STUDIES ON CAPTIVE REARING OF SPOTTED GRUNTER, *POMMADASYS COMMERSONNII* (*PISCES* : *HAEMULIDAE*) UNDER AMBIENT CONDITIONS.

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by

NTOBEKO BACELA

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My father remains my inspiration, sacrificed his family and ultimately, his life ....

TABLE OF CONTENTS

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ABSTRACT

The effects of stocking density, size grading, feeding frequency and ambient temperature on the growth performance and size variation of spotted grunter, *Pomadasys commersonnii* were investigated. The time that would be required to rear the species to market size was modelled. An area where maximum growth rate could be achieved under ambient temperature conditions, and therefore the location of a commercial farm within the distribution range of spotted grunter along the coast of South Africa, was predicted.

The growth performance of spotted grunter was not significantly affected by stocking density. Growth performance seemed to improve with increasing stocking density. Competitive behaviour was absent among fish in the various stocking densities. Growth in terms of fork length and body weight was not significantly different between stocking densities. The highest specific growth rate, best food consumption, food conversion ratio and protein efficiency ratio of the fish were recorded at a density of 6.4 kg/m^3, whereas the best condition factor was recorded at a density of 3.8 kg/m^3. The lack of significant difference in many of the growth parameters between the various stocking densities suggest that juvenile spotted grunter could be reared at densities higher than 6.4 kg/m^3. Further investigations are needed to determine the optimal initial stocking density of juvenile spotted grunter under ambient temperature and photoperiod conditions.

Replacing the largest fish with average sized fish did not have a significant effect on the specific growth rate and competitive behaviour based on the relationship between the coefficient of variation and average size.

Feeding frequency had a significant effect on food consumption, food conversion and protein efficiency ratio, and not on size increase, specific growth rate and condition factor. Its effect on competitive behaviour could not be conclusively explained. The best food conversion ratio recorded when feeding once a day showed that although the fish consumed a limited amount of food, they utilised the food that was fed most effectively. It is suggested that the fish be fed three times a day. The survival of juvenile spotted grunter was 95.6 % when feeding three times a day compared to 90 and 90.2 % when feeding once and five times a day, respectively.

Fluctuating ambient temperature had a dramatic effect on specific growth rate and food consumption of spotted grunter. Growth modelling showed that the fish could be reared to a market size of 550 g (270 mm FL) in 19 months under ambient temperature conditions (23.2 ^{0}C) at Richard's Bay. The optimal predicted rearing period of 19 months is approximately seven months less than that calculated for fish in the wild, and can possibly, be reduced further by feeding a balanced diet. The overall food consumption (on a dry weight basis) in the three size classes ranged from 0.15 ± 0.16 to 0.38 ± 0.35 % body weight per day. Food conversion ratio improved with increasing fish size. This relationship was attributed to diet quality and more specifically, the protein : energy ratio. As a result, fish in the large size class had the best overall protein efficiency ratio. Maximum specific growth rates of 1.5, 0.84 and 0.74 % body weight per day were recorded from the small, medium and large size classes in the peak of summer with average daily temperature ranging from 21 to 22 ^{0}C. Positive slopes in the coefficient of variation against fish size in the large size class indicated the presence of competitive behaviour which was attributed to the onset of adolescence. The information from this study can be used for pilot production of spotted grunter. Further research should be undertaken to investigate captive reproduction of the species.

CHAPTER 1.

INTRODUCTION

Marine fish aquaculture in South Africa is in the early stage of research and development. Several species have been spawned and reared through metamorphosis. They include carpenter, *Argyrozona argyrozona*; roman, *Chrysoblephus laticeps*; galjoen, *Distichius capensis*; slinger, *Chrysoblephus puniceus* and santer, *Cheimerius nufar* (Garrat, 1991; Cook, 1995; Davies, 1996). Spotted grunter, *Pomadasys commersonnii* was identified six years ago for evaluation as a candidate for aquaculture by Professor T. Hecht of the Department of Ichthyology & Fisheries Science at Rhodes University. The species is valued by anglers as a premier game fish in estuaries (Day *et al.*, 1981); the price per kilogram of spotted grunter is competitive and the fish is presently decommercialised and natural growth rates are also favourable (Wallace, 1975; Wallace & Schleyer, 1979; T. Hecht, Department of Ichthyology & Fisheries Science, Rhodes University, Grahamstown, South Africa; personal communication).

A knowledge and understanding of the biology of a candidate aquaculture species are prerequisites for successful aquaculture. The natural history of spotted grunter has been widely studied. The species is euryhaline and can tolerate salinities ranging from 0 to 74 ppt (Wallace, 1975; Day *et al.*, 1981). The fish is an Indo-Pacific species and occurs from Mozambique to False Bay (Smith, 1950; 1961; Wallace, 1975; Whitfield, 1990; van der Elst, 1993). Spotted grunter are particularly common in KwaZulu-Natal and the Transkei (van der Westhuizen & Marais, 1977; Blaber, 1981; Day *et al.*, 1981). The species becomes less abundant towards the south because of the transition to a temperate environment (Day *et al.*, 1981). Spotted grunter are dependent on estuaries where the juveniles greatly exceed the number of adults (Wallace, 1975). They are recruited from the shallow coastal marine environment into the estuaries during summer. They grow at a rate of 1.2 to 1.5 cm per month in summer but more slowly in winter and at the end of the first year may reach 160 to 200 mm TL (Wallace & Schleyer, 1979). At this stage they emigrate to the sea (Day *et al.*, 1981, Wallace & Schleyer, 1979). Males mature at 260 to 380 mm TL and females between 280 and 420 mm TL (Wallace, 1975; Wallace & Schleyer, 1979). The fish continue growing after sexual maturity at a rate of 600 to 700 g *per annum* (Wallace & Schleyer, 1979). A ten year old fish may weigh 5200 g at 770 mm TL and they are known to attain 10 kg at 920 mm TL (Wallace & Schleyer, 1979). Movements of adult spotted grunter at sea are poorly understood. Wallace (1975) suggested that there is a possibility of a long shore spawning migration but no evidence was presented to support the contention. Tagging report by Beckley & Bullen (1995) showed that spotted grunter were recaptured in the vicinity where they were tagged. However, tagging returns were very poor (Beckley & Bullen, 1995).

Spawning occurs in the shallow marine environment from July to December (Day *et al.*, 1981; Wallace, 1975). Adults in spent reproductive condition return periodically to the estuaries to feed during spring and summer (Wallace, 1975 b; Wallace & Schleyer, 1979; Day *et al.*, 1981; Blaber, 1981). Larvae develop offshore and enter open estuaries with the flood tide. This environment is associated with abundance of food and sheltered conditions (Whitfield, 1990).

Spotted grunter are pelagic and benthic feeders during the larval and post-larval stages (Whitfield, 1990; Hecht & van der Lingen 1992). Between 20 and 40 mm, juveniles feed on zooplankton, mostly copepods. Between 50 and 100 mm TL the fish become benthivorous, feeding on polychaete worms, bivalves, crabs and shrimps. Diet of larger fish in estuaries is mainly comprised of mud prawn, *Upogebia africana*; sand prawn, *Callianassa kraussi*; pencil bait, *Solen cylindraceus* as well as penaeid prawns (van der Westhuizen & Marais, 1977; Day *et al.*, 1981; Whitfield, 1990). Filamentous algae have also been found in the stomach contents of certain specimens, although the significance of this is not known (van der Westhuizen & Marais, 1977). Wallace (1975) found that the spotted grunter feed on filamentous algae on an opportunistic basis when the salinity in Lake St. Lucia exceeded 70 ppt. In Natal estuaries, the spotted grunter feed on bivalves and bivalve siphons (Blaber, 1983), with foraging occurring mainly in the early morning and at dusk (Blaber, 1983). In the St. Lucia and Kosi systems, the diet of juveniles is mainly comprised of chironomid larvae, harpacticoid copepods and tanaid *Apseudes digitalis*. In areas where the macro benthos is limited the spotted grunter is also a scavenger, when judged by the presence of undigested but unidentifiable food material in the stomachs contents (Blaber, 1983). However low numbers and diversity of macro benthos may also exclude the presence of the spotted grunter from a particular area (Blaber *et al.*, 1984). The diet of the spotted grunter is therefore dictated by available food items in the area where it is found (Blaber, 1983).

Captive studies to determine oxygen consumption; salinity requirements; optimal diet; feeding frequency; optimal rearing temperature; optimal rearing photoperiod and their effects on growth of spotted grunter were conducted by Du Preez *et al.* (1986); Bussiahn (1992); Deacon & Hecht (1996); Deacon (1997) and Irish (1997). A study on a suitable anaesthetic for the species and dosage were conducted by Deacon *et al.* (1997). These studies were undertaken to determine the conditions which juvenile spotted grunter require in a hatchery environment. The following discussion summarises the studies of juvenile spotted grunter under captive conditions.

Fish experimentation necessitates regular handling of fish for measurement. Fish are subjected to stress during handling and can sustain injuries leading to mortality. An organic substance, 2-phenoxyethanol was evaluated and an effective concentration was determined for use as an anaesthetic (Deacon *et al.*, 1997). Investigations of the potential of 2-phenoxyethanol were prompted by cost considerations. The substance was cheaper when compared to commonly used anaesthetics such as tricaine methanosulphate (MS-222) and benzocaine hydrochloride. The latter anaesthetics were also reportedly dangerous because they accumulate in fish muscle tissue and cause deeper anaesthesia when used repeatedly. Deacon *et al.*(1997) demonstrated that 2-phenoxyethanol concentration ranging from 0.2 to 0.5 ml/l can be used safely to anaesthetise juvenile spotted grunter. This range of concentrations did not have any significant negative effects on growth of juvenile spotted grunter.

The effects of temperature and body weight on oxygen consumption of spotted grunter were studied by Du Preez *et al.* (1986). Investigations were conducted over three different temperatures ranging from 15 to 25 ^{0}C. Oxygen consumption was doubled at night when compared to the day. Oxygen consumption of smaller fish increased more than that of larger fish when temperature was elevated. Oxygen consumption decreased when the fish were deprived of food (Du Preez *et al.*, 1986).

Deacon & Hecht (1995, 1996) studied the thermoregulatory behaviour and implications on growth performance of the spotted grunter under captive conditions. Temperature was found to be the most important controlling factor of growth, condition factor and food conversion. Optimal temperature for growth of these juveniles was found to be 24.5 ^{0}C (Deacon & Hecht, 1996). Du Preez *et al.* (1986) found that lowering the temperature to 10 ^{0}C resulted in complete loss of appetite and mortality of spotted grunter.

The effect of photoperiod on the growth of juvenile spotted grunter was also investigated by Deacon & Hecht (1996). These authors found that photoperiod did not have a significant influence on the specific growth rate and food conversion ratio. The condition factor was however, significantly higher in fish that were reared in a photoperiod regime of 12L:12D compared to lower and higher regimes (Deacon & Hecht, 1996). Deacon & Hecht (1996) suggested that juvenile spotted grunter are predominantly diurnal, based on comparatively lower growth when reared under shorter light conditions. Lower growth under longer light hours was attributed to inadequate feeding frequency to satisfy swimming activity. Adult spotted grunter are caught mainly at night by anglers, thus indicating a nocturnal foraging behaviour (Du Preez *et al.*, 1986). The above observations of juvenile and adult spotted grunter suggests an ontogenic change in response to light which may influence feeding behaviour (Deacon & Hecht, 1995; 1996; Du Preez *et al.*, 1986).

Salinity tolerance and effects on growth, food conversion ratio and protein efficiency of juvenile spotted grunter in captivity were investigated by Bussiahn (1992) and Deacon (1997). A mortality of 29 % was observed when juvenile spotted grunter were kept in water with a salinity of 5 ppt. Bussiahn (1992) found that juvenile spotted grunter were isosmotic when the concentration of the external medium was 12 ppt and higher. Mortality would occur when fish were unable to maintain a stable blood plasma osmolality. Osmoregulation of juvenile spotted grunter was tested over a salinity range of 5 to 35 ppt and blood plasma osmolality varied by less than 5 %. Higher mortality at the lower experimental range of salinity implies that the fish could no longer sustain their blood plasma osmolality within this range. Growth, food conversion and protein efficiency ratios were not significantly different for fish that were reared in water with salinities of 12 (isosmotic), 25 and 35 ppt (Deacon 1997).

The effects of feeding frequency on growth of juvenile spotted grunter under controlled laboratory conditions were investigated by Deacon (1997). Significant improvements in growth performance, food conversion ratio and condition factor of juvenile spotted grunter were observed when feeding the fish three times a day. Higher feeding frequencies did not result in a higher growth rate. The best food conversion ratio corresponded to feeding the fish three times a day. This feeding frequency corresponded to a feeding rate of 14 % wet body weight per day (Deacon, 1997). Feeding frequency was found to increase with gut passage time. The optimal feeding frequency corresponded with a gut passage and evacuation time of six hours.

The dietary requirements of juvenile spotted grunter have been studied by Irish (1997). The optimal protein requirement for juvenile spotted grunter was found to be 40 %. Optimal dietary protein to energy ratio was also investigated and was 26.7 mg/kJ. Amino acid profiles of juvenile spotted grunter and its natural diet were determined and lysine was found to be the most limiting amino acid. Crystalline lysine supplementation at 4.3 % per gram of dietary protein resulted in improved growth. Irish (1997) found that juvenile spotted grunter could utilise plant protein obtained from *Spirulina* and defatted soya bean meal, although optimal inclusion levels were not investigated.

Commercial aquaculture practise strives to minimise operating costs. The hatchery phase of the operation is the most critical in commercial aquaculture and takes place for a relatively short period when compared to growing the fish to a marketable size. Relatively high costs of maintaining optimal water quality, temperature and photoperiod can be afforded for a hatchery when farming a commercially valuable marine species. Adjustments to reduce costs can be realised in the grow-out phase by keeping fish in pens, cages or tanks where water volumes and currents will ensure optimal water quality. Natural and optimal fish rearing temperature and photoperiod can be traded off by choosing a geographical locality where ambient temperature and photoperiod approach optimal conditions.

The first aim of this study was to investigate the effects of stocking density, size grading and feeding frequency on the growth performance of juvenile spotted grunter that were reared in captivity under ambient temperature and photoperiod. Fish performance under the various environmental conditions was evaluated by the determination of size variation, growth rate, food consumption, food conversion ratio, protein efficiency ratio and condition factor. The following hypotheses were developed. The growth of fish is influenced by environmental conditions under which the species is kept. Unfavourable environmental conditions include competitive behaviour, stocking density, inadequate ration size and feeding frequency.

If resources such as space and food are limited in an environment then competition would occur and develop into dominance hierarchies among fish (Purdom, 1974). Competition would result in size variation because the fish would grow at different rates under conditions where resources are limited (Purdom, 1974). It is important to distinguish between size variation as an attribute of natural variability or dominance hierarchies (Purdom, 1974). The distinction between size variation as either an attribute of natural variability or dominance hierarchies is achieved by the comparison of the coefficient of variation of average size of fish (Purdom, 1974; Zar, 1996). If competition occurs in a population, then the variation coefficient will increase with the average size of the fish, otherwise it will remain constant (Purdom, 1974). The presence of dominant fish in a population will result in the suppression of the growth of subordinates (Jobling, 1981). The slope of the relationship between the variation coefficient and average size is a measure of the degree of competition in a fish population (Purdom, 1974; Jobling, 1981; Zar, 1996). Therefore, a suitable stocking density and feeding frequency can be determined by comparing the degree of competition among groups of juvenile spotted grunter. Rearing juvenile spotted grunter under a suitable stocking density and feeding frequency could be insufficient to control size variation occurring as a result of natural variability. If size variation in juvenile spotted grunter occurs as a result of natural variability, then size grading can be effectively used as a controlling measure in an aquaculture situation.

The second aim of this study was to determine the time it would take to rear spotted grunter to a marketable size under ambient temperature and photoperiod. The influence of temperature and photoperiod on the growth performance of fish has been discussed earlier. The dependence of the growth of spotted grunter on rearing temperature was evaluated to suggest a suitable geographical locality where a commercial aquaculture facility for the species could be situated. Knowledge gained from the present study will facilitate pilot production of spotted grunter using juveniles caught in the wild. Future studies need to focus on reproduction and larval rearing of the species.

CHAPTER 2.

EXPERIMENTAL SYSTEMS AND GENERAL METHODS

System specifications

All experiments were carried out at the Rhodes University Marine Laboratory in Port Alfred (26^0 53' E, 33^0 36' S). Three sets of tanks in two partially recirculating systems, of which the lay-out is presented in Figure 2.1, were used to conduct the experiments.

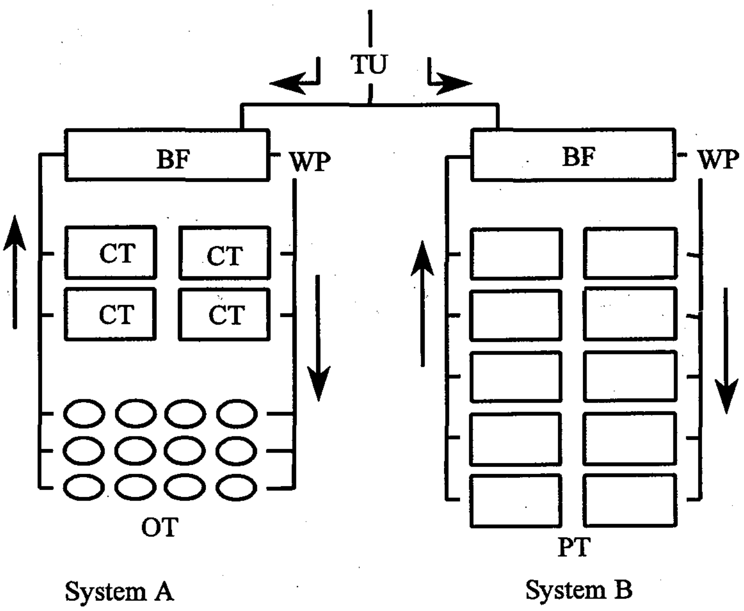

Figure 2.1. A lay-out of the two systems, A and B, in which the experiments on juvenile spotted grunter, *P. commersonnii* were conducted. Arrows = direction of water flow. Details of water flow to and from individual tanks are described in the text. Abbreviations : TU = top up water inlet, BF = biological filter, WP = water pump, CT= concrete tanks with operating volume of 1500ℓ, oval tanks with an operating volume of 90ℓ, PT = plastic tanks with an operating volume of 1000ℓ.

System A had four rectangular concrete tanks with individual operating volumes of 1500 ℓ and twelve oval plastic tanks with individual operating volumes of 90 ℓ. The tanks were linked to a biological filter with an operating volume of 4000ℓ. System B had ten plastic tanks, each with an operating volume of 1000ℓ, linked to a biological filter with an operating volume of 4000ℓ. The two systems were supplied with partially recirculated water originating from the Kowie estuary at a rate of 12 litres per minute using a 4.5 kW pump. River water temperature was recorded to the nearest degree twice a day and this is illustrated in Figure 2.2, together with photoperiod.

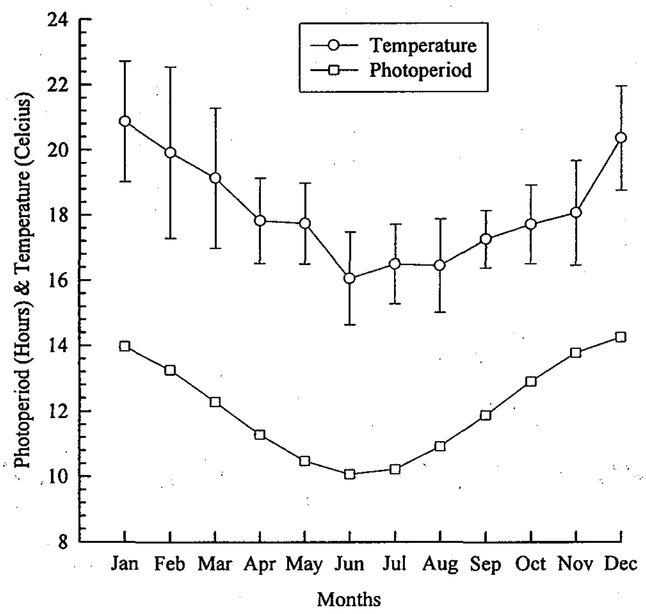

Figure 2.2. Water temperature and photoperiod at the Rhodes University Marine Laboratory, Port Alfred.

