Cape Peninsula
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A multi-species mariculture system: A holistic approach to ornamental culture.

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DECLARATION

I, Jason Hayden, declare that the contents of this thesis represent my own unaided work, and that the thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

Signed..................................... **Date....................................**

ABSTRACT

Coral reefs are in a worldwide state of crisis due to overexploitation. One of the factors contributing to the over exploitation is the marine ornamental industry. This industry utilises a diversity of organisms, comprising approximately 1470 species of fish and more than 300 species of invertebrates. Between April and December 2007, five of the 18 companies who had import permits for South Africa, imported a total of 359 different ornamental species, 252 of these were fish species while the remaining 107 species were invertebrates. During these nine months a total of 32 005 individual organisms were imported into South Africa by the five companies. There were two groups of fish that represented the highest import volumes. These were *Amphiprion spp.* and *Pomacentradae spp.*, as well as the *Gobidae spp.* These groups represented 38% and 19% respectively of the total number of fish imported.

Aquaculture has the potential to substantially reduce the harvesting pressure on coral reef organisms globally. A small-scale multi-species mariculture system was designed and constructed for benthic egg-laying species of fish (brood stock), corals, and ornamental algae. The system was designed to be low cost and easy to operate. The total capital costs for the system was R15 680.70.

In order to estimate the potential yield of an aquaculture facility it is important to know the growth rate of the proposed species under pilot conditions. The use of artificial lighting regimes in aquaculture comes at a financial cost. It is for this reason that it is important to know what lighting scenario yields the highest growth rate of corals. The effects of photoperiod were tested on *Sinularia sp.* of coral. Two photoperiods were tested, namely: $Group_8$ (8:16 h light:dark cycle) and $Group_{12}$ (12:12 h light:dark cycle). No significant difference in weight was found between $Group_8$ and $Group_{12}$ ($p = 0.975$). There was however a significant increase ($p = 0.002$) in Surface-area Pixel Value (SPV) for $Group_8$ (1996.73 millipixels pixel^{-1} day $^{-}$1) compared to $Group_{12}$ (983.73 millipixels pixel^{-1} day $^{-1}$). The use of a 8:16 h light:dark cycle can thus yield coral of a larger size but not necessarily a higher mass.

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GLOSSARY

DEAT: Department of Environmental Affairs and Tourism

MCM: Marine and Coastal Management

SARS: South African Revenue Services

CITES: Convention on International Trade in Endangered Species

RAS: Recirculating aquaculture systems

Small-scale systems: Systems with a capacity of less than 10 000 litres of water

Live rock: Encrusted or sessile invertebrate assemblages attached to a hard substrate, such as dead coral, reef rubble or rock.

CHAPTER ONE
GENERAL INTRODUCTION

"Through the window of my mask I see a wall of coral, its surface a living kaleidoscope of lilac flecks, splashes of gold, reddish streaks and yellows, all tinged by the familiar transparent blue of the sea."

(Cousteau 1971)

1.1 Introduction

For many years people have wondered at the splendour of coral reefs around the world. Coral reefs are one of the oldest and most complex ecosystems on earth. They are home to a diversity of life, rivalled by no other ocean environment. Coral reefs are in a worldwide state of crisis, experiencing widespread declines in the abundance of corals, fishes and other organisms (Bruckner 2001). According to Bryant *et al.,* (1998), 58% of the world's coral reefs are threatened by human activities such as coastal development, destructive fishing, over exploitation of marine resources, marine pollution, and terrestrial runoff. One of the factors contributing to the over exploitation of reef organisms is the marine ornamental industry. This industry utilises a diversity of organisms, comprising approximately 1470 species of fish (Wabnitz *et al.* 2003) and over 300 species of invertebrates (hard and soft coral, echinoderms, holothurians, crustaceans and bivalves) (Pomeroy *et al.* 2006). The estimated number of ornamental fish harvested annually from coral reefs across the globe, is approximately 30 million individuals (Wood 2003). Of these about 8 million are exported to the USA, 8 million to Europe and the rest to countries such as Japan, Australia and South Africa (Wood 2003). Invertebrates constitute about 20% of trade by value (Wood 2003), and the number of specimens involved is likely to run into millions.

There are approximately 45 countries that supply the marine ornamental trade (Pomeroy *et al.* 2006). Approximately 85% of the marine ornamentals exported to the United States and Europe are captured from reefs in the Philippines and Indonesia. Other countries that supply significant quantities to the international market are, Brazil, Maldives, Vietnam, Thailand, Sri Lanka, Puerto Rico, Australia, Hawaii, Eritrea and Kenya (Wood 2001, Daw *et al.* 2001).

The aquatic ornamental trade includes both freshwater and marine organisms as well as aquarium products. The marine portion comprised 4–10% of the total fishes traded (Biffar 1997, Sadovy and Vincent 2002) but 10–20% of the total value of the ornamental industry (Andrews 1990). The global wholesale value of the ornamental industry was estimated at 1 billion dollars in 2001 (Olivier 2001, Zion *et al.* 2008), while the export value of ornamental fish alone was estimated at 264 million dollars in 2005 (Zion *et al.* 2008, FAO 2007), which represented a 50% increase with respect to the 2001 export data (Olivier 2001, Zion *et al.* 2008, FAO 2007).

The majority of marine aquarium fish and invertebrate species are still harvested from the wild (Wood 2003, Pomeroy *et al.* 2006, Mous 1999). An increase in harvest rates could lead to a dispute on the sustainability of the marine ornamental trade. Due to the highly selective nature of this activity and the large numbers of individual organisms collected, the potential for over-exploitation is extremely high (Wood 2003, Sadovy and Vincent 2002, Wood 1985).

As with the use of any natural resource, there are a number of problems and issues concerning the collection of marine ornamental species. The potential environmental and biological impacts of the fishery have been recognised for many years and include: overharvesting of fish and invertebrates, changes to the ecology of the reef due to collecting, degradation of coral reefs due to physical damage inflicted by collectors, degradation of reefs from use of cyanide and other poisons, loss of biodiversity (Wood 2003).

Destructive collection practices such as the use of sodium cyanide contributes significantly to the degradation of coral reefs (Andrews 1990, Wood 1985, Shuman *et al.* 2005). The large scale use of this chemical does not only affect fish but destroys most invertebrate life, including the delicate corals that it comes into contact with (Rubec 1988). Rubec (1988) estimated that of the fish exposed to sodium cyanide at a capture site, only 10% are captured, 50% die entombed in the coral and the remainder of the fish are consumed by predators. Furthermore, of the fish caught, it is estimated that more than 80% die *en route* to the marine hobbyist due to delayed mortality (Rubec 1988). Vine and Hecht (1998) estimated that less than 2% of the fish imported from Indonesia and Sri Lanka into South Africa survived to reach the hobbyist. Statistics such as these, coupled with the depletion of many reef species, has sparked concern about the impact of the marine ornamental trade on coral reefs.

The increase in demand for these marine ornamental species can be supplied by two entities, namely: wild collection and the aquaculture industry.

The international market demands, volume, variety and reliability from suppliers. The fisheries can supply this variety (1470 species) (Wabnitz et al. 2003), volume (30 million individuals) (Wood 2003) and reliability (based on natural supply). However, it is the general consensus of the scientific and conservation communities that the methods and rates of harvesting wild, live reef organisms cannot be sustained (Pomeroy *et al.* 2006).

As with many unsustainable resources, decision-makers, conservationists and the industry are looking for economically and ecologically sustainable solutions (Pomeroy *et al.* 2006). Aquaculture is increasingly being cited as one of the most promising solutions for reducing harvesting pressure on coral reef organisms (Adam 1997, Andrews 1990, Birch 2005, Pomeroy *et al.* 2006).

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Pomeroy *et al.* (2006) investigated the feasibility of small-scale aquaculture (<10 000 litre capacity) as a solution for reducing fishing pressures on coral reefs in the Indo-Pacific region. They established that for small-scale aquaculture to be a viable solution it would need to be initiated to allow for the culture of the major live reef species that are traded internationally using appropriate technologies that are feasible at a community level as well as socially and culturally compatible. Small-scale aquaculture would also need to be profitable enough to realistically meet the livelihood needs as an alternative to fishing, as well as provide sufficient incentive (i.e. returns) to displace, and not merely supplement, wild-harvest effort.

Aside from these conditions, there are some factors that need to be considered if small-scale aquaculture is to compete with the wild harvest efforts. Small-scale aquaculture facilities should provide a variety of organisms to the international market (Oellermann 1999), using reliable technologies and techniques that can provide a constant supply of organisms to the market place.

1.2 Market related issues

Pomeroy *et al.* (2006) established that if small-scale aquaculture was going to provide a viable solution to wild harvesting, then it needs to focus on the major live reef species that are traded internationally, as well as establish the value of these species.

There are a number of market related questions that can help assess the feasibility of a small-scale aquaculture facility in South Africa, namely:

- What species are the most popular and most abundantly imported?
- What is the total value of these species during the study period?
- What is the local demand (based on the total number of organisms imported during the study period)?

1.3 Small-scale aquaculture technologies development

Investigations on the feasibility of commercially viable marine ornamental species have traditionally been on mono-culture systems (Avella et al. 2007, Figueiredo *et al.* 2008, Frankes and Hoff 1982, Hargreaves 2003, Hecht and Britz 1990, Hoff 1996, Krom *et al.* 2001, Oellermann 1999, Olivotto *et al.* 2003, Olivotto *et al.* 2006, Tlusty 2002, Wu 1995). Pomeroy *et al.* (2006) investigated the feasibility of a mono-culture system using clownfish as a representative species. These authors found that the production of clownfish in the Philippines can be profitable. However capital investment requirements and operating costs were too high for clownfish to be an alternative or supplementary livelihood for small-scale fishers, who often lack investment capital.

Instead of testing the feasibility of small-scale mono-culture systems, the feasibility of a poly-culture/multi-species system should be tested. Unfortunately, there are few published papers in this field and much of the available literature is found in the "gray" literature or is anecdotal.

McManus (1997) noted that small-scale mariculture should be developed as a species-diverse enterprise lending itself to the integration of multiple products on a single farm. A large proportion of fish exported from source countries are benthic egg-laying species of the family *Pomacentridae* (Pomeroy *et al.* 2006). The most popular live invertebrate species in the marine ornamental trade are hard corals (*Scleractinia*), soft coral (*Alcyonacea*), live rock (i.e., encrusted or sessile invertebrate assemblages attached to a hard substrate, such as dead coral, reef rubble or rock), and reef-dwelling crustaceans (Wood 2003, Daw *et al.* 2001, Gasparini *et al.* 2005). Since the market demands variety of organisms, a facility that can incorporate a number of these species in one system is aligned with market trends. However high capital and operating costs are major drawbacks with current small-scale multi-species system designs. These factors need to be kept in consideration when designing a small-scale aquaculture system.

To make environmentally friendly aquaculture competitive, it is necessary to raise its revenues (Wood 2003). This can be achieved by decreasing the cost of filtration and increasing productivity per unit of feed, which can account for almost half of production costs. In integrated aquaculture, the waste nutrients are not considered as a burden but as a resource for the auxiliary culture of commercially marketable algae (Losordo and Westerman 1994, Zucker and Anderson 1999). The sale of these commercially marketable algae can increase the revenue of the venture as well as offset the operational costs. These algal based filtration systems are less expensive than high end bacterial based filtration systems and hence decreases the capital costs. A culture system that diversifies its products by integration therefore makes sense, not only economically but also ecologically (Neori *et al.* 2004).

Small-scale aquaculture must use appropriate technologies that are feasible at a community level and be socially and culturally compatible (Neori *et al.* 2004). The use of commonly available parts to construct filtration and control equipment can eliminate the need to source expensive aquaculture equipment. This will also greatly improve the accessibility of this technology in rural areas where aquaculture equipment is not available.

1.4 Investigation of coral growth rate

In order to investigate the potential yield of any system, it is important to know the growth rate of each species contained in that system. Only a minute fraction (0.03%) of corals traded for aquaria are bred in captivity (Pomeroy *et al.* 2006), and coral propagation is limited due to the poor survival rates of most corals in tanks (Green and Shirley 1999). The high mortality of cultured and captive corals has been attributed to poor knowledge about critical life history parameters and the required culture conditions (Wabnitz *et al.* 2003, Green and Shirley 1999).

Since many corals contain symbiotic photosynthetic algae (zooxanthellae), light is a critical factor for coral survival (Calfo 2001). Artificial lighting at suboptimal intensities, wrong spectral composition and photoperiod, impairs the metabolic efficiency of corals and this may be a key factor for the poor survival of corals in aquaria (Anthony and Hoegh-Guldberg 2003). Surprisingly, detailed experimental studies on the effects of different artificial light scenarios on the performance of corals in aquaria are uncommon (Riddle and Olaizola 2002).

There are a number of techniques used to measure growth rates of corals, most of which require direct handling of tissues, which stresses the corals (Calfo 2001). Most of these techniques involve disturbing the coral through handling/weighing and this can result in biased measurements of growth. Corals are ornamental species and are bought by the hobbyist based on appearance/size and not weight. Since corals are purchased on a visual/size basis, an approach was needed to establish growth rate based on apparent visual growth.

By using digital imagery and computer analysis, it is possible to determine the surface-area pixel value (SPV) of a particular coral. The increase/decrease of the surface-area pixel value over time could be used as a measurement of apparent visual growth. This method requires no direct handling and therefore minimises the stress on the coral.

1.5 Objectives of the study

This study was separated into three groups of objectives, namely:

Investigation of South African marine ornamental Market:

- Determine the local demand for marine ornamentals by using the total number of organisms imported into South Africa as an indicator.
- Establish which species are the most popular and most abundantly imported?
- Determine which species represent the highest value?
- Determine if there is a consumer preference to aquacultured species.

System design related objectives:

- Design and construct a small-scale multi-species system for benthic egg-laying fish species, corals and ornamental algae.
- Developing aquaculture technologies that are cost and energy efficient and more accessible to small-scale operations.

Coral growth rate objectives:

- Determine whether photoperiod influences the growth rate of the coral *Sinularia sp.*
- Assess the approach of using computer analysis of digital images as a measurement of growth and condition of *Sinularia sp.*

CHAPTER TWO
AN INVESTIGATION OF THE SOUTH AFRICAN MARINE ORNAMENTAL MARKET

2.1 Introduction

The art and science of keeping ornamental aquatic organisms has a long history. Aquarists have been keeping aquatic organisms from as far back as the Sumerians, who kept fish in ponds at least 4 500 years ago, to the first known marine aquarists, the Romans (Schlacher *et al.* 2007). For most of history, ornamental aquatic organisms were reserved for the wealthy, but soon after the art of glass making reached a point where it was possible to produce sheets of glass, it was possible for the middle class to afford home aquaria. Due to improved husbandry techniques the marine ornamental trade has increased exponentially in the past decade, making fish keeping one of the most popular hobbies in the world (Wood 2003, Figueiredo *et al.* 2008, Green and Shirley 1999).

The ornamental fish industry consists of both freshwater and marine organisms. Although freshwater species predominates the international trade, the percentage of the marine constituent is increasing rapidly (Livengood and Chapman 2007). The marine ornamental constituent of the market is not only increasing in volume but most notably in value, as marine species fetch higher values on a per fish basis (Figueiredo *et al.* 2008). Adam *et al.* 1997 reported that of the total number of ornamental fish traded, 96% were freshwater species while marine species only consisted of 4%. Even though marine species only contributed 4% of the total number of fish, the total value was an estimated 20% of the total value (Pomeroy *et al.* 2006).

The classic supply chain for marine ornamentals begins with collectors and extends down through the distribution networks (Figure 2.1). At each of the steps of the marine ornamental supply chain there are a number of shortfalls such as ammonia poisoning, transport delays, insufficient insulation in packaging and stress that cause substantial mortalities.

Taking into account fish mortality on the reef, and conservatively estimating an average mortality of 30% (Rubec *et al.* 2001), at each step of the chain from collector, to exporter, importer, wholesaler, and retailer, the overall mortality for marine fish from reef to retailer was estimated to exceed 90% (Adam 1997).

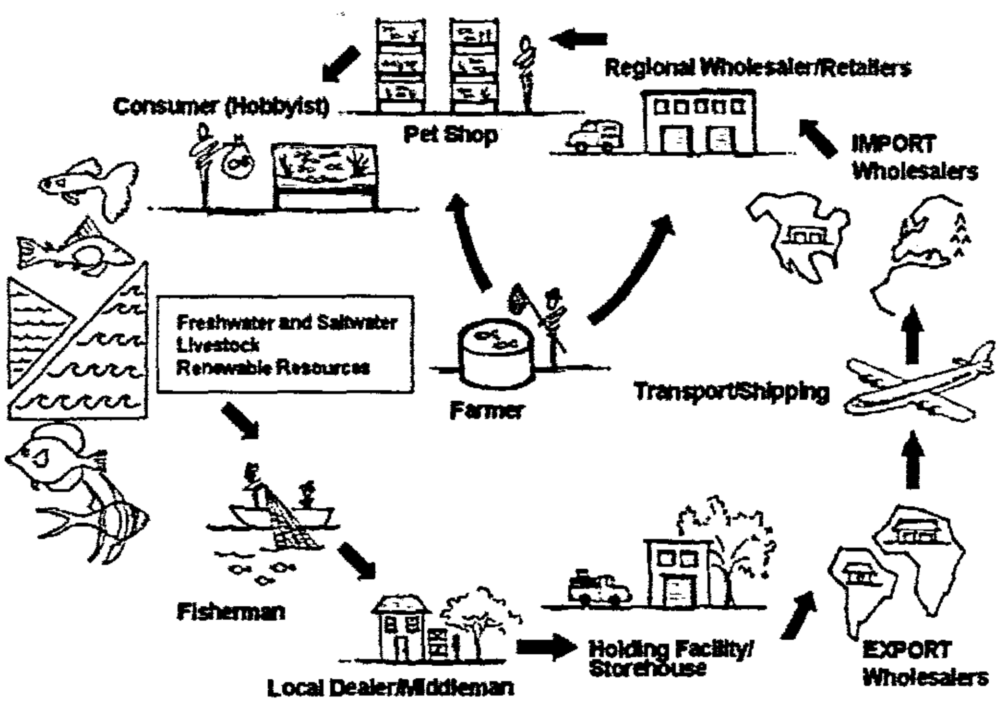

Figure 2.1: A schematic representation of the supply chain in the marine ornamental industry (Rubec 1988, Medley *et al.* 1993).

An economically and ecologically sustainable solution to wild harvesting of marine ornamental organisms is needed. Aquaculture is increasingly being cited as one of the potential solutions in reducing the harvesting pressures on coral reef organisms (Pomeroy *et al.* 2006, Figueiredo *et al.* 2008).

Before starting an aquaculture venture one needs an understanding of the intricacies of the market demand. To estimate the extent of the market, a comprehensive market study that answers specific market/industry related questions is necessary.

Although much effort has been focused on the assessment of the international trade in marine ornamentals (Wood 2001, Wabnitz *et al* 2003) and the potential impact of the trade in Hawaii (Randall 1987), Florida (Adams *et al* 2001), Sri Lanka (Wood 1985), the Philippines (Albaladejo and Corpuz 1981), Puerto Rico (Saadovy 1992), Eritrea (Daw et al. 2001) and the Maldives (Adam 1997), little effort has been given to the design of appropriate mariculture systems that are capable of supplying this market. There has only been one study done on the South African marine ornamental industry in the past, which was an unpublished report (Vine and Hecht 1998).

There are a number of market related questions that need to be answered to establish if the aquaculture of marine ornamentals in South Africa is an economically viable solution. Some of these market related questions are:

1. What species are being imported?
2. What are the most abundantly imported species?
3. What is the value of these species?
4. How many marine ornamental organisms are imported annually?
5. Is there a consumer preference to either wild caught or aquacultured species?

In order to establish the extent of the South African trade in marine ornamental organisms, a market survey and analysis of government import records was carried out to establish imports of marine ornamentals into South Africa, in terms of volume, value and species composition. This study aims to answer these questions, to provide an understanding of the South African market.

