THE POTENTIAL OF ABALONE STOCK ENHANCEMENT IN THE EASTERN CAPE PROVINCE OF SOUTH AFRICA

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ABSTRACT

The largest abalone in South Africa, the perlemoen, *Haliotis midae*, occurs along approximately two-thirds of the country's coastline, but has only been the target of an extensive commercial fishery in the south-western part of South Africa. Large-scale illegal fishing has however proliferated throughout its entire range over the last 10–15 years, which has had serious effects on stock abundance and once productive populations are facing economic collapse. Abalone stock enhancement has been put forward as an addition or alternative to traditional fisheries management practices, which can potentially rehabilitate overfished abalone populations and enhance natural production. The aim of this project was to investigate the potential of abalone stock enhancement for managing an area in the Eastern Cape Province, which was being subjected to intense illegal fishing pressure. A research approach was adopted to investigate the scale and effects of this poaching and to investigate the survival of artificially cultured abalone seed in the natural environment. A model of a commercial-scale ranching operation was investigated to assess the economic feasibility of such a scheme.

Analysis of poaching cases and research samples from Cape Recife indicated high levels of fishing effort that appeared to be causing the observed declines in emergent abalone abundance and average size. Poaching cases from Cape Recife contributed 32% of the total number of cases of known origin in the Eastern Cape Province from 1998–2002, with the majority of the cases (82%) originating from within the Port Elizabeth metropole. There was an exponential increase in the number of poaching cases in the Eastern Cape Province (r^2=0.967) and Port Elizabeth over this period but actual annual total catch stabilized, particularly at Cape Recife, where estimates of CPUE declined significantly from 2000–2002 ($p<0.001$). The annual proportion of emergent abalone under the MLS from Cape Recife was always >85% in confiscations and research collections, and did not change significantly over the period of examination. Comparison of illegal catches with an adjacent site indicated that the emergent abalone population at Cape Recife had a significantly higher proportion of undersized emergent animals ($p<0.001$) and they were significantly smaller than the abalone from the closest site, Noordhoek, and other areas in Port Elizabeth from 2000–2002 ($p<0.001$). The apparent declines in emergent abalone abundance indicated by the poaching data were corroborated by sampling of emergent abalone abundance at Cape Recife. Numbers of abalone declined significantly from 125.6 to 53.8 per 20min count ($p<0.001$), from April 1998–October 2001 and density declined from 1.3 to 0.8m^{-2} over a similar period ($p<0.001$). Juvenile density did not change over this period, although there were significant differences in density observed between two different habitats ($p<0.001$).

Initial releases of cultured juvenile abalone showed that they could be distinguished from their wild counterparts for at least a year after release, by their different shell colouration. Short-term, small-scale trials (7–10 days) using animals between 17 and 30mm SL had mean survival rates of 64–82% (mean

70.4%) and the effect of size on survival was not significant in most cases, although the power to detect differences was low. Attempts to measure the effect of habitat on survival were not conclusive, although refuges under sea urchins appeared to be favoured by both seed and wild abalone, although urchins were not an absolute requirement for survival. Similar medium-term trials (31–74 days) in sheltered sites yielded mean returns of 53.1% using 25mm SL animals and similar trials in a more exposed area had more variable survival rates of between 18.4 and 73.6%, after 25–27 days. A comparison between careful hand-seeding and surface-scattering seed release methods in the open-ocean habitat showed no significant differences in survival rate after 41 days. Larger seed survived significantly better than the smaller seed when scattered on the surface ($p<0.0001$) and the smaller seed survived significantly better when seeded carefully by hand onto the substrate ($p<0.028$). Further medium-term releases of large numbers of seed abalone, released using the surface-scattering method in open-ocean habitat, gave mean survival rates of 32.8% over periods of 83–114 days. Assessment of a seeding trial using release modules to seed juvenile animals in the open-ocean was hampered by poor sea conditions and difficult to search substrates, and a mean recovery rate of 3.1% was obtained for the sites that were sampled. Movement of seed was low in the more sheltered sites, and also appeared to be affected by the amount of available habitat. Growth of seed was measured using changes in shell colouration and there were significant differences between areas. An average growth of 1.6mm.month^{-1} shell length was calculated for all areas.

The potential for commercial scale abalone ranching to be used to enhance a territorial user right fishery was investigated using a model of economic feasibility. Internal rates of return of 30.3 and 36.9% were obtained from two harvest regimes using different harvest sizes. There was a high degree of risk associated with these figures owing to a lack of consistent seed survival rate estimates, and the input parameters, which are subject to variation, showed a significant effect on profitability. The operation of this type of ranching scheme is probably not economically feasible as a stand-alone operation but could probably be operated effectively in conjunction with an existing abalone farm. By adding a small wild catch component the profitability of a ranching scheme could be significantly improved.

The results of the present study indicate that high levels of poaching at Cape Recife have led to declines in emergent abalone abundance, which will probably lead to stock collapse in the near future. This implies that fisheries managers have failed to fulfil the provisions of fisheries policy in South Africa. The present results from seeding trials show that cultured juveniles can survive and make a contribution to overall stock abundance. Furthermore, while there are obstacles to economic feasibility, commercial ranching has the potential to be a valuable addition to current abalone management strategy.

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And lastly, thanks to my brothers for the support and especially my parents, who laid the platform and provided the means for my education. Mom, I’m sorry you cannot be here to share this with me, but my thoughts are with you always.

Dedicated to my Parents

CONTENTS

CHAPTER 1

GENERAL INTRODUCTION

The South African abalone, *Haliotis midae*, or perlemoen as it is known locally, is one of the most important commercial species worldwide. It is the only one of six endemic South African Haliotids which is exploited on a commercial scale and an organized fishery has existed for over 50 years (Newman 1969, Tarr 1992). Its flesh is highly sought after in the Far East where the major markets for abalone products exist (Oakes and Ponte 1996, Cook 2000). Its documented natural range is between Cape Columbine on the west coast of South Africa to Port St. Johns, on the east coast (Figure 1.1, Muller 1984), although Fielding (1995) found no evidence of them occurring north of the Mbashe River mouth in his survey performed more recently.

Fisheries for abalone have existed globally for millennia (Siegfried *et al.* 1985, Sloan and Breen 1988) but it was only in the last quarter of the 20th century that declining catches began to cause concern amongst fisheries managers (Shepherd *et al.* 1992, Gorfine 2002). Abalone natural history makes them highly susceptible to over-fishing (Tegner and Butler 1989). Although they are capable of moving significant distances (Newman 1966), they have a largely sedentary mode of living probably only moving when forced to by space, food limitations or disturbance (Tarr 1995). They also generally live in shallow water, close to the shoreline where their algal food is most commonly available, and thus their natural distribution is unlikely to change rapidly, making them a predictable target. The larger more sought after individuals aggregate in high density beds thought to be associated with spawning behaviour (Newman 1967b, Shepherd 1986), or possibly in response to food availability or other environmental factors (Tarr 2000). This means that the largest, most fecund individuals are the first to be targeted by fishermen. In addition, their broadcast spawning behaviour and subsequent planktonic larval stage is highly vulnerable to the vagaries of the environment making recruitment unpredictable (Tegner and Butler 1989, McShane 1996, Sasaki and Shepherd 1996). In South Africa, a threat to the *H. midae* fishery in the Hermanus/Walker Bay region has been posed by an influx of the rock lobster, *Jasus lalandii*, which has denuded certain areas of the sea urchins that provide shelter for the juvenile abalone (Tarr *et al.* 1996). Finally, their susceptibility to recruit-overfishing ensures that they are under constant threat. An increase in demand resulting in increased fishing effort must however be seen as the underlying cause for the decline of most abalone fisheries. Fisheries managers have responded by reducing the take of abalone in many fisheries and in some cases resorted to a complete ban on fishing activities (Tarr 1992, McCormick *et al.* 1994).

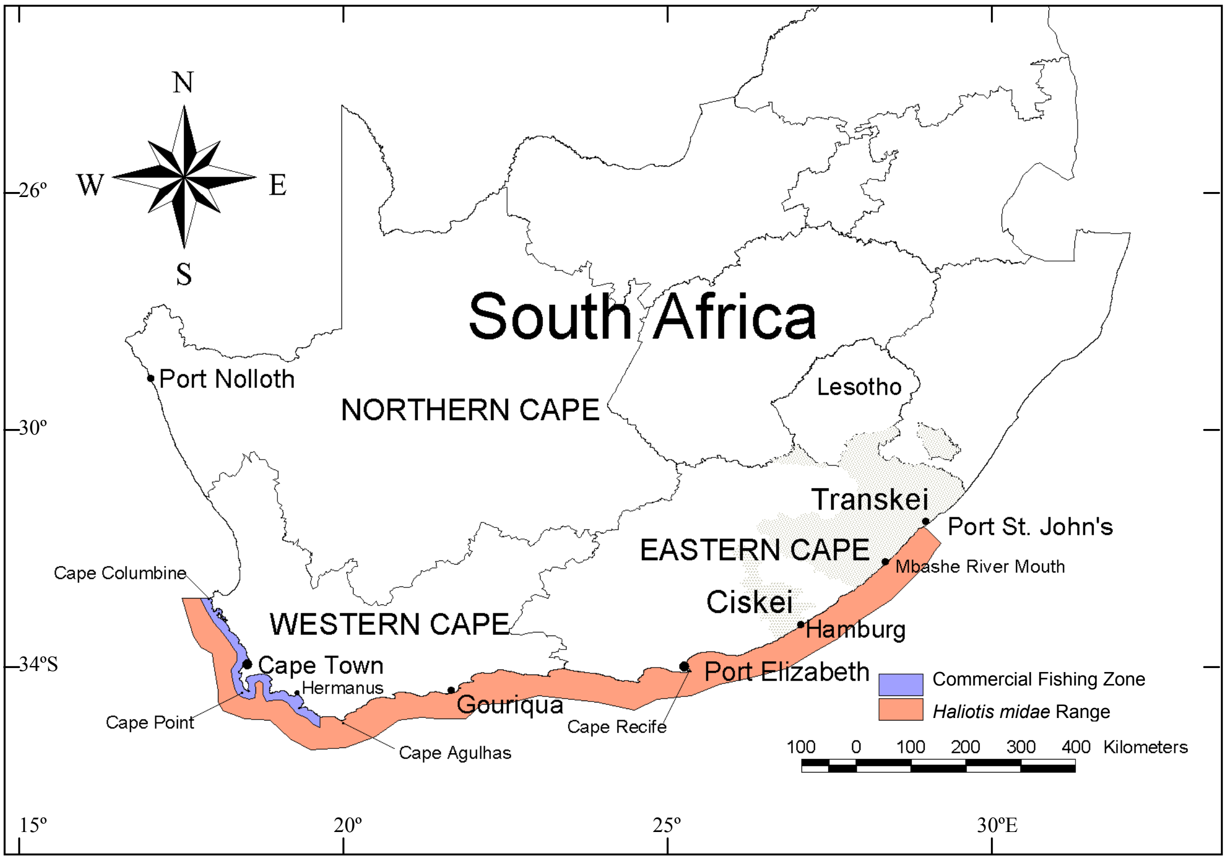

Figure 1.1 **A map of South Africa with provinces outlined, showing the range of *H. midae* and the commercial fishing zone in the south-western Cape.**

A summary of the scientific work done on natural *H. midae* biology highlights the paucity of knowledge on this species and in particular those populations found outside of the south-western Cape commercial fishing grounds. Newman (1966) initiated work on *H. midae's* ecology when he described its movement, differences in productivity related to distribution (Newman 1969), and growth (Newman 1968). Most of this work was performed in the south-western Cape near Cape Town. He also published a review of the state of abalone research in South Africa (Newman 1967a). Barkai and Griffiths (1986, 1987) subsequently published two studies that investigated dietary intake, consumption, absorption efficiency, respiration and excretion of *H. midae*. They later calculated an energy budget for this species (Barkai and Griffiths 1988). Tarr (1987) published a popular overview of *H. midae* biology and its fishery, followed by a comprehensive review of the fisheries history, status and prospects (Tarr 1992). Tarr (1993) then completed a stock assessment for *H. midae* in the main fishing grounds in the south-western Cape, which included other aspects of *H. midae* biology. This study incorporated a survey of an isolated population at Bird Island in the Eastern Cape Province (Tarr 1986). At the same time, Wood (1993) completed a study on aspects of the biology and ecology of *H. midae* in the Eastern Cape Province (Wood and Buxton 1996a, 1996b). Further work by Tarr (1995) questioned previous work showing slower growth rates for *H. midae* in the south-western Cape compared to the Eastern Cape Province, as well as the high rates of movement calculated by Newman (1966). Fielding (1995) confirmed Wood's (1993) finding that *H. midae* in the Eastern Cape Province matures at a smaller size than their south-western Cape conspecifics. On the basis of yield- and egg-per-recruit modelling Fielding (1995) concluded that the Transkei stocks had a limited potential for exploitation. A possible link between the reduction in the number of the sea urchin, *Parechinus angulosus* and a decrease in numbers of juvenile *H. midae* in the most productive commercial fishing grounds, following an influx of rock lobster *Jasus lalandii*, was noted by Tarr *et al.* (1996). This association was further studied by Day (1998) and, Day and Branch (2000a) who suggested that juvenile *H. midae* are in fact dependant on the presence of *Parechinus angulosus*. They postulated that this dependency has important implications for the well being of the commercial fishery. Tarr (2000) once again reviewed the fishery as a whole, and Dichmont *et al.* (2000) discussed the modelling of *H. midae* abundance.

Although the distribution of H. *midae* encompasses at least 1500 kilometres of coastline, Newman (1969) observed as early as the 1960s that there were differences in the "productivity" of the stock, as measured by commercial catches, which he ascribed mainly to mean annual temperature differences within the range. Three separate yet adjacent areas were identified in terms of the exploitation rates of the species, with the changeover points occurring at Cape Point and Cape Agulhas (Figure 1.1). More recently Sweijd (1999) documented a "major genetic discontinuity" at Cape Agulhas which is also seen as an important biogeographic boundary separating the South African coastline into the "East" and "West" Coasts. Importantly, the *H. midae* populations in the Eastern Cape Province are considered to be patchily distributed (Wood 1993), which is almost certainly dictated by the availability of suitable substrate. The length of the Eastern Cape Province coastline, poor access to many parts and unpredictable sea conditions also make diving surveys difficult to perform (Tarr 2000). The centralized nature of government fisheries administration and research facilities, which are situated in the south-western Cape, its focus on the commercial fishery combined with a lack of funding and manpower has resulted in research effort being concentrated in this area. These circumstances were further complicated by the political dispensation that existed in South Africa prior to 1994, which saw quasi-independent countries being formed within the present boundaries of South Africa. These countries administered their own resources including their fisheries. Two of these “Independent Homelands”, The Republic of Ciskei and The Republic of Transkei, were situated along the present coastline of the Eastern Cape Province (see Figure 1.1) and their combined coastlines constituted a significant amount of the total known available abalone habitat. These contrasts, combined with the paucity of scientific data, particularly on the distribution and abundance of East Coast populations, has resulted in differences developing between the two areas with respect to the commercial and recreational exploitation rates, and the management of the resource.

The commercial fishery in the south-western Cape (see Figure 1.1), where the resource is associated with extensive kelp beds, has been in existence since 1949 (Newman 1964, in Tarr 2000) and is characterized by high catch rates and strict regulation. A minimum size limit of 11.43cm shell breadth was implemented in 1954 but otherwise unlimited fishing was initially allowed and catches peaked in 1965 with a total catch of 2800t (Tarr 1992, 1993). After the implementation of a production quota in 1970 and subsequently a management quota (TAC) in 1983, the resource was considered to be well managed and sustainable and as recently as 1992 an appraisal of the fishery suggested a positive future (Tarr 1992). Annual catches remained relatively stable around the 600t.year^{-1} mark until the 1996/1997 season. In the Eastern Cape Province, two small commercial fisheries developed. A “quasi-legal” fishery operated in the Republic of the Transkei from 1988–1991 and catches of over 50t.year^{-1} were reported for a few years (Cook 1992, Pers. Comm. Muller, Marine Growers (Pty.) Ltd., 2000). The official catch statistics indicated lower returns, but this was interpreted by Fielding *et al.* (1994) as a means to reduce licence fees by the fishermen, which were calculated on the previous years catch. A small experimental fishery (3t TAC) was also initiated during 1992 near Hamburg, in the Ciskei (Tarr 2000). Following recommendations by Wood (1993) a reduced size limit of 100mm shell breadth was set for this fishery, because of a smaller age at maturation and smaller maximum size compared to the south-western Cape. This fishery continued operating after the Republic of the Ciskei was reintegrated into South Africa. In the mid-1990s the issuing of further experimental quotas in the Eastern Cape Province was mooted, but subsequently shelved after the extent of illegal fishing became apparent (Tarr 2000).

Recreational exploitation rates also differ sharply between the two areas although the size (11.43cm shell breadth) and daily bag limits remain the same. Telephonic surveys revealed that in the 1993–1994 season recreational fishers accounted for 548t of *H. midae* in the south-western Cape, whereas annual recreational catches have been estimated at 13t.year^{-1} in the Eastern Cape Province (Tarr 2000).

THREATS TO THE RESOURCE

Although the outlook for the commercial fishery in the south-western Cape was considered good until fairly recently, subsequent biological and socio-political events have led to changes in resource use and availability of abalone throughout South Africa. The reasons behind these changes can be separated into three main issues: 1) An influx of rock lobster occurred in the two traditionally most productive commercial fishing sectors (see above, Tarr *et al.* 1996); 2) the previously unquantified effort levels of recreational divers became better understood (Pers. Comm., A. Mackenzie, MCM, 1995, Tarr 2000) and; 3) illegal fishing became a significant feature of *H. midae* resource utilization throughout its range. This has forced fisheries managers to reassess the state of the resource (Tarr 2000) and has led to significant changes to the management of the fishery as a whole. The previously unquantified impact of recreational divers on the resource was elucidated after comprehensive telephonic polls were conducted. These gave annual recreational catch estimates of 400–550t which was nearly the yield of the commercial fishery (see Moore 1982, Tegner and Butler 1989). This led to measures being implemented to limit the recreational take and this philosophy culminated in a recreational “target” TAC being set in the 1998/1999 season. Progressively tighter restrictions have since been placed on recreational fishers to make available a proportion of this TAC for new entrants from previously disadvantaged communities into the commercial fishery. The ecological shift that was observed in the two traditionally most productive commercial fishing sectors is believed to have led to an increase in the mortality of juvenile *H. midae* (Day 1998, Tarr 2000, Day and Branch 2000a, Day and Branch 2000b). Since *Jasus lalandii* does not occur in large numbers on the east coast of South Africa and recreational catches are low in the Eastern Cape Province, these two factors were only relevant in the south-western Cape. The third and probably most important influence, that of illegal fishing or poaching, has had potentially dire consequences for the *H. midae* resource throughout its range. Accounts of poaching activities have become a weekly feature in the national press (*e.g.* Figure 1.2, TML 1998), and a recent newspaper report suggests that national government is contemplating a complete ban on all forms of abalone diving (Gosling 2002).

Police, residents, hamstrung by legalities, can only watch helplessly as divers plunder r

Brazen poachers

Herald Reporters

IN a brazen act of defiance, perlemoen poachers were back in the water at Schoenmakerskop yesterday despite mounting public outrage and the arrest of Springbok Chad Alcock's brother.

And even as the divers were bobbing in the sea off the picturesque coastal village, many of its angry residents were waving placards outside Louis le Grange Square in Port Elizabeth to protest against the continued "rape" of the coast.

Yesterday's protest followed a day of high drama on Tuesday in which police seized 400kg of perlemoen at a Kwazakhele butchery and arrested Brett Alcock, 28, elder brother of the Springbok scrumhalf.

Now a 30-man task force has been set up to crack down on the poachers who are waging a reign of terror, threatening to kill local residents and even a top policeman who is investigating their racket.

The brazen attitude of the poachers was demonstrated by several divers who were at Brett Alcock's bail hearing yesterday. They approached a Herald staffer and told him they were working together with the police in their illegal activities and that they would be back in the water soon.

And when a Herald investigation team went to Schoenies yesterday afternoon — this turned out to be exactly the case.

Several of the same vehicles used by the poachers the previous day were in the car park. Six men were photographed diving off the reef at the eastern edge of the village.

These photographs — taken with a doubled-up 800mm lens — are the first reasonably close-up images of the gang.

But police and fuming residents were forced to watch them from the shore because they are hamstrung by the law.

Police are compelled to catch the suspects with the shellfish in their possession.

But the divers do not leave the water with their booty. They store their mesh bags containing perlemoen underwater, to be retrieved at night.

The Herald took a photograph of another man — almost certainly a member of the gang — carrying a mesh bag over the rocks. But police who confronted him covered it containe clothes.

A police spokesman c yesterday that no action possible against ye divers but indicated th was planned.

The officer — who nerves are shot as he identified by the gang and his life — is a key memb anti-perlemoen poaching task force that was fo Tuesday.

"I have three plans th put into action to trap th But we're taking it step he said.

The poaching gangs tremely sophisticated, working with ce night-sight binoculars an of vehicles, some of wh used for reconnaissan many of which were hire tracing.

"They use safe houses get the perlemoen out of try either dried, canned The end destination is

BUSINESS AS USUAL . . . The brazen perlemoen poachers returned to work on the reef at Schoenmakerskop early yesterday despite a growing outcry over their presence.

Brazen defiance – Editorial comment on Page 4

Figure 1.2 An excerpt from an Eastern Province Herald headline story (November 12, 1998).

The major increase in the abalone poaching phenomenon in South Africa has been exacerbated by the profound socio-political changes that saw South Africa hold its first democratic elections in 1994 (Hutton *et al.* 1997, Tarr 2000). The issue has been the subject of much debate, and in a bid to find workable solutions, serious attempts have been made to determine its root causes (Hauck 1997, Hauck and Sweijd 1999, Hauck 1999). Three main themes emerged from these studies into why people became involved in poaching, *viz.* "need, greed and politics". The fact that poverty exists in many coastal communities is seen as a very strong motivator for some people to become involved in illegal activities. The lucrative nature of poaching has however also seen many people give up legitimate employment to start poaching. From a political perspective, the allocation of fishing rights were in the past seen to reflect the prevailing political dispensation and since 1994 there has been increased pressure on government to redress past “inequalities”. The re-evaluation by government of fishery policy that consequently took place has been slow however, which has resulted in illegal fishing occurring in some cases and the scale of these transgressions has surprised the authorities. The fact that illegal fishing was considered by the public and the police services to be less important, in the context of high crime levels throughout the country, meant that law enforcement measures have been focussed elsewhere, which has resulted in large numbers of people becoming involved in abalone poaching. The declining South Africa Rand : US Dollar exchange rate, which has led to ever higher prices being paid locally for abalone, has encouraged more people to become involved in poaching. Corruption within law enforcement agencies has also contributed to the proliferation of illegal fishing (Tarr 2000). Given the scenario described above, it is not surprising that abalone poaching has become a widespread and lucrative activity. This has led to the formation of poaching syndicates with connections to international organized crime syndicates (Chinese Triads), who export the abalone through Hong Kong. Abalone poaching certainly existed prior to this period but was limited to relatively small groups, which conducted their operations on a small scale. That scenario has changed dramatically with many poachers operating with apparent impunity in the face of perceived inadequate law enforcement measures. The effects that poaching has had on the natural resource is reflected in the steady decline of the commercial TAC since the 1996/1997 season as well as an almost complete cessation of fishing in the traditionally most productive fishing sector (Table 1.1, Tarr 2000, Stuttaford 2001).

