

How to design a marine reserve for rabbitfish (*Siganus fuscescens*)

by

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Dedication

This thesis is dedicated to the memory of Greg Bott. His life, support, and inspiration as a husband and friend will never be forgotten. You, too, were my saving grace.

Table of Contents

<i>List of figures and tables</i>	vii
<i>Abstract</i>	viii
<i>Glossary of Filipino terms</i>	ix
<i>Acknowledgements</i>	x
<i>Chapter 1: Introduction</i>	1
<i>Chapter 2: Population dynamics and spawning profile of S. fuscescens</i>	
<i>Methods</i>	7
<i>Collection</i>	7
<i>Measurements</i>	8
<i>Histology of gonads</i>	9
<i>Otolith removal, preparation and reading of daily growth increments</i>	10
<i>Growth</i>	12
<i>Mortality</i>	13
<i>Yield per Recruit</i>	15
<i>Results and Discussion</i>	
<i>Growth</i>	17
<i>Length/Weight Relationship</i>	17
<i>Length at Age</i>	17
<i>Length/Frequency Analysis</i>	19
<i>Direct aging of otoliths</i>	23
<i>Mortality</i>	25
<i>Recruitment</i>	28
<i>Timing</i>	29
<i>Maturity</i>	33
<i>Fecundity</i>	35
<i>Behaviour</i>	37
<i>Management</i>	38

<i>Chapter 3: Daily Movement Patterns and School Dynamics of S. fuscescens</i>	
<i>Methods</i>	42
<i>Site Selection</i>	42
<i>Time of Study</i>	43
<i>Observations</i>	44
<i>Analysis</i>	45
<i>Results</i>	46
<i>Discussion</i>	52
<i>Chapter 4: The design of a marine fishery reserve (MFR) for Bolinao</i>	55
<i>Modelling the effects of an MFR on spawning stock biomass per recruit and yield per recruit</i>	58
<i>Designing an MFR for S. fuscescens</i>	61
<i>Applying the movement results to the proposed marine reserve</i>	64
<i>Conclusion</i>	67
<i>References</i>	68

List of figures and tables

Figure 1:	Bolinao (with seagrass distribution).....	2
Table 1:	Samples collected by site	8
Figure 2:	Observed and fitted length at age in <i>S. fuscescens</i>	18
Figure 3:	ELEFAN's modal progression analysis to fitted length frequency data	20
Table 2:	Estimates of growth and mortality	22
Table 3:	Oxytetracycline marks	24
Figure 4:	Catch curve using selection ogive	27
Table 4:	Spawning profile	28
Table 5:	Monthly recruitment of <i>S. fuscescens</i> (May 1987-April 1988)	29
Figure 5:	Distribution of spawners and sites for marine reserves.....	32
Table 6:	Fecundity estimates	36
Figure 6:	Yield/recruit and biomass/recruit	39
Figure 7:	Daily rates of activity	47
Table 7:	Linear regression of school dynamics and movement	48
Table 8:	Multiple regression of school dynamics and movement	49
Table 9:	Linear regression: how a change in school affects activity	50
Table 10:	Relative home range and maximum length	50
Figure 8:	Home range and length of fish	51

Abstract

The purpose of this thesis is to design the size, shape and location of a marine fishery reserve targeting *Siganus fuscescens* (*barangen*) in Bolinao, Pangasinan, The Philippines. Movement and daily activity patterns were studied to approximate territory size, characteristics of schools and schooling behaviour, the degree of activity and feeding throughout the day, and where *S. fuscescens* could be found at night. Samples were taken from various gears monthly to determine length/weight relationships and distribution and size of spawners. From these data, fecundity, spawning dates, growth (K) and natural (M) and fishing mortality (F) were estimated. Furthermore, some otoliths were removed to determine an age/length relationship. Daily rings were validated with an oxytetracycline marking experiment, and fish were aged by counting these daily growth rings under a microscope.

Population dynamics were estimated using FiSAT, a fisheries modelling program developed by ICLARM and FAO. An estimate of K was given using both the age/length data fitted to a von Bertalanffy growth curve and using ELEFAN to approximate K from length frequency analysis using the modal progression analysis. Natural mortality (M) was estimated using Pauly's M equation, and fishing mortality (F) was approximated using a catch curve. Previously collected data of yields by gear of *S. fuscescens* were used to obtain yield/recruit and biomass/recruit estimates.

The above information and previously known information on the behaviour and biology of this species was then used to model the potential success of a future marine reserve in Bolinao, using the predictive marine reserve yield models of Demartini (1993) and Russ et al. (1992). Two sites are proposed for a marine reserve in Bolinao, and a potential increase in yield to the fishery is predicted. The two sites were selected due to being potential spawning sites and known feeding areas. Suggestions for future general management of this species are made, such as maximizing production by decreasing the effort of the *padas* fishery, and minimizing the removal of ripe spawning individuals.

Glossary of Filipino terms

<i>bagoong</i>	-	fish paste
<i>baklad</i>	-	fish corral
<i>banca</i>	-	small boat with bamboo supports
<i>barangen</i>	-	rabbitfish
<i>basnig</i>	-	purse seine
<i>nasa</i>	-	bamboo traps
<i>padas</i>	-	juvenile Siganids
<i>pana</i>	-	speargun
<i>parisris</i>	-	floating gillnet

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Aysha Soter-Parsons and company: For distracting me and showing me what matters.

Chapter 1: Introduction

The coral reef fisheries in the Philippines account for approximately 10 to 15% of the country's total yield (Carpenter, 1977), and 50% of these fish are caught by subsistence and artisanal fishers (Smith et al., 1980). Bolinao is a small fishing village located on the northwestern tip of the Pangasinan province on Luzon, The Philippines (Figure 1). The Bolinao reef is a fringing reef, with an extensive reef flat and reef slope, divided by a reef crest. Large patches of seagrasses (*Enhalus* and *Thalassia*) and *Sargassum* beds are dispersed throughout the reef flat and approaching the reef crest. The fishery in Bolinao has been overfished, often using destructive, non-sustainable fishing practices (McManus et al., 1992). The Bolinao fishery accounts for 35% of the employment for a population of 50,000 (McManus et al., 1992), and is highly dependent on the harvest of *Siganus fuscescens* (Houttuyn, 1782), accounting for 26% of the total catch (Aragones, 1987; Campos et al., 1988; McManus et al., 1992).

Siganus fuscescens have a high market value, as they are a preferred food fish locally and nationally. Adults are harvested and eaten fresh or dried and eaten as a snack, and the juveniles are harvested and fermented with salt to make *bagoong* (fish paste), a popular condiment. Siganids are one of the most important food fishes in the Philippines due to their year-round abundance (Alcala, 1979), suitability for mariculture (Bryan and Madraisau, 1977; von Westernhagen and Rosenthal, 1976;

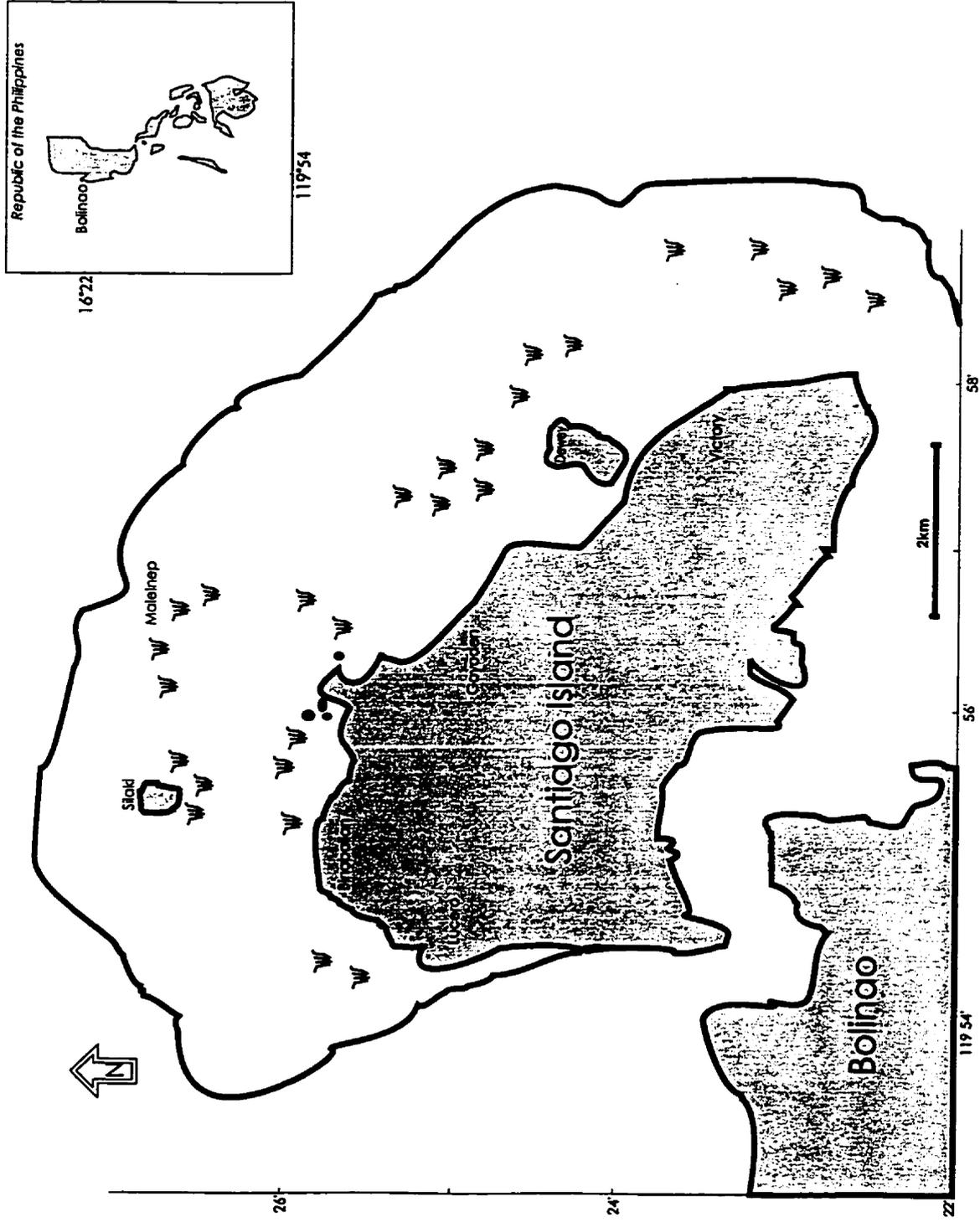


Figure 1: Bolinao (with seagrass distribution)

Popper and Gundermann, 1976; Tahlil, 1978), and high growth rate (Horstmann, 1975).

S. fuscescens is in the order Perciformes, family Siganidae (rabbitfishes).

Siganidae have a single genera *Siganus*, which are characterized by having three soft rays between their inner and outer spine, and seven anal fin spines (FishBase, 1995).

S. fuscescens is called the dusky or sandy spinefoot in the U.S., the dusky rabbitfish in Australia and *barangen* in the Philippines. *S. fuscescens* are widely distributed throughout the estuaries, intertidal, and marine habitats of Indo-Pacific and eastern Mediterranean. The body is olive green or brown, with a silvery belly and small spots. When frightened, *S. fuscescens* displays a mottled colour and projects its venomous spines.

There has been some confusion in the taxonomy of *S. fuscescens* (de la Paz and Aragonés, 1990), which has been misidentified as a small-spot form of *S. canaliculatus* (Lam, 1974). For this paper I have used many examples of *S. canaliculatus* for the reasons that the research cited may have actually been for *S. fuscescens* and not *S. canaliculatus* and that these two species are closely related, often found in the same area schooling together, and have similar spawning habits.

S. fuscescens are caught in seagrass and *Sargassum* beds using a variety of gears which target the fish at different stages of their life cycle and daily behaviour patterns. Gill nets are used by fishers in rafts or small boats (*bancas*), who throw off nets into seagrass beds to catch schools while they feed; spawning fish are caught in

fish corrals (*baklads*), which are arranged primarily to catch the fish during their spawning migration; spearguns (*pana*) are used to catch sleeping fish, which lie on their sides on the bottom of seagrass beds, and; purse seines (*basnig*) with a lantern platform are used to catch the phototactic juveniles (*padas*) at night. *S. fuscescens* are also caught using bamboo traps (*nasa*), and floating gillnets (*parisris*).

A marine reserve has been proposed for Bolinao, targeting *S. fuscescens* in order to increase the yields of this lucrative fishery which have declined in recent years. In order to design a marine fishery reserve to increase the stocks of a particular species, knowledge of its growth, movement patterns, mortality, and time and location of spawning help to make better decisions on where and how large a marine reserve should be. As studies on the population dynamics and movement patterns of Siganids in general, and *S. fuscescens* in particular, have been neglected, this thesis has examined these areas in order to better design a marine reserve for Bolinao and to predict potential benefits to the fishery.

Studies of the movement of fish have been important in determining home range (Ball, 1947; Gunning and Shoop, 1963; Luckhurst and Luckhurst, 1978; Fish and Savitz, 1983; Bozeman et al., 1985; Mesing and Wicker, 1986; Savitz et al., 1993), migration routes (Mesnig and Wicker, 1986; Savitz et al., 1993), and suitability of a species for a marine reserve (Man et al., 1995; DeMartini, 1993; Russ et al., 1992). Movement studies reveal patterns of behaviour which can be used in management of fisheries, such as territory, schooling behaviour and spawning areas. Many movement studies are conducted using tag and recapture (Ball, 1947), ultrasonic tracking (Hart and Summerfelt,

1975; Savitz et al., 1993), radio-tagging (Mesing and Wicker, 1986), and radio telemetry (Savitz et al., 1983), yet when there are limited resources and time, direct observation of a species with relatively limited movement may prove a valuable technique in learning about movement patterns, territory, spawning areas and behaviour (Keenleyside, 1962; Bachman, 1984; Griffith, 1972; Fausch and White, 1981). As territory can be affected by the season (Winter, 1977; Langhurst and Schoenike, 1990), have daily fluctuations (Bohlin, 1978; Helfman, 1986; Savitz et al., 1993), changes due to fluctuations in resources (Chapman and Bjornn, 1969; Ford, 1983), and change during spawning (Mesnig and Wicker, 1986; Savitz et al., 1993), direct observation of the species may give a more complete picture of how the movement and feeding varies throughout the day.