The concrete tanks in system A were used for acclimatisation of juvenile spotted grunter that had been caught from the wild. Details about the capture of fish from the wild will be discussed later. The oval plastic tanks were used for the stocking density and size grading experiments and were stacked in a metal frame as shown in Figure 2.3. Each of the tanks was supplied with water at a rate of 4 litres per minute, equivalent to water replacement of 2.667 times per hour. The tanks were aerated continuously and cleaned when required.

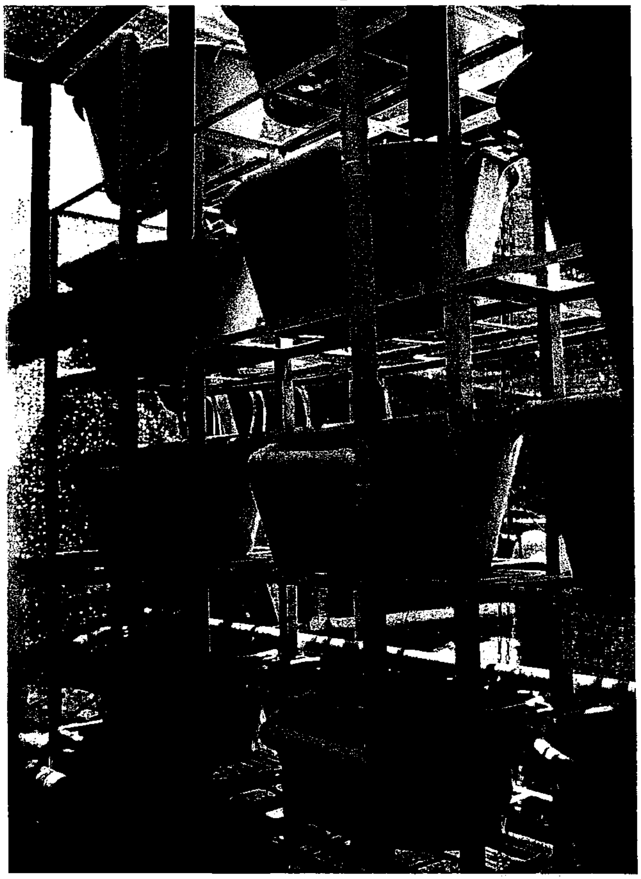

Figure 2.3. The oval plastic tanks in which the stocking density and size grading experiments in juvenile spotted grunter, *P. commersonnii* were conducted. The tanks were stacked vertically and covered with shade net to exclude predators and prevent the fish from jumping out.

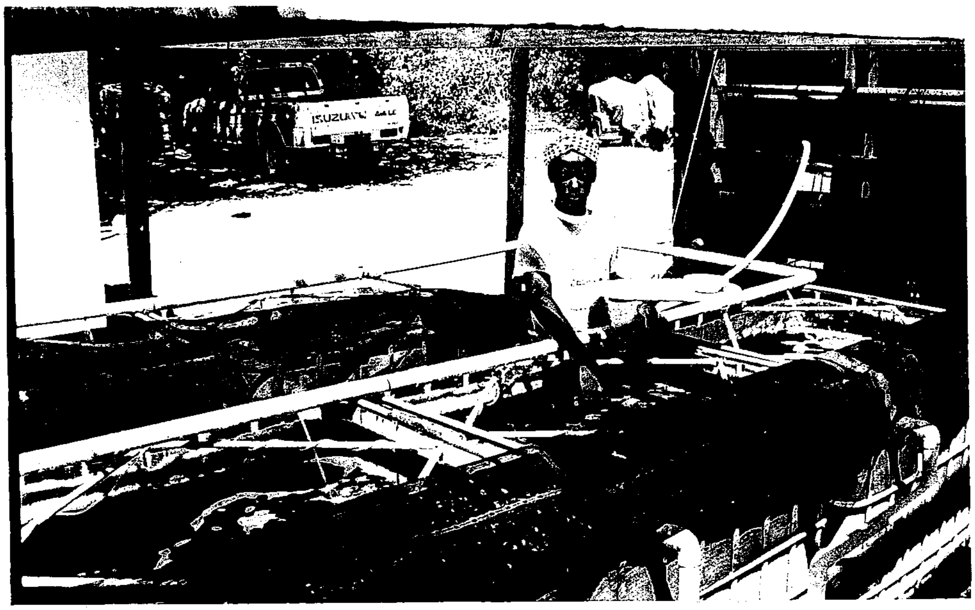

Figure 2.4. The battery of plastic tanks in which the grow-out and feeding frequency experiments on juvenile spotted grunter, *P. commersonnii,* were conducted. The tanks were covered with shade net to exclude predators and prevent the fish from jumping out.

The system in which the feeding frequency and grow out experiments were carried out consisted of nine 1000 ℓ tanks made of plastic (Figure 2.4). The tanks were arranged in two batteries and each was supplied with water pumped from the biological filter at a rate of 30 litres per minute. The rate is equivalent to a turn over of 1.8 times per hour per tank. The tanks were aerated continuously and cleaned when required.

Water quality

Oxygen content and temperature were monitored daily, whereas pH, ammonia, nitrite and salinity were monitored weekly during the experiment. Oxygen ranged from 8.3 to 4.0 mg/ℓ and pH ranged from 8.2 to 8.0. Ammonia and nitrites were less than 0.02 mg/ℓ. Salinity ranged from 32 to 35 ppt.

General experimental methods

Juvenile spotted grunter were collected from the Great Fish estuary (33^0 30' S; 27^0 07' E) on the south east coast of South Africa using a 12 m x 3 m (15 mm stretched mesh) seine net. The seine net did not have a bag to minimise injury. The fish were normally caught in water with salinity ranging from 5 to 12 ppt and then transported to the laboratory. The fish were acclimated to a salinity of 32 to 35 ppt by exchanging water at a rate of 1 mℓ/second. The water exchange rate also allowed gradual temperature equilibration between the transportation and acclimation water. Dead fish were removed the next morning following transfer into acclimation tanks. Thereafter, dead fish were removed before each feeding time. Fish were kept in the acclimation tanks for four weeks without handling. Four weeks was sufficient for full recovery and feeding of juvenile spotted grunter. During the acclimation fish were fed an optimal pellet diet developed by Irish

(1997) and chopped pilchards, *Sardinops sagax* to satiation two or three times a day (De Silva & Anderson, 1995).

Schulein *et al.* (1995) reported that environmental factors had a significant influence in the oil:meal ratio of pelagic fish, including *S. sagax*. A single large quantity of pilchards (1.5 tons) was therefore purchased at one time and stored at -20^{0}C. The proximate composition of pilchards and the nutrient specifications of the pellet diet are presented in Tables 2.1 and 2.2. The proximal composition of pilchard was determined by the Department of Animal and Poultry Science, University of Natal, Pietermaritzburg from ten fish that were selected randomly from the stock. The specifications and the proximal composition of the pelleted feed were taken from Irish (1997).

Table 2.1. Formulation and proximate composition of the pellet diet (after Irish 1997).

Nutritional specification for the pellet diet	
Ingredient	**% Composition**
Danish fishmeal	44
Casein	14
Pregelatinised starch	27
Fish oil	4.5
Vegetable oil	2.2
Mineral mix[1]	4
Vitamin mix[2]	2
Crystalline L-Lysine	0.2
Cellulose	2.1
Proximate composition	
Crude protein (%)	45.3

Ash (%)	13.96
Moisture (%)	34.04
Fat (%)	6.7
Gross Energy (MJ/kg)	18.95

[1]Mineral mix (g/kg): 74g Potassium; 516g vermiculite RSU; 14g salt; 0.05g ammonium chloride; 31g choline chloride; 0.31g cobalt; 0.15g copper; 1.5g iron; 0.05g iodine; 0.22g manganese; 41g magnesium; 1.0g zinc; trace selenium.

[2]Vitamin mix (IU or g/kg): 500 000 IU vitamin A; 400 000 IU vitamin D_3; 10 000 IU vitamin E; 1,0 IU vitamin K_3; 0.25 IU vitamin B_1; 1.5 IU vitamin B_2; 0.5 IU vitamin B_6; 25.0 IU vitamin C; 2.5 IU niacin; 0.09 IU Folic acid; 0.025 IU biotin; 2.5 IU calpan; 2.5 IU inositol.

Table 2.2. Proximate composition of the pilchard, *Sardinops sagax* that were fed to spotted grunter during experimentation.

Proximate composition of *Sardinops sagax* (dry weight basis)	
Crude Protein (%)	82.218 ± 5.741
Crude lipid (%)	3.544 ± 1.724
Ash (%)	6.296 ± 0.846
Moisture (%)	74.051 ± 1.495
Gross Energy (MJ/kg)	20.582 ± 1.133

After the acclimation period, the required number of fish was distributed to the experimental tanks and acclimated for two weeks. The fish were weighed to the first decimal point and fork length was measured to the nearest millimetre at the beginning of each experiment and thereafter at two week intervals. Fish were starved for 36 hours before they were measured. The fish were starved to ensure that stomachs were empty. The fish were anaesthetised in 0.2 mg/ℓ of 2-phenoxyethanol whenever handling was necessary. This concentration has no significant effect on growth rate of spotted grunter (Deacon *et al.*, 1997).

Monitoring of fish performance

Fish growth was measured in terms of body weight and length increment. In addition, feeding rate, specific growth rate (SGR), food conversion ratio (FCR), protein efficiency ratio (PER), coefficient of variation (V) and condition factor (CF) were used to assess the effects of the various experimental conditions (Purdom, 1974, De Silva & Anderson, 1995).

Feeding rate is the amount of feed consumed (on a dry weight basis) by fish over time (De Silva & Anderson, 1995). It is expressed as a percentage of wet body weight of fish (De Silva & Anderson, 1995). Therefore :

$$\% \text{ Feeding rate} = (\text{dry weight of feed consumed} / \text{wet body weight}) \times 100$$

Food conversion ratio (FCR) is a ratio of the weight of dry feed consumed and wet body weight gained by fish (De Silva & Anderson, 1995). It quantifies the efficiency of a fish in assimilating the nutrients that are contained in a diet. A low value of FCR indicates a good experimental outcome and generally ranges between 1.2 and 1.5 for animals that have been fed balanced diets (De Silva & Anderson, 1995). FCR is expressed as follows:

$$\text{FCR} = \text{Dry weight food consumed (grams)/ wet body weight gained (grams)}$$

Specific growth rate (SGR) is a measure of fish body weight gained over time and is expressed as follows (De Silva & Anderson, 1995):

$$\text{SGR} = (\mathit{ln}\ W_t - \mathit{ln}\ W_o)/t - t_o$$

where $\mathit{ln}\ W_o$ is the natural logarithm of the initial wet weight of fish; $\mathit{ln}\ W_t$ is the natural logarithm of the wet body weight of fish after a specified time, t and t is time in days.

Protein efficiency ratio (PER) is a measure of how well a protein source in the diet supplies amino acids to the fish (De Silva & Anderson, 1995). PER also indicates the goodness of the balance between energy and the amount of protein in the diet (De Silva & Anderson, 1995). High PER values are associated with fat fish (De Silva & Anderson, 1995). The mathematical expression is as follows:

$$PER = \text{Wet body weight gained} / \text{dry weight of protein ingested}$$

Coefficient of variation is defined as the ratio between standard deviation and the mean (Zar, 1996). It can be used to evaluate the effects of different experimental conditions as discussed in Chapter 1. The coefficient of variation (V) is a fraction and is usually expressed as a percentage as follows:

$$V = (\text{standard deviation} / \text{mean}) \times 100$$

Condition factor is the relationship between the length and body weight of fish. It assumes that heavier fish of a given average length are healthier (Bolger & Connolly, 1989). Condition factor (CF) can be used to detect the overall health of fish under changing environmental factors (Bolger & Connolly, 1989). The mathematical expression is as follows:

$$CF = \text{Fish wet weight (grams)} / \text{Fish length (mm)}^b$$

where b is the slope of a length on body weight relationship.

Statistical methods

All experiments were replicated in duplicate or triplicate and one way analysis of variance (ANOVA) was conducted to compare replicates. Kruskal - Wallis one way ANOVA on ranks was carried out when samples did not follow normal distribution. The length and body weight data from the fish were pooled when there was no significant difference replicates. Length and weight data were transformed into natural logarithmic values to obtain slopes, which were used to describe growth rates during the experiments (Dr H. Kaiser, Department of Ichthyology & Fisheries Science, Rhodes University, Grahamstown, South Africa; personal communication). Analysis of covariance (ANCOVA) and Tukey's multiple range test was conducted to compare growth rates in the density, size grading and feeding frequency experiments. The effect of temperature on growth was assessed by a correlation of temperature with food consumption. Analysis of variance (ANOVA) was also conducted to test for differences between fish performance parameters in all experiments. All Pair wise Multiple Comparison Procedure (Student - Newman - Keuls Method) was used when significant difference occurred between fish performance parameters.

CHAPTER 3.

THE EFFECT OF STOCKING DENSITY ON THE GROWTH OF JUVENILE SPOTTED GRUNTER.

Introduction

The desire of aquaculturists to maximise yield from farmed fish brings challenges when optimal growth of a given species is to be realised. These challenges include the maintenance of water quality; satisfying the nutritional requirements of the specific species and the effects of social interactions among the farmed species. Stocking density is one of the important considerations in the commercial farming of any species. Density is known to affect feeding behaviour and consequently, the growth rate of fish (Leatherland & Cho, 1985).

Stocking density has varying effects in different species. In Nile tilapia, *Oreochromis niloticus*, stunted growth has been observed when stocked at high density and the fish attained sexual maturity early than expected (Mair & Little, 1991). Using plasma cortisol measurement, Laidley & Leatherland (1988) found that stress levels in rainbow trout, *Onchorhynchus mykiss* increased with stocking density. The authors, however also found that there was a critical minimum stocking density below which the fish were also severely stressed. Jorgensen *et al.* (1993) reported similar observations in the arctic charr, *Salvelinus alpinus*. They found that a stocking density of 15 kg/m^3 resulted in markedly depressed growth rates. Better growth rates were reported at a stocking density of 60 kg/m^3, which were not significantly different after doubling the stocking density to 120 kg/m^3 (Jorgensen *et al.*, 1993).

In studies on the walleye, *Stizostedion vitreum vitreum* growth rate has also been positively correlated to stocking density up to a threshold density beyond which there were no further advantages (Fox, 1991). Observations on juvenile *Clarias gariepinus* also showed no significant difference in growth performance at different densities (Kaiser *et al.*, 1995).

Species such as the red sea bream, *Pagrus major*; the gilthead sea bream, *Sparus aurata*; turbot, *Scophthalmus maximus*; the European sea bass, *Dicentrarchus labrax* and the yellowtail, *Seriola quinqueradiata*, are some of the more common commercially farmed marine species. The optimal stocking densities under which these species are farmed, market sizes and the time taken to grow the fish to that size are summarised in Table 3.1.

Table 3.1. Summary of stocking density, initial and final weight and the grow-out period of some common marine aquaculture species.

Species	Initial stocking density (kg/m^3)	Initial weight (g)	Final weight (g)	Grow-out period (months)	Reference
P. major	10	-	300	15	Ungson *et al.*, 1995.
S. aurata	60	80	200	12	Pitt *et al.*, 1977.
S. maximus	5.7	3	400	12	Purdom *et al.*, 1972.
D. labrax	1.5	30	250	24	Anonymous, 1987; Girin, 1979.
S. quinqueradiata	2.5 to 10	0.5	1000	12	Fujiya, 1976.

This brief review leads to the conclusion that the effects which stocking density has on growth of fish varies with the species under consideration. No studies on the effect of stocking density on growth have been conducted on any South African marine fish species. The present experiment was aimed at investigating the effects of stocking density on growth of juvenile spotted grunter reared under ambient light and temperature conditions.

Materials and methods.

The experiment was conducted in twelve 90 ℓ oval plastic tanks (Figure 3.3 and see Chapter 2 for more details). Fish in the concrete tanks were starved for 36 hours to ensure stomach emptiness and anaesthetised in 0.2 mg/ℓ phenoxy-ethanol to minimise handling stress. The initial fork length and body weight were measured to the nearest millimetre and first decimal point to select fish that were going to be used for the experiment (Tables 3.2a and 3.2b in results). Four triplicate groups, each consisting of five, ten, twenty and forty fish were distributed randomly into each of the oval plastic tanks. The fish were fed chopped pilchards to satiation two times a day (Table 2.2 for nutritional composition of the pilchards). The experiment was conducted for three months from November to February. During this period the average temperature was 20.5 ± 1.816 ^{0}C.

The fork length and body weight were measured fortnightly to monitor the growth performance of the fish during the experiment. The water temperature, salinity and oxygen content were measured twice a day. The water flow was maintained at 4 litres per minute, i.e. total turn over in 22 minutes 30 seconds.

Statistical analyses

Fork length and body weight data were transformed into natural logarithmic values to minimise heteroscedasticity (Zar, 1996). Analyses of variance (ANOVA) were carried out in fork length and body weight data to establish whether replicates differed significantly from each other within treatments. The Kruskal - Wallis ANOVA on Ranks was conducted when normality was failed. All Pairwise Multiple Comparison Procedures (Dunn's Method) were followed to isolate the replicates or replicates that differed from others.

Standard deviations at 95 % confidence limits and variance were calculated for average fork length and body weight data. Coefficient of variation, specific growth rate, food consumption, food conversion ratio, protein efficiency ratio and condition factor were calculated to describe the growth of the fish. Analysis of covariance in slopes of fork length and body weight over time was conducted to compare the growth between stocking densities.

Results

There was no significant difference between the replicates, except where the fish were reared at a stocking density of 10 fish/90ℓ. This allowed the length and body weight data of the fish that were held in the various replicates to be pooled for further analysis. One replicate of fish that were stocked at a density of 10 fish/90ℓ was excluded from the analysis because of mortality that was caused by predators and thieves. The summary statistics of the juvenile spotted grunter before and after the experiment are presented in Tables 3.2 (a) and (b).

Table 3.2 (a). The initial and final fork length (FL ± standard deviation) of juvenile spotted grunter, *P. commersonnii*. Experiment period = 3 months.

Number of fish/90ℓ		**5**	**10**	**20**	**40**
Stocking density (kg/m^3)		**0.7**	**1.1**	**3.8**	**6.4**
Mean FL (mm)	Initial	67.7±7.7	67.6±8.9	71.4±8.6	67.1±12.2
	Final	94.3±8.9	97.6±9.9	98.7±10.1	96.5±14.9

Min. FL (mm)	Initial	50.0	51.0	48.0	39.0
	Final	76	77	73	61
Max. FL (mm)	Initial	77.0	85.0	88.0	95.0
	Final	106	115	120	130

Table 3.2 (b). The initial and final body weight (BW ± standard deviation) of juvenile spotted grunter, *P. commersonnii*. Experiment period = 3 months.

Number of fish/90ℓ		**5**	**10**	**20**	**40**
Stocking density (kg/m³)		**0.7**	**1.1**	**3.8**	**6.4**
Mean BW (mm)	Initial	4.1±1.3	4.8±1.9	5.6±1.9	4.9±2.6
	Final	13.2±3.3	15.8±4.8	16.7±4.9	16.3±7.6
Min. BW (mm)	Initial	1.8	2.0	1.8	0.6
	Final	7.6	6.5	6	3.6
Max. BW (mm)	Initial	6.2	9.5	10.3	13.3
	Final	17.4	25.5	28.5	37.7

The increase in fork length and body weight of the fish is illustrated in Figures 3.1 (a) and (b).

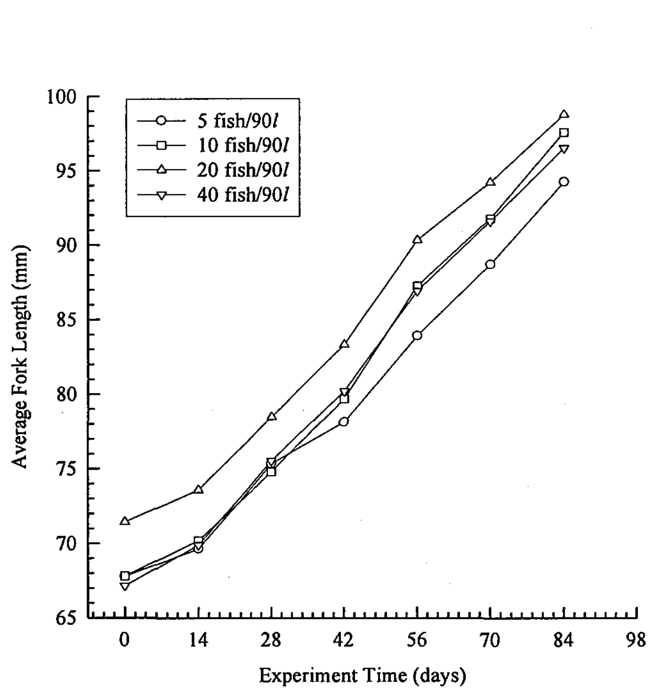

Figure 3.1 (a). Increase in average fork length of juvenile spotted grunter, *P. commersonnii* that were stocked at various densities.