2.2 Materials and methods

2.2.1 The survey questionnaire

Vine (2007) formulated a survey to establish the status of the marine ornamental industry in South Africa. The study was however not completed due to the difficulty of contacting hobbyists in large numbers. The questionnaire met the requirements of the present study and it was decided to use the same format, but a different method of distribution. The questionnaire was separated into two sections: the hobbyist section and the industry section (Appendix A). The questionnaire was distributed using two methods: a regional (Cape Town area) and a national method (Internet forum).

2.2.2 Regional study

The regional survey was conducted in Cape Town, South Africa. In order to reach a large number of hobbyists, questionnaires were given to hobbyists at each of the sea water collection sites in Cape Town, namely: the Two Oceans Aquarium and the Marine and Coastal Management (MCM) Research Aquarium of the Department of Environmental Affairs and Tourism (DEAT). In order to ensure that the majority of hobbyist that use natural sea water were reached, the survey was conducted over a two month period. On the 15th of June 2008, 50 questionnaires were given to the receptionist at the Research Aquarium, as well as the receptionist at the Two Oceans Aquarium in Cape Town. The receptionists were asked to hand out a questionnaire to everyone who came to collect water. The hobbyists who received the questionnaire could either fax or e-mail the questionnaire back to the author or hand it back to the receptionist. On the 15th of August 2008 the questionnaires that were handed back as well as the questionnaires that were not distributed were collected from the two water collection sites.

2.2.3 National study

In order to establish a national census of the status of the marine ornamental industry in South Africa, an internet based survey was conducted. For continuity reasons the questionnaire used in the regional study was used for the national survey. In order to reach a national audience www.sareefkeeping.com was contacted and was used to conduct the survey. A separate thread was opened with the questionnaire attached and members were asked to complete the questionnaire and make any comments. This site has the largest marine aquarist member base of 1420 members across South Africa.

2.2.4 Analysis of import data

Companies importing marine ornamental fish into South Africa need to obtain a permit from Marine and Coastal Management (MCM): Department of Environmental Affairs and Tourism (DEAT). According to DEAT (2008) the import requirements are as follows:

- Original, completed, signed and dated application form. As well as a species list including the scientific names of the species to be imported.
- Certified copies of company registration documents or ID document depending on the name of the applicant on the permit application form.
- Certified copies of valid Department of Trade and Industry import permits/ permits notifications. This is not necessary for Namibia, Swaziland, Lesotho and Botswana.
- Certified copy of a valid tax clearance certificate from the South African Revenue Services (SARS) in the name of the applicant.
- Original certificate of origin from previous shipment.
- Original health certificate of previous shipment.

Import permits and invoices from all importers supplying the marine ornamental industry in South Africa are collected and filed by MCM but are not captured electronically.

Five of the 18 companies issued with import permits supplied invoices. Complete invoice data from the five companies were available from April to December 2007 and were captured for this study. Invoices prior to this date were not available as it was not legislation to supply invoices to obtain a permit prior to 2007. Further studies should be conducted when larger data sets become available for more accurate predictions. In order to estimate annual figures, a few assumptions are made. Firstly, it is assumed that the 13 companies that did not supply invoices imported the same average number of organisms as those five companies that did supply invoices. Secondly, the numbers and values of imported organisms are taken to be consistent from month to month throughout the year. Each invoice contained data on species composition, volumes and price. The species data were separated into 31 categories, 22 categories for fish, 3 for coral and 6 for other invertebrates (Table 2.1).

Table 2.1: Categories used by importers to classify imported organisms

Fishes
Amphiprion and *Pomacentradae* (Clownfish and damsels)
Chaetodontidae (Butterfly fish)
Scorpaenidae (Scorpion and lion fish)
Pomacanthidae (Angel fish)
Zanilidae (Heniochus and Moorish idols)
Platacidae (Batfish)
Balistidae (Trigger fish)
Canthigasteridae and *Tetraodontidae* (Puffers)
Syngnathidae (Seahorse and Pipefish)
Monacanthidae (File fish)
Acanthuridae (Tangs and Surgeon fish)
Lutjanidae (Perches and Snapper)
Labridae (Wrasses and Birdfish)
Serradidae (Groupers)
Siganidae (Rabbit fish)
Plectorhynchus (Sweetlips)
Callyodontidae and *Holocentridae* (Parrot and Squirrel)
Carangidae and *Mullidae* (Jack, Travally and Goatfish)
Gobidae (Blennies and Gobies)
Ostraciontidae (Box and Cow fish)
Miscellaneous
Fishes from the great barrier reef
Coral
Coelenterata (Sea anemones)
Hydrozoa (Hard live coral)
Anthozona (Soft live coral)
Other invertebrates
Echinoidermata
Crusiacea
Porifera (Sponges)
Mollusca
Marine algae
Annelid (Tubeworms)

The number and price of each species imported was recorded for each shipment and separated into its corresponding category. The data was categorised according to

- Most frequently imported fish.
- Most frequently imported category of fish.
- Most frequently imported coral.
- Most frequently imported category of coral.
- Most frequently imported other invertebrate.
- Most frequently imported category of other invertebrate.
- The category of fish representing the highest value.
- The category of coral representing the highest value.
- The category of other invertebrate representing the highest value.

2.3 Results:

2.3.1 Survey questionnaire results

The regional survey yielded a response rate of 7.9% while the national survey yielded only a 1% response rate (Table 2.2). The national survey consisted of 57.1% of the respondents from Gauteng province and 42.9% from the Western Cape (Table 2.2). There were no respondents from any other province. In both the regional and national surveys, 100% of the respondents were male, with an average age of 47 (regional) and 31 (national).

100% of the respondents of both the national and regional surveys indicated that they would be willing to pay more for aquacultured species. The amount that was indicated was between 10-35% more for aquacultured species (Table 2.2). None of the respondents indicated that they had reared any marine ornamental fish, but 14% of the national respondents had propagated invertebrates, comprising mainly soft corals (Table 2.2).

The regional study indicated that an average of R3 166.67 was spent on equipment and R2 966.67 on livestock (Table 2.2). The national study indicated an average of R6 985.71 was spent on equipment and R6 214.29 on livestock (Table 2.2). Regionally equipment consisted of 52% and livestock consisted of 48% of the expenditure (Table 2.2). While nationally equipment consisted of 53% and livestock consisted of 47% of the expenditure (Table 2.2).

Nationally the average size if aquariums kept was 390.8L while in Cape Town it was 490L. The average aquarist in Cape Town kept only one aquarium while nationally the average was two.

Table 2.2
Results of the national and regional surveys on the marine ornamental industry in South Africa

	Regional	National
Number of people who received/viewed the survey	38	667
Number of people who returned the survey	3	7
Response rate	7.9%	1%
Hobbyist Demographics		
Western Cape	100%	42.9%
Gauteng	0%	57.1%
Average age	47	31
Gender		
Male	100%	100%
Female	0%	0%
Number of years keeping marine ornamentals	3.7	6.3
Number of hobbyists who have reared marine ornamental fish		
Yes	0%	0%
No	100%	100%
Number of hobbyists who have reared any marine ornamental invertebrates		
Yes	0%	14%
No	100%	86%
Preference for captive bred species over wild caught animals		
Yes	100%	100%
No	0%	0%
Willingness to pay more for captive bred species		
Yes	67%	86%
No	33%	14%
Average Number of marine aquaria per hobbyist	1	2
Average size of aquaria	490L	390.8L
Average expenditure per hobbyist per year on marine aquaria		
Livestock	R2966.67	R6214.29
Equipment	R3166.67	R6985.71

2.3.2 Import data results

Between April and December 2007, five of the 18 companies that had import permits, imported a total of 359 different ornamental species of which 252 were fish species while the remaining 107 species were invertebrates (Appendix B). During this nine month period a total of 32 005 individual organisms were imported into South Africa by the five companies (Appendix B). It needs to be highlighted that all of the organisms imported during this period were wild caught/collected species.

A total cost of R16 646.83 for the nine months was spent (Appendix B). This does however not include shipping costs which is a substantial constituent of the total cost.

There were two groups of fish that represented the highest import volumes. These were *Amphiprion spp.* and *Pomacentradae spp.* (clowns and damsels) as well as the *Gobidae spp.* (Figure 2.2). These groups represented 38% and 19% respectively of the total number of fish imported (Figure 2.2). Within the *Amphiprion spp.* and *Pomacentradae spp.* (clowns and damsels) group, the blue green damsel *Chromis coeruleus* was the most frequently imported. *Chromis coeruleus* represented 17% of the *Amphiprion spp.* and *Pomacentradae spp.* group (Table 2.3). The clownfish *Amphiprion ocellaris* was the second most frequently imported representing 16% of the group (Table 2.3). The most abundantly imported fish within the group *Gobidae*, was *Salaris fasiatus* representing 11% of the group (Table 2.4). The remaining 20 fish groups all represented less than 10% of the total imports each.

Of the 359 different ornamental species imported between April and December 2007, 107 of those species were invertebrates. Soft corals, represented 37% of the total invertebrate volume imported (Figure 2.3), while representing 72% of the total coral imports (Figure 2.4).

From the value comparisons the fish group that represented the highest value was the group, *Pomacanthidae* (Angels fish) which represented 22% of the total value of fish imported but only 8% of the volume (Figure 2.6). The invertebrate group that represented the highet value was the soft corals (Anthozoa), which represented the highest volume as well (Figure 2.7).

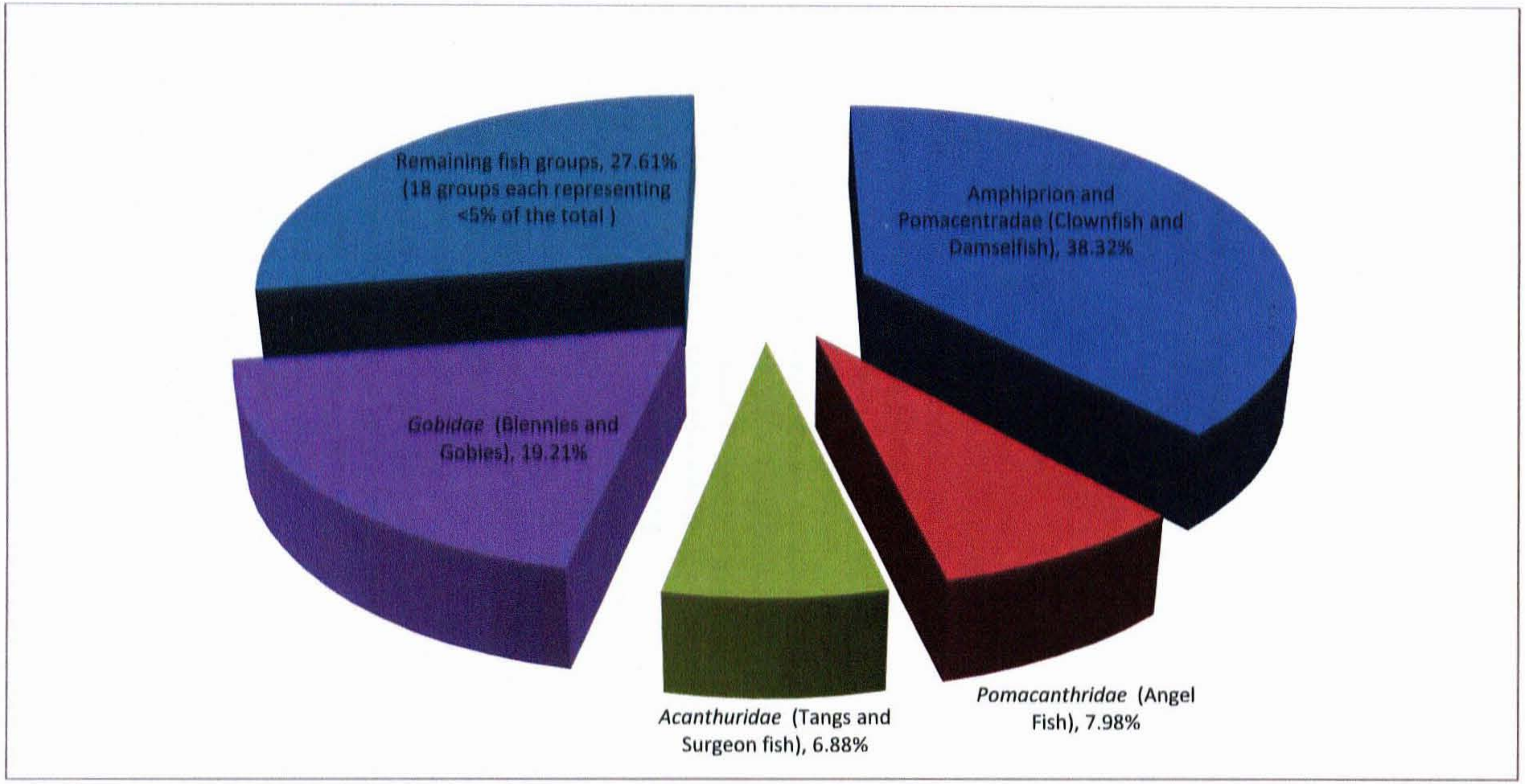

Figure 2.2: The representation (%) of each fish group imported into South Africa by the five companies that supplied data between April 2007-December 2007

Table 2.3: A breakdown of species composition of the Group *Amphiprion* and *Pomacentradae* and the corresponding percentage make up of the group

Species Name	number	percentage
Assorted damsels	197	3%
Assorted clowns	113	1%
Amphiprion akallopisos	101	1%
Amphiprion clarkaii	347	5%
Amphiprion allardi	120	2%
Amphiprion sandaracinos / orange skunk clown	44	1%
Amphiprion ephippium / fire or saddle clown	252	3%
Amphiprion frenatus / red tomato clown medium	233	3%
Amphiprion frenatus / red tomato clown large	6	0%
Amphiprion polymnus / saddle back clown	267	4%
Amphiprion melanopus / tomato clown	5	0%
Amphiprion ocellaris / percula clown local	1199	16%
Amphiprion percula / indonesia red percula clown	431	6%
Amphiprion percula / black percula clown medium	393	5%
Amphiprion perideration / pink skunk clown	128	2%
Amphiprion sebae / brown & white clown	25	0%
Amphiprion xanthurus / black & white clown	25	0%
Premnas biaculeatus / maroon clown small to medium	111	1%
Abudefduf saxatilis sexifasciatus / sargeant major	5	0%
Paraglyphidodon oxydon / neon or blue velvet damsel	20	0%
Paraglyphidodon melas / blue fin damsel	16	0%
Chrysipiera spp. (Yellow tail blue damsels)	727	10%
Dascyllus aruanus / three stripes hamburg damsel	5	0%
Dascyllus carneus / freckled white damsel	15	0%
Dascyllus melanurus / four stripes or zebra damsel	214	3%
Dascyllus trimaculatus / three spots or domino damsel	461	6%
Pomacentrus vailu / local blue devil	6	0%
Pomacentrus coeruleus / blue damsel	318	4%
Pomacentrus alleni / electric blue damsel	34	0%
Pomacentrus coelestis / yellow belly neon damsel	107	1%
Chrysipiera cyanea / redtail blue damsel	132	2%
Dascyllus & pomacentrus asst / assorted damsel	8	0%
Chromis coeruleus - viridis / blue green damsel	1285	17%
Chromis species / bicolor chromis	82	1%
Premnas biaculeatus (golden maroon clown)	108	1%
TOTAL	7540	100%

Table 2.4: A breakdown of species composition of the Group *Gobidae* and the corresponding percentage make up of the group

Species Name	number	percentage
Assorted unidentified Blennies	117	3.10%
Asoorted unidentified Gobies	451	11.93%
Assorted unidentified Dragonetts	8	0.21%
Pterosynchiropus spp. Mandirin fish	252	6.67%
Amblyeleotris spp.	4	0.11%
Signigobius biocellatus	35	0.93%
Salaris fasiatus	420	11.11%
Aeoliscus strigatus / Razor fish	50	1.32%
Anthias pleurotaenia / Square anthias	78	2.06%
Anthias pleurotaenia / Yellow anthias	17	0.45%
Anthias squamipinnis / Red lyretail coral fish	184	4.87%
Anthias species / pink anthias	56	1.48%
Anthias species / Tiger queen anthias	35	0.93%
Cryptocentrus cinctus / yellow goby large	42	1.11%
Dactyloptena orientalis / scooter blenny	45	1.19%
Meiacanthus kamoharai / Stripped blenny	2	0.05%
Meiacanthus smithi / eye-blow blenny	28	0.74%
Gobiodon species / Coral gobies	2	0.05%
Cryptocentrus species / watchman gobies	29	0.77%
Elicanthus oceanups / Neon goby	75	1.98%
Escenius bicolor / Bicolor goby	30	0.79%
Nemateleotris decora / Flame goby	153	4.05%
Nemateleotris magnificus / Fire goby	349	9.24%
pseudochromis spp.	180	4.76%
Pseudochromis diadema / Skunk gramma	169	4.47%
Pseudochromis pacagnellae / Royal gramma	258	6.83%
Pseudochromis porphyreus / Purple gramma	103	2.73%
Ptereleotris evides / Scissortail / rocket	123	3.25%
Synchiropus picturatus / Spotted mandarin	84	2.22%
Synchiropus splendidus / Mandarin fish	43	1.14%
Gramma loreto / Royal gramma	30	0.79%
Valenciannea strigata / White goby	170	4.50%
Valenciannea sexguttata	116	3.07%
Valenciennea puellaris	16	0.42%
Valenciennea strigata	8	0.21%
Valenciennea fasciatus	17	0.45%
TOTAL	3779	100%

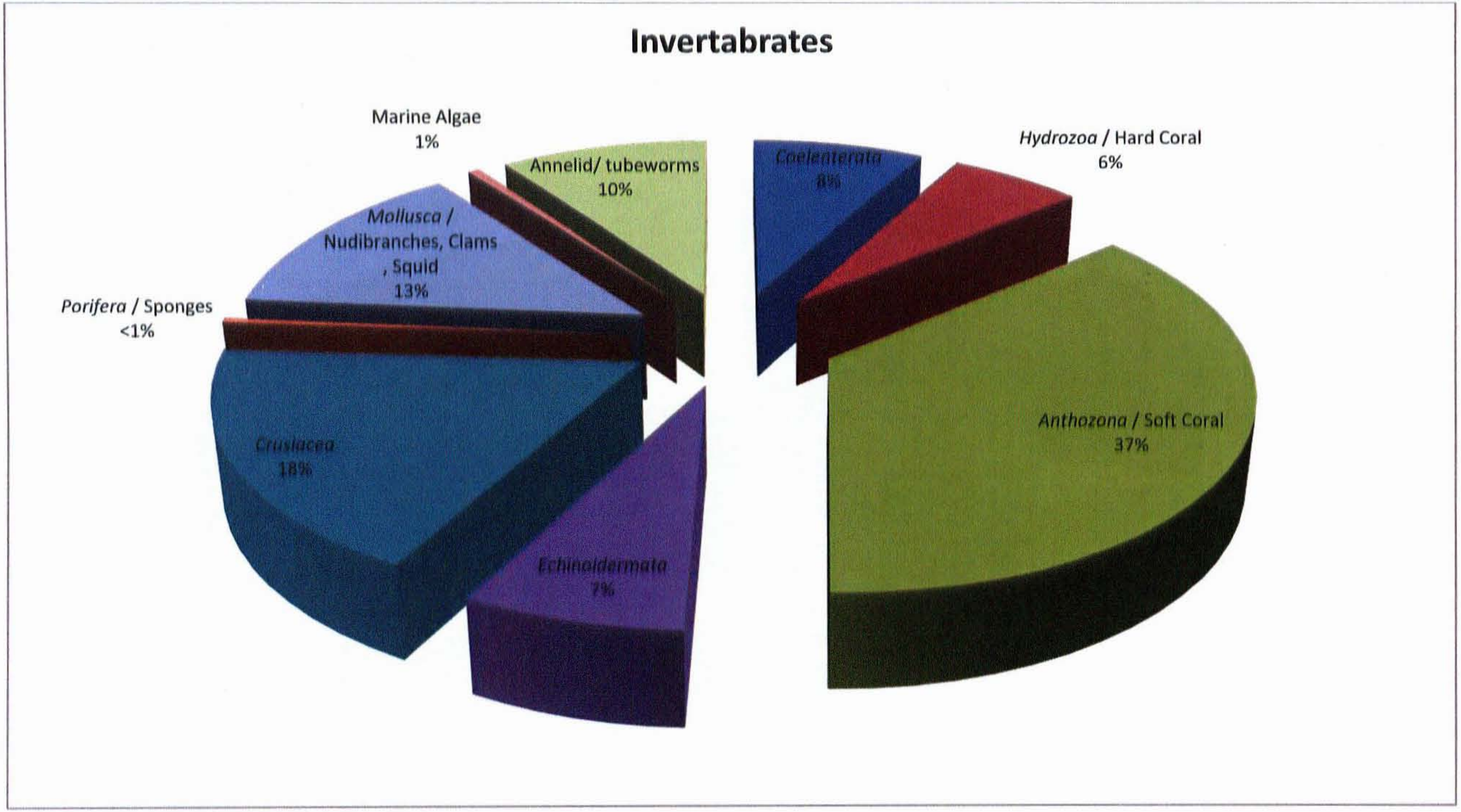

Figure 2.3: The representation (%) of each invertebrate group imported into South Africa by the five companies that supplied data between April 2007- December 2007