S. fuscescens is a schooling species which feeds continuously throughout the day, primarily on epiphytes and the terminal ends of the seagrass *Enhalus*. Schooling can benefit a species through early detection and reaction to a predator (Godin and Morgan, 1985; Bertram, 1987; Lazarus, 1979), by obtaining information about foraging and risk of predation (Ryer and Olla, 1991), having more time to forage due to group vigilance (Siegfried and Underhill, 1975; Morgan, 1988), being more able to find resources (Pitcher, 1982; Krebs et al., 1982), having a hydrodynamic advantage (Partridge and Pitcher, 1979; Blake, 1983), and, due to the above advantages, having enhanced growth rates (Davis and Olla, 1992). Chapter 3 looks at how the changes in school size, the size range of individuals within a school, habitat and depth affect both relative territory and activity. This information is then used to make management recommendations such as

the size and location a marine reserve would need to be to protect a particular portion of the spawning stock.

Before a marine reserve may be designed or any management measures focussing on *S. fuscescens* are initiated, a better understanding of the fundamental biology and abundance should be known. Chapter 2 focusses on updating the population dynamics which were known and recorded by del Norte and Pauly (1990) for *S. fuscescens* in Bolinao in 1987, and to supplement that information with direct aging, the location and time of spawning, and estimates of fecundity. With a better understanding of fish age when they are recruited to the fishery and when they first spawn, comes better management considerations as to whether or not the fish are being taken from the fishery before they reach spawning age, and thus cause a loss of recruitment. Furthermore, understanding whether or not the same individual can spawn more than once, and how often gives clues as to how to manage this species. There has been a lack of information about the age at length of Siganids, and very little known about both the population dynamics and biology of *S. fuscescens* in particular.

Chapter 4 is an attempt to design a marine fishery reserve by integrating the results from the population dynamics in Chapters 2 and the movement results of Chapter 3. Both quantitative and qualitative results will be used in order to estimate potential yields and in choosing a size and location for the reserve. This study will be used in the design of a local marine fishery reserve in Bolinao, and can also be used to increase the general knowledge of Siganids and *S. fuscescens* in particular.

Chapter 2: Population Dynamics and Spawning Profile of *S. fuscescens*

Other studies have examined the population dynamics of *S. fuscescens* in Bolinao (del Norte and Pauly, 1990), yet important information such as direct aging, spawning frequency and location have been unknown. This chapter gives a more comprehensive look at the Bolinao *barangen* stock, focusing on growth, mortality, yield/recruit and spawning. This addition to the knowledge of the population dynamics of *S. fuscescens* should give a more complete picture of the growth and an updated account of the mortality and yield/recruit, leading to suggestions for management and protection.

Methods and Materials

Collection

Fish were collected from fishers at their gear, and GPS coordinates were taken for the location of their catch. Samples were taken around the northern coast of Santiago Island, in the regions of Lucero, Binabalian, Silaki Island, Malelnep and Dewey, from 16°23-27N and 119°54-59E. Length/weight measurements were taken from fish corral, gillnet, speargun and trap from April to September, 1996. Although fish corral and gillnet samples were taken at least once per month, and up to four times per month, not all gears could be sampled every month due to problems in sampling during the rainy season and availability of boats and time of fishing (e.g. speargun collections are done from midnight to 3:00a.m.).

Table 1: Samples collected by site

<i>SITE</i>	<i>GEAR</i>	<i>N</i>	<i>E</i>	<i>DATE</i>	<i>TIME</i>
1	gillnet	16°25.86	119°55.8	06-17-96	1:47 pm
2	trap	16°25.76	119°55.6	06-17-96	3:07 pm
3	corral	16°24.86	119°57.3	06-17-96	8:00 am
4	corral	16°26.01	119°56.7	07-12-96	6:30 am
5	gillnet	16°26.04	119°56.4	07-12-96	6:30 am
6	corral	16°26.14	119°56.1	07-12-96	6:30 am
7	corral	16°22.31	119°58.3	07-19-96	6:30 am
8	gillnet	16°26.02	119°55.9	07-19-96	2:00 pm
9	gillnet	16°26.22	119°55.4	07-19-96	2:00 pm
10	gillnet	16°26.23	119°55.9	07-19-96	2:00 pm
11	corral	16°24.86	119°57.3	08-14-96	7:00 am
12	gillnet	16°25.38	119°56.6	08-14-96	7:00 am
13	gillnet	16°25.97	119°55.8	08-16-96	3:00 pm
14	corral	16°22.06	119°57.9	08-23-96	6:30 am
15	corral	16°22.6	119°58.8	08-23-96	6:30 am
16	corral	16°24.45	119°58.1	08-23-96	6:30 am
17	gillnet	16°26.01	119°55.5	08-23-96	6:30 am
18	corral	16°26.38	119°55.8	08-30-96	8:30 am
19	corral	16°22.06	119°57.9	08-30-96	8:30 am
20	gillnet	16°24.86	119°57.3	09-09-96	6:00 am
21	gillnet	16°25.89	119°55.9	09-13-96	4:30 pm

Measurements

Standard length to the nearest millimeter, total weight to the nearest gram and gonad weight to the nearest milligram were taken. Gonads were removed, and one sample

per gonad stage each sampling date was preserved for histological sections to confirm the stage of gonad maturation. Gonadosomatic indices of samples were recorded on random samples of fish >5cm SL for each gear sampled from June to September.

To determine fecundity, 1% of the gonad weight was removed and the eggs were counted by teasing them apart in a petri dish and projecting the image from an overhead projector onto a wall, where the eggs were counted and multiplied by 100.

Histology of Gonads

Gonads were sectioned to stage them as ripening, ripe or spent, and to estimate the amount of time between these stages. The paraffin technique used was:

1. Fixed in formalin, 3% to 5%.
2. Washed in tap water.
3. Dehydrated in ethyl alcohol:
 - a. 30% - 1 hour
 - b. 50% - 1 hour
 - c. 70% - 1 hour
 - d. 85% - 1 hour
 - e. 95% - 1 hour
 - f. 100%- 1 hour
4. Cleared: one hour each.
 - a. 75 parts ethyl alcohol, 25 parts xylene
 - b. 50 parts ethyl alcohol, 50 parts xylene

- c. 25 parts ethyl alcohol, 75 parts xylene
- d. 0 parts ethyl alcohol, 100 parts xylene (2 changes)
5. Paraffin filtration: 60°C to 65°C temperature.
 - a. Equal volume of xylene and soft paraffin of 46°C and 48°C.
 - b. Pure soft paraffin of 46°C to 48°C
 - c. Equal volume of soft paraffin (46°C-48°C) and hard paraffin (57°C-59°C).
 - d. Pure hard paraffin (57°C-59°C).
6. Embedded in pure hard paraffin (57°C-59°C).
7. Affixed tissue block.
8. Sectioned in rotary microtome (9 microns to 10 microns).
9. Affixed tissue sections in the microscope slide.
10. Stained with Hematoxylin-eosin stain: mounting in balsam.
11. Dried, cleaned, and labeled.

Otolith Removal, Preparation and Reading of Daily Growth Increments

The sagittae were chosen for reading due to the ease with which they are extracted and read in general and in Siganids in particular (Mangaoang, 1982). The asterisci, when available, were also read to obtain a more accurate reading. To remove the otoliths the freshly caught *S. fuscescens* were cut ventrally from the anal pore straight through the isthmus. The gills and organs were removed and the tissue was scraped away from the hindbrain. Using a pair of pointed dissection scissors, the fish palate was cut diagonally, deeper posteriorly and shallower anteriorly. Cotton wool was used to remove any excess

liquid and expose the otoliths in each otic capsule. A pointed probe and narrow forceps were used to extract the otoliths, and they were stored dry in small paper envelopes.

The dry otoliths were mounted on a glass slide using a drop of cyanoacrylate glue. Then they were ground using 30 μ m paper for coarse grinding and 3 μ m paper for fine grinding to better expose the daily growth increments.

Sagittae were read using oil immersion on a light microscope with 1250X magnification onto an image analysis system using Optimas 5.2 to increase the size of the image, and a medium filter to enhance the contrast between the daily increments. The asterisci were read directly from the microscope at 1000X magnification. Each otolith was read twice, and some otoliths were chosen blindly to test the precision of the reader. A coefficient of variation was computed to test the precision of the two readings of each otolith, and an ANOVA was used to test if the daily increment counts from the asterisci and sagittae of the same fish were significantly different.

To validate the use of daily growth increments of the otolith, the fish were injected with oxytetracycline hydrochloride and raised in an aquarium for 30 days. Oxytetracycline marks the otolith on the day of injection, so that the number of daily growth increments can be counted from the date of the injection to the date of death. The oxytetracycline marks were then viewed using a microscope which used ultraviolet light to illuminate the fluorescent band.

The fish used in the calibration experiment were collected over a period of four days at night, when they are sleeping and easier to catch (inclusive period September 14 to 17, 1996). A total of 78 siganids were collected and stored in a 330 litre aquarium until

injection. Many of the fish appeared sensitive to being handled (developing a bacterial infection where they were touched), and only eleven fish survived the injection. The fish were given an injection of oxytetracycline hydrochloride in the coelomic cavity, between the pelvic fins (McFarlane and Beamish, 1987). The dosage was selected to be 50 mg/kg of fish, in a 2mg/ml sterile saline solution (Ferreira and Russ, 1992). The eleven surviving fish were reared in a 330 litre aquarium for 30 days and fed a combination of *Enhelus* and TetraMin fish food. After 30 days, the standard length and weight were measured and the otoliths removed. The otoliths were stored in a black sealed case to prevent the light breaking down the oxytetracycline in the otoliths.

Growth (K)

The age at length data were fitted to the von Bertalanffy growth curve (Gayanilo Jr. et al., 1994):

$$L(t) = L_{\infty} [1 - \exp(-K(t-t_0))]$$

using a sum of squared errors (SSE) to obtain a best fit:

$$SSE = \sum_i \{L_i - L_{\infty} [1 - \exp(-K(t_i - t_0))]\}^2.$$

L_i = length of fish i

t_i = age of fish i

t_0 = hypothetical age at which the fish would have zero length

L_{∞} = asymptotic length

K = curvature parameter which determines how fast the fish approaches L_{∞}

Growth was also estimated using ELEFAN (Electronic Length Frequency Analysis) direct fit of length frequency data using FiSAT (FAO-ICLARM Stock Assessment Tools) version 1.1, a computer program developed by ICLARM (International Center for Living Aquatic Resources Management) and FAO (Food Agriculture Organization). First, the data are restructured into peaks and troughs by dividing each frequency by the frequency average of the peak, and subtracting 1. A vonBertalanffy growth curve passes through the highest R_n score, which is the ESP/ASP (explained sum of peaks and available sum of peaks). The ESP is the sum of the peaks and troughs that a vonBertalanffy curve passes through, whereas an ASP is the maximum score a curve can have. The curve of the line fitted follows the inverse von Bertalanffy growth equation, where relative age is a function of length. Thus, the ESP/ASP ratio is a measure of how close a curve can come to a best fit.

Mortality

Natural mortality (M) is an important component in estimating total mortality (Z) and yield per recruit. When estimates of M are too high, then the maximum sustainable yield estimation can be too conservative, resulting in a loss of production, whereas estimating M too low can lead to overfishing and loss of production. As natural mortality is very difficult to measure directly, indirect estimates using parameters which affect natural mortality, such as growth and temperature, are used to give a general

approximation. Natural mortality was computed using Pauly's empirical M formula (Sparre et al., 1989), which is a regression analysis of M on K (per annum), using L_{∞} and average annual surface temperature (T) based on 175 different fish stocks in the following linear relationship:

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

Natural mortality was also estimated using Rickhter and Efanov's formula (Sparre et al., 1989), where M is related to t_{m50} , the age where 50% of the population is mature, where:

$$M = 1.521/(t_{m50}^{0.72}) - 0.155 \text{ per year}$$

Total mortality (Z) is fishing mortality (F) plus natural mortality. Z was estimated using a length-converted catch curve in FiSAT (Gayanilo Jr. et al., 1994), which gives an estimation of Z from the length-frequency data. This method consists of a plot of the natural log of the frequency of different sizes plotted against their relative ages and estimates Z from the slope of the descending curve using the following formula:

$$\ln(N_i/\Delta t_i) = a + b \cdot t_i$$

N = the number of fish in length class i

Δt_i = the time needed for the fish to grow through that length class i

t = the corresponding age of the midlength of class i

b = an estimate of $-Z$

Z was also estimated using the Jones and van Zalinge method (Sparre et al., 1989), where Z is the slope of a regression on $C(L, L_\infty)$ (the cumulated catch of fish at length L and above) multiplied by K :

$$\ln[C(L, L_\infty)] = a + Z/K \ln(L_\infty - L)$$

Only those lengths which represent that portion of the population which are fully recruited and not too close to L_∞ are used. This estimation of Z gives a narrower confidence interval than the linearized catch curve.

Yield/Recruit

Yield/recruit is used to estimate the contribution a recruit would make in its lifetime to the stock. Yield/recruit assumes that the population has reached equilibrium, that recruitment is constant, and that all fish of a cohort are hatched on the same date. Yield/recruit gives an estimate of a maximum sustainable yield, which allows a manager to maximize production by controlling the fishing effort. Yield/recruit was estimated

using Beverton and Holt's model, which examines the dependence of yield on growth, fishing mortality and age at first capture. The yield of a single year class from the age of first capture to the maximum age a fish will reach is an integral of F , the number of fish present and their mean weight. Yield/recruit was estimated by fitting the age at length per capture to a selection curve using FiSAT (Gayanilo Jr. et al., 1994) in the following form:

$$Y'R = \sum P_i((Y'/R)_i G_{i-1}) - ((Y'/R)_{i+1} G_i)$$

$(Y'/R)_i$ = relative yield/recruit computer from the lower limit of class i using:

$$(Y'/R)_i = EU^{M/K} \{1 - ((3U/(1+m)) + ((3U^2/(1+2m)) - (U^3/(1+3m)))\}$$

$$U = 1 - (L_c/L_\infty)$$

$$m = (1-E)/(M/K) = (K/Z)$$

$$E = F/Z$$

P_i = probability of capture between L_i and L_{i+1}

$$G_i = \prod r_j, \text{ and}$$

$$r_j = (1-c_j)^{S_i} / (1-c_{j-1})^{S_i}$$

$$S_i = ((M/K)(E/(1-E)))P_i$$

A selection curve was used rather than knife-edged recruitment to the fishery as the fishery has some size selection in their catch, focussing on larger fish.