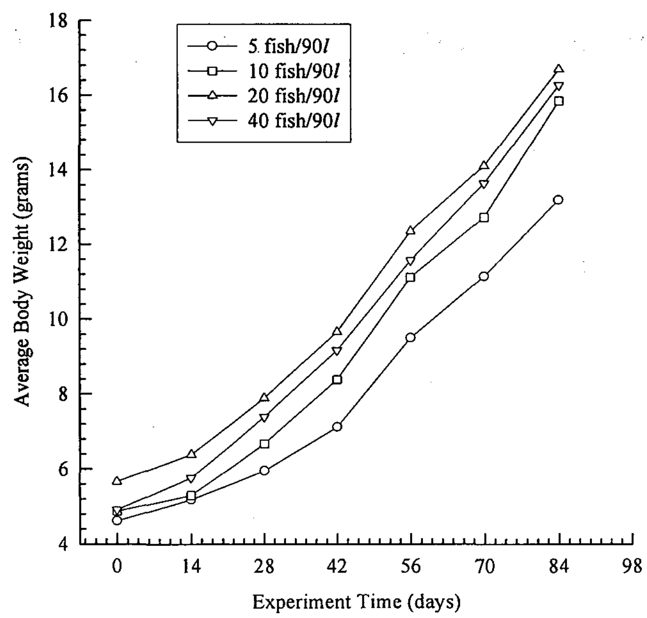

Figure 3.1 (b). Increase in average body weight of juvenile spotted grunter, *P. commersonnii* that were stocked at various densities.

Linear transformed growth models which are presented in Tables 3.3 (a) and (b) were developed from the fork length and body weight data so that statistical comparisons could be made between growth rates of the fish.

Table 3.3 (a). Growth models of juvenile spotted grunter, *P. commersonnii* that were stocked at various densities (FL = Fork length in mm). Growth rates of the fish are represented by the slopes of the models.

Number of fish/90ℓ	Regression equation	r^2	P	DF*	F-ratio
5	$ln\text{FL} = 4.2 + 0.00406^{a} \times \text{days}$	0.57	< 0.0001	3	134.1
10	$ln\text{FL} = 4.19 + 0.00458^{a} \times \text{days}$	0.571	< 0.0001	3	183.6
20	$ln\text{FL} = 4.25 + 0.00413^{a} \times \text{days}$	0.514	< 0.0001	3	442.3
40	$ln\text{FL} = 4.18 + 0.0458^{a} \times \text{days}$	0.355	< 0.0001	3	445.4

*Degrees of Freedom. Common superscripts signify growth rates that are not significantly different from each other.

Table 3.3 (b). Growth models of juvenile spotted grunter, *P. commersonnii* that were stocked at various densities (BW = Body weight in grams). Growth rates of the fish are represented by the slopes of the models.

Number of fish/90ℓ	Regression equation	r^2	P	DF*	F-ratio
5	$ln\text{BW} = 1.42 + 0.0134^{b} \times \text{days}$	0.602	< 0.0001	3	152.8
10	$ln\text{BW} = 1.45 + 0.015^{b} \times \text{days}$	0.606	< 0.0001	3	212.1
20	$ln\text{BW} = 1.64 + 0.0137^{b} \times \text{days}$	0.555	< 0.0001	3	523.2
40	$ln\text{BW} = 1.44 + 0.0151^{b} \times \text{days}$	0.389	< 0.0001	3	515.5

*Degrees of Freedom. Common superscripts signify growth rates that are not significantly different from each other.

The growth models show a general increase in the rate of fork length and body weight gain with increasing stocking density, despite the lower rate shown by the fish that were reared at a density of 20 fish/90ℓ.

The growth rates of juvenile spotted grunter were not significantly different between groups that were reared at the various stocking densities. Therefore, the experimental stocking densities did not significantly affect the growth rate of juvenile spotted grunter (Table 3.4 a).

Table 3.4 (a). Summary of the statistical analysis of the effects of stocking density on the growth parameters of juvenile spotted grunter, *P. commersonnii.*

Parameter	F-ratio	Degrees of freedom	Significance level
Fork length &body weight increase	0.42	3	0.05
Variation coefficient (fork length)	0.47	3	0.05
Variation coefficient (body weight)	0.5	3	0.05
Specific growth rate	0.761	3	0.52
Food consumption	9.44	3	< 0.0001
Food conversion ratio	16.2	3	0.0016
Protein efficiency ratio	16.9	3	0.0014
Condition factor	2.2*	3	0.532

*H-ratio from Kruskal-Wallis One Way ANOVA on Ranks.

The coefficient of variation in fork length and body weight of fish at all stocking densities decreased with time (Figures 3.2 a and b) and the slopes were negative (Table 3.4 b).

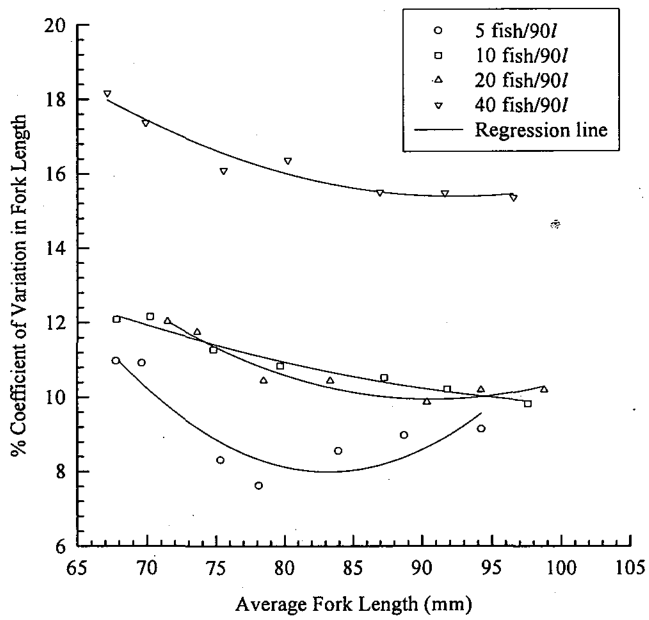

Figure 3.2 (a). Variation coefficient in fork length of juvenile spotted grunter, *P. commersonnii* that were stocked at the various stocking densities.

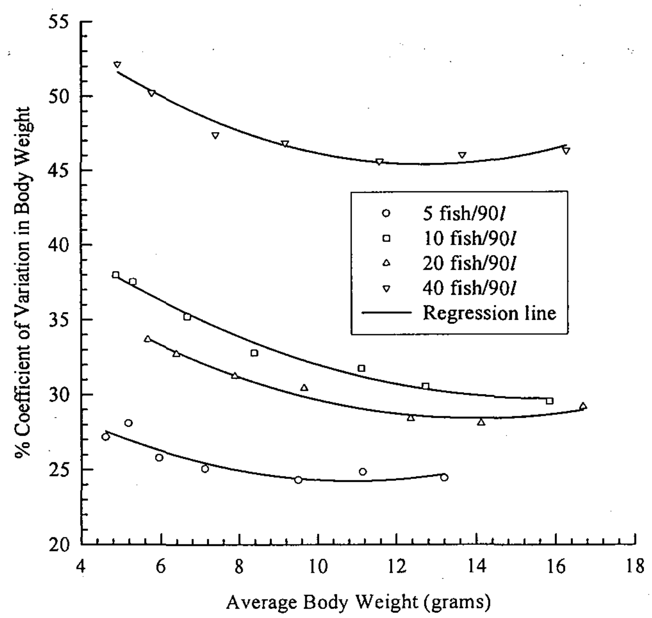

Figure 3.2 (b). Variation coefficient in body weight of juvenile spotted grunter, *P. commersonnii* that were stocked at the various stocking densities.

Table 3.4 (b). Quadratic regression parameters of variation coefficients in size of juvenile spotted grunter, *P. commersonnii* that were reared at the various densities.

Parameter	Number of fish/90ℓ	Partial slopes		r^2
		β_1	β_2	
Variation coefficient (fork length)	5	-2.14	0.0129	0.810
	10	-0.313	0.00143	0.971
	20	-1.01	0.006	0.946
	40	-0.746	0.004	0.941
Variation coefficient (body weight)	5	-1.83	0.084	0.822
	10	-2.17	0.069	0.986
	20	-2.13	0.076	0.979
	40	-2.59	0.102	0.957

Although variation coefficients were not significantly affected by stocking density (Table 3.4 a), there were some interesting trends which emerged from the data. The highest slope of length variation was observed in fish that were reared at a density of 5 fish/90ℓ, while the lowest was recorded in fish that were reared at 10 fish/90ℓ. The slope of body weight variation in fish that were reared at a density of 20 fish/90ℓ was the highest (0.00219), while the lowest (-0.00383) was recorded in fish that were reared at a density of 10 fish/90ℓ.

There was no significant difference in specific growth rates between fish that were reared at the various stocking densities (Table 3.4 b and Figure 3.3).

Table 3.4 (b). Summary of the statistical analysis between the growth parameters of juvenile spotted grunter as a result of stocking density.

Parameter	Number of fish/90ℓ	Student-Newman-Keuls Mean
Specific growth rate	5	1.25 ± 0.455^a
	10	1.4 ± 0.553^a

	20	1.29 ± 0.367[a]
	40	1.43 ± 0.303[a]
Food consumption	5	2.78 ± 0.673[b]
	10	2.37 ± 0.501[c]
	20	2.1 ± 0.392[c]
	40	1.98 ± 0.325[c]
Food conversion ratio	5	2.31 ± 0.168[d]
	10	1.84 ± 0.192[e]
	20	1.75 ± 0.147[e]
	40	1.51 ± 0.0614[e]
Protein efficiency ratio	5	0.529 ± 0.0374[f]
	10	0.666 ± 0.0695[g]
	20	0.699 ± 0.0563[g]
	40	0.804 ± 0.0326[h]
Condition factor	5	1.5710 ± 0.172[i]
	10	1.6573 ± 0.181[i]
	20	1.6661 ± 0.201[i]
	40	1.6219 ± 0.289[i]

Values that have a common superscript are not significantly different from each other as opposed to those which have uncommon superscripts.

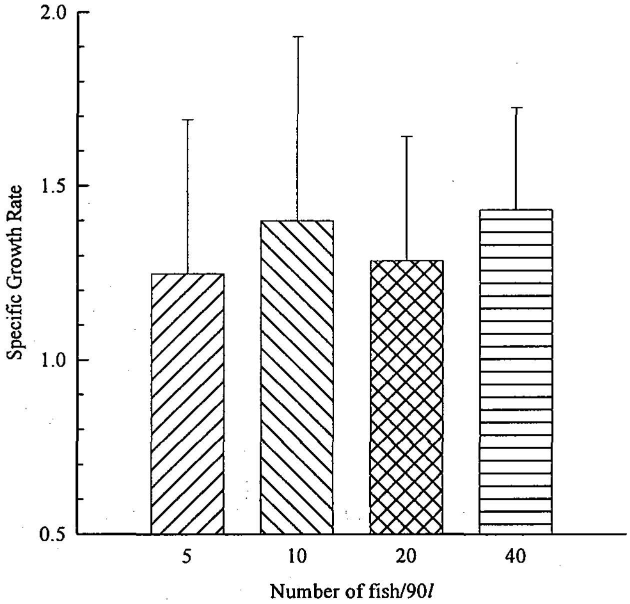

Figure 3.3. The specific growth rates of juvenile spotted grunter, *P. commersonnii* that were stocked at various densities.

It was, however, observed that juvenile spotted grunter at the highest density of 40 fish/90ℓ had the highest specific growth rate and those at 5 fish/90 ℓ had the lowest specific growth rate (Table 3.4 b).

Food consumption was not significantly different between fish that were reared in stocking densities of 10; 20 and 40 fish/90ℓ (Table 3.4 b). Fish that were reared at a density of 5 fish/90ℓ had the highest food consumption of 2.78 ± 0.673 % body weight per day (Table 3.5 b), while the lowest food consumption of 1.98 ± 0.325 % body weight per day was recorded at the highest stocking density of 40 fish/90ℓ (Table 3.4 b). Overall daily food consumption decreased with increasing stocking density ($p < 0.0001$; Figure 3.4).

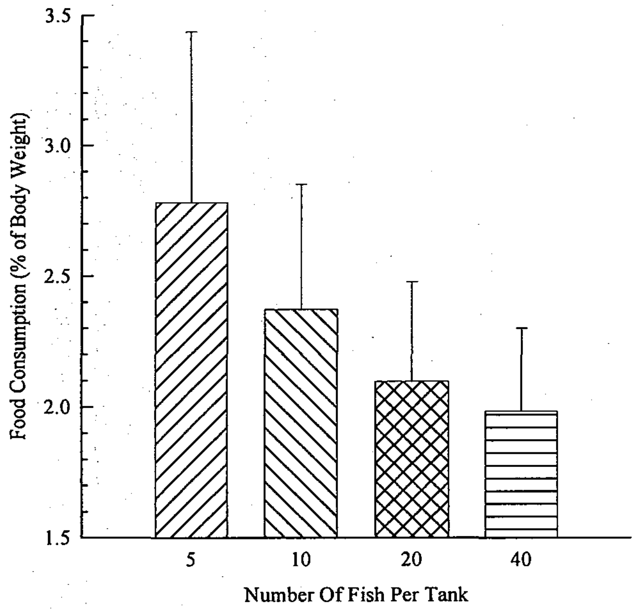

Figure 3.4. Daily food consumption of juvenile spotted grunter, *P. commersonnii* that were stocked at various densities.

Food conversion ratio improved significantly ($p = 0.002$) with increasing stocking density (Figure 3.5).

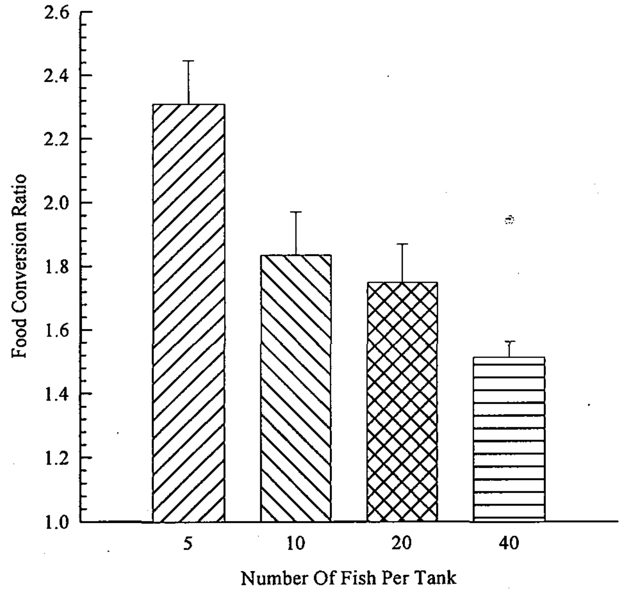

Figure 3.5. Food conversion ratios of juvenile spotted grunter, *P. commersonnii* that were stocked at various densities.

Stocking juvenile spotted grunter at a density of 5 fish/90ℓ resulted in the highest food conversion ratio of 2.31 ± 0.1685 when compared to fish that were reared at the higher densities (Table 3.4 b). Juveniles spotted grunter that were reared in the highest stocking density had the best food conversion ratio of 1.51 ± 0.0614 which was not significantly different from that of fish reared at 10 and 20 fish/90 ℓ (Table 3.4 b).

Protein efficiency ratio improved (p = 0.001) with stocking density (Figure 3.6).

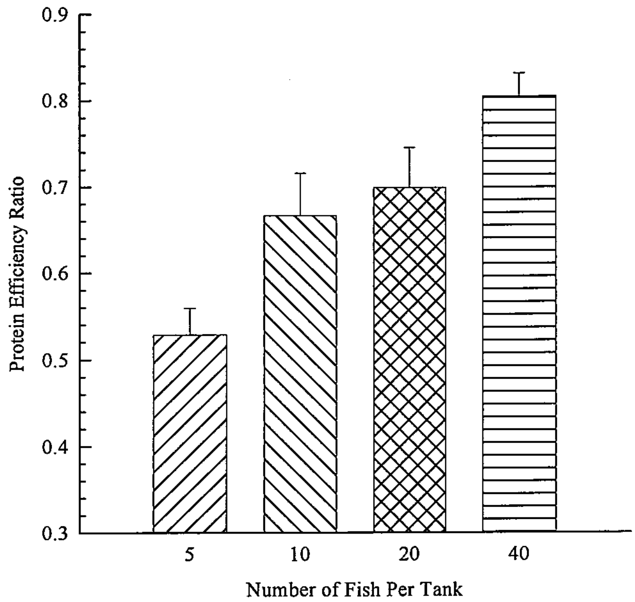

Figure 3.6. Protein efficiency ratios of juvenile spotted grunter, *P. commersonnii* that were stocked at various densities.

The protein efficiency ratios at stocking densities of 10 and 20 fish/90ℓ were not significantly different from each other. However, the protein efficiency ratio was significantly different at the extreme stocking densities. The highest protein efficiency ratio of 0.804 ± 0.0326 were recorded in fish that were reared at a density of 40 fish/90ℓ, while the lowest protein efficiency ratio was recorded at 5 fish/90ℓ (Table 3.4 b).

Stocking density had no significant effect on condition factor ($p = 0.532$) (Figure 3.7 and Tables 3.4 a and b).

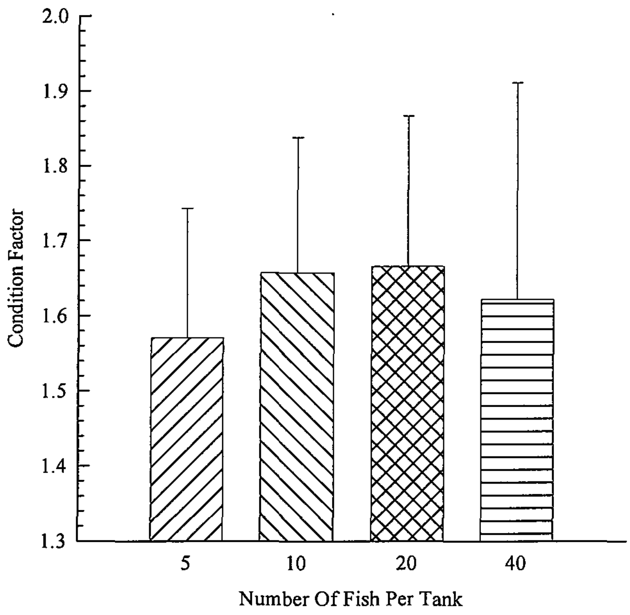

Figure 3.7. Condition factor of juvenile spotted grunter, *P. commersonnii* that were stocked at various densities.

The results obtained in the experiment can also be expressed in terms of total biomass and stocking rate (Table 3.5).

Table 3.5. The initial and final stocking densities of juvenile spotted grunter, *P. commersonnii*.

Number of fish/90ℓ	**Biomass (grams)**		**Stocking rate (kg/m^3)**	
	Initial	**Final**	**Initial**	**Final**
5	64.6	197.9	0.7	2.2
10	97.5	317	1.1	3.5
20	340	1002	3.8	11.7
40	574.75	1773.3	6.4	19.7

These data show that the experimental period of three months was of a sufficient duration for the fish to double their size. In fact, the average monthly increase in biomass of the fish was 100 %.

Discussion.

This experiment was the first attempt in investigating the effects of stocking density on the performance of juvenile spotted grunter. The growth models showed that growth rate increased, although not significantly, with stocking density. Similar results were reported by Kaiser *et al.* (1995) in their studies on *Clarias gariepinus*. The relationship between stocking density and growth rate of spotted grunter contrasts those which have been recorded in the rainbow trout, *Onchorhynchus mykiss*, where growth rate was inversely related to stocking density, but also not significantly different (Laidley & Leatherland, 1988). The lack of significant difference in the growth rates between the various stocking densities in this experiment showed that juvenile spotted grunter could be reared at stocking densities higher than 6.4 kg/m^3. This suggestion is supported by the fact that the highest specific growth rate in this experiment resulted from rearing juvenile spotted grunter at the highest stocking density.