Table 1.1 Total allowable catch of the commercial fishery in the south-western Cape from 1996–2001.

Season	1996/1997	1997/1998	1999/2000	2000/2001
Total Allowable Catch (tons)	550	530	500	388

By the late 1990s poaching in the Eastern Cape Province was occurring on a similar scale to that in the south-western Cape. Law enforcement records indicated that the highest levels of poaching were occurring in the Port Elizabeth municipal area (see Figure 1.1), although this might be an artefact of compliance activities (Coetzee 1998). One area in particular - Cape Recife, appeared to be being heavily and indiscriminately targeted, with a high proportion of poached animals being under the minimum legal size (MLS). The apparent concentration on

Cape Recife by poachers is probably because of its well-known, easily accessible abalone population, its relatively favourable diving conditions and its proximity to a large urban area, but at the same time being outside the residential areas. The authorities, the public and scientific institutions voiced concern over the illegality of these acts and although the law enforcement agencies met with some success in apprehending suspects, it was obvious that they were not curbing the poaching activities significantly. It was clear that if the poaching continued, the abalone population at Cape Recife would quickly become decimated.

Unlike the south-western Cape, large rural communities living by traditional subsistence agriculture and resource harvesting exist in parts of the Eastern Cape Province, and utilize shallow-water marine resources for food and income (Siegfried *et al.* 1985, Robertson and Fielding 1997). With the increase in the organization of poaching activities, abalone have been increasingly targeted by this group. Since these people do not dive, the utilization of many of these marine resources is often only possible during spring low tides when the sea is very calm and they are therefore termed “waders”. Given the lack of available harvesting time, the fishers place a premium on maximizing effort. This has resulted in large numbers of people, particularly women and children, becoming involved in these fishing activities. The high effort levels combined with a finite resource has had predictable effects on these shallow water resources with complete stripping of any edible organisms becoming the norm within the intertidal and shallow subtidal zones.

In early 2001, in response to political pressure and in a bid to curb illegal abalone fishing by “waders” in the former Ciskei, the government began allocating “subsistence” permits to “local community members” (SA 2000). In common with the existing small-scale commercial fishery operating in this area, the MLS was set at 100mm shell breadth, with certain other restrictions also applying (Pers. Comm. D. Mostert, MCM, 2001). The poor economic development in this area has resulted in high levels of unemployment and poverty and poor access to formal education. These factors combined with a lack of a comprehensive management and implementation plan resulted in this “subsistence fishery” quickly moving beyond the control of fisheries managers and as a result the rights to fish were withdrawn after only three months. Fishing rights were subsequently reinstated in October 2002.

ABALONE FARMING AND STOCK ENHANCEMENT

The high prices being obtained for abalone also led to interest in the artificial culture of abalone in South Africa during the 1980s (Cook 1998). The technology to artificially spawn and grow abalone was developed by the Japanese (Hahn 1989), but it was only after Genade *et al.* (1988) spawned *H. midae* for the first time, that interest was stimulated in South Africa. It took a further ten years for industry and research institutions to join forces and to begin active efforts to develop commercial farming (Sales and Britz 2001). The technology developed rapidly, using a combination of technology transfer from abroad and local innovation (Cook 1998, Sales and Britz 2001), enabling South African farms to make rapid progress relative to countries which had been farming for longer. By 2001 there were 12 farms at various stages of development that had a projected output of 500–800t.year^{-1} (Sales and Britz 2001). Most of these farms possess their own hatchery facilities and on growing is undertaken in land-based tanks using either a natural or artificial diet, or a combination of both (Cook 1998).

Since large amounts of artificially cultured juvenile larvae have become available in South Africa, stock enhancement of *H. midae* has been contemplated. This has led to two abalone stock enhancement projects being initiated in South Africa (Sweijd *et al.* 1998, De Waal 2002). Stocking of aquatic creatures, of one form or another has probably been occurring ever since humans began catching and keeping aquatic animals (Welcomme 1998), and stock management objectives have often been implicit or explicit in these actions. Kobayashi (1980) described how salmon were impounded on a river to protect their spawning effort as early as 1762. In the late 1800s, Norway and the United States followed quickly by Japan began the artificial rearing of salmon and cod for the purposes of stock enhancement (Masuda and Tsukamoto 1998, Kitada 1999), see also Welcomme (1998). This early “production phase” of fish stocking continued until the mid 20th century and was characterized by emphasis being placed on putting as many individual eggs or early stage-fish into the water as possible (Richards and Edwards 1986, Leber 1998), but without subsequent rigorous evaluation of the results (Grimes 1998). The ecological relationship between the stocked fish and the habitat into which it was placed was not properly understood (Radonski and Martin 1986). Subsequently, disillusion with the apparent success of these efforts led to emphasis shifting away from these efforts to other fields of fisheries management (Leber 1998).

The justification for renewed interest in stock enhancement is not hard to find. The latter half of the 20th century has seen a stabilizing in world fisheries catches (New 1997, Grimes 1998) and many individual stocks have been reduced significantly (Bartley 1999). These effects have been caused by a combination of environmental degradation, pollution and overfishing (Munro and Bell 1997, Bartley 1999). Stock enhancement programs have been implemented using a wide variety of fish and shellfish species and abalone in particular, as well as vertebrate species (Taubes 1992, Munro and Bell 1997, Masuda and Tsukamoto 1998, Imamura 1999). This has paralleled the increase in marine aquaculture capabilities (Leber 1998).

From a theoretical perspective there are two main reasons for attempting stock enhancement. Munro and Bell (1997) and Doherty (1999) argue that the main theoretical motivation for stock enhancement is the possible existence of unutilized trophic resources, caused primarily by variable settlement, defined here as the abundance of post-metamorphic juveniles, which contribute to demersal juvenile abundance (Munro and Bell 1997). These shortages in post-larval stages may also occur because of a lack of pre-metamorphic stages resulting from excess fishing pressure The second but less favoured reason is that population bottlenecks result from density dependant effects after settlement. These could be caused by competition for food or space limitation for example.

From a practical perspective, consideration also has to be given to why enhancement practices are embarked upon under a given scenario. Although the reasons for stocking are many and varied (Cowx 1994, Bartley 1999), the main reason enhancement practices arise, is to improve yields from fisheries, either because catches have decreased in a particular area, usually associated with habitat degradation or overfishing (Hilborn 1998, Cowx 1998, Olla *et al.* 1998), or in more extreme cases they do not occur there.

Cowx (1998) divides the reasons into four main categories (see also Welcomme 1998):

1. *Mitigation*. These activities are usually associated with human activities not directly related to fishing but which may disturb the habitat of a species (Grimes 1998). Examples of this would be dam building or the inundation of coastal habitat by harbour building. In these cases fish may be stocked to compensate for potential losses. Artificial reef construction is often used in these cases to replace lost habitat.
2. *Enhancement*. This is the principal method whereby stocks are augmented owing to perceived or real lowering of production from a fishery. Often the reasons for the poor production can not be identified.
3. *Restoration*. When a restraint to the recovery or improvement of a stock is removed stocking may be undertaken to re-establish previous levels of stock. These restraints could include reduced water quality, habitat degradation or overfishing (poor management). This type of stocking is usually of a temporary nature.
4. *Creation of new fisheries*. This is the most contentious type of fish stocking since it attempts to establish a species in an area where it does not occur naturally and is closely related to the issue of accidental or intentional release of exotic species, which often have deleterious effects on the natural ecology. The intention of this type of stocking is to make use of unused niches to improve fish yields and to allow new areas to be utilized. The introduction of *H. midae* on the Northern Cape Province coast can be considered in this category.

Contemplation of stock enhancement measures, particularly for sedentary species such as abalone, raises the issue of user access rights. Recently, Territorial User Right Fisheries (TURFs), which limit the use of resources by restricting access on an area basis, have gained renewed acceptance as an alternative to open-access fisheries which have become prevalent in the developed world (Caddy 1999, Bartley 1999) and which are seen as damaging from an environmental and socio-economic perspective (Christy 1982). The exclusivity inherent in area-based management systems such as TURFs are ideally suited to stock enhancement programs. The rights that need to be exercised to ensure that TURFs operate effectively, are essentially the goals of stock enhancement programs *viz.* 1) Control access to territory (resource); 2) Determination of the nature of resource usage; 3) Rights to resource extraction and; 4) Rights of tenure to ensure profitability on capital investment (Christy 1982). These shared goals mean that TURFs can often be considered as part of stock enhancement initiatives.

SUMMATION

The poaching situation that had developed in the Eastern Cape Province and in particular the area around Port Elizabeth, provided the motivation to begin investigation into abalone stock enhancement, within the natural range of *H. midae*. Abalone seeding and commercial-scale ranching was seen as a potential tool to rehabilitate and enhance the natural abalone stock that occurs there. With this is in mind, a commercial abalone farmer, Mr. Connie Muller of Marine Growers (Pty.) Ltd., situated near Port Elizabeth, approached the Department of Ichthyology and Fisheries Science at Rhodes University with an idea to explore abalone seeding and ranching at Cape Recife. Marine Growers were producing juvenile abalone in excess to their normal production needs. A research partnership was subsequently set up between these two organizations and permission was sought from the relevant authorities to begin seeding experiments. Cape Recife was seen as an ideal place to undertake this investigation since it had a well known abalone population that had been studied before (Wood 1993) and was apparently one of the primary sites being targeted by poachers in and around Port Elizabeth. In addition, the leeward side of Cape Recife has relatively calm waters compared to the Eastern Cape Province in general, which would facilitate the diving aspect of the study.

AIM AND OBJECTIVES

The aim of this study was to investigate the potential for abalone seeding technology to be used as a tool for stock enhancement and management of natural populations of *Haliotis midae* in the Eastern Cape Province.

Specific objectives, relating directly to the thesis structure, are as follows:

- While the stock enhancement of *H. midae* in the Eastern Cape Province provided the motivation for this study, it was important to know the scale of illegal fishing and to monitor the status of the natural stock in the area where seeding experiments were being considered. This would facilitate an assessment of the effects of poaching on the natural stock and also the potential benefits associated with the stock enhancement measures. The growth rate of wild juveniles was also investigated in Chapter 2 to compare with seed growth rate.

- The main objective of Chapter 3 was to measure the survival rate of introduced abalone seed at Cape Recife. Several issues, such as seed identification, release methodology, seed growth rate and movement, and the influence of seed size on survival needed to be investigated.
- The possible large-scale rearing of juvenile abalone, placing them in the sea, managing them and the associated natural stock would incur significant costs. The economic feasibility of a stock enhancement project, based on the results of Chapter 3, was addressed in Chapter 4.
- Chapter 5 presents a discussion of the study as a whole and addresses specific considerations for management and future work.

CHAPTER 2

AN INVESTIGATION INTO THE EXTENT OF ILLEGAL FISHING AND ITS EFFECTS ON THE *HALIOTIS MIDAE* POPULATION AT CAPE RECIFE

INTRODUCTION

Without quantification of the scale of poaching activities in the study area and its possible deleterious effect on the natural abalone population, the implementation of an alternative management scheme using stock enhancement measures and an associated area-based fishery would be difficult to justify. While anecdotal reports from compliance authorities and the public suggested that illegal fishing of abalone was depleting the *H. midae* resource at Cape Recife, an objective study was required to confirm the scale of illegal fishing and its effects on the local abalone population.

In his review of abalone stock assessment models Breen (1992), stated that "Stock assessments have seldom been successful in determining or predicting the status of any abalone fishery". In fact, the accurate estimation of abalone abundance has proved to be difficult in many previous studies (*e.g.* Beinssen 1979, Prince 1992, Tarr 1993, Findlay and Willerton 1996, Hart *et al.* 1997, Dichmont *et al.* 2000, Officer *et al.* 2001b). The propensity of abalone for forming dense aggregations, their ability to both disperse and then reaggregate in response to fishing and their cryptic behaviour are the main reasons for these problems (Gorfine 2002). Poor sea conditions and variation in diver power can exacerbate these problems.

Fishery dependant and fishery independent methods are used to obtain estimates of abalone abundance. The first, that of catch per unit effort (CPUE), indirectly measures changes in the levels of a stock due to fishing (Fishery Dependant). The method assumes that CPUE varies in proportion to stock size (Breen 1992). When CPUE is used in conjunction with stock depletion methods such as the Leslie-De Lury model, estimates of absolute biomass can be reached (Shepherd and Johnson 1991, Breen 1992). Alternatively, direct methods of abundance estimation can be used (Fishery Independent Surveys) and these can either be density counts, or timed collections and searches. Although time-based surveys and indirect

CPUE data are obtained in a different manner, from research divers and commercial fishers respectively, they suffer from similar problems, which are outlined below.

The assumption that CPUE accurately reflects stock abundance is widely held and often used in fisheries biology, but it is equally recognized that this assumption is not always valid, especially for abalone (Breen 1992, Prince 1992, Gorfine 2002). Significantly, there have been cases where commercial divers have detected declining stocks (Prince 1992), or where there has been a collapse of a fishery, while the CPUE has remained relatively stable (Tegner *et al.* 1989, Shepherd and Baker 1998, Gorfine 2002). Several studies have outlined reasons for the unsuitability of CPUE and timed searches for estimating stock abundance (*e.g.* Sloan and Breen 1988, Breen 1992, Prince 1992, McShane 1994, Hart and Gorfine 1997, Gorfine 2002). These reasons can be summarized as follows:

1. *Diver Power and Handling Time:* The efficiency of divers can vary and this can play an important role in affecting catch rates. The efficiency of a single diver may vary from day to day depending on numerous factors, and exogenous factors such as heterogeneous habitat type or sea conditions usually play an additional role (Hart *et al.* 1997). Efficiency can also vary between different divers and this can significantly affect catch rates. While standardization of diver power has been attempted (Beinssen 1979, Shepherd 1985, McShane 1994), there appear to be insurmountable problems limiting the success of these attempts (Dichmont *et al.* 2000).
2. *Spatial Distribution Affecting Variability in Catchability:* The tendency for abalone to aggregate is well documented (Hines and Pearse 1982, Shepherd 1986, Shepherd 1986, Sloan and Breen 1988, Prince 1992, Shepherd and Partington 1995) and appears to be a characteristic of abalone populations worldwide (Keesing and Baker 1998). As a result, the search time is not necessarily proportional to the numbers of individuals (Sluczanowski 1986), since catch rates can be maintained at a stable level by divers moving from one aggregation to another (Day and Leorke 1986, Gorfine and Dixon 2001). In addition, reaggregation of abalone after fishing also allows divers to return to a previously fished area and maintain previous catch rates even though the overall level of abundance has decreased (Officer *et al.* 2001a). CPUE also assumes that catchability of abalone remains the same (*i.e.* fish re-disperse after fishing, Breen 1992), but this assumption is violated by reaggregative behaviour (Prince 1992, McShane 1994). Abalone’s ability to move significant

distances (Newman 1966), especially when disturbed, means that their spatial distribution can change over a relatively short period (Prince 1989).

3. *Difficulties with accurately estimating effort:* Additional factors associated with the accurate estimation of fishing effort can lead to further difficulties. Problems such as the recording of diving days rather than time actually spent diving (Fielding *et al.* 1994, Gorfine and Dixon 2001), the variable efficiency of vessels, the effect of season on fishing intensity and the tendency for quotas to decrease effort because catches are guaranteed, all contribute to inaccurate measures of effort (Sloan and Breen 1988).

These factors can interact at different levels to make accurate abundance estimation unreliable (McShane 1994) and many authors have concluded that CPUE is an unreliable estimator of stock abundance or "should be used with extreme caution" (Breen 1992). In spite of their potential inaccuracy, however, these methods have been used for stock assessment purposes in the past and are currently used to manage the *H. midae* fishery in the Western Cape Province, although FIS data is now being collected to supplement CPUE data (Tarr 2000). Forster *et al.* (1982) used timed counts to estimate the abundance of *Haliotis tuberculata* off Guernsey and Jersey, but this survey was subsequently criticized by Findlay and Willerton (1996). McShane (1994) successfully used timed counts, and he argued that collection rates can be used to obtain precise estimates of abundance, and that this method can be used over large spatial scale to assess heterogeneous stocks. Hart *et al.* (1997) concluded that timed collections may work under certain circumstances, but that their reliability may be uncertain.

As an alternative to CPUE and time-based survey methodologies that are discussed above, density measurements may be effective for estimating the abundance of reef-dwelling animals (Seber 1982, Andrew and Mapstone 1987, Krebs 1989), but logistical problems tend to mitigate against their usefulness. If the area to be sampled is large and is complex with respect to topography and algal cover, sampling can be time consuming and expensive (Breen 1980). In addition, sea conditions need to be favourable (McShane 1994, Tarr 2000). The patchy distribution characteristic of abalone due to their patchy habitat (Wood 1993) and their tendency to aggregate also leads to high variances associated with low mean densities, that can result in imprecise abundance estimates, particularly if there is low replication (Sloan and Breen 1988, Shepherd and Johnson 1991, McShane 1994). The cryptic nature of abalone may also lead to underestimates of abundance, especially of juveniles (Prince *et al.* 1988, McShane 1994). Early recruits and juveniles exhibit a strategy of seeking shelter from predators under rocks, in crevices and under sea urchins (Tegner and Butler 1989, Tarr *et al.* 1996, Day and Branch 2000a). This cryptic behaviour is exhibited until the abalone are large enough (80–100mm SL) to be invulnerable to most predators. Space limitations, greater food availability and higher reproductive success cause larger juveniles to move into more open or emergent positions (Officer *et al.* 2001a). Sampling can therefore be targeted at either emergent or cryptic modes and there is generally little size overlap between groups.

Population size structure using size-frequency data has been used to monitor the health of abalone stocks (Schiel and Breen 1991). This method relies on three main assumptions that need to be taken into account (Wood 1993): 1) Spatial variation in growth is known to occur in abalone (Day and Fleming 1992), which could result in different population size structures occurring between sites; 2) Settlement and recruitment patterns may vary in both time and space leading to biased size structures (Shepherd 1998) and; 3) Natural mortality may also change in time and space both within and between sites (Shepherd and Breen 1992). Failure to fulfil these assumptions may lead to erroneous conclusions being made concerning the health of the abalone stock. In the absence of other data however, this method could be of value for providing baseline information, especially when assessed on an area-by-area basis.

Population size structure can be used to measure growth rates in abalone but it is generally accepted that the slowing of growth rates with age leads to the coalescing of cohorts (Gorfine 2002). This prevents accurate measurement of growth for emergent abalone unless an accurate method is available for age determination (McShane and Smith 1992, Wood 1993).

H. midae stock abundance has been estimated using most of the methodologies described above. CPUE methods have been criticized and fishery independent abalone surveys (FIS) have also been instituted (Tarr 2000, Dichmont *et al.* 2000). Problems with high variances in abalone densities and inaccurate estimates of available habitat have, however, led to unlikely estimates of total emergent biomass (Tarr 1993). Changes in population size structure have also been used as an indicator of stock abundance in South Africa (Tarr 2000). An increase in the proportion of fishable stock (*i.e.* the proportion above minimum legal size) was seen as an indicator of improving resource strength, but the assumption of constant recruitment is not necessarily valid (Tarr 2000). A combination of these techniques, as well as CPUE fishery statistics are now used to set total allowable catch (TAC) for each commercial fishing sector in the south-western Cape, although no specific model was applied to analyse data objectively (Tarr 1992, Dichmont *et al.* 2000).

Since the Eastern Cape Province stocks have never been subject to extensive legal fishing, no attempts have been made to monitor changes in abundance of any *H. midae* populations in the Eastern Cape Province, although previous studies have measured abundance and population size structure at selected sites (Newman 1969, Tarr 1986, Tarr 1993, Wood 1993, Fielding 1995). Newman (1969) measured population size structure and growth at Cape Recife, but only cryptic juveniles were sampled.

MOTIVATION OF METHODS

At the outset of this study it was recognized that estimates of total stock size at Cape Recife would not be feasible given the logistical constraints of the research team. The purpose of this study was only to monitor qualitative changes that may have occurred owing to the perceived increase in fishing effort. To obtain meaningful estimates, all sources of data needed to be considered. Although no legal fishery existed at Cape Recife, compliance authorities began collecting data from confiscated illegal catches when the scale of poaching activity in the Eastern Cape Province became apparent. This information represented a potentially useful source of fisheries data, which could be used in lieu of traditional fisheries dependant data described above. There have been few attempts to use illegal fishery data worldwide and indeed there appears to be a paucity of this type of quantitative information for most commercially exploited abalone resources (Gorfine *et al.* 2002).

While fishery dependant abundance estimation of abalone has been widely criticized, the lack of a long time series of data for Eastern Cape Province *H. midae* populations and logistical constraints on direct abundance measurement necessitated the use of this data source. These data could provide an indication of stock utilization and distribution of effort. With assumptions of constant recruitment and natural mortality, objective statements might be made concerning changes in stock abundance and crude estimates of CPUE would provide a further source of information on stock levels.

Other sources of abundance data also needed to be considered since it is preferable that more than one type of assessment method be used for estimating animal abundance (Seber 1982, Krebs 1989). Fishery independent surveys were chosen as another source of data. Data was collected by research divers using time-based and area-based survey techniques that were discussed above. Despite the practical constraints involved with these methods, they were considered as a necessary complement to the fishery dependant data.

When this study was first initiated timed searches were seen as a cost-effective and more practical alternative to area-based counts. Diving conditions were generally poor and the shallow water resulted in strong surge, which made timed searches easier to perform compared to transect counts. While time-based abundance estimates have been heavily criticized, some authors have found that they can be a reliable relative estimator of abundance, especially if diver efficiency is standardized (Fielding 1995, Shepherd and Partington 1995). If the same experienced divers perform the collections, the searches are conducted under similar sea conditions and the handling time of abalone is minimized this method can be useful (Gorfine 2002). Since sea conditions had to be very favourable to dive at all at the study site, and the abalone would only be counted and not collected, it was felt that the use of timed counts was justified.

The research personnel changed soon after the project began and there were concerns that changes in diver power may bias future counts. It was therefore decided that area-based estimates of abalone abundance should also be used to measure abalone abundance at Cape Recife. Transects were therefore used to measure emergent abalone abundance, and plots and quadrats were used to measure cryptic abalone abundance. Population size structure and length-frequency data could be used to assess changes in emergent abalone abundance and growth in juveniles respectively. The measurement of cryptic abalone growth would enable a comparison with seeded *H. midae* growth measured in Chapter 3.

AIM

The aim of this chapter was to assess the extent of illegal fishing at Cape Recife, to measure its qualitative effects, and to establish a baseline of stock abundance estimates to facilitate the evaluation of the proposed enhancement experiments to be conducted in the following chapter.

METHODS

Study Area

Stock enhancement experiments and direct observations on the natural abalone population were conducted in the vicinity of Cape Recife (34˚ 01' 44" S, 25˚ 42' 28" E, see Figure 1.1), a prominent rocky headland forming the western point of Algoa Bay. The metropolitan area of Port Elizabeth, the third largest along the coast of South Africa, is situated on the shores of Algoa Bay (Figure 2.1). The fieldwork described below was conducted exclusively in the Cape Recife Nature Reserve on the southern edge of the suburban area. The inshore area is popular amongst recreational shore-anglers and free-divers (abalone, spear-fishing and occasionally rock-lobster).