Results and Discussion

Growth

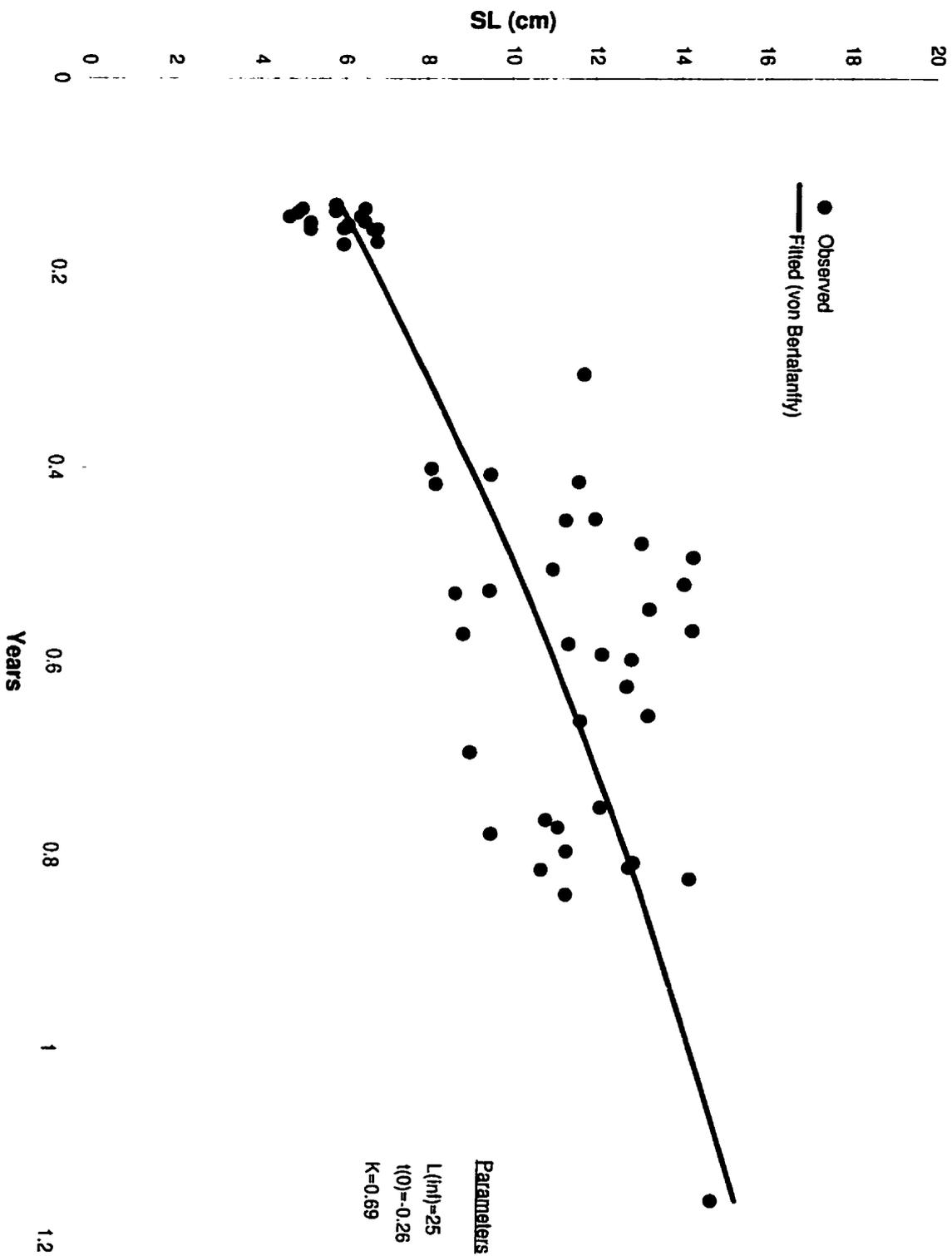
Length/Weight Relationship

The length/weight relationship of a fish is a non-linear relationship, which can be transformed into a linear equation by taking the logs on both sides. The length/weight relationship was approximated by using 818 individual measurements of length and weight, with the slope (b) = 2.8 and the intercept (a) = -3.1. These coordinates are then fitted into the form $W=aL^b$, where a linear regression on the length/weight relationship gives the slope ($e^a = 0.0439$) ($R^2 = .978$, $P = .001$). Length estimates were used instead of weight, as weight measurements were only taken for 410 of the measurements.

Length at Age

An accurate prediction of L_{∞} (the mean asymptotic length for individuals in a stock) is an important component in estimating growth (K). Although in this paper L_{∞} was estimated at 25cm SL, Horstmann (1975) found *S. fuscescens* in a Cebu market to be up to 597g (approximately 29.5cm), yet his sample was from the 1970s in Cebu and may be a population with a different length/weight relationship and no growth overfishing. K was estimated at 0.69 by fitting the age at length data to the von Bertalanffy Growth Function, with L_{∞} as a set parameter of 25cm (Figure 2). When L_{∞} was not set, and the von Bertalanffy Growth curve estimated the best fit through the age at length data provided,

Figure 2. Observed and fitted length at age in *S. fuscescens*



it approximated an L_{∞} value of 12.4cm. This was not used as: 1) lengths used in the length frequency analysis had values up to 19.5cm; 2) an L_{∞} of 25cm being used by del Norte and Pauly (1990) in previously published data on this stock, and; 3) a personal observation of a pair of approximately 24cm individuals in the wild, and; 4) the high standard error (0.715) for the K value estimated at 0.69 as there is a high degree of variation at age at length and there are no representative lengths (i.e. ages) for over 15cm and under 4.7cm, leaving 10cm in the high range and 4cm in the lower range to be estimated without data. Although no fish close to L_{∞} were found in the market or in the samples collected in the wild, this could be due to the high fishing pressure (a harvest rate of over 99%), and thus fish are caught before reaching L_{∞} .

Length-frequency analysis

K was also approximated using ELEFAN's direct fit of length frequency analysis (Figure 3) to fit the growth curve to the length frequency data (with L_{∞} as a set parameter). Only the fish corral gear was used, as it is less selective than other gears. Table 2 presents the different estimates of K, Z and F (with L_{∞} set at 20 and 25cm) for the direct aging data fitted to the von Bertalanffy Growth Curve, and for the two estimates made by ELEFAN using the fish corral only and fish corral with gillnet for the fall and spring cohorts. Estimates of 0.75 and 0.8 had the highest R_n (goodness of fit index of ELEFAN) scores (not 0.69 as the length at age data suggests), yet due to the known variation in age at length, the missing lengths mentioned above and another estimate of K at 0.85 for the same population in 1988 (del Norte and Pauly, 1990), the ELEFAN estimate of K with L_{∞}

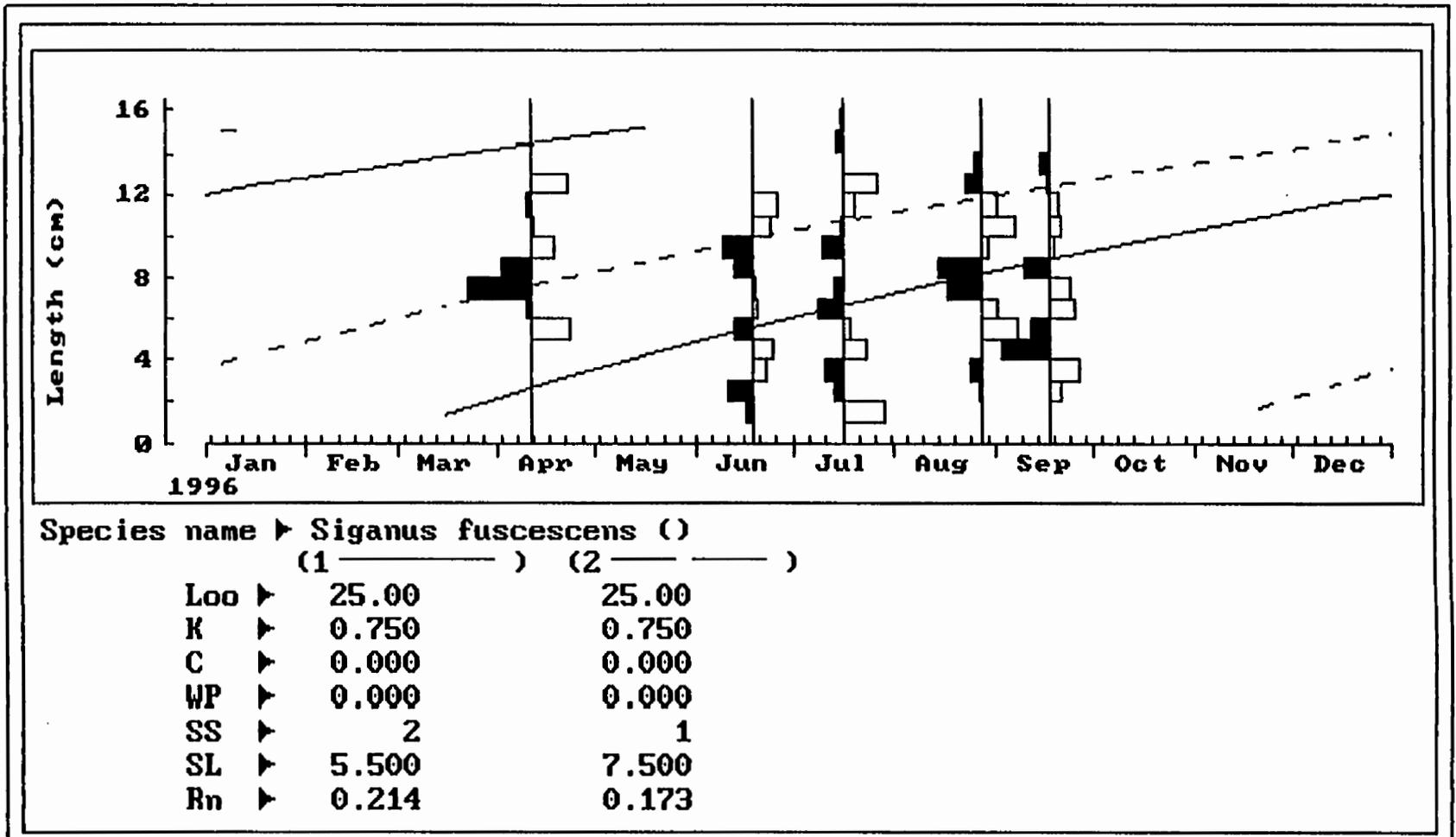


Figure 3: *ELEFAN's modal progression analysis to fitted length frequency data.*

The peaks are generated by taking a moving average frequency over five length groups and subtracting 1. The black bars and the white bars represent the positive and negative peaks respectively. The solid line is the spring cohort and the dotted line the fall cohort.

set at 25cm was selected as the best estimate. ELEFAN estimated two different K values: 0.75 for the spring cohort and 0.8 for the fall cohort. As these two estimates are quite close, and since the direct aging von Bertalanffy growth curve estimated 0.69, the lower estimate was used. Yet, it is possible that the two cohorts have different growth curves, as the fall recruitment occurs during the hot rainy season when productivity is high, and thus the fall recruits may have a higher growth rate.

As there are sampling biases, it was difficult to define a discrete cohort by length alone. These sampling biases were: larger individuals not being caught, and thus represented in this analysis; using only five months of data to interpret one year of growth; using only 1 gear of eight possible gears make a length frequency analysis incomplete; and although recruitment was in two pulses, lower levels of recruitment appear to occur continuously and even the pulses occur over several months, making it difficult to define a discrete cohort by length alone. Furthermore, the direct fit of length frequencies will have much variation and may be biased by the small sample sizes and high catches at one length class. Therefore, only one estimate of K was chosen, as there is not enough certainty in the data to warrant two different growth curves. Future studies using a longer time series of length frequency analysis, as well as direct aging of fish which have been sexed and represent the full range of ages should be used to get a better understanding of variations in K over seasons and between sexes.

Table 2: Estimates of Growth and Mortality

	<i>Von Bertalanffy: Length at Age</i>		<i>ELEFAN Corral Only</i>				<i>ELEFAN Corral & Gillnet</i>			
			Fall		Spring		Fall		Spring	
L_{∞}	20	25	20	25	20	25	20	25	20	25
K	1.04	0.69	1.1	0.8	1.0	0.75	0.75	0.8	0.9	0.75
Z	6.23	6.86	7.35	"	"	"	6.70	"	"	"
F	4.74	5.37	5.86	"	"	"	5.21	"	"	"

Two cohorts could be easily distinguished from the direct fit of length frequency analysis (Figure 3). Yet, each of these cohorts had several months which could have been predicted as the month of recruitment by selecting a different peak length or sample. This is probably due to spawning continuing over several months, making each cohort come from three to four months of spawning, and not a single month. As the fish were of similar size, the fish from different months in the same spawning peak often overlapped once the fish became older and the sizes had more natural variability. Also, as some spawning occurred in between spawning peaks, there was some presence of minor peaks not appearing to belong to either cohort. A more complete sample of gears, with some knowledge of the gear's selectivity would help to better approximate K by including larger size classes and more sampling of the new recruits, both lacking in this study.

Direct aging of otoliths

Aging is an important component in estimating growth, as it provides a direct age at length measurement rather than a relative aging applied from length frequency analysis. Aging was done to get a better understanding of growth in general, and age at reproduction in particular. Knowing the age provides information on what is the age at first reproduction, whether a recruit from the first spawning peak may spawn by the second spawning peak, and how many times a fish may be able to spawn in its lifetime.

S. fuscescens have daily growth increment rings on their otoliths, with the asterisci easier to read than the sagittae. Both the sagittae and the asterisci were removed because they are large enough to remove with the naked eye and also often coming out together, attached by the semicircular canals. The daily growth increments of the sagittae were closer together and more susceptible to overgrinding, which resulted in splitting of the growth increments. Most of the sagittae from the older fish had to be read with the help of an image analysis system to magnify the image and enhance the contrast between growth increments. The asterisci needed very little grinding and had more space between the growth increments, making them easier to read with the microscope alone. Yet, the nucleus of the asteriscus was sometimes hard to read, as the growth increments were very faint. Secondly, as the asterisci are formed approximately two weeks after the metamorphosis of the larvae, the absolute age is unknown. When both the sagittae and asterisci could be read from the same fish, an estimate could be made of when the asterisci were formed by taking the mean difference between these two readings, and adding the number of days (13) onto the mean asteriscus count.