Jorgensen *et al.* (1993) reported that the growth rate of the arctic charr, *Salvelinus alpinus* was not significantly improved at stocking density greater than 60 kg/m^3. Similar observations had been reported in studies of the walleye, *Stizostedion vitreum vitreum* (Fox, 1991). Therefore, further experimentation should focus on the determination of a stocking density beyond which there would be no further improvement in the growth rate of juvenile spotted grunter under ambient temperature and photoperiod conditions.

Stocking density did not have a significant effect on size variation in spotted grunter. In fact, the variation coefficient of fork length and body weight of the fish showed a general decrease with time in all the stocking densities. This is in marked contrast to juvenile silver bream, *Rhabdosargus sarba*, which showed an increase in the variation coefficient of length over time (Leu, 1994). This means that the size variation in juvenile spotted grunter is a result of natural variability and not competition as is the case with *R. sarba* (Purdom, 1974; Leu, 1994). The absence of competition in juvenile spotted grunter encourages the rearing of the fish in stocking densities greater than 6.4 kg/m^3. These observations lend further support to the data base that spotted grunter is an ideal aquaculture species. The negative slopes of the relationship between the variation coefficient and average size suggest size grading of juvenile spotted grunter is not necessary. However, size grading should be conducted to establish whether the growth of the fish would be improved.

The feed consumption of juvenile spotted grunter decreased with increasing stocking density. This relationship is in contrast to that reported by Jorgensen *et al.* (1993) in their studies on the arctic charr. Fox (1991) and Oellermann (1995) in studies on juvenile hybrid catfish, *Clarias gariepinus* x *Heterobranchus longifilis* and the walleye, *Stizostedion vitreum vitreum* also showed that feed consumption increased with stocking density. The fact that the lowest food consumption coincided with the best growth rate implies that increasing the stocking density resulted in better feed utilisation in juvenile spotted grunter. This suggestion is supported by the significant improvement of the food conversion and protein efficiency ratios when the stocking density of the fish was increased.

This experiment showed that the overall growth performance of juvenile spotted grunter increased with stocking density. Most of the growth performance parameters indicate that the optimum initial stocking density for the rearing of juvenile spotted grunter is beyond the present maximum of 6.4 kg/m^3.

CHAPTER 4.

THE EFFECT OF SIZE GRADING ON THE GROWTH OF JUVENILE SPOTTED GRUNTER.

Introduction

Observations of living organisms, including fish, have shown that their growth will always result in size variation even if they are equal in age (Purdom, 1974; Fausch & White, 1986; Nortvedt & Holm, 1991; Metcalfe, 1994; Nakano, 1995; Ryer & Olla, 1995; Alanara, 1996; Johnsson *et al.*, 1996). Size variation occurs when fish grow at different rates. Different growth rates among fish is caused by genetic and epigenetic factors (Koebele, 1985; Metcalfe *et al*, 1990; Malison & Held, 1992; Metcalfe, 1994; Mikheyev, 1995). The genetic quality confers varying degrees of metabolic rate in fish irrespective of their initial size so that those that have a higher metabolic rate subsequently grow faster (Metcalfe, 1994). Epigenetic factors mediate size variation and include spatial distribution of food, food supply and maintenance of territories (Koebele, 1985; Metcalfe *et al*, 1990; Malison & Held, 1992; Metcalfe, 1994; Mikheyev, 1995; Ryer & Olla, 1995; Johnsson *et al.*, 1996). Uneven spatial distribution of food, limited food supply and territoriality result in the establishment of dominance hierarchies, where the growth of subordinate fish will be suppressed by those which are dominant, thus increasing size variation.

Size variation, as a result of dominance hierarchies, is a potential source of problems in aquaculture because it can result in unnecessary costs by having fish that require more rearing time to reach a desired size (Purdom, 1974; Koebele, 1985; Metcalfe *et al*, 1990; Malison & Held, 1992; Metcalfe, 1994; Ryer & Olla, 1995; Johnsson *et al.*, 1996). Salmonids are among the most studied groups of fish in which dominance and its implications to aquaculture has been described (Fausch & White, 1986; Nortvedt & Holm, 1991; Metcalfe, 1994; Nakano, 1995; Ryer & Olla, 1995; Alanara, 1996; Johnsson *et al.*, 1996). Dominance in salmonids becomes established within the first few weeks of feeding. It appears to have a genetic basis favouring fish with a higher metabolic rate irrespective of their initial size. Fish with a higher metabolic rate subsequently grow faster (Metcalfe, 1994). Dominant fish tend to be larger in size and directly or indirectly suppress growth of subordinates (Metcalfe, 1994). The observations of Metcalfe (1994) confirmed earlier studies that were conducted by Purdom (1974) who attributed size variation to dominance hierarchies. Mikheyev (1995) concluded that dominance hierarchies resulted from competition for limited space which confers aggression.

Aggressive behaviour has been reported in captive populations of the Atlantic salmon, *Salmo salar* and other species and has been shown to decrease feeding motivation of smaller individuals resulting in decreased growth rate (Koebele, 1985; Knights, 1987; Nortvedt & Holm, 1991; Malison & Held, 1992; Umino *et al.*, 1992; Efthimiou *et al.*, 1994; Leu, 1994; Johnsson *et al.*, 1996; Alanara, 1996). Aggression decreased when *Salmo salar* was grown with the arctic charr, *Salvelinus alpinus*, and this was attributed to shading effect provided by the arctic charr (Nortvedt & Holm, 1991). In the beginning of the experiment the salmon was aggressive towards the arctic charr but the situation was reversed later when the charr grew bigger (Nortvedt & Holm, 1991). Duoculture significantly improved the growth rate and mean size of salmon (Nortvedt & Holm, 1991).

Limited supply and uneven spatial distribution of food contributed to the promotion of dominance hierarchies (Malison & Held, 1992). Most salmonid farming establishments employ automatic feeding schedules were food is always available when the fish demand it. This practise does not seem to alleviate the establishment of dominance behaviour as suggested by Metcalfe (1994). A study that was conducted on juvenile chum salmon, *Onchorhynchus keta* concluded that limiting the distribution of food to one place was the problem. Fish that received food from one place were more aggressive than those that received food distributed evenly on the water surface of the holding facility, although the amount of food was equal in the two cases. Size variation was greater in fish that received food from one place. However, after several months, aggressive behaviour was not significantly different between the two groups. On the other hand Ryer & Olla (1995) found that even spatial distribution of food was a solution as it reduced aggression and resulted in improved growth of chum salmon, *Onchorhynchus keta*. The conditions under which the two studies were conducted were not the same. The response of fish to influences of food availability is varied and depends on the species under investigation, as well as the conditions under which the observations were carried out.

Size grading is standard practise in the commercial culture of marine species such as the sea bass, *Dicentrarchus labrax,* the Japanese sea bream, *Pagrus major* and turbot, *Scopthalmus maximus* to control size variation. The fish are graded so that fish of similar size are always in the same cage (Singh, 1991; Alvial & Trujilo, 1993). Fry of the gilt head seabream, *Sparus aurata* are graded once size variation has reached 300 % in a population, to minimise aggressive behaviour which culminates in cannibalism of the smaller fish by large ones (Tandler, 1993; Efthimiou *et al.*, 1994). Size grading in commercial marine species is usually conducted at 32 to 40 days after hatching and during stocking into grow-out facilities. It is also conducted once the juveniles have grown seven to ten fold and thereafter, during harvest (Singh, 1991; Alvial & Trujilo, 1993; Chao *et al.*, 1993; Efthimiou *et al.*, 1994).

A conclusion can be made that dominance, food availability and its spatial distribution affect the growth of fish. Food availability may promote the establishment of dominance hierarchies among fish, sometimes resulting in size variation. Dominant fish may be aggressive towards subordinate fish and suppress their growth even if food is not a limiting factor (Purdom, 1974; Koebele, 1985; Mikheyev, 1995). Dominance hierarchies among fish may cause size variation with time depending on the species (Knights, 1987; Kamstra, 1993). Duoculture and size grading are effective tools to reduce size variation when this occurs as a result of dominance hierarchies, although their effect depends on the species (Knights, 1987; Nortvedt & Holm, 1991; Kamstra, 1993).

The aim of this experiment was to investigate the effect of size grading on the growth of juvenile spotted grunter in captivity under ambient temperature and photoperiod conditions. Size grading in this case refers to removal of the largest fish in specified intervals. The assumption, based on the literature which was discussed earlier, was that size variation among groups of juvenile spotted grunter would increase over time. The increase in size variation would result in the development of dominance hierarchies where bigger fish would suppress the growth of subordinate ones. Size grading by removing the bigger fish would theoretically decrease size variation, thus resulting in uniform growth of juvenile spotted grunter.

Materials and methods.

Juvenile spotted grunter were caught from the Great Fish River estuary, acclimated and sorted as described in Chapter 2 and 3. Six groups of fish were placed in the 90 ℓ oval tanks, of which two groups contained 20 fish and four groups contained 40 fish per tank. The fish were fed moist pellets five times a day to satiation to ensure that food was not a limiting factor (Table 2.1 for the nutritional composition of the moist pellets).

The fork length and body weight of the fish in all the tanks were measured every 14 days. Every 14 days the largest fish was removed from the two replicate groups at 20 fish/90ℓ and from two replicate groups at 40 fish/90ℓ. The removed fish was replaced with a fish of the mean size in each tank. The fish that were used for replacement were taken from two holding tanks. The fish that were held in the remaining two tanks at a density of 40 fish/90ℓ were only measured and no fish were added or removed and served as the control groups. The experiment was conducted for three months.

Statistical analyses

Fortnightly length and body weight data were ranked and averages calculated. Data from fish that were greater than and including the average were excluded from subsequent analysis as the experimental hypothesis entailed that the growth performance of the smaller fish would improve in the absence of larger fish.

The average fork length and body weight were recalculated after the exclusion process. Thereafter, the coefficient of variation was calculated to assess the effects of the removal of the largest fish on the growth performance of other fish. The specific growth rate and condition factor were determined. The average fork length, body weight and the coefficient of variation were plotted against size.

One Way ANOVA and All Pairwise Multiple Comparison Procedures (Student-Newman-Keuls Method) were conducted to test whether variation coefficients and condition factors were significantly different between treatments. Kruskal-Wallis One Way ANOVA on Ranks was conducted to compare variation coefficients.

Results

There was no significant difference between replicates of experimental and control groups ($p < 0.0001$). This made pooling of replicates possible. The increase in size of the fish over the experimental period is illustrated in Figures 4.1 (a) and (b).

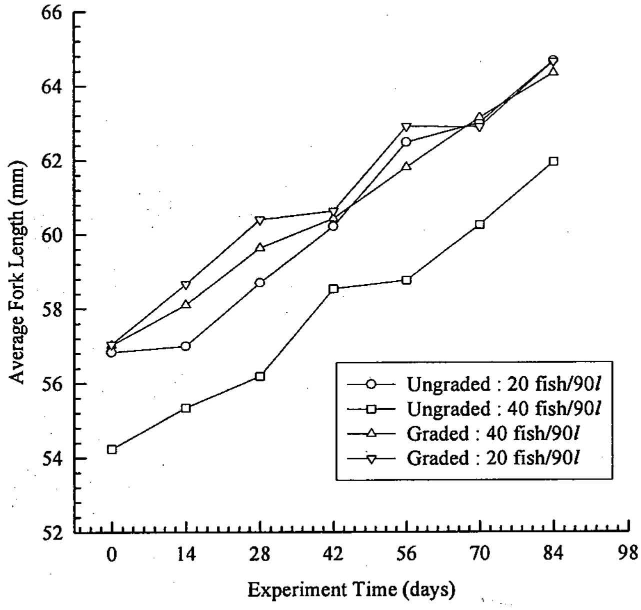

Figure 4.1 (a). The effect of removal of the largest fish every 14 days on the average fork length increment of juvenile spotted grunter, *P. commersonnii* reared at stocking densities of 20 and 40 fish/90ℓ. Graded = removal of the largest fish after 14 days; Ungraded = no removal of the largest fish after 14 days.

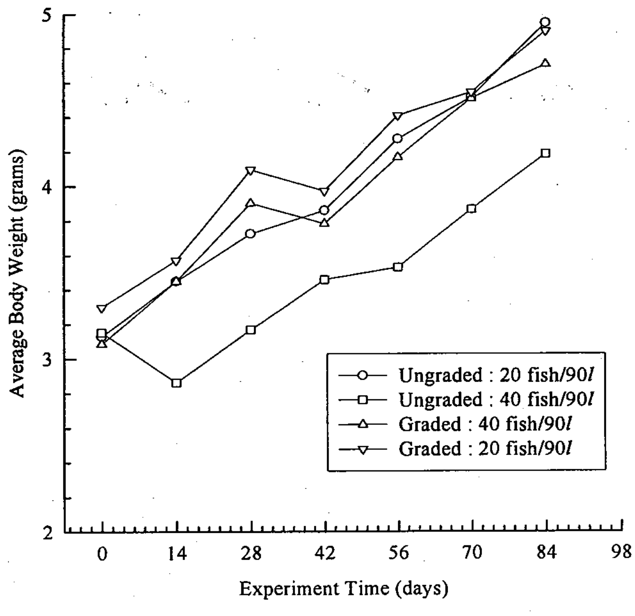

Figure 4.1 (b). The effect of removal of the largest fish every 14 days on the average body weight increment of juvenile spotted grunter, *P. commersonnii* reared at stocking densities of 20 and 40 fish/90ℓ. Graded = removal of the largest fish after 14 days; Ungraded = no removal of the largest fish after 14 days.

The information in Figures 4.1 (a) and (b) has been summarised in Table 4.1 (a). The regular removal of the largest individual did not improve the growth of fish at a stocking density of 20 fish/90ℓ in terms of length. In fact, the ungraded fish grew better by 0.3 %.

Table 4.1 (a). The initial and final size ± standard deviation of ungraded and graded juvenile spotted grunter, *P. commersonnii*. Experiment period = 3 months. Graded = removal of the largest fish after 14 days; Ungraded = no removal of the largest fish after 14 days.

Statistic		**20 fish/90ℓ**		**40 fish/90ℓ**	
		Ungraded	**Graded**	**Ungraded**	**Graded**
Average Fork Length (mm)	**Initial**	56.8 ± 4.9	57.0 ± 6.0	54.2 ± 3.9	57.2 ± 3.9
	Final	64.7 ± 5.6	64.6 ± 5.4	61.9 ± 4.9	64.3 ± 3.5
Average Body Weight (grams)	**Initial**	3.1 ± 0.8	3.3 ± 0.9	3.1 ± 1.0	3.1 ± 0.6
	Final	4.9 ± 1.2	4.9 ± 1.2	4.2 ± 0.9	4.7 ± 0.7

In terms of weight, the ungraded fish also grew better than the graded fish, by a margin of 9.6 %. At a density of 40 fish/90ℓ size grading resulted in improved growth by 16.1. However , the opposite was observed in terms of growth in length. The effect of size grading on the absolute growth rate in the two stocking densities is summarised in Table 4.1 (b).

Table 4.1 (b). The effect of removal of the largest fish every 14 days on the absolute growth of juvenile spotted grunter, *P. commersonnii*. Graded = removal of the largest fish after 14 days; Ungraded = no removal of the largest fish after 14 days. The percentage was calculated as the increase on the initial body weight and fork length.

Absolute Growth	**20 fish/90ℓ**		**40 fish/90ℓ**	
	Ungraded	Graded	Ungraded	Graded
In terms of fork length (%)	13.9	13.3	14.2	12.4
In terms of body weight (%)	58.1	48.5	35.5	51.6

The effect of size grading on the coefficients of variation in size of juvenile spotted grunter is illustrated in Figures 4.2 (a) and (b).

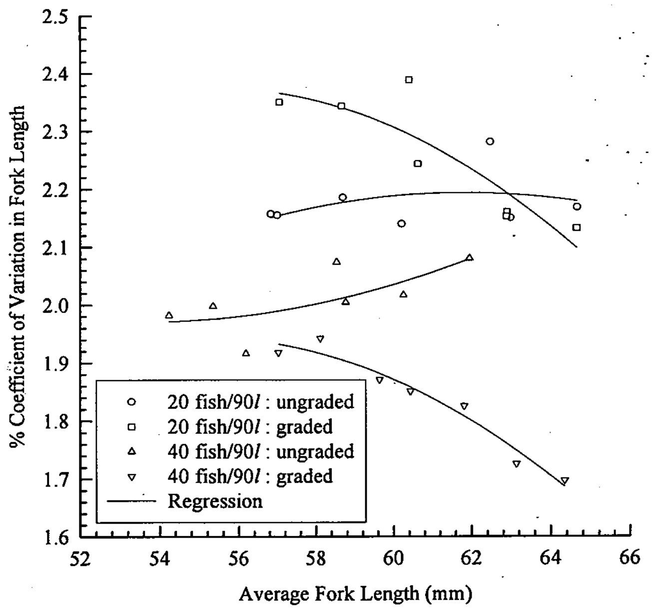

Figure 4.2 (a). The effect of removal of the largest fish every 14 days on the coefficient of variation in fork length of juvenile spotted grunter, *P. commersonnii* reared at stocking densities of 20 and 40 fish/90ℓ. Graded = removal of the largest fish after 14 days; Ungraded = no removal of the largest fish after 14 days.

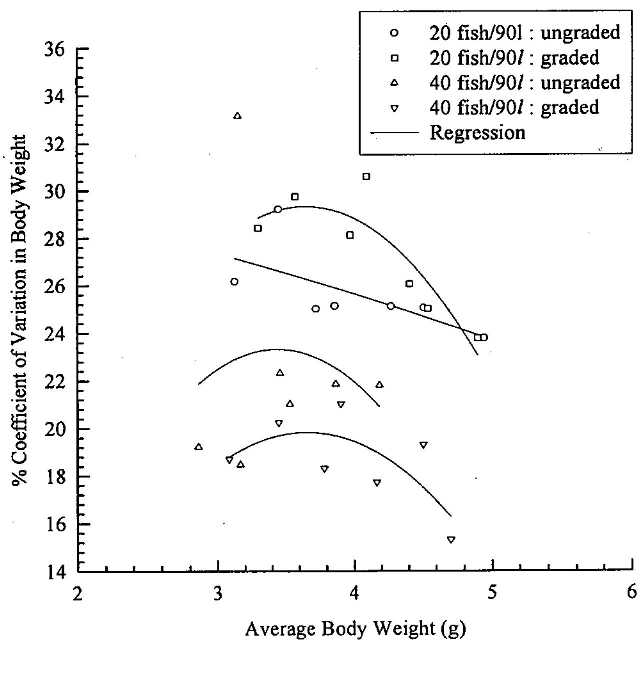

Figure 4.2 (b). Th e effect of removal of the largest fish every 14 days on the coefficient of variation in body weight of juvenile spotted grunter, *P. commersonnii* reared at stocking densities of 20 and 40 fish/90ℓ. Graded = removal of the largest fish after 14 days; Ungraded = no removal of the largest fish after 14 days.

The coefficient of determination, r^2 which described the amount of variability in the variation coefficient as accounted by its correlation with average fish size, was very low in ungraded fish (Table 4.2 a). This implied that the variation coefficient was not dependent on the average size of juvenile spotted grunter. Nonetheless, quadratic models yielded the best description of the relationship between the coefficient of variation and average size of the fish.

Table 4.2 (a). The effects of removal of the largest fish every 14 days on the coefficients of variation in size of juvenile spotted grunter, *P. commersonnii* reared at stocking densities of 20 and 40 fish/90ℓ. The effects are represented by partial slopes of quadratic regressions. Graded = removal of the largest fish after 14 days; Ungraded = no removal of the largest fish after 14 days.

Parameter	Number of fish/90ℓ	Partial slopes		r^2
		β_1	β_2	
Variation coefficient (fork length)	20 (ungraded)	2.03	-0.016	0.13
	20 (graded)	3.33	-0.030	0.77
	40 (ungraded)	-1.18	0.011	0.49
	40 (graded)	1.71	-0.016	0.96
Variation coefficient (body weight)	20 (ungraded)	-0.87	-0.12	0.45
	20 (graded)	29.2	-4.00	0.79
	40 (ungraded)	30.1	-4.37	0.03
	40 (graded)	23.6	-3.22	0.50

It was interesting to note that among graded fish, the models resulted in smaller partial slopes at 40 fish/90ℓ than at 20 fish/90ℓ, which meant that size grading decreased the coefficient of variation (Table 4.2a)

Size grading did not have a significant effect on the specific growth rate of juvenile spotted grunter over the entire experimental period (Tables 4.2b and 4.2c).