The geology of the eastern Cape coastline is complex (Marker 1988) and this is reflected in the Cape Recife area. Several geological features are characteristic of the study area. The major underlying rock is hard quartzite, which forms the "foundation" of the Cape, and outcrops to a greater or lesser degree throughout this area. Overlying this are a number of different substrates including quartzite boulders and cobbles, aeolian deposits (fossilized sand dunes) that are weathered to a greater or lesser degree, and mobile and stable sand deposits. This geology, coupled with the various geomorphological and ecological processes, gives rise to a very complex sub-tidal habitat. The distribution of wild abalone is largely dependant on the substrate type, owing to their sedentary nature and habitat requirements. The heterogeneous substrate was reflected in the variable distribution of *H. midae*.

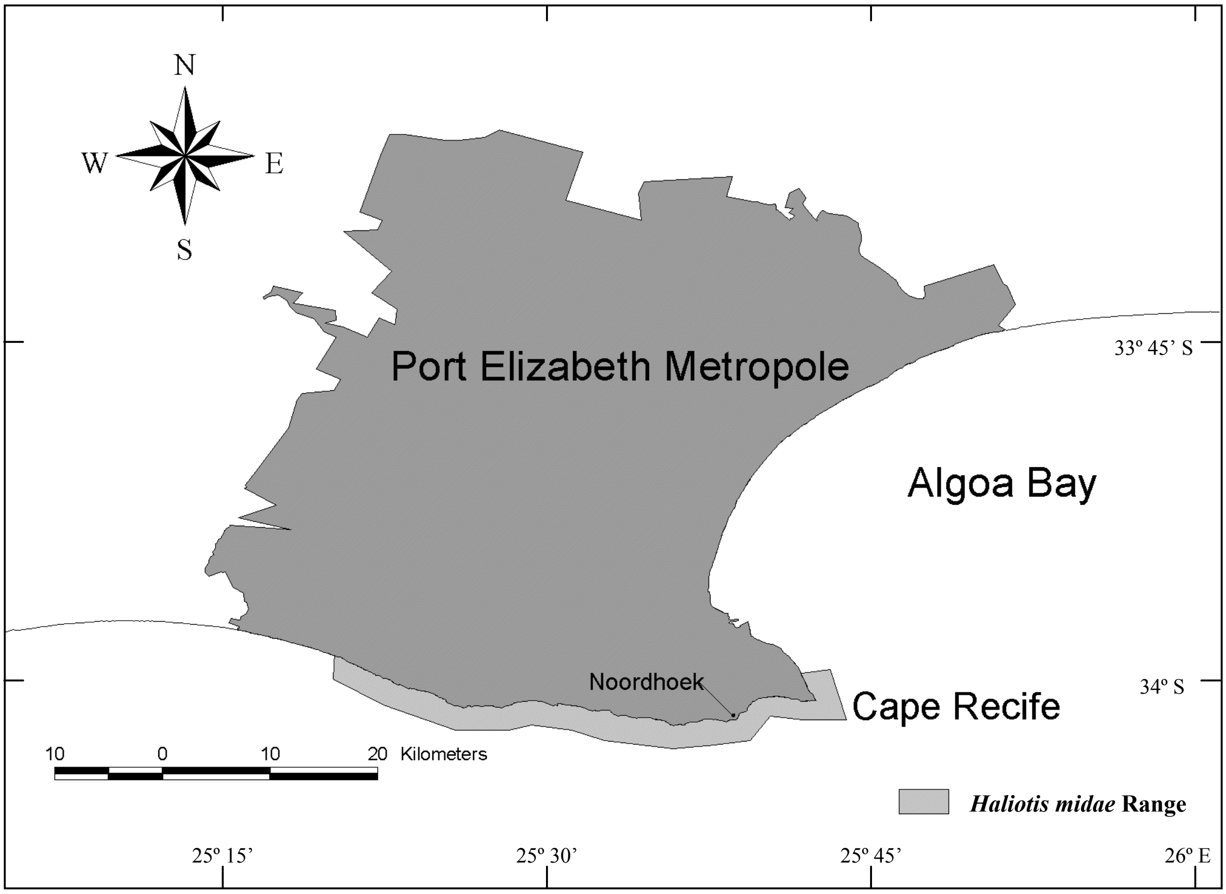

Figure 2.1 Location of the Cape Recife study area and Noordhoek in relation to the Port Elizabeth Metropole. Extensive sandy beaches limit the range of *H. midae* to the east and west.

After numerous exploratory dives in the study area, it was decided that the habitat of *H. midae* could be classified on a macro-scale into three categories (Figure 2.2). The criteria for this differentiation were subjective but were based on the degree of wave exposure, substrate type, habitat relief, algal types and, to a lesser extent, depth (Table 2.1). Wood (1993) made a similar assessment at Cape Recife but his study was conducted in a smaller area. The area immediately north of Cape Recife (Habitat 1, Figure 2.3) consisted predominantly of a gently shelving substrate, made up of an aeolian deposit base, with an overlying layer of cobbles that were embedded in a consolidated sand-biota matrix. A few solid quartzitic reef outcrops occurred within this area. This habitat extended up to 200m offshore in places. The outer boundary consisted of shifting sandbanks at a depth of 3–4m below MSLW, which appeared to be influenced by prevailing swell and current patterns.

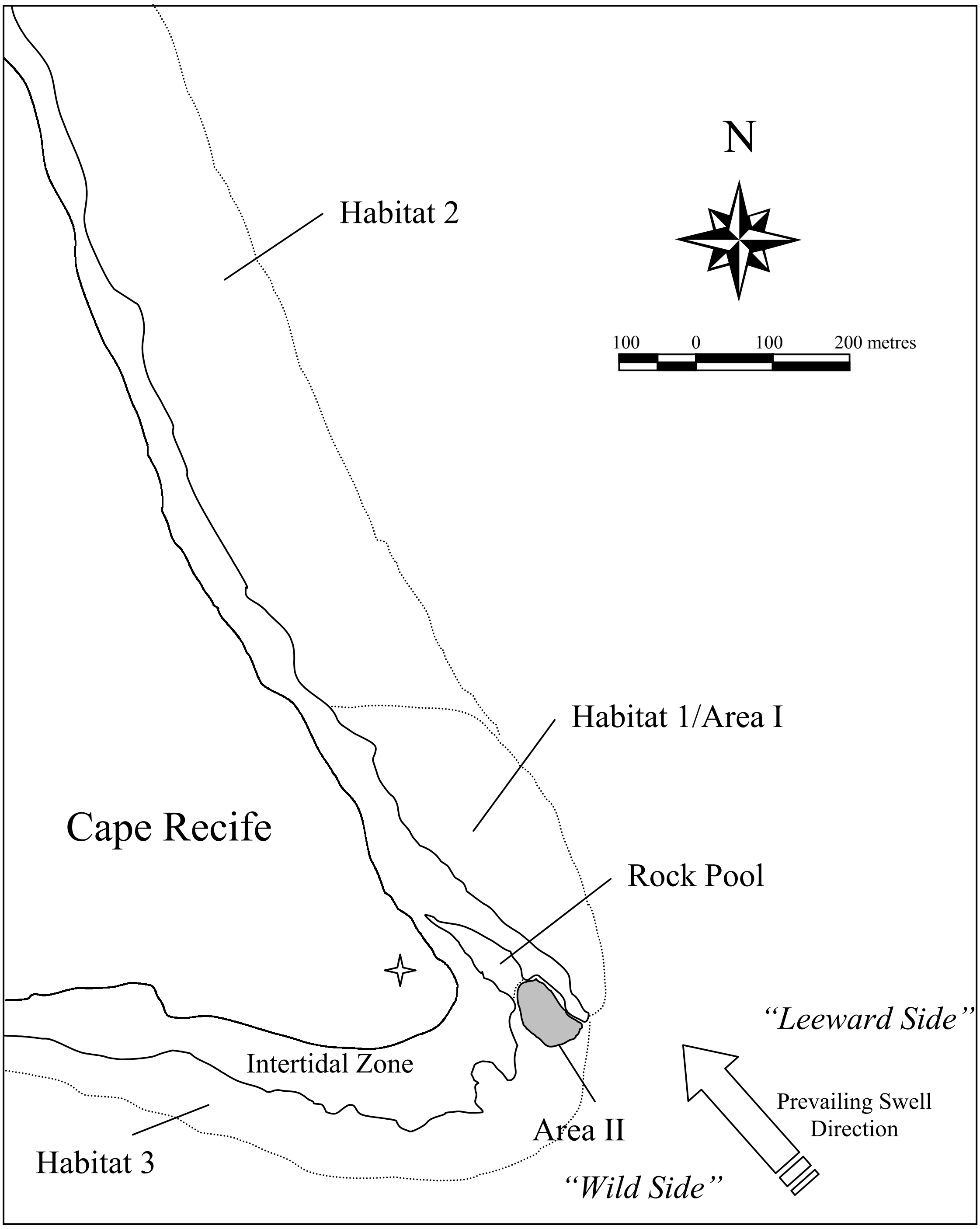

Figure 2.2 Study site at Cape Recife, with the main habitat types and sampling areas indicated.

Table 2.1 **A description of the three main habitat types encountered in the study area at Cape Recife.**

Area	Depth (MSLW)	Wave Exposure	Profile	Substrate	Main Algal Components
Habitat 1	0.5–3.0m	Low - Medium	Low	Mixed stable cobbles (predominant) and mostly low-relief solid reef.	Mixed, *Plocamium spp.* dominated.
Habitat 2	1.0–5.0m	Medium	Low - Medium	Variable, mixed substrate. Solid reef of various types predominates. Sand patches.	Mixed, variable.
Habitat 3	0.5–4.0m	High	Medium - High	Solid outcropping quartzite reef interspersed with cobble-filled (unstable) gullies.	Mixed, geniculate Rhodophyta predominate, encrusting algae also prevalent.

The second broad habitat category (Habitat 2, Figure 2.3) was found further to the north. Although Habitat 1 did extend into this area, the overlying cobbles were not a prominent feature and the aeolian deposits became increasingly more incised with crevices, deep, narrow fissures and gullies as one moved into deeper water. This gradually gave way to patchy quartzitic reef outcrops, sand patches and flat aeolian shelves. The physical habitat in the second area was more diverse in nature. The outer limit of this area was once again sand deposits at around 5m below MSLW.

Figure 2.3 Photograph of parts of Habitat 1 and 2 at the Cape Recife study site. Note the aeolian shelves in the intertidal area (foreground).

The third broad habitat area identified (Habitat 3, Figure 2.4) was on the “Wild Side” of Cape Recife to the south west of the point. This area has borne the brunt of the prevailing southwesterly swells and this in combination with the exposed quartzite rock has given rise to a very different habitat than the two areas within Algoa Bay. Habitat 3 was characterized by patchy but large, solid quartzitic reefs surrounded by deeper gullies with cobbles on the bottom. These cobbles were less stable than in the other habitats owing to the higher wave energies encountered in this area.

In addition to the three habitats described above, there existed at low tide a large shallow rock pool (Figure 2.2, approximately 150 x 50m) that was significantly different in appearance to the rest of the habitats. This can probably be attributed to its shallowness and sheltered position. Its physical characteristics are described in detail in Chapter 3 (Figure 3.5).

Figure 2.4 Photograph of a part of Habitat 3 at the Cape Recife study site. Note the prominent outcrops of quartzite and deep gullies in between.

Fishery Dependant Catch Data

The poaching data was collected from confiscated and abandoned samples obtained from the compliance activities of the South African Police Services (SAPS) and Marine and Coastal Management (MCM). Samples originated from widespread localities throughout the Eastern Cape Province, but with a specific focus on Port Elizabeth and its immediate surroundings. During their operations, samples of poached abalone were obtained from various sources. Bags of poached abalone were found in the sea, washed ashore, hidden in the coastal bush or simply abandoned by fleeing poachers. Alternatively, catches were confiscated during the arrest of suspects involved in poaching activities. This occurred either at the diving site, en route away from the coast or further afield when the frozen abalone were being transported or being stored elsewhere for further processing or export. Unless the abalone were confiscated at the dive site it was not possible to establish precisely where the catches were made. Cases from September 1997 to the end of June 2002 were analysed. To allow for a comparison on a yearly basis, the catch rate for the second half of 2002 was assumed to be the same as the first 6 months and the data was simply extrapolated. Fishing effort was measured as the number of cases, the mass of confiscated catch and the number of abalone in each catch.

Most of the abalone samples consisted of shucked and eviscerated specimens. Individual animals were identified to the species level, counted and then weighed to the nearest gram. The catches consisted almost entirely of *H. midae* but a few specimens of *Haliotis spadicea* were sometimes present. In the case of very large samples a subsample was taken to obtain a representative size distribution. For the purposes of this study, only data for *H. midae* were collected. For the categorization of these abalone into legal and sub-legal groups, the figure of 176 grams was used as a weight equivalent to an abalone of the minimum legal size of 114mm shell breadth. This is a figure derived from morphometric work done in the course of Marine and Coastal Managements extensive involvement with *H. midae* research and compliance activities (Pers. Comm., A. McKenzie, MCM, 2001). This includes investigations to determine weight loss associated with dehydration and freezing in conjunction with normal morphometric measurements (shell length, shell breadth, MCM, unpublished data). The figure of 176g is seen as conservative in the sense that it probably overestimates the size of the live animal (Pers. Comm., A. McKenzie, MCM, 2001) and therefore the figures quoted for undersized *H. midae* should be seen as minimum estimates. This conversion formula is also used in court by expert state witnesses to indicate the proportion of undersized abalone.

An attempt was made to convert the poached sample weights back to whole mass and hence shell breadth, using existing morphometric data from the Eastern Cape Province (Wood 1993). This was however abandoned after the dehydration data were examined. The substantial time dependant weight loss made accurate estimates difficult given the inconsistencies of handling between catches. Similar observations have been made by Gorfine (2001) for live, commercially caught abalone in Victoria, Australia.

Fishery Independent Stock Appraisal

Timed Searches

A series of 20 minute timed searches were performed in Areas I and II (Figure 2.2), to assess emergent *H. midae* abundance. A random sample of all emergent *H. midae* was also collected to obtain a representative population size distribution.

Transecting

Transect counts were performed in Area I within Habitat 1 (Figure 2.2) and prior to seeding in Habitat 2. The transect lines were 10 x 2m, and were laid randomly, but aligned perpendicularly to the coast. All emergent *H. midae* were collected to obtain a profile of the population size structure.

Quadrats

During the seeding experiments performed in the rock pool (see Chapter 3), where clearly defined plots were sampled, all wild *H. midae* were collected to obtain size-frequency and density data. These plots were usually $10m^2$ in area and were either circular or rectangular. Subsequently, $4m^2$ plots were also sampled in the same manner. These plots were specifically chosen for their suitable juvenile abalone habitat and can therefore not be considered random counts. Similar methods were used in the grid area ($10m^2$ plots) but these can be considered random counts (see methods in Chapter 3). Later, during rapid assessment of areas where mass seedings had been performed, randomly deployed $1m^2$ quadrats were used for the sampling of both wild and seeded *H. midae* in that area.

Data Analysis

Morphometric Conversions

A shell length (SL) to shell breadth regression was calculated from collections of live animals and shells, from Areas I and II and is illustrated in Figure 2.5. The non-isometric relationship is described by a power function. The resulting equation is used where conversion from shell breadth to SL was necessary. The minimum legal size of 114mm shell breadth is equal to 140.2mm SL using this regression. All shell sizes are presented as shell length.

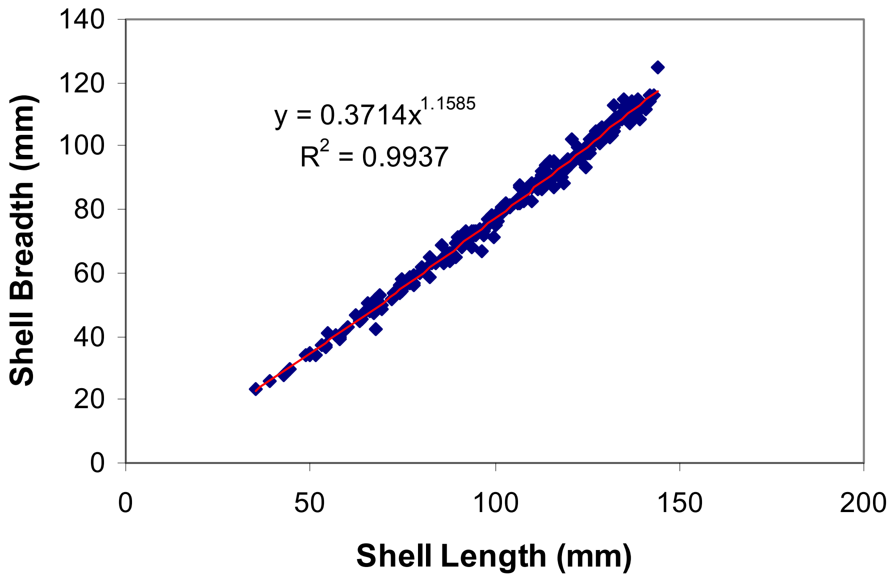

Figure 2.5 **The shell length to breadth regression of live *H. midae* and shell collections from areas I and II (n=288).**

Size Distributions

As already discussed, *in situ* emergent abalone assessments were expected to sample larger animals and as a rule there was little overlap between sampling methods for cryptic and emergent *H. midae*. To allow a more objective comparison to be made, *H. midae* <80mm SL were excluded from emergent size distribution analyses.

Statistics

To measure changes in abalone abundance using population size structure, a Chi-square test for multiple proportions was used to compare the proportion of undersized animals between samples (Zar 1999, p. 562). This method was applied to both poaching data and research collections. *Post-hoc* Tukey-type tests were used to test for further significance between individual samples.

Absolute changes in abalone size were measured to assess the impact of poaching at Cape Recife. The mean size of abalone from poached catches were compared between years using parametric ANOVAs or non-parametric ANOVAs, if data could not be normalized. A similar approach was used to compare the mean size of samples collected at Cape Recife by research divers. When significant differences were detected from parametric tests, *post-hoc* Tukey tests for unequal *n* were then used to test for differences between two samples. The mean sizes of poached catches were also compared using Kruskal-Wallace ANOVAs and Mann-Whitney U tests were used to determine where significant differences occurred.

To measure changes in abalone abundance, timed counts and density measurements were compared using Student t-tests and in the case of the density measurements where counts were low or contained a large number of zeros, the square root transformation, $x'=\sqrt{(x+0.5)}$, was used as suggested by Zar (1999).

Growth

Preliminary attempts were made to resolve cohorts of juvenile *H. midae* using Bhattacharya's Gaussian method using the FISAT II computer program (Gayanilo and Pauly 2000). Knowledge of spawning time and growth rate from the studies of Newman (1969), Tarr (1986) and Wood (1993) were used to inform the choosing of appropriate cohorts for analysis. Since the nature of this analysis is fairly subjective, more rigorous attempts to resolve separate cohorts were not attempted, especially since there was evidence of overlap between older cohorts, which is well known amongst abalone species (Shepherd and Breen 1992).

RESULTS

Stock Utilization

Compliance records between 1997 and 2002 showed that the highest proportion of cases originated from Cape Recife. Of the 264 cases analysed, 65 (24.6%) could be directly linked to the Cape Recife study area (Figure 2.6). The second most numerous category was that of cases of unknown origin, followed by cases from Noordhoek, the area adjacent to Cape Recife to the west (see Figure 2.1). When the cases of unknown origin were excluded from the analysis, Cape Recife contributed 32% of the cases, Noordhoek 27% and the rest of the metropolitan area of Port Elizabeth 23%. The balance of known cases (18%) originated from multiple localities, which encompassed almost the entire range of *H. midae* in the Eastern Cape Province (see Figure 1.1).

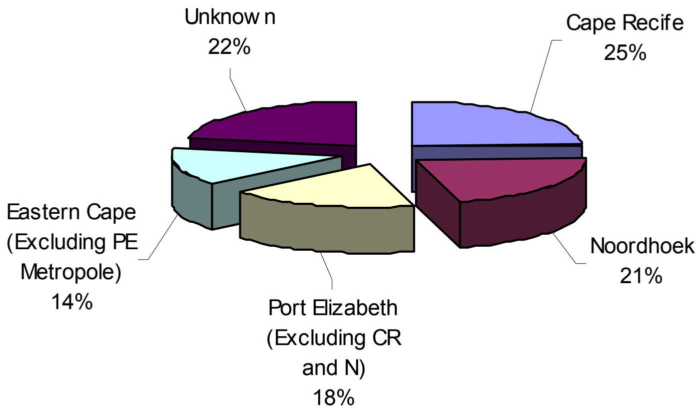

Figure 2.6 Distribution of poaching cases in the Eastern Cape Province by area from 1997–2002 (CR = Cape Recife, N = Noordhoek, PE = Port Elizabeth).

For the first three years that data were available, the numbers of cases for all areas showed a gradual increase (Figure 2.7). From 2000 onwards this trend continued but there appeared to be an exponential aspect to the increases. An exponential curve is fitted to the total number of cases to illustrate this (r=0.983). The total mass of confiscations for Cape Recife and the Eastern Cape Province as a whole increased steadily from the time data became available up until the end of 1999 (Figure 2.8). There was a notable increase from 1999 to 2000 but thereafter the annual figure has remained fairly stable with a slight decline for both groups in 2001.

To obtain an estimate of the whole mass of abalone caught, an eviscerated to whole mass regression curve was calculated using a sample of abalone from another site in the Eastern Cape Province. This delivered a mean annual confiscated catch at Cape Recife for 2000–2002 of 718kg whole mass. Law enforcement authorities estimate that they intercept between 5 and 10% of the total illegal catch, which would equate to between 7 and 14 tons of live abalone being caught at Cape Recife annually from 2000.