A coefficient of variation (CV) was calculated for each pair of readings of each otolith (CV=3.51% for the asteriscii and 2.93% for the sagittae). As readings from both sagittae and asteriscii could be taken from a single fish, there are multiple readings for some fish (up to four where all otoliths were present). The CV measures the degree of precision between the counts, and not the accuracy (this can only be calculated with aging experiments where the absolute age or time being represented is known).

Table 3: Oxytetracycline Marks

Sagittae No.	Read 1	Read 2	CV
1a	32	32	0.00%
1b	35	31	8.57%
2	30	30	0.00%
3	25	25	0.00%
4	36	36	0.00%
5	26	26	0.00%
6a	33	33	0.00%
6b	31	31	0.00%
7a	32	33	2.18%
7b	28	28	0.00%
	mean=	30.65	

The presence of daily growth increments was validated by injecting the fish with oxytetracycline and raising them for 30 days (Table 3). The mean count of daily growth increments is 30.65 days, thus validating the presence of daily growth increments. The oxytetracycline rings were only present on the sagittae and not the asteriscii, although the

reason for this is unknown. Along different parts on the edge of the sagittae it was difficult to count the rings, as a large black border along the edge could mask up to 20 growth increments. As the amount of daily growth rings varied on different positions on the edge of the sagittae, certain sagittae readings without the oxytetracycline marks may be underestimated.

Age/length keys were also constructed, but due to some missing ages at lengths, the key was too incomplete to get a reasonable estimate of K .

Mortality

Natural mortality is often highest in areas with a high mean annual temperature (Pauly, 1980) and among abundant schooling species (Eckert, 1987), while predation accounts for most of the post-settlement mortality (Doherty and Sale, 1985). The natural mortality of *S. fuscescens* was estimated at 1.49 using Pauly's empirical M formula, and 3.22 using Rikhter and Efanov's formulation. Both of these estimates are relatively high, but for different reasons. Pauly's estimate of M is high due to the high mean annual temperature of Bolinao (28°C), which increases natural mortality, whereas the Rikhter and Efanov's M of 3.22 is high due to faster growing fish having higher natural mortality. Although Pauly's M model may have given a potential underestimation of M due to not accounting for the local abundance and schooling behaviour, this may be corrected by the assumption that predation accounts for a large amount of natural mortality, yet locally there has been a removal of most of the top predators. Pauly's estimation of M was used due to its wide application in tropical fisheries and the direct relationship between M and

K.

Total mortality (Z) was estimated at 7.35 using a catch curve (Figure 4), although the assumption that all fish of a cohort were hatched at the same time may be an invalid one, as successive spawning occurred most months. A high growth rate with much variation of age at length makes these separate cohorts hard to distinguish past a certain size. Only the fish corral gear was used in the catch curve, as gillnets are more size selective (the fish corral had a range of 1.5cm and 15.5cm SL fish, whereas the gillnet's range was only 5.5cm to 15.5cm SL), and therefore do not represent the true range of lengths available in the population. Z was also estimated at 10.25 using the Jones and vanZalinge method. The Z obtained from the catch curve was used as a more accurate approximation of Z as the age at which the fish is recruited into the fishery is not knife-edged, and the catch curve allowed for a selection curve.

Z is high relative to other fisheries probably due to the tremendous fishing pressure throughout the life of *S. fuscescens*. The *padas* industry is one of the largest of its kind in Bolinao (Aragones and dela Paz, 1989), which focusses on catching juveniles of only 1.5 to 2.5cm SL. As the fishing pressure begins so early, production is minimized and total mortality is high. Most fish are caught before they reach spawning size, and many more are harvested at first or second spawn. As the gears targeting the *padas* was not represented in the catch curve and both F and M may be quite high during this stage (F for the tremendous fishing effort and M for predation of the juveniles), Z is probably an underestimation. Yet, the difference in Z does not have a great affect on the yield/recruit prediction as fishing mortality ($F = Z - M$) is high (5.862), and thus the harvest rate

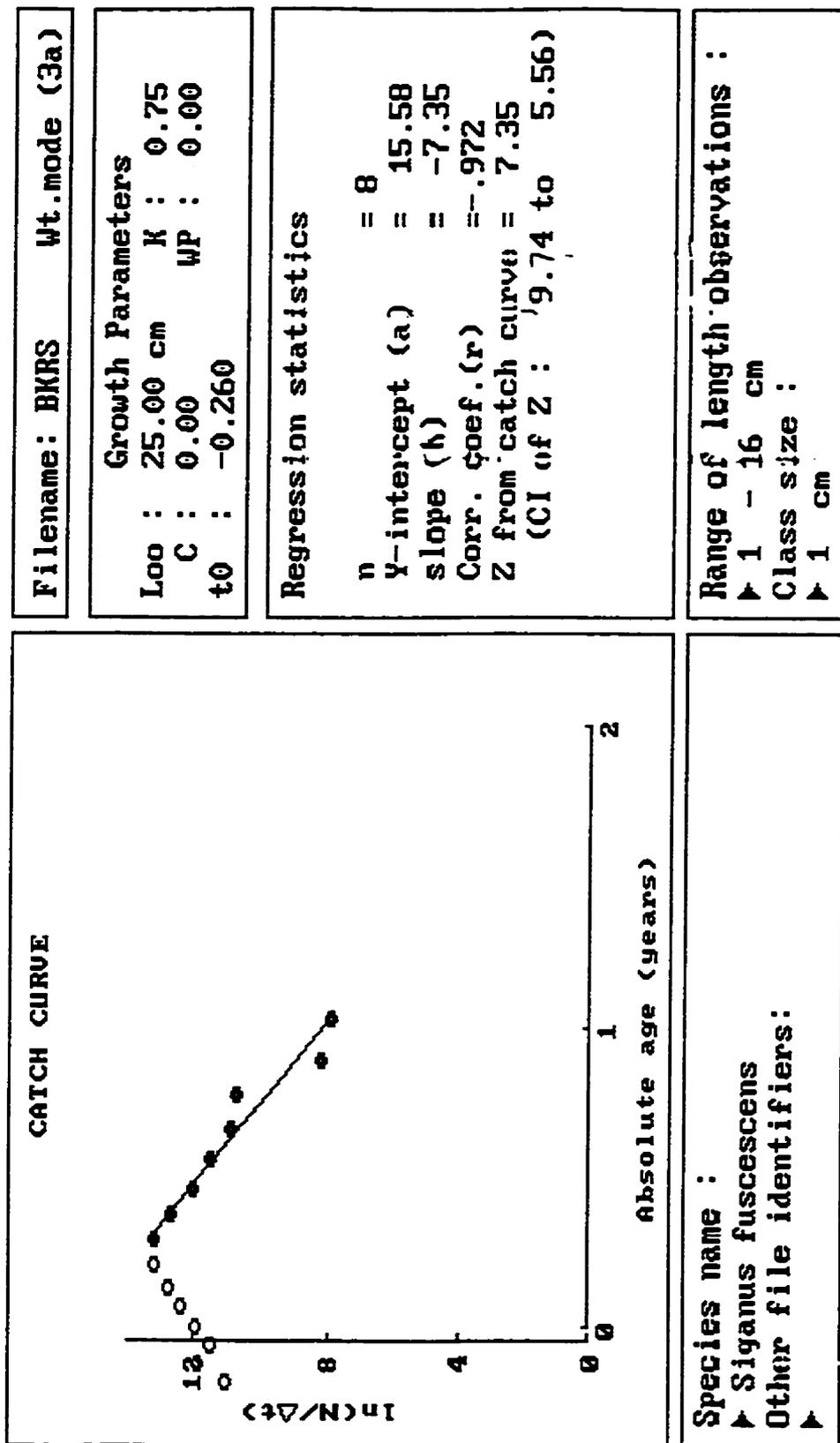


Figure 4: Catch curve using selection ogive

remains over 99%, with a minimal increase.

Recruitment

The timing of ripe gonads appears to coincide with the lunar calendar, with ripe gonads present on and shortly after the new moon, and spent or ripening gonads found at other times (Table 4). August had the highest number of spawners found per sample, although the sample size was small ($n=10$) and some spawning groups may have been missed due to infrequent sampling and not consistently sampling in spawning areas.

Table 4: Spawning profile

Date	Sites	N	R*	%R	Condition	New Moon
June 17	3	64	15	23.4	Ripe	June 16
July 12	3	71	12	16.9	Semi-ripe	July 15
July 19	4	53	11	20.8	1 ripe, 10 spent	
August 14	2	10	5	50.0	Fully ripe	August 14
August 16	1	16	1	6.3	Ripening	
August 23	4	42	4	9.5	Ripening	
August 30	2	28	1	3.6	Ripening	
September 9	1	33	6	18.2	Ripening	Sept. 12
September 13	1	36	3	8.3	Ripening	
September 18	1	21	0	0		

*R = Gonads in reproductive stage (ripening, ripe or spent)

Table 5: Monthly recruitment of *S. fuscescens* May 1987-April 1988 (del Norte and Pauly, 1990)

Month	Recruitment	Biomass (t)	Catch (t)
May '87	13,660,000	44.9	8.02
June	8,460,000	46.2	10.84
July	5,440,000	43.1	6.44
August	8,580,000	46.2	9.53
September	11,760,000	46.0	7.99
October	12,750,000	45.1	8.10
November	9,220,000	44.0	9.36
December	5,990,000	42.6	7.57
January '88	6,340,000	42.5	7.41
February	8,740,000	43.0	10.92
March	11,790,000	40.0	6.10
April	13,590,000	40.1	4.58

Some recruitment was found for every month, although two pulses following the spawning peaks occurred, one from March to May and the second from September to October.

Timing

The spawning cycle of Siganids is dictated by the timing of the new moon (Manacop, 1937; Bryan et al. 1975; Hasse et al., 1977; Okada, 1966). Lam and Soh (1975) suggest that photoperiod may also affect spawning times, although their research

was in a controlled 18 hour photoperiod, which does not relate to the natural environment of *S. fuscescens* in Bolinao. *S. canaliculatus* spawns 4-7 days after the new moon in The Philippines (Manacop, 1937) and 5-7 days (McVey, 1972) or 4-5 days (Hasse et al., 1977) after the new moon in Palau, and is initiated by an environmental stimulus such as receding tides and time of day (Manacop, 1937; McVey 1972; Hasse et al., 1977).

Alcala and Alcazar (1979) and Alcala (1979) also found the GSI of *S. canaliculatus* to be highest during the new moon. From the sampling of gonads of individuals around the time of spawning, my study suggests that spawning peaked on the evening of the new moon and could continue for up to 3 days (Table 4). Only one sampling date shows ripe individuals three days after the new moon. The knowledge from the local fishers and other research done on Siganids help to substantiate these claims. Rodriguez (1997), an anthropologist who interviewed local Bolinao fishers found that they predict spawning times by first observing large schools of *S. fuscescens* around the fish corrals on the day of the new moon, and continue to see spawning for three successive days, when the abundance of spawning schools increases. Although the abundance of the schools may increase, my study showed many more spent fish than ripe on the third day of spawning on one sampling date in July (Table 4), suggesting that most of the spawning was done on the first two days. Fishers predict the end of spawning by checking the gonads for spent or ripe fish (Rodriguez, 1997). As there were spent and ripe fish found together three days after the new moon (Table 4), it is probable that not all fish spawn on one day.

Although there appear to be marked peaks in spawning, there was evidence of some

spawning taking place every month of the sample (from June to September) (Table 4). Local fishers found that *S. fuscescens* spawned almost every month, where they would migrate northeasterly to deeper seagrasses around Dewey on the night of the new moon (Rodriguez, 1997). As Figure 5 illustrates, spawners were mostly found in two areas. These areas were not often able to be sampled (n=4 in Site 1, n=3 in Site 2), which could contribute to a low percentage of potential spawners per month due to having the area around the proposed site sampled more often (n=15), where few spawners were found. Figure 5 shows the high percentage of spawners in the seagrass areas of Sites 1 and 2.

Although there is a higher percentage of spawners recorded for non-peaked times, those months with higher percentages also had more sites sampled, and thus a better representation of potential spawners. The local fishers found *S. fuscescens* to spawn almost every month, although two definite peaks occur from March to May (major spawn, lasting approximately three nights) and August to October (minor spawn, usually lasting only one night) (Rodriguez, 1997). This reflects the recruitment pulses, with the highest recruitment pulses mirroring the spawning pulses, from March to May and September to October (Table 5). Alcalá (1979) found that the percentage of spawners increased over a four-month period (from January to April, peaking in April and then decreasing) suggesting a percentage of the population spawning every month, peaking at certain times.

Hasse et al. (1977) found *S. canaliculatus* to have successive spawning at four-week intervals with later spawnings being of lesser magnitude. Post-spawning individuals break up into smaller schools and return to shallower seagrass areas on the reef flat (Rodriguez, 1997).

