>Figure 6</b> Hepato-Somatic Index                 | 53   |
| <b>Figure 7</b> Gonado-Somatic Index                 | 54   |
| <b>Figure 8</b> Correlation between HSI & GSI        | 55   |
| <b>Figure 9</b> Fulton's Condition Factor            | 56   |



## LIST OF TABLES

|   | <b>Page</b> |
|---|-------------|
| <b>Table 1</b> Fishable areas (km <sup>2</sup> ) of Mauritian fishing banks   | 6           |
| <b>Table 2</b> Production and effort on the banks in 1995   | 8           |
| <b>Table 3</b> Annual production (t) by banks in the Mauritian Exclusive<br>Economic Zone   | 10          |
| <b>Table 4</b> Minimum size of demersal species in Mauritius. (From the<br>fifth schedule of Mauritian fisheries legislation.)                                  | 12          |
| <b>Table 5</b> Wet weight of Lethrinids from banks fisheries 1977 – 1992  | 35          |
| <b>Table 6</b> Length-weight compositions of the "dame berri" <i>Lethrinus</i><br><i>mahseha</i> ) caught on banks in the Mauritian Exclusive<br>Economic Zone. | 41          |
| <b>Table 7</b> Length frequency data table  | 57          |

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## **Growth and reproductive biology of *Lethrinus mahsena* from the St Brandon stock.**

### **Abstract**

*Lethrinus mahsena* (family Lethrinidae), commonly known as 'Dame Berri', is the most important species fished from the St Brandon bank. It is a protogynic hermaphrodite and is generally found associated with the sea-bed in areas of sand or coral.

Most of the studies concerning *Lethrinus mahsena* on the Mauritian banks have been made by using data from Saya de Malha and the Nazareth banks. No report of studies made in St. Brandon about *Lethrinus mahsena* were found. This project is probably the first of the type in St Brandon.

The main objective of the project was to investigate certain growth and reproduction parameters for *Lethrinus mahsena*. Data were collected between July 1998 and October 1999. The parameters to be determined were the life span, growth rate, length at first capture, natural mortality, total mortality, fishing mortality and length-weight relationship of the fish from the St Brandon bank.

The length and weight data obtained from sampling have been used to calculate the above parameters. For calculation purposes the following packages have been used: FAO-ICLARM Stock Assessment Tools (FiSAT), BASICA and EXCEL.



The values of 'a' and 'b' in the formula  $W=aL^b$  were found to be 0.0165 and 3.0007 respectively. This was in accordance with data reported from Saya de Malha ( $a = 0.012$  and  $b = 3.160$  by Bertrand *et al* in 1986. The Fulton's condition factor (cf) was also calculated and no general trend was found during the sixteen months of study. The asymptotic length ( $L_{\infty}$ ) was found to be 63 cm and the growth constant K was found to be 0.12 in 1999. The total mortality Z, natural mortality M and fishing mortality F were calculated as 0.65, 0.34 and 0.31 respectively. The Gonado Somatic Index (GSI) was directly related to the Hepato Somatic Index (HIS) between July 1998 and August 1999 and was inversely related for the last two months implying that spawning may have started by September 1999. The length at first capture ( $L_{c50}$ ) was found to be 31.8 cm, that is, it exceeded the value of the length at maturity ( $L_{m50}$ ) which was found to be below 30 cm. Data were in accordance with those from Saya de Malha and Nazareth bank.

However, due to the limited data available and *Lethrinus mahsena* being a slow growing fish, further studies need to be carried out. A wider sampling time span is thus suggested. The sample was taken from a commercial catch and thus the sample was biased due to gear selectivity.

For proper management measures, otolithometry should be performed so as to obtain better age data for analysis. This project having been interrupted in the middle of the sampling period, such data was not available.

## **Growth and reproductive biology of *Lethrinus mahsena* from the St Brandon bank**

This report has been prepared following collection of a series of data of fish length and weight on the banks of St-Brandon. It covers the work carried out from July 1998 to December 1999.

The data were collected by an M.Phil student for award towards a post-graduate degree. However, the candidate abandoned the project after 16 months of sampling. The data already collected were used for this report. The best possible use of existing data have been made. However, several gaps exist in the data collected. For example, data on otolith and gut contents were not made available and thus this report is unable to present a complete picture of age and reproductive biology of *Lethrinus mahsena*.

## 1.0 Aims of project

The aim of the project is to understand certain key aspects of the growth and reproductive biology of *Lethrinus mahsena* so as to help decision makers apply appropriate measures for sustainable fisheries management on the St-Brandon Bank. These include age of the fish, spawning time, spawning frequency and mortality rate estimation.

### 1.1 OBJECTIVES

To determine:

- The asymptotic maximum length,  $L_{\infty}$
- Growth Coefficient, K
- Length/Weight relationship
- Condition factor
- Gonado-Somatic Index (GSI)
- Hepato-Somatic Index (HSI)
- Relationship between GSI and HSI
- Natural mortality, M
- Total Mortality, Z
- Fishing mortality, F
- Lc50
- Spawning period/frequency



## 2.0 INTRODUCTION

Fishes of the family Lethrinidae (commonly known as Emperor) constitute an important fishery in Mauritius as well as in other areas of the world. They are among the economically important fishes in the tropical countries and represent a large part of the commercial fishing for Mauritius.

Lethrinidae are widespread throughout warm waters of the world. They are highly valued food fish in many tropical countries, for example, Seychelles (Mees, 1989), Mauritius (Ardil, 1986), Australia (Kailola *et al.*, 1993), the Caribbean (Thompson and Munro, 1974), Hawaii (Okamoto, 1982; Parrish *et al.*, 1997) and Tonga (Langi *et al.*, 1992). They represent both a cheap source of protein, and, where they form the basis of an export trade, an important component of the national economy of many developing countries. Fisheries based on these species are therefore important both to artisanal and semi-industrial fishermen.

Pressure from the increasing trends in the human population is currently the subject of concern over coral reef fish exploitation. The biology of exploited species is also a contributing factor for such concern (their slow growth, low reproductive capacity and low rates of natural mortality makes them vulnerable to overfishing (Koslow *et al.*, 1988; Russ, 1991; Haight *et al.*, 1993a). The localisation of stocks that results from fragmented habitats on coral reefs, combined with particular fish life history strategies, would suggest that reef fish stocks may provide more limited yields than previously believed (Smith, 1978). Sound management advice is therefore important for the long-term sustainability of fisheries targeting these species.

Studies of age structure and growth rates of a fish population are an essential component in the assessment of exploited population dynamics (Rowling and Reid, 1992). Von Bertalanffy growth parameters ( $L_4$ ,  $K$ ,  $t_0$ ) are inputs into many assessment methods which estimate further biological and fishery parameters (*e.g.* mortality, yield-per-recruit). Hence, they are important for fisheries management.

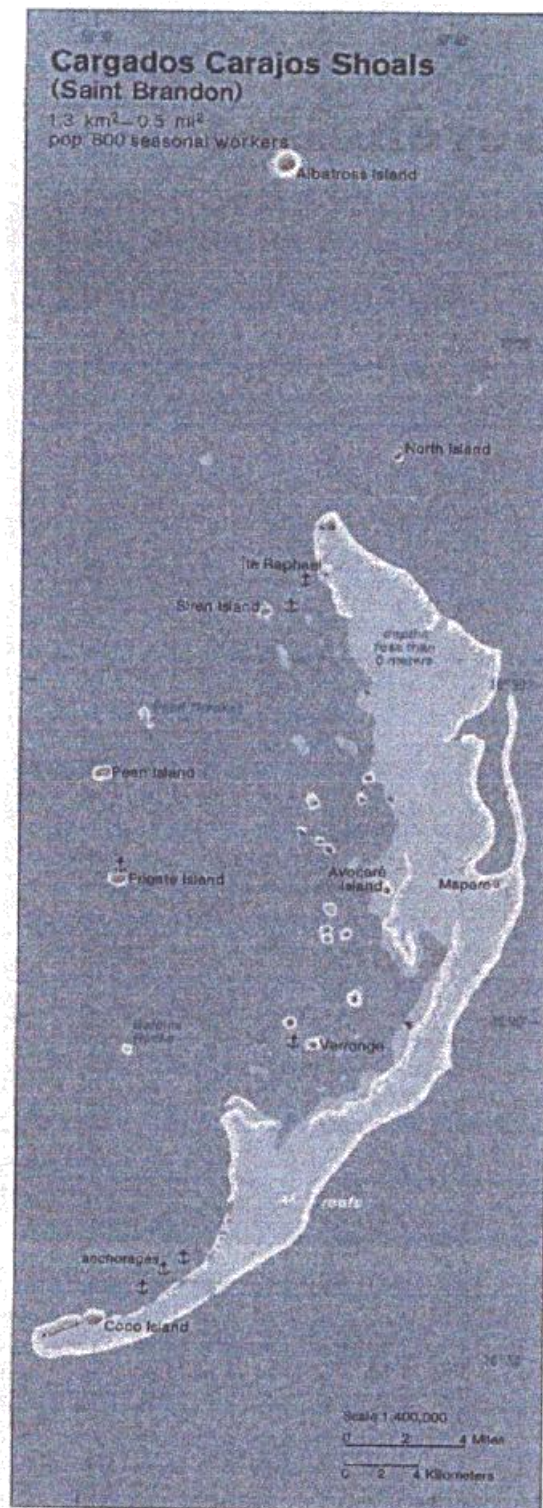
### 3.0 LITERATURE REVIEW

#### 3.1 MAURITIAN FISHERY

The Mauritian fishery is based on fishing on the relatively shallow banks to the north of Mauritius: Cargados Carajos (St Brandon), Nazareth and Saya de Malha banks. Part of Saya de Malha is in international waters but Mauritius exercises traditional fishing rights there. Fishing began in the eighteenth century, with salted fish coming from the copra islands of St. Brandon, Agalega and Chagos Archipelago.

**Table 1 Fishable areas (km<sup>2</sup>) of Mauritian fishing banks. (AFRC).**

| Banks         | Fishing Grounds | Code | Area Km <sup>2</sup><br>fishable |
|---------------|-----------------|------|----------------------------------|
| Saya de Malha | Saya North      | SMN  | 4000                             |
|               | Saya South      | SMS  | 8500                             |
| Nazareth      | Nazareth        | NAZ  | 10000                            |
| St Brandon    | Albatross       | ALB  | 3000                             |
|               | St Brandon      | StB  | 3000                             |



**Figure 1: Map of Cargados Carajos (St-Brandon)**



More extensive exploitation of the banks began in the mid 1960s (Samboo and Mauree, 1988). Fishing currently occurs from refrigerated mother vessels which carry up to twenty 6-8m pirogues or 'dories'. Three fishermen operate from each dory, using handlines rigged with between three and eight baited hooks (Samboo, 1983). Up to 1,000 fishermen are currently employed, 500 of whom are regularly active, spending 37 up to 150 days at sea per annum.

**Table 2 Production and effort on the banks in 1995**

| Bank          | Fishing days | Travel days | Bad weather days | Catch (t)   | %          | Fmen days    | CPFD (kg)   |
|---------------|--------------|-------------|------------------|-------------|------------|--------------|-------------|
| Saya de malha | 892          | 199         | 168              | 2682        | 52.4       | 46400        | 57.8        |
| Nazareth      | 525          | 128         | 71               | 1609        | 31.4       | 26734        | 60.2        |
| St Brandon    | 206          | 57          | 30               | 469         | 5.8        | 5008         | 59.8        |
| Chagos        | 94           | 31          | 22               | 217.7       | 4.3        | 5042         | 43.2        |
| Albatros      | 125          | 89          | 16               | 312.2       | 6.1        | 6364         | 49.1        |
| <b>Total</b>  | <b>1842</b>  | <b>504</b>  | <b>307</b>       | <b>5291</b> | <b>100</b> | <b>89548</b> | <b>57.2</b> |

The fishing trips for La Derive, the fishing company from which the sample was obtained, is about twelve days. The vessel of the company is quite small and has no dories. For each trip there are four handline fisherman and one master fisherman. The catches on each fishing campaign consist of Dame Berri (*Lethrinus mahsena*), Capitaine (*Lethrinus nebulosus*), Caya (*Lethrinus rubrioperculatus*), Vielle (*Epinephelus* sp), Cordoniers (*Siganus sutor*), Cateaux (*Scarus* sp), Mulletts (*Mugil* sp), Carangues (*Caragoides* sp) and a few other species. The target species for this study (*Lethrinus mahsena*) comprises about 85-90% of the catch.

In general the banks fishery contributes about 60% of the marine catch in Mauritius. In 1993 and 1994, catches from the Mauritian banks reached 5,000t, but still failed to meet domestic demand. Fish exports are therefore controlled, since it is necessary to import the deficit in order to meet requirements (Morel, 1989).