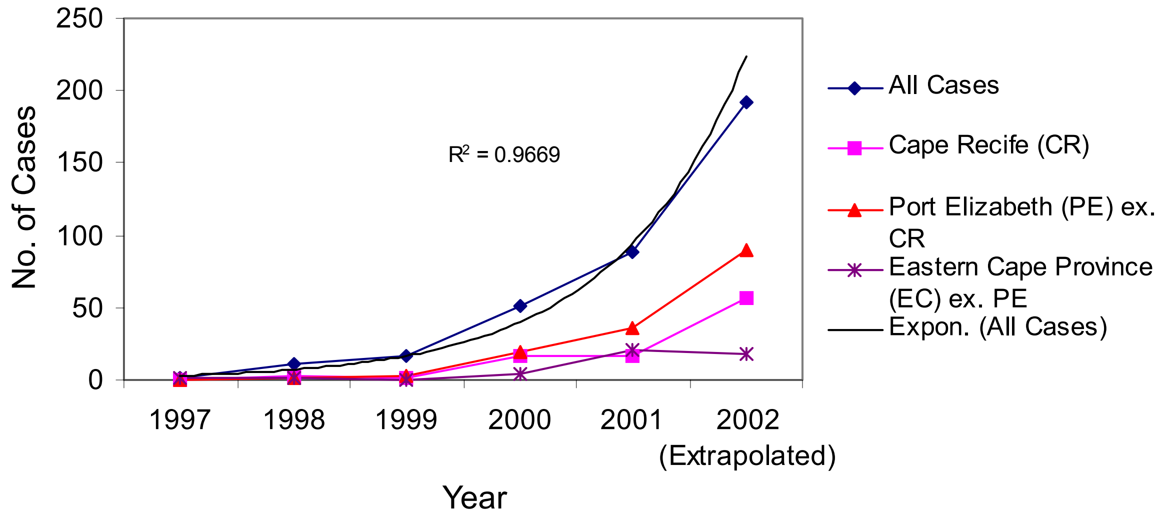

Figure 2.7 **Annual number of poaching cases for the Eastern Cape Province from 1997 to 2002.**

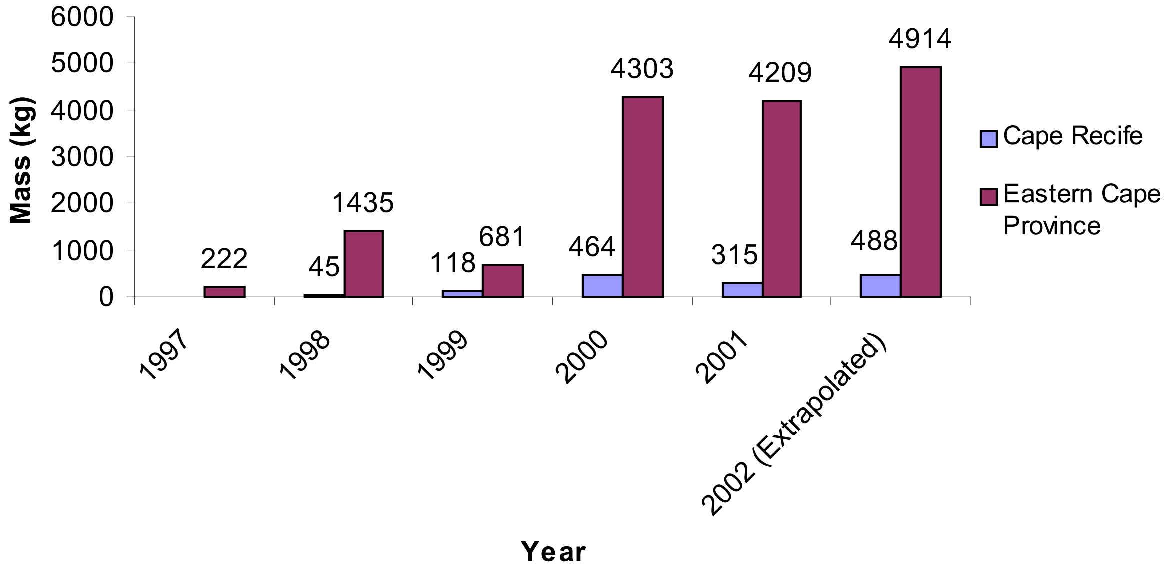

Figure 2.8 **Total annual mass (Eviscerated weight) of confiscations for Cape Recife and the Eastern Cape Province from 1997–2002. The MLS is 114mm shell breadth or 176g flesh mass.**

Stock Abundance

Population Size Structure

Estimates of stock abundance that were obtained from compliance confiscations and *in situ* measurements tended to corroborate each other. Direct comparisons were not possible owing to unreliable conversion factors. The proportion of undersized abalone from poaching records is presented in Figure 2.9 for Cape Recife, Noordhoek and the rest of the Eastern Cape Province. No cases were attributable directly to Cape Recife in 1997 but a combined sample for Cape Recife and a site nearby had an undersized proportion of 89.5%. The sample sizes were also low for Cape Recife in 1998 and 1999 (n=3 and 2 respectively) as well as for Noordhoek in 1999 (n=1) and the rest of the Eastern Cape Province in 1997 (n=2). It is evident that by the time poaching data started to be collected, a high proportion of undersized individuals were present in many of the samples and by the first half of 2002, a quarter of the cases from Cape Recife consisted entirely of undersized animals. A Chi-square comparison for multiple proportions indicated significant differences between Cape Recife and Noordhoek for years 2000–2002 (df=5, Chi=948.678, $p<0.001$), with Cape Recife consistently showing the highest proportion of undersized animals each year. *Post hoc* Tukey-type tests indicated that there were no differences between samples from Cape Recife for years 2000–2002, but that yearly samples for Noordhoek differed significantly from all of those from Cape Recife (Table 2.2). The samples from Noordhoek in 2000 were also significantly lower than 2001 and 2002.

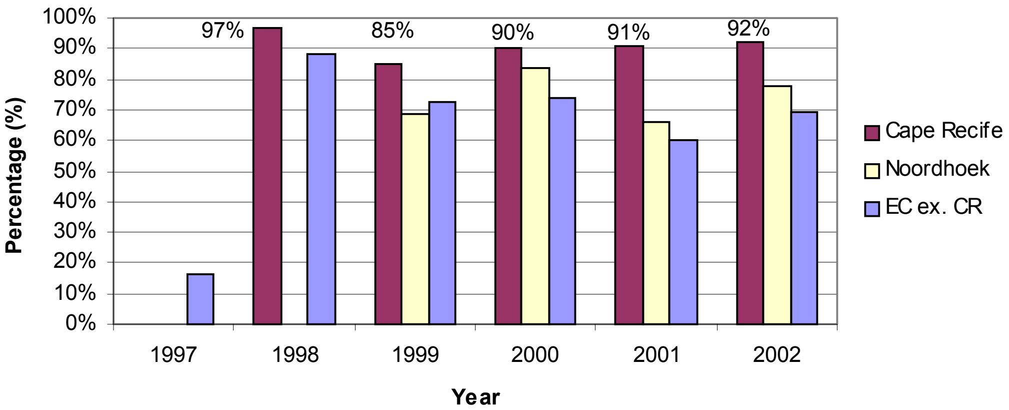

Figure 2.9 The proportion of undersize abalone in confiscated catches from Cape Recife (CR), Noordhoek and the balance of the Eastern Cape Province (EC) from 1997 to 2002.

Table 2.2 **Results of Tukey comparisons, testing for differences in proportions between sites and years for Cape Recife and Noordhoek (asterisk denotes significance at the 5% level).**

Compare	$q_{0.05,\infty,6}$	q	Conclusion
CR 2000 vs N 2000	4.03	6.14*	Reject H_0: CR 2000 ≠ N 2000
CR 2000 vs N 2001	4.03	20.06*	Reject H_0: CR 2000 ≠ N 2001
CR 2000 vs N 2002	4.03	11.45*	Reject H_0: CR 2000 ≠ N 2002
CR 2001 vs N 2000	4.03	5.99*	Reject H_0: CR 2001 ≠ N 2000
CR 2001 vs N 2001	4.03	19.67*	Reject H_0: CR 2001 ≠ N 2001
CR 2001 vs N 2002	4.03	11.19*	Reject H_0: CR 2001 ≠ N 2002
CR 2002 vs N 2000	4.03	6.21*	Reject H_0: CR 2002 ≠ N 2000
CR 2002 vs N 2001	4.03	19.79*	Reject H_0: CR 2002 ≠ N 2001
CR 2002 vs N 2002	4.03	11.38*	Reject H_0: CR 2002 ≠ N 2002
N 2000 vs N 2001	4.03	13.38*	Reject H_0: N 2000 ≠ N 2001
N 2000 vs N 2002	4.03	4.87*	Reject H_0: N 2000 ≠ N 2002

The analysis of the proportion of undersized animals measured from research collections from Cape Recife were high and ranged between 89 and 98% (Figure 2.10). Although similar to the poached samples there was generally a higher proportion of undersized animals in the *in situ* samples. Emergent abalone were generally scarce in the study area and as a result sample sizes of emergent abalone were low. Data from some samples taken at similar times were therefore pooled to obtain a larger sample size. This resulted in four *in situ* size distribution profiles. A multiple Chi-square analysis of undersize proportions showed no significant differences between these four samples (df=3, Chi=4.174, $p>0.05$).

Mean Size

An analysis of the size composition of individual poaching cases from Cape Recife indicated that the size range of abalone that were being targeted was increasing, although the sample size for 1998 and 1999 was small (Figure 2.11). The mean mass of individual abalone in confiscated samples from Cape Recife was consistently lower than for Noordhoek and the rest of Port Elizabeth (Figure 2.12). A two-way fixed effects ANOVA on Log transformed data for years 2000–2002, indicated significant differences between the size of abalone for year and site (df=4, F=61, $p<0.001$). *Post hoc* Tukey tests for unequal *n* (Table 2.3) revealed that the mean size of catch had declined significantly at Cape Recife from 2000 to 2001.

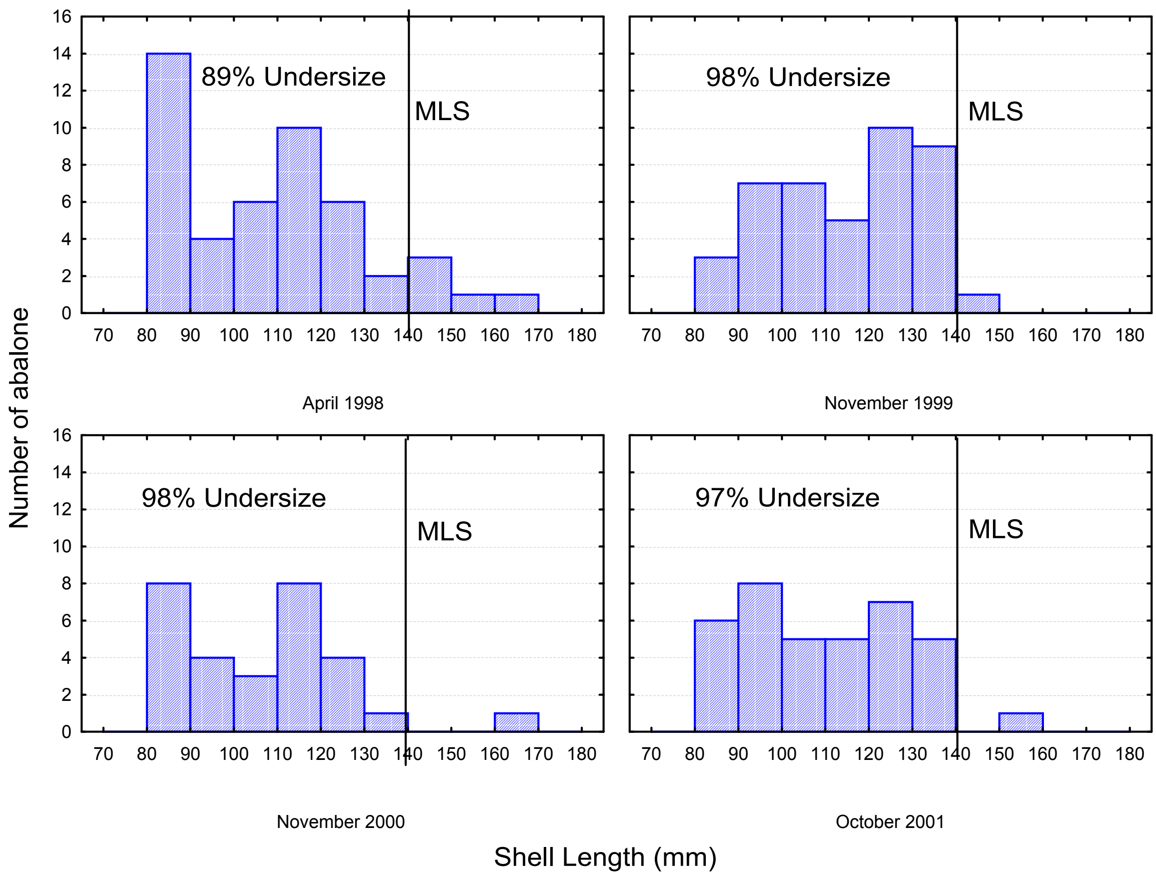

Figure 2.10 Population size structures of emergent *H. midae* sampled at Cape Recife from April 1998 to October 2001. The proportion of undersize animals is shown.

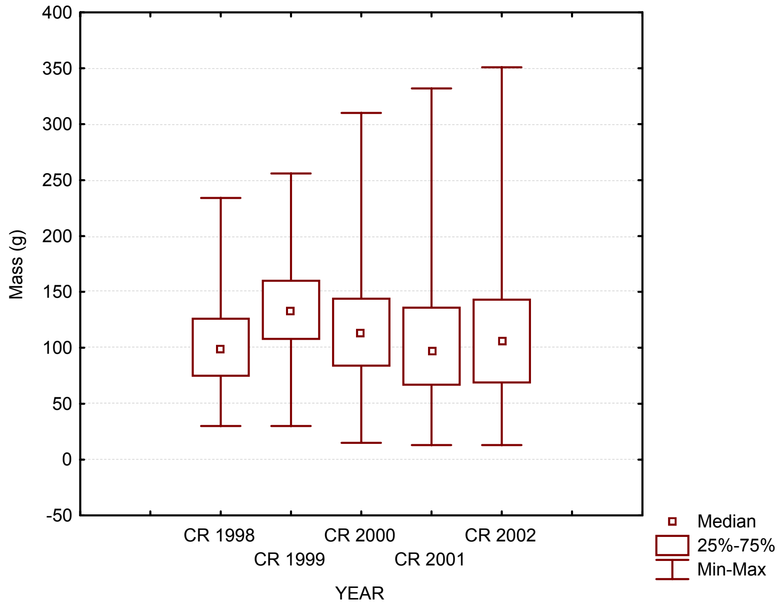

Figure 2.11 The size distribution of confiscated *H. midae* from Cape Recife (CR) from 1998–2002.

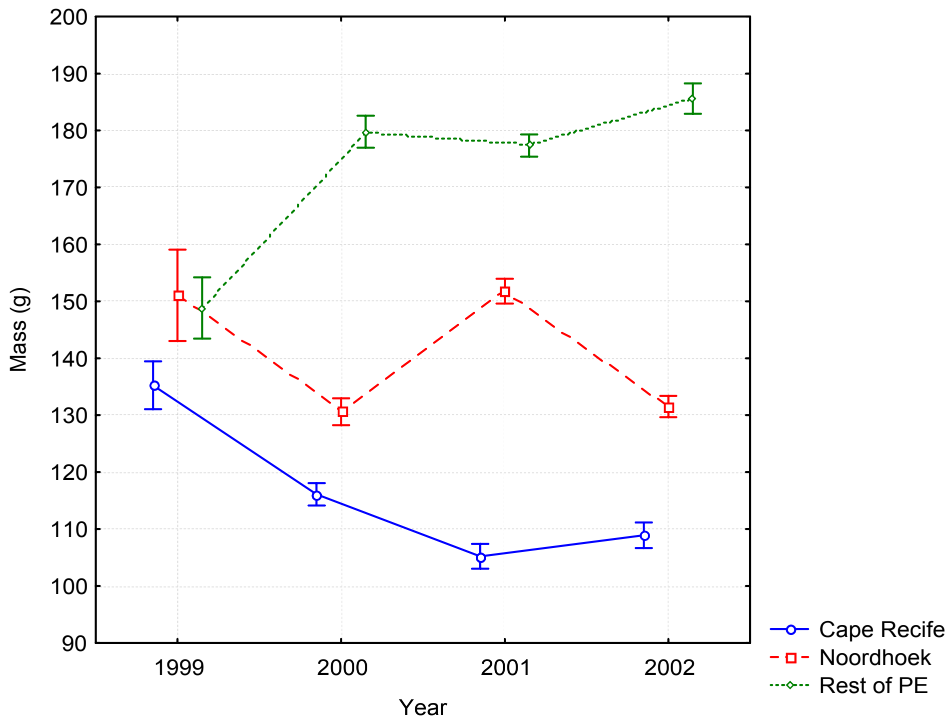

Figure 2.12 The mean mass of confiscated *H. midae* from three areas in Port Elizabeth (95% confidence limits are indicated by vertical bars).

There was, however, no significant difference between 2001 and 2002. The mean size for Noordhoek was significantly different each year, with the mean size increasing from 2000 to 2001 and then decreasing again. There were no significant differences between years for the balance of the Port Elizabeth sites. An examination of the mean size (shell length) of emergent animals sampled *in situ* at Cape Recife showed no significant differences using a Kruskal-Wallace ANOVA (H (3, n=155) =5.828, p=0.1203; Figure 2.13).

Table 2.3 Results of Tukey tests comparing mean size of animals from poaching cases from the Port Elizabeth (PE) metropole.

	Site	Year	{1}	{2}	{3}	{4}	{5}	{6}	{7}	{8}	{9}
1	Cape Recife	2000		<0.001	<0.001	<0.001	<0.001	<0.01	<0.001	<0.001	<0.001
2	Cape Recife	2001	<0.001		0.807	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
3	Cape Recife	2002	<0.001	0.807		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
4	Noordhoek	2000	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001
5	Noordhoek	2001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	<0.001
6	Noordhoek	2002	<0.01	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001
7	Rest of PE	2000	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		0.999	0.999
8	Rest of PE	2001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.999		1.000
9	Rest of PE	2002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.999	1.000	

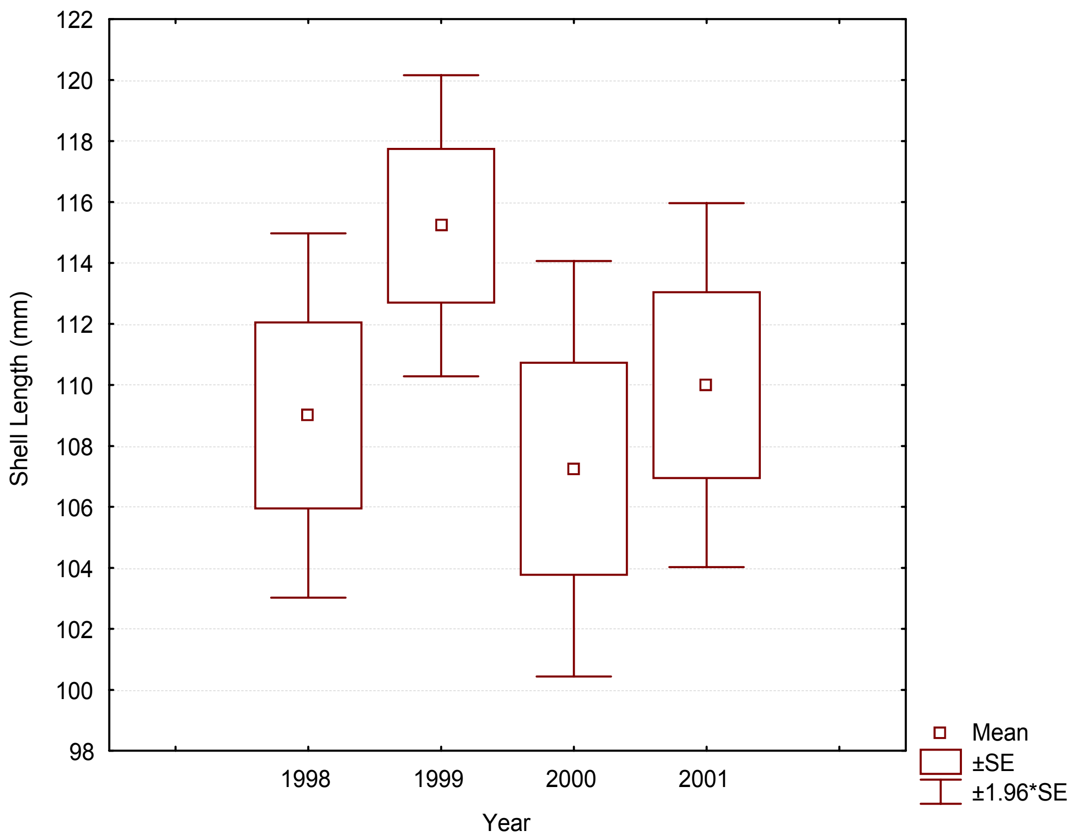

Figure 2.13 **Mean shell length of emergent *H. midae* sampled at Cape Recife from 1998 to 2001.**

Measures of Abundance: Emergent Abalone

The apparent anomaly between the number of cases and the total catch shown in Figure 2.7 and Figure 2.8, is explained when the mean size of each confiscated catch is analysed for Cape Recife. The mean mass of each case, which can be considered as a crude index of CPUE, showed a significant decline from 1999–2002 (Figure 2.14). A Kruskal-Wallace ANOVA indicated differences between years 2000–2002 ($H(2, n=59) = 16.20$, $p<0.001$). Furthermore, *post hoc* Mann-Whitney U tests showed significant differences between 2000 and 2002, and 2001 and 2002 (Table 2.4).

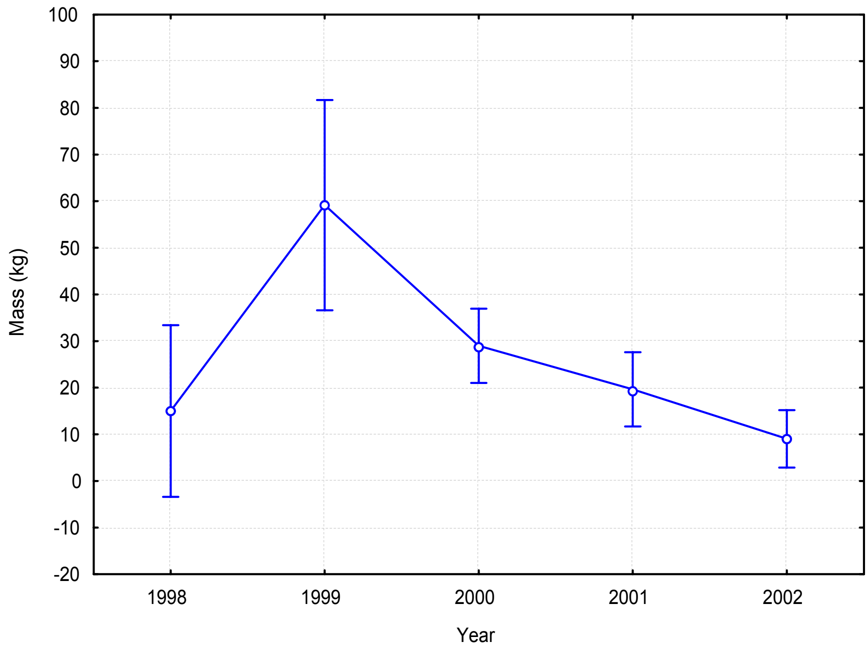

Figure 2.14 Mean mass of confiscated catches from Cape Recife (95% confidence limits are indicated by vertical bars).

Table 2.4 Results of Mann-Whitney U tests comparing the mean mass of cases from Cape Recife between 2000 and 2002.

Group	Group	Z	p
2000	2002	3.618	<0.001
2001	2002	2.915	<0.01
2000	2001	0.829	0.423

Both timed searches and transect counts indicated decreases in stock size at Cape Recife over the study period. In April 1998, timed searches were conducted in areas I (n=8) and II (n=10). The mean counts were 130.8 and 121.5 respectively. A t-test (with separate variance estimates) showed no significant differences between these two areas. The data were pooled and compared to the collections made in October 2001, which had a mean count of 53.8, using Student's t-test. There was a significant difference between these samples ($df=20$, $t=9.93$, $p<0.001$, Figure 2.15).

Emergent density data were only collected for 1999 (n=6 Habitat 2, n=9 Area I) and 2001 (n=5 and 6 both from Area I). The samples for each year were tested for differences using t-tests but no significant differences were found. They were then pooled and the yearly data were compared. A t-test with separate variance estimates on the data revealed highly significant differences between years (df=14.02, t=-3.432, p<0.001). The mean densities for 1999 and 2001 were 1.3 and 0.8m^{-2} respectively (Figure 2.16).