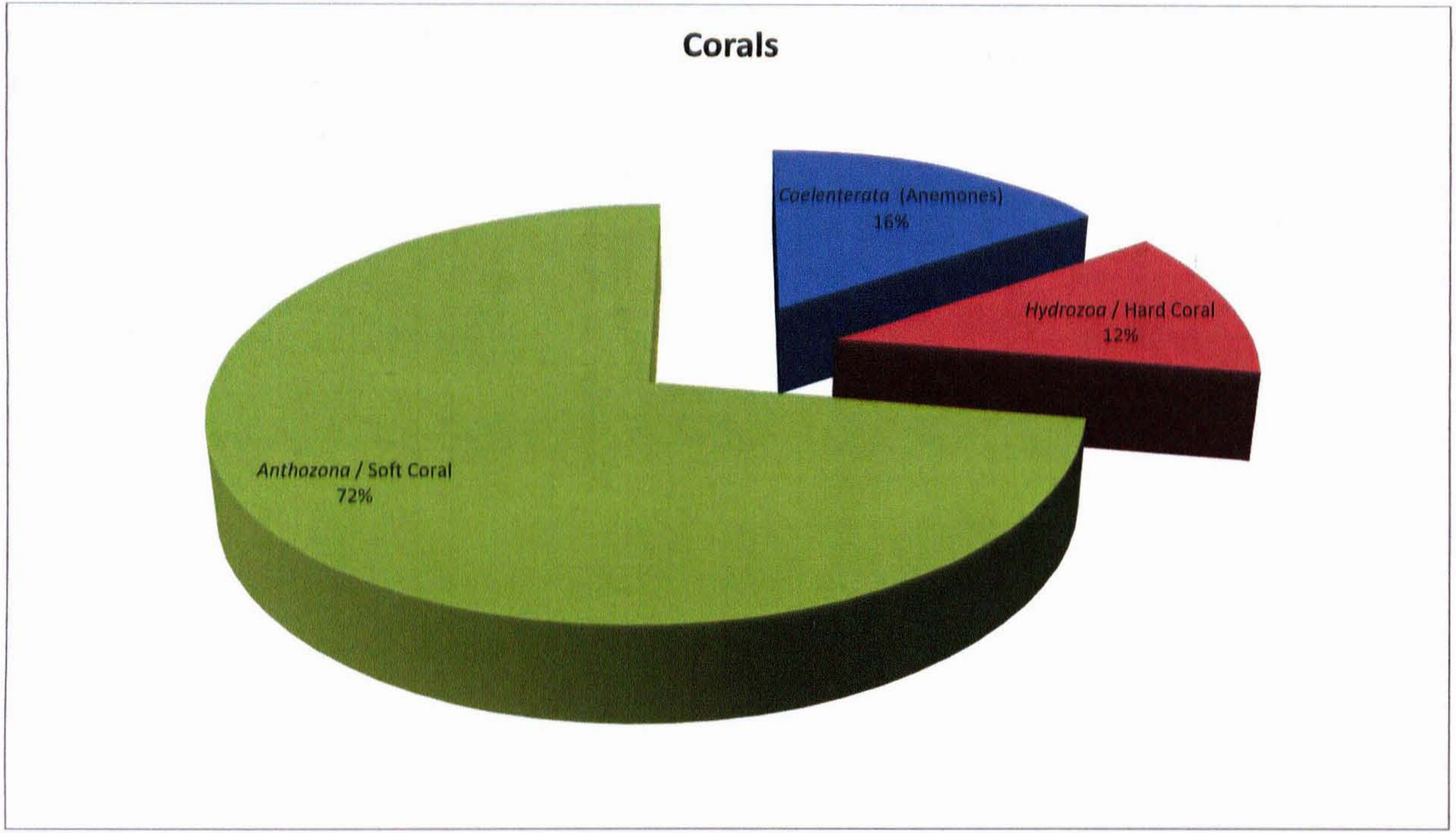

Figure 2.4: The representation (%) of each coral group imported into South Africa by the five companies that supplied data between April 2007-December 2007

Table 2.4: A breakdown of species composition of the Group Soft corals and the corresponding percentage make up of the group

Species Name	Number	Percentage
Capnella spp.	10	0.22%
Nephthea spp.	78	1.73%
Kenyan tree coral	319	7.07%
Clavularia spp. / clove polyps	212	4.70%
Ricordia spp.	222	4.92%
Zoanthid spp.	715	15.84%
Assorted unidentified *Actinodiscus spp.*	473	10.48%
Actinodiscus spp. / green	192	4.25%
Actinodiscus spp. / luminous	13	0.29%
Actinodiscuis spp./ striped	4	0.09%
Actinodiscus spp. / orange hairy	2	0.04%
Actinodiscus spp. / blue	27	0.60%
Actinodiscus spp. / red	62	1.37%
Anthelia spp. / local star polyps	87	1.93%
Anthelia xenile / green star polyps	34	0.75%
Anthelia xenile / local xenile	120	2.66%
Anthelia xenile/ pumping xenile polyps	15	0.33%
Ephizoathus spp. / cabbage polyps	3	0.07%
Carotalcycon sagamianum / sea pen	28	0.62%
Gorgonid spp. / live gorgonian	2	0.04%
Lithophyton arboreum / tree	211	4.68%
Lemnalia spp.	25	0.55%
Lobophytum spp.	329	7.29%
Metridium senile / sea cauliflower	9	0.20%
Rhodactis gigantea / elephant ear mushroom	56	1.24%
Scleronephthya spp.	10	0.22%
Sinularia spp.	296	6.56%
Sarcophyton spp. / soft leather	512	11.35%
Gorgonid spp. / sea fans	447	9.90%
TOTAL	4513	100.00%

Table 2.5: A breakdown of species composition of the Crustaceans and the corresponding percentage make up of the group

Species Name	Number	Percentage
Assorted unidentified shrimp	6	0.27%
Lysmata rathbunae / peppermint shrimp	195	8.65%
Lysmata amboinensis / cleaner shrimp	548	24.30%
Enoplometopus debelius / purple lobster	25	1.11%
Hymenocera picta / harlequin or clown shrimp	12	0.53%
Hippolysmata grahamii / painted skunk shrimp	10	0.44%
Libia tessellata / pompom crab	9	0.40%
Odontodactylus scyllaris / mantis shrimp	3	0.13%
Periclimenes spp. / sexy shrimp	8	0.35%
Periclimenes spp. / fire shrimp	205	9.09%
Periclimenes brevicarpalis / transparent shrimp	4	0.18%
Panulirus dasypus / spiny blue lobster	2	0.09%
Assorted unidentified hermit crabs	870	38.58%
Petrolisthes maculatus / anemone crabs	76	3.37%
Rhynchocinetes spp. / dancing shrimp	183	8.12%
Stenopushidpidus spp. / boxing shrimp	76	3.37%
Eca spp.	20	0.89%
Assorted unidentified crabs	3	0.13%
TOTAL	2255	100%

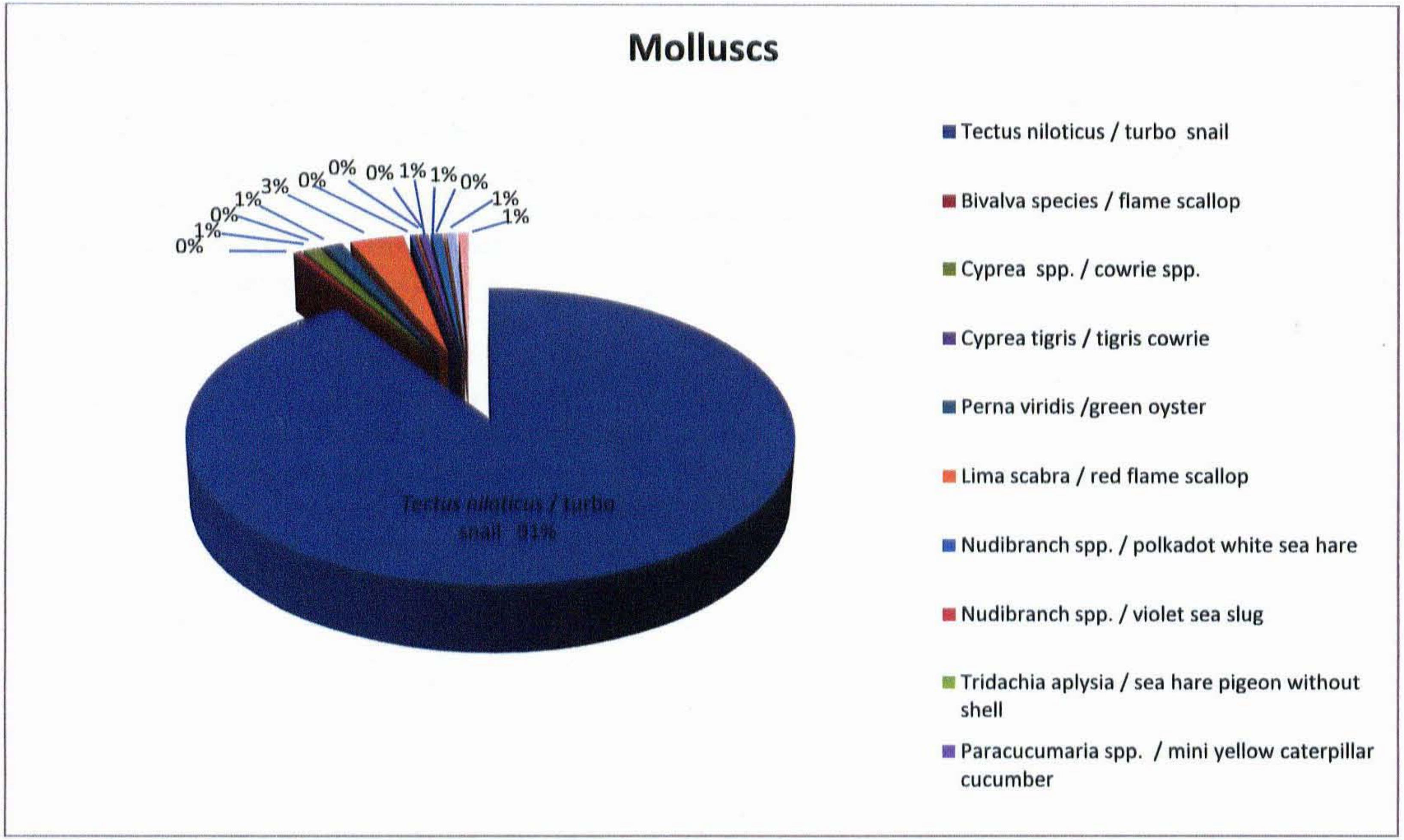

Figure 2.5: A breakdown of species composition of the Group Molluscs and the corresponding percentage make up of the group

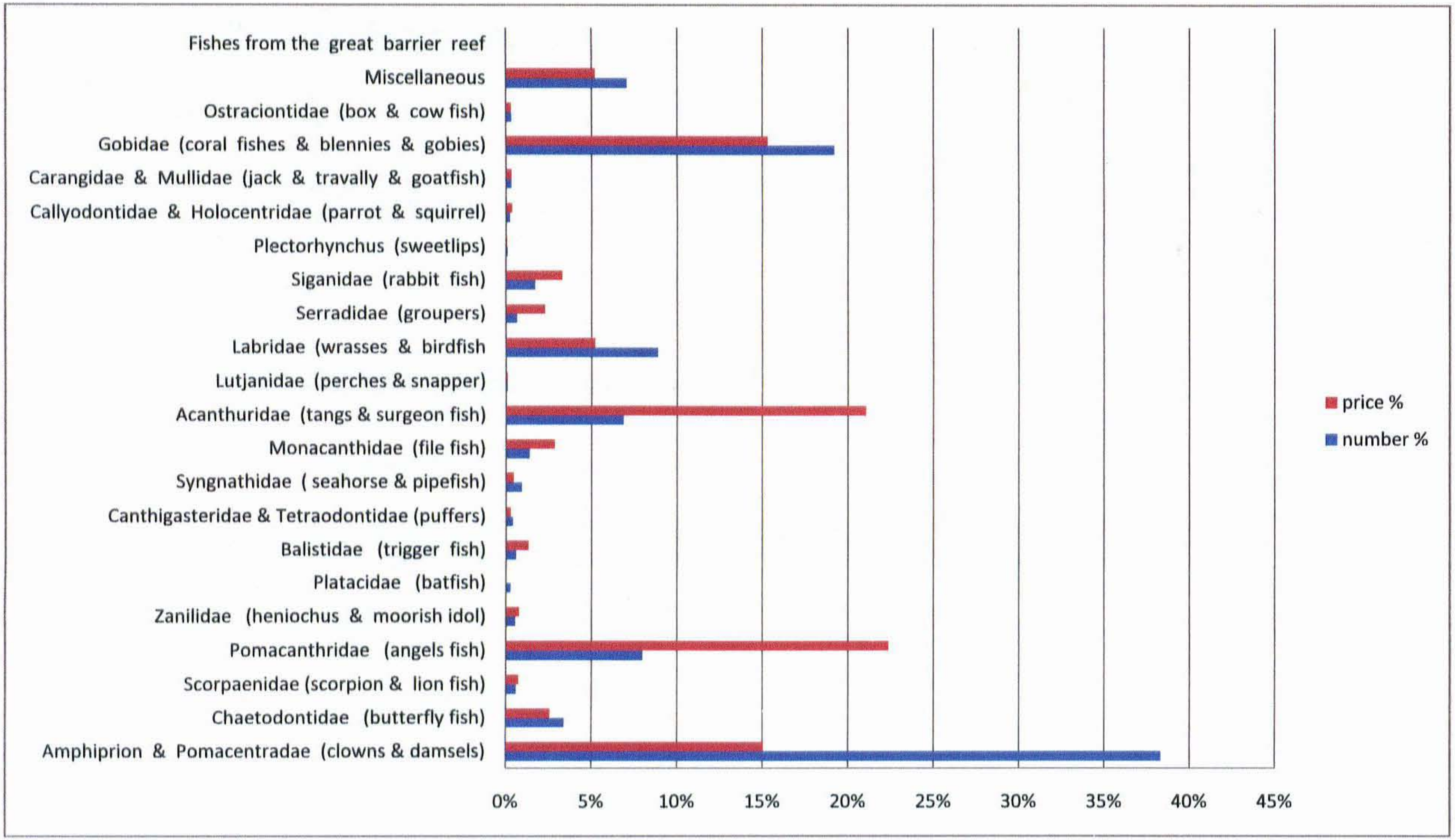

Figure 2.6: A graphical comparison between per-unit import value and volume of fish imported between April 2007- December 2007

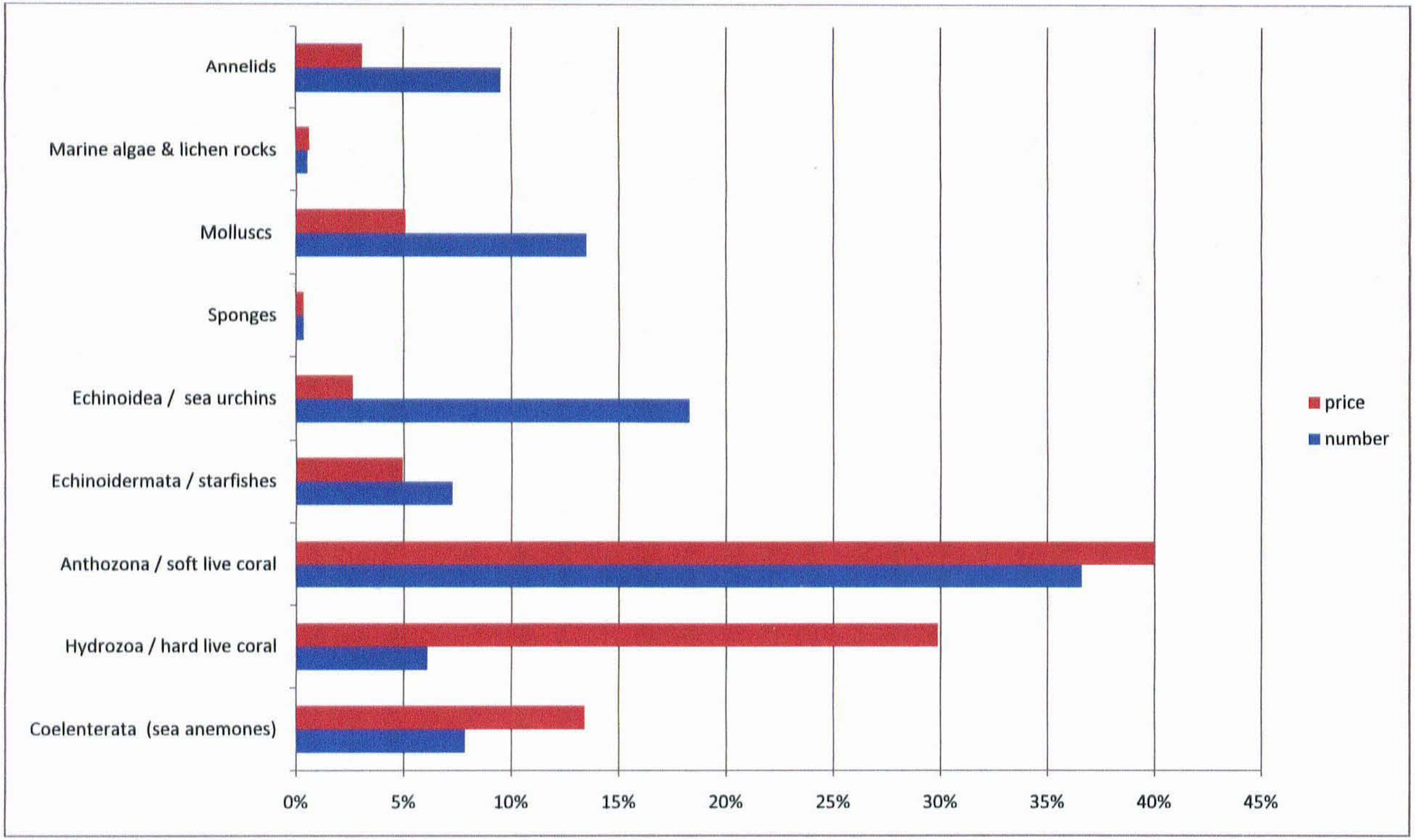

Figure 2.7: A graphical comparison between per-unit import value and volume of invertabrates imported between April 2007- December 2007

2.4 Discussion

2.4.1 Survey questionnaire

The response rate to this survey was extremely low. The regional survey yielded a response rate of 7.9% while the national survey yielded only a 1% response rate. There can be a number of reasons for the lack of willingness to respond to such a survey. One reason is the sense of paranoia amongst hobbyist. The national survey was conducted on a South African marine ornamental forum website (sareefkeeping.com). The members were asked to make any comments about the survey, on this forum. Some interesting comments were made, for example:

Member1: " Who is to say that this person is not trying to organise an exclusive licence for themselves and using this survey for their own benefit."