**Table 3 Annual production (t) by banks in the Mauritian Exclusive Economic Zone**

| Year | Vessels | Saya de Malha | Nazareth | St<br>Brandon | Chagos | Albatross | Total catch |
|------|---------|---------------|----------|---------------|--------|-----------|-------------|
| 1977 | 8       | 1587          | 1482     | 95            | 32     | -         | 3196        |
| 1978 | 8       | 1529          | 1198     | 97            | -      | -         | 2824        |
| 1979 | 6       | 372           | 1407     | 77            | -      | -         | 1856        |
| 1980 | 5       | 277           | 955      | 172           | -      | -         | 1404        |
| 1981 | 4       | 378           | 874      | 140           | 81     | -         | 1473        |
| 1982 | 7       | 1701          | 1282     | 43            | 135    | -         | 3161        |
| 1983 | 8       | 1245          | 920      | 112           | -      | 3         | 2280        |
| 1984 | 9       | 833           | 1104     | 283           | 143    | -         | 2363        |
| 1985 | 13      | 2207          | 1072     | 386           | 163    | -         | 3828        |
| 1986 | 15      | 2767          | 1200     | 533           | 127    | -         | 4627        |
| 1987 | 13      | 3363          | 1475     | 374           | 237    | -         | 5449        |
| 1988 | 13      | 2651          | 1448     | 727           | 314    | -         | 5140        |
| 1989 | 13      | 2177          | 837      | 407           | 133    | 130       | 3684        |
| 1990 | 10      | 1410          | 914      | 347           | 300    | 135       | 3106        |
| 1991 | 13      | 1782          | 793      | 369           | 358    | 161       | 3463        |
| 1992 | 15      | 2825          | 980      | 446           | 317    | 194       | 4762        |
| 1993 | 17      | 3173          | 1358     | 590           | 195    | 261       | 5577        |
| 1994 | 16      | 3167          | 1591     | 224           | 307    | 232       | 5521        |
| 1995 | 15      | 2682          | 1609     | 470           | 218    | 312       | 5291        |
| 1996 | 15      | 2283          | 1253     | 432           | 321    | 135       | 4424        |

|      |    |      |      |     |     |     |      |
|------|----|------|------|-----|-----|-----|------|
| 1997 | 14 | 1798 | 1720 | 316 | 306 | 270 | 4410 |
| 1998 | 13 | 2054 | 1086 | 400 | 81  | 76  | 3697 |
| 1999 | 13 | 2107 | 1121 | 341 | 127 | 226 | 3922 |

Catches from the banks are primarily demersal species. The main components of the catch are species from the family Lethrinidae, particularly *L. mahsena*. This is the dominant species on Saya de Malha, comprising around 90% of the total catch weight (Ardil, 1986; Bertrand *et al.*, 1986)

The majority of the remainder of the catch comprises species of the families Lutjanidae and Serranidae. Until recently the Sacré Chien Blanc, *Pristipomoides filamentosus* was not targeted by Mauritian vessels, since it is found at depths of over 200m in these locations; this meant that a large amount of effort was required by handline fishermen for potentially little gain. Extremely limited fishing on Saya de Malha had occurred for this species by vessels from other nations. In 1997, however, a Mauritian fishery for *P. filamentosus* was initiated, comprising a single mothervessel and five modified dories equipped with electric reel fishing gear.

It should be noted that most of the studies concerning *Lethrinus mahsena* on the Mauritian banks have been made by using data from Saya de Malha and the Nazareth banks. **No studies about *Lethrinus mahsena* have been made in St. Brandon till now.**

### 3.2 CURRENT MANAGEMENT REGIME

The objective of Mauritian Government policy was to increase fish production to 20kg *per capita* (in excess of 10,000t in total), to stimulate frozen fish consumption, and develop the fishery to a level sufficient to replace fish imports. Overall, the goal was to provide a source of protein at an affordable price.

Current Mauritian legislation for the banks fishery relates to species prohibition (due to their potential for ciguatera), minimum sizes for certain fish species, price controls on frozen banks fish, and to a total allowable catch (TAC) quota system, which forms the main management tool.

The restrictions on ciguatoxic fish apply to shallower water species, and do not affect the species under study. Discarding undesirable fish has the potential to result in increased mortality which will not be identified through catch data analysis. However, the impact on Mauritian banks is felt to be minimal; targeting of desired species, through selection of fishing location or hook size, is believed to be effective and the fishery is relatively monospecific. It presents a greater problem in Chagos, as this area sustains a more multi-species fishery.

Legislation on minimum length relates principally to the artisanal coastal fishery. A number of fishing companies are now paying a reduced rate for what they consider undersized fish, or refusing to purchase them, due to both difficulties in selling small individuals on return to port, and the perceived size limits. Usually where catches of undersized fish do occur, these are seized on return to port.

In order to ensure that fish were available to all social classes, price controls on the banks fishery were initially introduced. Price controls have since proved useful as a management tool to reduce effort. When controls were removed between 1981 and 1987, both prices and fishing effort increased.

**Table 4 Minimum size of demersal species in Mauritius. (From the fifth schedule of Mauritian fisheries legislation.)**

| Scientific Name              | Local name     | Minimum size (cm) |
|------------------------------|----------------|-------------------|
| <i>Lethrinus sp.</i>         | Capitaines     | 30                |
| <i>Parupeneus barbarians</i> | Rougets        | 20                |
| <i>Lethrinus mahsena</i>     | Dame Berri     | 30                |
| <i>Polysteganus baissaci</i> | Guelles Pavees | 30                |
| <i>Naso unicornis</i>        | Licornes       | 30                |

A non-transferable quota system was introduced in 1994 for Mauritian banks fisheries. Maximum sustainable yields for each bank were estimated through the Thompson and Bell method (1934). These estimates were reduced by 10% in order to determine the Total Allowable Catch (TAC) from each bank. The TAC was initially allocated on a per vessel basis, based on historical performance. This value related to total fish catch, with no reference to species. It was also recommended that the number of vessels should be limited to seventeen (the number operating at that time), and that vessels dropping out of the fishery should not be replaced. The system was amended in 1995. The catch quota was then applied to companies rather than individual fishing vessels. Quotas reflected the historical performance of each company, and could be traded off in whole, or part, if unutilised. This was a single quota, allocated for the whole of the Mauritian banks, rather than by an individual bank. TAC in 1995/96 was set at 4,750t.

The management rule currently in place calls for an annual 5% decrease in TAC until 'consistent signs of stock recovery' are identified. Such signs include increases in catch rate and catch mean length. These are monitored annually. Routine assessments are also performed, for example, using length-based methods of total mortality estimation.



### 3.3 LETHRINIDS

The Emperor family (Lethrinidae) are tropical and sub-tropical bottom feeding carnivorous (Fischer and Bianchi, 1984). They are generally found either on coral reefs and rocky areas or soft substrates. Species are not thought to be territorial, and generally form small shoals. Spawning aggregations also occur.

Lethrinids are carnivorous, feeding on crustaceans, echinoids, molluscs, and small fishes. They are generally caught close to the bottom as they search for food. *L. mahsena* is generally found associated with the seabed in areas of sand or coral, and is commonly caught at depths ranging from 25 - 50m. The species feeds primarily on benthic crustaceans, molluscs and echinoderms (Kulbicki, 1988).

*L. mahsena* is described as a protogynous hermaphrodite (Bertrand, 1986). Few females are said to exceed 35cm in fork length (FL), and few males are less than 20cm FL. Sex reversal occurs around 5-6 years of age, approximately 2 to 3 years after the earliest onset of sexual maturity (Bautil and Samboo, 1988). On Saya de Malha bank, the species has a single spawning season from October to February (Bertrand, 1986).



**Figure 2**      *Lethrinus mahsena* (Forsskal, 1775)

Photo courtesy: John E. Randall

### 3.4    **FAO IDENTIFICATION**

*Lethrinus mahsena* (Forsskal, 1775) forms part of the family of Lethrinidae. These are perch like fishes with large heads, deep sub orbital space and terminal mouth. The lips are often thick and fleshy, maxilla concealed, without supplementary bone, mostly slipping below infra orbital bones. The outer teeth of the jaws are uniserial, caninelike, conical. The enlarged canines in front of the jaws point outward in adults. The palate is toothless.

The dorsal fin is continuous with 10 spines and branched (soft) rays. The anal fin has 3 spines and 8 branched rays. The pectoral fins are moderately long and pointed, with 13 branched rays, the pelvic fins have 1 spine and 5 rays. The caudal fins are forked. The scales are ctenoid and moderate in size. *Lethrinus mahsena* has 4 scale rows between the

lateral and median dorsal fin spines (excluding the very small scales at the base of the dorsal fin). The cheeks, upper surface of the head and pre orbital area are scaleless.

The body coloration is grey with tints of red. The edge of the pectoral fins and the pelvic fin axils are red.

### **3.5 THE MECHANICS OF LENGTH SAMPLING**

At first sight nothing appeared to be simpler than sampling for length. It seemed to be a matter of just going to some convenient point and measuring a proportion of the fish that are available. In order to avoid latter difficulties in using the data, some practical points were carefully considered.

These included:

- ◆ What characteristics (example total length, fork length or standard length) were to be measured, and in what units and with what precision?
- ◆ How the measurements to be recorded?
- ◆ How many fish were to be measured.

It should be noted that since the otoliths and scales were spoiled, the anatomical methods were not used in determining age of the fish.

### **3.6 WHY STOCK ASSESSMENT?**

Capture fisheries exploit living and, hence, renewable resources. In the overwhelming majority of cases, fisheries resources are “common property”. In many cases they are also “open access” –i.e., fishing license are not required, or are available at nominal fees, or other limitations to entry are not effectively enforced. Open and free access generally

implies competition for the resources which, in an unregulated fishery leads to biological and economic overfishing.

Biological overfishing has different effects (growth and/or recruitment overfishing with regard to single species, ecosystem overfishing with regard to a multispecies resource). Economic overfishing is also multifaceted. When one considers the first boat operating in a fishery, "trouble" actually when a second unit starts fishing, thus reducing the biomass (and hence, catch/effort and economic returns) available to the first unit. Progressive reduction of the resource then occurs, until there are so many units that the boats cannot manage to break even, and fishery operators clamor loudly for subsidies ( for example in the form of tax reductions on fuel or gear, subsidies for the renewal of boats, or even more research and management).

At the level of the society, trouble begins when the difference between the total revenue in a fishery and the total cost of fishing –i.e. the net economic yield or resource rent – starts to decline. Fisheries resource rents can be considerable, but are dissipated in unmanaged fisheries.

Providing a basis for a rational management of exploited resources thus involves dealing with a wide variety of issues, ranging from political problems to socioeconomic and resource conservation issues.

In essence, the ultimate goal of fish stock assessment is to provide technical advice to maintain the productivity of fish stocks.

A few fisheries resources in the world may still be underexploited – particularly in inland water bodies in which a combination of factors (remoteness, lack of suitable gear and crafts, lack of markets, or insecure conditions) have hindered the build-up of fishing capacities. To account for such cases, fish stock assessment should also:

- Evaluate the potential yields of underutilized water bodies, taking the need for resource conservation into account;
- Consider adoption and improvement of suitable fishing gear and craft combinations (for example through fishing trials), and of processing methods and marketing;
- Define technical assistance schemes that allow a phased growth of the fisheries, and the adjustment of effort to those levels leading to high, but sustainable yields.

Living aquatic resources have become a major source of food protein, especially in the tropics, providing a quarter of the total animal protein in many developing countries and up to three quarter in some others. Yet despite their importance, tropical and subtropical fisheries are most badly managed (if not all) – the resources are generally overexploited and the fisheries overcapitalized.

Fisheries scientists alone cannot remedy this situation; however, they can provide the biological advice required to rehabilitate stocks that are mismanaged. The methodology for this exists. It consists of various refinements of standard assessment techniques,



together with the judicious application of new methods developed for use in tropical waters.

### **3.6.1 Basic Concepts of Fisheries Science**

Fish are usually not seen, counted or weighed before they are caught, and hence fisheries research has, from the very start, depended on indirect inferences (mathematical and statistical) for quantifying the vital statistics of fish populations required for fisheries management.

Thus, some of the earliest applications of mathematics and statistics (outside of the physical sciences) are those of fisheries biologists. However, when describing the dynamics of an exploited aquatic resource, the first concept that needs defining is that of the stock.

## **3.7 REPRODUCTIVE BIOLOGY OF THE FISH**

The study of the reproductive aspects is also important for the determination of spawning periods and frequency. This provides valuable fisheries management guidelines (e.g determination of closed fishing seasons) for the regulation of the fishery.

## **3.8 ASSESSMENT OF AGE AND GROWTH**

The ability to accurately determine the age and growth rate of fish are essential features of population dynamics and stock assessment. Such knowledge is crucial for

- (1) analysing the reproductive strategy of the fish,
- (2) development of resource management plans,

- (3) evaluation of the effect of various environmental or genetic factors on one or on various populations (by comparing the growth rate and the abundance of the age class of which it is made),
- (4) determination of population dynamics.

Growth can be estimated by a number of methods. In temperate fish species, growth is frequently determined using age data derived from counts of annual growth rings in hard tissues such as otoliths. Such annual banding is believed to be formed in many tropical species, although the process is said to be complicated by reduced seasonality (Manooch and Drennon, 1987). For this reason, and due to financial constraints, cheaper length-based methods of growth assessment are more commonly used. However, these methods are not particularly well suited to long-lived, slow-growing species, such as *Lethrinids*. These methods commonly utilise modes in length frequency data (assumed to represent individual cohorts) to estimate growth parameters. In slow growing species, modes representing fish cohorts frequently overlap, offering limited information on growth. Under such circumstances, the accuracy of growth parameters derived through length-based methods is uncertain.

The method of separation of modal classes (considered to correspond to distinct age classes) of the length – frequency distribution was the first to be applied to the determination of growth (Peterson, 1891). The early tropical fish growth studies used length-frequency analysis. However, the superimposition of successive modal classes and difficulty of collecting representative, non-selective population samples are a frequent source of problems in the application of this method (Mathews, 1974; Morgan, 1983; Morales-Nin, 1989).

The relative uncertainty inherent in all growth determination methods suggests the use of two independent techniques to confirm the findings. The use of length-frequency analyses and the simultaneous interpretation of growth marks probably offer the best results.

The International Centre for living Aquatic resources Management (ICLARM) and the Kuwait Institute for Scientific research meeting on the theory and application of stock assessment methods based on length-frequency analyses which was held in 1985 (Pauly, 1987), concluded that length-frequency analyses methods are made much more precise by the inclusion of information on growth obtained through the use of an independent method, usually based on otolith reading (Morgan, 1987).

Length-frequency analysis and structural features of hard parts such as spines and otolith have been used in many cases on several types of species for the determination of age and growth.