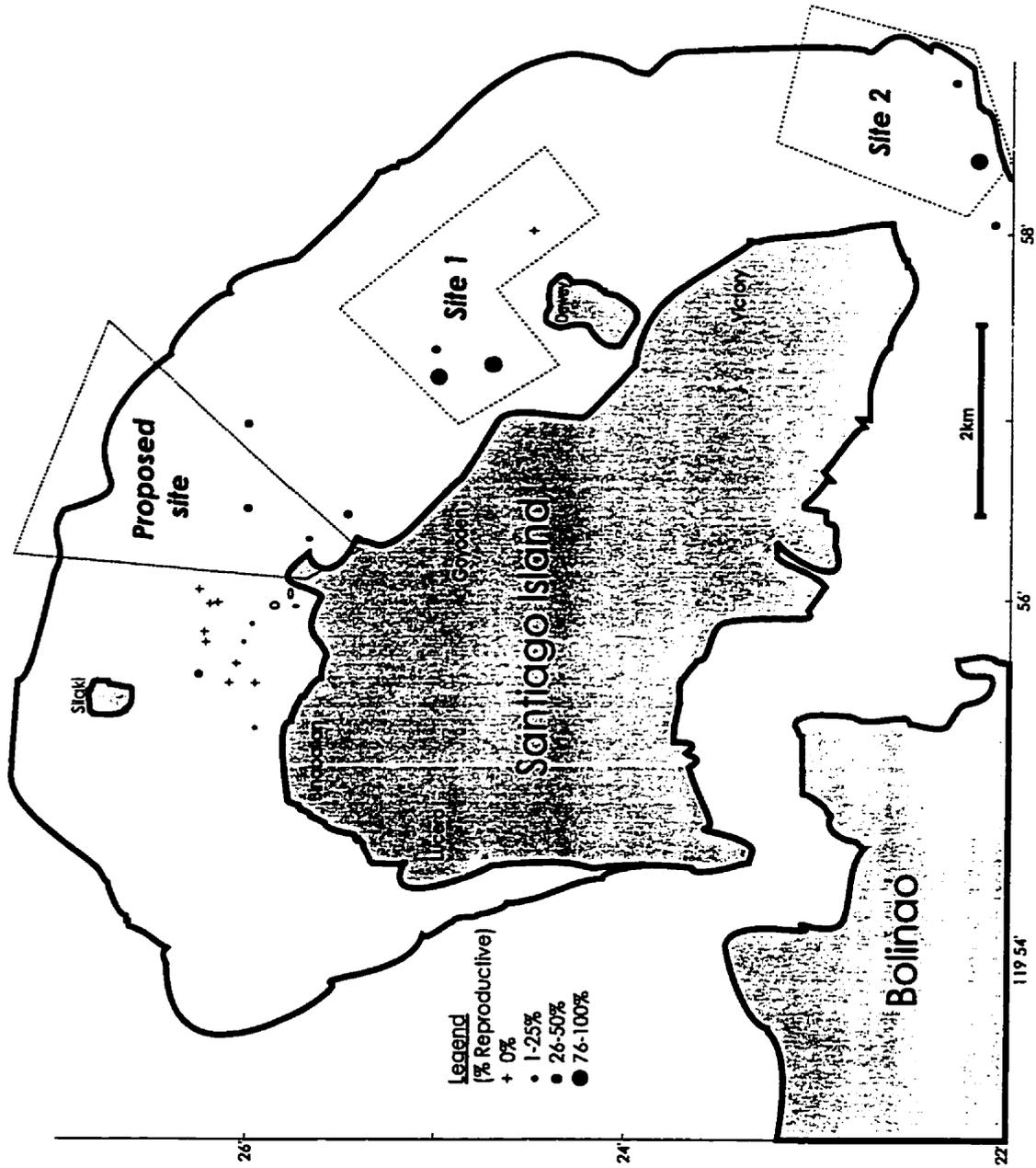


Figure 5: *Distribution of spawners (June to September, 1996) and sites for marine reserves.* The proposed site is the previously proposed site in Maleinep, and Sites 1 and 2 are the marine reserves proposed in this thesis.

Siganids may spawn throughout the year (Hara et al., 1986; Alcalá, 1979), with some females having multiple spawnings per year (Alcalá, 1979; Hasse et al., 1977). Bryan et al. (1975) found females of *S. canaliculatus* to be ripe only 1.5 months after first spawning, and Hasse et al. (1977) found larger females of *S. canaliculatus* (> 17cm SL) to spawn more than once per spawning season. My study showed that those individuals which were spent had released all their eggs, rather than saving some for a later spawn. As Alcalá (1979) found *S. canaliculatus* to release all their eggs at one time, the repeated spawning must be due to a re-ripening, and not due to being a batch spawner. *S. canaliculatus* have been found to have successive spawning from March to May (Hasse et al., 1977), and two spawning peaks, one from January to April, and a second minor peak from July to September/October (Lam, 1974 and Lavina and Alcalá, 1974) .

Maturity

This study showed that *S. fuscescens* are able to spawn by three months of age, and the recruits from one spawning pulse would, theoretically, be able to spawn by the next peak five to six months later. As the youngest spawner was only 7.2cm SL (or 70 days old), it could be that the first spawn occurs before a spawning peak, with multiple spawnings per year. Bryan et al. (1975) found females of *S. canaliculatus* to be ripe only 1.5 months after first spawning, and as *S. fuscescens* spawns younger and a portion of the population appears to spawn most months, then *S. fuscescens* may spawn at least twice per year and up to six times per year. It would be useful to have a more detailed analysis on the proportion of spawners per month throughout the year, and an average fecundity

for these times, as this could provide a better estimate of the number of times an individual may spawn per year and an individual's potential annual contribution to the population.

Although *S. canaliculatus* have been noted to mature earlier than other species of Siganids at 10.6cm SL for males and 11.6cm SL females (Tacon et al. 1989), or 12cm SL at approximately 7 months of age (Hasse, 1977), I found *S. fuscescens* mature at 7.2cm SL for males and 8.8cm SL for females (70 and 117 days respectively). Another study on this population found sexually mature *S. fuscescens* in Bolinao as small as 5.0cm SL for males and 5.6cm SL for females (de la Paz and Aragonés, 1988). It is the ability to spawn at such a young age that helps to ensure the breeding success and resulting high yield of *S. fuscescens* in Bolinao. It is possible that the smaller size at maturity is the result of growth overfishing, due to the fishing pressure selecting those individuals which grow slower and mature at a smaller size. These smaller individuals then, could be the same age as the larger fish. An aging study done on wild and captive *S. canaliculatus* found a high growth rate ($K=1.73$) for this species (Mangaoang, 1982). The age at maturity then for *S. canaliculatus* would be 63 days for males and 72 days for females. As *S. fuscescens* are exhibiting slower growth and a similar age at sexual maturity, there is some evidence of growth overfishing. Data on *S. fuscescens* populations which have not been so heavily fished will help to test this hypothesis.

As fishing pressure selects the smaller juveniles for fish paste and the larger adults due to a high market price, it is a benefit for the fish to grow fast in the juvenile stage and grow slow as an adult. The fishing pressure past 2.5cm SL is much lower, because fish greater than this size are too large for fish paste.

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Fecundity

Fecundity was estimated to be between 123,500 to 504,800 from 11 to 15cm SL (Table 6). Fecundity estimates for *S. canaliculatus* range from 11.1-11.5cm 154,420 to 660,000 (Alcala and Alcazar 1979; Lam 1974; Hasse et al. 1977; Woodland 1979; Tseng and Chan 1982; Madeali 1985), ovaries weighing 14-39g and containing eggs of one size (Hasse et al., 1977). Fecundity is generally exponentially related to fish size, with larger fish being the major contributors to new recruits (Plan Development Team, 1990). It appeared in this study that estimates were more related to the spawning time (i.e. the month of the sample) than the size of the fish. This could be due to producing more eggs on particular months, with more minor production of eggs other months, or it could be due

to sampling at different stages of gonadal maturation (the August samples being fully ripe and the July samples being three days short of fully ripe). The general rule, however, is that fecundity is exponentially related to fish size,

Hara (1987) found that *S. guttatus* with a GSI of >7.0 may spawn, and Hasse et al. (1977) considered *S. canaliculatus* to be in "spawning condition" with a GSI >2 (determined to be the approximate value at which gonads began to enlarge rapidly prior to spawning).

Table 6: Fecundity estimates

SL	Fecundity	Date
12.3	123,500	August 14
13.0	168,600	August 14
12.4	178,200	August 14
13.1	186,000	August 14
11.5	378,000	July 12
11.0	435,800	July 12
14.4	469,800	July 12
15.0	504,800	July 12

Reproductive fish (fish which were either ripening, spent or ripe) were primarily found in two areas, one just west of Dewey Island and the second on the southeastern tip of Santiago Island (Figure 5).

Behaviour

Siganids gather into large schools to spawn (Manacop, 1937; Hasse et al., 1977), migrating to deeper waters (De La Paz and Aragonés, 1990) in a location with easy access to the open sea, which may aid dispersal of pelagic eggs (Randal, 1961). Spawning schools of *S. canaliculatus* in the 1930s were up to 100m², and decreased to only 10m² by the 1970s (Hasse et al., 1977). Hasse et al. (1977) suggest that there may be a minimum number of fish per school required for successful spawning, as the spawning schools appear to be much larger than the feeding school size. As my study found only 9% of the population spawning in September, perhaps *S. fuscescens* does not have such large spawning schools as a requirement to spawn, as Hasse suggests.

McVey (1972) and Avila (1984) observed the female Siganid nudge the male's abdomen to encourage the release of milt before she would release her eggs, yet the local fishers found the opposite, the males nudging the female's belly (Rodríguez, 1997). The females rub their belly on the bottom substrate to induce the release of eggs (Rodríguez, 1997), which are laid on the bottom in shallow waters, especially in and around fish corrals (Manacop, 1937). Manacop's observation of spawning around fish corrals may have more to do with the fishers placing the corrals in areas where they already know spawning to occur, and thus maximize their catch, rather than an attraction of the Siganids to the structure of the corral. Conversely, the fish may aggregate around fish corrals because of the structure making the bottom currents less strong, and thus it could make it easier to spawn or for the eggs to be laid.

The local fishers found that the females do not eat for the duration of spawning

(up to four days), or until they release their eggs (Rodriguez, 1997). The large spawning schools break up again into smaller schools to resume feeding after spawning (Hasse et al., 1977). Lam (1974) and local fishers find that Siganids "disappear" after spawning (Rodriguez, 1997), although this may be a result of the fish breaking into the smaller schools and returning to shallower water to feed, away from the fish corrals.

Management

Yield per recruit was estimated using a selection curve (Figure 6). A selection curve was used instead of knife-edged recruitment, with the assumption that there is some selectivity of larger fish. The selection curve assumed that 14.3% of 3cm fish are recruited into the fishery, up to 100% at 9cm. It is important to note that this selection curve and the yield/recruit model is only estimating those individuals which survived the *padas* fishery. As no catch data of the *padas* fishery was available, the estimates used are for the post-*padas* fishery, and thus will be an overestimation of the abundance.

As there was no total catch estimate for 1996, an average of the total catch from July 1988 to June 1991 was used. There was little fluctuation from year to year for each month of this period, therefore it is assumed that a mean of these three years would be similar to the catch for 1996. The maximum sustainable yield (MSY) is 0.43 for a 21g fish (9.1cm SL). The yield/recruit is relatively small (only 36% of L_{∞}), due to the high natural mortality. This results in maximizing the fishing effort to reduce the loss of production, or catching the fish before they die of natural causes. The E^{-1} (exploitation rate at which the marginal increase of relative yield-per-recruit is 1/10th of its value at

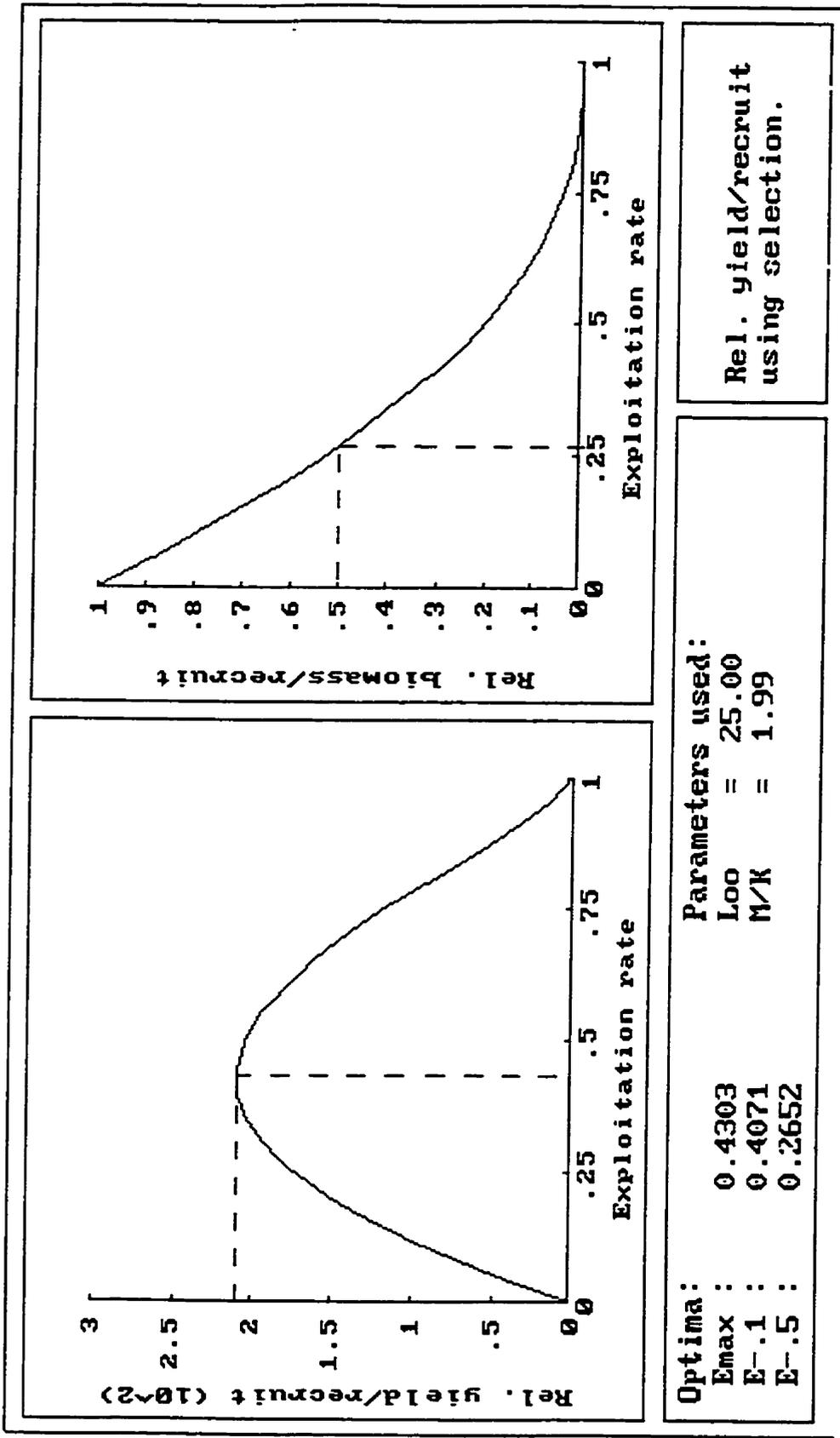


Figure 6: Yield/recruit and biomass/recruit

$E=0$), a more conservative estimate for managing the stocks gives an estimate of 0.41. As these values are not very different, the choice between which estimate is a better estimate is the better one to use is not crucial.

There is evidence of growth overfishing in Bolinao, as *barangen* caught fifteen years ago are said to be twice the size of the fish found today, and are now much less abundant (Rodriguez, 1997). This change is most likely due to increased fishing pressure, since the number of fish corrals have increased from 10 to 70 in the last twenty years (Rodriguez, 1997). As the fishers often catch pre-spawning Siganids still filled with roe, there is a great loss of both recruitment and spawners.