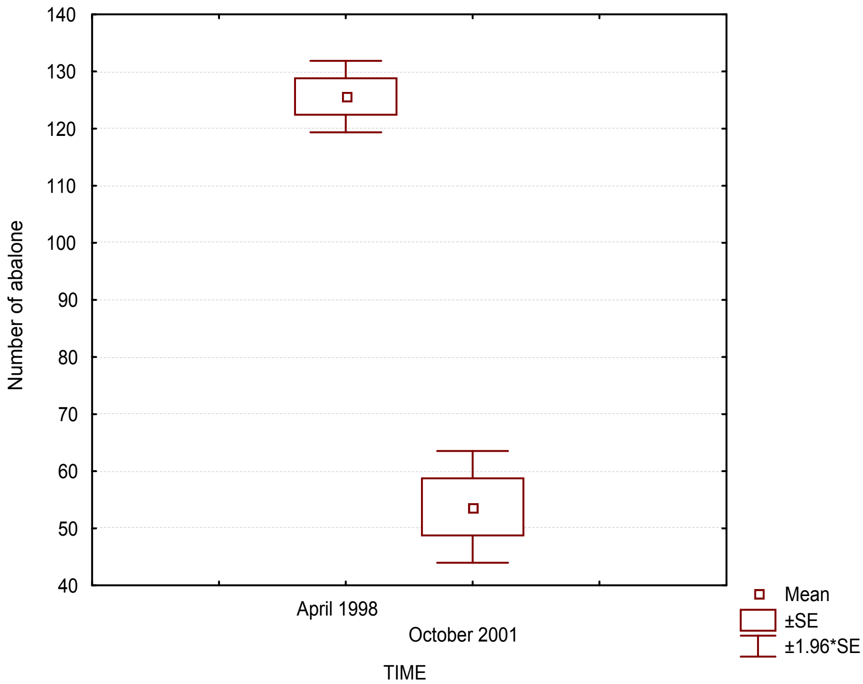

Figure 2.15 Mean of 20 minute timed counts made at Cape Recife in April 1998 and October 2001.

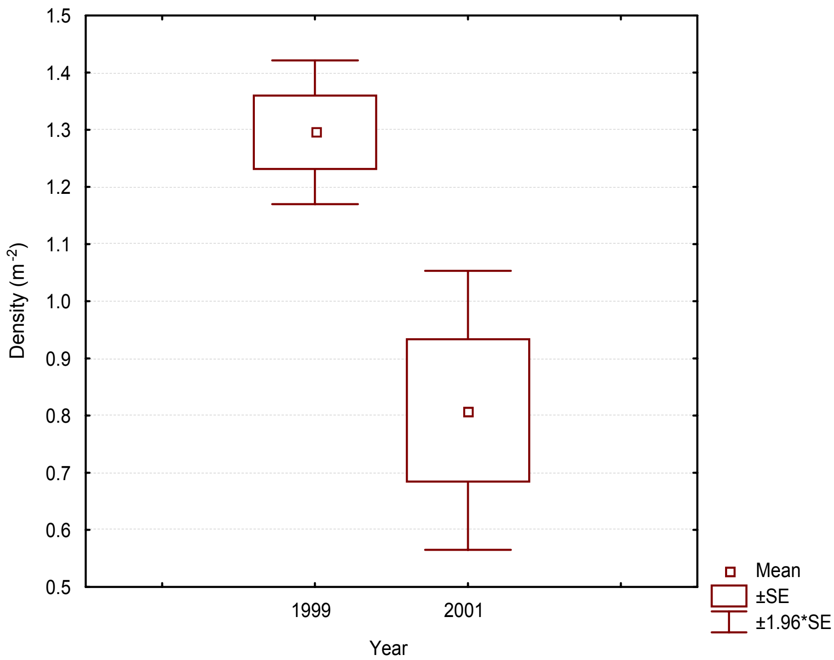

Figure 2.16 Mean density of emergent *H. midae* at Cape Recife measured in 1999 and 2001.

Juvenile abalone were especially abundant in the fringes of the rock pool that were used for seeding experiments, but only four abalone greater that 80mm SL were found there. A one-way ANOVA to test for differences in density on three separate sampling occasions (December 1999–December 2000) in this area found no significant differences (df=2, F=2.250, p>0.133). All abalone were found in cryptic positions and the average density of was 12.9m^{-2} (n=22). Similarly, a one-way ANOVA on square-root transformed data also revealed no significant differences between samples of juvenile abalone from other areas (April 1998–September 2001; df=6, F=1.481, p>0.207). The mean density for these groups was 2.3m^{-2}. A comparison of pooled data between the two areas revealed that there were significant differences in juvenile abalone density (df=27.373, t=7.813, p (2 sided) <0.001).

Juvenile Growth

Three cohorts from the rock pool area and one from Area II were resolved by the FISAT II software (Figure 2.17 and Figure 2.18). Only one cohort from the rock pool was analysed to measure growth rate. The growth rates calculated from the differences between the mean cohort length from the rock pool gave a growth rate of 2.19 and 1.93mm.$month^{-1}$ for the two periods under consideration and an average monthly value of 2.02mm. For the cohort in question, the growth rate calculated would indicate that spawning took place at the beginning of August 1999. What appeared to be the same cohort could also be identified from the sample taken from Area II in the middle of April 2000 (Figure 2.18). A second strong cohort was observed in the rock pool during December 2000, which again suggests a spawning at a similar time of the year (Figure 2.17c). These results will be discussed in conjunction with the results of seed growth rate in Chapter 3.

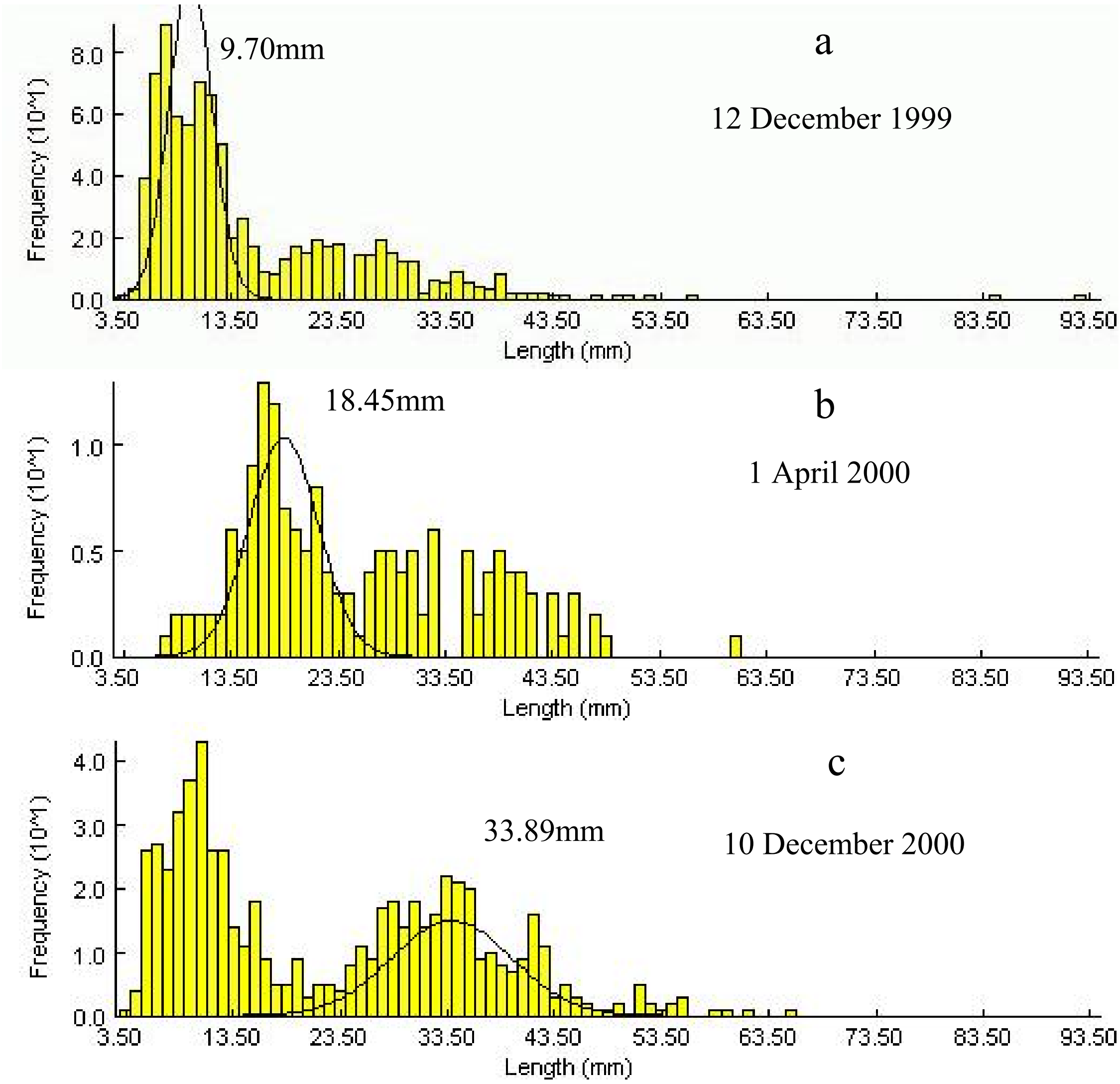

Figure 2.17 Size-frequency distribution of *H. midae* recovered from the rock pool. The mean shell length of the fitted distribution is indicated (n=850, 162 and 625 respectively).

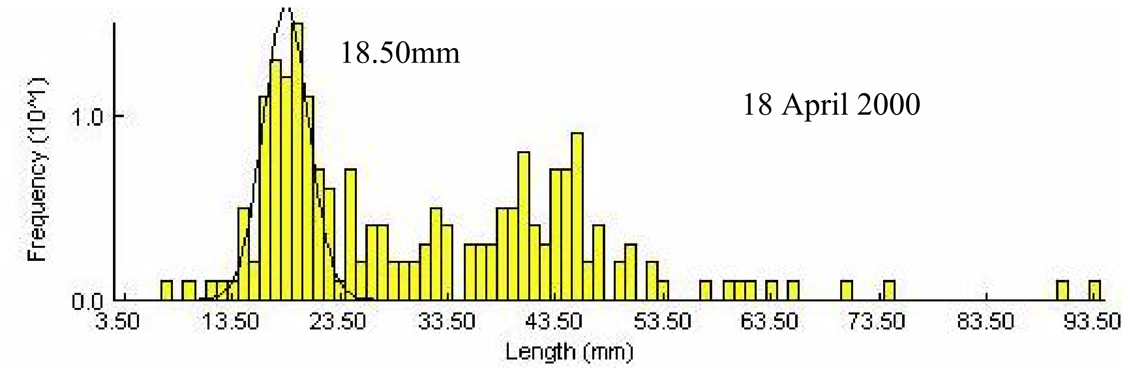

Figure 2.18 Size-frequency distribution of *H. midae* recovered from Area II in April 2000. The mean size of a fitted distribution is indicated (n=204).

DISCUSSION

By documenting declines in catch per unit effort and establishing a relative baseline of abalone abundance, the use of compliance records to monitor resource use were successful. These data also indicated high levels of poaching, with Cape Recife contributing a significant component to the confiscated catches. Cape Recife also had a significantly higher proportion of animals below the MLS and their absolute size was smaller compared to other diving sites in Port Elizabeth. Research surveys at Cape Recife also showed high levels of undersized animals and estimates of emergent abalone abundance using timed counts and density measures showed significant declines over the study period. The observed declines in emergent abalone abundance, measured using compliance records and research data, have serious implications for population sustainability.

Poaching Effort and Distribution

Although compliance records indicate that Cape Recife represented the highest proportion of illegal cases in the Eastern Cape Province, these data should be viewed with some caution as law enforcement activities can be highly selective in both time and space. This could have introduced bias into the data, especially when comparing effort levels (number of cases) and mass of catches, between different areas. These data do indicate a marked increase in poaching activities at Cape Recife over the study period, while anecdotal reports on poaching activity indicate that fishing effort was increasing. Although there was an increase in compliance efforts over the study period, this has been largely in response to increases in poaching activity (Pers. Comm., C. Coetzee, SAPS - Crime Information Management Centre, 2000). In addition, an obvious increase in the number of illegal fishers at Cape Recife was noted over the course of the study. By June 2002, large numbers of poachers were present at Cape Recife on a daily basis and appeared to be fishing with impunity. This trend was also apparent in areas both within the greater Port Elizabeth metropole and the Eastern Cape Province in general where the number of reported cases were 36 and 88 respectively in 2001. Crime intelligence reports have estimated that compliance operations intercept between 5 and 10% of illegal catches which would equate to minimum total catches of 3 and 40 tons meat weight respectively from Cape Recife and the Eastern Cape Province in 2001. These figures can be multiplied by a factor of 3 to obtain a rough estimate of whole mass, *viz*. 9 and 120 tons for Cape Recife and the Eastern Cape Province respectively (unpublished data, MCM, 2002). The data also supports the conclusion that the illegal fishers are prepared to exploit the resource at any level, exemplified by the increasing number of smaller animals in the samples and that some samples only contain undersized individuals. In summary, the data are indicative of the high level of illegal activity and show that the management and compliance regime was inadequate to curb these activities.

Abalone Abundance at Cape Recife

The examination of all the data that were used to estimate abalone stock abundance at Cape Recife indicate that emergent abalone numbers had declined significantly over the course of this study. Timed counts, absolute density and CPUE decreased during the study period (1998–2001). Mean size of poached and *in situ* animals and the proportion of undersized animals at Cape Recife stayed the same or decreased but were all significantly lower than the samples from Noordhoek, the adjacent area indicating that Cape Recife was subject to heavier fishing pressure.

There was a tendency for the proportion of undersize animals collected by researchers at Cape Recife to be higher than from the poached samples. The smaller sample sizes collected by the researchers or possible selectivity of poachers for larger animals may explain these discrepancies. The most likely explanation however is that the figure of 176g for the mass of MLS animals is probably an underestimate. A conservative size estimate was deliberately set to ensure that when this figure was used in court, prosecutors could be sure, despite morphometric variations related to space and post catch dehydration, that eviscerated abalone weighing less 176g were definitely undersize (Pers. Comm., A. McKenzie, MCM, 2001).

The lack of significant changes in mean size and population size structure, except for the mean size of poached animals between 2000 and 2001, suggests that fishing activities had already depleted the resource at Cape Recife before this study began. No comparable historical data exists for Cape Recife, but measurements from other sites in the Eastern Cape Province indicate noticeably larger sized animals. Tarr (1993) found that an average of 62% of abalone that were sampled at Bird Island were below the MLS compared to the 97%

undersize measured in this study at Cape Recife in 2001. Similarly, Fielding (1995) measured a mean of 76% of undersize animals in the Transkei, where *H. midae* is known to reach a lower maximum size. If his most northerly sample is excluded, justified by the lower maximum sizes encountered on the fringe of the *H. midae* range, this figure decreases to 67%. Importantly, his collections included animals of less than 80mm SL (cracks and crevices were searched) in contrast to the collections in this study. By including these smaller sized animals the proportion of undersized animals will be biased upwards in comparison to this study. While the assumptions of similar growth, recruitment and natural mortality may not be met for these populations, the large differences between Cape Recife and the other populations in the Eastern Cape Province suggest that fishing pressure has probably removed a large proportion of the adult population at Cape Recife.

A comparison of the proportion of undersized animals and the average size of animals in each poached catch between Cape Recife and other areas in Port Elizabeth indicated that the animals at Cape Recife were significantly smaller, and that there was a trend to smaller animals being found as one moved closer to Cape Recife. This is consistent with personal observations. Anecdotal reports that suggest that poachers targeted Cape Recife first due to its relatively benign diving conditions and then moved progressively further afield in Port Elizabeth. While the possibility exists that the unfished population of *H. midae* at Cape Recife consisted of smaller animals than areas nearby, this is probably unlikely. The proximity of Cape Recife to Noordhoek, separated by approximately 5km of sandy beach, the fact that large individuals were still being found at Cape Recife in 2002 and that this area has historically been considered a prime recreational diving area (for abalone), suggests that natural differences between local populations could not account for these differences and that fishing mortality was the most likely cause of these observations.

The most conclusive evidence for stock declines at Cape Recife came from CPUE, density and timed count measurements. They all declined significantly over the period that data was available. The method to estimate CPUE was crude but it did show significant declines in catch rate with time. While CPUE indices have been shown not to be a good indicator of stock abundance, Prince (1992) argues that declining CPUE may be an indicator of declining abalone abundance under high levels of effort. Fedorenko and Sprout (1982) suggested that CPUE could be an effective indicator of declining stock size. Keesing and

Baker (1998) also argue that catch/effort data may be useful on a fine spatial scale when making within site comparisons, as in this study. Furthermore, they postulate that if the degree of aggregation does not change substantially, relative measures can be accurate. While an accurate measurement of aggregation was not made in this study, the relatively homogeneous habitat encountered in the sample area, the absence of noticeable clumping of emergent abalone, and the low overall density even at the start of the study suggests that this requirement was fulfilled.

The CPUE evidence was corroborated by declines in estimates of abundance of emergent *H. midae* at Cape Recife using timed searches. These surveys revealed significantly lower levels of abalone at the end of the study compared to the beginning. While diver calibration was not attempted, and the divers who performed the second count were different from the first, these results are still considered valid due to the large difference measured. As previously mentioned, the timed searches could only be conducted under calm conditions and were conducted in the same general habitat area, thereby nullifying, to some extent, the effects of changing sea conditions and heterogeneous habitat. The second dive team was also more experienced than the first, which would have tended to increase sampling efficiency, rather that to decrease it. This would suggest that the differences in abundance were accurate, or possibly greater than measured in the timed searches. Hart *et al.* (1997) found that transect and timed search techniques were both robust and sensitive enough to detect decreases in population size, but the timed search method tended to underestimate the change.

Abundance estimates of emergent *H. midae* using density measures also declined through the duration of the study. Although there were typically high variances between transect counts, significant differences were still apparent between 1999 ($1.3m^{-2}$) and 2001 ($0.8m^{-2}$). No historical density data exists for emergent animals at Cape Recife. Tarr (1993), Wood (1993) and Fielding (1995) all measured abalone density of emergent animals in the Eastern Cape Province and obtained mean figures between 0.17 and $1.63m^{-2}$. While figures obtained in this study fall within this range, a direct comparison is difficult, since differences in habitat availability between study sites could have a marked effect on density measurements. The density measurements in this study were typically conducted in “prime” abalone habitat, which was known to have higher abundances of emergent abalone previously. The fact that CPUE, timed search and density estimates of abundance at Cape Recife all showed significant decreases suggests that these data are representative of actual stock declines.

Settlement and Juvenile Growth

Although significant differences were observed in juvenile abalone density between two areas at Cape Recife, there were no significant changes in juvenile abundance within these areas over time. Given that the two sampling areas were immediately adjacent to each other and the only physical barrier that existed between them was a 20–30m wide rocky berm at low tide, it seems unlikely that there would be any differences in the overall availability of fertilized gametes. There were also very few mature *H. midae* in the rock pool. The only other factors that could account for these differences would either be a difference in settlement rate or post-settlement mortality. It is difficult to speculate on which may be more important but it is likely that a combination of these two factors play a role. It is obvious that there is a degree of water entrapment in the rock pool at low tide, which could result in the concentration of free-swimming larvae and the calm water may also enhance settlement (McShane 1992, Shepherd and Partington 1995). Acting in opposition to this is the apparent lack of suitable settlement substrate in this area (see Chapter 3 for habitat description). In contrast, the abundance of cryptic habitat in the rock pool compared to the other site, may account for the higher densities found here, by enhancing post-settlement survival. In addition, this habitat appears to be severely constrained with respect to species number and abundance in comparison to nearby open-water areas. This may mean there are fewer predators in this area. The absence of emergent sized *H. midae* in the rock pool means that this hypothesis of lowered mortality must only apply to cryptic size classes. A lack of empirical studies on the relationship between stock size and recruitment for abalone has been noted in a review by McShane (1995) and the studies that do exist are equivocal *e.g.* (Prince *et al.* 1988, Shepherd *et al.* 1992, Tegner *et al.* 1992). If there is a strong stock-recruit relationship then my data indicates that stock size has not decreased. However, in light of the other evidence presented above that stock abundance has decreased at Cape Recife, it seems more likely that recruitment is not related to stock abundance at Cape Recife at current abundance levels.

Summation

While there was no evidence to suggest that egg production, as evidenced by decreases in settlement, had been negatively affected by the increase in fishing effort during the study period, the sustainability of the *H. midae* population at Cape Recife is undoubtedly threatened as almost all other measures of stock abundance showed progressive declines. It has been noted for abalone, that when CPUE indices decline, fishing levels have already reached unsustainable levels (Tegner *et al.* 1989, Shepherd and Baker 1998). However, Breen (1992) concluded that without further analysis, declines in CPUE can not be used to say whether stock levels have reached lower than desirable levels. Given the lack of knowledge on *H. midae* stock-recruit relationships, it is difficult to make conclusive statements with respect to impacts on future recruitment and hence stock sustainability at Cape Recife. In contrast, there is sufficient evidence to suggest that growth overfishing is already occurring at Cape Recife (Gulland 1983). More seriously, uncontrolled fishing has been implicated in the collapse of the previously most productive commercial sector for *H. midae* in the south-western Cape (Tarr 2000) and it seems likely that a similar situation may occur at Cape Recife in the near future.

In conclusion, the results presented in this chapter show that the emergent abalone stock has declined at Cape Recife. CPUE measures have also declined which indicates unsustainable fishing effort. Recruitment appears to be stable at present but is probably under threat particularly if present levels of illegal fishing effort are not curbed. These findings suggest that present management and compliance efforts are inadequate to ensure the sustainability of the *H. midae* population at Cape Recife. Alternative management strategies, which could include abalone ranching and area-based fisheries (TURFs), need to be considered to ensure the continued health and sustainability of this resource. The exclusivity inherent in sole access to an area-based fishery has important consequences, the most important of which is that it creates an incentive for the rights-holder to manage the resource in a sustainable manner to ensure long-term social or economic benefits. This desire to ensure long-term sustainability should encourage rights-holders to endeavour to prevent illegal fishing in their area.

CHAPTER 3

HALIOTIS MIDAE STOCK ENHANCEMENT EXPERIMENTS AT CAPE RECIFE

INTRODUCTION

Abalone Enhancement

Worldwide

Owing to shortages of land and progressive declines in wild catches, Japan was the first country to initiate abalone stock enhancement efforts with reports beginning in the early 1970s (Momma 1972, Tegner and Butler 1989), although work began prior to this. There were also attempts at this time to introduce cultured seed into areas off mainland China but these met with limited success and were abandoned (Qing Nie 1992). Due largely to declines in natural populations and with rehabilitation or increasing natural production as the main aims, seeding attempts have since been made by a variety of countries, including the United States, Mexico, New Zealand, Australia, Canada and South Africa (Tegner 2000).