Literature on the determination of age and growth of fish in the Indian Ocean are very few. Despite the economic importance of some of them, few scientific studies have reported in their biology. Previous age and growth studies on *Lethrinus Lentjan*, *Lacepede* 1802 or *Lethrinus mahsena*, Forsskal 1775 from the red sea have been conducted by Hashem and Shakour (1981), Kedidi (1984) and Kedidi et al. (1984). Reports on the subject have been given by Toor (1968) for Indian waters, Aldonov and Druzhinin (1978) for the sulf Aden, Loubens (1980) or the New Caledonia lagoon, El Dossany (1987) for the Arabian Gulf and Bertrand (1988) for Saya de Malha, Indian Ocean – Wassel E A (1990) for the red sea and the Arabian Gulf.

The use of scale reading as an ageing technique for *Lethrinus mahsena* was used by Wassel, (1900). The result of the study was validated by the data obtained from otolith analysis.

Growth parameters can be determined through a number of methods (as defined by Morales-Nin, 1992):

- ❖ **Anatomical method:** counting the regular growth marks formed in hard

tissues such as scales, otoliths, vertebrae, spines and tail bones (sclerochronology) (Meunier, 1988)

- ❖ **Length-frequency analysis:** studying the progression of identifiable modal size classes through time;
- ❖ **Direct estimate:** extrapolating direct measurements of growth rate from individual specimens to the stock as a whole. For example, this can be achieved through mark and recapture studies or direct monitoring of the growth of captive fish of known age.

Marking and subsequent recapture of fish, or monitoring the growth of captive fish of known ages are two direct estimation methods. However, for practical reasons this method has not been used.

### 3.8.1 Anatomical methods

The anatomical method involves counting regularly formed marks on hard tissues (Manooch, 1987). Such growth units are simple structures composed of protein-rich and protein-poor layers embedded in a calcium carbonate (aragonite) crystal lattice, forming a bipartite structure composed of discontinuous and continuous zones. These are thought to relate to regular/seasonal changes in the environment or biology of the fish.

Anatomical ageing methods were first used in 1759, when vertebrae were used to age a number of species, including eels and pike (Henderstrom, 1959). Vertebrae have since been used to age a number of species (*e.g.* Edwards, 1985; Liu and Yeh, 1991). Scales have been used for ageing since 1898 (*e.g.* Van Oosten, 1923, 1929; Carlander, 1987). However, scales are frequently difficult to read, and may underestimate ages (Beamish and McFarlane, 1987). They are subject to reabsorption during periods of starvation and



stress (Mugiya and Watabe, 1977), and are commonly lost and regenerated during the life of a fish (Thompson and Munro, 1983b). As a result, scales have seldom been used successfully to age adult emperors (Manooch, 1987). Other hard tissues, such as urohial bones (Espinosa and Pozo, 1982) and spines (Edwards, 1985), have also been used for ageing. For emperors, however, the most common hard part used for ageing is the otolith. Since then, these structures have been used.

It has been demonstrated, however, that tropical fish have a longer spawning period than temperate fish (Lowe-Mc Connell, 1987), recruitment is limited to one or two seasons of the year. This limitation may arise out of spawning fluctuations or out of the juvenile and larval mortality which governs and limits recruitment to specific periods (Bakun *et al.*, 1982; Victor, 1982; Robertson *et al.*, 1988).

The estimation of growth in tropical marine fishes has long been considered problematic due to the supposed lack of annual rings in their hard structures (scales, otoliths and vertebrae) and their 'continuous' spawning which was assumed to render impossible the analysis of tropical fish base on the study of length frequency data (Mohr, 1921).

The deposition of annual growth ring (annulae) in the calcified tissues of bony fishes is at least partly caused by seasonal changes in the environment. These periodic changes (temperature cycles, availability of food) are in temperate zones. Several authors, do, however, mention the presence of annual growth rings in tropical fish otoliths (Poinsard and Toadec, 1966; Quasim, 1973; Manooch III, 1987).

The causes of this cyclical annual growth are unclear: -

- (1) some authors link them to spawning periods and others to water temperature changes (who do I notice?).
- (2) As annual growth rings are present in immature fish, ring formation probably follows an internal rate of growth synchronised to seasonal environment variations



(3) A new application of otolith growth structure analysis was developed by Pannella (1971; 1974; 1980), who showed that the concentric shells (microscopic lamella) (Hickling, 1931) were formed daily. Daily growth increments offer a very promising field of study with many applications (Campana and Neilson, 1985)

These anatomical methods make it relatively easy to determine age and growth (Bagonal and Tesh, 1978; Casselman, 1983; Beamish and McFarlane, 1987).

Nonetheless, annulae and growth study cannot assume specific periodicity in growth marks, and so this must be determined for each age class of the stock studied (Beamish and McFarlane, 1983). However, it was realised during the 1960's and 1970's that tropical marine fishes generate annual rings in their hard parts under a wide range of conditions. Also, it was found that growth could be estimated for many tropical fish stock by analysis of seasonal growth rings (Bayagbona, 1963; Poinard and Thoade, 1966; Longhurst and Pauly, 1987; Morales-Nin, 1989).

Pannella's discovery (1975) of the daily periodicity of the very fine striations within otoliths, previously described by Hickling (1931), offered a new growth determination method. Daily growth increments have been applied to determine growth rates (Shubik, 1976), to establish the duration of the larval stage of coral fishes (Victor, 1982), and to determine fishes growth (Brothers, 1979; Ralston, 1985).

In the past decade there has been a looming conflict between age estimations based on the pattern of checks in the sulcal side of the otolith that usually yield estimates of age (e.g., Beamish 1979), and estimate of age based on daily microincrement method (e.g., Ralston and Williams 1988) that usually yield younger ages.

According to Pannella (1980), rings deposited annually give the most accurate estimate of age for many species of fishes. The presence of daily increments (Pannella, 1971) allows accurate ageing of larval fishes, when properly verified (Campana and Neilson, 1985;

Geffen, 1987). In addition to age estimates, otoliths can be used to generate information about a fish's somatic growth history from back-calculations of fish size (Brothers 1987). The premise for back-calculating length-at-age (Rice, 1987) is that otolith growth and somatic growth are coupled and widths of otolith increments are proportional to somatic growth rates.

Recent studies suggest this relationship between otolith and somatic growth may be complicated by an endogenous rhythm which causes otolith growth to continue even when somatic growth has stopped (Radke et al., 1985). The result is an uncoupling of otolith growth and somatic growth which produces larger, heavier otoliths in slower growing individuals. However, other studies have shown uncoupling at temperatures above the optimum for growth, perhaps driven by metabolic processes (Mosegaard et al., 1988) and resulting in larger otolith in faster growing fishes.

The otolith grow by the surface deposition of materials, a cyclical process dependent on internal calcium metabolism rates (Simkiss, 1974) and on amino acid synthesis. This result in the formation of daily growth increments in the otolith, made up of a continuous or incremental unit and a check unit (Pannella, 1971). The incremental zone is made up of needle-like aragonite microcrystals surrounded by the organic matrix and laid down across the surface of the otolith. The check zone or unit is mainly made up Concentric shells of organic matter (Moral-Nin, 1986).

The thickness of the increment and density of the microcrystals depends on the stage of growth (Irie, 1960). In active periods of growth, for example, the increments are thick well developed check units and slow periods of the increments are finer and microcrystals are more compact and continuous.

As bodily growth and otolith growth are closely linked, the increment thickness reflects the rate of growth, recording periods of environmental and physiological stress and growth fluctuations caused by age-linked metabolism slow down (Moral-Nin, 1986).

The daily deposition of increments should, in theory, allow an extremely precise determination of age. Many authors have used these increases to determine the age of larvae and juveniles (Campana and Neilson, 1985; Palomera et al., 1988; Bergstad, 1984) and in some studies in adult fish (Darayatne and Gjosacter, 1986, Ralston and Miyamoto 1981, Morales-Nin and Ralston, 1990; Uchimaya et al., 1986); (Uchimaya and Stuctchater 1981).

The use of both whole or sectioned otoliths for ageing fish is now a common research tool in the study and stock assessment of temperate fish species (Gulland, 1983). Until relatively recently, however, they had not been employed on a large scale for tropical species. This was related to two factors. Fisheries in tropical regions are frequently less developed when compared to their temperate counterparts, attracting a lower research effort. Perhaps more importantly, there has been a historical perception that the tropical marine environment was relatively constant. Fish were assumed to respond to this by growing and spawning continuously throughout the year. Hence, they lacked 'growth checks' from which an incremental otolith structure would arise (Fowler, 1995).

The discovery of daily increments in otoliths of tropical fish by Panella (1971) altered this perception. The existence of daily rings has since been confirmed in a number of tropical species (Panella, 1974; Brothers *et al.*, 1976; Brothers and Mathews, 1987; Morales-Nin, 1989). The study of otolith microstructure requires either a powerful light microscope or Scanning Electron Microscopy (SEM). SEM has been recognised as a successful technique for ageing both larval, juvenile and adult fish (Brothers and McFarland, 1981; Ralston and Miyamoto, 1981; Brouard and Grandperrin, 1984; Radtke, 1987; Smith and Kostlan, 1991; Bach and Chauvelon, 1994). However, the method is generally confined to areas of the otolith corresponding to faster-growing juveniles; decreased growth rates in older individuals result in closely spaced or merged daily bands that cannot be separated (Manooch, 1987). Although the time spent exhaustively counting individual daily rings can be reduced by certain techniques (Ralston and Miyamoto, 1981; Ralston and Miyamoto, 1983; Ralston and Williams, 1988a; Smith and Kostlan, 1991; Williams and Lowe, 1997), the costs in both equipment (*e.g.* SEM) and

time involved in this method are potentially prohibitive both for long term assessment programmes and for developing countries. The use of annual rings offer the only real method for ageing large numbers of relatively long lived fish, and thus offers the best basis for stock assessment and management.

Increased confidence in the use of tropical otoliths for ageing purposes led to a number of studies assessing annual rings (Lou, 1992; Newman, 1995; Williams *et al.*, 1995; Fowler, 1995). Loubens (1978) investigated the legibility of annual rings using low power light microscopy in a number of families of tropical species, including Lethrinidae. Annual rings have since been identified in a number of snappers, groupers and emperors (Loubens, 1980; Mason and Manooch, 1985; Manooch, 1982; Manooch and Drennon, 1987; Morales-Nin, 1988; Morales-Nin and Ralston, 1990; Ferreira and Russ, 1992; Francis *et al.*, 1992; Sadovy *et al.*, 1992; Rocha-Olivares and Gomez-Munoz, 1993; Milton *et al.*, 1995; Manickchand-Heileman and Philipp, 1996).

There are a number of alternative methods to age fish using otoliths. For example, Boehlert (1985) and Worthington *et al.* (1995a) have suggested the use of otolith weight as a non-subjective, cost-effective methodology for age determination. This method offers a rapid means of monitoring stock status (Williams *et al.*, 1995). Otolith weight has been found to be a good predictor of age in a number of tropical species (Ferreira and Russ, 1994; Newman, 1995).

In addition to age determination, increments have been used to validate annulae periodicity (Pannella, 1980; Victor and Brothers, 1982) to determine changes in growth (Morales-Nin, 1986), to detect life transitions to estimate recruitment and mortality (Methot, 1981, 1985; Robertson *et al.*, 1988) and in taxonomic studies.

Length-based methods and otolith-based methods are jointly applied to determine growth of various tropical marine species important to the fisheries of their respective areas.



### 3.8.2 Biochemical Methods

A rapidly expanding field involves ageing and life-history analysis through biochemical methods. Instantaneous growth rates have been investigated using RNA/DNA and ADP/ATP ratios (*e.g.* Buckley, 1979) or the uptake of  $^{14}\text{C}$ -labelled glycine by scales (*e.g.* Ottaway and Simkiss, 1979). Other chemical elements can also be used. For example, both  $^{210}\text{Pb}/^{226}\text{Ra}$  disequilibria and  $^{18}\text{O}/^{13}\text{C}$  stable isotope ratios show age-related trends (Seyama *et al.*, 1991; Coutant and Chen, 1993; Sadovy and Severin, 1994; Fowler *et al.*, 1995; Milton *et al.*, 1995). However, such relationships may not hold for all species; no clear pattern was found in the relationship between strontium and calcium in the otoliths of *Pristipomoides filamentosus* (Radtke, 1987). As in the reading of daily rings, the cost of the specialised equipment required to perform the analysis would be prohibitive for fisheries institutions in developing countries

### 3.8.3 Length Frequency Analysis

When compared to direct assessment of growth using hard tissues, length-based methods have a number of advantages (Pauly, 1987);

- sampling is generally cheaper than that for age-based methods, since this method does not require fish to be purchased for data collection;
- direct ageing methods are labour intensive. Large amounts of data for length-based methods can be collected in a short time;
- ageing methods require experienced trained personnel to perform the work. The skills and training necessary for collecting length frequency data are minimal;
- large amounts of historical length frequency data are commonly available;
- a number of models are size rather than age related (*e.g.* food conversion efficiency (Pauly, 1981), gear selection (*e.g.* Hamley, 1975; Pope *et al.*, 1975), recruitment to fishing grounds (Pauly and Morgan, 1987), maturity (Gulland, 1987) and marketability and price).



Given these points, length-based methods have become common in all types of fisheries, including those for emperors.

### 3.6.3.1 Basis for length-based methods of growth assessment

Length-based methods of growth assessment are based on the theoretical ability to relate modes in length frequency distributions to cohorts. Hence, methods assume no large variations in individual growth rate, or in recruitment (Gulland, 1987). Based on this assumption, a growth curve can be fitted to modes in a single length frequency distribution, or to modes tracked through a time series of length frequency data. The majority of work has used the growth curve developed by Von Bertalanffy (1934). This takes the form:

$$L^t = L_{\infty} (1 - e^{-k(t-t_0)})$$

where

$L_{\infty}$  'asymptotic maximum length' of the fish (the maximum length a fish could theoretically achieve)

$K$  growth rate of the fish

$t_0$  theoretical age at which a fish has zero length

This equation is also called the Von Bertalanffy Growth Function (VBGF).