The local fishers have observed less fish in the fall spawn, and suggest it may be due to intensive fishing during the spring spawn and throughout the summer (Rodriguez, 1997). Although Rodriguez (1997) notes a strong seasonality in the catch, this could be due to inclement weather conditions during the rainy season, making it difficult for fishers to go out on the water and resulting in a decreased effort rather than decreased abundance. Yet, this seasonality is mostly just present in the fish corral catch, as this gear is set up mostly to catch migrating fish during the peak spawning periods when the fish become more active.

Siganids have continued to be abundant, regardless of the strong fishing pressure. This may be due to the removal of the top predators, their young age at first reproduction, having some spawning occur almost every month, having multiple spawnings per individual per year, and an abundance of their preferred habitat, seagrass beds.

Managing the fisheries must focus on controlling the fishing effort during the two

critical growth stages where exploitation is highest, the *padas* (which results in a loss of production) and ripe females (which results in a spawners, and thus recruitment). These destructive exploitation patterns have already been considered as a main cause in the decline of the fishery (McManus et al. 1992, Calvelo and Gignon, 1974). The *padas* fishery of Bolinao is the most developed in the Philippines, with the most intense fishing effort, resulting in large commercial quantities of *bagoong* (a fish paste) (Aragones and dela Paz, 1989). The local fishers recognize both of these practices as being detrimental to a sustainable fishery and have suggested restricting the *padas* fishery and taking pregnant females (Rodriguez, 1997) .

It is important to note that yield/recruit does not give an indication that there is recruitment overfishing. Thus, if *S. fuscescens* is harvested before reaching sexual maturity, the stock could collapse. As the MSY estimates are only an estimate of maximizing production and have no safety feature to protect recruitment overfishing, a marine reserve could provide an alternative to imposing size restrictions on the fishery, which would be very difficult or impossible to impose due to the high management cost and effort in monitoring the catch of a highly populated and informal fishery.

Chapter 3: Daily Movement Patterns and School Dynamics

The movement patterns for schools of *Siganus fuscescens* in Bolinao, Pangasinan, Philippines were observed to determine how much the fish moved (activity) and how far they travelled (relative home range). Habitat, depth, number of individuals per school and size range within a school were examined to see if any of these factors were related to movement. Relative home range and activity were approximated to design a size and location of a potential marine reserve in the area. Other factors related to the suitability of this species for a marine reserve (i.e. do larger fish aggregate in smaller schools) were examined and discussed.

Methods and Materials

Site Selection

Following interviews with local fishers and scientists associated with the Marine Science Institute of the University of the Philippines, the seagrass beds in Bolinao were surveyed using a series of 20 minute manta tows, where a snorkeller is towed behind a boat. After twenty minutes the boat stops and the snorkeller records on the slate where: 1) there were large patches of seagrass (the primary habitat of *S. fuscescens*), and; 2) schools of *S. fuscescens* were located. From this survey two sites were chosen: Silaki and Malelnep.

Silaki. The Silaki site was chosen due to the abundance of *S. fuscescens*, the density of seagrass, and the partial seclusion that the island offered, which made the water calmer

and easier for snorkelling. The habitat at Silaki consisted of long blades of *Enhalus* intermixed with short *Thalassia*, and dense bottom detritus around the base of the seagrass blades. Several small patches of hard coral (*Acropora*) was intermixed with the seagrass patches.

Malelnep. The second site was chosen within Malelnep, the area of a proposed marine reserve. This area was farther from shore (approx. 500m), and close to the reef slope. Malelnep's habitat was short *Enhalus*, intermixed with patches of *Sargassum* and a sandy bottom.

Two sites were chosen rather than a single site to ensure that any movement patterns observed were due to the general behaviour of the species rather than site specific results.

Time of Study

Two "dawn to dusk" observations were undertaken where a single school of *S. fuscescens* was followed between 05:00 and 19:00 for the purpose of trying to follow the same school from its initial movement (i.e. time of waking), to its final movement (i.e. sleep). A single school did not remain constant, however, as both the density and size classes often merged and split with other schools. During the "dawn to dusk" experiment, a school was found at dawn, and watched constantly until sleep (at dusk). Movement observations were recorded for a twenty minute interval at the beginning of each hour for the daylight hours (approximately 06:00 to 18:00).

The remainder of the observations took place within a two week period for either a morning or afternoon/evening, where a different school was located and observed for each

twenty minute observation.

Observations

Using snorkeling gear, the site was surveyed until a school was located, at which point the observer followed the school for two minutes before any observations were recorded. This time was used to allow the school to habituate to the observer. After only 10 to 40 seconds the fish would resume feeding and the observer would follow the school, keeping an approximate distance of 2m.

The initial size class and school size was recorded at the start of each observation. The size class was approximated within 2cm, and if several size classes were present in the same school, the maximum and minimum sizes within the school were recorded. Any changes of the size class or school size within each twenty minute observation were noted as soon as the change occurred.

Habitat characteristics were recorded at the beginning of each twenty minute observation, such as the approximate depth and the dominant substrate type(s) of seagrass, seagrass with hard coral, or seagrass and sand.

For every minute within a twenty minute observation the distance the school moved from the beginning to the end of that minute was approximated to the nearest 0.5M. The distance the school travelled from the initial time (minute 0) to the end (minute 20) was estimated to the nearest 0.5M. Short distances were estimated by using a best guess, and longer distances (>3M) were marked using a habitat sketch and later measured with a weighted measuring tape.

Analysis

A linear regression was done using SPSS 6.1.3 to test the effect of school size, size of fish (standard length), depth and substrate on the activity and relative home range. The activity is the cumulative distance a school moved, calculated by summing each distance the school moved each minute. Relative home range is the distance a school moved from the beginning of the observation to the end, calculated by measuring in a straight line the distance travelled from the original position at the start of the twenty minute observation to where the school was at the end. Thus, although the activity could be quite high (i.e. 2000m), if the school moved great distances in the twenty minutes, the relative home range could still be 0 if the school ended up in the same spot as it started. Also, a linear regression was done to test if school size, depth, or substrate was correlated with the size of the fish in the school, to see if larger fish were in smaller or larger schools or preferred a particular substrate or depth.

A multiple regression was done using the stepwise method to see if a combination of the above variables could usefully explain a greater proportion of the variance than any single variable in a simple linear regression.

A linear regression was done for those observations where school size and/or the size of the fish changed within the twenty minutes observed. An average activity per minute was calculated for the two different school characteristics (i.e. the first school size and the second school size), and a linear regression was performed to see if this change in school size or size of fish affected the activity.

Results

S. fuscescens was first observed in small schools at 06:20 hours, approximately one hour after dawn. Individuals buried themselves under the bottom detritus to sleep at dusk, and emerged from this nesting site at dawn. The fish appear to be inactive throughout the night as the fishers catch *S. fuscescens* by spearfishing at night when the fish are unresponsive and lying sideways on the bottom of seagrass beds. Individuals emerging from the substrate shortly after dawn spent approximately the first thirty minutes reforming into schools. The fish began actively feeding once they were organized into schools. *S. fuscescens* were found to be feeding continuously throughout the day until dusk, when the fish would break up into smaller schools, and then individually bury themselves in the bottom detritus to sleep (between 18:30 and 19:00), with no obvious peaks in movement throughout the day (Figure 7).

A linear regression on the effect of school size on activity and home range showed that larger schools are more active but do not travel farther (Table 7). Both the activity and home range had a highly significant correlation with the size of the fish and accounted for the greatest percentage of variance, with the larger fish being more active and having a larger relative home range. Depth had a significant correlation with the activity of a school, but not the relative home range. Thus, schools in deeper waters are more active but are not travelling farther. Although there was no significant difference detected (possibly due to the small sample size of the larger fish), the schools with the larger individuals (12cm to 16cm,

Activity (m/20min)

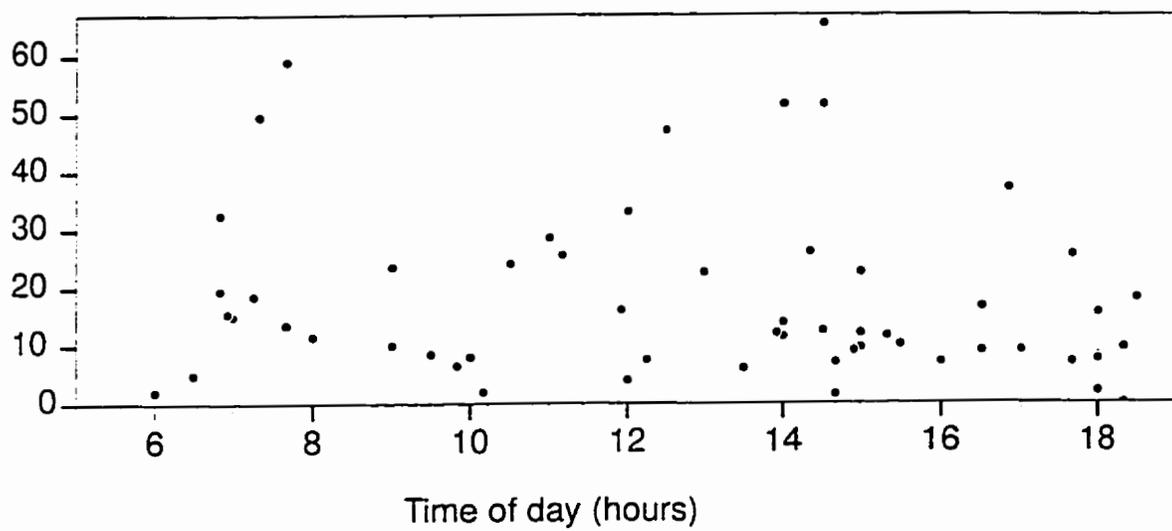


Figure 7: Daily rates of activity

n=4) were found in deeper water (> 2m), whereas in schools with smaller fish (maximum size 4cm to 10cm, n=21), >50% were found shallower than 2m in a total depth range of only 1.2-4.6m. There was no significant correlation between habitat type and movement patterns, although I observed that most schools were located close to a hard coral. A significant correlation may not have been detected for habitat as only the habitat that the school was in at the beginning of the observation was recorded, and thus the different habitats that the fish were in during the twenty minutes were not recorded. A linear regression on the activity and relative home range between the two sites showed no significant difference.

Table 7: Linear Regression of School Dynamics and Movement

Test	R	R ²	Sig.
School Size:			
School size and activity	.311	.096	.019
School size and relative home range	.118	.014	No
School size and size of fish	.111	.012	No
Size of fish (standard length):			
Size of fish and activity	.418	.175	.001
Size of fish and relative home range	.469	.220	.000
Depth:			
Depth and activity	.400	.160	.002
Depth and relative home range	.268	.072	No
Depth and size of fish	.134	.018	No
Depth and school size	.132	.017	No
Habitat:			
Habitat type changes activity	.191	.037	No
Habitat type changes relative home range	.152	.023	No

A multiple regression testing fish size (maximum and minimum lengths of fish in a school), school size, depth and substrate on activity and relative home range showed that maximum size and depth are the two variables which explain the most variance (adjusted $R = .269$) on activity, whereas maximum size was the only variable with a significant affect on the variance of relative home range (Table 8).

Table 8: Multiple Regression on School Dynamics and Movement

Test	R	R ²	Adj.R ²	Sig.
Activity - Maximum size then depth	.544	.295	.269	.000
Relative home range - Maximum size	.469	.220	.204	.000

An increase in the school size and immigration of larger fish into a school during a twenty minute observation was examined to test the effect this had on the activity of the school using a regression analysis (Table 9). The regression was tested on the cumulative distance a school moved before and after an immigration or emigration of fish within the school. Both an increase in school size and an increase in fish length within the school had a positive correlation with activity. The result showed significantly higher activity with larger schools and with larger individuals within a school, the maximum size (SL) of the fish in the school having a greater affect. Thus, the larger fish in the school dominated the movement patterns, increasing the rate of movement.

Table 9: Linear Regression: How a change in the school affects activity

Test	R	R ²	Adj.R ²	Sig.
Immigration of fish into a school increases activity	.594	.353	.289	.042
Larger fish joining a school increases activity	.610	.372	.310	.035

The relative home range plotted against activity showed that relative home range increased with larger fish (Table 10, Figure 8). Both the slope and the average distance travelled per twenty minutes increased with larger fish (Table 10). The relative home range was significantly different in the 8cm ($P=.01$) and 10-16cm ($P=.01$) size classes, but not in the smaller size classes (4-6cm). This suggests that larger fish travel farther, and are more directional in their movement. Although both large and small fish may have been active, only the larger fish often travelled away from the seagrass patch they were originally feeding on. Smaller fish showed no correlation ($R^2=0.05$) between activity and relative home range than did larger fish (8cm, $R^2=0.44$; >8 cm, $R^2=0.41$), suggesting that there is more variation in the directedness of the movement of the smaller fish (Figure 8).