Member2: "I would be far more comfortable responding to a survey from ORI (Oceanographic Research Institute) as there would be far more control over the data that is collected and far better use made of it. I have no knowledge of Jason (the author) nor do I know very much about the institution that he is affiliated with."

Member3: "I am very worried about this survey! And would feel a lot better if there were some names behind it! I have to agree with the original statements by member1 and member2! And I'm not sure we should jump into this without understanding it to the full."

Member3: "I just feel a survey like this should not be taken too lightly! As it can lead to happenings that participants may not have supported had they known the outcome."

The author made it clear that the main objective for this study was information pertaining to mariculture, but not limited to it. Even though the intent and credentials of the author were made clear, the scepticism persisted. This scepticism could have been the reason for the low response rate.

Even with a relatively low response rate the study yielded some interesting results. One of the main outcomes of this study was to determine if there is a consumer preference to aquacultured species rather than wild caught species. 100% of the respondents of both the national and regional surveys indicated that they would be willing to pay more for aquacultured species. The amount that was indicated was between 10-35% more for aquacultured species (Table 2.2). This willingness to pay more for aquacultured species, suggests that hobbyists are concerned with the impact that the hobby has on the environment. The main problem facing the commercial culture of marine aquarium fish in South Africa is the relatively low cost of imported fish (average cost of Clownfish R13.88, Appendix B). However if hobbyists are willing to pay 10-35% more for aquacultured species then commercial culture might be competitive.

A significant proportion of the ornamental industry (including fresh water species) has been supplied by hobbyists and entrepreneurs in the past (Vine and Hecht 1998). The proportion of this supply, in the marine ornamental industry, has not yet been studied in South Africa. Moe 1999 conducted a survey at the Marine Ornamentals Conference in Honolulu Hawaii. Of the 324 respondents to Moe's survey, 55% indicated that they conduct casual/small scale culture of marine ornamentals, while 26% indicated a strong culture effort. This survey gave some insight into the effort that international hobbyists put into culturing marine ornamentals. In order to gain a South African perspective, two questions pertaining to this subject were included in the current survey. None of the respondents indicated that they had spawned and reared any marine ornamental fish, but 14% of the national respondents had propagated invertebrates, consisting of mainly soft corals (Table 2.2). It must however be highlighted that because of the relatively low response rate, this might not be an accurate depiction. It may just be a case of the hobbyists who are doing small scale aquaculture are not completing the survey.

The aquatic ornamental trade includes livestock as well as aquarium products, such as filtration equipment, lighting, food and many more other high valued products. The percentage these products contribute to the South African market has not been assessed in the past. This survey gave some estimation on how much hobbyist are spending on equipment and livestock.

The regional study indicated an average of R3 166.67 was spent on equipment and R2 966.67 on livestock (Table 2.2). The national study indicated an average of R6 985.71 was spent on equipment and R6 214.29 on livestock (Table 2.2). the national study consisted of hobbyists from across the country, including Johannesburg, where the cost of marine fish keeping is substantially higher than in coastal cities. It is for this reason that the national study showed a higher expenditure. Regionally, equipment consisted of 52% and livestock consisted of 48% of the expenditure. While nationally, equipment consisted of 53% and livestock consisted of 47% of the expenditure. This suggests that hobbyist spend approximately the same on equipment as on livestock.

2.4.2 Import data

2.4.2.1 Fish imports

There two groups of fish that represented the highest import volumes were *Amphiprion* and *Pomacentradae spp.* (clowns and damsels) as well as the *Gobidae spp.* These groups represented 38% and 19% respectively of the total number of fish imported (Figure 2.2). According to Pomeroy *et al.* (2006) there are about 25 species of marine ornamental fish being cultured but only 17 of these are commercially viable (Hecht and Britz 1990). Moe (1999) reported that there were 32 species that have been cultured commercially. Of the 32 species 47% were clownfish species while 28% were from the group *Gobidae*. This shows that internationally, species that are being commercially cultured are those that represent high imported volumes.

Investigations of the aquaculture feasibility of these commercially viable species have been traditionally mono-culture scenarios (Pomeroy *et al.* 2006). McManus (1997) noted that small-scale mariculture should be developed as a species-diverse enterprise lending itself to the integration of multiple products in a single farm. Both the international and South African markets demands a variety of organisms from an aquaculture facility, this study has shown that a large variety of the fish that are imported into South Africa are culturable species. If a multi-species approach is taken a substantial percentage of the fish imported could be substituted with aquacultured species.

2.4.2.2 Invertebrate imports

The most popular live invertebrate species in the international marine ornamental trade are hard corals (Scleractinia), soft coral (Alcyonacea), live rock (i.e., encrusted or sessile invertebrate assemblages attached to a hard substrate, such as dead coral, reef rubble or rock), and reef-dwelling crustaceans (Pomeroy *et al.* 2006). Moe (1999) found that there were a total of 65 invertebrates being cultured commercially. Of the 65 species 83% were corals, the most popular coral group were the hard corals which represented 59% of the coral constituent, while the second most popular group was the soft coral which represented 41% of the corals being cultured. The most frequently imported group of invertebrate imported into South Africa, was coral, representing 51% of the total invertebrate imports (Figure 2.3). In contrast to the international market which favours hard corals (Wood 2003), the most abundantly imported group of corals were the soft corals, representing 72% of the coral imports (Figure 2.4). This could be because of two reasons, either the South African market has a higher demand for soft coral or it could be due to permit or cost conditions. The majority of the soft corals imported are not, Convention on International Trade in Endangered Species (CITIES) listed species, whereas a large percentage of hard corals require CITIES permits for importation. These permits are more difficult to obtain, and it might be for this reason that hard corals are not imported as frequently. These permits come at an additional cost and therefore increase the retail value of the associated hard corals, to extremely high prices, these high prices might deter the hobbyist.

2.4.2.3 A comparison between value and volume

Visually there seems to be an inverse relationship between unit-price and volume. Organisms that cost less seem to be imported in higher numbers than species of higher value. When this relationship was tested using a Spearman rank correlation, the results showed that there was no significant relationship ($p = 0.14$).

The group of fish that represented the highest volume imported was the *Amphiprion spp.* and *Pomacentradae spp.* (clowns and damsels), which represented 38% of the total fish imported, however this group only represented 15% of the total value of fish imported. The group Pomacanthidae (Angels) represented only 8% of the fish import volume, but a total of 22% of the value. When deciding on an aquaculture species it is important to take this into consideration. A fish that represents a high value will be able to yield higher returns with lower volumes, while a fish that represents a lower per-unit value will need to be cultured in higher volumes to yield the same return as the high per-unit valued species. There is however a limitation to culturing the high valued *Pomacanthidae* (Angels) species. These species are all pelagic spawners with small pelagic fry. There has been limited success with culturing these species and no success with culturing these on a commercial scale (Moe 1999).

The invertabrate group that represented the highest value (36.6%) was the soft corals (Anthozoa), which represented the highest volume (37%) as well. This group is a species diverse group consisting of 31 different species. All of the soft coral species that were imported can be propogated asexually. This makes these species viable for small-scale aquaculture. The second most valued group were the hard corals (Hydrozoa) which represented 30% of the total invertabrate import value. This group however only represented 6% of the total volume. This is contrary to international trends which represents hard corals as the group representing the highest value (Olivotto *et al.* 2006).

CHAPTER 3
DESIGN AND CONSTRUCTION OF A MULTI-SPECIES MARICULTURE SYSTEM

3.1 Introduction

The aquaculture industry that started developing rapidly in the late 1960s has become a major global industry, producing 60 million tons a year, with huge annual revenues in excess of US$ 70 billion worldwide (Moe 1999). With the increase in environmental awareness and the consequent stringency in environmental legislation, recirculating aquaculture systems (RAS) were developed to try deal with the ecological problems associated with aquaculture (FAO 2007). This approach was originally developed to provide a solution to the environmental problems generated by the traditional pond and flow-through aquaculture systems, since it enables the treatment of polluted water within a closed loop, offers improved control of effluent discharge, and allows complete environmental control (Singer *et al.* in press). Moreover, RAS have certain ecological and economic advantages as it facilitates a reduction in the amounts of water and energy required and reduces land use (van Gorder 1994). In addition, it provides the geographical freedom to set up aquaculture systems in "nontraditional" farming areas (Singer *et al.* in press); for example, small RAS, such as the one presented in this study, producing lucrative marine ornamental species might be suitable for small-scale aquaculture production in urban areas (Shnel *et al.* 2002).

Aquaculture has the potential to substantially reduce the pressure on coral reef organisms (Pomeroy *et al.* 2006). According to Pomeroy *et al.* (2006) There are a number of conditions that must be met for small-scale aquaculture to be a viable solution to fishing pressure, some of which are:

- Small-scale aquaculture technologies must be initiated to allow for the culture of the major live reef species that are traded internationally.
- Appropriate technologies should be used that are feasible at a community level as well as socially and culturally compatible.
- Ornamental aquaculture needs to be profitable enough to realistically meet the livelihood needs as an alternative to fishing, as well as provide sufficient incentive (i.e. returns) to displace, and not merely supplement, wild-harvest effort.
- The culture of coral reef organisms should be economically more sustainable than continued harvest of wild stocks at present rates of extraction.

The primary competition to small-scale aquaculture in South Africa is the relatively low cost of imported wild caught fish (Pomeroy *et al.* 2006). The following needs to be considered if small-scale aquaculture is to compete with wild caught organisms.

- Small-scale aquaculture facilities should provide a variety of organisms to the international and local markets.
- Reliable technologies and techniques should be developed to provide a constant supply of organisms to the market place.

Previous studies, traditionally investigated the viability of marine ornamental mono-culture systems (Vine and Hecht 1998). Pomeroy *et al.* (2006) investigated the feasibility of a mono-culture system using clownfish as a representative species. These authors found that the production of clownfish in the Philippines could be profitable but capital investment requirements and operating costs were considered high for clownfish to be an alternative or supplementary livelihood for small-scale fishers, who often lack investment capital. Developing a system that can reduce the production costs as well as capital investment requirements would drastically increase the feasibility of providing an alternative or supplementary livelihood for small-scale fishers.

According to McManus (1997) small-scale mariculture should be developed as a species-diverse enterprise lending itself to the integration of multiple products on a single farm. An investigation of the marine ornamental market showed that, internationally the most abundantly imported group of fish were benthic egg-laying species of the family Pomacentridae (Avella *et al.* 2007, Figueiredo *et al.* 2008, Frankes and Hoff 1982, Hargreaves 2003, Hecht and Britz 1990, Hoff 1996, Krom *et al.* 2001, Oellermann 1999, Olivotto *et al.* 2003, Olivotto *et al.* 2006, Tlusty 2002, Wu 1995). The fish group that represented the highest import volumes into South Africa during 2007 were also benthic egg-laying species, representing 38% of the total fish volume (Figure 2.2). The most popular live invertebrate species in the international marine ornamental trade are soft coral (Alcyonacea),hard corals (Scleractinia), live rock (i.e., encrusted or sessile invertebrate assemblages attached to a hard substrate, such as dead coral, reef rubble or rock), and reef-dwelling crustaceans (Pomeroy *et al.* 2006). The most abundantly imported group of invertebrates into South Africa was corals, particularly soft corals (Figure 2.3).

Since the international and South African market demands variety of organisms (Wood 2003, Wood 2001, Daw *et al.* 2001, Wood 1985, Gasparini *et al.* 2005), a facility that can incorporate a number of the most abundantly imported species in one system is in line with market trends.

Traditionally multi-species systems were associated with high capital and operating costs. These factors need to be kept in consideration when designing an economically viable small-scale aquaculture system.

The objective of this chapter was to design and construct a multi-species recirculating system capable of producing three groups of organisms, namely: benthic egg-laying species of fish, corals, both hard corals (*Scleractinia*) and soft coral (*Alcyonacea*) and ornamental algae. The reason for choosing these species is that benthic egg-laying fish species and coral represented the most abundantly imported species into South Africa (Figure2.2 and Figure 2.3).

The system was designed to minimise the capital and operating costs, through two mechanisms. Firstly by converting operation and filtration costs into profit through the culture of commercially marketable algae. Secondly, minimise the capital costs through the development of small-scale aquaculture technologies that are feasible at a community level and cost efficient. The use of commonly available parts to construct filtration and control equipment can eliminate the need to source expensive aquaculture equipment. This could greatly improve the accessibility of this technology to rural communities where aquaculture equipment is not available.

3.2 System description

The system that was separated into four main sections (Figure 3.1), namely:

- the benthic egg-layer brood stock system,
- the coral propagation system,
- the macro-algae system and
- the filtration system.

Figure 3.1: 3D representation of the experimental system design

3.2.1 Benthic egg-layer brood stock system

In the natural environment, benthic egg-laying species seldom venture far from their territory; therefore relatively small, shallow tanks can be used. Traditionally these fish are kept in tanks of 114 litres (Wood 2003), keeping with the tradition, this system used 115 litre tanks. This system consisted of 4 banks of 4 tanks. The top tank of each bank was supplied with water by a 25mm inlet with a tap to control the flow rate. Each tank had an overflow box with a 50mm hole drilled in the base for an outlet. The outlets were alternated on opposite sides of each tank to facilitate an even flow through each tank (Figure 3.1). It needs to be highlighted that grow-out facilities were not tested in this study. There have been sufficient previous studies that have dealt with the matter. The system was stocked with the maximum suggested stocking density (Hoff 1996) of 24 fish that were imported from Singapore. Fish were fed twice daily on a diet of black mussel and Aquanutro® until satiation. Illumination was provided by natural light augmented by 15 Watt energy saver bulbs. Two pairs of fish were kept in each tank and were separated using a tank divider. There were no other competitive fish or invertebrates with the brood stock pairs. These fish were provided with a piece of PVC pipe as a refuge and a place to lay their eggs. In addition these pipes were easy to remove from the tank with minimal disturbances to the eggs.

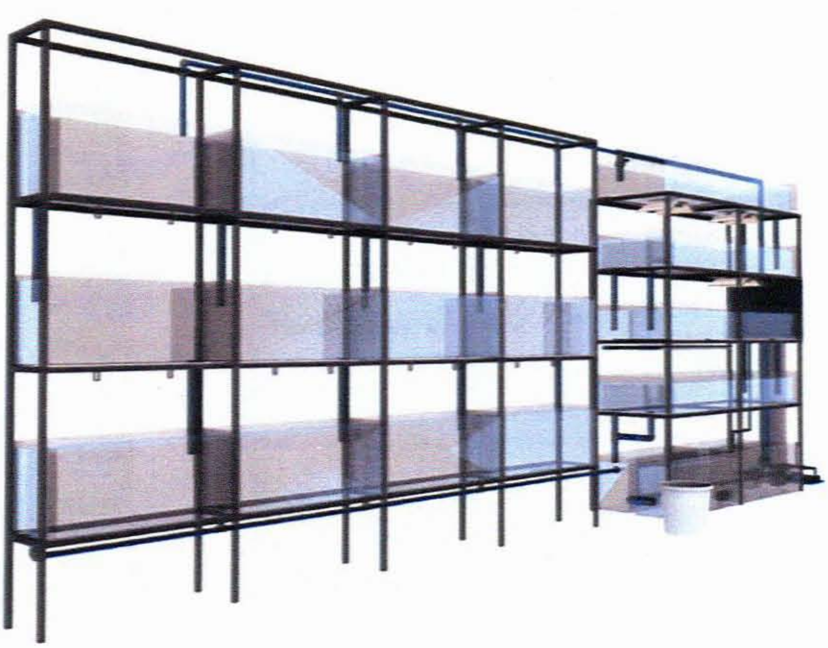

Figure 3.2: 3D representation of the experimental system. View from the benthic egg-layer brood stock system

Table 3.1: List of possible fish species that could be cultured using the proposed system

3.3.2 Coral propagation system

Invertebrate culture of marine ornamentals is not based on conventional loading capacities and feeding rates, but on horizontal space (Oellermann 1999, McManus 1997). Although volume and flow rate are important for optimum water quality, limits to production are based primarily on how many animals can be placed in the given horizontal space (Pomeroy *et al.* 2006). It was for this reason that the coral propagation tanks were designed as long, wide, shallow tanks (200 cm long x 60 cm wide x 30 cm high). The system contained a bank of four tanks. The top tank of the bank was supplied with water by a 50mm inlet with a tap to control the flow rate. Each tank had an overflow box with two 50mm hole drilled in the base for an outlet. The outlets were alternated on opposite sides of each tank to facilitate an even flow through each tank (Figure 3.3).

Fischer *et al.* 2007 found that corals survived better under metal halide lamps with a Kelvin rating of ≥14000 K. Light was provided to each tank by two 70W metal halide lamps (15 000 K), these were suspended 25cm from the water surface to decrease the effect of the heat produced by these lamps.

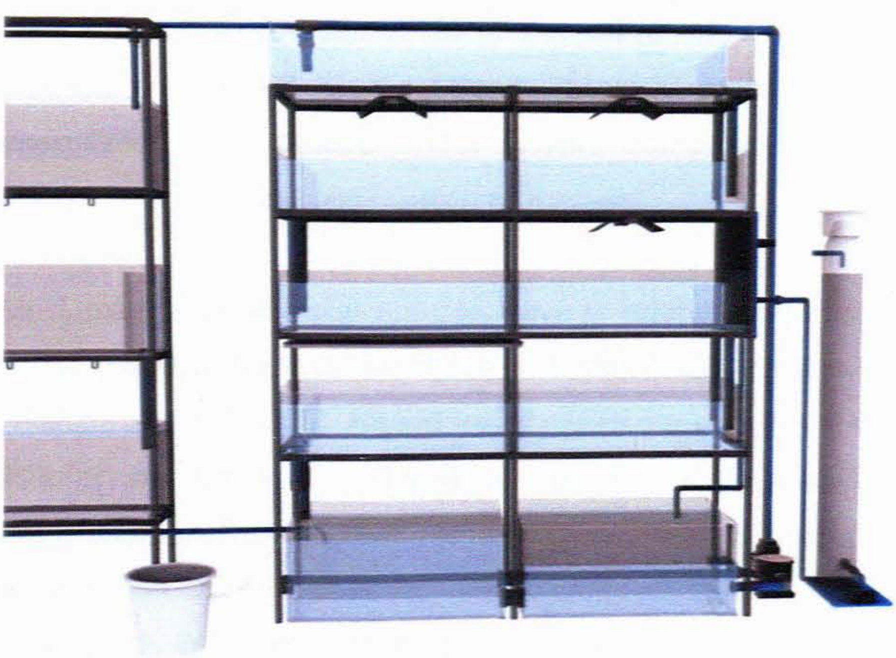

Figure 3.3: 3D representation of the experimental system. View from the coral propagation system

3.3.3 Filtration systems

3.3.3.1 Mechanical filtration

- Settling tanks: settling tanks are "filters" that rely on the principle that the higher the flow rate of water the more suspended particulate matter can be kept in suspension and vice versa. When water is slowed down some of the particulate matter settles out. The effluent water from the different components of the system ran directly through four settling tanks. The settling tanks were connected by 50mm PVC pipe. Each tank flowed from the bottom of the one tank to the top of following tank, which slowed the flow of water and allowed settlement. These tanks were also utilised to house the heating equipment.
- Filter sponge: Filter sponge was inserted in the first settling tank to remove the larger particulate matter before it reaches the biological filtration. It is important that larger particulate matter does not enter the biological filtration system as it could cause a build up of sludge which ultimately decreases the efficiency of the biofilter.