If the assumption of limited individual growth rate and recruitment variation holds, growth can be described by a single set of von Bertalanffy growth parameters which best describes the pattern of modes in the length frequency data.

One of the first uses of length frequency based methods was by Petersen (Petersen, 1891; Petersen, 1892) on length data for the eel-pout *Zoarces viviparus*. Using a single length frequency distribution, different relative ages were attributed to individuals comprising

prominent modes in the sample. Subsequently, methods of assessment progressed to graphical (*e.g.* Harding, 1949), and then to computer-based methods (*e.g.* Hasselblad, 1966). Increases in computer processing power allowed the estimation of parameters using more complex models (*e.g.* the parametric models of Sparre (1987) and Pope (1987)).

As defined in Majkowski *et al.* (1987), there are two general groups of Von Bertalanffy growth parameter estimation methods using length frequency data: ‘parametric’ and ‘non-parametric’ methods.

### 3.9 PARAMETRIC METHODS

Parametric methods such as MIX (MacDonald and Pitcher, 1979), require information on the shape of modes in length frequency data. Early methods assumed that age class peaks could be approximated through normal distributions (*e.g.* Bhattacharya, 1967), converting length frequency distributions into a series of age frequency distributions. More complex parametric models are no longer constrained by this assumption, which a number of studies found to be invalid (*e.g.* Morgan, 1987).

Improvements to parametric techniques have been devised (*e.g.* Schnute and Fournier, 1980; Sparre, 1987; Pope, 1987). For example, samples can be weighted using catch per unit effort data, and related to the von Bertalanffy growth function. If mortality rate and initial cohort strength are assumed, the likely position and relative strength of each cohort in subsequent samples can be calculated. Expected and observed frequencies are then compared statistically. A large number of assumptions are required for these improvements and, in turn, a large number of parameters must be estimated.

A more feasible approach is represented by the computer program MULTIFAN (Fournier *et al.*, 1990). This method assesses growth through the analysis of multiple length frequency data sets, using a maximum likelihood estimation procedure. By using a

number of length frequency distributions to produce global parameter estimates, the number of significant age classes that can be resolved (and, hence, analysis sensitivity) is increased. The model again assumes that lengths in each age class can be described by normal distributions. However, the method is robust to limited deviations from the models hypothesis of where and how individuals should be distributed in the length frequency data.

Parametric methods have not reached the prominence of non-parametric methods in tropical fisheries. In part, this may be a result of the data intensive nature of these methods. Alternatively, it may represent a lack of availability; methods such as ELEFAN (see below) have been incorporated into a number of stock assessment computer packages, such as FiSAT (Gayanillo *et al.*, 1994) and LFDA (Holden *et al.*, 1995). These packages are readily available to tropical fisheries institutions, and are capable of running on relatively basic computer equipment.

### 3.10 NON-PARAMETRIC METHODS

Non-parametric methods, such as the Electronic Length Frequency Analysis (ELEFAN, Pauly and David, 1981; Pauly, 1987) use the number and positions of peaks in a single or series of length frequencies to estimate growth. Growth curves, derived through a specified growth model and using growth parameter sets selected from a specified range, are fitted. The coincidence between observed and expected modes in length frequency distribution(s) is used to indicate the suitability of that growth parameter set.

The 'Length Frequency Data Analysis' package (LFDA; (Holden *et al.*, 1995) is used. This package incorporates three non-parametric length-based methods of growth assessment; Shepherd's Length Composition Analysis ('SLCA'; Shepherd, 1987a), PROJection MATrix Method ('Projmat'; Rosenberg *et al.*, 1986; Basson *et al.*, 1988), and ELEFAN (Pauly and David, 1980; Pauly, 1987; Brey *et al.*, 1988).

Basic descriptions of the methods are presented below.

#### **3.10.1 Shepherd's length composition analysis (SLCA)**

This method estimates the best-fitting L4 and K parameter set by maximising a goodness-of-fit function. This function, which is based on a sine wave, is positive at predicted modal lengths, and negative at predicted inter-modal lengths. To score the fit, a correlation coefficient between the data and test function is calculated; test function values for each length class are weighted by the square root of the number of individuals present in that length class, and summed across all examined length classes. Growth parameters which best describe the length distribution therefore maximise the resulting score function.

#### **3.10.2 Projection matrix method (PROJMAT)**

PROJMAT uses a modification of a method originally used to forecast catch at length by projecting length compositions forward in time (Shepherd, 1987b). In this method, a 'projection matrix' is derived to project length classes through time, using a given set of growth parameters and growth equation.

This method requires more than one length frequency distribution. An initial distribution is projected forward to the time of the second distribution, based on the growth parameters and matrix. The resultant frequency distribution is then being compared to the true sampled distribution, through an unweighted least-squares score function. The most appropriate growth parameters therefore provide the best fit between the observed and expected distributions.

### 3.10.3 Electronic length frequency analysis (ELEFAN)

To assess the fit of growth parameters, ELEFAN first restructures the length distribution. This restructuring, using a 'moving average frequency' (Pauly, 1987), denotes peaks (above the moving average) and troughs (below the moving average) in the distribution. Peaks receive a positive value, while troughs are assigned a negative value. A growth curve is then derived, based on a selected set of  $L_{\infty}$  and  $K$  values, and compared to the restructured length distribution. That growth curve is then scored by summing the restructured values for each length class the growth curve passes through ('explained sum of peaks'; ESP). Hence, it is a function of the proportion of available peaks hit and troughs avoided by that curve. The 'available sum of peaks' (ASP) for the distribution represents the maximum score which could be obtained by a single growth curve, being the sum of maximum restructured values for each peak. The ratio ESP/ASP is then maximised by varying the growth parameter set, to identify the best fitting growth parameters

### 3.10.4 About FiSAT

The FiSAT (FAO-ICLARM Stock Assessment Tools) is the product that resulted from merging the Compleat ELEFAN (Electronic Length Frequency ANalysis) package developed at ICLARM (International Center for Living Aquatic Resources Management) (Gayanilo *et al.* 1980) with LFSA (Length-based Fish Stock Assessment) developed at FAO (Sparre 1987). All routines in the earlier packages and some new, useful routines are included in FiSAT.



### 3.11 ESTIMATION OF GROWTH IN TROPICAL SPECIES

As described in previous text, otoliths have been used to age an increasing number of tropical species. However, in the study locations, and for many other tropical locations, growth assessments are performed using non-parametric length-based methods (*e.g.* Posada and Appledorn, 1996).

Such assessments are suitable where there is evidence of discrete modes in the length data (Shepherd *et al.*, 1987; Gulland and Rosenberg, 1992). Such modes are favoured where growth is rapid (generally correlating with a short lifespan), and spawning season is restricted (MacDonald, 1987). In such cases, length-based methods have been used with great success.

As a result of these factors, the methods are considered to have limited applicability for long-lived, slow growing species (Mees and Rousseau, 1997). The biology of such species results in the superimposition of successive modal classes, reducing the information available with which to estimate growth parameters. Furthermore, modes in the data, which are assumed to represent individual cohorts, may actually represent a number of age-classes.

Langi (1990) noted difficulties in deriving growth parameter estimates using ELEFAN for three species of deepwater snapper. Reservations over the use of length-based methods for assessing growth in slow growing individuals were also expressed by MRAG (1996b). In that study, there was no evidence of modal progression in any of the length data collected from a number of tropical reef species in Seychelles. On analysis, length-based methods indicated a number of possible parameter combinations were valid, resulting in considerable uncertainty over the growth estimates.

Although a number of simulation studies have examined the accuracy of length-based growth parameter estimates (*e.g.* Hampton and Majkowski, 1987; Rosenberg and

Beddington, 1987; Basson *et al.*, 1988; Isaac, 1990), these studies have generally concentrated on data for relatively fast growing species, for which these methods are considered more appropriate. Such studies have not been performed explicitly for slow growing species. Furthermore, such studies have examined the impacts on growth parameter estimates alone. Given the potential for uncertainty in growth parameters to be transferred into further parameter estimates, and hence stock assessments and management, it is prudent to examine this potential 'knock-on' effect. Such studies are of particular interest for emperors, given that length-based growth estimates are generally used for such species, and that fisheries based upon them require accurate management to remain sustainable.

### **3.12 THE EFFECTS OF FISHING ON POPULATIONS**

Fishing can act either directly at the level of the population or community through the removal of individuals, or indirectly through effects on growth, the removal of predator or prey species, or the modification of habitats.

For lethrinids, its slow growth rate, low rates of recruitment and natural mortality, and prolonged attainment of sexual maturity make it particularly sensitive to overfishing (Russ, 1991). Since the species is favoured for consumption or sale, it is commonly targeted by fishermen (Munro, 1983b; Koslow *et al.*, 1988), while its aggressive nature and relatively large size also make it particularly vulnerable to fishing gears (Munro and Williams, 1985).

The effects of fishing may be observed as changes in the relative abundance of a species in a fish community (changes in species composition, or 'ecosystem overfishing'; *e.g.* Russ, 1991; Watson *et al.*, 1996; Russ and Alcala, 1998). However, this section aims to provide the reader with a background to those effects of fishing impacts on size and age composition, growth, and reproductive characteristics.

**Table 5 Wet weight of Lethrinids (in tonnes) from banks fisheries 1977 – 1992**

| YEAR | VIELLES | SIGANIDS | LICORNES | GOAT & PARROT | LETHRINIDS   | OCTOPUS | TUNA | OTHERS |
|------|---------|----------|----------|---------------|--------------|---------|------|--------|
| 1977 | 163     | 273      | 234      | 342           | <b>344</b>   | 278     | 31   | 456    |
| 1978 | 154     | 194      | 232      | 322           | <b>354</b>   | 229     | 28   | 451    |
| 1979 | 130     | 226      | 238      | 260           | <b>284</b>   | 306     | 25   | 476    |
| 1980 | 92      | 169      | 86       | 119           | <b>235</b>   | 143     | 12   | 379    |
| 1981 | 91      | 121      | 84       | 164           | <b>282</b>   | 100     | 15   | 355    |
| 1982 | 65      | 147      | 85       | 124           | <b>260</b>   | 65      | 16   | 292    |
| 1983 | 134     | 156      | 88       | 142           | <b>311</b>   | 110     | 21   | 408    |
| 1984 | 182     | 171      | 112      | 170           | <b>329</b>   | 118     | 15   | 278    |
| 1985 | 142     | 140      | 104      | 147           | <b>294</b>   | 116     | 16   | 375    |
| 1986 | 133     | 148      | 112      | 123           | <b>295</b>   | 133     | 14   | 369    |
| 1987 | 119     | 151      | 120      | 191           | <b>331</b>   | 197     | 22   | 466    |
| 1988 | 102     | 137      | 110      | 176           | <b>343</b>   | 133     | 107  | 371    |
| 1989 | 138.6   | 164.5    | 129      | 194.6         | <b>202.7</b> | 154.6   | 95.4 | 464.4  |
| 1990 | 147     | 174      | 127      | 214           | <b>215</b>   | 180     | 102  | 815    |
| 1991 | 141     | 167      | 131      | 205           | <b>206</b>   | 173     | 98   | 537    |
| 1992 | 159     | 189      | 149      | 232           | <b>233</b>   | 195     | 109  | 509    |

Fishing can directly affect the accuracy of growth estimates derived from either length or age data. Due to gear selectivity, fishing commonly targets specific sizes. Therefore, catch samples are unrepresentative of the underlying population structure. In turn, over periods of sustained fishing, gear selectivity may remove larger size classes from the population. This will truncate the size range, and hence reduce the information on which growth parameter estimates are based.

Fishing can also indirectly affect growth, and hence the parameters used to describe it, through 'density dependent growth' (Beverton and Holt, 1957). Where individual growth is limited by population density (*e.g.* through competition for food resources), decreases in population density due to fishing may allow growth rate to increase (Gulland, 1983).

Since density dependent growth has been identified in both marine and freshwater fish populations, the assumption of static life history parameters in fish stock assessment models may be inappropriate.

The use of uncertain growth parameters may have serious effects on the outputs of assessments. Critically, it may lead to the over-exploitation of the resource. Alternatively, it may result in under-exploitation, which may have undesirable socio-economic impacts (*e.g.* loss of jobs or reduction in food supply). In many tropical species, as a result of slow growth and overlapping modes in length frequency data, length-based growth parameter estimates contribute toward this uncertainty; age-based methods of growth estimation may reduce uncertainty, improving management assessments, and hence resource use.

### **3.13 EFFECTS ON SIZE AND AGE STRUCTURE**

Since fishing is commonly directed at larger, older individuals (Bohnsack, 1982; Munro, 1983b; Thompson and Munro, 1983b; Polovina, 1986; Koslow *et al.*, 1988; Ralston and Kawamoto, 1988; Samoilys, 1988; Russ and Alcala, 1989; Gulland and Rosenberg, 1992), it is expected to affect both the length structure and age structure of an exploited fish population (Craik, 1981; Russ and Alcala, 1989; Russ, 1991; Jennings and Lock, 1996). When fish are caught before they grow to the optimum marketable size (*i.e.* before that required to maximise yield), it is termed 'growth overfishing' (King, 1995).

Visual census studies have identified decreases in the mean size of predatory fish populations associated with exploited reefs (*e.g.* Bohnsack, 1982; Craik, 1981; Russ, 1985). Reduction in mean length has also been identified in the length structure of the exploitable phase of the population. In Australian waters, Rowling and Reid (1992) found a decreasing trend in mean length of Gemfish (*Rexea solandri*) over six years. Thompson and Munro (1983b) showed substantial shifts in mean size and size structure in both lutjanids and serranids on Jamaican reefs subjected to differing levels of fishing effort. Cuellar *et al.* (1996) identified a decline in mean length over time in an exploited



population of the snapper *Rhomboplites aurorubens*, in the southeast USA. A compensatory decline in the length at maturity was also identified. Ralston and Kawamoto (1988) found a substantial difference in the modal size of *P. filamentosus* between areas of high and low fishing pressure in Hawaii.