Table 10: Relative Home Range and Maximum Length (cm SL)

Max. Length (SL)	Slope of regression (b)	Activity m/20 minutes	Rel. home range m/20 minutes	Average movement/min.
≥ 10 cm	5.4	30.4m (SD=41.8)	6.97m (SD=6.24)	1.52m (SD=2.09)
8cm	5.0	21.0m (SD=14.5)	5.10m (SD=4.85)	1.05m (SD=0.73)
< 8 cm	4.1	14.3m (SD=14.2)	2.80m (SD=2.79)	0.71m (SD=0.71)
All	4.7	20.8m (SD=25.1)	3.96m (SD=4.06)	1.04m (SD=1.28)

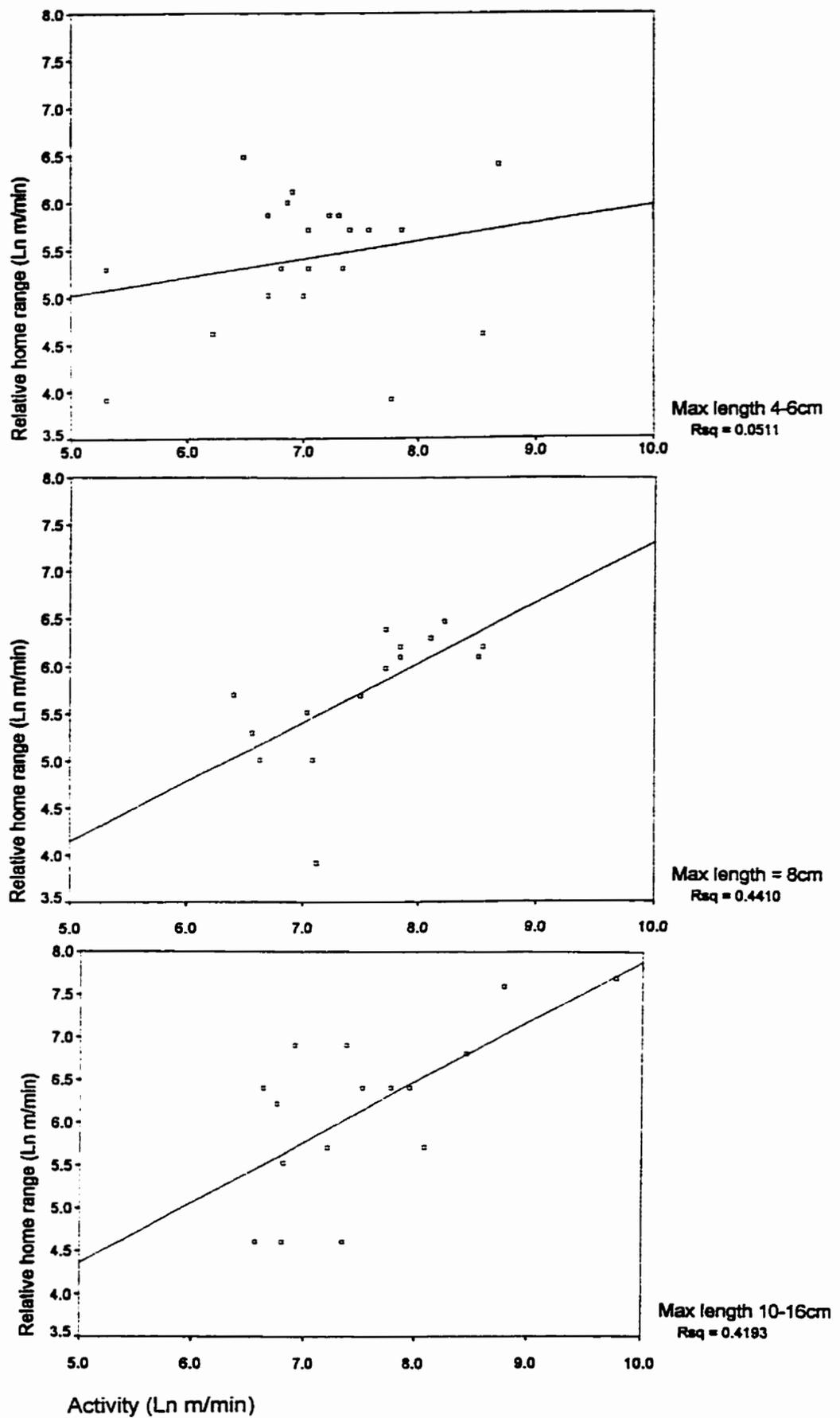


Figure 8: *Size of relative home range and length of fish*

Discussion

Although there were no obvious peaks in movement or feeding over the day for *S. fuscescens* (Figure 7), Hara (1986) found that feeding of *S. guttatus* had moderate peaks between 07:00 and 09:00 and 18:00 and 19:00. Although there were peaks in feeding, some degree of feeding was observed all day for both *S. guttatus* (Hara, 1987) and *S. canaliculatus* (Hasse et al., 1977).

Schooling species are often found in groups of a similar length (Breder, 1951, 1954; Radakov, 1973; Shaw, 1975; Pitcher, Magurran and Edwards, 1985), with active sorting of sizes (Musinic, 1977). Schooling with others of the same size may actually have a hydrodynamic advantage (Partridge and Pitcher, 1979; Blake, 1983). For both the activity and relative home range, the larger fish in the school dictated how far (relative home range) and how much (activity) the school moved. Thus, although smaller fish have a lower activity and relative home range, in the schools with a large range in size, the small fish moved at the same rate as the larger fish in the school, possibly to stay in the protection of a larger school. Pitcher et al. (1985) suggests that schooling with similar sized fish is a behavioural tendency rather than a rigid constraint and Hasse et al. (1977) found that since larger fish have a larger home range, the smaller fish must remain active or risk separation from the school. This schooling pattern was supported here as when there was a large range in the size of fish within a school, the school was often unstable as the smaller fish were often not able to maintain the speeds of the larger fish, and the smaller fish were eventually left behind. This

breaking up of size classes was noted in those observations where the characteristics of the school changed in the twenty minutes observed.

When Hasse et al. (1977) studied the feeding and home range of *S. canaliculatus* he found that: three week old fish (4cm SL) had a 1.5m² home range, with feeding lasting 5-60 seconds before the school would move 0.5m in a random direction and resume feeding; seven week old fish (6.5cm SL) fed in the same method but had a 3m² home range and moved 1-2m at a time before resuming to feed; adult fish (>10cm SL) fed in a quarter-hectare area, moving 1-3m per minute while feeding. In this study, fish between < 8cm SL moved an average of 0.71m before resuming to feed, whereas fish 8cm SL moved 1.05m and 10+cm fish moved an average of 1.52m (Table 10). These findings are similar to those in the study by Hasse et al. (1977), although there are no quantitative results for absolute home range estimates.

Hasse et al. (1977) also found the larger fish in schools of *S. canaliculatus* dominating feeding behaviour. The largest fish observed in this study were a pair of approximately 24cm SL, which the observer was only able to follow for a maximum of four minutes because the fish travelled at great speeds and were wary of the observer. I am assuming then that, since no other individuals of such large size were seen or caught (maximum size caught in a length/frequency sample was 19.8cm) that either: 1) due to intense fishing pressure of the larger individuals there are few existing large individuals left (supported by the length frequency data obtained where out of 818 fish sampled, only 6 were over 15cm and there were no fish found in the market at the size I observed); 2) the larger individuals are more timid and move very quickly, both their size and behaviour making

them hard to track as an observer and hard to catch in most gears used; or 3) large fish have a large home range, travelling far and moving quickly between seagrass beds making them less likely to find or observe.

An increase in school size can increase the speed at which a school travels (Fitzsimmons and Warburton, 1992). With *S. fuscescens*, school size showed a significant correlation with activity (Table 7 and 9).

Hasse et al. (1977) found school sizes of three-week old juveniles were much larger (between 21-595) than adult fish, but by six weeks old the school size reduced dramatically (12-32). In this study school size and size of fish were not significantly correlated, but the youngest fish observed in this study were approximately five weeks of age, and thus may not have the increased school sizes of the juveniles observed in the above study. The largest fish in the sample (16cm SL) were in the smallest school of only four individuals, and two brief observations of a pair of 24cm SL *S. fuscescens* could be an indication that school size becomes smaller as the fish grow past a certain size. As the sample size in this study is small on schools with large fish (n=4 of fish between 12 to 16cm) and the asymptotic length for this species is 25cm, then it is possible that fish in this larger size range that were not observed are found in smaller schools. The smaller school size with the few large individuals that were observed could be due to being less sensitive to predation (making it less beneficial to school), or a function of extreme growth overfishing, where there are so few large individuals remaining in the population that school size becomes very reduced.

Chapter 4: The Design of a Marine Fishery Reserve for Bolinao

Marine reserves are a closed area which offer protection to a marine habitat through a restriction to fishing or other activities which may perturb that habitat. Marine reserves can be selected to protect a portion of the environment which may include a fragile ecosystem or an endangered species, or be for tourism or recreational purposes. Marine reserves can also increase fishing stocks by protecting one or more parts of a life cycle such as spawning or feeding grounds or an area of juvenile settlement.

The choice of where and what size and shape a marine reserve should be is often an arbitrary one. Little is known as to how best to increase fishing stocks or how to protect a critical habitat or species as there has been few studies on the movement patterns or life history of most species, including the dispersion of the larvae and juveniles, and even less is known as to the effect a marine reserve will have on the abundance and movement of a particular species or an area in general. A particular concern to many fisheries managers is if the fish spawned in the marine reserve will recruit to the same area, and thus if the benefits of increased recruitment are felt locally.

Different criteria are used to determine the design and location of a marine reserve, including sociological, economic, and biological concerns. If a marine reserve is established to increase fishing stocks, then the potential yield which is lost from closing an area to fishing must be made up for through an enhancement of the yield due to an emigration of individuals to the fished area from the marine reserve. One example of

how sites are chosen which integrate social and biological criteria is SMART (Simple Multi-attribute Rating Technique) which weights the biotic diversity, management costs and the effects of a marine reserve on the fishermen to score potential sites (Bakus et al., 1982).

The damage to Philippine reefs due to destructive fishing practices and overfishing has been widely documented (Yap and Gomez, 1985; Luchavez et al, 1984; Gomez et al., 1981; Smith et al., 1980). Protecting the marine habitat through implementing marine reserves has been a popular conservation strategy in the Philippines since 1940 (Alcala, 1988). Marine reserves have offered a low effort alternative to gear restrictions and licencing, which are difficult to implement in a country like the Philippines where funds to manage the fisheries are limited and the fishery is very dispersed along the densely populated coastal regions. Community-based coastal resource managed marine reserves have been successfully implemented in many regions of the Philippines, with the community involved in the management and decision-making of the marine reserve (Alcala, 1988; White, 1987; Castaneda and Miclat, 1981; Marine Conservation and Development Program, 1986).

In designing a size and location of a marine fishery reserve for *S. fuscescens*, both the results of DeMartini (1993) and Russ et al.'s (1992) models and the known biology and spawning distribution of the species were considered. Management of the marine reserve and site selection by the fishers of Bolinao, who will be the managers and most affected by the implementation of the marine reserve, is a crucial step in choosing a site. The local fishers will have a kind of community ownership of the marine reserve, as they

will be the ones who actively manage the marine reserve to improve the sustainability of their livelihood.

A recognition of the customary rights of the fishers to the proposed sites and having local participation in choosing the site and method of management will help to ensure the future success of a proposed marine reserve. As different users will be affected by the location and presence of a marine reserve differently, the effect a potential marine reserve would have on these users and their livelihood should be addressed. Once the different groups agree on a location, the site can be submitted to the mayor of Bolinao for implementation.

Bolinao has been selected as a suitable site for a marine reserve due to the fishers expressing interest to a local community-based coastal resource management group, and also due to the declining fishery. This chapter will only offer choices of where a marine reserve would best suit the spawning behaviour and movement patterns of *S. fuscescens*, and then the choice of implementation will be made locally. McNeill and Fairweather (1993) tested whether there should be several small or one large marine reserves by measuring the diversity and abundance of fish in small and large seagrass patches. They found that larger seagrass patches had a higher biodiversity and abundance of fish, and that several small marine reserves increase the spawning stock biomass (SSB) less than one larger marine reserve due to the increased surface area resulting in increased transfer rates. Thus, two choices of a single site for a marine fishery reserve to target *S. fuscescens* in Bolinao are given.

As fishing pressure is most intense during the spawning migrations and juvenile

settlement, these critical life history stages should be protected. The distribution of juveniles is unknown, and thus targeting an area to protect the juveniles during settlement is problematic. As some information of spawning routes (Rodriguez, 1997) and distribution of reproductive individuals (Figure 5) is known, protecting the spawning stock is the aim of the two proposed sites.

Modelling the effects of a marine fishery reserve on spawning stock biomass per recruit (SSB/R) and yield per recruit (Y/R).

Polacheck (1990) developed a model based on Beverton and Holt's (1957) equation to determine the potential yield resulting from a closed area. The model separates the two regions as an area where no fishing occurs (analogous to a marine reserve) and a fished area, and approximates a transfer rate between the two areas. The assumptions of the model are that: 1) fishing pressure remains constant, so that if an area becomes inaccessible to a fisher (i.e. due to protection), then this effort gets displaced to the surrounding area, and; 2) fishing does not alter habitat or emigration, so that neither changes in habitat nor increased density will affect the distribution of the fishes between the two areas. This second assumption is problematic, as it may be assumed that density will affect distribution, with the fish living inside the protected area emigrating outside of the boundaries once the density increases. Although a higher density is often maintained within a marine reserve, there may be limits to the density a fish will withstand before it travels to a lower density outside of the protected area.

DeMartini (1993) modelled the potential effect of a marine reserve on Y/R and SSB/R, based on Polacheck's (1990) model for three kinds of reef fish, representing three ranges of movement and growth: 1) a jack, which represents a slow-growing, long-lived and far-ranging species; 2) a damselfish, representing a fast-growing, short-lived and territorial species, never ranging from a particular coral head, and; 3) a surgeonfish, a species selected as an intermediate species between 1) and 2). DeMartini (1993) selected three appropriate values of T_{1s} (the emigration rate from a closure, or "transfer rates"), for each of the three types of fish. With the assumptions that fishing does not affect habitat or alter the emigration rate from the closure, and that fishing mortality remains constant, DeMartini modelled the effect of different sized marine reserves on Y/R and SSB/R for the three fish types.

Of the three fish types, the surgeonfish more closely mimic the movement patterns, L_{∞} and growth (K) of *S. fuscescens*, although the estimates for growth and natural mortality are lower for the surgeonfish. DeMartini found that the marine fishery reserves increased the SSB/R substantially, but the Y/R marginally, due to the reserve acting as a growth refuge and having an increased density, and the gain in recruitment only marginally making up for the loss of yield from the closed area.

Russ et al. (1992) modelled the effects of reestablishing a marine reserve on Sumilon Island in increased yield/recruit for a species of fusilier (*Pterocaesio pisang*), with a similar transfer rate (0.3) to the surgeonfish (0.25) used in DeMartini's study. Russ et al. found that only under high levels of fishing mortality does a marine reserve substantially increase the Y/R. With an F of 2.0, a loss of 0.1% in Y/R was found, versus

a gain of >10% at an F of 4.0. DeMartini may not have found such substantial increases in Y/R, as he only tested up to an F of 3.0 for the surgeonfish.