Table 4.2 (b). Student-Newman-Keuls analysis of the effect of removal of the largest fish every 14 days on the specific growth rate and condition factor of juvenile spotted grunter, *P. commersonnii* reared at stocking densities of 20 and 40 fish/90ℓ. Graded = removal of the largest fish after 14 days; Ungraded = no removal of the largest fish after 14 days.

Parameter	Number of fish/90ℓ	Student-Newman-Keuls Median
Specific growth rate	20; ungraded	0.504[a]
	20; graded	0.393[a]
	40; ungraded	0.506[a]
	40; graded	0.550[a]
Condition factor	20; ungraded	*0.930 ± 0.152[b]
	20; graded	*0.966 ± 0.167[b]
	40; ungraded	*0.826 ± 0.129[c]
	40; graded	*1.011 ± 0.117[b]

***Means.** Values that have a common superscript are not significantly different from each other as opposed to those which have uncommon superscripts.

Table 4.2 (c). Significance tests summary of the effects of removal of the largest fish every 14 days on the specific growth rate and condition factor of juvenile spotted grunter, *P. commersonnii* reared at stocking densities of 20 and 40 fish/90ℓ.

Parameter	H or F- ratio	Degrees of Freedom	Significance Level
Specific growth rate	*0.555	3	0.9066
Condition factor	13.2	3	< 0.0001

***H-ratio**

However, it was interesting to observe that fish reared at 40 fish/90ℓ had better specific growth rates than the fish at 20 fish/90ℓ. In fact, the best specific growth rate resulted from graded fish reared at 40 fish/90ℓ, whereas graded fish reared at 20 fish/90ℓ had the worst. The overall specific growth rates are illustrated in Figure 4.3.

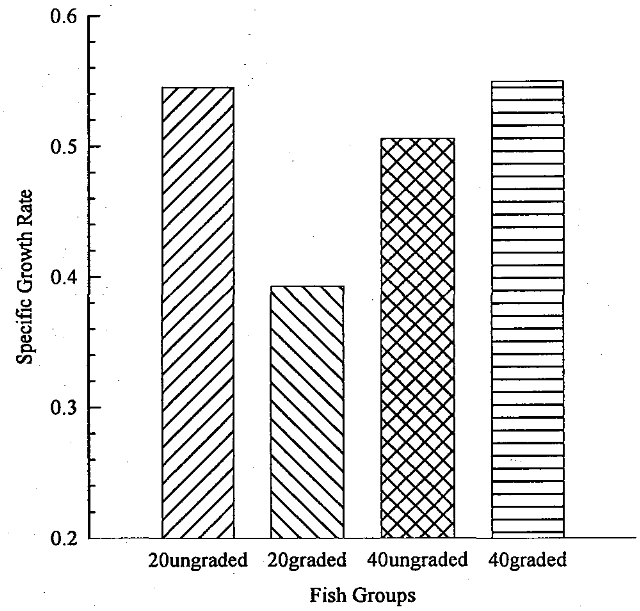

Figure 4.3. The effect of removal of the largest fish every 14 days on the specific growth rates of juvenile spotted grunter, *P. commersonnii* reared at stocking densities of 20 and 40 fish/90ℓ. Graded = removal of the largest fish after 14 days; Ungraded = no removal of the largest fish after 14 days.

There was no significant difference in the condition factor of graded and ungraded fish at a density of 20 fish/90ℓ and graded fish at 40 fish/90ℓ (Figure 4.4 and Table 4.2 b). However, ungraded fish at a density of 40 fish/90ℓ had a significantly low condition factor.

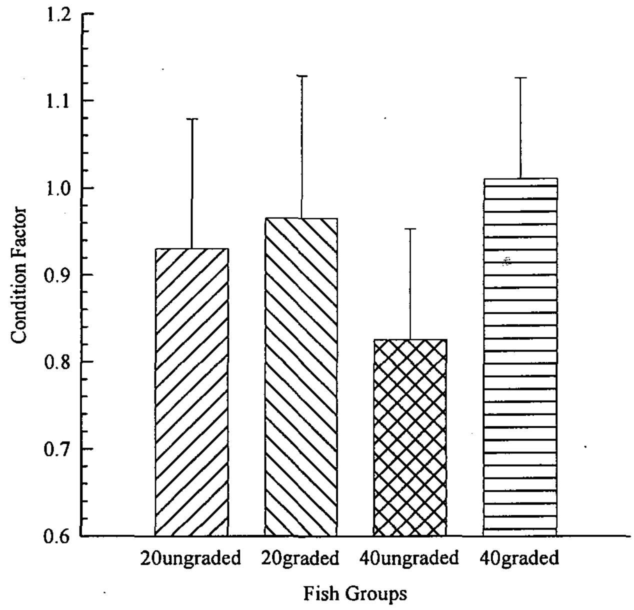

Figure 4.4. The effect of removal of the largest fish every 14 days on the condition factor of juvenile spotted grunter, *P. commersonnii* reared at stocking densities of 20 and 40 fish/90ℓ. Bars = Standard Deviation. Graded = removal of the largest fish after 14 days; Ungraded = no removal of the largest fish after 14 days.

Discussion

The independence of the coefficient of variation on average size among ungraded juvenile spotted grunter means that there was no competitive behaviour in the experimented stocking densities (Purdom, 1974).

Studies on commercially cultured fish such as salmon, sea bass, sea breams, turbot and groupers showed that size grading was necessary on three to four occasions during the production life span of a cultured species (Fausch & White, 1986; Nortvedt & Holm, 1991; Singh, 1991; Alvial & Trujilo, 1993; Chao *et al.*, 1993; Efthimiou *et al.*, 1994; Metcalfe, 1994; Nakano, 1995; Ryer & Olla, 1995; Alanara, 1996; Johnsson *et al.*, 1996;). For example, the first phase of size grading in *Epinephelus tauvina* and *Dentex dentex* is necessary at the post-larval stage 38 to 40 after hatching because of large size variation in newly hatched larvae (Chao *et al.*, 1993; Efthimiou *et al.*, 1994), resulting in cannibalism. The second grading usually takes place when the juveniles are stocked in the grow-out facilities at the approximate size of 50 to 60 mm TL (Chao *et al.*, 1993; Efthimiou *et al.*, 1994). The third phase of grading is when the fish have grown seven to ten-fold and lastly, during harvest (Singh, 1991; Alvial & Trujilo, 1993; Chao *et al.*, 1993; Efthimiou *et al.*, 1994). The conclusions reached here were therefore not unexpected because the experimental period was three months, a fifth of the predicted rearing period to market size of the spotted grunter (Chapter 6). The effect of size grading on the growth of the species below and above the size range in this study is not known. Firm conclusions on the existence of competitive behaviour and subsequently, dominance hierarchies as well as possible mitigating measures would therefore, be made when the growth over the production life span of the spotted grunter is known.

Further studies should, however be, focussed on the effect of size grading on the growth of juvenile spotted grunter at densities higher than the range in this study. This suggestion is supported by the fact that removal of the largest fish at 40 fish/90ℓ resulted in the best condition factor. The studies should also reflect on the size of the species over the entire rearing period until the fish reach a marketable size.

CHAPTER 5.

THE EFFECTS OF FEEDING FREQUENCY ON THE GROWTH OF JUVENILE SPOTTED GRUNTER

Introduction

The total amount of feed that is fed to fish increases with feeding frequency, whereas the instantaneous amount of feed consumed decreases with increasing feeding frequency (Chua & Teng, 1978).The influence of feeding frequency on the growth of fish becomes less beneficial when environmental temperature approaches the extremes of a species tolerance range. Lovell (1989) showed that food intake by the channel catfish, *I. punctatus* was not significantly different when they were fed once or twice a day under ambient temperature conditions. When the fish were reared under optimal temperature conditions, a feeding frequency of two times a day resulted in maximum feeding rate and body weight gain of channel catfish (Lovell, 1989). Webster *et al.* (1993; 1994) found that there was no significant difference in growth and food conversion ratio between feeding once or twice a day when channel catfish were reared under sub-optimal temperature conditions. High variability in the recommended feeding frequency in *Clarius gariepinus* has been reported in many studies such as Hoogendoorn (1980), Uys & Hecht (1985), Hecht & Appelbaum (1987), Appelbaum & van Damme (1988), Anderson & Fast (1991), Haylor (1993) and Buurma & Diana (1994). When Atlantic cod, *Gadus morhua* were reared at a lower temperature, food consumption decreased. The decrease of food consumption was more a function of feeding frequency than ration size (Waiwood *et al.*, 1991; Folkvord & Ottera, 1993).

Charles *et al.* (1983) reported that the optimal feeding frequency for juvenile *Cyprinus carpio* was three times a day. This feeding frequency resulted in a high food consumption and growth rate (Charles *et al.*, 1983). Feeding frequency did not have a significant effect on growth rate of juvenile bighead carp, *Aristichthys nobilis*, although survival was increased when the fish were fed three times a day (Carlos, 1988). Maximum growth rate and a good food conversion ratio was reported for juvenile *Epinephelus tauvina* when these were reared at a feeding frequency of once every two days (Chua & Teng, 1978). The instantaneous ration size was also high in fish that were reared at this feeding frequency (Chua & Teng, 1978).

The effects of feeding frequency on the growth performance of juvenile spotted grunter (mean initial total length = 50.2 ± 2.9 mm), *Pomadasys commersonnii* under optimal temperature conditions was studied by Deacon (1997). The fish were fed semi-moist pellets to satiation at feeding frequencies ranging from one to five times a day. When the fish were fed three times a day they grew significantly faster than at any of the other frequencies.

The above discussion shows that feeding frequency has variable effects on the growth performance and survival of different species in different ways. Feeding frequencies exercised under fish farming practises ranges from 1 to 6 times a day throughout the temperature tolerance range of a species (Grayton & Beamish, 1977; Hoogendoorn 1980; Marian *et al.*, 1981; Singh & Srivastava, 1984; Uys & Hecht, 1985; Chiu *et al.*, 1987; Hecht & Appelbaum, 1987; Appelbaum & van Damme, 1988; Abud, 1990; Anderson & Fast, 1991; Yakano *et al.*, 1993; Haylor, 1993; Buurma & Diana, 1994; Talbot, 1994; Deacon, 1997). The effects of feeding frequency on the growth of spotted grunter are not known under ambient temperature conditions.

The present experiment was aimed at establishing the effects of feeding frequency on the growth and survival of juvenile spotted grunter, *Pomadasys commersonnii* under ambient temperature and photoperiod conditions.

Materials and methods

Juvenile spotted grunter were caught in the Great Fish River estuary. General details about the experimental system and fish acclimation were covered in Chapter 2. The fish were divided into three triplicate groups and randomly distributed into nine 1000ℓ plastic tanks. They were fed chopped pilchard at feeding frequencies of one, two and three times a day, to satiation. The quantity of food consumed by fish in each of the tanks was recorded on a dry weight basis after each feeding. Summary statistical information about the fish that were used are presented in Table 5.1.

Table 5.1. Group statistics of juvenile spotted grunter, *P. commersonnii* that were used in the feeding frequency experiment.

Statistic	**Daily Feeding Frequency**		
	Once (75 fish/1000ℓ)	**Three times (70 fish/1000ℓ)**	**Five times (76 fish/1000ℓ)**
Average fork length (mm)	140.0 ± 18.7	139.5 ± 19.3	136.4 ± 21.3
Average body weight (g)	51.8 ± 21.5	51.6 ± 21.5	49.1 ± 23.9
Initial biomass (g)	3834.4	3561.2	3686.1
Initial stocking density (kg/m^3)	3.8	3.6	3.7

The number of fish in each replicate was not the same because of mortality prior to the initiation of the experiment. Once a fortnight individual fork length and body weight of fish were measured to the nearest millimetre and 0.1 g, respectively. Prior to measuring and weighing, the fish were starved for 24 hours and anaesthetised in 0.2 mg/ℓ phenoxyethanol. Temperature and water quality were monitored as described in Chapter 2. The experiment was undertaken over three months.

Statistical analyses

One Way Analysis Of Variance (ANOVA) was conducted on fork length and body weight data to test for equality of variance. Data from replicates of the treatment were pooled if there was equality of variance. Average fork length and body weight, standard deviation, variation coefficients of fork length and body weight data, specific growth rates, food consumption, food conversion ratio, protein efficiency ratio, condition factor and survival of the fish were determined. The average fork length and body weight; variation coefficients, specific growth rates and survival were plotted against time. An analysis of covariance was conducted to compare growth rates. The significance of the effect of feeding frequency on the various growth parameters between replicates was tested using One Way ANOVA, Kruskal-Wallis One Way ANOVA on Ranks and All Pairwise Multiple Comparison Procedures (Student-Newman-Keuls Method).

Results

The effect of feeding frequency on the growth performance in terms of fork length and body weight of juvenile spotted grunter is illustrated in Figures 5.1 (a) and (b) and described by the models in Table 5.2.

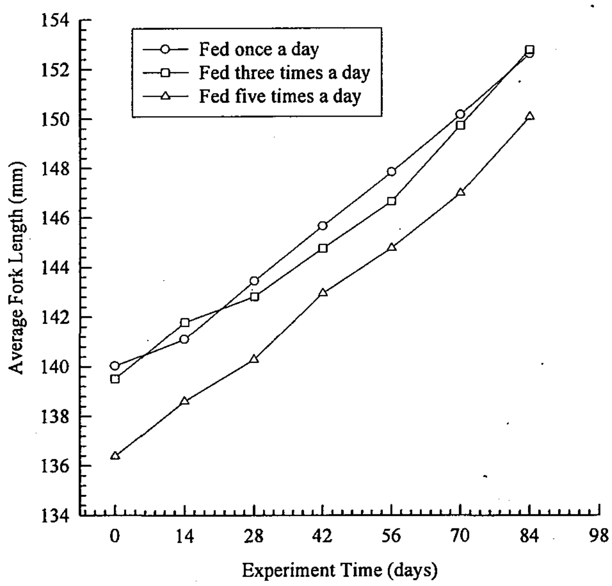

Figure 5.1 (a). The effect of feeding frequency on the average fork length of juvenile spotted grunter, *P. commersonnii.*

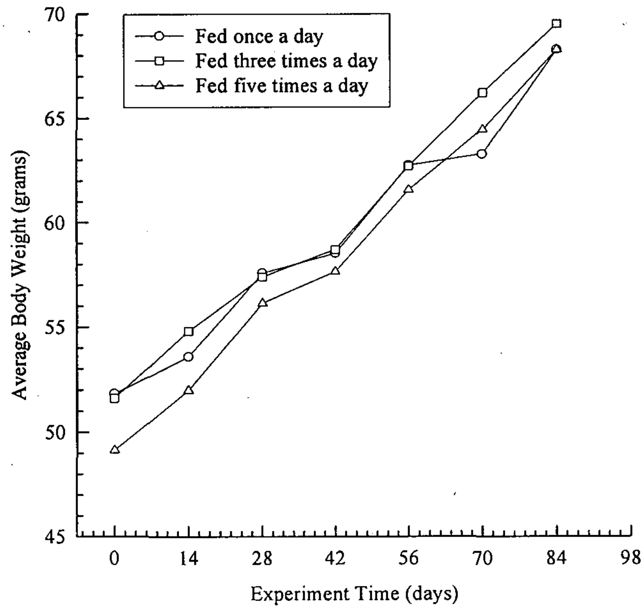

Figure 5.1 (b). The effect of feeding frequency on the average body weight of juvenile spotted grunter, *P. commersonnii.*

Table 5.2. Growth models of juvenile spotted grunter, *P. commersonnii* that were reared at various feeding frequencies. Slopes that have a common superscript are not significantly different from each other.

Parameter	Number of meals/day	Model	r^2	P	F-ratio
Growth rate (fork length, FL)	One	lnFL = 4.93+0.00105^{a}xdays	0.0485	< 0.0001	24.9
	Three	lnFL = 4.92+0.00107^{a}xdays	0.0375	< 0.0001	18.2
	Five	lnFL = 4.90+0.00117^{a}xdays	0.0392	< 0.0001	19.6
Growth rate (body weight, BW)	One	lnBW = 3.86+0.0032^{b}xdays	0.0456	< 0.0001	23.4
	Three	lnBW = 3.85+0.0034^{b}xdays	0.0458	< 0.0001	21.0
	Five	lnBW = 3.78+0.0038^{b}xdays	0.0417	< 0.0001	20.9

Although the slope of the growth models showed a trend for improved growth rate in length and in weight, feeding frequency did not have a significant effect ($p = 0.05$) on the growth of the fish in terms of fork length and body weight.

The effect of feeding frequency on the coefficients of variation in fork length and body weight are illustrated in Figures 5.2 (a) and (b). Competitive behaviour among the fish, as indicated by the coefficient of variation and average size, could not be tested because of the mortalities recorded at feeding frequencies of one and five times a day.

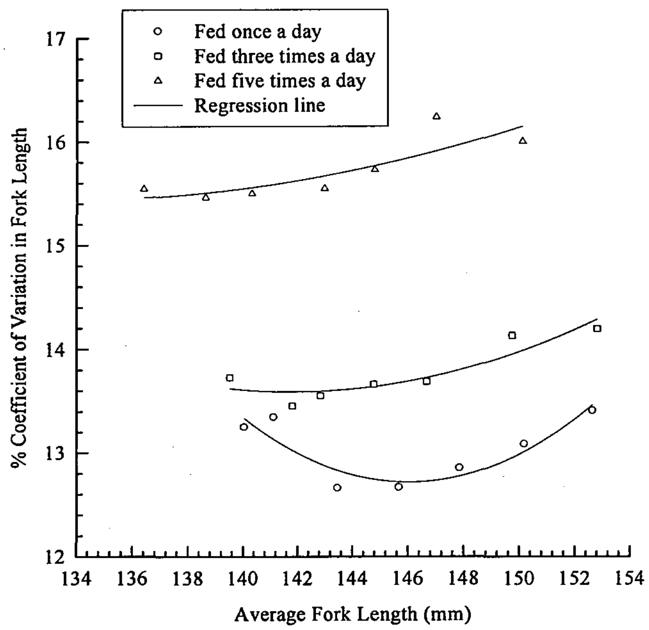

Figure 5.2 (a). The effect of feeding frequency on the coefficient of variation in fork length of juvenile spotted grunter, *P. commersonnii.*

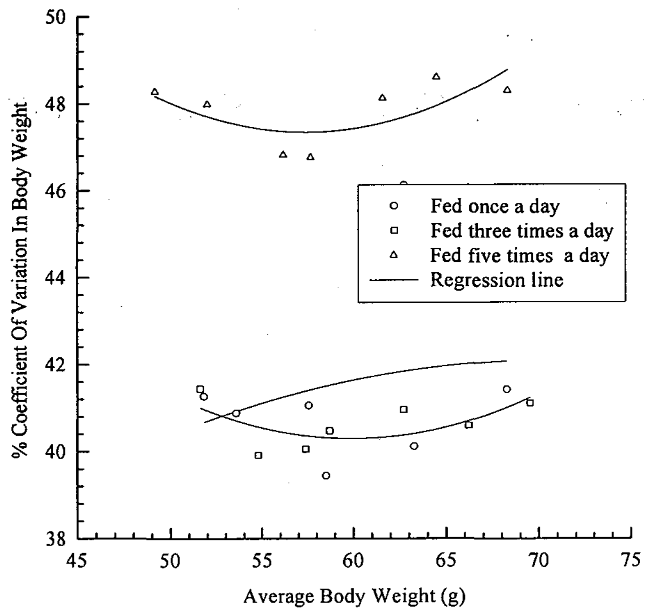

Figure 5.2 (b). The effect of feeding frequency on the coefficient of variation in body weight of juvenile spotted grunter, *P. commersonnii.*

The effect of feeding frequency on the specific growth rate over the whole experimental period is illustrated in Figure 5.3.