3.3.3.2 Biological filtration

When synthesizing the treatment of recirculating aquaculture waters and the mitigation of environmental impacts of aquaculture (Watson and Hill 2006), two main practical approaches have emerged: bacterial dissimilation into gasses and plant assimilation into biomass. This system incorporates both bacterial dissimilative (Figure 3.4) and plant assimilation processes.

Most marine ornamental species have a relatively low tolerance for nitrogenous waste products such as ammonia or nitrite when compared to freshwater species (Watson and Hill 2006). Nitrate toxicity is also a concern at levels which would have little or no impact on freshwater species. For example, in the anemonefish *Amphiprion ocellaris*, high nitrate levels (i.e., 100ppm) reduce growth of juveniles and delay metamorphosis of larvae with subsequent decline in growth and survival (Krom *et al.* 2001, Wu 1995, Lee and Jones 1990). Invertebrates such as corals may be especially affected. For example, the rate of skeleton building declined by up to 50% in corals exposed to 20ppm of nitrate (Frankes and Hoff 1982).

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Bacterial assimilation:

Through a series of oxidation and reduction processes (Frankes and Hoff 1982), bacterial biofilters break down organic pollutants into harmless gaseous N_2 and CO_2 (Figure 3.4 from Hargreaves 2003).

Abalone shells were used as bio-media for the aerobic biofilter, because of the low cost and high surface area for bacterial growth. Abalone shells are one of the waste products of the South African abalone aquaculture industry (pers obs). The utilisation of waste products can reduce the overall waste of the aquaculture industry. The bacterial biofilter consisted of six bags of abalone shells, placed in the second settling tank to maximise the surface area available for bacterial population.

Live rock:

Live rock is rock that has been collected from the coral reef which is encrusted with living organisms such as algae and other invertebrates. This rock forms the primary biological filtration of home marine aquaria, and performs a number of functions. Live rock contains both nitrifying (on the porous surface of the rock) and denitrifying bacteria (in the anaerobic centre of the rock). This is advantages because this type of filtration does not only reduce NH_3 /NH_4 and NO_2 (as in aerobic filtration) but also assimilates NO_3 (Figure 3.4). A total of approximately 100kg of live rock was used, 5kg in each brood stock tank and the rest was kept in the third settling tank.

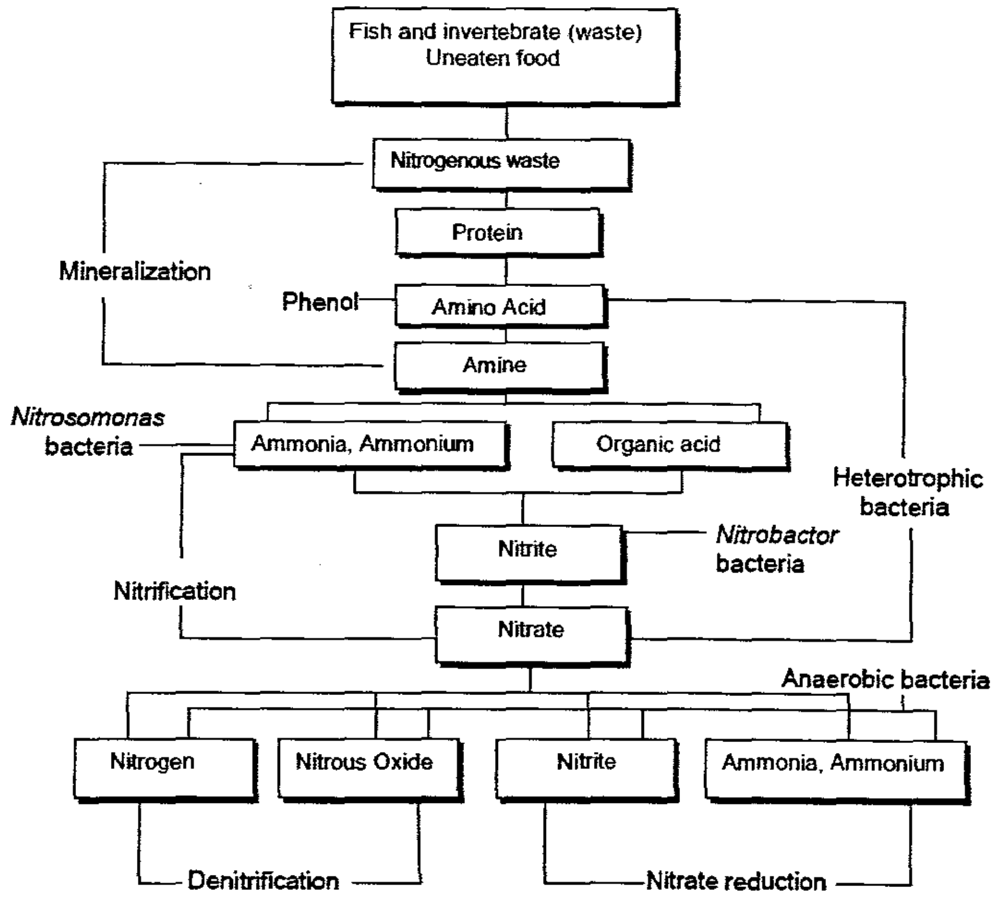

Figure 3.4: Biochemical reactions in a recirculating mariculture system (Hargreaves 2003)

3.3.3.3 Macro-algae system

Biofiltration by algae, are assimilative, and therefore increases the assimilative capacity of the environment for nutrients (Hargreaves 2003). With solar energy the excess nutrients (particularly C, N and P), plants are able to photosynthesize thereby creating new biomass. This operation recreates in the culture system a mini-ecosystem, wherein, if properly balanced, plant autotrophy can counter fish and microbial heterotrophy, not only with respect to nutrients but also with respect to pH, oxygen and CO_2 (Hargreaves 2006). Plant biofiltration can thus, in one step, greatly reduce the overall environmental impact of fish culture and stabilise the culture environment.

To make environmentally friendly aquaculture competitive, it is necessary to raise its revenues (Hirata *et al.* 1994, Rai *et al.* 2000). This can be achieved by increasing productivity per unit of feed, which, can account for almost half of production costs. The waste nutrients are considered in integrated aquaculture not as a burden but as a resource, for the auxiliary culture of commercially marketable algae (Losordo and Westerman 1994, Zucker and Anderson 1999). A culture system that diversifies its products by integration (polyculture) therefore makes much sense, not only economically but also ecologically (Neori *et al.* 2004).

Marketable biofilter organisms such as algae are essential to the commercial viability of integrated mariculture farms (Neori *et al.* 2004). The choice of macro algae species for inclusion in an integrated system depends upon meeting a number of basic criteria:

- high growth rate and tissue nitrogen concentration;
- ease of cultivation and control of life cycle and
- resistance to epiphytes.

Beyond these basic criteria, the choice of algae will be influenced by the intended application. An optimal system would include algae that incorporate both value and bioremediation (Neori *et al.* 2004). Growth rate is, to a large extent, defined by morphology (Neori *et al.* 2001) generally speaking, the higher the ratio of surface area to volume (SA/Vol), the faster the specific growth rate. Taking these criteria into consideration, *Caulerpa serrulata* was used as the algae of choice for the culture. The main factor for using this species was its marketability, which is the primary factor when considering the culture of ornamental macro algae.

3.3.3.4 Automated top-up system

The salinity in closed systems is not constant because the concentration of salts in the water increases with the increased evaporation. In order to replace this evaporated water and thus maintain the salinity at acceptable values, an automated top-up system was used. The salinity for most marine ornamental culture systems is maintained consistently between 33 and 35ppt (Hoff 1996). Instant Ocean Hatcheries which at the time was the largest closed cycle commercial marine tropical fish farm in the world, kept the salinity of their brood stock at 28ppt (Hoff 1996). The salinity of the system was kept relatively constant (28ppt +/- 2ppt), this was accomplished by using an electronic float-switch, RSF33W100RC (RS Components International), coupled to a pump situated in a fresh water reservoir. The salinity was kept slightly lower than the normal concentrations to decrease the salt costs for inland operations. The salinity was measured daily for the first two weeks and thereafter bi-weekly measurements were taken.

3.3.3.5 Electronic Temperature controller

Temperature affects almost all biochemical, physiological, and life history activities of fishes (Neori *et al.* 2004). Consequently, water temperature is a vital aspect of the aquatic habitat. Reliable and adequate temperature control methods are crucial to marine ornamental production, as many reef dwelling species are extremely intolerant to temperatures above or below a certain narrow range (Littler and Littler 1980). Most commercially important species are found in waters 10-20m deep (Abramovitch-Gottlib *et al.* 2002). At these depths, most tropical reef ecosystems are within a few degrees of 25°C on a year round basis (Watson and Hill 2006). An electronic temperature controller was designed and constructed to provide accurate control of both heating and cooling in one integrated unit. The original controller was designed by Richard Crossland from the United Kingdom. An updated version of the controller designed by Richard Crossland was constructed by the author and Reg De Toit from Radion Electronics. Commercially available controllers come at a significant cost. The controller used in this study was designed to be cost effective, simple to use and capable of accurate temperature control. Details on the construction of this controller are supplied in the text of this study, the knowledge of which is not required for its operation.

The main functions and specifications of the controller were:

- User definable set points for four outputs,
- User definable alarm output for over and under temperature values, with a kill lights function on high temperature alarm,
- A temperature range of 21.0 to 29.9 °C,
- A resolution and accuracy of 0.1 °C,
- Minimum and maximum temperature recorder,
- Temperatures and information displayed on a LCD matrix,
- A button control for menu and data entry

The operation settings were programmed as follows:

- Heating on at 24.9°C and off at 25.0 °C
- Cooling Fans on at 25.5 °C and off at 25.2 °C
- Chiller-unit on at 26.0 °C off at 25.2 °C (coolers should always switch off simultaneously)
- Alarm sounds if temperature goes below 24 °C or above 28.0 °C
- Lights1 on at 8:00 and off at 20:00
- Lights2 on at 10:00 and off at 20:00

The microchip and programme code

The original design incorporated the programmable microchip PIC16F873 which was superseded by the PIC16F873A, but to allow for future programming it was decided to use a PIC16F876A chip. Standard .HEX code was used for the chip, and was programmed using a standard programmer and Microchips MPLAB program suite.

Testing and Calibration

The controller unit made use of a 10k NTC bead thermistor from RS components. In order to test if the controller was working correctly, a 22k pot (potentiometer) was connected in place of the thermistor. The variable resister RV1 was adjusted fully anticlockwise, to show the best readable display on the LCD of the controller. The 22K pot was then adjusted, allowing for delay, and then the output voltage across pin: 2 of the PIC16F876A chip was measured. It measured 2.68 volts which was correct for the display temperature of 25°C.

In order to eliminate bias the 10k NTC bead thermistor was calibrated with an environmental data logger DrDAQ, which is manufactured by Pico Technologies®. The DrDAQ temperature probe was placed in a 25 litre bucket with a heater set at 24°C (Figure 3.5). The water inside the bucket was circulated using an airstone. Once the temperature stabilized a Crison MM40 high grade reference thermometer was used to check the accuracy of the DrDAQ temperature probe. This probe considered to be accurate to the second decimal place. Once this was completed the controller's thermister was placed inside the bucket (Figure 3.5). There are two variable resisters inside the controller, namely VR1 and VR2 (Figure 3.6). The VR2 was set to its midway point and the temperature displayed on the LCD screen was noted at 22.1°C (Figure 3.6), the actual/DrDAQ temperature was 28.7°C (Figure 3.7). The temperature was then set by turning VR2 clockwise (every full clockwise rotation increased the displayed temperature by 0.2°C) until the display read 28.7°C (Figure 3.7 and Figure 3.8). Once this was done the heater was set to 30°C and then removed. This was done to measure the accuracy of the controller over the range of 30°C down to 16°C (Figure 3.10). Over this range the thermistor showed no signs of deviation.

Figure 3.5: DrDAQ temperature probe was placed in a 25 litre bucket with a heater set at 24°C.

Figure 3.6: Variable resister VR2 was set to its midway point and the temperature displayed on the LCD screen was noted at 22.1°C

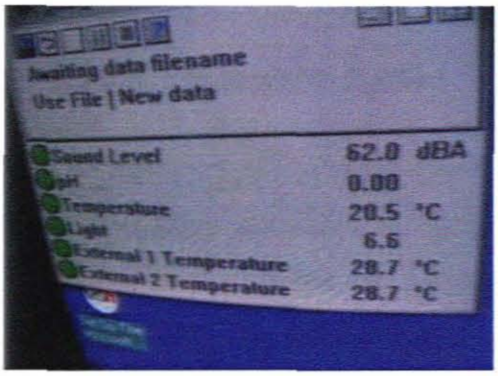

Figure 3.7: DrDAQ temperature indicated 28.7°C

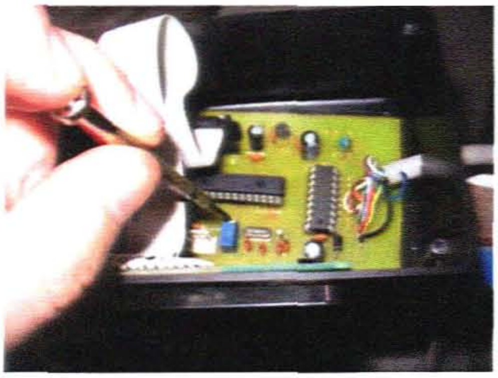

Figure 3.8: The temperature was then set by turning VR2 clockwise until the display read 28.7°C

Figure 3.9: The temperature of the controller measured the same as DrDAQ

Figure 3.10: The heater was set to 30°C and then removed, to measure the accuracy of the controller over the range of 30°C down to 16°C.

3.3.3.6 Foam fractionation

The continuous elimination of toxic metabolites and particulate matter is important in recirculating aquaculture systems (Watson and Hill 2006). Managing particulate matter and different chemical compounds is vital for the successful operation of recirculating aquaculture systems. The presence and accumulation of particulate wastes in recirculating aquaculture systems (faeces, uneaten feed, parasites, and bacterial flocks) can cause a decline in water quality that can increase stress to organisms being cultivated (Watson and Hill 2006). Foam fractionation is a water treatment technology that can be easily added to systems to directly remove dissolved and fine suspended solids. The process of foam fractionation, also known as flotation, protein skimming, or air stripping, has been described by Gregory and Zabel (1990), Lawson (1994), Timmons (1994), and Summerfelt (1999). The wastewater is passed downwards through a contact chamber (counter current). Bubbles produced with a venturi, near the bottom of the chamber move upwards against the wastewater flow (Brambilla *et al.* 2008). Surface-active particles become attached to these bubbles so that the density of the bubble–solid aggregates is lower than that of the water (Timmons 1994, Cripps and Bergheim 2000). They rise to the surface, the bubbles break, and the associated surface-active material is released as foam and discharged as waste (Brambilla *et al.* 2008).

A venturi driven protein skimmer was designed and manufactured at a fraction of the price of commercially available products.

The design used, was that of a counter current system. A counter current system increases the contact time of the air/water interface hence increasing the efficiency of the protein skimmer as well as increasing oxygen uptake. Ozone gas was used in the foam fractionator to remove fine organic particles (Brambilla *et al.* 2008). The ozone was generated by a HAILEA HLO-800 ozonizer and added via the venturi.

3.3 System parameters

3.3.1 Materials and methods

The system was stocked with 24 fish and 5 coral colonies that were imported from Singapore. Fish were fed twice daily on a diet of black mussel and aquanutro® until satiation. In order to access if the system could sustain the stocking density, NO_2, NO_3, NH_3, NH_4 and PO_4 were measured using Sera® test kits. The Sera® test kits show a certain colour, depending of the quantity NO_2, NO_3, NH_3, NH_4 or PO_4 in the test sample. By comparing the colour of the test solution with the colour chart provided, one can determine the concentration in mg/l. A Crison MM40 multi-meter was used to collect pH, conductivity, temperature and TDS data, while an Eclipse 45-65 refractometer was used to establish NaCl concentrations (ppt). All of the above mentioned data was collected between the 24th of May 2007 and 13th of July 2008, on a bi-weekly basis, excluding December 2007. A total of 32 measurements were taken in the time series from 24th May 2007 to 13th of July 2008.

3.3.2 Results

3.3.2.1 Temperature

The mean temperature of the system was 24.99°C (SD = 0.907), between the 24th of May 2007 and 13th of July 2008, excluding December 2007.

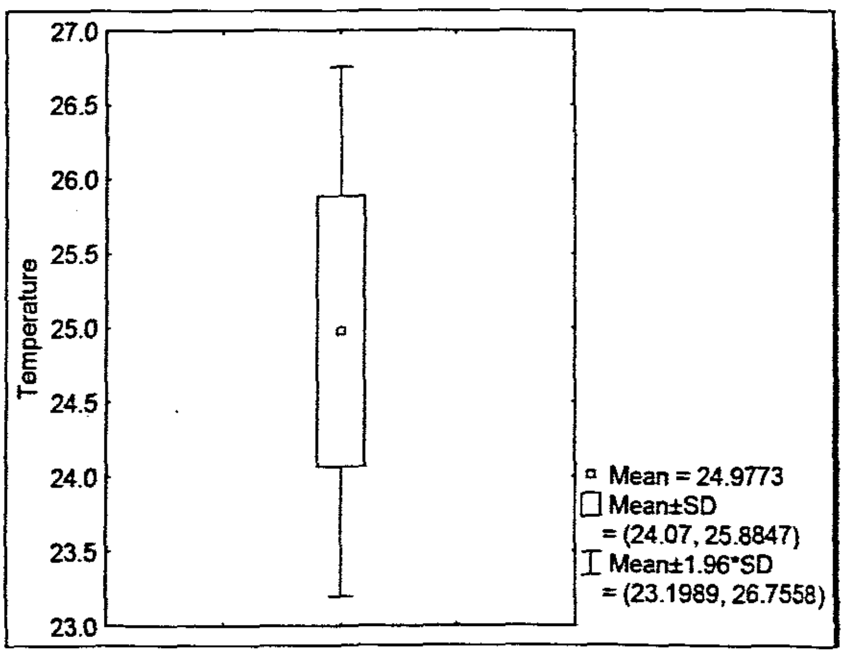

Figure 3.11: Box and whisker plot representing the mean temperature +- the standard deviation (0.907) and the mean +- the standard deviation (0.907) times 1.96.

3.3.2.2 pH

The mean pH of the system was 8.36 (SD = 0.093), between the 24th of May 2007 and 13th of July 2008, excluding December 2007.

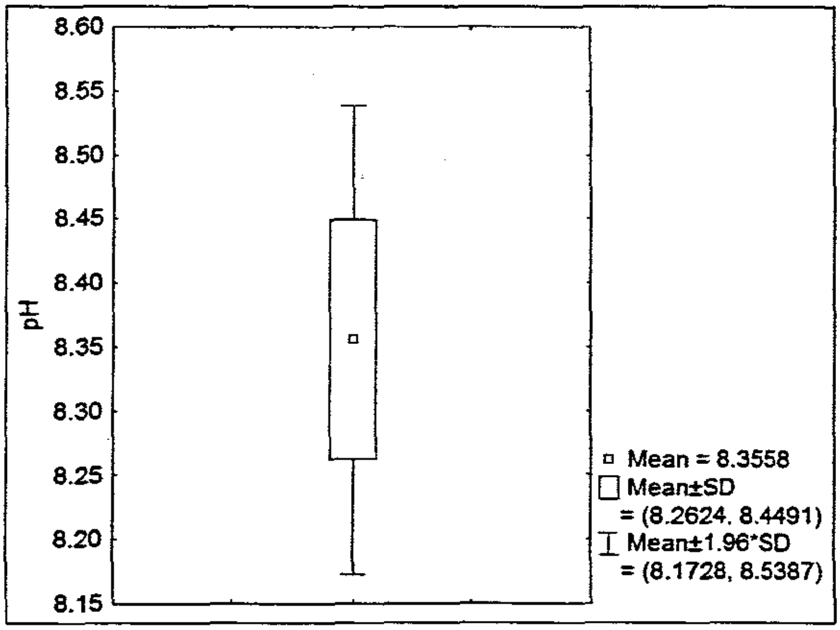

Figure 3.12: Box and whisker plot representing the mean pH +- the standard deviation (0.093) and the mean +- the standard deviation (0.093) times 1.96.