While a number of studies have identified changes in catch length structure, studies of the effects of fishing on age structure are limited. The removal of larger individuals due to gear selectivity may result in 'juvenescence' (Ricker, 1963). This is the successive elimination of older, more fecund size classes. From the limited studies of exploited age structures, the results have been somewhat equivocal. Ralston and Kawamoto (1985) demonstrated that a decrease in the age of entry of *P. filamentosus* to the fishery in Hawaii from 4 yrs to 1.8 yrs was related to an increase in fishing mortality. However, Russ *et al.* (1995) showed no significant differences in the size or age structure of the coral trout *Plectropomus leopardus* within and outside closed areas of the Great Barrier Reef. This was attributed to the short duration of the closure (3 to 4 years) relative to the longevity of the species (14+ years). The lack of studies investigating the effects of fishing on the age structure of exploited tropical fish populations may be a result of the perceived or real difficulties in ageing tropical species (Russ, 1991). This indicates a gap in the knowledge of the effects of fishing on tropical fish populations.

### 3.14 EFFECT ON THE SPAWNING STOCK

Changes in size and age composition may have an effect on the spawning stock ('recruitment overfishing', Russ, 1991). This will depend on the relationship between length at capture and length at maturity. Munro (1983a) noted that approximately half of the species studied in the Jamaican trap fishery became vulnerable to gears well before maturity. It was hypothesised that relatively low catch rates at high levels of effort in the region could be related to local recruitment failure. Rowling and Reid (1992) identified a significant decline in both mean length and abundance of the spawning stock of gemfish, which was attributed to the effects of exploitation. However, such studies are potentially confused by recruitment occurring from outside the local area, and through natural fluctuations in annual recruitment levels.



The selective effects of fishing have particular significance where a species is a protogynous or protandrous hermaphrodite; individuals change sex with size (female to male and male to female, respectively). Size selective fishing may decrease the numbers of females or males in the population, thereby affecting sex ratios, and the reproductive potential of the population (*e.g.* Thompson and Munro, 1983). Such effects on a protogynous species may be minimal, as long as the availability of males does not become limiting, while those on a protandrous species may be more significant (Bannerot *et al.*, 1987).

The factors controlling the point at which a species changes sex have not been identified, although several have been implicated. These include behavior, sex ratio or relative sex ratio (Munro and Williams, 1985). Where sex change is controlled by the sex ratio of the population (social control), effects of fishing on that sex ratio and reproductive potential may be minimized. Where the controlling factor is endogenous, the effects of fishing may be pronounced (Russ, 1991; Jennings and Lock, 1996). Since *L. mahsena* is described as a protogynous hermaphrodite, such changes are of specific interest in the study locations.

### **3.15 EFFECTS ON GROWTH**

Two mechanisms have been suggested through which fishing can affect growth. The first hypothesis suggests that, over time, fishing has an effect on the genetic structure of an exploited population. The second mechanism is based on the release of competitive influences on growth through the removal of individuals by fishing.

Parma and Deriso (1990) postulated that due to intraspecific (between individual) differences in growth rates, (which have some genetic basis) fishing will selectively remove larger (and in theory, faster growing) individuals. Selection against faster growing individuals would result in a fished population containing a larger proportion of slower growing fish (Backiel and LeCren, 1978; Favro *et al.*, 1979; Laevastu, 1992).

Zhao *et al.* (1997) found such a temporal decrease in size-at-age in a fished population of the vermillion snapper *R. aurorubens*. Through simulation, however, Martinez-Garmendia (1998) implied that evolutionary changes in growth may be modest, and are likely to be overshadowed by other density dependent responses.

Gulland (1983) hypothesised how the Von Bertalanffy growth parameters  $L_4$  and  $K$  would vary with stock density, and hence with fishing pressure. Such 'density dependent growth' is thought to arise due to competition either between individuals of the same species (intraspecific competition), or between species (interspecific competition). Since growth is critically dependent on food supply, competition for food resources leads to a reduction in individual growth, compared to the growth of a single isolated individual able to command the same food supply. The removal of individuals through fishing would result in a decline in population density (biomass or numbers), leading to an increase in the growth rate of remaining individuals. As a result, size-at-age would increase, the opposite effect to that suggested by Parma and Deriso (1990). Fishing has been shown to reduce the biomass of lethrinids (Russ, 1985; Polunin and Roberts, 1993; Jennings *et al.*, 1996). A detectable decrease in abundance can occur over a short time. Russ and Alcala (1989) showed that the initiation of fishing on a previously unfished reef in the central Philippines resulted in a 94% decrease in the density of lethrinids after 18 months.

Density dependent growth has also been identified in tropical marine fish species (*e.g.* Doherty, 1982; Jones, 1984a, 1987a, 1987c). Jones (1991) stated that "the effect [of density dependent growth] may be large enough to have an impact on the structure of reef fish populations". Booth (1995) observed a reduced growth rate in large groups of damselfish (*Dascyllus albisella*) compared with that in smaller groups. Munro (1983b) indicated that snappers (Lutjanidae) must compete both amongst themselves and with other species for food and space. This suggests that a reduction in the level of competition would lead to an increase in growth rate at certain biomass levels, although Parrish (1987) stated that the diversity of potential prey might reduce the impact of competition among snappers.

The effects of fishing on the growth of emperors have not been reported. Although density dependent growth may occur, a lack of accuracy and precision in growth and abundance assessments may mask any relationship (Backiel and Le Cren, 1978). Current growth estimates for these species are derived through length-based methods, which are not considered sufficiently accurate to identify changes in growth resulting from the effects of fishing (MRAG, 1996b). The use of otoliths and other hard parts for ageing may go some way to rectify this problem.

The study of population age structure and growth rate is important in the assessment of the potential productivity of exploited fish stocks (Rowling and Reid, 1992). The biology of a species, including its growth rate, determines the way in which individuals and populations are affected by fishing. An understanding of the effects of fishing on a species is therefore vital for the appropriate monitoring of exploited stocks, and the incorporation of fishery induced changes into stock assessment criteria and methods.

The effects of fishing on length and age structure, or changes in growth rate due to density dependence, will also have direct consequences on growth estimates derived using either length- or age-based methods.

**Table 6** Length-weight compositions of the "dame berri" (*Lethrinus mahseha*) caught on banks in the Mauritian Exclusive Economic Zone.

| Banks         | Year | Mean length (mm) | Mean weigh (g) | No. of fish sampled |
|---------------|------|------------------|----------------|---------------------|
| Nazareth      | 1989 | 361              | 773            | 561                 |
|               | 1990 | 349              | 848            | 363                 |
|               | 1991 | 324              | 572            | 871                 |
|               | 1992 | 355              | 787            | 373                 |
|               | 1993 | 305              | 511            | 1518                |
|               | 1994 | 336              | 644            | 1173                |
|               | 1995 | 305              | 540            | 2785                |
| Sava de North | 1989 | 293              | 396            | 700                 |
|               | 1990 | -                | -              | -                   |
|               | 1991 | 295              | 504            | 152                 |
|               | 1992 | 300              | 491            | 1605                |
|               | 1993 | 300              | 478            | 848                 |
|               | 1994 | 309              | 537            | 1974                |
|               | 1995 | 317              | 531            | 1462                |
| Sava de South | 1989 | -                | -              | -                   |
|               | 1990 | -                | -              | -                   |
|               | 1991 | -                | -              | -                   |
|               | 1992 | 296              | 422            | 754                 |
|               | 1993 | 295              | 491            | 3340                |
|               | 1994 | 303              | 507            | 3924                |
|               | 1995 | 283              | 421            | 1150                |
| St Brandon    | 1993 | 321              | 577            | 906                 |
|               | 1994 | 312              | 563            | 587                 |
|               | 1995 | -                | -              | -                   |
| Albatros      | 1993 | 341              | 768            | 432                 |
|               | 1994 | -                | -              | -                   |
|               | 1995 | -                | -              | -                   |
| Chagos        | 1993 | 347              | 823            | 185                 |
|               | 1994 | 299              | 485            | 664                 |
|               | 1995 | -                | -              | -                   |

## **4.0 MATERIALS AND METHOD**

### **4.1 DEFINING AND DESIGNING OF A SAMPLING STRATEGY**

After the literature review and looking at some scientific papers about the work done on other fish species, a sampling strategy was set up for the collection of data. Without a proper sampling scheme, the data collected cannot be dealt with in a meaningful way. For instance, the sample size for length and weight measurements and the parameters to be measured are decided at this stage.

### **4.2 FIELD AND LABORATORY WORKS**

The field works started with a reconnaissance whereby a first trial sampling was done to assess all the possible methods put forward for carrying out the research. This was also done to assess the possible difficulties that could be encountered once the research is initiated.

After assessing all the difficulties of sampling in the field and in the laboratory, the sampling of fish at the fish landing station was initiated. The number of annual samplings depended on the frequency at which the fishing boat landed at that station. Sampling was not possible at fixed intervals since the fishing operations were sometimes disturbed by bad weather conditions and the fishing boat landed a few weeks later than expected.

The first part of the project is mostly concerned with the determination of fish age and growth through anatomical methods and length-frequency analysis.

The data collected in the field were mostly for the length frequency analysis. The total lengths of random samples were used for obtaining data about the length - frequency of a particular stock. Usually it is difficult or even impossible to obtain pure random samples. Juveniles fish are not captured and therefore these fish tend to be under-represented on



the samples. The selectivity of the fishing gear used therefore does not allow the sample to be representative of the whole fish stock.

On the other hand, a more or less random sample is used at the landing station to eliminate any biased samples.

#### **4.3 FISH FOR THE STUDY**

Random samples of this fish *Lethrinus mahsena* were obtained from the commercial fishery operating in the waters of St Brandon.

At monthly intervals samples of  $150 \pm 20$  are used on each sampling occasion. In the field the total length of the fish, the fork length and the mass of individual fish are measured. On each sampling occasion an additional number of fish is brought to the laboratory for further investigation.

#### **4.4 LABORATORY WORKS**

The laboratory works consist of:

1. Reading and recording of the fork length and total length of the fish sample
2. Weighing and recording the mass of the fish.
3. Removing and storing the otolith for later studies
4. Removing the gonads : Recording of their weight  
Storage for further study

5. Removal of the gut
  - a. measuring the gut content
  - b. Analysis of gut content
  - c. Measuring mass of food inside the gut
5. Removal of scales and storage for further study. However, the otoliths and scales were not stored properly and thus could not be used for analysis.

#### 4.5 DATA ANALYSIS

For calculation of the required parameters, the following packages were used: FAO-ICLARM Stock Assessment Tools (FISAT), LENA (in BASICA), Growdata (in BASICA) and MS EXCEL.

FISAT was used to calculate growth rate ( $K$ ) and the asymptotic length or length at infinity ( $L_{\infty}$ ) using both ELEFAN I and the Shepherd's method and the results were confirmed with LENA (Powell-Wetherall Plot). The calculation of natural mortality coefficient,  $M$  was performed using Pauly's  $M$  Equation, and the total mortality,  $Z$  using the Length Converted Catch Curve Analysis. The length at first capture, i.e, the length at which 50% of the fish of that size was caught ( $L_c 50$ ), was calculated using the selectivity curve analysis (Growdata).

The package FiSAT was used to find out the growth curve of the fish. The age of the fish can be determined using the length of the fish or vice versa. It is to be noted that the value of " $t_0$ ", i.e. age at which length is zero, was taken as -0.6 year (Soondron *et al*, 1999).

##### 4.5.1 Powell-Wetherall Plot

Wetherall (1986), following up on work by Powell (1979), suggested a simple method to estimate the asymptotic length ( $L_{\infty}$ ) and the ratio of the coefficients of mortality and growth ( $Z/K$ ), using only length-frequency data from a fish catch. This is based on the well-known equation of Beverton and Holt (1956):

$$Z = K [(L_{\infty} - L)/(\bar{L} - L)]$$

Which estimates the total instantaneous mortality coefficient (Z), in a steady-state population with constant exponential mortality and Von Bertalanffy growth, from the mean length ( $\bar{L}$ ) of a random of fish above length  $L'$ . When using the above equation, it is assumed that  $L'$  and the VBGF parameters  $K$  and  $L_{\infty}$  are given.

#### 4.5.2 Pauly's M empirical Equation

These equations were derived from 175 independent sets of estimates of  $M$  and predictor variables for most tropical species. Two options are provided; (1) for cases when  $L_{\infty}$  is available and (2) for cases when  $W_{\infty}$  is available.

##### *Input parameters*

Growth parameters  $L_{\infty}$  (in cm) or  $W_{\infty}$  (in g) and  $K$  ( $\text{year}^{-1}$ ) and  $T$  [mean annual habitat temperature (in  $^{\circ}\text{C}$ )]. The values of  $L_{\infty}$  to be used should refer to or approximate total length.

##### *Functions*

Option 1:  $L_{\infty}$  is given

$$\ln(M) = -0.0152 - 0.279 \ln(L_{\infty}) + 0.6543 \ln(K) + 0.463 \ln(T),$$

and

Option 2:  $W_{\infty}$  is given

$$\ln(M) = -0.4851 - 0.0824 \ln(W_{\infty}) + 0.6757 \ln(K) + 0.4687 \ln(T)$$

##### *Output*

Estimate of  $M$ .

#### 4.5.3 Length-converted catch curve

The basic model of the length-converted catch curve consists of a plot of the natural logarithm of the numbers of fish caught in various age groups ( $C_i$ ) against their corresponding age or age group ( $t_i$ ), i.e.:

$$\ln(C_i) = a + b * t_i$$

and  $Z$  is estimated from the slope  $b$ , with sign changed, of the descending right arm of the plot.