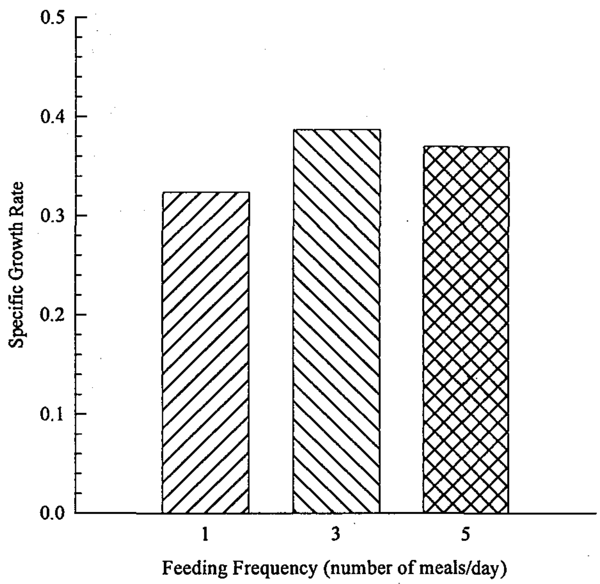

Figure 5.3. The effect of feeding frequency on the specific growth rate of juvenile spotted grunter, *P. commersonnii.*

Feeding frequency did not have a significant effect on the specific growth rate of the fish (Table 5.3 a). However, it was interesting to note that the best specific growth was recorded in fish that were fed three times a day.

Table 5.3 (a). Significance tests summary between the growth parameters of juvenile spotted grunter as a result of feeding frequency. Means that have a common superscript are not significantly different from each other as opposed to those which have uncommon superscripts. * The significance of the effect of feeding frequency on food conversion ratio was not tested because of mortalities which necessitated pooling of the replicates in each of the feeding regimes.

Parameter	Feeding frequency	Student-Newman-Keuls Mean
Specific growth rate	Once a day	0.324
	Three times a day	0.387

	Five times a day	0.370
Food consumption	Once a day	0.601[a]
	Three times a day	0.741[b]
	Five times a day	0.844[c]
Food conversion ratio	Once a day	*1.89
	Three times a day	5.20
	Five times a day	4.81
Protein efficiency ratio	Once a day	0.646[d]
	Three times a day	0.234[e]
	Five times a day	0.254[e]
Condition factor	Once a day	2.47[f]
	Three times a day	2.58[f]
	Five times a day	2.55[f]

Feeding frequency had a significant effect ($p < 0.0001$) on food consumption (Table 5.3a and Figure 5.4).

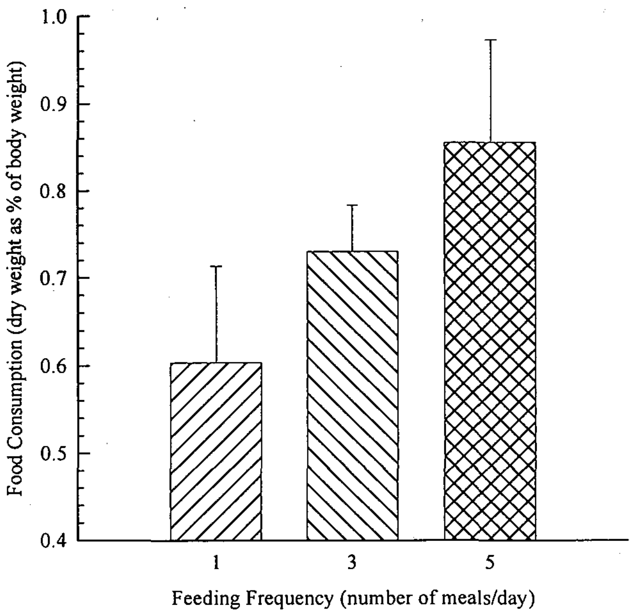

Figure 5.4. The effect of feeding frequency on the food consumption of juvenile spotted grunter, *P. commersonnii*. Bars = Standard Deviation.

Those fish fed once a day had 275 % and 255 % better food conversion ratio than those fed twice and three times a day (Figure 5.5 and Table 5.3a).

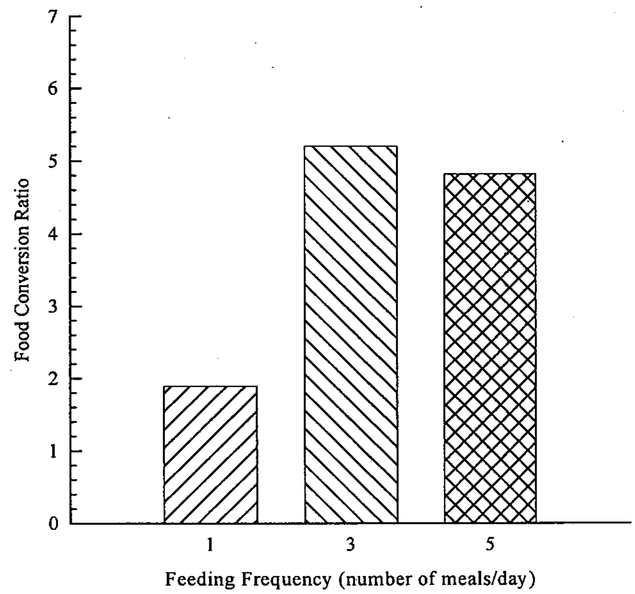

Figure 5.5. The effect of feeding frequency on food conversion ratio of juvenile spotted grunter, *P. commersonnii*. Bars = Standard Deviation.

Figure 5.6 illustrates the effect of feeding frequency on protein efficiency ratio. There was no significant difference in the protein efficiency ratio between the fish which were fed three and five times a day (Table 5.3a).

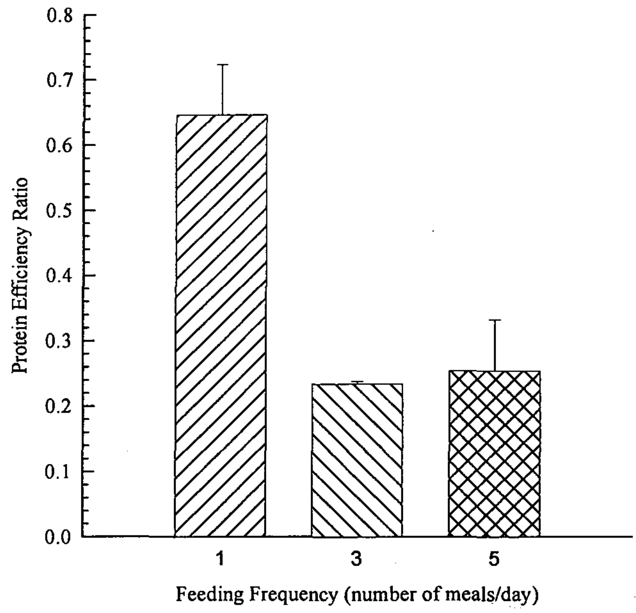

Figure 5.6. The effect of feeding frequency on the protein efficiency ratio of juvenile spotted grunter, *P. commersonnii*. Bars = Standard Deviation

The fish that were fed five times a day had the lowest protein efficiency ratio. This might be explained as being the result of high gut evacuation rate and low nutrient assimilation. Feeding the fish once a day resulted in the highest protein efficiency ratio, which was significantly different from that of other treatments (Table 5.3 b).

Table 5.3 (b). Significance tests summary of the effects of feeding frequency on the growth parameters of juvenile spotted grunter.

Parameter	H or F-ratio	Degrees of freedom	P
Growth rate (fork length)	0.000	2	0.050
Growth rate (body weight)	0.050	2	0.050
Specific growth rate	*0.97	2	0.615
Food consumption	*29.4	2	< 0.0001
Protein efficiency ratio	40	2	0.0003
Condition factor	*2.82	2	0.2447

***H-ratio**

This shows that although the fish consumed a limited amount of food, they utilised the food ingested most effectively.

Feeding frequency did not significantly affect the condition factor (Figure 5.7) of juvenile spotted grunter (Table 5.3 b).

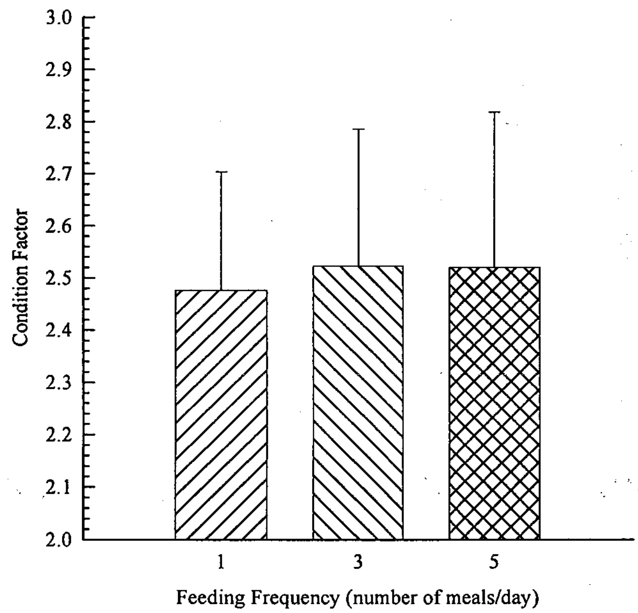

Figure 5.7. The effect of feeding frequency on the condition factor of juvenile spotted grunter, *P. commersonnii*. Bars = Standard Deviation.

The survival of juvenile spotted grunter ranged from 90 to 95 %. Feeding three times a day produced better survival than feeding once and five times a day (Figure 5.8).

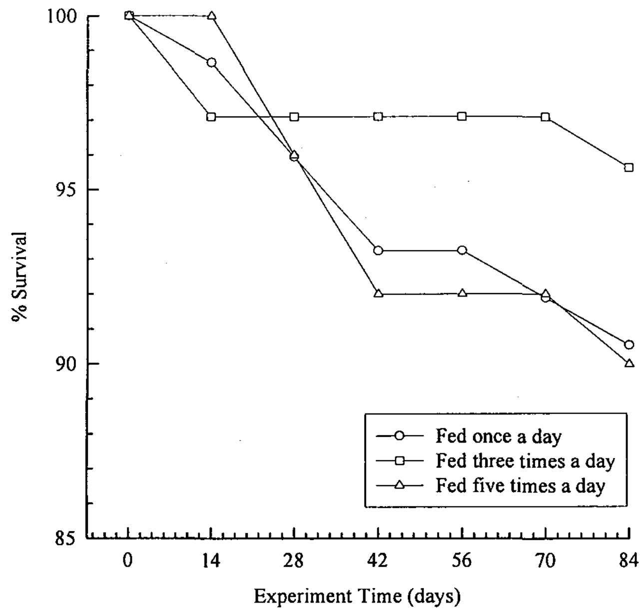

Figure 5.8. The effect of feeding frequency on survival of juvenile spotted grunter, *P. commersonnii.*

Discussion

The fact that growth response to varying feeding frequency is species specific is best illustrated by two serranid species. For example, in the red spotted grouper, *Epinephelus akaara* optimal growth was reported when the fish were fed four to six times a day, while the estuary grouper, *E. tauvina* grew best when fed once a day (Yakano *et al.* 1993). The spotted grunter is therefore not an exception to the specificity in growth response to varying feeding frequency showed by other marine fish species.

Deacon (1997), who investigated optimal feeding frequency of juvenile spotted under constant optimal temperature conditions, found that increasing the feeding frequency to five times a day improved the specific growth rate, whereas in this study it decreased. It must be born in mind however, that these investigations were carried out under ambient temperature conditions (range = 15 to 19.5 ^{0}C). The observed specific growth rates at the three feeding frequencies were not corroborated by the food conversion ratios in this study (Table 5.3 a). The high food conversion ratios at feeding frequencies of three and five times a day could have been a result of exaggerated ration sizes as some of the food was lost to the system drainage before it could be consumed by the fish. The good food conversion ratio at a feeding frequency of once a day was not surprising as the food was limited and could not have been wasted by the fish.

Increasing the feeding frequency had a significant influence on food consumption of juvenile spotted grunter. However, fish that were fed five times a day had the lowest protein efficiency ratio despite the fact that they consumed the greatest quantity of food. This was probably a consequence of a high gut evacuation rate (Deacon 1997). Feeding the fish once a day resulted in the highest protein efficiency ratio which was significantly different from that of other fish. This shows that although the fish consumed a limited amount of food, they utilised the food that was available most effectively. The trend in the protein efficiency ratio corroborates the recorded specific growth rates.

Feeding frequencies did not significantly affect the condition factor of juvenile spotted grunter under ambient temperature conditions. However, it was interesting to note that the highest condition factor was recorded in those fish fed three times a day, followed by feeding five times and once a day. When reared under optimal temperature conditions, the highest condition factor in spotted grunter was recorded at a feeding frequency of five times a day (Deacon, 1997).

The cause of fish mortality in this study could not be explained although the type of diet (pilchards) and rearing temperature (average = 17.1 ^{0}C) might have played a role. No fish mortality was recorded under optimal dietary (Table 2.1) and temperature (24.5 ^{0}C) conditions (Irish, 1997; Deacon, 1997).

In conclusion; feeding frequency did not have a significant effect on food conversion ratio, growth rate and condition factor of juvenile spotted grunter. However, feeding three times a day produced the best condition factor and survival of the fish. Therefore a feeding frequency of three times a day is recommended for rearing juvenile spotted grunter under ambient temperature conditions.

CHAPTER 6.

GROWTH OF JUVENILE SPOTTED GRUNTER UNDER AMBIENT TEMPERATURE CONDITIONS.

Introduction

Knowledge of the approximate time required to rear a candidate aquaculture species to market size is a prerequisite for the commercialisation of the culture technology. The rearing time of a species in captivity is dependent on the growth rate, which is influenced by biotic and abiotic factors (Jobling, 1994). Biotic factors which influence fish growth include the genetic make-up of the stock, fish size, social behaviour, food, su tained exercise, hormonal manipulations and reproductive state (Jobling, 1994). Abiotic factors that influence fish growth include temperature, salinity, photoperiod and oxygen availability (Jobling, 1994).

An understanding of the interactions of fish with its thermal regime is important to aquaculture because temperature is the primary environmental factor controlling key physiological and biochemical processes that determine growth (Beitinger & Fitzpatrick, 1979; Konstantinov *et al.*, 1989). An increase in temperature results in increased food intake and metabolism, up to a critical maximum beyond which the equilibrium of metabolic activities will be unstable (Jobling 1994). The optimum temperature for growth is that at which maximum growth is recorded. Further increase in temperature will cause decreased food intake and metabolism which may result in mortalities when fish tolerance limits of the fish are exceeded (Jobling 1994).

Fry (1971) postulated that if given a choice, a fish species will forage in a temperature zone where its growth performance will be maximised.

Benefits of fluctuating temperature *vis-a-vis* constant temperature in terms of growth performance in fish have been reported by Spigarelli *et al.* (1982) and Konstantinov *et al.* (1989). Improved efficiency of oxygen consumption, physiological state, food utilisation and growth rate through the minimisation of energy losses in juvenile common carp, *Cyprinus carpio*, coho salmon, *Oncorhynchus kisutch*, gold fish, *Carassius auratus* and tilapia, *Oreochromis mossambicus* were recorded under fluctuating temperature compared to constant temperature conditions (Konstantinov *et al.*, 1989). Spigarelli *et al.* (1982) in studies of brown trout, *Salmo trutta*, concluded that little, if any improvement in the growth performance could be found by rearing fish in fluctuating temperature compared to constant temperature. Gross conversion efficiencies were not significantly different between the treatments although food consumption, growth and lipid deposition were significantly higher in fluctuating temperature treatments than under constant temperature conditions (Spigarelli *et al.*, 1982).

Literature on the effects of temperature on growth performance of marine fish under culture conditions is limited. Deacon & Hecht (1995) studied behavioural thermoregulation of juvenile spotted grunter, *Pomadasys commersonnii* and implications to growth performance. The study confirmed the postulate of Fry (1971) that a fish species will forage in a temperature zone where its growth performance will be maximised. A subsequent study (Deacon & Hecht, 1996) found that optimal growth, condition and food conversion of juvenile grunter occurred at 24.5 ^{0}C.

The advantages and disadvantages of controlled rearing conditions and the implications on operating costs were discussed in Chapter 1. It was concluded that adjustments to reduce costs can be realised in the grow-out phase by keeping fish in pens, cages or tanks where water volumes and currents will ensure optimal water quality. Optimal rearing temperature can be traded off by locating the aquaculture facility in an area where ambient temperature approaches optimal conditions.

The present experiment was conducted to : (a) Determine the growth performance parameters namely; growth rate, food consumption and conversion ratio, protein efficiency ratio and condition factor of spotted grunter, *P. commersonnii* under ambient temperature conditions; (b) Estimate the time that would be required to rear the fish to market size and (c) to recommend a suitable geographical location in South Africa where spotted grunter could achieve maximum growth rate under ambient temperature conditions.

The criterion to decide on the market size for spotted grunter was based on a telephonic market survey covering forty premier sea food restaurants in Johannesburg, Durban and Cape Town, and eight national wholesale fish distributors (Prof. T. Hecht, personal communication; Department of Ichthyology & Fisheries Science, Rhodes University, Grahamstown, South Africa). The respondents expressed overwhelming interest to the possibility of obtaining spotted grunter in the legal market as the species is presently decommercialised. The respondents however, require a reliable supply. The restaurant sector require pan size fish from 550 to 800 g. Market sizes and rearing periods for other marine fish that are cultured under ambient temperature conditions are presented in Table 6.1.

Table 6.1. Market sizes and rearing periods for other marine fish that are cultured under ambient temperature conditions.

Species	Family	Common name	Market size (grams)	Rearing period (months)	Reference
Epinephelus suillus	*Serranidae*	Red spotted grouper	600	10	(Liao, 1993)
E. malabaricus	*Serranidae*	Malabar grouper	600	10	(Liao, 1993)
E. fuscoguttatus	*Serranidae*	Brown marbled grouper	600	10	(Liao, 1993)
Sciaenops ocellatus	*Sciaenidae*	Red drum	450	12	(Liao, 1993)
Plectropomus leopardus	*Serranidae*	Coral trout	600	10	(Liao, 1993)
Chanos chanos	*Chanidae*	Milk fish	600	6	(Lee, 1995)
Pagrus major	*Sparidae*	Red Sea bream	600	18	(Foskarini, 1988)
Sparus aurata	*Sparidae*	Gilthead bream	200	12	(White, date unknown)
Seriola quinqueradiata	*Carangidae*	Yellow tail	1000	12	(Fujiya, 1976)
Scophthalmus maximus	*Bothidae*	Turbot	400	12	(Purdom *et al.*, 1972)
Dicentrarchus labrax	*Serranidae*	Sea bass	250	24	(Girin, 1979)

Materials and methods

Juvenile spotted grunter, were caught in the Great Fish River and acclimated to captive conditions as described in Chapter 2. The fish were divided into three size classes (small, medium and large) and distributed into nine 1000 ℓ plastic tanks, which provided 3 replicates per size class. The number of fish, biomass, mean size (± standard deviation) and initial stocking density in each size class are shown in Table 6.2.

Table 6.2. The number, biomass, mean size and initial stocking density of the small, medium and large spotted grunter used in the grow-out experiment.

Statistic		**Size Class**		
		Small (43 fish)	**Medium (30 fish)**	**Large (14 fish)**
Mean	FL (mm)	106.0 ± 17.9	181.7 ± 24.781	252.29 ± 11.9
	Weight (g)	21.2 ± 11.6	113.6 ± 43.9	303.0 ± 39.0
Biomass (kg)		0.91	3.41	7.4
Density (kg/m^3)		0.9	3.4	7.4

One and two replicates of the medium and large size classes, respectively, suffered accidental mortality during the experiment. These results were therefore excluded from Table 6.2 and subsequent analysis. All fish were fed chopped pilchard twice a day to satiation. The proximate composition of the pilchards is shown in Table 2.2. The food fed was recorded on a dry weight basis to determine food consumption, specific growth rate, food conversion and protein efficiency ratios.

Oxygen content and temperature were monitored daily, whereas pH, ammonia, nitrite and salinity were monitored weekly during the experiment. Oxygen ranged from 4.0 to 8.3 mg/ℓ and pH ranged from 8.0 to 8.2. Ammonia and nitrites were less than 0.02 mg/ℓ. Salinity ranged from 32 to 35 ppt.

The fish were measured for fork length and body weight every fortnight after being starved for 36 hours. Handling of the fish was preceded by anaesthetisation in a 0.2 mg/ℓ of 2-phenoxyethanol solution. Fork length and body weight of the fish were measured to the nearest millimetre and 0.1 g, respectively.

Three replicates of small fish could have been reared to market size. However, this procedure was not followed because it would have prolonged the experimental. Therefore, three size classes were reared simultaneously until the average size of the small and medium classes overlapped with the initial mean size of the medium and large classes, respectively. The experiment was carried out for six months.

Statistical analyses

One way analysis of variance was conducted to test for significant difference in fork length and body weight data between replicates of each fish size class. If there was no significant difference between the replicates, then data from the replicates were pooled (Zar, 1996). Further data analysis was divided into two sections to cover the first two objectives in the introduction.