3.3.2.3 Salinity

The mean salinity of the system was 29.8 ppt. (parts per thousand) (SD = 7.341), between the 24th of May 2007 and 13th of July 2008, excluding December 2007.

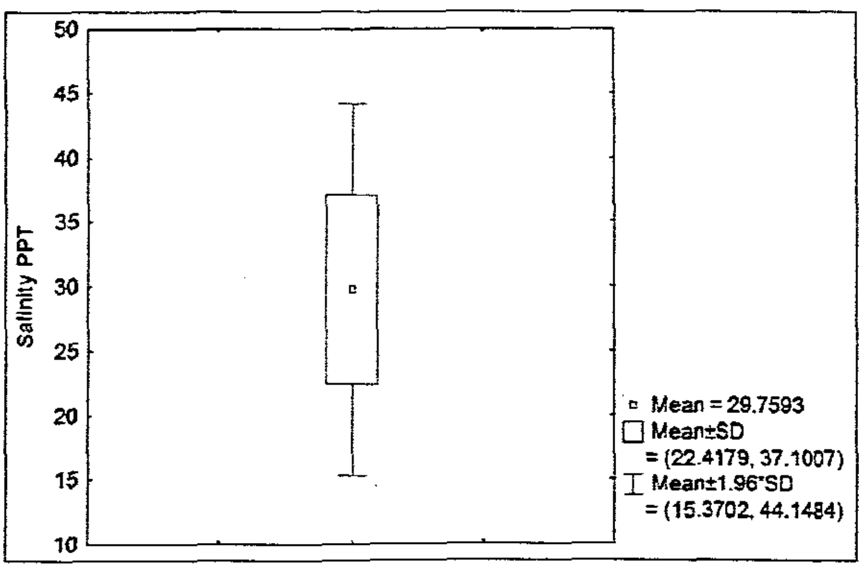

Figure 3.13: Box and whisker plot representing the mean salinity +- the standard deviation (7.341) and the mean +- the standard deviation (7.341) times 1.96.

3.3.2.4 Nitrogenous waste

During the cycle period of the system there was an increase in Ammonia and Nitrite concentrations to 0.25 ppm and 0.05 ppm respectively. There were zero measurable Nitrates or Phosphates during the period between the 24th of May 2007 and 13th of July 2008, excluding December 2007.

***Table 3.1*: Summery Statistics for Ammonia/Ammonium, Nitrite, Nitrate and Phosphate.**

	Valid N	Mean	Minimum	Maximum	Standard Deviation
Ammonia/Ammonium	113	0.039823	0.000000	0.250000	0.091895
Nitrite	113	0.011062	0.000000	0.050000	0.020846
Nitrate	113	0.000000	0.000000	0.000000	N/A
Phosphate	113	0.000000	0.000000	0.000000	N/A

3.3.3 Discussion

3.3.3.1 Temperature

Temperature affects almost all biochemical, physiological, and life history activities of fishes (Brambilla *et al.* 2008). Consequently, water temperature is a vital aspect of any aquaculture system. The system was controlled by an electronic temperature controller which was set to maintain the temperature at 25°C. The mean temperature of the system was 24.99°C, between the 24th of May 2007 and 13th of July 2008, excluding the month of December 2007 (Figure 3.11). This indicates that the controller was efficient at controlling the temperature of the system at the prescribed temperature.

3.3.3.2 pH

The controlling factor for pH in most aquaculture facilities is the relationship between algal photosynthesis, carbon dioxide (CO_2), and the bicarbonate ($HC0_3$-) buffering system:

$$CO_2 + H_2O \underset{\text{Sunlight}}{\overset{\text{Chlorophyll}}{\Leftrightarrow}} C_6H_{12}O_6 + O_2 \quad (1)$$

Equation 1

$$CO_2 + H_2O \Leftrightarrow H_2C0_3 \Leftrightarrow HC0_3^- + H^+ \quad (2)$$

Equation 2

At night, respiration by bacteria, plants, and brood stock organisms results in oxygen consumption and carbon dioxide production, the reaction in equation 2, goes from left to right, first producing carbonic acid (H_2C0_3), then bicarbonate $HC0_3$- and H^+ ions; the increase in H^+ causes the pH to drop. During sunlight, respiration continues, but algae use CO_2 for photosynthesis (Equation 1). To counteract the fluctuations in pH caused by the algae production in this system, abalone shells ($CaCO_3$) were used to buffer the water. The mean pH of the system was 8.36, between the 24th of May 2007 and 13th of July 2008, excluding the month of December. This is well within the ideal pH range for both fish and invertebrates (Tango and Gagnon 2003).

3.3.3.3 Salinity

The salinity for most marine ornamental culture systems is maintained consistently between 33 and 35 ppt (Abramovitch-Gottlib *et al.* 2002). The mean salinity of the system was 29.8 ppt, between the 24th of May 2007 and 13th of July 2008, excluding December 2007 (Figure 3.13). The salinity was kept at a slightly lower value because if artificial sea water is used, it can substantially decrease the operating costs as well as decrease the osmotic stress on brood stock organisms (Hargreaves 2003).

3.3.3.4 Nitrogenous waste and Phosphate

Water reuse is limited by the accumulation of waste products excreted by fish, such as, ammonia, nitrite, nitrate, carbon dioxide, and particulate and dissolved faecal solids (Avella *et al.* 2007, Figueiredo *et al.* 2008, Frankes and Hoff 1982, Hargreaves 2003, Hoff 1996, Calfo 2001, Abramovitch-Gottlib *et al.* 2002). Nitrate and phosphate levels accumulate in the water of recirculating systems as a result of biofiltration at a rate dependent on stocking density and water replacement rate (Hoff 1996). It is common practice to replace 10% of the volume of the system on a monthly basis to reduce the build up of nitrate and phosphate (Neori *et al.* 2004, Troell *et al.* 2003). This was however not necessary because both nitrate and phosphate concentrations remained zero throughout the duration of the experiment. Two 10% water replacements were done, to replace trace elements that are removed by the algae and coral within the system. On the 18th of June 2007, prior to stocking the system, a 10% water change was done and then another 10% water change on the 11th of January 2008.

3.4 Cost analysis

Small-scale systems should reflect appropriate levels of management intensity, complexity and capitalisation. The system in this study used low levels of management and low capital inputs. The system can be run by one person and there was no need for additional labour, which decreased the monthly expenses and hence increased the profit margin. This system was designed to operate at almost any location, and hence the land costs would be dependent on the location.

Pomeroy *et al.* (2006) highlighted that capital investment requirements and operating costs were too high for clownfish culture to provide a sufficient livelihood for rural communities. In 2006, Pomeroy *et al.* (2006) estimated the total equipment cost for small scale mariculture of *Amphiprion spp.* to be USD $5 915, this equates to approximately R47 320 ($1 = R8.00 @ 2006 exchange rate). In comparison the system of the current study, capable of culturing not only benthic-egg laying species like *Amphiprion spp.,* but corals and ornamental algae as well, cost R15 680.70 (Table 3.2) which is substantially less than Pomeroy's estimation.

Table 3.2: Equipment investment costs for a small-scale multi-species mariculture system

Equipment	Rands
Glass for aquariums	2022.94
Silicone sealant	52.16
Plumbing	1856.73
Electrical	2507.72
Metal for stands	779.98
Filter media	1
Lighting	4556.8
Foam fractionator	1505
Electronic controller	300
Top-up float switch	144.22
Supply pump	988.44
Heaters	210
Chiller	755.71
Total	**15680.7**

Table 3.3: Variable costs for a small-scale multi-species mariculture system

Variable cost		Monthly costs
Electricity	58.15 kWh/day @ R0.4738/kWh	R826.54
Water	+/- 80 l/day of evaporated water @ R3.33 /kl	R7.99
Feed	+/- 150g of black mussel/day @ R49,90 /kg	R224.55
Total		**R1059.80**

CHAPTER 4
AN INVESTIGATION OF THE EFFECTS OF PHOTOPERIOD ON THE CORAL *SINULARIA SP.*

4.1 Introduction

Coral reefs are one of the most productive, diverse, and complex ecosystems on earth (Hargreaves 2003, Hoff 1996). Human pressures on coral reefs are escalating at exceptional rates and spatial scales, and reefs are declining globally at an alarming rate (Pomeroy *et al.* 2006). There are numerous factors that contribute to the worldwide degradation of coral reefs (Hargreaves 2003). One of these factors is the global marine ornamental pet industry. The global trade in live corals was conservatively estimated at one million pieces annually and almost all (96%) of this came from wild populations (Villanueva *et al.* 2005, Forsman *et al.* 2006, Rhyne *et al.* 2005, Tanner 1995).

The aquaculture industry has the potential to make a valuable contribution to the sustainable use of these marine resources. Development of appropriate culture techniques for corals will reduce wild harvests and their negative environmental impacts on coral reefs (Schlacher *et al.* 2007).

In 1999 only 0.03% of corals traded for the marine ornamental industry were cultured (Green and Shirley 1999). There is a generally poor survival rate for propagated corals in aquaria (Schlacher *et al.* 2007). The high mortalities of cultured and captive corals have been attributed to poor knowledge about critical life history parameters and required culture conditions (Green and Shirley 1999).

The growth and survival of reef building corals are dependent on the ability of their intracellular symbiotic algae (zooxanthellae) to receive sufficient light for photosynthesis (Wabnitz *et al.* 2003, Green and Shirley 1999). Light is vital for the function of this symbiotic relationship, as the metabolic needs of the host are met by the translocation of high-energy photosynthesis from the algae (Calfo 2001). In addition, photosynthesis of the zooxanthellae provides energy for calcification and removes protons thereby resulting in light enhanced calcification of the coral (Kinzie *et al.* 1984). Therefore, the diel metabolism of corals are synchronised with the daily course of light intensities (Anthony and Hoegh-Guldberg 2003).

Lighting at suboptimal intensities, spectral composition or photoperiod can impair the metabolic efficiency of corals. Thus light may be a key factor for the poor survival of corals in captivity (Muscatine 1990, Muscatine 1980, Muscatine 1973). Detailed experimental studies on the effects of artificial light on the performance of corals in aquaria are however infrequent (Barnes and Chalker 1990, Barnes and Crossland 1982, Goreau 1963). There are even fewer published studies on the effects of photoperiod on coral growth.

There are a number of techniques used to measure coral growth: buoyant weight technique (Franzisket 1969, Falkowski *et al.* 1990), X-radiographs (Riddle and Olaizola 2002), skeletal linear extension (i.e. length changes) (Calfo 2001), wet weight technique (Abramovitch-Gottlib *et al.* 2002, Yap *et al.* 1998), dry weight technique (Carricart-Ganivet and Barnes 2007), , calcification (Schlacher *et al.* 2007, Tomascik 1990), density (Schlacher *et al.* 2007) and Alizarin red S staining (Goffredo and Lasker 2006). All of the above mentioned techniques require handling of coral, which causes stress (Houlbrèque *et al.* 2003).

A method that does not require handling of coral, is counting the number of proto-branches (Carricart-Ganivet 2004). This method is however not an accurate measurement of growth as coral can increase the basil and branch diameter without increasing the number of proto-branches. Another method that does not require handling of coral and hence does not stress coral, is the use of digital photographs to determine growth. This method was used by Nakamura and Yamasaki (2005) to measure growth of *Pocilloporid* corals while Forsman *et al.* (2006) used under water photographs to determine the growth of the corals *Porites lobata* and *P. compressa*.

Corals are ornamental species and are bought by the hobbyist based on appearance/size and not weight. Through digital imagery and computer analysis, the surface-area pixel value (SPV) for a particular coral can be determined. The increase/decrease of the surface-area pixel value over time thus measures an increase in surface area and thus apparent visual growth.

The objectives of this investigation were to:

- Determine whether different photoperiods (8:16 h and 12:12 h light/dark cycle) influence the growth rate of the coral *Sinularia sp.* and
- assess the approach of using computer analysis of digital images as a measurement of growth of *Sinularia sp.*

4.2 Materials and methods

4.2.1 Coral source and fragmentation

A single colony of *Sinularia sp.* (Figure 4.1) was imported from Singapore on the 20th of June 2007. The colony was fragmented on the 24th of March 2008, to ensure that the growth was not affected by stress caused by transportation and acclimation to captivity. Twelve fragments each consisting of no less than three branches on each stem (Figure 4.2), was attached to abalone shells using elastic bands until they self adhered to the shells (Figure 4.3). A "settling-in period" of two weeks was allowed before commencing with data acquisition.

Figure 4.1: Mother colony of *Sinularia sp.*

Figure 4.2: Fragmentation of colony

Figure 4.3: Attachment of colony

4.2.2. Experimental design

The twelve coral fragments were randomly split into two groups of six fragments ($Group_{12}$ and $Group_8$). These were kept in coral propagation tanks (200 cm long x 60 cm wide x 30 cm high). $Group_{12}$ was provided with a photoperiod of 12hrs light and 12hrs dark, while $Group_8$ was provided with a photoperiod of 8hrs light and 16hrs dark. Light was provided to each tank by two 70W Metal halide lamps (15 000 K) suspended 25cm from the water surface. These 70W Metal halide lamps (15 000 K) have a wide spectral distribution in the visible range (400 nm to 700 nm) with a peak at 454 nm.

Each coral fragment was secured 4cm away from the front pane of the tanks (to ensure a fixed focal length). Temperature, salinity (% NaCl), pH, NO_3, NO_2, NH_3/NH_4 and PO_4 was recorded bi-weekly throughout the duration of the experiment.

4.2.3 Wet weight technique

Once a month for three months, each coral fragment was lifted from the tank and excess water was removed from the abalone shell with a paper towel. Excess algal growth on the shell was removed using a fine haired toothbrush and paper towel. The weight of each individual fragment plus the shell was then measured to the nearest 0.01g using an electronic balance (RADWAG WLC 3/A2). The maximum time a fragment spent out of water was less than 2min. The growth rates of samples were calculated using the formula:

$$\mu = \left(\frac{m_1 - m_0}{m_0} \times \Delta T\right) \times 100$$ (Martin, Le Tissier 1988)

Equation 3

where, μ is the average growth rate measured in mg g^{-1} day^{-1}, m_0 is initial weight, m_1 is the weight at the end of the experiment, and ΔT is the number of days between the two measurements of weight (Schlacher *et al.* 2007).

4.2.4 Surface-area pixel value technique (SPV)

Each coral fragment was secured 4cm away from the front pane of the tanks, to ensure a fixed focal length. Web cams (iSonic IS-WOOI, 640x480 pixels) were mounted in front of each coral fragment, 1cm from the front pain of the tank (Figure 4.4). The coral was thus a total of 5cm from the camera. Photographs were taken of each coral fragment on a bi-weekly basis for a total of three months. Photographs were taken against a blue background to facilitate the isolation of images from the background.

Figure 4.4: Web cams (iSonic IS-WOOI, 640x480 pixel) mounted in front of each coral fragment

Commercial software was used for image analysis (Photoshop CS3 Extended®). An adaptive threshold was used to isolate the coral from the blue background. The image was converted to solid black and white and measurements were taken using the "record measurement" function that is offered on Photoshop CS3 Extended® (Figure 4.5). SPV, perimeter, circularity, height and width was recorded.

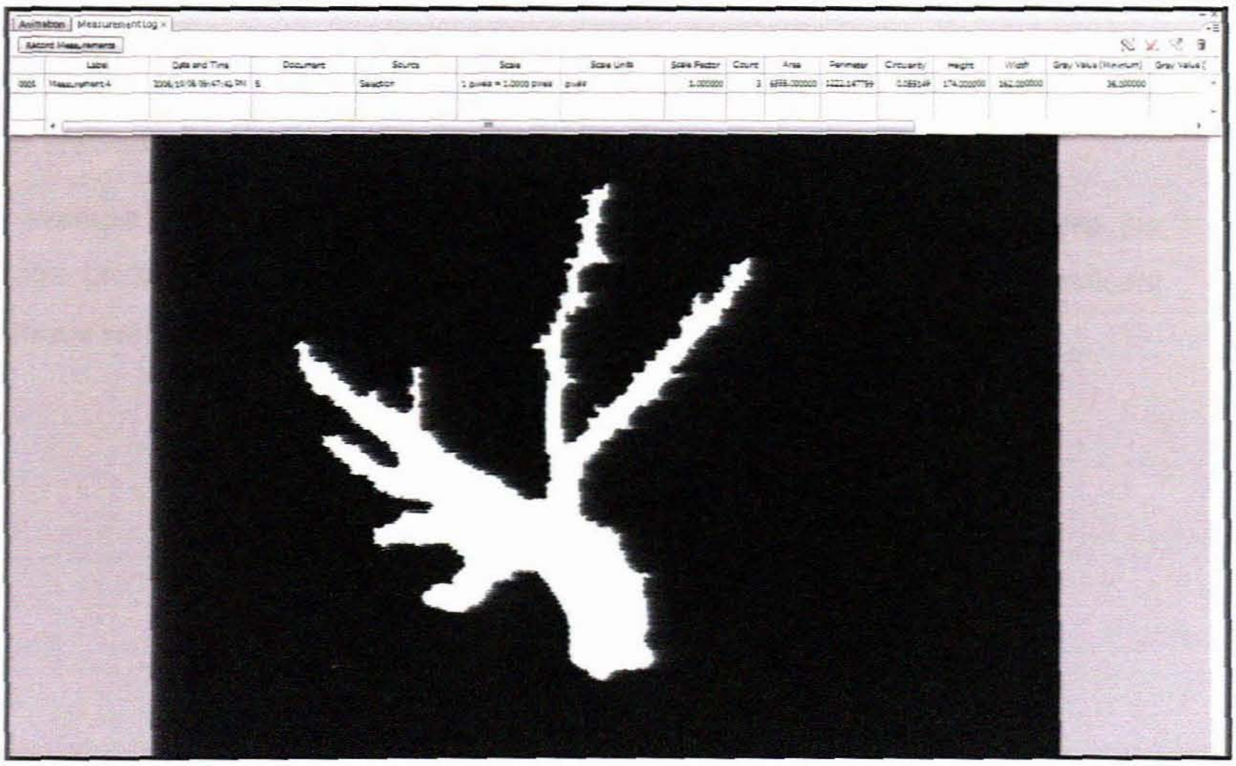

Figure 4.5: Surface-area Pixel Value (SPV) measurement in Photoshop CS3 Extended®

The SPV growth rate of samples were calculated using the formula:

$$\mu_{spv} = \left(\frac{p_1 - p_0}{p_0} \times \Delta T\right) \times 100$$ modified from (Lirman 2000)

Equation 4

where, μ_{spv} is the average growth rate measured in millipixels pixel^{-1} day^{-1}, p_0 is initial SPV, P_1 is the SPV at the end of the experiment, and ΔT is the number of days between the two measurements.

4.2.4 Data analysis

The raw data from both the wet-weight and SPV measurements were compared using a two tailed Student t-test. Both wet-weight and SPV data was normally distributed. Using SPSS the significant difference between the two photoperiods ($Group_8$ and $Group_{12}$) was calculated. Differences were considered significant at $p<0.05$.

4.3 Results

4.3.1 Wet-weight technique

The average growth rate for $Group_8$ was 0.60 mg g^{-1} day^{-1} (Table 4.1), while the average growth rate for $Group_{12}$ was 0.59 mg g^{-1} day^{-1}(Table 4.1). No significant difference was found between $Group_8$ and $Group_{12}$ (p-value = 0.97).