The following assumptions are involved here:

- $Z$  is the same in all age groups used in the plot.
- All age groups used in the plot were recruited with the same abundance (or the recruitment fluctuations were small and of random character).
- All age groups used in the plot are equally vulnerable to the gear used for sampling.
- The sample used is large enough and covers enough age groups to effectively represent the average population structure over the period considered.

In practical terms the estimation of  $Z$  from a length-converted catch curve then involves the following steps (assuming that the sample used is large enough and covers enough age groups to effectively represent the average population structure over a period of time considered):

- (1) Pooling of catch data to obtain a single, large sample representative of the population for the period under consideration;
- (2) Construction of the catch curve proper, using the large sample in (1) and a set of growth parameters;
- (3) Estimation of  $Z$  from the descending right arm of the catch curve.

Pooling of sample (such as monthly catches) over a relatively long period (at least one year) is particularly important in short-lived fish and shrimps, as their whole population

structure is affected by seasonal 'pulses' of recruitment, generally one or two per year (Pauly and Navaluna, 1983). Also, to prevent a single, larger (monthly) sample from unduly affecting the total (annual) sample, the samples may all be given the same weight, by conversion to percentages prior to adding to obtain a single overall sample.

There are many alternatives to a scheme where each sample is given the same weight. For example, it might be more appropriate to weight the samples by the square roots of the size when the fishery catch is not known, or by the catch when it is. However, empirical studies into appropriate sample sizes and weighting factors for length-converted catch curves are still lacking. Thus, it will be best to always compare the results obtained using the three weighting options incorporated in FiSAT, and to use their correspondence (or the lack thereof) as a basis for further decisions or studies.

The length-weight relationship of the fish was determined using MS EXCEL as a tool and the values of 'a' and 'b' were found using the formula  $W = aL^b$  (where "W" represents the weight and "L" the length of the fish).

The Gonado-Somatic Index (GSI) and Hepato-Somatic Index (HSI) were calculated by the formulae

$$\text{GSI} = \frac{100 \times \text{Gonadal Weight}}{\text{Total Body weight}}$$

and

$$\text{HSI} = \frac{100 \times \text{Liver Weight}}{\text{Total Body weight}}$$

respectively (Goldinho et al, 1974).



#### 4.5.4 Modal progression analysis (MPA)

Prior to the discovery of daily and seasonal rings in fish otoliths and scales, the detailed analysis of length-frequency data was, besides mark-recapture studies and direct observation of captive fish, the only method available to draw inferences on growth of the tropical fishes, and indeed the only method that could be applied routinely (Pauly, 1987). A great deal of confused terminology surrounds the use of length-frequency data in growth analysis, and before discussing this approach it is necessary to clarify the terms which we shall use.

Here, we use the term *modal progression analysis* (MPA) for the method in which several length-frequency samples are plotted sequentially, and where the apparent shift of modes is used to infer growth. In MPA the first step, “linking”, is the identification of means or modes representing cohorts, after which subjective identification of the means or modes perceived to belong to the same cohort of fish enables the tracing of growth curves, or the computation of growth increments between modes. Thus, in MPA, the issue is not the attribution of ‘ages’ to the various groups- as in the Petersen method- but the linking of means perceived to belong to the same cohort.

There is a number of methodologies that can be applied to decomposed distributions into their components as the initial step in MPA, but only one will be used here – the Bhattacharya’s method, as incorporated in FiSAT.

##### 4.5.4.1 Bhattacharya’s method

Bhattacharya (1967) developed a methodology useful for splitting a composite distribution into separate normal distributions when several age groups (cohorts) of fish are contained in the same sample. The key advantage of this method is that it is straightforward to understand (Pauly and Caddy, 1985).

The Bhattacharya method basically consists of removing normal distributions, each representing a cohort of fish, from a mixture of distributions, starting on the left-hand side of the overall distribution. Once the first normal distribution has been identified, it is

subtracted from the total distribution and the procedure is repeated as long as it is possible to identify distinct normal distributions.

It should be noted that, due to the limited data available, the length frequency data of the 16 samples taken was pooled into four bigger samples named sample A, sample B, sample C and sample D respectively and for the length/weight relationship, the data was pooled in one whole sample for better results.

## 5.0 RESULTS

Figure 3 shows the length frequency data for the 16 different samples. For convenience purposes to determine the modal progression, the figures were placed one below the other and were considered as one figure.

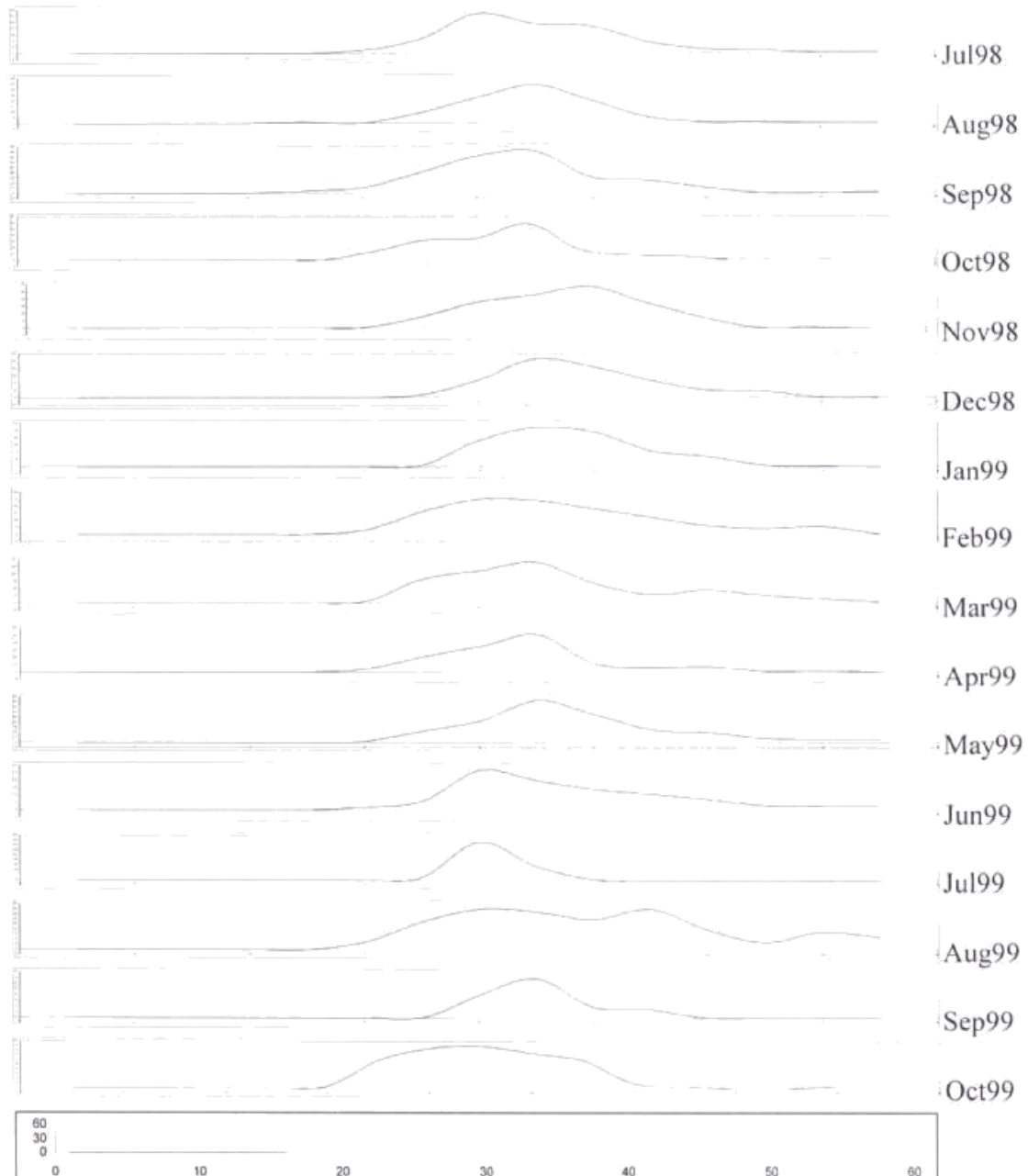
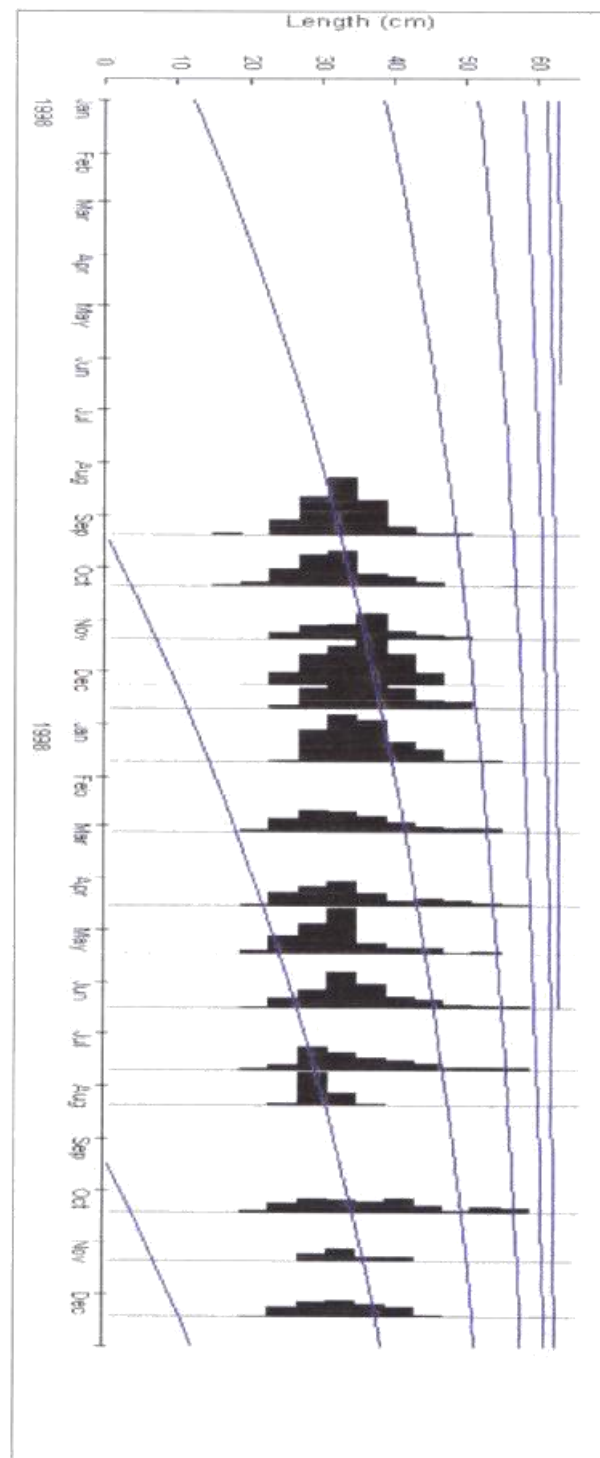


Figure 3: Length Frequency Data for the 16 samples of *L. Mahsena*



**Figure 4: Modal Progression Analysis-MPA (FiSAT)**



### Length / Weight Relationship

723 pairs of data comprising the length and weight of *Lethrinus mahsena* were used to determine the values of 'a' and 'b' in the formula  $W = aL^b$ . The software MS EXCEL was used to input the data and to plot the graph of weight against length of the fish. The values of 'a' and 'b' were found to be 0.0165 and 3.0007 respectively. Figure 4 shows the graph of the length/weight relationship of *Lethrinus mahsena*.

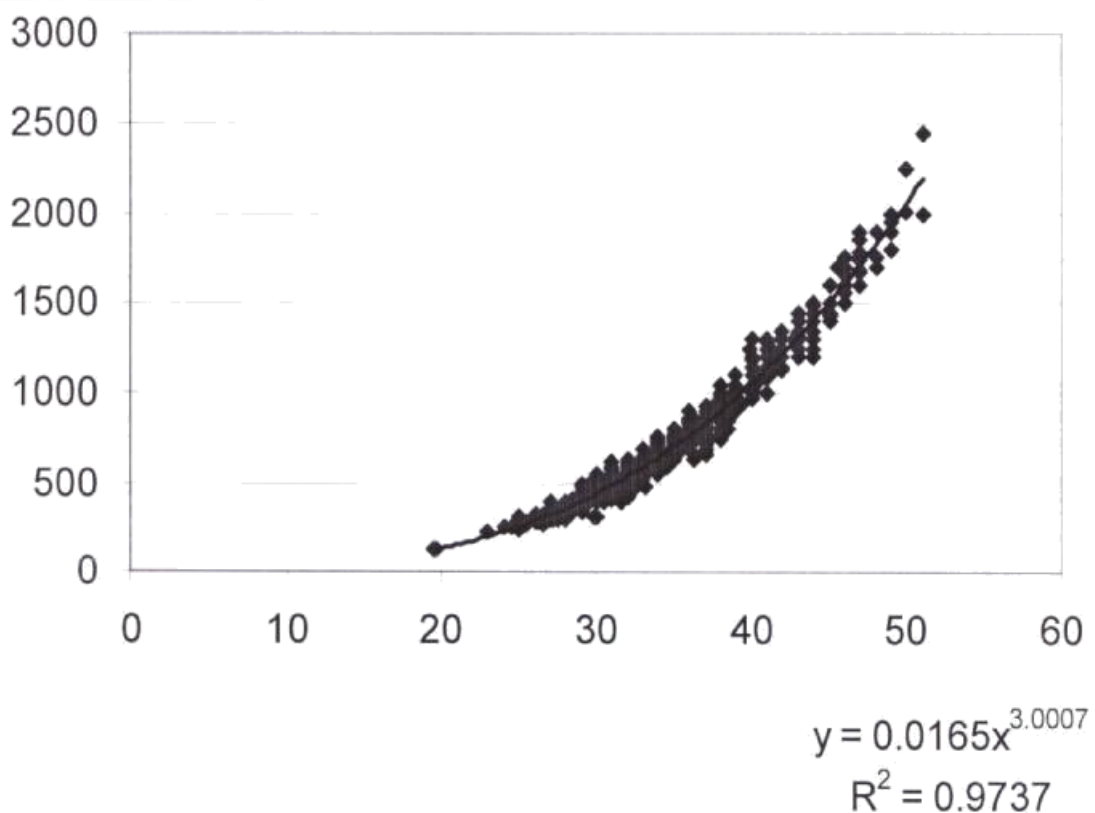


Figure 5- Length/Weight Relationship of *Lethrinus mahsena* (Dame Berri) on the St. Brandon Bank

### Gonado-Somatic Index (GSI)

Figure 6 shows the Gonado-Somatic Index (GSI) of *Lethrinus mahsena* on the St Brandon Bank.