Section 1

The average fork length and body weight in the three size classes were calculated and plotted against time. The relationship between fork length and body weight of spotted grunter during the grow-out experiment was described as follows:

$$ln\text{ (Average fork length)} = \alpha + [\beta \text{ x } ln\text{ (Average body weight)}],$$

where α is the intercept, and β is the slope of the size function.

The above function was used to obtain either length or weight from the other. The coefficient of variation in size, growth rate, food consumption and conversion ratio, protein efficiency ratio and condition factor were determined in the three size classes for the entire experimental period.

Derivation of formulae for the growth performance parameters was discussed in Chapter 2. The grow-out period of 196 days was accumulated to 588 days (3 size classes x 196 days). This was then plotted against data from the three size classes to obtain a composite growth curve. The influence of temperature on food consumption and growth rate was investigated.

Section 2

Simple linear regression was used to describe the dependence of growth rate and food consumption on rearing temperature as follows:

$$x = \alpha + (\beta \text{ x temperature}),$$

where x is growth rate or food consumption, α is the intercept and β is the slope of the function.

Section 3

The Von Bertalanffy Growth Model (VBGM) was used to determine the theoretical age at zero length for the small size class, thus making it possible to estimate the time that was required to rear the fish from hatching to final market size. The application of the VBGM in this experiment was not different from the traditional application, which is to fit length-at-age data and the determination of the associated parameters (see later) (Hopkins, 1992). However, seasonal growth had to be taken into consideration in this experiment as the length-at-age data was collected in fortnightly intervals. Therefore, the characterisation and exclusion of seasonal and temperature effects on growth was necessary before the application of the model, because seasonal and temperature effects are not accounted for in the Von Bertalanffy Growth Model

(Hopkins, 1992; Dr. A. J. Booth, personal communication; Department of Ichthyology & Fisheries Science, Rhodes University, Grahamstown, South Africa; Dr. K. N. I. Bell, personal communication, J. L. B. Smith Institute of Ichthyology, Grahamstown, South Africa). The seasonal growth component in the data was identified and excluded using a combination of linear regressions and the Harmonic Model (Batschelet, 1981; Bell, personal communication). The dependence of growth rate on temperature and season can be described according to the following relationship:

$$\text{Growth (mm/day)} = \alpha + (\beta_1 \text{ x } \mathit{sin}\text{Rdoy}) + (\beta_2 \text{ x } \mathit{cos}\text{Rdoy}) - (\theta \text{ xTemperature})$$

where α = intercept; β = measure of the effect of season; θ = measure of the effect of temperature; R = Radians; doy = day of the year.

Season was described as a function of *sine* and *cosine* components from the Harmonic Model and is related to temperature as follows (Batschelet, 1981):

$$\text{Temperature} = \alpha + (\beta_1 \text{ x } \mathit{sin}\text{Rdoy}) + (\beta_2 \text{ x } \mathit{cos}\text{Rdoy})$$

Growth rate was dependent on season as follows:

$$\text{Growth (mm/day)} = \alpha + (\beta_1 \text{ x } \mathit{sin}\text{Rdoy}) + (\beta_2 \text{ x } \mathit{cos}\text{Rdoy})$$

The Von Bertalanffy Growth Model (VBGM) estimates the length, L_t and weight, W_t of fish at time t, as follows (Hopkins 1992):

$$L_t = L_\infty (1 - e^{-K(t - to)})$$

$$W_t = W_\infty (1 - e^{-K(t - to)})^\beta$$

where L_∞ and W_∞ are maximum theoretical sizes of fish; t_0 is the scaling constant which sets the theoretical origin of the growth curve and may represent the age of fish at initial size in an experiment; β is a slope that is derived from the length and weight relationship:

$$W = \alpha L^\beta$$

K, the Brody growth coefficient, is the rate at which L_∞ is attained. The weight function of the VBGM is used to fit weight-at-age data and is generally applied in stock assessment and yield optimisation which was not relevant to this experiment (Ricker, 1975). The length function of the VBGM was, therefore, used to estimate the time that would be required to rear the spotted grunter to marketable size. The value of L_∞ is the *x*-intercept of the Gulland & Holt Plot and can also be calculated using the relation (Hopkins, 1992):

$$L_\infty = -(\alpha/\beta),$$

(For α and β, see the Gulland & Holt Plot relation below)

The Gulland & Holt Plot is based on a linear relationship between the rate of length increase and average length. The relationship is as follows:

$$\text{Growth rate} = \alpha + (\beta \times \text{average fork length})$$

where α = *y*-intercept and β = slope of the Gulland & Holt Plot.

The scaling constant t_o, was estimated by rearranging the Von Bertalanffy growth function and substituting known values so that:

$$t_o = - \ln [L_\infty/(L_t - L_\infty)] / -K$$

Multiple linear regression was used to describe the temperature dependence of fish growth rate as follows:

$$\text{Length increase/day} = \alpha + (\beta \text{ x average fork length}) + (\theta \text{ x temperature})$$

The description of this dependence was used to estimate the time that would be required to rear juvenile spotted grunter to market size and growth rate under mean temperature conditions. The estimation of rearing time and growth rate under mean annual temperature conditions at selected locations within the distribution range of the species along the South African coast enabled recommendation of an area where maximum growth rate can be achieved. Growth rate is defined as average length change over time, implying that:

$$\text{Rearing time} = \text{Average length} / \text{Growth rate}$$

Results

The results are presented in four sections. The first section deals with the growth of the fish and the associated growth performance parameters. The second section deals with the influence of ambient temperature on the growth rate and food consumption of the fish. The third section deals with the estimation of the rearing period for the fish to market size under ambient temperature conditions. The fourth section deals with the location of a suitable geographical locality in South Africa where spotted grunter could achieve maximum growth rate under ambient temperature conditions.

Section 1

The mean water temperature in which the grow-out experiment was conducted is illustrated in Figure 6.1.

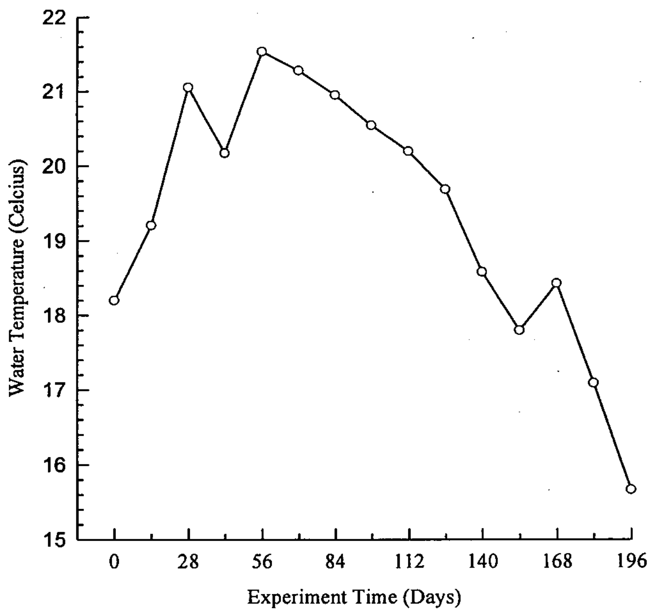

Figure 6.1. The mean water temperature during the grow-out experiment on spotted grunter, *Pomadasys commersonnii*. The experiment was conducted from 24 November 1996 to 18 June 1997.

The average water temperature for the entire growth period of six months was 19.4 ± 1.71 ^{0}C. It was 18.2 ^{0}C at the beginning and 15.7 ^{0}C at the end of the experiment, with a maximum of 23 ^{0}C recorded on the 56 th day. The maximum recorded temperature corresponded with the peak of summer.

Size variation was monitored during the rearing period and is presented in Figures 6.2 (a) and (b).

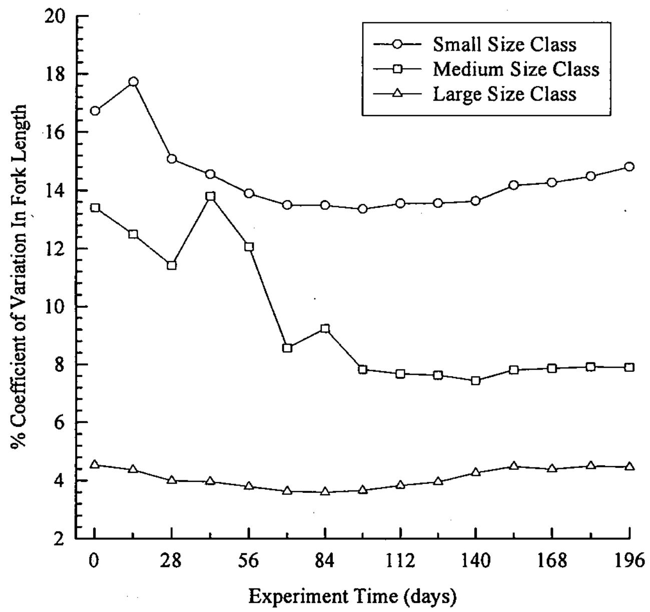

Figure 6.2 (a). Fork length variation in the three size classes of spotted grunter, *P. commersonnii* during the experiment period.

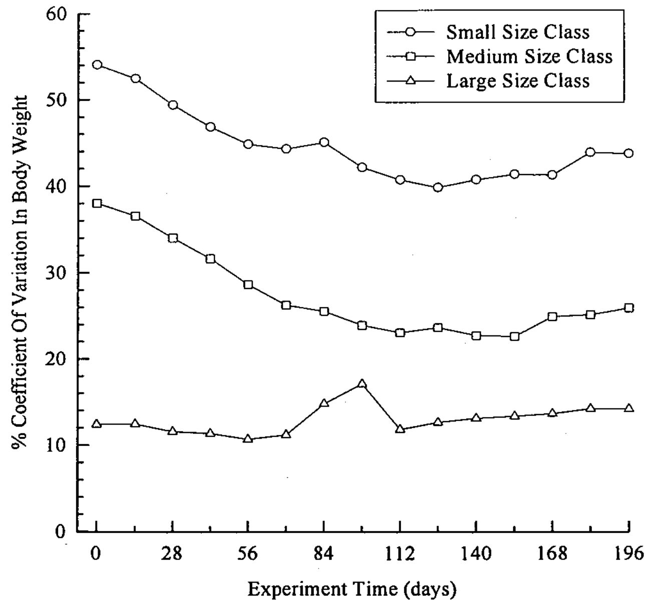

Figure 6.2 (b). Body weight variation in the three size classes of spotted grunter, *P. commersonnii* during the experiment period.

Periodic peaks of size variation were observed which were associated with increasing temperature. The fluctuation in size variation for fork length was more evident among small and medium size classes. This would be expected because the fish had more scope for growth than the large size class. A peak of size variation in body weight (Figure 6.2 b) was observed between day 56 and 112 and more pronounced in the large size class. When the fish were affected by the change in rearing temperature, the effect was prolonged in large fish. An increase in size variation was also observed from day 154 onwards. A possible explanation for the increase in size variation was that, changes in rearing temperature influenced the growth rates of the individual fish, of which the extent depended on the size of the fish and its position within the hierarchial population structure. The association of size variation with fish social hierarchy was discussed in Chapter 4. Observations in this experiment imply that sub-dominant fish were more influenced by temperature variation than dominant fish. This phenomenon was also observed in

The slopes of the size variation curves are presented in Table 6.3 (a). The slopes decreased from the small to the medium size class.

Table 6.3 (a). The slopes of variation coefficients in the size of spotted grunter, *P. commersonnii* that were reared at various stocking densities.

Parameter	Size Class	Slope	r^2	P	F-ratio
Variation coefficient (fork length)	Small	-0.00992	0.244	0.061	4.21
	Medium	-0.0319	0.713	< 0.0001	32.2
	Large	0.00169	0.0926	0.2701	1.33
Variation coefficient (body weight)	Small	-0.0538	0.613	0.0006	20.6
	Medium	-0.0663	0.657	0.0002	24.9
	Large	0.0126	0.222	0.0765	3.7

Slopes of size variation over time in the large size class were positive. A possible explanation for the transition to a positive slope is that, social hierarchies were developing among the fish in the large size class and were associated with the onset of adolescence. Social hierarchies among sexually mature spotted grunter that were caught from the wild had also been personally observed in captivity, where predominantly large fish bit the subordinate fish. It is not known whether the sex of fish influenced aggressive social behaviour among the adult fish.

The overall food consumption in the three size classes was inversely related to fish size and ranged from 0.15 ± 0.16 to 0.38 ± 0.35 % body weight per day (Figure 6.3).

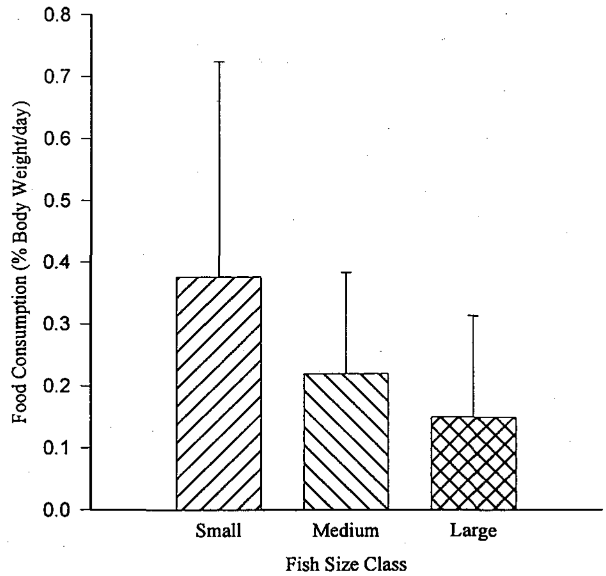

Figure 6.3. Food consumption in three size classes of spotted grunter, *P. commersonni* reared under ambient temperature conditions. Bars = Standard Deviation.

The specific growth rate in the three size classes was also inversely related to fish size and ranged from 0.28 ± 0.2 to 0.86 ± 0.51 % body weight per day (Figure 6.4).

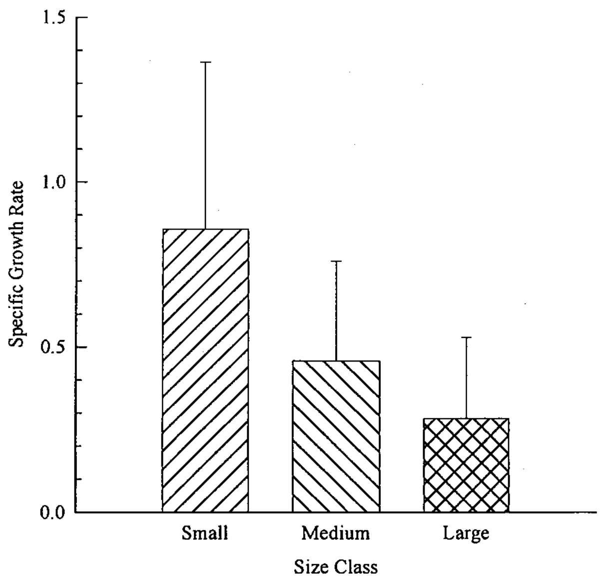

Figure 6.4. The specific growth rate in the grow-out of three classes of spotted grunter, *P. commersonnii*. Bars = Standard Deviation.

An interesting trend was observed, in which food conversion ratio improved with increasing fish size (Figure 6.5).

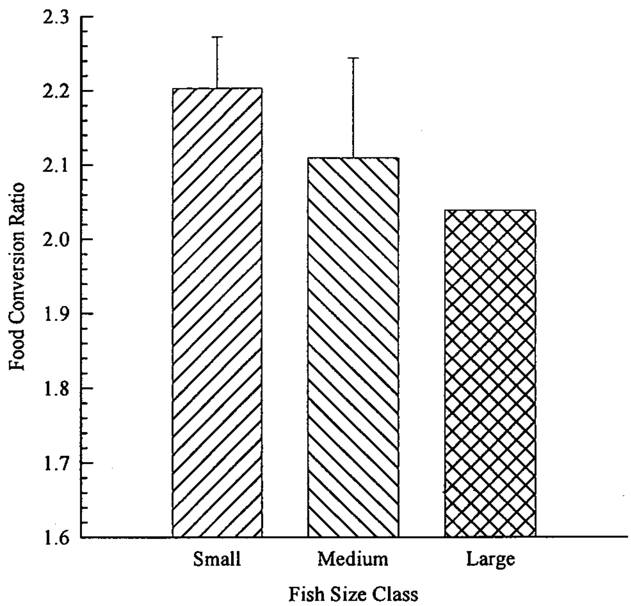

Figure 6.5. Overall food conversion ratio of the three size classes of spotted grunter , *P. commersonnii.* Bars = Standard Deviation.

A possible explanation for the observed trend in food conversion ratio was that pilchard, in terms of the protein : energy ratio, became more suitable with increasing fish size. As a result, fish in the large size class had the best protein efficiency ratio (Figure 6.6).

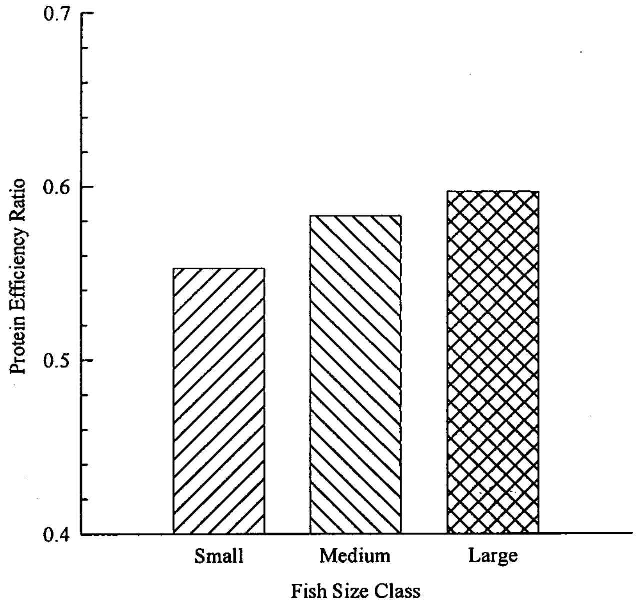

Figure 6.6. Overall protein efficiency ratio in the three size classes of spotted grunter; *P. commersonnii.*

Section 2

Rearing temperature had a significant effect on food consumption and specific growth rate of the fish. The lowest food consumption was recorded when rearing temperature was between 15 and 19 ^{0}C (cf. Figure 6.7 and Figure 6.1). Fish in all size classes ceased feeding when the temperature was below 17 ^{0}C, thereby causing loss of body weight.

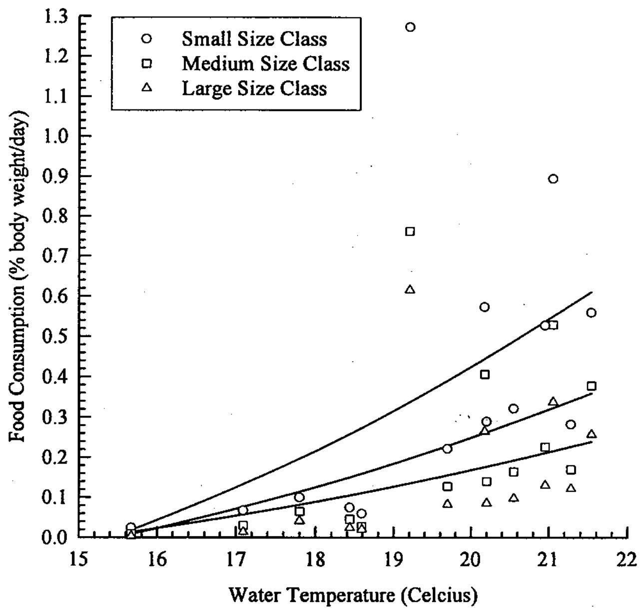

Figure 6.7. The relationship between ambient temperature and food consumption of three size classes of spotted grunter, *P. commersonnii*. Lines: Top = small size class; Middle = medium size class; Bottom = large size class.

The effect of rearing temperature on the specific growth rate of the three size classes was described by the functions in Table 6.3.

Table 6.3. The effect of ambient temperature on the specific growth rates in three sizes classes of spotted grunter, *P. commersonni*.

Size class	Temperature effect	r^2	F	P
Small	sgr = -4.03 + 0.251 x temperature	0.74	34.2	<0.0001
Medium	sgr = -2.72 + 0.163 x temperature	0.89	99.4	<0.0001
Large	sgr = -1.90 + 0.113 x temperature	0.63	20.7	0.0006

The functions in Table 6.3 show that increasing temperature significantly influenced the specific growth rate although the influence decreased with increasing fish size.