South Africa

Prior to the initiation of this project, other abalone stock enhancement projects had been initiated in South Africa. One abalone seeding project reached an exploratory phase in the mid-1980s (Tarr 1986), but was subsequently abandoned, a trial abalone seeding project had been completed (Sweijd *et al.* 1998) and a third had begun (De Waal 2002). The first actual introductions began with a trial seeding of *H. midae* in False Bay near Cape Town in September 1995 (Sweijd 1995), which served as a precursor to experimental releases of cultured seed at Port Nolloth on the west coast of South Africa (Sweijd *et al.* 1998). The Port Nolloth releases were exceptional not only because they were the first serious attempts at abalone stock enhancement in South Africa, but also because this area is approximately 400km beyond the natural range of *H. midae* (see Figure 1.1, Muller 1986). Fossil deposits of an extinct species, *H. saldanhae* are, however, found nearby (Kensley and Pether 1986). The kelp bed environment into which these releases were made is very similar to where *H. midae* occurs naturally in the south-western Cape (Eekhout *et al.* 1992), and it was hypothesized that introductions of *H. midae* into this area could initiate a new fishery in an economically impoverished area. The introduction of seed into areas where natural populations of abalone do not occur does have some precedent (Sweijd *et al.* 1998). Saito (1979) reported on the introduction of *H. discus hannai* into an area beyond its natural range, which subsequently formed the basis for a productive fishery. More radically, raft culture and seeding of *H. rufescens*, the Californian red abalone, was proposed in Chile, after laboratory based studies were conducted in this country (Godoy *et al.* 1992).

The initial releases in South Africa demonstrated that artificially cultured *H. midae* juveniles could be successfully introduced into the natural environment. Mean minimum survival rates of approximately 30% after six months were obtained and the seed exhibited seasonally variable growth rates that were similar to those of naturally occurring populations elsewhere in South Africa. A preliminary economic evaluation suggested that commercial scale ranching could be viable on the west coast of South Africa. Abalone ranching efforts continued in this area, with De Waal (2002) investigating various aspects of the enhancement process including the capacity of the habitat to support seeded juveniles, the identification of optimal site characteristics and an investigation into the population dynamics of seeded populations in terms of economic viability.

Seeding Issues

Appropriate evaluation of stock enhancement efforts has received deserved attention in recent years but needs to be done in with the desired objectives of the project in mind (Hilborn 1998). Measuring the proportion of seed in commercial catches, the ratio of cultured animals in relation to the contribution of natural recruitment and the increase in total catches can be used to evaluate the contribution of seeded animals (Munro and Bell 1997, Bartley 1999). Measuring survival rate is the most direct way of assessing the contribution of seeded animals to wild stocks, but this is often not an easy task, particularly with abalone.

Problems with Estimating Survival Rate

Many abalone seeding projects have been plagued by large amounts of unaccounted for seed (Ebert and Ebert 1988), which has led to uncertain estimates of seed survival. While other methods such as counting the number of shells of dead seed, have been used to estimate seed survival, absolute counts of live seed remains the most reliable method, but depends on locating and identifying the seeded animals. As is the case with wild abalone, the cryptic behaviour and potential movement of abalone seed from within the search area can significantly affect their catchability, which has led to led to uncertainty and debate regarding the fate of seeded abalone (Tegner and Butler 1985, McCormick *et al.* 1994, Rogers-Bennett and Pearse 1998, De Waal 2002).

Differentiating stocked animals from their wild counterparts is a key issue in the assessment of stock enhancement efforts (Howell 1998, Laurec 1999, Bartley 1999). New advances in tagging have benefited some fish species, but effective abalone tagging remains problematic. The introductions of *H. midae* made prior to this study were outside its natural range and all the abalone found in this area were assumed to have been artificially introduced (Sweijd *et al.* 1998). The area into which the releases were to be made in this study supported an extensive natural population of *H. midae* (Newman 1969, Wood 1993) and a means of distinguishing seed *H. midae* from their wild counterparts was therefore required.

Genetic profiling has been demonstrated to be an effective tool for monitoring seeded abalone (Gaffney *et al.* 1996) and mitochondrial and micro-satellite DNA techniques have been developed to facilitate differentiation of different abalone populations (Sweijd 1999). This work was however ongoing at the time of the initiation of this study and could not be used during the project. A physical tagging method was therefore chosen to identify seeded abalone in this study.

Source and Choice of Juveniles

There are various factors that can influence the survival rate of stocked animals and these need to be considered during the implementation phase of any enhancement project (Cowx 1994). These included the source and choice of animals to be stocked (*i.e.* hatchery raised or wild caught and their size), the manner in which the animals are transported prior to release, the release method, the timing of release (time of day and season), the habitat into which the animals are placed, and the stocking density (McCormick *et al.* 1994, Munro and Bell 1997).

Size

As with most types of fish and shellfish stocking, abalone can be introduced at various stages of their life cycle. This issue has been explored extensively ever since abalone enhancement efforts began and was reviewed by McCormick *et al.* (1994). The hatchery rearing of abalone incurs significant costs, so from an economic perspective it is preferable to release seed as young as possible (Tong *et al.* 1987). This philosophy has culminated in several attempts to seed Haliotid larvae, with variable results (Preece *et al.* 1997). Conversely, it is postulated that larger sized animals may be better able to cope with the rigours of life in the wild and also that potential trophic bottlenecks may be avoided, thereby obtaining more favourable survival rates (Munro and Bell 1997, Doherty 1999).

Wild adult abalone have also been transplanted in an attempt to increase the reproductive potential of depleted populations and to improve natural production (Henderson *et al.* 1988, Emmet and Jamieson 1989), and have met with some success (Tegner 2000). The most important aspect of abalone stocking, however, remains the introduction of the cryptic, juvenile stages of abalone.

While there is a perception that, larger juveniles will survive better than smaller ones owing to their ability to escape predation (Munro and Bell 1997), this is not necessarily the case for the juvenile stages of abalone. Saito (1984) demonstrated that survival is size-dependant for *H. discus hannai*, as did Zhao *et al.* (1991) with the same species. In contrast, Schiel and Weldon (1987) found no differences in predation rates between two size classes of *H. rufescens* in the laboratory and Schiel (1992) found no first order effect of size on survival in field trials using *H. iris*.

Hatchery Bred Seed

There has been a growing realization that hatchery raised juveniles have poorer survival rates than their wild conspecifics because they have not adapted to the natural environment (Howell 1994). In some cases wild caught animals have been transplanted to overcome this problem (Kojima 1981, Tegner and Butler 1985). The reduced fitness of hatchery seed is postulated to occur because of a reduced tolerance to stress and an increased vulnerability to predation (Munro and Bell 1997). Reduced tolerance and a higher vulnerability to stress may occur because of poor nutrition and a lack of sensorial and behavioural stimulation in the hatchery environment (Olla *et al.* 1998). Schiel and Weldon (1987) demonstrated clear differences in survival between hatchery and wild juvenile *H. rufescens* in a simulated natural habitat. Similarly, transplanted wild juvenile *H. iris* showed a higher survival rate than hatchery raised animals (Schiel 1992). Many of these problems can be overcome by preconditioning or acclimation of seed prior to release (Cowx 1994), with acclimated animals having better survival rates than un-acclimated counterparts. Another cause of decreased fitness in hatchery raised juveniles stems from the use of low numbers of broodstock and the selection for desired aquaculture production traits, which can lead to a loss of genetic variability and consequently a decreased ability to survive in the wild (Smith and Conroy 1992, Sweijd 1999).

Handling and Transport

The condition of seed can also be significantly affected by handling, transport conditions and shipping time prior to release (McCormick *et al.* 1994), but this issue is not widely addressed in the literature (Shepherd *et al.* 2000). Mortality even before release can be high (Schiel 1993) and steps need to be taken to ensure that seed quality is not compromised by poor transport methods. This has led to the use of collector-transporters such as those advocated by Ebert and Ebert (1988) and Sweijd *et al.* (1998). Anaesthetics have also been used to minimize transport stress and De Waal (2001) showed that the survival of *H. midae* was not affected by the use of magnesium sulphate during packing and transport of seed as long as sufficient time was allowed for the seed to recover prior to introduction into the natural environment.

Release Method

The complementary issues of release methodology and artificial habitat provision have received attention in Haliotid enhancement efforts. The use of release modules stems from the need to minimize the stress associated with handling and transport and to protect abalone seed from predation, while individual hand-seeding is seen as labour intensive and inefficient (Ebert and Ebert 1988, Tegner and Butler 1989). Various methods have been used to protect seed after being reintroduced into the natural environment. Momma (1972), Tegner and Butler (1989) and Seki and Taniguchi (2000) used oyster shells in wire baskets to protect seed. Tegner and Butler (1989) also used plastic sheeting to exclude predators and McCormick *et al.* (1994) used plastic tubing placed inside chicken wire to protect the abalone seed. Ebert and Ebert (1988) used a "collector-transporter" made out of PVC pipes placed inside a concrete box which had a delayed time-release mechanism to maximize seed survival. The trials conducted by Sweijd *et al.* (1998) and De Waal (2002) have employed a similar device to the "collector-transporter" mentioned above, to release *H. midae* seed.

Timing of Release

The timing of release has also been shown to influence survival rate for some species (Leber *et al.* 1997), and Shepherd *et al.* (2000) postulated that abalone are best released during late afternoon, when fish predation is likely to be at its lowest. Seki and Taniguchi (2000) also found time of year was an important factor when seeding *H. discus hannai*.

Habitat

The reliance of juvenile Haliotids on cryptic refuges for survival is well documented, but quantification of suitability presents theoretical and logistical problems. This is especially true if large areas are to be seeded, for example, during ranching operations. Kojima (1981) showed that seed survival depended on the amount of protection that a particular habitat provided. The provision of artificial substrates has been shown to improve seed survival (Inoue 1976). In addition, artificial substrates have been used to monitor abalone abundance and these have been shown to support significantly higher densities than the natural habitat (Hayashi and Yamakawa 1988).

Of particular interest is the role that sea urchins can play in the provision of cryptic refuge for juvenile Haliotids and their importance to survival. Sea urchins are known to be an important group in temperate water ecosystems (Andrew 1993), especially in the creation and maintenance of so-called barren environments (Andrew and Choat 1985, Shepherd and Godoy 1989, Day and Branch 2000a, Day and Branch 2000b). Furthermore, interactions between abalone and sea urchins have been postulated for some time (Tegner and Levin 1982, Andrew and Underwood 1992, Day and Branch 2000a, Day and Branch 2000b). These interactions may be negative (*i.e.* competition for food, Shepherd 1973) or beneficial (*i.e.* urchins providing shelter, fulfilling a food-trapping role or maintaining favoured substrate for settlement, Tegner and Dayton 1977, Day and Branch 2000b). Most importantly, Rogers-Bennett and Pearse (1998) found that *H. rufescens* seed recovery was higher in areas where urchin spine canopy microhabitat was available and Kojima (1981) found seed *H. discus discus* sheltering under sea urchin spines. Day and Branch (2000a) showed that the presence of wild juvenile *H. midae* is closely correlated with the presence of the sea urchin, *Parechinus angulosus*, and that the abalone strongly favoured under-urchin refuge in the area where these experiments were performed. These observations have led to postulations that *H. midae* juveniles depend on the presence of sea urchins for survival (Tarr *et al.* 1996, Day and Branch 2000a). By inference, this would mean that *H. midae* seed would also depend on sea urchins for survival. In contrast, De Waal and Cook (2001) has demonstrated that the presence of sea urchins was not essential for the survival of *H. midae* in seeding trials conducted off the coast of the Northern Cape Province in South Africa.

Stocking Density and Growth

The choice of how many animals to introduce into a specific environment also needs to be considered before stocking is undertaken (Cowx 1994, Howell 1998). Stocking density can influence survival rate and growth, and while each site's carrying capacity is likely to be locale-specific depending on available habitat (De Waal and Cook 2001, De Waal 2002), some idea of appropriate stocking densities can be obtained from the measurement of the biomass of unexploited populations (Munro and Bell 1997). Future mortality and dispersal of seed, and the abundance of other species filling a similar trophic role also needs to be taken into account.

The question of seed growth rate is also addressed in this study. The growth rate of seed is important because it determines how soon the abalone will reach harvestable size, which is critical to the economic sustainability of any seeding project. Growth rate will also determine how soon seed can begin to contribute to the reproductive output of the stock (Day and Fleming 1992). Variation in growth rates over time may also be used to monitor density-dependent effects resulting from possible food limitation.

Aim and Objectives

The aim of this study was to investigate the feasibility of seeding hatchery-raised *H. midae* juveniles into an area depleted by overfishing. A series of trials were conducted to investigate various aspects of the seeding process with the implementation of commercial ranching in mind. These included studies on the influence of large-scale habitat variation on seed survival, small-scale habitat requirements of seed, seed growth, and the influence of seed size, stocking density and release method on seed survival.

The trials were conducted in chronological order with the results of the previous ones determining the focus of the subsequent trials.

- In Trial 1, there was an emphasis on releasing relatively large numbers of cultured juvenile abalone into the three main habitat types at Cape Recife (described in Chapter 2). The influence of macro-scale habitat differences on seed survival were investigated as well as seed identification and growth.
- Owing to poor diving conditions encountered in the open-ocean during the previous trial, Trial 2 was conducted in a large sheltered rock pool, which had suitable habitat for juvenile abalone. Small-scale variation in habitat suitability, seed size and stocking density were investigated in relation to short-term seed survival.
- Trial 3 was conducted over a longer time period in the rock pool to measure the effects of habitat and seed size on survival. Seed growth was also measured.
- Due to the very sheltered conditions encountered in the rock pool, it was hypothesized that the survival rates measured there would not be applicable to the open-ocean environment. Trial 4 released seed into a less sheltered habitat where the effects of habitat on seed survival were investigated.
- The results of Trial 2 were not conclusive in determining whether habitat suitability, seed size and density played a role in seed survival. As a result, Trial 5 used a more stringent experimental protocol to quantify these effects.
- The release methods used in the four previous small-scale releases were time consuming and it was hypothesized that they may not be appropriate for the release of large numbers of seed abalone in the open-ocean habitat. Two different methods of releasing seed were therefore compared in Trial 6. The effect of seed size on survival and seed growth were also measured.

- The results of the previous trial showed that the release of seed using surface-scattering may be appropriate for large-scale releases in the open-ocean environment. This hypothesis was tested in Trial 7 by measuring medium-term survival after having released large numbers of seed using the surface-scattering release method. Seed growth was also measured.

GENERAL METHODS

Seed

An abalone farm, Marine Growers (Pty.) Ltd. supplied all the abalone seed used in the stocking experiments. Adult abalone collected from within the study area were used to produce the seed abalone, which were held under normal grow-out conditions. In cases where it was important to use a uniform seed size the animals were taken from the same grow-out basket or from adjoining ones with the same life history and stocking densities.

Predation

A list of potential abalone predators was compiled during diving and seeding operations at Cape Recife.

Data Analysis

Statistical analyses were performed using *Statistica 6.0* for Windows®.

TRIAL 1 – EFFECT OF LARGE-SCALE HABITAT VARIATION ON SEED SURVIVAL

Introduction

Wood (1993) recognized two broad habitats used by *H. midae* at Cape Recife. This study was conducted over a wider area in the same vicinity and at least three main habitats were identified as being utilized by *H. midae* (see Chapter 2, Table 2.1). This experiment set out to compare survival between these three different areas. Variation in survival between the different habitats would be important for planning and implementing large-scale ranching operations.

Methods

Tagging and Growth

Although the seed abalone exhibited a distinct colouration from their diet on the farm, it was not known whether this would be sufficient to identify them after being placed in the sea. All the seed abalone were therefore tagged using Hallprint® shellfish tags. They were made of depolarized polyethylene to enhance adhesion using Cyanoacrylate type glues ("Superglue"). The tags were rectangular in shape (9mm by 4mm), with rounded ends and were yellow in colour. They were 0.18mm thick enabling them to conform to the abalone shell. A unique alphanumeric code on each tag enabled the identification of each seed abalone, which would also enable the collection of accurate growth data.

The abalone that were used in this experiment were tagged over a period of 14 days. Each abalone was placed on a moist sponge to get rid of excess moisture before the tag was affixed. A small bead of glue was placed on the shell next to the spire and a tag was pressed into it using forceps. The shell length was then recorded along with the tag's code, while the glue was allowed to set. If the abalone could not be replaced into water within a few minutes it was sprayed with a fine mist of seawater to prevent dehydration and additional stress. During the tagging process each individual abalone was kept out of seawater for the shortest possible time (maximum 5 minutes). Tagged abalone were placed in the standard farm baskets in batches of either 500 or 1000 until they were seeded. During tagging the juvenile abalone appeared to be more stressed when the water temperature was high. For this reason tagging operations were not conducted when the water temperature was over 24°C, although it was usually below 22°C.

Tag loss proved to be a problem prior to release. The period between tagging and release varied between 112 and 152 days. Dislodged tags were counted on a regular basis. Losses ranged between 10.6 and 44.8% with a mean of 25.5% for each basket and increased with time before release (Figure 3.1). Mortalities in the baskets prior to seeding were relatively low and ranged between 2.7 and 6.5% with a mean of 4.5% per basket (Figure 3.1) and occurred predominantly in the first and second week after tagging. Since mortality in the farm baskets is normally low, these deaths were likely to have been caused by a combination of stress associated with the tagging procedure and a warm water event that caused higher than usual mortalities throughout the farm during the same period.

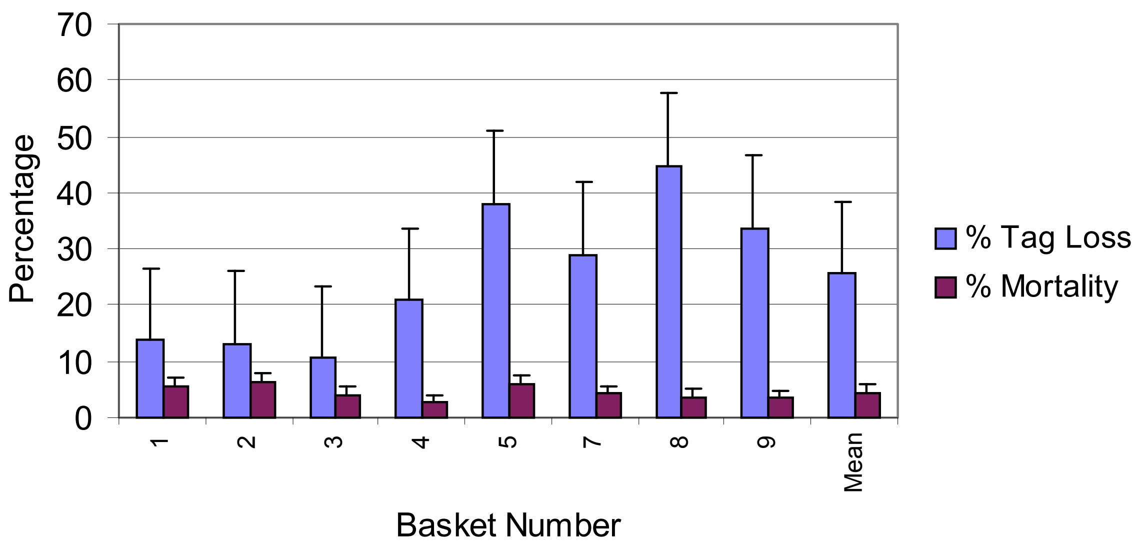

Figure 3.1 Tag loss and mortality of seed in farm baskets prior to release in Trial 1 (+1 SD)

When the seed were released they had grown considerably since they were tagged and measured and a second measurement of each animal was not possible due to time constraints. Two subsamples were taken to obtain an estimate of growth during this time.

Seeding Areas and Experimental Design

Site selection was undertaken in conjunction with the assessment of the status of the existing natural abalone stock within the study area (see Chapter 2). Reconnaissance dives from the shore and from a boat were performed in order to find suitable areas for seeding. As previously mentioned, three broad habitat categories were identified within the Cape Recife study area and this experiment was designed to compare survival between the different habitats.

Three seeding sites were chosen within each habitat type, although in the Boiler area (Habitat 2) an extra site was identified to perform a trial release. A solid substrate was obviously the primary criterion for selection but once this had been fulfilled, reconnaissance dives were performed at each particular site to establish the presence of wild abalone and also the availability of cryptic habitat. This cryptic habitat often coincided with the presence of sea urchins. In addition the sites had to be characteristic of the area (see Chapter 2 and Table 2.1 for descriptions), while still being accessible for diving.

Six point releases were made of 1000 animals per site (2 release modules within 4m of each other) and 8 point releases were made of 500 animals (1 release module) each (Figure 3.2 and Table 3.2). Each site was marked with a heavy weight with a length of buoyant polyethylene rope attached to it.

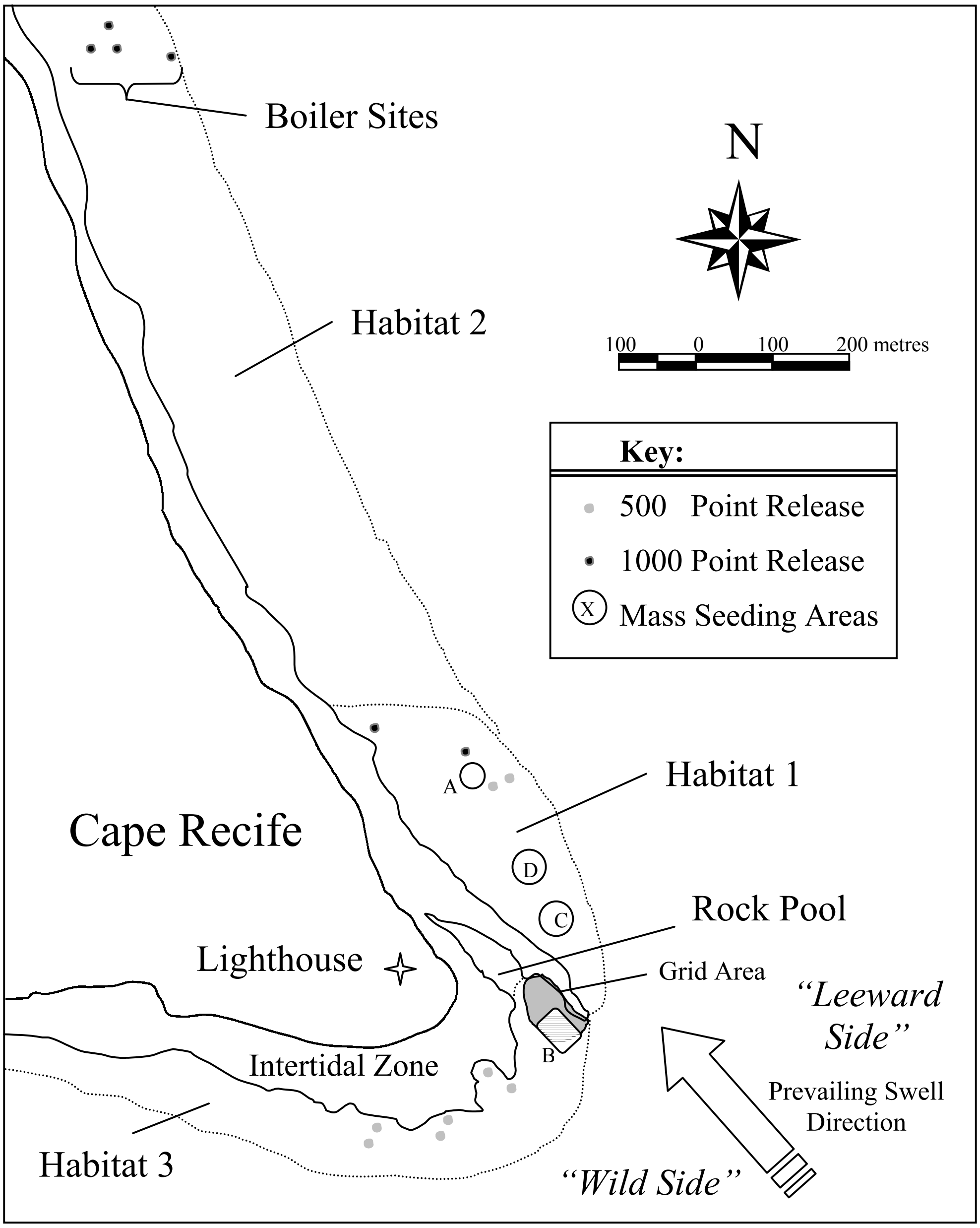

Figure 3.2 **Study site at Cape Recife, with the main habitat types and seeding sites indicated.**

Release Method

The success of *H. midae* seeding trials performed on the Namaqualand coast of South Africa using release modules (Sweijd *et al.* 1998, De Waal 2002), prompted the adoption of this method for releasing abalone in this trial. These release modules were very similar to that of the "collector-transporter" first described by (Ebert and Ebert 1988).