Many studies on the positive effects of marine reserves have been recorded, such as: increasing biodiversity, abundance and density (Craik, 1991; Lane et al., 1991; Cole et al., 1990; Alcala and Russ, 1990; Castilla and Bustamante, 1989; White, 1987; Russ and Alcala, 1989); providing protection for critical stages in the life cycle of a species such as juvenile settlement or spawning sites; increasing the yield of adjacent areas due to emigration of individuals from within the reserve to outside of the marine reserve boundaries (Russ, 1985); and providing a growth refuge (Craik, 1991; Lane et al., 1991; Cole et al., 1990; Castilla and Bustamante, 1989; Buxton and Smale, 1989; Russ and Alcala, 1989), which may increase the spawning stock biomass and the number of large, highly fecund adults (MacDiarmid and Breen, 1992), which can lead to increased recruitment. Yet, there have been few tests before and after the establishment of a marine reserve which can quantitatively measure the effect of a marine reserve. Sumilon Island in the Philippines is one of the few examples of this, where after 10 years of a local marine reserve protecting 25% of the local reef, protective management failed and fishing resumed within the protected area (Alcala and Russ, 1990). The yield and biodiversity was measured during and after protection, and Alcala and Russ (1990) found that yield decreased by 54% after only two years of resumed fishing. This study showed that marine reserves can increase a yield to local fishers due to emigration of individuals out of the marine reserve.

Designing a marine fishery reserve for S. fuscescens

Samples of *S. fuscescens* were collected and their GPS coordinates were recorded (Figure 5). As their gonads were removed and staged, a distribution of spawners and an approximation of when spawning occurred was made (Chapter 2). As it would be beneficial to select an area for a marine reserve where both feeding and spawning occur, two sites meet this criteria: site one is just north of Dewey and site 2 is off the southeast tip of Santiago Island (Figure 5). Both of the sites selected are seagrass patches where a high percentage of spawners were found and cover approximately 2km², although site 2 includes a portion of the reef crest. Based on the estimates of SSB/R for surgeonfish of DeMartini and Russ et al.'s estimate of yield/recruit for the fusilier, an increase in both SSB/R and Y/R may be predicted as: 1) *S. fuscescens* has very high fishing mortality ($F=5.9$), and DeMartini found that with a higher fishing mortality (1.15), appreciable gains of >20% could be made for marine reserves covering 10-20% of the stock, whereas Russ et al. found gain of >10% in Y/R with an F of 4.0; 2) *S. fuscescens* has a high growth rate (.75), which can rapidly increase biomass; 3) *S. fuscescens* is short-lived and harvested as juveniles, which have implications in that ages at sexual maturity and first capture were more influential in increasing the SSB/R than either the transfer rate or the refuge size as minor changes in when a short-lived species is caught can heavily influence both the recruitment and mortality, and; 4) *S. fuscescens* presumably has a low transfer rate (although the rate during spawning migration is unknown), and changing the transfer rates up to fivefold only changed the SSB/R by <10%. The estimate of Y/R given in Chapter 2 shows that there is a large scope to increase the yield of the fishery, as fishing

mortality is so high. Any decrease in growth overfishing could have an appreciable effect on the catch rates, granted the adults emigrate outside the marine reserve.

The two sites proposed are based on protecting the feeding areas and spawning grounds of the adults, but do not address the protecting the *padas*. As the juvenile settlement areas are unknown, it is possible that one or both of the proposed sites could incorporate this stage of the life cycle. A knowledge of juvenile settlement, distribution and movement patterns would help in choosing an appropriate site to protect. Yet, as little is known of the juveniles, the implications of not protecting this vulnerable stage of the life cycle must be addressed. Although implementing a marine reserve could increase the number of highly fecund individuals, and thus the larval export, enough to compensate for the high mortality due to the *padas* fishery, it may be more effective to examine restricting the *padas* fishery in addition to the implementation of a marine reserve. This way the two most critical stages in the fishery will be addressed and future benefits, such as increased yield to the fishery, would most likely be increased.

There has been a proposed marine reserve submitted to the mayor of Bolinao for the Malelnep region targeting *S. fuscescens*, although no spawners were found in this region and a low density of feeding *S. fuscescens* are present (personal communication, Domeng Ochavillo). The reasons for the proposed marine reserve in the Malelnep region are due to a high catch in the fish corrals in this region during the spawning migrations in the spring and fall, and a high biodiversity of the region in general. Although very few *S. fuscescens* were caught in the fish corrals in the fall migration (personal observation and communication with local fishers), it is possible that the bulk of the catch is in the spring

migration. It is not known where they spawn, although it appears to be in the deeper seagrass beds, close to the reef crest (chapter 2). There appears to be several spawning areas because the catch of *S. fuscescens* during the spawning migration is widely distributed between the fish corrals in Malelnep and Dewey (I have no data for the southern region of Santiago Island, where site 2 is located, although as there is a high concentration of fish corrals in the area, they are also probably erected to catch *S. fuscescens* during their spawning migration).

Although either of the two sites suggested could potentially offer high levels of protection, due to the unknown routes that *S. fuscescens* takes during the spawning migrations, they may venture out of the protected area to spawn. As a portion of the population spawns most months, it is unknown what effect this will have on the transfer rate, as it is unknown what portion of the population will be spawning, if that portion of the population migrates each month or only during spawning peaks, and if the spawning population will leave where they are feeding to a different seagrass patch. Although it is assumed that spawning may take place in, or close to, the two proposed sites where ripe individuals have been found, the spawners found in the areas may not be residents (i.e. may not feed in the area they are spawning in, but come from a nearby seagrass patch). As the transfer rates only affected the SSB/R by <10% in DeMartini's model, the spawning migration may not substantially decrease the benefit of implementing a marine fishery reserve in either site, although the intense fishing pressure on *S. fuscescens* during the spawning migration may affect the SSB/R more than DeMartini suggests.

Applying the movement results to the proposed marine reserve

For the implementation of a marine reserve targeting the spawning stock of *S. fuscescens*, different considerations must be made:

- 1) An increased density may affect the behaviour of *S. fuscescens*, such as the movement patterns. Increased local density in reef fish affects both territory size (Norman and Jones, 1984), and can reduce the growth rate (Jones, 1986). An increase in density may increase the size of schools and the density of schools within the boundaries of the marine reserve. Although it is unknown whether school size, activity or relative territory is density dependent, an assumption may be made that as the population becomes denser within the marine protected area than outside of it, the fish within the marine protected area would migrate out of the marine protected area to find areas less populated. This "spillover effect" (the number of fish leaving the boundary of the marine protected area) is to some degree necessary to ensure a benefit to the fishery, although limiting the amount of fish crossing the marine reserve boundary is a goal to maintain a certain portion of the spawning stock remains within the marine protected area. As the larger, more productive fish may be found in smaller schools, and a certain interschool distance must be assumed, a larger area must be protected than if a marine protected area were targeting all sizes and not just potential spawners.
- 2) Since the goal of this marine reserve would be to protect a portion of the spawning stock (i.e. 20%), and since these larger spawners have a larger relative territory, the size of the marine reserve should be modeled on the size of the relative territory of these larger spawners, and not the population as a whole. The general rule of protecting

20% of the SSB was following evidence that stocks are more likely to collapse when the SSB is lower than 20% (Goodyear, 1989). As the absolute size of the marine reserve sites are unknown, as well as the total habitat size of *S. fuscescens* in the area, the proposed sites are only approximations of this rule.

The larger, more productive individuals are assumed to be found in smaller schools (although no significant correlation was detected), and since these fish also moved farther, then the marine reserve would need to be larger to ensure a necessary density of fish within the marine reserve.

- 3) Although no interschool spatial distribution was recorded in this study, a minimum space between schools was visually estimated to be 5m. This approximation is necessary to determine how many schools could be maintained in a specified area.
- 4) Since substrate complexity had a marginal affect on movement, the marine reserve would not necessarily need to be placed in an area with many hard and/or soft corals. However, I did observe that schools were often found a short distance from a hard coral. An area which incorporated a seagrass bed and some hard coral cover may be preferable since the hard coral increases refugia to hide from predators.
- 5) As only the larger fish were found in deeper waters, and fish in deeper waters swam farther (possibly due to their size and not the depth), a proposed marine reserve should either encompass the deeper areas of the seagrass patch or include a buffer zone on the deeper portion of the seagrass patch to optimize the amount of spillover.
- 6) On only one occasion did a school cross the seagrass boundary onto a sandy substrate, although they returned within that twenty minute observation. As the schools

stayed within that bed of seagrass, a marine protected area which encompasses one continuous seagrass bed, surrounded by another substrate type which acts as a kind of biogeographical barrier would be ideal to optimize the "spillover effect".

7) As this marine reserve is designed to protect a portion of the spawning stock, there are two options for the location: 1) to place the marine reserve in the seagrass beds where spawning occurs; or 2) to protect the spawners by protecting a general feeding area which is large enough to encompass 20% of the spawning stock. As feeding and spawning may occur in the same area, placing the marine protected area where they are known to spawn is presumed preferable. In addition, fishing pressure is highest at the times of spawning on the spawning grounds, so protecting a portion of the spawning area may protect a greater proportion of spawners than protecting a feeding area alone.

8) As there is a spawning migration, and thus the home range or territory changes during this time, an allowance for a path to the spawning grounds should be made or the marine protected area should be placed on a spawning ground.

9) The movement of *S. fuscescens* is mostly affected by habitat, such as seagrass patchiness and biogeographically barriers. In the movement study (chapter 3), only 2% of the schools observed in twenty minute observations (n=56) crossed the seagrass patch into another substrate type (sand). Although this is what has been observed, it is likely that larger fish would have a larger transfer rate due to their increased activity, propensity to travel into deeper waters and larger distance traveled per day. In addition, as I only observed one pair of 24cm fish, and since they quickly moved in and out of the local seagrass study site, it is likely that those highly fecund fish that are larger than 10cm

(which were rarely observed), will venture out of the local seagrass patch into other surrounding areas. Thus the boundary of the marine fishery reserve will be dictated by the size of the patch of seagrass rather than an arbitrary size selected (i.e. 10% of the area), and the transfer rate from the protected seagrass bed may be low during non-spawning times, unless an increased density within the reserve changes the movement patterns so that the schools will range farther to select an area of lower density.

DeMartini found gains of >5% of the SSB/R occurred in marine reserves protecting only 10% of the stock, although a greater rate of increase occurs in marine reserves protecting 25% of the stock for surgeonfish.

Conclusion

S. fuscescens is a good candidate for a marine reserve as they do not require a pristine area with a complex habitat (as such an area does not exist in the Bolinao reef flat), they have limited movement and territory, and they remain in the same general area to sleep and feed. A marine reserve in Bolinao could enhance the fisheries stocks in general, and *S. fuscescens* in particular. With a local conservation strategy, the Bolinao community can ensure that the marine environment can provide a sustainable resource base and that the livelihoods of the fishers can be protected for many years to come.

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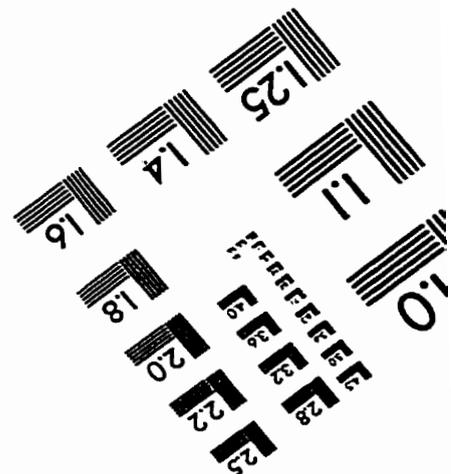
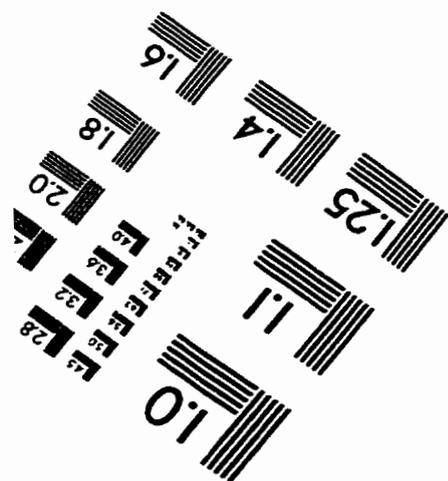
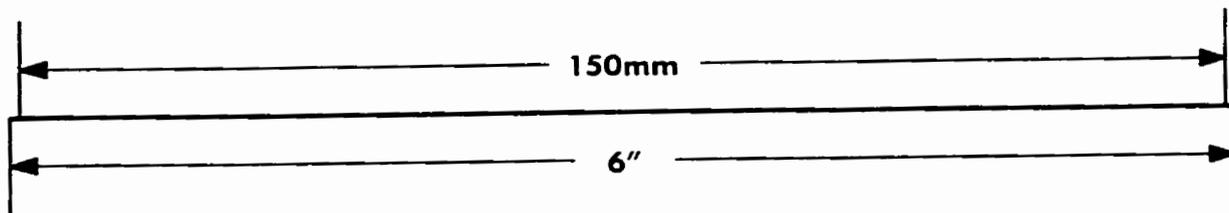
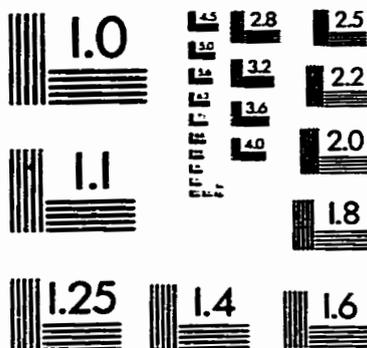
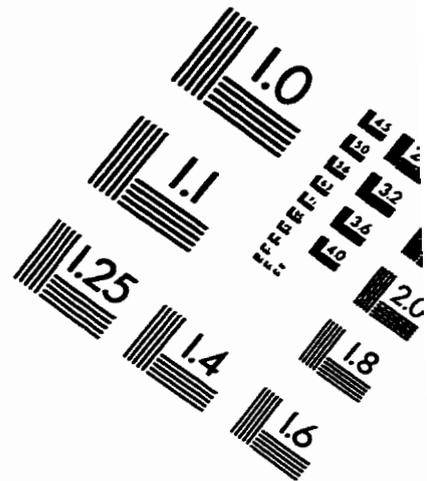
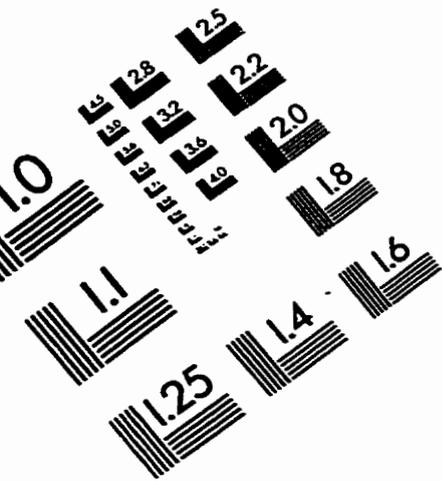
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IMAGE EVALUATION TEST TARGET (QA-3)



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