Table 4.1: Summary statistics for Wet-weight technique

Wet-weight growth data	
Average growth mg g^{-1} day^{-1} (8hours)	0.60
Standard Deviation (8 hours)	0.40
Count (8 hours)	18
Standard Error (8 hours)	0.09
Average growth mg g^{-1} day^{-1} (12hours)	0.59
Standard Deviation (12 hours)	1.41
Count (12 hours)	18
Standard Error (12 hours)	0.33
Pooled Standard Deviation	1.04
Degrees of freedom	34
t-value	0.03
p-value	0.97

4.3.2 Surface-area pixel value technique

The average SPV growth for $Group_8$ was 1996.73 millipixels $pixel^{-1}$ day^{-1}(Table 4.2), while the average SPV growth for $Group_{12}$ was 983.73 millipixels $pixel^{-1}$ day^{-1} (Table 4.1). A significant difference was found between $Group_8$ and $Group_{12}$ (p-value = 0.002). The average growth rate of $Group_8$ showed a higher growth than $Group_{12}$.

Table 4.2: Summary statistics for Surface-area pixel value technique

SPV (surface-area pixel value)	
Average SPV millipixels $pixel^{-1}$ day^{-1} (8hours)	1996.73
Standard Deviation (8 hours)	2352.66
Count (8 hours)	144
Standard Error (8 hours)	196.06
Average SPV millipixels $pixel^{-1}$ day^{-1} (12hours)	983.73
Standard Deviation (12 hours)	3164.26
Count (12 hours)	144
Standard Error (12 hours)	263.69
Pooled Standard Deviation	2788.15
Degrees of freedom	286
t-value	3.08
p-value	0.00225

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4.3.3 Water parameters

Temperature, salinity, pH, NO_3, NO_2, NH_3/NH_4 and PO_4 all were well within the ideal range (Hoff 1996) with a small standard deviation, for the duration of the experiment.

Table 4.3: Water quality during experiment period

Date	Temperature	salinity ppt	pH	NO^3	NO^2	NH^3/NH^4	PO^4
04-Apr-08	24.7	30	8.3	0	0	0	0
11-Apr-08	25.6	28	8.46	0	0	0	0
14-Apr-08	27.1	21	8.58	0	0	0	0
17-Apr-08	26.3	30	8.54	0	0	0	0
21-Apr-08	25	29	8.39	0	0	0	0
24-Apr-08	25	30	8.51	0	0	0	0
28-Apr-08	25.6	31	8.43	0	0	0	0
01-May-08	25.8	22	8.51	0	0	0	0
05-May-08	24.7	30	8.47	0	0	0	0
07-May-08	24.5	30	8.55	0	0	0	0
12-May-08	24.5	31	8.33	0	0	0	0
15-May-08	24.7	29	8.34	0	0	0	0
19-May-08	26.3	31	8.34	0	0	0	0
22-May-08	24.7	31	8.43	0	0	0	0
26-May-08	24.7	31	8.32	0	0	0	0
29-May-08	23.8	32	8.13	0	0	0	0
02-Jun-08	24.7	32	8.42	0	0	0	0
09-Jun-08	24.7	30	8.54	0	0	0	0
13-Jun-08	24.8	30	8.53	0	0	0	0
16-Jun-08	24.7	31	8.22	0	0	0	0
19-Jun-08	24.4	30	8.39	0	0	0	0
23-Jun-08	24.6	31	8.37	0	0	0	0
26-Jun-08	24.4	29	8.47	0	0	0	0
Average	**25.0**	**30**	**8.42**	**0**	**0**	**0**	**0**
Standard deviation	**0.76**	**2.71**	**0.11**	**NA**	**NA**	**NA**	**NA**

4.4 Discussion

The use of artificial lighting regimes in aquaculture comes at a financial cost. In order to estimate the potential yield of an aquaculture facility it is important to know the growth rate of the proposed species under farm conditions. Corals are ornamental species and are bought by the hobbyist based on appearance/size and not weight. It is important to determine the growth of a farmed product based on the parameters a buyer would use.

The measurement of wet-weights found that $Group_8$ and $Group_{12}$ grew at 0.60 mg g^{-1} day^{-1} and 0.59 mg g^{-1} day^{-1} respectively. No significant difference was found between $Group_8$ and $Group_{12}$ ($p = 0.975$). This would imply that the coral grew equally well under both lighting scenarios. However SPV analysis of growth found the there was a significantly increased ($p = 0.002$) growth rate in $Group_8$ (1996.73 millipixels $pixel^{-1}$ day^{-1}) compared to $Group_{12}$ (983.73 millipixels $pixel^{-1}$ day^{-1})

A substantial amount of the literature that deals with the effects of light on corals, used the standard recommendations of a 12:12 h light:dark cycle (Titlyanov *et al.* 2005). The results of this study would suggest, the use of an 8:16 h light:dark cycle may yield a significantly higher apparent visual growth.

It must be highlighted that the corals represented did not grow in terms of weight but in terms of surface area. This would be an index of coral expansion. Coral expand and contract under different environmental conditions. Light, flow and the presence of planktonic prey are the primary environmental factors that influence coral expansion (Titlyanov *et al.* 2005). Light and flow are dominant over prey presence (Titlyanov *et al.* 2005). There was no planktonic food available within the experiment system and the flow rate was kept constant. The only parameter that differed between the two groups was the photoperiod. Levy *et al.* (2001) found that maximum coral expansion occurred at low light intensities (0–40 µmol m^{-2} s^{-1}) Levy *et al.* (2001) however did not test the effects of photoperiod in coral expansion. The results represented in this study supports the fact that light is a governing factor on coral expansion, but not only in terms of intensity (Calfo 2001, Schlacher *et al.* 2007, Houlbrèque *et al.* 2003, Levy *et al.* 2006) but in terms of periodicity as well.

The increase in surface area/size of coral under a shorter photoperiod can thus relate to an increase in the marketability of the farmed product, as corals are ornamental species, and are bought by on appearance/size basis.

CHAPTER 5
CONCLUSIONS

According to Pomeroy *et al.* (2006) some forms of small-scale aquaculture of live coral reef organisms can be a useful solution to reducing pressures on coral reefs while being economically feasible. There were however a number of limiting factors that curbed the growth of small-scale producers, namely: high capital investment, high operating costs, access to markets, access to technology, technical capacity and operational management issues (Levy *et al.* 2001). This study aimed at addressing some of these issues by taking a holistic, multi-species approach to ornamental aquaculture. There were three groups of objectives for this study, namely: Market related objectives, system design related objectives and coral growth rate objectives.

From the market study, it was concluded that there was a substantial demand for marine ornamental organisms in South Africa. Between April and December 2007, five of the 18 companies who had import permits, imported a total of 359 different ornamental species, consisting of a total of 32 005 individual organisms.

The group of fish that represented the highest import volumes (38%) was the group *Amphiprion spp.* and *Pomacentradae spp.* (clowns and damsels). The most frequently imported group of invertebrate imported into South Africa, was coral, representing 51% of the total invertebrate imports. Within each of the above mentioned groups there was a high diversity of organisms, this implies that the South African market demands a variety of organisms. The market study has shown that the most abundantly imported fish and invertebrate groups are culturable species.

From the survey study it was established that there was a consumer preference for cultured species, 100% of the respondents of both the national and regional surveys indicated that they will be willing to pay more for aquacultured species. The amount that was indicated was between 10-35% more for aquacultured species. This is a positive result for small-scale aquaculture ventures as it increases the marketability of their product.

One of the major threats to aquaculture of marine ornamentals in South Africa is the low cost of imported wild fish (Oellermann 1999). If the consumer is willing to pay more for aquacultured organisms then this alleviates the competition between wild caught and aquacultured organisms.

The market study showed that the most abundantly imported species of fish were benthic egg-laying species and the most abundantly imported invertebrate group was corals. A multi-species mariculture system was designed and built to produce these species. This system was designed to minimise the capital and operating costs, through two mechanisms. Firstly by converting operation/ filtration costs into profit through the culture of commercially marketable algae. Secondly, minimise the capital costs through the development of small-scale aquaculture technologies that are feasible at a community level and cost efficient. To minimise the technical capacity and operational management, a cost effective electronic controller was designed to control parameters such as photoperiod and temperature.

The total capital costs of the system was R15 680.70 which is substantially less than the R47 320 capital, estimated by Pomeroy *et al.* (2006) for a small-scale aquaculture facility in the Philippines.

In order to estimate the potential yield of an aquaculture facility it is important to know the growth rate of the proposed species under farm conditions. The use of artificial lighting regimes in aquaculture comes at a financial cost and hence it is important to know what lighting scenario yields the highest growth rate.

Two photoperiods were tested, namely: $Group_8$ (8:16 h light:dark cycle) and $Group_{12}$ (12:12 h light:dark cycle). No significant difference in weight was found between $Group_8$ and $Group_{12}$ (p = 0.975). There was however a significant increased (p = 0.002) in SPV for $Group_8$ (1996.73 millipixels $pixel^{-1}$ day $^{-}$1) compared to $Group_{12}$ (983.73 millipixels $pixel^{-1}$ day $^{-1}$). The use of a 8:16 h light:dark cycle can thus yield coral of a larger size but not necessarily a higher weight. This can be an advantage to small-scale facilities as corals are bought on a size basis and not on a weight basis. By using a 8:16 h light:dark cycle the facility can substantially reduce the running costs of lighting.

The system proposed in this study has the potential to supply a large proportion of the local demand. The low capital and running costs, compact design and ease of operation make this system ideal for poverty relief programmes. This system can provide fisher communities with a valuable alternative income to wild harvest. As it is a closed system, it can be operated without the need of a salt water source, and can be used for inland projects.

Recommendations for future research

There are currently no accurate trade statistics on the marine ornamental industry in South Africa. Improved monitoring of imports and exports of marine ornamental organisms is needed to better understand the potential, growth and sustainability of this industry. Since there was only a limited amount of invoices supplied by the import companies to date, a longer term study would be advantageous once there is sufficient data available. In order to obtain this data MCM would need to be more stringent on the criteria for importation of marine ornamental organisms. Legislation would need to be established that prohibits companies to import organisms without providing invoices that highlight each species imported.

In order to establish the viability of small-scale marine ornamental culture, a study of comprehensive consumer preference is needed. Consumer outreach programmes to increase the demand for aquacultured products can help increase the marketability of such products. Price analysis of both production and consumption is needed to determine the viability of small-scale facilities. In order to obtain a larger data set from hobbyists a more aggressive approach would need to be taken. A competition where hobbyists could win a prise if they participated in the survey might increase the number of people participating in the survey.

A full-cycle feasibility study on this system would be an advantage. Production estimations of fish (number of fish per unit time), coral (growth in terms of SPV and weight) and algae (weight per unit time) would be advantageous for comparative and production reasons.

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APPENDICES

APPENDIX A:

Cape Peninsula
University of Technology

Contact: Jason Hayden
Tel: 084 551 8804 e-mail: nosajhay@yahoo.co.uk

Marine ornamental survey

A brief survey has been put together to assess the local **marine ornamental** sector from a hobbyist and retail perspective. Even if you are a "part-time" hobbyist, please complete the survey and pass it on to anyone else who keeps marine ornamentals in South Africa as the more completed surveys I receive, the more realistic the results will be. Your participation in this survey will contribute to a better understanding of the marine ornamental industry in South Africa. Details of all questionnaires will be kept confidential and not shown to anyone else so please feel free to supply any additional information you think may be of use in the survey.

The survey consists of two sections – hobbyist and retail. Please only complete the section(s) relevant to your interest in the marine ornamental sector.

Hobbyist survey

1) Where do you live (city)?...................................... Date: ....

2) Name (optional).. Age ..... Sex .....

3) How many years have you been keeping marine fish? ....

4) Do you have a valid permit to collect marine ornamentals? ....

5) What percentage of fish do you –

Catch yourself	%
Buy from petshop	%
Obtain from other hobbyists (caught locally)	%
Import directly yourself (if so, please ALSO complete industry survey)	%

6) How often do you go collecting ornamentals?
.... days a year.

7) Where do you usually collect from? Please provide a breakdown of the different areas (i.e. 20% Transkei (please be specific – i.e. coffee bay), 80% PE).......................................

8) What species (and numbers) have you collected this past 12 months

9) Have you successfully spawned and reared any marine ornamental fish. Please list species and average number reared per spawning.

Species	Number reared to juveniles (per spawning)

10) Have you successfully reared any marine ornamental invertebrate (corals, shrimps, nudibranchs etc). Please list species and average number reared per cutting/spawning – list corals only if you sell/cull/give-away excess.

Species	Number reared (per spawning)

11) If offered the choice, would you buy captive bred species rather than wild caught animals?
Yes... / No... / Indifferent...

12) If you answered yes to the above, would you be willing to pay more for captive bred animals?
No... / Yes... (up to what % more? ....)

13) How many marine aquaria do you currently have running? .... what are their sizes?
....

14) Do you start other aquaria during the summer months when fish can be collected? If so, how many?
....

15) Approximately, how much do you spend on marine livestock and equipment per year?

Livestock	R
Equipment	R

16) Are you a member of an active aquarium/aquarist club? If so, what club?
....

17) Do you buy aquarist magazines? If so how often ....and how much do you spend ....

Thanks very much for your time and input.

Please either a) email the completed questionnaire to nosajhay@yahoo.co.uk (when you save the file, please add your name to the beginning of the survey filename) or b) print it out and fax (021-531 2781).

Industry survey

ALL INFORMATION WILL BE KEPT CONFIDENTIAL

Date :..................

Your Name (optional) : .... Name of business (optional) ....

Location of business (city) .... Years in operation : ....

Would you mind if I contacted you? If not, please provide a phone number/email ....

1) Where does your business fit into the **marine ornamental** industry? If the business contributes to more than one, please indicate the percentage contribution of each

Retail only (petshop)	%
Wholesale (livestock)	%
Wholesale (equipment)	%
Commercial breeder	%
Aquarium installations	%
Maintenance contracts	%
Other (please specify)	%

2) What percentage of your **marine ornamental** income comprises of sales of

Marine livestock	%
Equipment for marine tanks	%
Other (please specify)	%

("Other" could be aquarium installations, aquarium maintenance etc)

3) In terms of percentages, what contributes to the cost of importing marine livestock items?

The livestock itself	%
Transport/shipping	%
Compensation for DOA livestock	%
Import duties/VAT	%
Other (please specify)	%

4) How often do you import marine livestock from
local wholesalers .... and/or overseas ....

5) How many active marine hobbyists do you estimate live in your city ....

Livestock

6) What percent of your average livestock order comprises of

Goldfish and koi	%
Freshwater tropical fish	%
Marine fish	%
Corals	%
Other invertebrates	%

7) Species and retail value of imported marine fish

Family	Approx number imported per year	Average retail value
Angelfish – pygmy's		
- others		
Damsels – clownfish		
- others		
Groupers – goldies		
- others		
Surgeonfish and tangs		
Butterflyfish		
Dottybacks		
Triggers, puffers, boxies		
Moorish idols		
Rabbitfish		
Gobies		
Scorpionfishes		
Wrasse, parrotfish		
Seahorses, pipefish		
Others – names please!		

8) Species of marine invertebrates

Family	Approx number imported per year	Average retail value
Soft corals – leathers		
- zooanthids		
- *Capnella* (Kenya coral tree)		
- star polyps (i.e., *Pachyclavularia*)		
- *Xenia*		
- mushrooms		
- other? Names		
Hard corals (names)		
Anemones – normal		
- *Cerianthus* (tube anemones)		
Molluscs – octopus, clams, limpets		
Crustaceans – shrimps, crabs		
Sea cucumbers		
Urchins		
Tubeworms		
Jellyfish		
Giant clams		
Other – names please!		

9) Where do you purchase your marines from? Please provide percentages for each country.

	Fish	Invertebrates
National wholesaler	%	%
Singapore	%	%
Sri Lanka	%	%
Fiji	%	%
USA	%	%
Kenya	%	%
Mocambique	%	%
Mauritius	%	%
Bali	%	%
Other – names please!	% ±100 %	% ±100 %

10) Have you ever imported/bought CITES listed organisms (i.e. hard corals, giant clams) without a permit?......
Yes ...... No

11) If yes, why?

I did not know a permit was required	
I occasionally only import a few items	
It is too much trouble to apply for the permit	
Other (please specify)	

12) If given the choice, do you preferably purchase captive bred marine species? ...Yes ... No

13) If not, why?

Too expensive	
Not available	
Inconsistent supply	
Other (please specify)	

14) If yes, what percent of your marine stock do captive-bred contribute (in terms of stock value)?

Fish	%
Corals	%
Other invertebrates	%

15) Where do you purchase your marine captive bred animals from?

Local (same city/province)	
National	
International – please provide countries	

16) Have you ever been offered locally caught marine fish or inverts to be sold in your shop? ....

17) If so, typically what species (species names if possible)

18) Is your business a member of an active aquarium/aquarist club? If so, what club?
....

19) Do you sell aquarist magazines? If so how many per month ....

20) Do you feel there is scope for a locally produced marine hobbyist magazine? ....

Thanks very much for your time and input.

Please either a) email the completed questionnaire to nosajhay@yahoo.co.uk (when you save the file, please add your name to the beginning of the survey filename) or b) print it out and fax (021-531 2781).