From the graph, it can be seen that the value of the GSI drops from 0.43 in July 1998 to zero in the following month before increasing gradually, with small irregularities, until September 1999. After this month, there is a sudden decline in the GSI.

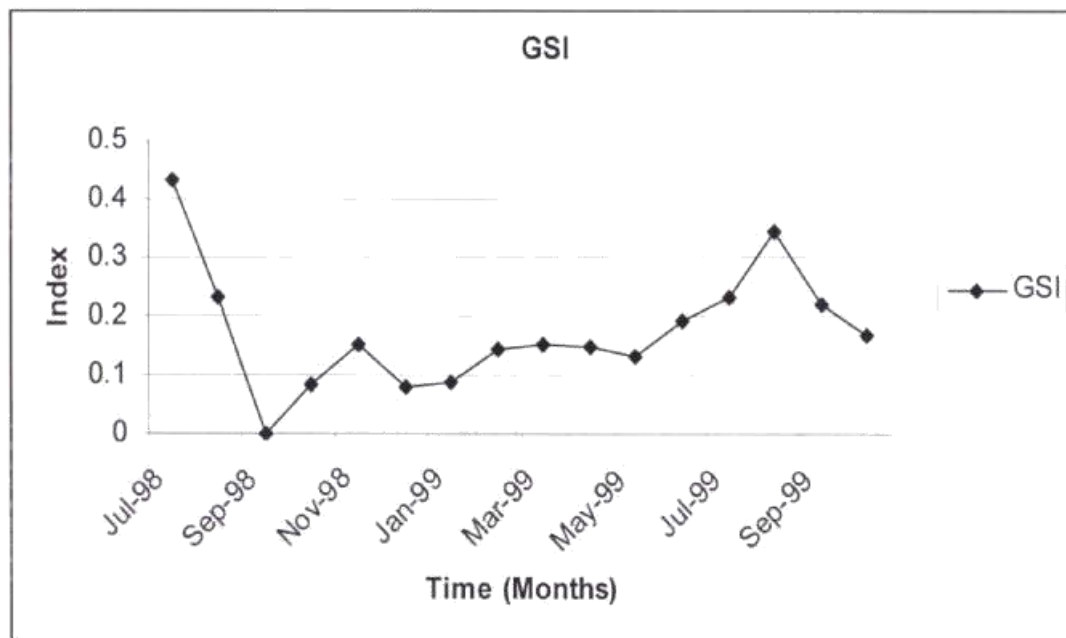


Figure 6: Gonado-Somatic Index (GSI) of *Lethrinus mahsena* on the St. Brandon Bank

### Hepato-Somatic Index (HSI)

Figure 7 shows the Hepato-Somatic Index (HSI) of *Lethrinus mahsena* on the St Brandon Bank.

The graph shows that, just like the GSI, there is a drastic drop in the HSI by September 1998. Apart from some minor irregularities, the values of the HSI remains more or less constant from October 1998 to July 1999 before its starts to increase.

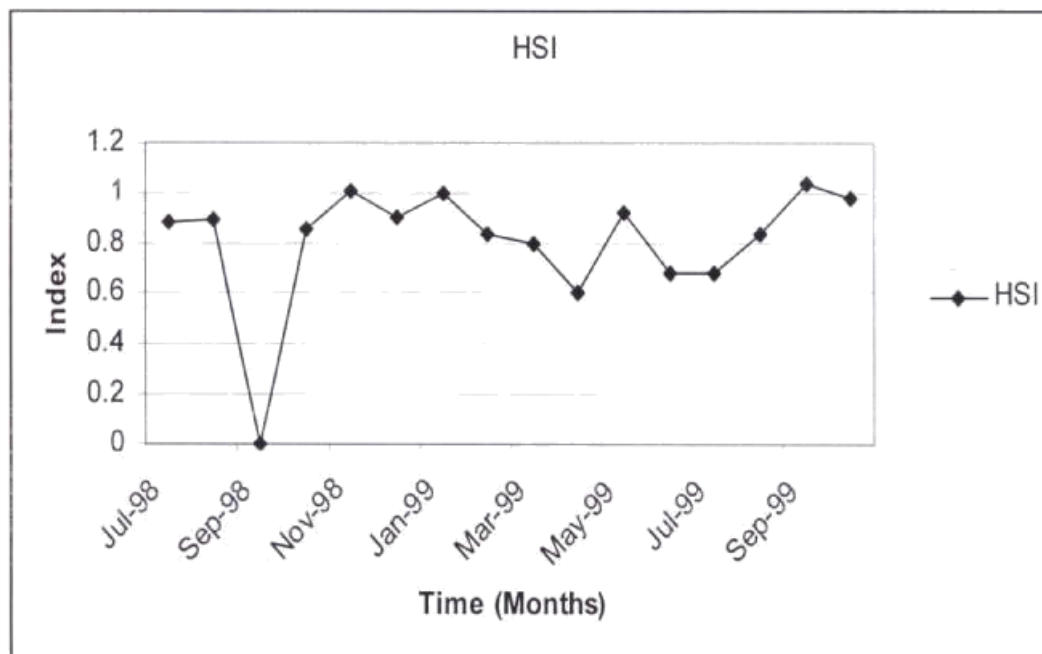


Figure 7: Hepato-Somatic Index (HSI) of *Lethrinus mahsena* on the St. Brandon Bank

### Correlation Between GSI and HSI

Figure 8 shows the correlation between the GSI and the HSI of *Lethrinusd mahsena* on the St. Brandon Bank.

It can be clearly seen from the graph that the GSI is directly related to the HSI from July 1998 to July 1999 while for the remaining months of sampling they become indirectly related. It can also be noted that in general, the values of the GSI is by far lesser than that of the HSI.

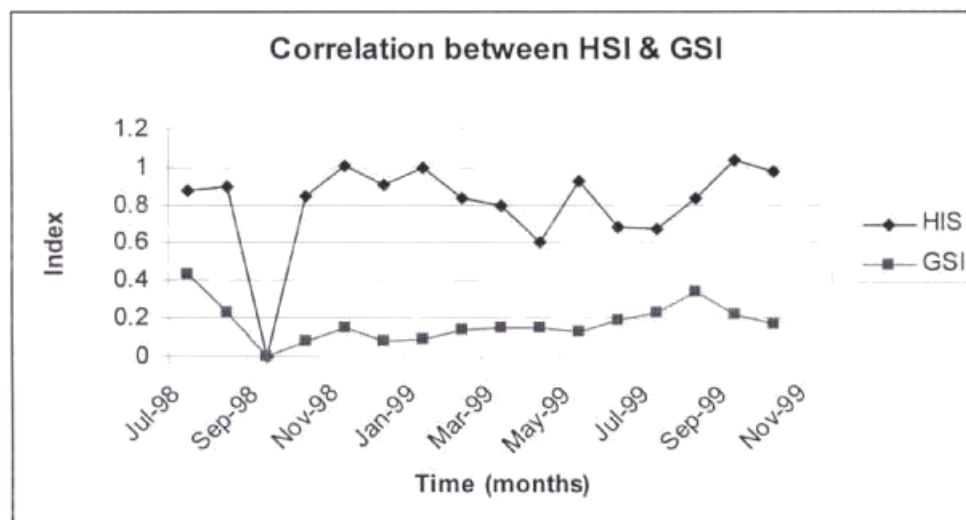


Figure 8: Correlation between HSI & GSI of *Lethrinus mahsena* on the St. Brandon Bank



### Fulton's Condition Factor (CF)

Figure 9 shows the Fulton's Condition Factor (CF) of *L. mahsena* on the ST. Brandon Bank.

No general trend in CF can be observed from the graph. The values of CF are very irregular along the months.

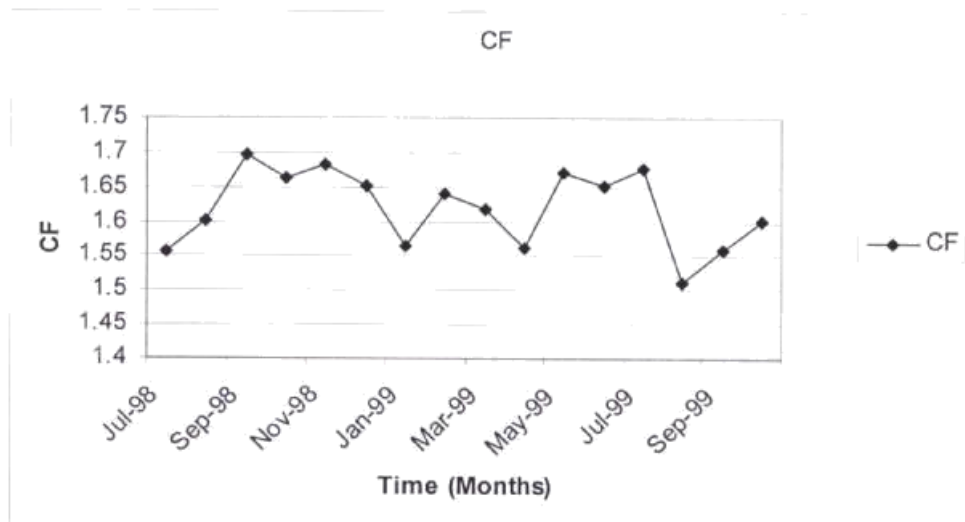


Figure 9: Fulton's Condition Factor of *Lethrinus mahsena* on the St. Brandon Bank

### Data Table

Table 7 shows the length frequency data of *L.mahsena* on the St. Brandon bank.

Due to the limited amount of data available, the four different four-month samples were pooled together into one sample in order to calculate the value of Lc50. At the same time, the values of  $L_{\infty}$ , K, Z, M and F were also calculated for the grouped data.

**Table 7: Length frequency data over a period of 16 months, divided by four evenly distributed quarters of four months:**

| <i>Sample</i>       | <i>L<sub>∞</sub></i> | <i>K</i>    | <i>Z</i>    | <i>M</i>    | <i>F (Z-M)</i> | <i>Lc50</i> |
|---------------------|----------------------|-------------|-------------|-------------|----------------|-------------|
| Sample 1            | 63                   | 0.13        | 0.43        | 0.35        | 0.08           | -           |
| Sample 2            | 63                   | 0.25        | 0.98        | 0.53        | 0.45           | -           |
| Sample 3            | 63                   | 0.10        | 0.41        | 0.29        | 0.12           | -           |
| Sample 4            | 63                   | 0.13        | 0.77        | 0.35        | 0.42           | -           |
| <b>Grouped data</b> | <b>63</b>            | <b>0.12</b> | <b>0.65</b> | <b>0.34</b> | <b>0.31</b>    | <b>31.8</b> |

From the table, it can be noticed that the value of the asymptotic maximum length,  $L_{\infty}$  remains constant for the four different sample as well as for the grouped data sample, that is, 63cm. The values of the growth constant, K varies from 0.10 to 0.25 with an average of 0.12 for the grouped data. The total mortality, Z is the sum of the natural mortality, M and the fishing mortality, F. The value of the length at first capture, Lc50 was found to be 31.8

## 6.0 DISCUSSION

### 6.1 LENGTH-WEIGHT RELATIONSHIP AND FULTON'S CONDITION INDEX (K)

The relationship between length (L) and weight (W) of fish can generally be expressed by the equation

$$W = aL^b$$

Where “a” is the multiplicative factor and the exponent “b” lies between 2.5 – 3.5 (usually close to 3) (Carlander, 1967,1977) has demonstrated from an extraordinarily large number of length-weight data, derived from a wide variety of fishes, that values of  $b < 2.5$  or  $b > 3.5$  are generally based on a very small range of sizes and/or that such values of  $b$  are most likely erroneous. When  $b=3$ , weight growth is called isometric, meaning that it proceeds in the ‘same’ dimension as the cube of length ( $L^3$ ). When  $b \neq 3$ , weight growth is allometric, meaning that it proceeds in a ‘different’ dimension (differing from  $L^3$ ). Allometric growth can be either positive ( $b > 3$ ) or negative ( $b < 3$ ).

Another way of relating length and weight is to define a condition factor (K or C) such that

The Fulton's Condition Factor is calculated as follows:

1. Assumes that an isometric length-weight relationship is the norm; hence  $b=3$  in the length-weight regression

2. Metric quantification

a.  $K = (W / L^3) \times 100$  (Bagenal and Tesch, 1978) ; W is in g; L is in cm

b. K varies from species to species and within species; a  $K = 1$  indicates that the fish is in the isometric “normal” condition

3. English quantification

a.  $C = (W / L^3) \times 10,000$ ; W is in pounds; L is in inches

b. The scaling factor differs between the two methods.