Maximum specific growth rates of 1.5, 0.84 and 0.74 % body weight per day were recorded from the small, medium and large size classes during mid-summer when the temperatures ranged between 21 and 22 ^{0}C (cf. Figure 6.8 and Figure 6.1).

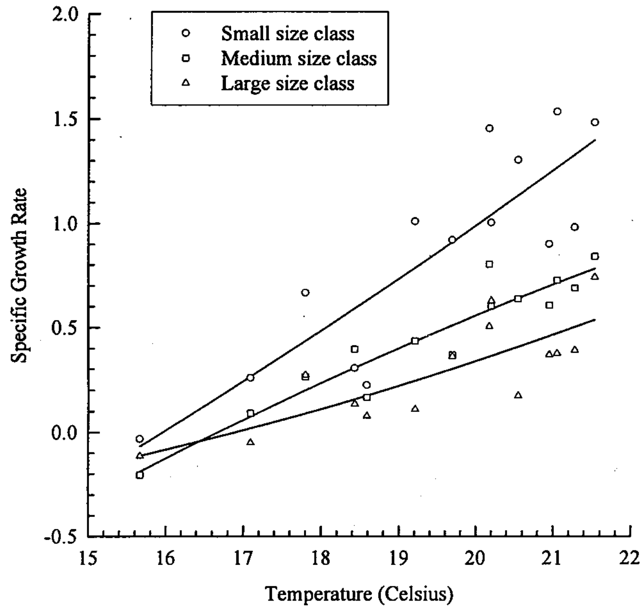

Figure 6.8. The relationship between ambient water temperature and specific growth rate of three size classes of spotted grunter, *P. commersonnii*. Lines: Top = small size class; Middle = medium size class; Bottom = large size class.

By the end of the experiment in July (winter), fish had begun losing weight, where specific growth rates of -0.03, -0.2 and -0.11 % body weight per day were recorded from the small, medium and large size classes with average temperature below 16 ^{0}C.

Section 3

From now onwards, the results will shift from dealing with individual size classes to dealing with growth of fish from juveniles until they reach market size. This was achieved by allowing the growth of fish in the small and medium size classes to overlap with the initial average sizes of the medium and large sized fish, respectively. Therefore, the grow-out period to the end of the experiment has been accumulated from zero to 588 days (ref. Statistical analysis, Section 1). Figure 6.9 shows the average growth of fish in the three size classes in terms of fork length and body weight. Figure 6.9 also showed periods of retarded length increase in all three size classes. The periods coincided with the approach of the winter season and lower temperatures, during which fish lost appetite and subsequently stopped feeding.

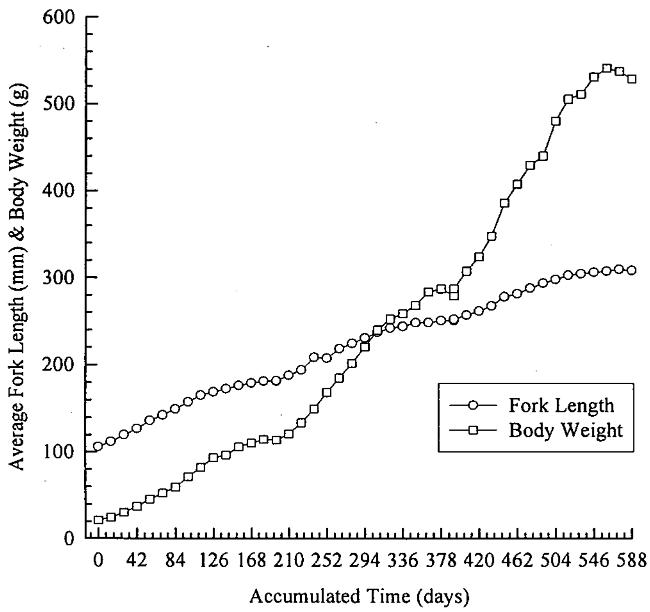

Figure 6.9. Average fork length and body weight of the three size classes of spotted grunter, *P. commersonnii* which were reared simultaneously over six months.

The Gulland & Holt Plot showing growth rate versus average size with seasonal effects included is illustrated in Figure 6.10 (a).

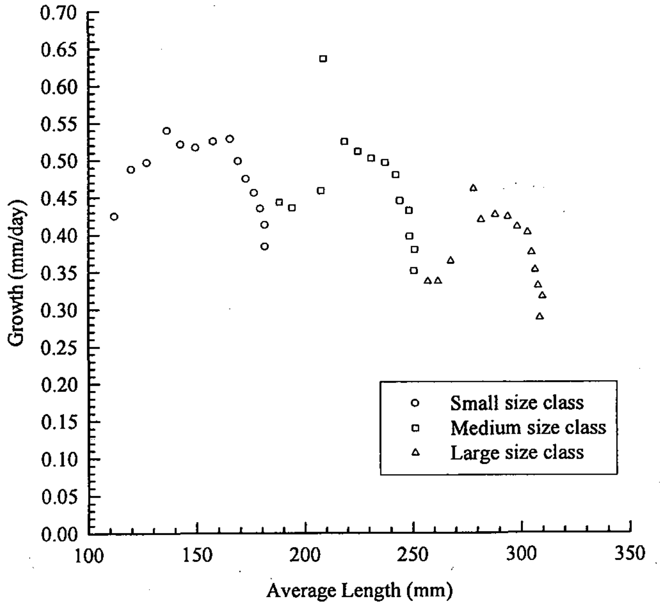

Figure 6.10 (a). The Gulland & Holt Plot showing the relationship between growth rate (mm/day) and average fork length of the three size classes of spotted grunter, *P. commersonnii*. Seasonal effects have not been excluded.

The dependence of growth rate on the rearing temperature and season was described according to the following relationship:

$$\text{Growth rate} = 0.486 + (0.0922 \times \textit{sin}\text{Rdoy}) + (0.0978 \times \textit{cos}\text{Rdoy}) - (0.00617 \times \text{Temperature})$$

$$(r = 0.659, r^2 = 0.435; \text{F- ratio} = 9.75; P < 0.0001)$$

Season was related to temperature as follows:

$$Temperature = 17.9 + (1.63 \times sinRdoy) + (2.73 \times cosRdoy)$$

$r = 0.960$; $r^2 = 0.922$; $P < 0.0001$; F- ratio = 230.8).

Growth rate was related to season as follows:

$$Growth\ rate = 0.375 + (0.0821 \times sinRdoy) + (0.0810 \times cosRdoy)$$

$r = 0.658$; $r^2 = 0.433$; $P < 0.0001$; F - ratio = 14.9),

When the seasonal influence on growth, described above, was eliminated, the Gulland & Holt Plot took the form illustrated in Figure 6.10 (b) with $\alpha = 0.521$; $\beta = 6.506$ exp-4 and $L_\infty = 800.864$ mm. The scaling constant, $t_o = - 218.23$.

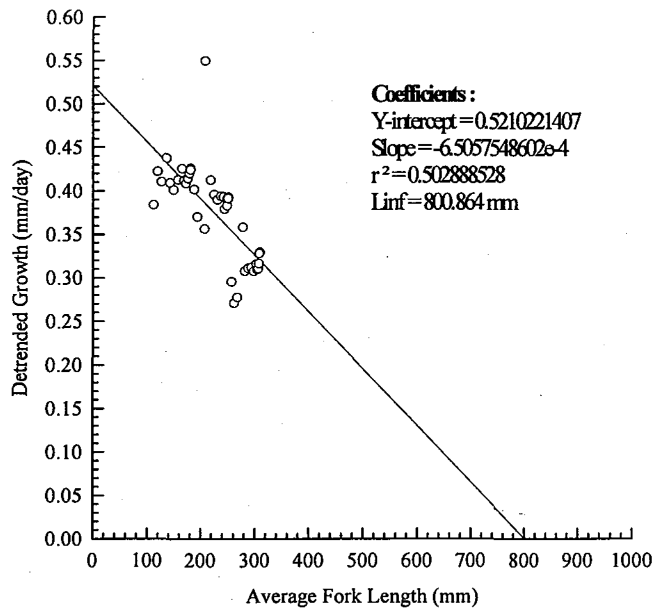

Figure 6.10 (b). The Gulland & Holt Plot of spotted grunter, *P. commersonnii* when the seasonal component was eliminated.

The relationship between the average fork length and body weight of spotted grunter that were reared in captivity during the grow-out experiment is illustrated in Figure 6.11.

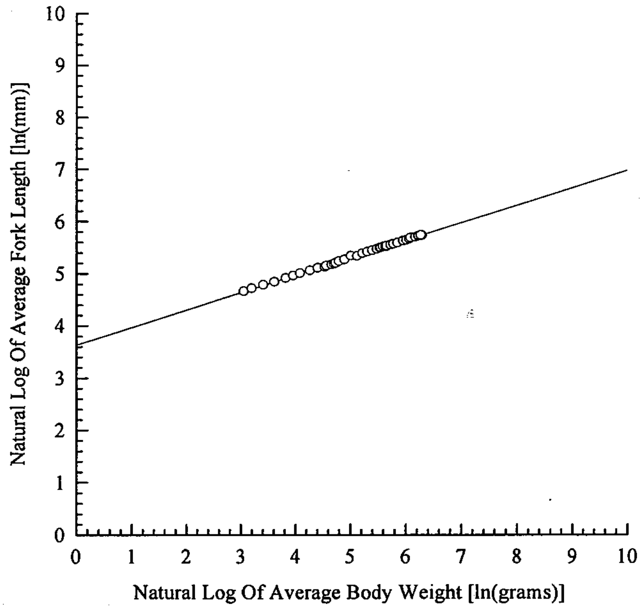

Figure 6.11. The relationship between fork length and body weight of captive spotted grunter, *P. commersonnii.*

The relationship between average fork length and body weight was described as follows:

Ln (Average fork length) = 3.64 + [(0.334 x *ln* (Average body weight)]

($n = 45$; $r = 0.999$; $r^2 = 0.999$; F- ratio = 36470.8; $P < 0.0001$)

The average fork length of the small size class in the beginning of the experiment was 106 mm and the estimated age at that length was 218.23 days. The experiment was terminated after 196 days when the average fork length of the large size class was 308.64 mm. The accumulated time at the end of the experiment was 588 days. The estimated time that was required to rear spotted grunter from hatching to 308.64 mm FL was 806.23 days, ie. 218.23 days + 588 days = 2.2 years or 26.5 months. The corresponding body weight was 528.94 g. The estimated rearing time to 308.64 mm is comparable to the natural growth rate (Wallace & Schleyer, 1979).

Section 4

Using the data presented above, an attempt was made to predict the growth rate and rearing period of spotted grunter to market size at various locations within its distribution range along the coast of South Africa. Average annual sea water temperature records from selected locations were obtained (CSIR, 1998). The temperature measurements cover a depth of 5 metres dating from 1920 to 1993.

The dependence of the growth rate of spotted grunter on average size and temperature was described according to the following relation:

Daily length increase = 0.186 - (0.000639 x average fork length) + (0.0204 x temperature)

(F- ratio = 30.6; $P < 0.0001$; $r = 0.781$; $r^2 = 0.611$).

The definition of growth rate implied that :

Rearing time = Average length / Growth rate

If the target market size of spotted grunter is 550 g, then the corresponding calculated fork length would be 270 mm FL. The predicted growth rates in the selected locations are presented in Table 6.4.

Table 6.4. Predicted growth rates of spotted grunter, *P. commersonnii* reared under various average water temperature conditions and the corresponding locations along the coast of South Africa. The choice of locations was based on the natural distribution of the spotted grunter.

Location	Temperature	Predicted Growth Rate (mm/day)	Predicted Rearing Time	
			Years	Months
Hermanus (34°35'S;19°20'E)	16.889 ± 2.126 (1928 to 1986)	0.358	2.1	25.14
Plettenberg Bay (34°35'S;23°24'E)	19.2027 ± 2.2168 (1928 to 1986)	0.405	1.8	21.9
Port Elizabeth (33°35'S;25°26'E)	17.8 ± 1.47 (1928 to 1986)	0.350	2.11	25.34
* Port Alfred (33°36E,26°53'E)	18.042±2.249 (1988 to 1997)	0.381	1.94	23.25
East London (32°34'S;27°29'E)	21.203 ± 3.184 (1921 to 1993)	0.419	1.8	21.2
Durban (29°31'S;30°32'E)	23.056 ± 2.088 (1920 to 1993)	0.457	1.6	19.4
Richards Bay (28°29'S;31°33'E)	23.24 ± 2.051 (1920 to 1993)	0.461	1.6	19.2

* Temperature records were collected personally and include those available in the Department of Ichthyology & Fisheries Science, Rhodes University, Grahamstown, South Africa.

A conclusion can be made from Table 6.4 that, the shortest time that would be required to rear the spotted grunter to a market size of 550 g is 19 months and corresponds to a growth rate of 0.461 mm/day. The predicted rearing period and growth rate could be achieved at Richards Bay (28°29'S; 31°33'E). The predicted rearing period of 19 months in captivity is shorter than the 25.8 months calculated for wild fish of the same size sampled from Natal angling beaches, St Lucia and Durban Bay (Wallace & Schleyer, 1979).

Discussion

It is important to note that the present experiment was carried out over a period of six months from the end of November 1996 to the end of June 1997. This period represented summer, autumn and two weeks of winter; meaning that captive growth of spotted grunter for most (ten weeks) of winter and all of spring is not known. Be that as it may, the best growth rate and rearing period to market size of the fish would still be achieved in Richard's Bay. Therefore, the predictions in absolute figures are not as essential as the trends.

The predicted rearing period to market size of spotted grunter puts the species on the same level as most commercially propagated species such as Red Sea bream, *Pagrus major*; gilthead bream, *Sparus aurata*, followed by various serranids (Table 6.1). In fact, spotted grunter grow better than sea bass, *Dicentrarchus labrax* which take 24 months to reach 250 g (Girin, 1979).

Growth performance of spotted grunter under ambient temperature conditions is most likely to improve when fed a balanced diet compared to the pilchard which was used in this experiment. The effect of ambient temperature on the specific growth rate and food consumption of the fish in this experiment were expected when viewed together with the studies of spotted grunter by Deacon (1997). The average temperature of 18 ^{0}C at Port Alfred is well below the optimal temperature of 24.5 ^{0}C for spotted grunter (Deacon & Hecht 1995, 1996). The relationship between temperature and growth of the fish suggests that the species would have to be harvested towards the end of summer. However, the relationship between condition factor and temperature would have to be investigated to decide on the most suitable time of harvest.

Growth estimates obtained by a combination of the Von Bertalanffy Growth Model and the Harmonic Model are satisfactory. This is the first time that this has been achieved in aquaculture. However, the application of the two models is familiar in fisheries biology, although to a lesser extent in the case of the Harmonic Model (Batchelet, 1981; Hopkins, 1992; Bell *et al.*, 1995). It should also be noted that the approach to the experimental objectives was unorthodox, given that three size classes were reared and allowed to overlap, thereby enabling development of cumulative growth curves. Normally, replicate groups of fish would have been preferred and the fish allowed to grow to market size or until sufficient data were available to carry out projections. The latter method could not be undertaken within the available time.

The trends in the coefficient of variation data corroborates the suitability of spotted grunter as a mariculture species. The observed positive slopes in the coefficient of variation with fish size in the large size class suggests that competition among the fish is not a cause for concern. If so, size grading conducted early in the grow-out would be sufficient to nullify the effect. Secondly, the fact that competition is associated with sexual maturity would necessitate fish to be marketed before maturity because energetic resources would be invested in reproductive rather than somatic growth. Further studies should focus on the rearing of spotted grunter in Richard's Bay, and compare the results with those reported in this study.

In conclusion; it is predicted that spotted grunter can be reared to a market size of 550 g and 270 mm Flin a period of 19 months under ambient temperature conditions in Richard's Bay. The predicted rearing period is approximately 7 months shorter than the growth rate of wild spotted grunter in KwaZulu-Natal (Wallace & Schleyer, 1979), and can undoubtedly be further reduced by feeding a balanced diet (Irish, 1997). The species can compete well with established marine species which are presently being farmed on a commercial basis.

CHAPTER 7.

CONCLUDING DISCUSSION

The following discussion will attempt to put into perspective the studies presented in the foregoing chapters and highlight their relevance in commercial farming of marine fish in South Africa. The natural history of spotted grunter, *Pomadasys commersonnii* is fairly well understood (Smith, 1950; Smith 1961; Wallace, 1975; Marais, 1976; Marais, 1977; van der Westhuizen & Marais, 1977; Wallace & Schleyer 1979; Blaber, 1979, 1981, 1983; Day *et al.*, 1981; Blaber *et al.*, 1984; Whitfield,1990; van der Elst, 1993; Beckley & Bullen, 1995).

Captive rearing of this species was initiated following studies on its identification as a suitable candidate for mariculture. These studies included oxygen consumption; salinity requirements; formulation of an optimal diet; feeding frequency; optimal rearing temperature and optimal rearing photoperiod (Du Preez *et al.*, 1986; Bussiahn, 1992; Deacon & Hecht, 1996; Deacon, 1997; Irish, 1997). All of these studies were, however conducted under controlled environmental conditions which would be unaffordable if spotted grunter were to be reared on a commercial scale.

In this study, the effects of stocking density, size grading and feeding frequency on the growth performance of juvenile spotted grunter under ambient temperature and photoperiod were investigated. A study to determine the grow-out period of the fish under ambient conditions was also undertaken.

Analysis of the relationship between the coefficient of variation and average fish size in the present study led to the conclusion that, competitive behaviour among spotted grunter is not likely to affect the growth performance of fish in a commercial scale operation. However, there is a need to study size variation in continuously reared fish from larvae to market size. The growth performance parameters such as specific growth rate, food conversion and protein efficiency ratio improved with increasing stocking density, although condition factor decreased at the highest density of 6.4 kg/m^3. Overall the data suggested that the stocking density of 6.4 kg/m^3 was below the optimal rearing density for juvenile spotted grunter.

The size grading experiment corroborated the conclusion that juvenile spotted grunter can be reared at stocking densities higher than 6.4 kg/m^3. Studies on commercially cultured fish such as salmon, sea bass, sea breams, turbot and groupers showed that size grading was necessary for up to four times during the grow-out period of the species (Fausch & White, 1986; Singh, 1991; Nortvedt & Holm, 1991; Alvial & Trujilo, 1993; Chao *et al.*, 1993; Efthimiou *et al.*, 1994; Metcalfe, 1994; Nakano, 1995; Ryer & Olla, 1995; Alanara, 1996; Johnsson *et al.*, 1996; White, date unknown). Further studies should focus on the effect of size grading on the growth of juvenile spotted grunter at densities higher than the range in this study, where it is predicted that size grading will improve growth performance.

Feeding frequency did not have a significant effect on the growth performance of juvenile spotted grunter. However, feeding three times a day was found to be most suitable for rearing the fish under ambient temperature conditions because it resulted in the best condition factor and survival.

The present study has shown, as expected, that rearing temperature has a strong influence on the growth performance of spotted grunter. The maximum temperature of 21 ^{0}C in summer resulted in a better growth performance than during the winter, during which the temperature was below 16 ^{0}C. In fact fish stopped feeding and lost weight in winter. The latter situation is not beneficial to an aquaculture scenario. The growth performance of the fish during mid-summer was significantly lower than that reported by Deacon (1997) and Irish (1997) who conducted their experiments under optimal temperature conditions. Convectional heat exchange between the tank environment and the atmosphere was found to be more pronounced in winter than in summer, with tank water becoming colder by up to 4 ^{0}C than incoming water from the Kowie River estuary. Temperature difference between the two water bodies was less than 1.5 ^{0}C in summer.

Under the ambient temperature and photoperiod conditions at Port Alfred it was predicted that spotted grunter would require a minimum of 23 months to be reared to market size of 550 g and 270 mm FL. The optimal temperature for spotted grunter is 24.5 ^{0}C (Deacon, 1997). Modelling the growth of the fish against mean temperatures at various sites along the South African coast revealed that growth would be best at Richard's Bay, where the average annual temperature is 23.2 ^{0}C. At this temperature it was predicted that the fish could theoretically be reared to a market size of 550 g in 19 months. This study has clearly shown that the aquaculture potential of spotted grunter is similar to that of other marine species presently farmed on a commercial scale. Studies on the conditioning of broodstock, spawning and larval rearing can now commence to establish this species as a South Africa's first commercially viable marine aquaculture species.

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