APPENDIX B: Quantities and prices of marine ornamentals imported into South Africa by the five companies that supplied invoices between April and December 2007

Species/group name	Total number imported	Price in Rands
Amphiprion and pomacentradae (clowns and damsels)		
Assorted unidentified Damsels	197	8.9
Assorted unidentified Clowns	113	22.02
Amphiprion akallopisos	101	11.71
Amphiprion clarkaii	347	22.02
Amphiprion allardi	120	22.02
Amphiprion sandaracinos / orange skunk clown	44	22.02
Amphiprion ephippium / fire or saddle clown	252	30.45
Amphiprion frenatus / red tomato clown medium	233	9.37
Amphiprion frenatus / red tomato clown large	6	9.37
Amphiprion polymnus / saddle back clown	267	27.18
Amphiprion melanopus / tomato clown	5	23.43
Amphiprion ocellaris / percula clown medium	1199	5.62
Amphiprion percula / indonesia red percula	431	35.61
Amphiprion percula / black percula clown	393	35.61
Amphiprion perideration / pink skunk clown	128	11.71
Amphiprion sebae / brown and white clown	25	22.02
Amphiprion xanthurus / black and white clown	25	22.02
Premnas biaculeatus / maroon clown	111	32.8
Abudefduf saxatilis sexifasciatus / sargeant major	5	6.18
Paraglyphidodon oxydon / neon or blue velvet damsel	20	10.78
Paraglyphidodon melas / blue fin damsel	16	6.56
Chrysipiera spp. / yellow tail blue damsel	727	8.43
Dascyllus aruanus / 3 stripes hamburg damsel	5	5.15
Dascyllus carneus / freckled white damsel	15	5.62
Dascyllus melanurus / 4 stripes or zebra damsel	214	5.62
Dascyllus trimaculatus / 3 spots or domino damsel	461	6.56
Pomacentrus vailu / local blue devil	6	8.9
Pomacentrus coeruleus / blue damsel	318	6.56
Pomacentrus alleni / electric blue damsel	34	8.9
Pomacentrus coelestis / yellow belly neon damsel	107	8.9
Chrysipiera cyanea / redtail blue damsel	132	15.93
Dascyllus and pomacentrus asst / assorted damsel	8	8.9
Chromis coeruleus - viridis / blue green damsel	1285	6.09
Chromis species / bicolor chromis	82	8.9
Premnas biaculeatus (golden maroon clown)	108	32.8
Chaetodontidae (Butterflyfish)		
Assorted unidentified Butterflies	23	28.35
Chaetodon auriga / threadfin butterfly	27	31.86
Chaetodon collaris / pakistani butterfly small	28	37.48
Chaetodon citrinellus / speckled butterfly medium	5	28.35

Chaetodon ephippium / black-blotch butterfly medium	23	56.22
Chaetodon facula / saddle butterfly medium	19	56.22
Chaetodon kleini / orange butterfly medium	9	28.35
Chaetodon lunula / red striped butterfly medium	19	81.99
Chaetodon melanotus / black backed butterfly medium	16	28.35
Chaetodon meyeri / meyers butterfly large	1	28.35
Chaetodon octofasciatus / eight banded butterfly medium	3	14.06
Chaetodon ornatissimus / ornate butterfly medium	3	51.54
Chaetodon punctato / dot-dasch butterfly small	9	30.92
*Chaetodon punc*tato / dot-dasch butterfly medium	2	38.65
Chaetodon rafflesii / latticed butterfly small	9	28.35
Chaetodon speculum / one spot yellow butterfly small	4	28.35
Chaetodon trifascialis / megaprotodon butterfly medium	10	28.35
Chaetodon trifasciatus / redfin butterfly medium	2	28.35
Chaetodon unimaculatus / one spot butterfly medium	13	28.35
Chaetodon vagabundus / vagabond butterfly medium	13	28.35
Chelmon rostratus / copperbanded butterfly	361	14.06
Forcipiger flavissimus / forceps / yellow long-nose butterfly	67	49.2
Parachaetodon ocellatus / ocellate butterfly small	4	42.64
Scorpaenidae (Scorpion and Lionfish)		
Dendrochinus brachypterus / scorpionfish	5	65.6
Dendrochinus zebra / zebra lionfish	28	42.17
Pterois antennata / spot-fin lionfish	31	42.17
Pterois miles / dwarf lionfish	10	30.45
Pterois radiata / white fin lionfish	3	30.45
Pterois volitan / peacock lionfish	39	46.85
Erosa erosa / scorpaena plumieri / stonefish	1	46.85
***Pomacanthidae* (Angelsfish)**		
Assorted unidentified Angels	137	128.85
Centropyge bicolor / bicolor pygmy angel	200	41.23
Centropyge acanthops	165	124.16
Centropyge bispinous / coral beauty or purple pygmy angel	184	35.14
Centropyge heraldi / golden pygmy angel	125	36.55
Centropyge multifasciatus / banded or stripe pygmy angel	133	124.16
Centropyge nox / midnight pygmy angel	6	124.16
Centropyge eibli / orange stripe pygmy angel	99	30.45
Centropyge ferrugatus / rusty pygmy angel	81	32.8
Centropyg e tibicen / melas or white spot pygmy angel	72	28.11
Centropyge vrolicki / half black pygmy angel	25	128.85
Centropyge lorculus / flame pygmy angel	153	220.21
Euxiphipop navarchus / blue girdled majestic angel	27	304.55
Euxiphipop xanthometapon / yellow faced angel	22	304.55
Euxiphipop sextriatus / six barred angel	4	128.85
Chaetodonoplus melanosoma / grey poma or black velvet angel	3	121.82
Chaetodonoplus mesoleucus / vermiculated or yellowtail angel	5	121.82
Genicanthus lemark / striped swallow lemark	3	121.82
Holocanthus venustus / venus or blue/yellow angel	7	149.93
Pygoplites diacanthus / royal empress or regal angel	35	234.27

Pomacanthus chrysurus	5	121.82
Pomacanthus annularis / blue ringed angel juvenile	3	121.82
Pomacanthus annularis / blue ringed angel adult colour	6	121.82
Pomacanthus imperator / emperor angel juvenile	61	121.82
Pomacanthus imperator / emperor angel adult	8	126.51
Pomacanthus semicirculatus / blue koran angel	2	126.51
Zanilidae **(Heniochus and Moorish idol)**		
Heniochus acuminatus / white bannerfish	54	58.57
Zanclus canescens / moorish idol	56	39.83
Platacidae **(Batfish)**		
Platax orbicularis / orbiculate batfish small	5	4.69
Platax tiera / batfish small	19	4.69
Assorted unidentified Batfish	30	4.69
Balistidae **(Triggerfish)**	6	30.45
Balistes undulatus / undulate trigger	41	163.99
Balistoides niger / conspicillum / clown trigger small	11	25.77
Melichxthys vidua / pink tailed trigger	1	25.77
Pseudobalistes fuscus / blue linned trigger medium	17	25.77
Rhineacanthus aculeatus / humu humu nuku nuku	2	25.77
Rhineacanthus rectangulus / picasso trigger	21	14.52
Odonus niger (queen trigger)	2	67.94
Sufflamen	11	70.28
Xanthichthys auromarginatus / blue face trigger	6	49.67
Assorted unidentified Triggers		
Canthigasteridae **and** ***tetraodontidae*** **(puffers)**	10	23.43
Assorted unidentified Puffers	5	23.43
Arothron nigropunctatus / dog puffer medium	3	23.43
Canthigaster coronate	26	23.43
Canthigaster solandri / sharp - nosed puffer	32	23.43
Canthigaster valentini / sharp-nosed puffer	5	37.48
Diodon hystrix / porpuninefish small		
Syngnathidae **(seahorse and pipefish)**	71	17.8
Dukercampus dactyliophorus / zebra banded pipefish	104	16.4
Pipefish spp	10	16.4
Hippocampus kuda / reddish seahorse	1	16.4
Syngathus specifer / ordinary pipefish		
Monacanthidae **(Filefish)**	15	39.83
Chaetodemis pencilligerus / tussel or hairy filefish small	5	39.83
Chaetodemis pencilligerus / tussel or hairy filefish xl	3	39.83
Pervagor spilosoma / fan-tailed filefish	10	19.68
Pervagor tomentosus / red-tailed filefish	31	28.11
Cryprinocirrhites aprinus / spotted hawkfish	56	159.3
Cryprinocirrhites polyactus / red hawkfish	21	28.11
Cryprinocirrhites species / skunk hawkfish	130	63.25

Oxycirrhitus typus / longnose hawkfish	4	18.74
Assorted unidentified Filefish		
***Acanthuridae* (Tangs and surgeonfish)**		
Assorted unidentified Tangs	64	163.99
Ctenochaetus hawaiiensis	6	491.96
Ctenochaetus tominiensis	25	135.88
Ctenochaetus marginatus	16	154.62
Acanthurus glaucopareius / yellow - rimmed black surgeon	2	60.91
Acanthurus japonicus / powder brown sugreon	35	60.91
Acanthurus leucosternon / powder blue surgeon small -med	15	70.28
Acanthurus lineatus / clown surgeon medium	36	70.28
Acanthurus olivascens / olive or shoulder tang	40	84.34
Acanthurus triostegus / convict tang	6	56.22
Acanthurus achilles / achilles tang medium	1	84.34
Acanthurus pyroferus chockolate surgeon	33	70.28
Acanthurus sohal / sohal tang large	15	84.34
Naso Spp.	120	67.94
Paracanthurus hepatus / blue tang	257	63.72
Zebrasoma scopas / xanthurus / brown tang	87	84.34
Zebrasoma rostratum	4	84.34
Zebrasoma veliferum / sailfin tang	94	163.99
Zebrasoma desjardinii / sailfin tang	52	71.69
Zebrasoma flavescens / hawaii yellow tang	441	140.56
Zebrasoma xanthurus / purple tang	5	140.56
***Lutjanidae* (Perches and Snapper)**		
Lutjanus sebae / emperor snapper large	1	61.85
Assorted unidentified Snapper	10	37.48
Assorted unidentified Grunts	5	32.8
***Labridae* (Wrasses and Birdfish)**		
Assorted unidentified Wrasses	182	51.54
Anampses coeruleopunctatus / blue green wrasse	19	15.46
Anampses meleagrides / ywellowtail spotted wrasse	23	41.23
Anampses twisti	22	15.46
Coris africanus	3	44.51
Coris gaimard / red labrid - adult - ordinary	45	44.51
Diproctacanthus xanthurus / local cleaner wrasse	5	15.46
Gomphosus coeruleus / green birdfish medium	18	72.62
Gomphosus varius / brown birdfish	26	30.92
Halichoeres iridis	180	9.37
Halichoeres chloropterus / green labrid	122	9.37
Halichoeres centiquadrus / marbled wrasse	27	19.35
Halichoeres melanochir / yellowtail wrasse	272	15.93
Hemigymnus melapterus / bicolor wrasse	65	15.46
Labroides bicolor / red / yellow doctor	2	30.92
Labroides dimidiatus / blue doctorfish	246	14.06
Labroides species / striped doctor	6	12.88
Macropharyngodon meleagris / leopard wrasse	48	14.06

Macropharyngodon species / green face parrotfish	5	15.46
Navaculichthys taeniourus / reindeer wrasse	32	23.19
Pseudocheilinus hexataenia / six - lined wrasse	372	17.8
Thalassoma lunare / lyretail wrasse	22	23.19
Thalassoma species / red stripe wrasse	5	12.88
Serradidae **(Groupers)**		
Assorted unidentified Groupers	8	84.34
Calloplesiops altivelis / comet or marine betta	74	163.99
Cephalopholis argus / spotted grouper	5	30.92
Cephalopholis miniata / red grouper	4	77.31
Chromileptes altivelis / panther or pokadot grouper	40	65.6
Siganidae (Rabbitfish)		
Lo magnifica / redfin foxface medium	76	149.93
Lo magnifica / redfin foxfaced large	8	149.93
Lo vulpinus / fox faced / long-nosed rabbit	221	44.51
Siganus java / spotted rabbitfish	22	15.46
Siganus oramin / lined rabbitfish	5	15.46
Siganus virgatus / masked rabbitfish	6	22.49
Siganus stellatus	1	15.46
Plectorhynchus **(Sweetlips)**		
Harlequin sweetlips	4	28.11
Plectorhynchus chaetodonides / clown sweetlips	13	28.11
Ple ctorhynchus pictus / painted sweetlips	2	28.35
Callyodontidae **and** ***Holocentridae*** **(Parrot and Squirrel)**		
Choerodon fasciata / harlequin tuskfish	2	163.99
Bolbmetapon bicolor / bicolor parrotfish	37	41.23
Scarus species / parrotfish	2	93.71
Assorted unidentified Squirrelfish	3	41.23
Assorted unidentified parrotfish	3	93.71
Carangidae **and** ***Mullidae*** **(Trevally and Goatfish)**		
Gnathanodon speciosus / golden trevally small	44	39.83
Upeneus tragula / common goatfish	7	17.8
Parapuneus cyclostomus / yellow goatfish	13	29.05
Gobidae **(Coral fishes and Blennies and Gobies)**		
Assorted unidentified Blennies	117	28.11
Assorted unidentified Gobies	451	11.71
Assorted unidentified Dragonets	8	28.11
Pterosynchiropus mandarin	252	31.86
Amblyeleotris spp.	4	11.71
Signigobius biocellatus	35	11.71
Salarias fasciatus	420	26.71
Aeoliscus strigatus / razorfish	50	7.03
Anthias pleurotaenia / square anthias	78	58.57
Anthias pleurotaenia / yellow anthias	17	36.55

Anthias squamipinnis / red lyretail coralfish	184	53.88
Anthias spp. / pink anthias	56	53.88
Anthias spp. / tiger queen anthias	35	53.88
Cryptocentrus cinctus / yellow goby large	42	12.88
Dactyloptena orientalis / scooter blenny	45	13.12
Meiacanthus kamoharai / stripped blenny	2	10.31
Meiacanthus smithi / eye-blow blenny	28	25.77
Gobiodon spp / coral gobies	2	11.71
Cryptocentrus spp. / watchman gobies	29	7.97
Elicanthus oceanups / neon goby small	75	7.73
Escenius bicolor / bicolor goby	30	17.8
Nemateleotris decora / flame goby	153	63.25
Nemateleotris magnificus / fire goby	349	27.18
Pseudochromis spp.	180	22.49
Pseudochromis diadema / skunk gramma	169	22.49
Pseudochromis pacagnellae / royal gramma dottyback	258	22.49
Pseudochromis porphyreus / purple gramma	103	22.49
Ptereleotris evides / scissortail / rocket	123	18.04
Synchiropus picturatus / spotted mandarin	84	31.86
Synchiropus splendidus / mandarin	43	45.92
Gramma loreto / royal gramma	30	22.49
Valenciannea strigata (white goby)	170	21.08
Valenciannea sexguttata	116	63.25
Valenciennea puellaris	16	23.43
Valenciennea strigata	8	21.08
Valenciennea fasciatus	17	23.43
***Ostraciontidae* (Box and Cowfish)**		
Lactoria cornuta / long-horned cowfish	11	36.55
Ostracion cubicus / ordinary spotted boxfish	34	27.18
Assorted unidentified Boxfish	21	36.55
Miscellaneous		
Apogon nematopterus / spotted cardinal	490	8.9
Pterapogon kauderni / banggai cardinal	824	32.8
Antennarius striatus / striped angler	4	30.92
Antennarius species / angler or sargassum	1	20.62
Bodianus anthioides / scissortail hogfish	7	154.62
Bodianus axillaris / coral hogfish	2	36.08
Bodianus mesothorax / bicolor hogfish	3	36.08
Marble catshark	4	56.22
Chiloscyllium species / baby banded dogfish	4	56.22
Echeneis naurates / remora	3	41.23
Echeneis nebulosa / snowflake moray eel	13	39.83
Rhinomuraena amboinensis / blue/yellow ribbon eel	2	93.71
Rhinomuraena quaesita / black ribbon eel	8	93.71
Honeycomb stingray	1	56.22
Taeniora lymma / blue spotted sting ray	12	56.22
Chiloscyllium species / shark egg	2	46.85
Chiloscyllium species / banded shark	10	56.22

Fishes from the great barrier reef		
Hemiscyllium ocellatum / epauletted shark large	3	56.22
***Coelenterata* (Sea anemones)**		
Assorted unidentified Anemone	193	46.85
Actina spp. /flower-sand anemone	15	46.85
Discosoma spp. / ordinary sea anemone	139	27.18
Radianthus malu / pink or purple sea anemone	116	42.17
Radianthus ritterei /purple foot sea anemone	80	25.77
Radianthus ritterei / brown foot long tentacle anemone	2	25.77
Radianthus spp.	178	32.8
Stoichactis haddoni / mushroon anemone (sticky tentacles)	2	18.04
Stoichactis giganteus / clownfish anemone sticky tentacles	9	20.62
Cerianthus membrananacens / tube anemones assorted colour	58	67
Cerianthus membrananacens / mini tube anemones assorted colour	4	67
Quadricolor bubble tip	171	30.45
***Hydrozoa* (Hard coral)**		
Acropora spp.	155	210.84
Heliofungia spp.	7	154.62
Fungia fungites / common plate l green	5	51.54
Euphyllia glabrescens / grape -torch branch	150	92.77
Euphyllia fimbriata / hammer head branch	5	82.46
Nemenzophyllia turbida / fox	5	128.85
Caulastrea frucato / finger button	150	103.08
Gonioporo lobarta / jewel polyps medium	5	85.04
Ptetogyra goniastrea / moon	150	51.54
Ptetogyra sinnosa / cat's eye bubble	5	77.31
Catalaphyllia jarinei / elegant polyps	5	154.62
Trachyphyllia diplora / brainl assorted colour	6	51.54
Trachyphyllia spp. / bali metallic green brain	13	103.08
Favia spp.	90	51.54
***Anthozona* (Soft coral)**		
Capnella spp.	10	30.45
Nephthea spp.	78	28.11
Kenyan tree	319	30.45
Clove poyps/ *clavularia spp.*	212	30.45
Ricordia spp.	222	23.43
Zoanthids spp.	10	21.08
Zoanthids spp.	705	21.08
Actinodiscus ass.	473	18.74
Actinodiscus spp. / green ordinary mushroom attached on rock	192	16.4
Actinodiscus spp. / green super mushroom attached on rock	13	16.4
Actinodiscui spp.s/ stripe mushroom attached on rock	4	20.62
Actinodiscus spp. / orange hairy mushroom attached on rock	2	20.62
Actinodiscus spp. / blue mushroom attached on rock	27	30.45
Actinodiscus spp. / red mushroom attached on rock	62	30.45

Anthelia spp. / local star polyps	87	23.43
Anthelia xenile / green star polyps Indonesia	34	23.43
Anthelia xenile / local xenile polyps(blue/brown)/plain xenia	120	23.43
Anthelia xenile/ pumping xenile polyps / xenia pumping	15	23.43
Annelid / koko worm - hard shell tube worm -white colour Indonesia	1176	7.03
Ephizoathus species / fine cauliflower or cabbage polyps	3	25.77
Carotalcycon sagamianum / super sea pen	28	21.08
Gorgonid spp. / live gorgonian in many colours	2	21.08
Lithophyton arboreum / tree shape soft finger polyps	211	28.11
Lemnalia	25	30.45
Lobophytum	329	18.74
Metridium senile / dendronephthya / color sea cauliflower	9	28.11
Rhodactis gigantea / elephant ear mushroom	56	30.45
Scleronephthya species / assorted	10	28.11
Sinulcria spp.	296	25.77
Sarcophyton spp. / soft leather - toadstool ordinary size	512	28.11
Gorgonid spp. / sea fans	447	21.08
Echinoidermata **(Starfishes)**		
Asteriocea spp. / common sand colour starfish	35	14.06
Asteriocea truncatus / red starfish small	206	23.43
Asteriocea spp. / knobbed starfish large	6	21.08
Crinoidea spp / feather starfish in many colours	5	15.46
Linckia laevigata / blue starfish large	212	21.08
Ophiuroidea spp. / brittle serpent starfish large	121	21.08
Ophiuroidea spp. / colored brittle serpent starfish large	4	21.08
Starfish mixed	27	21.08
Echinoidea **(Sea urchins)**		
Assorted unidentified Urchins	218	28.11
Sand dollar	60	15.46
Crustaceans		
Assorted unidentified Shrimp	6	21.08
Peppermint shrimp *lysmata rathbunae*	195	21.08
Lysmata amboinensis (cleaner shrimp)	548	21.08
Enoplometopus debelius / purple -majestic lobster	25	28.11
Hymenocera picta / harlequin or clown shrimp	12	70.28
Hippolysmata grahamii / painted skunk shrimp	10	33.5
Libia tessellata / pampan crab	9	18.04
Odontodactylus scyllaris / ordinary mantis shrimp	3	28.11
Periclimenes spp. / sexy shrimp	8	21.55
Periclimenes spp. / fire shrimp	205	83.4
Periclimenes brevicarpalis / small transparent shrimp	4	12.88
Panulirus dasypus / spiny blue lobster	2	28.11
Assorted unidentified Hermit crabs	870	7.03
Petrolisthes maculatus / anemone crabs	76	27.18
Rhynchocinetes species / dancing -camel-horse shrimp	183	10.31
Stenopushidpidus / boxing or banded coral shrimp	76	21.08

Eca spp. / small crab (red or blue colour)	20	21.08
Assorted unidentified crabs	3	21.08
***Prolifera* (Sponges)**		
Desmacidon spp. / tubular form sponges (blue/purple/black)	15	23.43
Halichlona spp. / encrusting form (red/yellow/green)	12	21.08
Halichlona spp. / orange fan sponges	4	21.08
Sponges mixed	12	21.08
***Mollusca* (Sea slug, Clams , Squids)**		
Tectus niloticus / turbo algae eating snail	1515	6.09
Bivalva spp. / flame scallop with red feeders small	8	9.28
Cyprea spp. / cowrie spp	17	9.37
Cyprea tigris / large tigris cowrie	1	30.92
Perna viridis /green oyster	19	33.5
Lima scabra / large red flame scallop	55	25.77
Nudibranch spp. / pokadot white sea hare	4	14.06
Nudibranch spp. / violet sea slug	2	14.06
Tridachia aplysia / sea hare pigeon without shell	1	14.06
Paracucumaria golden / mini yellow caterpillar cucumber	9	16.4
Paracucumaria tricolor /super cucumber or sea apple cucumber	12	28.11
Cephalopoda octopoda / ordinary octopus large	1	20.62
Tridacna clam /live colourful clam - metallic blue or green	10	113.39
Fighting conch	10	30.92
Marine algae		
Valonia fastigata / dark green plant soft	2	25.77
Caulerpa racemorsa / grape like form green	28	25.77
Caulerpa crassifolia / fern like form green	25	25.77
Rhodophycea spp. / grape like form red	10	25.77
Total	32005	16646.83