#### 4. Problems with Fulton's K or C

a. K and C are not equivalent

b. Index values change depending on the length unit

c. Index values are not comparable among species

d. Index values increase with length for some species; probably because of the assumption that  $b = 3$

When weight growth is isometric ( $b=3$ ), we also have

$$K / 100 = a$$

Where 'a' is multiplicative factor in the equation  $W = aL^b$ . It must be emphasized, however, that the condition factor in a given fish species or stock can be compared to that of another species or stock only if the same units and definitions have been used (Same way of quantification). The units and definitions must always be stated.

In addition many variables, such as sex, time of year, stage of maturity and stomach content, influence the numerical magnitude of the condition factor. Comparisons should be made only when these variables are roughly equivalent among samples to be compared.

#### 6.1.1 Length/Weight Relationship

During this study, data pertaining to individual length and weight of the fish were collected. That is, the total length (L, in cm) and corresponding whole weight (W in g) for both males and females combined were taken. These were used in a power curve regression analysis (MS EXCEL) to estimate values for the parameters **a** and **b** in the



equation,  $W=aL^b$ . From the graph, the values of 'a' and 'b' in the above equation were found to be **0.0165** and **3.00079** ( $R^2 = 0.9737$ ) respectively, as shown in the figure 3.

From the graph, it can be seen that the length is proportional to the weight of the fish and the values of **a** and **b** are quite in accordance with results from the Saya de Malha banks. In 1986, Bertrand *et al*, reported  $a = 0.012$  and  $b = 3.160$  (for females) and  $a = 0.0164$  and  $b = 3.077$  (for males) there. It can be affirmed that these results are not significantly different and that as far as length/weight relationship is concerned, *Lethrinus mahsena* shows no great variation between the two banks.

### 6.1.2 Condition Factor, CF

The Fulton's condition factor (CF) was also calculated from the data collected using the equation  $CF = 100W / L^3$  where W and L are the total weight (g) and total length (cm) of fish respectively, as shown in the figure 9. Note that the annotation for the condition factor here is written CF instead of the traditional K so as to avoid confusion with the growth constant K.

The graph shows no general trend in CF amongst the months, be it for the fact that the sample has been taken over a too short range of time. There are great variations, however, in the CF along the 16 months of study.

The CF is vital in the determination of the 'weight-converted von Bertalanffy equation':

$$W(t) = W_{\infty} (1 - e^{-k(t-t_0)})^b.$$

if weight data is to be used to determine the growth parameters (for example, if there is no length data available).

## 6.2 GONADO-SOMATIC INDEX AND HEPATO-SOMATIC INDEX

### 6.2.1 Gonado-Somatic Index (GSI)

According to Goldinho et al (1974), the Gonado-Somatic Index (GSI), is expressed as a relationship (%) between the weight of the gonads and the total body weight of the fish and is calculated as follows:

$$GSI = \frac{100 \times \text{Gonadal Weight}}{\text{Total Body weight}}$$

The GSI is used:

- To study gonadal development and sexual maturation
- To determine the spawning time so as to take appropriate measures
- To see if there is any seasonal variation in spawning

Figure 7 shows the GSI of *Lethrinus mahsena* in St. Brandon during the 16 month of study.

### 6.2.2 Hepato-Somatic Index (HSI)

The Hepato-Somatic Index (HSI), in turn is the relationship between the weight of the liver and the total body weight of the fish and is calculated as follows:

$$HSI = \frac{100 \times \text{Liver Weight}}{\text{Total Body weight}}$$

Here, the HSI is being used as a function of the eating habit of the fish. The liver weight is assumed to represent the amount of food taken by the fish.

Figure 6 shows the HSI of *Lethrinus mahsena* in St. Brandon during the 16 month of study. From the graph, it can be observed that the values of HIS are more or less constant from July 1998 to July 1999 before they start to increase in the remaining sampling

months. During this period, it is assumed that spawning is taking place and this will be discussed in the next section.

### 6.2.3 Relationship between GSI and HSI

It is assumed that *Lethrinus mahsena* eats less during the spawning season and to prove this, the GSI and the HSI was plotted against time. If this assumption is true, the result should be the GSI not related to the HSI in the spawning season and directly related during the rest of the year.

The relationship between the GSI and the HSI of *Lethrinus mahsena* in St. Brandon is shown in Figure 8.

From the graph, it can be seen that from month 1 to 14, the GSI seem to be directly related to the HSI while for month 15 and 16, they start to divert and there is no relation. That is, when GSI start to decrease, HSI increases. This information may lead us to assume that spawning has started to occur by the 15<sup>th</sup> month, that is, by September 1999. This is very important information in order to determine appropriate measures to be taken during spawning seasons, for example, mesh size of fishing nets and fishing seasons.

### 6.3 LENGTH FREQUENCY ANALYSIS

Back-calculated lengths at age was used to estimate growth parameters  $L_{\infty}$ ,  $k$  and  $t_0$  of von Bertalanffy's growth equation

$$L^t = L_{\infty} (1 - e^{-k(t-t_0)})$$

The value of  $L_{\infty}$  was determined and undertaking linear regression of  $\text{Log}_e(1 - (L_t / L_{\infty}))$  against age provided values for  $K$  and  $t_0$ . These parameters were fitted into von Bertalanffy's equation and sizes of fish at successive ages were determined (theoretical lengths can then be computed and compared with the back-calculated sizes).

A chi squared goodness-of-fit is usually performed for the comparison between estimated and theoretical growth rates. Since there is no theoretical data available for St-Brandon yet, no comparison could be made.

It is worth noting that the length distribution in a sample from a specific population is the product of recruitment, growth, mortality and sampling errors. Annual variations in recruitment and individual variability in growth frequently mask the interpretation of modal classes in length frequency. The assumption that each modal class in a frequency distribution will correspond to a cohort and represent different age classes determined at regular intervals need to be made. The presence of modes in the length distribution depends on the distance between the medians, the extent of the variance, the proportion of each age in the population and the size of the sample studies.

Earlier studies (Bertrand, 1986) has shown that populations of this species show marked seasonal recruitment, where the identity of year classes is maintained and that growth is sufficiently swift to avoid excessive superimposition of the lengths of successive age classes. The same has been found by Wassef (1990) in a comparative growth studies of *L.mahsena* in the red sea. This enables methods of growth determination using the length frequency analysis.

Despite the fact that gear selectivity (as in this present study) influences the type of length frequency, this method was nevertheless used in growth determination and spawning. The smaller lengths, not fully recruited to the gear, were under-represented.

According to Hommer (1973) estimation of the parameters of each age class, such as average length and relative abundance, are enormously facilitated by having separate samples from one or more age class. A time sequence of length frequency distributions makes it possible to separate age classes, which might otherwise be obscured by the super-imposition of frequencies. Changes over time in each cohort can be analysed visually or by computerised methods developed from Hasselblad (1966), which separated the modal classes of the length-frequency. Various approaches can be used in the



process of selecting modes in a single frequency: - graphic methods which determines the area of the cumulative frequency and statistical methods based on maximum likelihood.

The determination of median lengths and relative abundance in each cohort is more precise when a sub sample of age data is available for one or more of the age classes present in the length-frequency (Hosmer, 1973). In view of this, the interpretation of the data from the readings of the otolith microstructure would help towards establishing the correlation of von Bertalanffy's parameters,  $L_{\infty}$  and  $k$ . errors in plotting from the same set of length-frequency data will be avoided. Age determination of a length-frequency sub sample makes it possible to know the number of age classes in a population and makes the calculation more accurate. Morgan (1987) applied age data to improve growth parameters calculated from length frequency.

In this study one of the main advantages of the length-based method was that the basic data were easy to obtain. Given the variation in the sizes and ages of fish caught in different times and places, only with length-based methods, it is likely to be practicable to collect statistically adequate information. However, collection of age data is often constrained by problems of interpretation and collection of catch and effort data by the operational complications of the commercial fishery. The collection of length data (as representing what is caught, if not always what is in the sea) is less constrained, and the sampling systems for length data that are statistically efficient.

Sampling design and sampling intensity was given some attention at the beginning of the study. However, there has been the problem of the chicken and the egg. A good design cannot be set up until something is known about the variability of the data, what analyses could be made with the data, and how the precision and reliability of the answers are affected by the sampling errors and by other sources of uncertainty. These questions cannot, however, answered until data are collected to show how length samples vary from place to place and from time to time, some preliminary analyses have been made with the data.



Initially, sophisticated design was not expected. The first stage was concerned merely with collecting as many data as can reasonably be done, making sure that there was as wide a spread as possible, with data being collected in all seasons (or all seasons in which fishing is done).

The values of the growth parameters for *lethrinus mahsena* in St. Brandon are shown in the table 7.

Compared to the data obtained by Soondron *et al* (1999), Bautil *et al* (1988), and Mees *et al* (1997) in Saya de Malha, the values of  $K$  and  $L_{\infty}$  are quite similar. Bautil *et al* (1988) found  $K = 0.1 \text{ year}^{-1}$  and  $L_{\infty} = 61.7$  in 1988, Soondron *et al* (1999) reported  $0.17 < K < 0.19$  and  $61.7 < L_{\infty} < 71.2$  respectively from 1997 to 1999, and Mees *et al* (1997) estimated  $K = 0.09 \text{ year}^{-1}$  and  $L_{\infty} = 64.3$  in 1999.

#### 6.4 MORTALITY

In fisheries biology, the most useful way to express the decay (= decrease) through time of a group of fish born at the same time (a cohort) is by means of 'instantaneous' rates. These rates, of which there are three (**Z**-total mortality, **M**-natural mortality, and **F**-fishing mortality), are defined by the equation:

$$Z = M + F$$

Obviously, when  $F = 0$ ,  $Z = M$ , which means that natural and total mortality have the same value when there is no fishing, i.e. in an unexploited stock. The unexpectedly high value of  $F$  in sample 2 (Table 7) can be attributed to the fact that it occurs in the summer period where most fishing occurs.

Fisheries biologists have two main jobs as far as mortalities are concerned:

- To estimate total mortality;
- To split their estimates of total mortality, where appropriate, into separate estimates of natural and fishing mortalities.

#### 6.4.1 Natural Mortality

Natural mortality (M), as defined in the literature, is caused by all possible causes of death except fishing. Direct estimates of M can therefore be obtained only from completely unfished stocks. Yet values of this parameter are needed, from exploited stocks, for most of the models currently used in fish population dynamics.

In exploited fish stocks, values of M may be obtained from estimates of total mortality (Z) from which fishing mortality (F) is subtracted, or by a plot of Z against fishing effort (f), M then representing the intercept (at  $f = 0$ ). These two approaches obviously have their limitations, the first in the fact that most exploitable fish stocks are currently exploited, the second in the total mortality and contemporary fishing effort data are very often unavailable.

This has led to various empirical models for the estimation of M from values of correlates, i.e. of parameters related to M (length). One of which is the Pauly's M empirical equation.

From the result obtained in FiSAT, the value of Z for the whole sample was 0.65 and that of M was 0.34. Hence the fishing mortality, F was calculated 0.31.

Here also, the values were quite in accordance the data from Saya de Malha. Soondron *et al* (1999) reported  $Z = 0.71$ ,  $M = 0.42$  and  $F = 0.28$ . However, it should be pointed out that here in St. Brandon, the fishing mortality is greater than that of the Saya de Malha bank (0.31 compared to 0.28). That is, the percentage of fish dying through fishing is greater in St. Brandon.

## 6.5 SPAWNING TIME / FREQUENCY

Since *Lethrinus mahsena* is a slow growing fish, determination of the spawning time and spawning frequency was difficult in this project because the sample taken was over a short period of time (16 months). According to data obtained from the Saya de Malha bank, the fish has a life span of 8-10 years. So, spawning may or may not have been taken place during these 16 months under study.

It should be noted that since the sample range was too small, the MPA calculated in FiSAT was compared to a manually made length-frequency figure (Figure 3). An attempt was made by visually trying to define the modal progression by placing the length-frequency charts one below the other but no cohort was prominent.

A larger sample size and range is thus recommended if the spawning time and frequency is to be determined.

However, the result obtained from the Gonado Somatic Index and the Hepato Somatic Index shows that spawning occurs around September 1999.

## 6.6 LC50 AND LM50

The length at which 50% of the fish population is caught (Lc50) and the length at maturity of the fish (Lm50) was also determined from data obtained about the length and minimum length of fish caught.

Lc50 should always be less than Lm50 if we want to have a balance in the population dynamics of the fish. When Lm50 exceeds Lc50, appropriate measures are required so as to restore the balance.

The value obtained for the Lc50 here is 31.8 cm. It exceeds the value of Lm50 which has been estimated to be below 30cm (Personal Communication, 2003). Thus, according to

the result, the population of *Lethrinus mahsena* in St. Brandon is still in good shape. However, since the sample size is small, further data collection is recommended.

## **7.0 CONCLUSION**

### **7.1 MANAGEMENT MEASURES**

Due to the limited data available, a proper management strategy could not be defined in this project. Thus, more data collection is recommended on the St-Brandon bank. However, the results obtained have allowed us to get an overview of the situation on St-Brandon. For example, since most of the parameters are more or less in compliance with the data from Saya de Malha, some of the measures applied there could be applied in St. Brandon also.

### **7.2 DATA COLLECTION**

There should be improvement in the raw data collection and care should be taken in the sampling procedure as very often the catch is segregated according to the size of the fish. Smaller sized fish should be included in the samplings performed in order to get a complete picture of the existing resources. Observer programs should be organized to collect more raw data on the fishing ground.

### **7.3 OTHER TECHNIQUES TO DETERMINE GROWTH PARAMETERS**

From studies carried out recently, it seems that age-based methods are more suitable and accurate than length-based methods. Otolith readings could be used to determine the growth parameters, provided they are well stored and well handled. Unfortunately, in this project, the otoliths stored were damaged, most probably due to its acidification in the formaldehyde. The age-based method also allows the determination of independent natural mortality. Other biological parameters such as sex ratio and length at recruitment should also be carried out. There is a need to evaluate age-based stock assessments in order to compare management performances with length-based methods.



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