It consisted of a rectangular, flat PVC base-sheet (6mm thick) with lengths of PVC pipe of 250mm, 200mm, 160mm and 110mm diameter, cut in half lengthwise, attached to it (Figure 3.3). The pipes were nested over each other and were held in place either by two central vertical pipes (25mm diameter) or by welding them on to the base sheet. The box dimensions of the release module were approximately 350mm long by 300mm wide by 150mm high. A series of semi-circular holes were also provided at the intersection between the half-pipes and the base-sheet to permit the circulation of water through the release module.

Figure 3.3 Release module in place on the seafloor. Note the ballast weight attached to the underside.

On the day of seeding the basket containing the abalone was removed from the tank and placed into a water filled basin. The abalone were then quickly removed by hand from the basket and placed into the release module. If the holding basket contained 1000 animals they were divided between two release modules and therefore each contained approximately 500 animals. Perforated semi-circular plastic doors were secured to each end of the release module with a broad elastic band. This also served to cover the holes on the side. It usually took approximately 5 minutes to fill a release module and once each release module was loaded, it was replaced back into an aerated growout tank until departure for the study site. The release modules were then placed in polyethylene bins with wet sponge and ice packs above and below to ensure the animals did not dehydrate or become heat stressed during transport. Care was taken to ensure that the ice packs did not come into direct contact with the seed, since this can cause tissue damage.

Transport and Release

Once loaded into the release modules, the abalone seed were transported from the grow-out facility to the study area by road. It took approximately 75–90 minutes for the seed to be transported from the farm to the release site. A small semi-rigid inflatable boat was used to seed sites further offshore and apart from the experiments conducted in the rock pool (see below), only the calmest days were suitable for diving. As a general guide the South African Weather Bureau “Ski-boat Report” swell prediction needed to be <1.5m.

Immediately prior to deployment in the sea, heavy ballast weights made of lead or iron were attached to the base of the release module to minimize disturbance by wave action. Wherever possible the release modules were placed into or next to cracks or crevices, or in the lee of reefs to facilitate the movement of the seed abalone into natural cover. This also served to protect the release modules from strong surge that was usually prevalent at the release sites. The covers for the release modules were removed within one hour after deployment. During this period, the release modules, seed behaviour and predator activity were carefully observed. In many cases unfavourable sea conditions prevented the divers from making prolonged observations. The release modules were then left in place from anywhere between one and six weeks depending on when the sea was suitable for retrieval.

Sampling and Field Observations

Effective sampling of these sites proved to be extremely difficult. The shallow habitat where the abalone were seeded ensured that underwater sampling was severely curtailed owing to the prevailing surge or wave action. As a result sampling was done on an *ad hoc* basis whenever sea conditions allowed. The minimum interval between release and recovery was 174 days. Sampling was carried out by two divers who searched the substrate in a circular manner radiating from the centre of the seeding site for a distance up to approximately 15m. Moveable boulders and sea urchins were turned over, and crevices were searched.

The seeded abalone proved to be readily distinguishable from their wild counterparts due to their paler shells or distinctive banding which resulted from their farm diet (Figure 3.4). Seed abalone and shells (of dead seed) were collected and counted and a note was made of how many seed and shells had tags affixed to them. Wild abalone were observed but not disturbed. If there was any doubt as to the origin of the abalone they were kept aside for more thorough cleaning of the shells using a scrubbing brush and dilute hydrochloric acid.

Seed recovery was expressed as a percentage of the total number of seed released at each site. Tag returns were expressed as a proportion of the total number of seed or shells recovered. No statistical analyses were performed owing to the low number of recoveries.

The planned method of measuring growth rate could not be used owing to the long period between measurement and release, and the high proportion of tag losses. However, the shell colour of the seed underwent a distinct change when introduced into the wild (see Figure 3.4). This provided the opportunity to accurately measure growth after release without using the artificial tags (Rogers-Bennett and Pearse 1998). In some cases the colour change was not visible or was faded or overgrown. In the case of fading or overgrowth, mechanical and acid cleaning of the shells usually revealed new growth. The shell length at time of release was measured (using the distinct light-dark boundary), subtracted from the shell length at time of recovery and divided by the number of days at large to obtain a daily growth increment. Daily growth increments of adjoining sites within the same release habitat were then compared using Student t-tests or Mann-Whitney U tests if the data was not normal or could not be normalized. The growth increment data was pooled if no significant differences were found between groups. A Kruskal-Wallis ANOVA test was then used to compare sites or areas and *post hoc* Mann-Whitney U tests were used to test for further differences.

Results

Tagging

Tag returns from the seed after placement in the sea were relatively low. Only the first site searched (Prelim site) had a tag return of over 50% and these seed were held for the shortest time prior to release. The mean tag return from all live retrievals was 13%. The retrievals of shells (of dead seed) had a higher proportion of tags still in place, with a total of 39%. Despite the loss of these tags, the seeded abalone were generally easily distinguishable from their wild counterparts, owing to their distinctive colouration, especially in the first year after release (Figure 3.4).

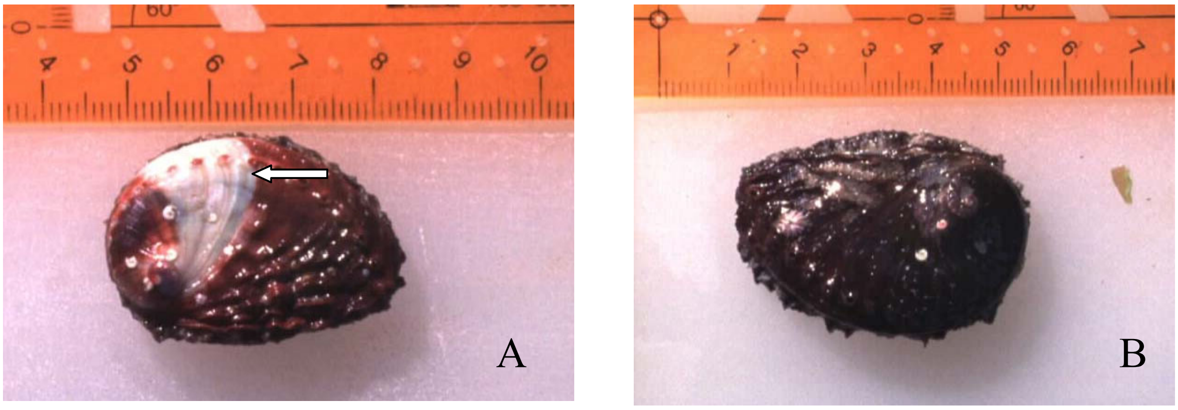

Figure 3.4 Contrast in shell colouration between cultured (A) and wild (B) juvenile *H. midae*. Note the marked change in shell colour (arrow) in the seed abalone after being introduced into the natural environment.

Seed Behaviour and Movement

Once the release module covers were removed, most of the seed appeared reluctant to move out of them immediately. A few that were close to the openings did begin to move towards a more cryptic position. In some cases this meant moving out of the release module and onto the natural substrate. These abalone then sought a cryptic position although these were not always immediately available. In these cases the seed were either left in the open or in a semi-cryptic position.

On the occasions that the release modules were visited the day after the release had taken place, most of the seed were observed to have left the release module. Although comprehensive searches were not conducted at this stage, so as not to disturb the seed or attract predators, the seeded abalone were observed in various positions on the adjoining reef. Most were in cryptic or semi-cryptic positions and some were noted under sea urchins. On one occasion a seed abalone was observed under an urchin while a wild juvenile abalone was occupying a non-cryptic position adjoining it.

The retrieval patterns of the seed were strongly associated with the release points and dispersion of the seed abalone did not appear to be significant. Most of the recovered seed were within a few metres of the release point, although in one case a single seed was found over 10m from the nearest release module after a period of two months. The emphasis on finding the maximum amount of surviving seed, which were generally more numerous closer to the release point, may have biased these observations. Some seed was also found inside the release modules up to six weeks post-release.

Predation

Several potential predators were observed in the study area during seeding operations (Table 3.1). Fish predators in particular were seen either consuming seed abalone or lurking with intent. It was interesting to note that large shoals of blacktail, *Diplodus sargus capensis*, were seen in the area where poaching activities had been occurring. These fish are normally wary of divers, particularly if using SCUBA, but they appeared to have lost their fear and approached within 1m of the research divers. When the divers began to remove emergent abalone or turn over boulders these fish became even bolder and would begin feeding within touching distance of the divers. It is surmised that this lack of fear may be linked to the poachers' propensity for shucking their catches underwater and stirring up sediment providing an easy meal for the fish. The attraction of predators in this manner to seeding sites is clearly counter-productive.

Octopus spp. are significant predators of small to medium *H. midae*, and on one occasion, during the deployment of a release module, a large octopus was seen making directly for a release module from at least 15m away. It was removed from the immediate area.

Table 3.1 **List of potential predators of juvenile *H. midae* observed during this study. Those marked with an asterisk were actually observed attempting to consume seed abalone.**

Species **or Group**	**Common Name**
Actiniaria*	Sea Anemones
*Boopsoidea inornata**	Fransmadam
Chirodactylus brachydactylus	Twotone Fingerfin
Chorisochismus dentex	Rocksucker
Clinidae*	Klipfish
*Clinus superciliosus**	Giant Klipfish
Diplodus cervinus hottentotus	Zebra
*Diplodus sargus capensis**	Blacktail
Gobiidae*	Gobies
*Gymnocrotaphus curvidens**	Janbruin
Lithognathus lithognathus	White Steenbras
*Octopus vulgaris**	Octopus
*Plagusia chabrus**	Cape Rock Crab
*Rhabdosargus holubi**	Cape Stumpnose
Sparodon durbanensis	Musselcracker

Very few shells were found relative to the number of unaccounted for seed abalone. In some cases only shell fragments were found, but it could not be determined whether the damage had occurred before or after death. Of all the shells that were collected, 27% (n=55) had bevelled drill-holes in them. In several cases more than one hole was found in a shell. It is surmised that these were made by *Octopus spp. b*ut this is purely speculative since other organisms are also known to drill their prey. For the sites that were searched, the average number of shells that were found equalled 1.6% of the total number of seed unaccounted for.

Survival

Owing to poor diving conditions only six effective searches were conducted during this experiment and two sites were visited twice. The nature of the substrate proved to be another significant constraint to effective searching. The sites where the predominant substrate consisted of solid rock were very difficult to search. In particular Boiler sites 2 and 3 had vertical fissures (approximately 1–1.5m deep and 10–30cm wide) which then flared out at the bottom creating a secondary level which provided apparently ideal habitat for cryptic abalone. Access to these areas was extremely limited. Comprehensive estimates of survival of abalone were therefore not obtained. Table 3.2 summarizes the average seed size, number released and recovery for each site.

Table 3.2 Summary of sites seeded in Trial 1.

Habitat	Site	Mean Size @ Release (mm)	No (n)	Recovery (%- First search after x days)	Comments
1	Beacon 1	33.2	1000	3.9 (212)	Not comprehensively sampled.
1	Beacon 2	42.2	966	3.1 (314)	Not comprehensively sampled.
1	Beacon 3a	29.2	482		Not sampled.
1	Beacon 3a	29.2	482		Not sampled.
2	Boiler Prelim	31.1	943	2.1 (174)	Not comprehensively sampled.
2	Boiler 1	33.0	935	3.1 (176)	Not comprehensively sampled.
2	Boiler 2	32.9	959		Not sampled.
2	Boiler 3	32.2	973		Not sampled.
3	Wild Side 1a	36.5	473		Not sampled.
3	Wild Side 1b	36.5	473		Not sampled.
3	Wild Side 2a	28.4	500		Not sampled.
3	Wild Side 2b	28.4	500		Not sampled.
3	Wild Side 3a	33.5	479		Not sampled.
3	Wild Side 3b	33.5	479		Not sampled.

Growth

Growth was quite variable between sites and ranged from 5.8–29.2mm.year^{-1} (Table 3.3). The mean for all plots was 17.5mm.year^{-1} (±11.68 SD).

Table 3.3 **Summary of growth rates measured in Trial 1.**

Site or Area	Valid n	Mean Daily Growth (mm)	Minimum Daily Growth (mm)	Maximum Daily Growth (mm)	Std. Dev.	Mean Annual Growth (mm)
Prelim	14	.016	.004	.041	.011	5.84
Habitat 1	41	.080	.040	.106	.014	29.2
Boiler 1	36	.048	.024	.077	.013	17.52

In three of the six retrieval samples the data were not normally distributed and no suitable transformations could be performed to rectify this. As a result some non-parametric analyses were used. No significant differences were found between the growth increments from the same site when sampled at different times even though the time at large varied by up to 197 days. This suggests that season did not influence growth rate of abalone. When the data from Beacon 1 were compared to Beacon 2 within the same general habitat area, no significant differences in growth increments were found. These data were then pooled and a Kruskal-Wallis ANOVA by rank showed significant differences between this area and the other two groups (Pooled Boiler 1 and Boiler Prelim; H (2, n=91) =64.29, $p<0.001$). *Post hoc* Mann-Whitney U tests showed significant differences between all groups (Table 3.4).

Table 3.4 **Results of Mann-Whitney U tests comparing three groups of growth data (not significantly different; Boiler Prelim, Boiler 1 and Habitat 1), two of which consisted of pooled data from the same plot and/or area (indicated by asterisk).**

Group	Group	Z	p
Boiler Prelim	Boiler 1*	-5.07760	<0.001
Boiler Prelim	Habitat 1*	-5.526	<0.001
Habitat 1*	Boiler 1*	6.585	<0.001

Gonad Development

Eighty-eight percent (15/17) of the retrievals from one site (Beacon 2) showed gonad development and could be sexed, after 413 days at large. Their size ranged from 57.3–74.3mm SL.

TRIAL 2 – SHORT-TERM EFFECTS OF DENSITY AND HABITAT ON ABALONE SEED SURVIVAL

Introduction

Poor sea conditions and low catchability hampered a satisfactory completion of Trial 1 and raised seemingly intractable problems with respect to the assessment of seeding trials at Cape Recife. This left most of the questions that were posed in that trial unresolved. The use of a more controlled environment was seen as a pragmatic alternative. The rock pool described in Chapter 2, which supported large amounts of wild juvenile *H. midae*, offered an environment that was more conducive to thorough experimentation. A substrate consisting largely of moveable boulders and calm water at low tide, meant that research divers could conduct their work more effectively.

Even though seeded abalone can exhibit elevated mortality for several months after introduction (Shepherd *et al.* 2000), the measurement of survival rates soon after introduction can be used to test the effects of the factors which may affect survival. It may also be used as an indicator of future survival.

The availability of suitable cryptic habitat is known to be important for the survival of juvenile abalone, but what determines this suitability is often not clear. This experiment set out to make meaningful estimates of habitat suitability and to test their influence on short-term seed survival. Although sea urchins do occur in the Eastern Cape Province, the habitat found here is very different from the south-western Cape (Day and Branch 2000a) and it was important to find out if the presence of sea urchins could influence the abundance and occurrence of wild juvenile *H. midae*, and by extension the survival of seed abalone. The abundance of wild juvenile abalone was also chosen as a way in which to measure habitat suitability for seed abalone. Reef rugosity, a ratio of the minimum distance between two points against the actual distance measured over the seafloor, is used as an index of relief (available open habitat), but does not take into account under-rock spaces which are utilized by juvenile abalone. This method was therefore adapted to take into account under-rock area and tested as a measure of habitat suitability. If habitat measures are to be used as indices of seeding site suitability, they should be applicable on a large-scale since ranching operations will be conducted over large areas. With this in mind, the number of large rocks within the seeding sites were counted, and a habitat suitability rank was assigned to each site to provide a rapid habitat assessment method. Abalone seed was also introduced at different densities to test its effect on survival.

Methods

Seeding Area

This trial was conducted over a 12-day period in December 1999 in a wide, shallow, rock pool due east of the Cape Recife lighthouse (see Figure 3.2). The pool was 0–0.5m deep at MSLW and was characterized by barren, rocky and sandy substrates. At low tide the pool was protected from the open ocean by an intertidal boulder berm on its eastern side and a narrow opening to the south. The actual study area was located mainly on the eastern edge where wave action had deposited boulders, approximately 10–50cm in diameter, resulting in a more complex 3-dimensional habitat (Figure 3.5). The relatively calm conditions in the rock pool had allowed large amounts of particulate organic matter and silt to deposit on the exposed surfaces. Very little algal growth was therefore present on the upper surface of the rocks, with few associated macroscopic benthic animals. The undersides of the boulders had a suite of fauna and flora, which seemed typical of the Cape Recife area (Figure 3.6). Of particular relevance, was the presence of crustose coralline algae on the exposed under-sides of the rocks. Juvenile *H. midae* and the sea urchin *Parechinus angulosus* were common in this habitat (See Chapter 2). One other rare endemic species of abalone, *H. parva* was found occasionally. Drift algae were relatively common amongst the spaces between the cobbles and were usually *Plocamium corallorhiza*. The water was very still at low tide and the rock pool appeared to act as a natural trap at times. The mean temperature recorded was 21.1°C and it ranged between 18.3°C and 27.5°C for the duration of the experiment.

Figure 3.5 Typical seeding substrate in the rock pool. Note silt-smothered upper surfaces of rocks.

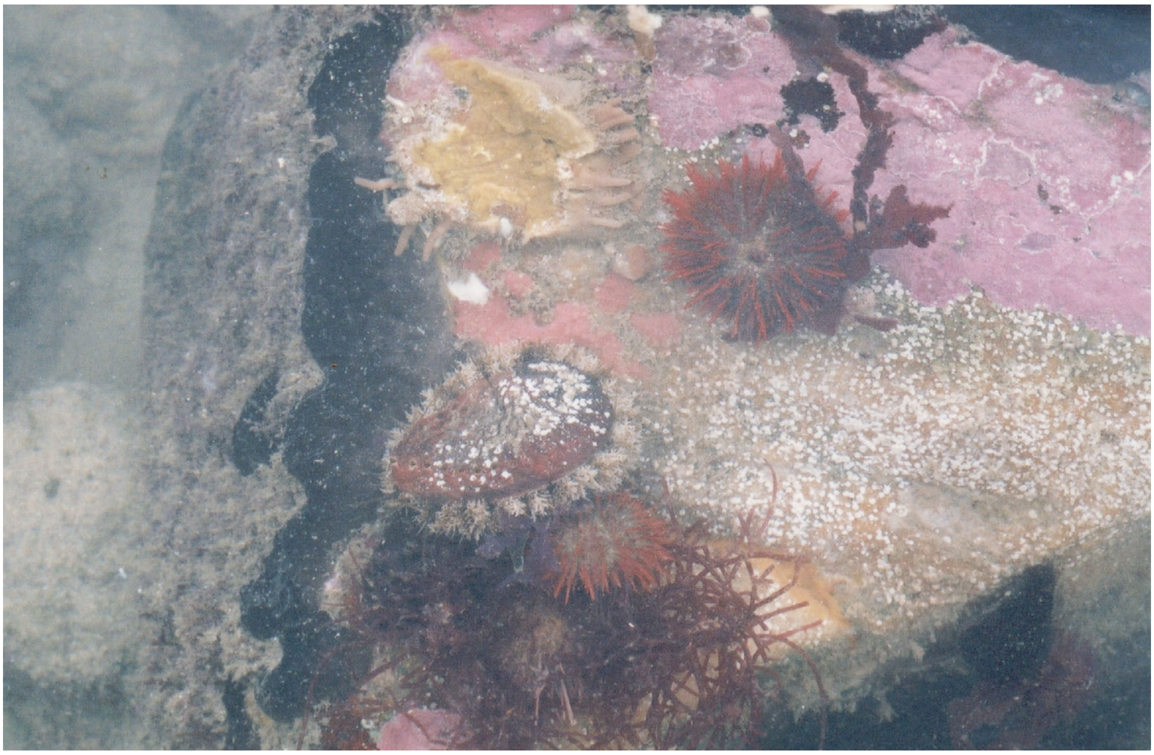

Figure 3.6 Underside of a rock found in the rock pool. Notice presence of crustose coralline algae, sea urchins, and immature *H. midae*.

Experimental Design

Prior to the delineation of the experimental plots, rocks were turned over to determine the presence or absence of juvenile abalone in the study area. Once it had been established that the area supported juvenile *H. midae*, nine plots were chosen and marked with prominent boulders or metal weights. Areas were chosen that included a large number of boulders, which provide vital cryptic habitat for juvenile abalone. Six rectangular (2m x 5m) and three circular (1.74m radius) experimental plots of 10m^2 each were set out at least 7.5m apart (Figure 3.7). The nine sites were randomly allocated abalone-seeding densities of 10, 20 or 40m^{-2}.

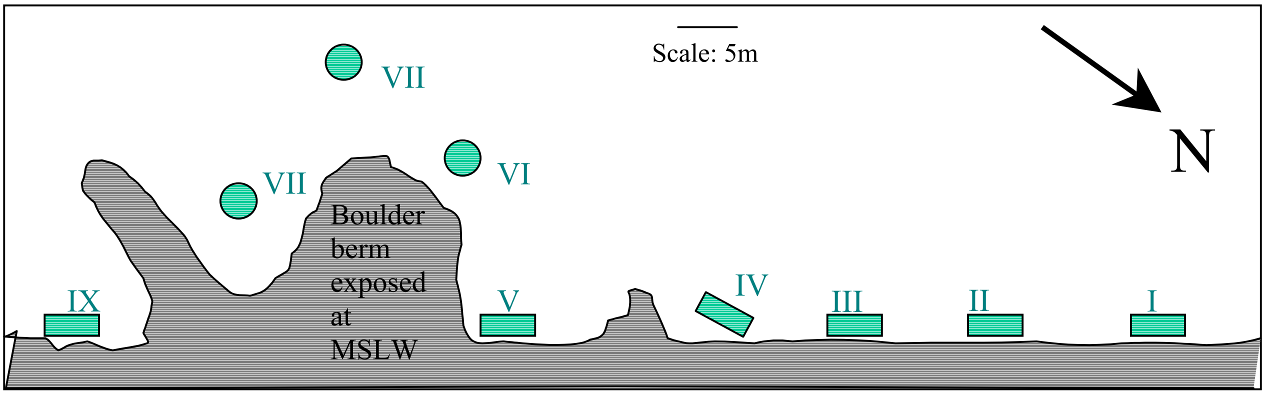

Figure 3.7 **Schematic illustration of experimental plot layout in the rock pool for Trial 2.**

Seed

The juvenile abalone used in this experiment were spawned 15 months previously. They had a mean shell length of 17.7mm (±2.3 SD). Two days before the actual seeding experiment began, the juvenile abalone that were to be used, were sorted into holding baskets. The abalone were anaesthetized using magnesium sulphate to facilitate handling, but recovered rapidly once returned to normal seawater.

Since there was some concern that the seed might migrate between the plots during the course of the experiment and therefore bias the survival estimates, four of the nine batches of animals were marked to enable the identification of seed from adjoining plots. Marking was done when the abalone were sorted into the holding baskets, using a miniature-grinding disc attached to a battery-operated hand-drill. The grinding disc was used to cut a shallow groove (approximately 0.6 x 2mm), into the upper shell layer next to the spire, so as to expose the nacre, to enable easy recognition. The abalone did not appear to suffer any adverse effects from the batching and marking process and no mortalities were recorded in the holding baskets on the abalone farm prior to seeding.

Release Method

During Trial 1 theoretical and practical constraints were noted with the use of the release modules and this is discussed at the end of this chapter. While handling of seed is known to increase stress, it was nonetheless seen as an alternative to the release modules. Hand seeding can also enable a more uniform seeding density to be achieved. The rectangular plots were seeded using two 1m^2 quadrats to assist the divers to seed the abalone at the correct densities. These were laid out next to each other and then flipped end-over-end down the length of the plot (Figure 3.8A). In the case of the circular plots a 2m^2 pie-shaped quadrat was rotated around the central marker until the whole plot had been covered (Figure 3.8B).

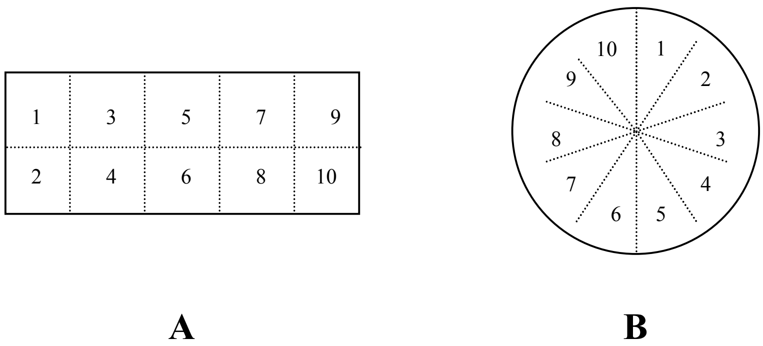

Figure 3.8 Schematic illustration of the method of laying out 1m^2 quadrats for releasing seed in the rock pool. A - illustrates the layout of the square quadrats in the rectangular plots and B - illustrates the layout of the pie-shaped quadrats in the circular plots.

A team of four people was used to seed the abalone into their respective plots. Since the water was very shallow, the only breathing equipment that was required by the divers was a snorkel. Two people stood in the shallow water with the appropriate holding basket and counted out the correct number of abalone that were required for each square metre. The abalone were placed, individually or in clumps of a few animals, into crevices or near to boulders. Wherever possible the abalone were distributed evenly throughout each square metre of the plot. In practice the seed abalone were often clumped owing to the heterogeneous nature of the substrate. Experience showed that the seed were quick to react once introduced into the water and did not need to be placed directly into a crevice or similar refuge. Care was also taken to prevent fish and other predators that were close by from interfering with the seed until they had gained a safe refuge.

Sampling and Field Observations

The boulders which were on the surface of the smooth underlying substrate, which consisted of flat rock or compacted sand, were easy to move which meant all cryptic habitats could be exposed. The plots were searched by flipping quadrats in the same manner to the way they were seeded (Figure 3.9A and B). Rocks and boulders were picked up or rolled away, with great care being taken not to crush or overlook any abalone. Once the plot had been searched, a one-metre wide fringe area was searched, followed by a second, one metre wide fringe (Figure 3.9). In this manner the plots were systematically searched, and all abalone (both wild and seeded), were collected. All the recovered abalone, both seeded and wild were characterized as being found under urchins or not under urchins. The shell lengths of all the wild and seeded abalone found under sea urchins were measured.

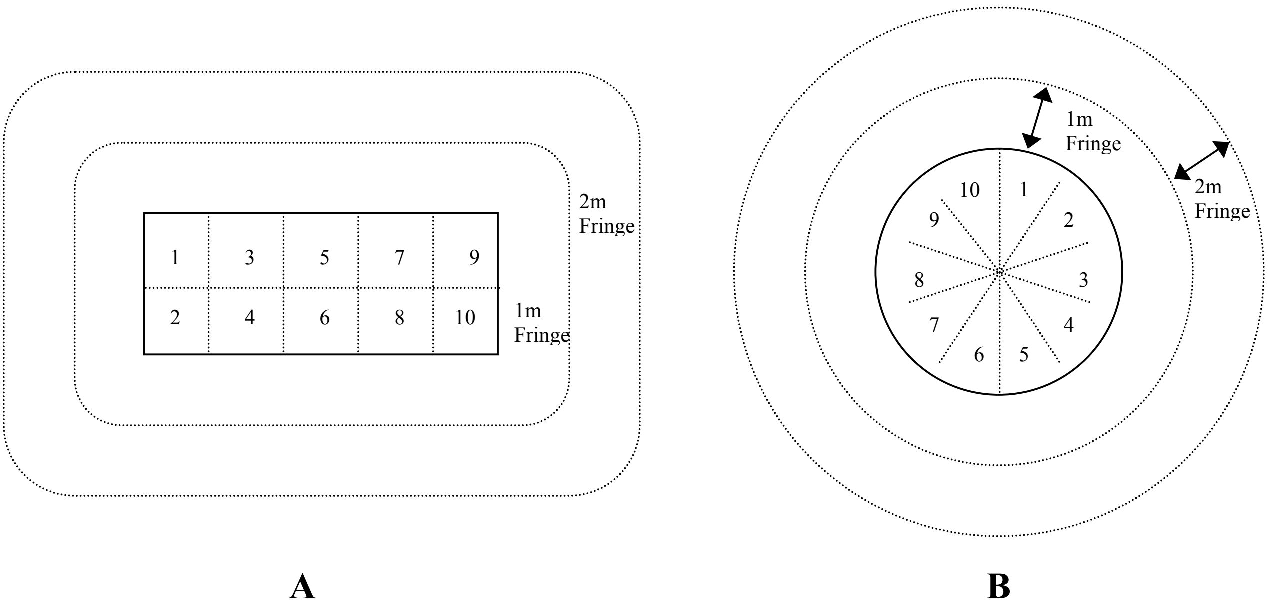

Figure 3.9 Schematic illustration of the method of sampling the plots in the rock pool. Note the 1m wide fringe areas that were searched to test for seed dispersal. A- sampling strategy in rectangular plots. B - sampling strategy in circular plots.

Habitat Assessment

When the plots were marked out, a subjective assessment of habitat suitability was performed on each one. A value between 1 and 5 (including positive or negative signs for borderline cases) was assigned after consensus had been reached between the two members of the research team who had experience in abalone fieldwork. This index was based on the apparent number of refuges that the plot could provide for juvenile *H. midae*. A site ranking of 5 indicated "ideal" seeding habitat to maximize survival, 3 indicated a site with average refuge availability (usually with at least 50% of the site covered by boulders) and 1 was the lowest rank, indicating flat, open substrate. At the same time the number of rocks with at least one dimension longer than approximately 30cm were counted, to provide another potential indicator of habitat suitability.

Before the plots were destructively sampled, another habitat grading technique was employed. Under-rock habitat area was expressed as a proportion of the total area. In the case of the rectangular plots a tape measure was laid down the length of the plot 30cm from each edge and in the centre. Two members of the dive team who were familiar with juvenile abalone habitat then counted how much of the substrate that fell under the tape measure would provide potentially suitable refuge for juvenile abalone. With the circular plots a similar technique was used except that the tape measure was laid through the centre of the circle and at least five evenly spaced diameters were counted.

Sea urchin and wild abalone density as a potential predictors of habitat suitability (*i.e.* influence on seed survival) was also measured. All the wild abalone were collected but, due to time constraints (the rock pool could only be sampled at low tide), four random quadrats from each plot were sampled for sea urchins. The diameter (including spines) of each sea urchin was also measured.

Data Analysis

Density

To test for similarity between survival between sites seeded at the same density, a Chi-square analysis was performed. The mean survival rate for each density was used as the expected value and deviations were calculated using the actual numbers of seed surviving and not percentage survival.

Size Differential Mortality

To test whether seed size was influencing survival, the released seeds' initial size distribution was compared to the retrieved seeds size distribution for each plot. A one-way ANOVA was used and Tukey *a posteriori* tests for unequal *n* were performed to assess where any differences lay. It was assumed that the growth increment for this short duration experiment would be negligible. The slow growth rate of abalone and the fact that the handling and stress of seeding would likely retard growth, albeit briefly, would tend to support this assumption.

Habitat

The habitat parameters were regressed with ARCSINE transformed percentage survival data, as suggested by Zar (1999) for proportional or percentage distributions, to test for potential relationships. Normality was assumed for the habitat parameters.

Sea Urchins

To assess the role that sea urchins play in the provision of refuge for seed and wild juvenile *H. midae*, a similar analysis to that used by Day (1998) was employed. In addition to the regressions outlined above, an index of selectivity of seed and wild abalone for under-rock or under-urchin habitat was calculated using Gabriel's (1978) method (cited in Day 1998). It was calculated using the following equation:

$$W = p_1q_2/p_2q_1 \ ,$$

where p_1 is the percentage of abalone occupying either under-rock or urchin habitat; p_2 is the percentage area available under rocks or urchins; $q_1 = (100 - p_1)$ and $q_2 = (100 - p_2)$. In logarithmic form W gives values between plus or minus infinity, with negative values indicating avoidance and positive values indicating active habitat selection. A value of zero indicates no selection for habitat.

The total area occupied by urchins in each plot was calculated using the formula: $Area_u = Pi.(d/2)^2.D$, where d is the mean diameter of the sampled urchins in each plot, including spines, and D is the mean density of urchins in each plot. The percentage contribution of under-urchin habitat was calculated using the formula: $\%_u = Area_u/10m^2.\%$ *area under-rock*, since all urchins were found under rocks. The method for calculating the proportion of under-rock area is described above. The remaining under-rock space was assumed to be available for occupation by abalone hence the area was calculated using the formula: $\%_r = 1 - \%_u$.

The percentage of available substrate was also plotted against the proportion of abalone (either wild or seeded) and compared visually against a hypothetical 1:1 line. Data points falling close to or on the line would indicate a weak preference for that substrate (Day and Branch 2000a). In addition, this relationship was tested for significance using a Chi-square test where the number of abalone expected to be using a particular refuge was calculated from the proportional contribution of that substrate to the total available area and was compared against the actual number occupying each substrate.

Results

Movement

An overall average of 13.3% of abalone were retrieved outside the immediate confines of the plots. These were, however, all found within 1m of the boundary and in most cases immediately adjacent to the edge of the plot, even though the 2m fringe was always searched. There was no evidence of mixing between marked and unmarked animals in different plots.

Survival

Since the plots were destructively sampled and the type of substrate was conducive to effective searching, it was assumed that most of the surviving seed were accounted for. The survival estimates presented here and indeed throughout this study must however still be seen as minimum figures as they are based on numbers of animals retrieved. The mean total survival for all 3 treatments was 68.2%. Table 3.5 shows actual returns for each plot as well as the percentage values and means (sample time varied between 7 and 10 whole days after release).

Table 3.5 **Seed and percentage survival from plots in Trial 2, grouped by stocking density.**

Seeding Density (m^{-2})	Seed Returns (n)	Seed Returns (%)	Group Means (%±1 SD)
	71	71.0	
10	73	73.0	73.0 ±2.0
	75	75.0	
	132	66.0	
20	105	52.5	55.5±9.4
	96	48.0	
	344	86.0	
40	282	70.5	76.1±8.6
	287	71.8	
		Overall Mean: 68.2±12.3	

Density

The survival data for the 20 and 40m^{-2} density plots departed significantly from their means (Chi-square=6.32, df=2, $p<0.04$ and Chi-square=7.80, df=2, $p<0.02$ respectively; Figure 3.10). Further comparisons between the different density groups were therefore not attempted.

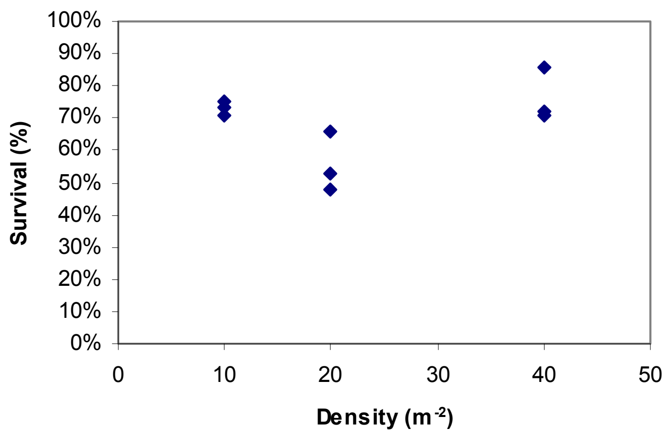

Figure 3.10 **Plot of seeding density and survival from Trial 2 (grouped by seeding density).**

Size

Some variation was noted between the released and retrieved seed sizes in the different plots (Figure 3.11). One-way ANOVAs comparing within-group variation found significant differences in the $10m^{-2}$ density plots (df=2, F=4.858, p<0.011). Tukey *a posteriori* tests, however, failed to show any differences in this group. The significance is likely to be an artefact resulting from the unequal sample sizes (Pers. Comm., S. Radloff, Dept. of Statistics, Rhodes University, 2001). An ANOVA of pooled treatments also failed to show significant size related differences. Furthermore, a t-test performed on the pooled plot retrievals and the initial seed size data also showed no significant differences (df=459, t=0.638, p>0.5). Unfortunately, only the size of the seed found under sea urchins was recorded, but it was assumed that these animals were representative of all the seed abalone.

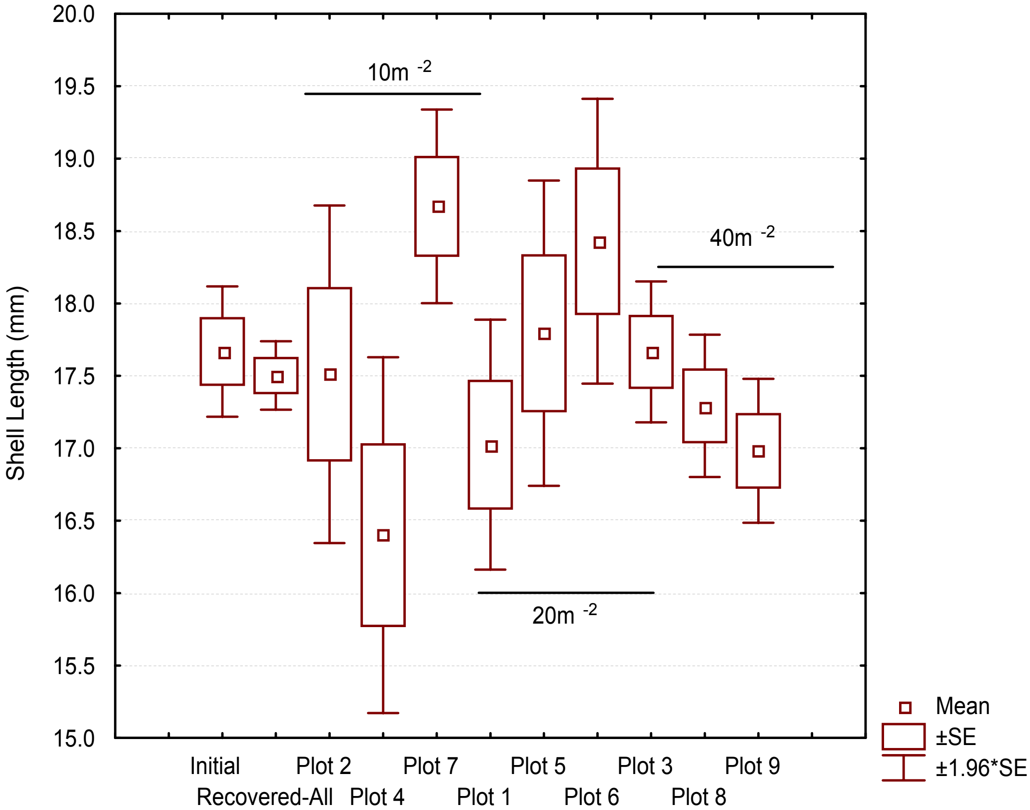

Figure 3.11 **Shell lengths of released and retrieved seed in Trial 2.**

Habitat

The results from the different density treatments were inconclusive, so the ARCSINE transformed survival data from all the treatments was regressed with the habitat parameters that were collected. The only significant correlations were between seed survival and wild density, and seed survival and urchin density (Table 3.6, Figure 3.12 and Figure 3.13).

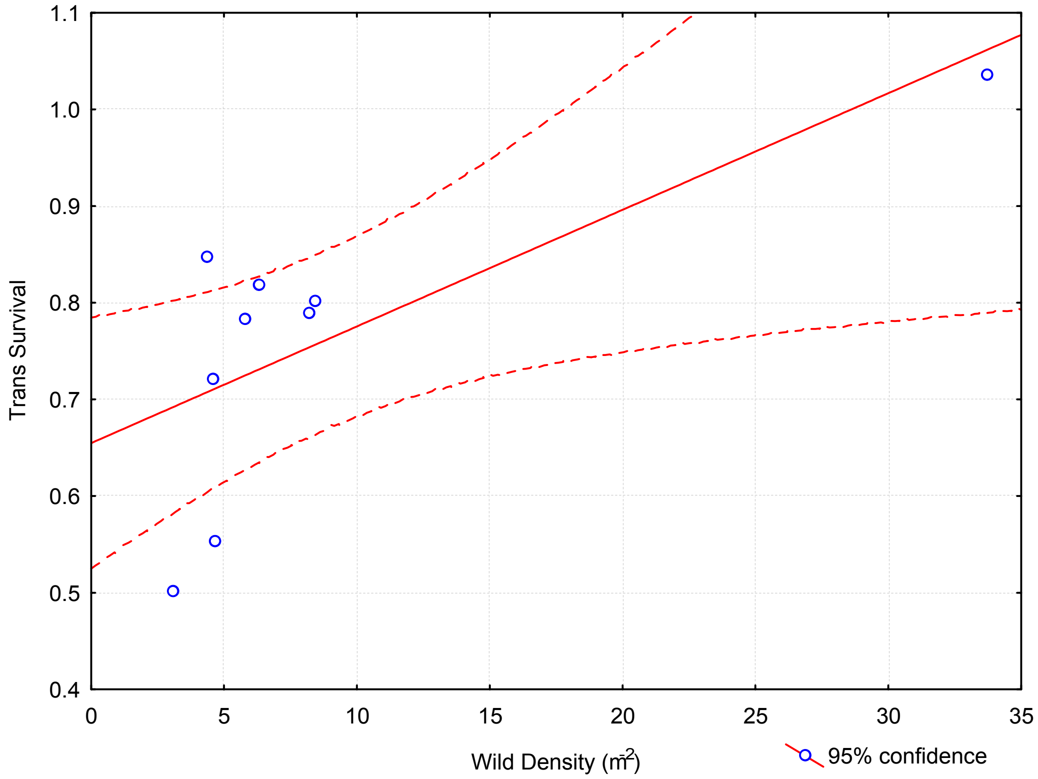

Figure 3.12 Correlation between wild *H. midae* density and seed survival in Trial 2.

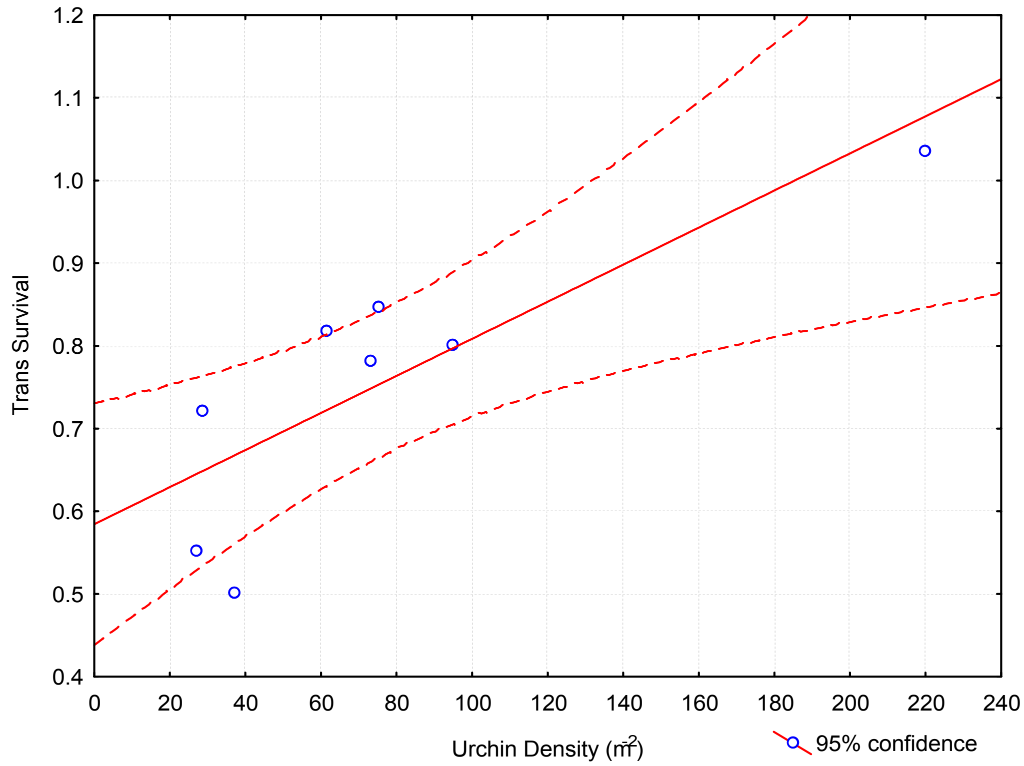

Figure 3.13 **Correlation between sea urchin density and seed survival in Trial 2.**

Table 3.6 **Correlation coefficients (r) and significance levels (p) for comparisons between habitat parameters and transformed survival data in Trial 2.**

	Wild Density (n=9)	**Urchin Density (n=8)**	**Habitat Suitability Ranking (n=9)**	**%Under-Rock (ARCSINE) (n=9)**	**Large Rocks (n=9)**
SURVIVAL	0.722 p=0.028	0.829 p=0.011	0.590 p=0.094	0.464 p=0.209	0.626 p=0.071

Sea Urchins

In addition to the significant correlation of seed survival with urchin density, there were also other indications that sea urchins were a preferred refuge for wild and seeded juvenile abalone. Sea urchins and abalone were never found in the open, even though this habitat contributed the most to the available area. Since the open habitat was clearly not viable, it was excluded from calculations of the percentage of available habitat. The average amount of available space under urchins in all plots was low (8%), but the proportion of wild and seed abalone found under them was much higher, 50% and 30% respectively (Figure 3.14). In contrast, the area under the rocks contributed 92% of the useable habitat but only 50% and 70% of the wild and seed abalone respectively occurred there. The selectivity indices calculated for the two habitats are shown, with positive values being found for the under-urchin habitat as opposed to the under-rock habitat that had low negative values (Figure 3.15).

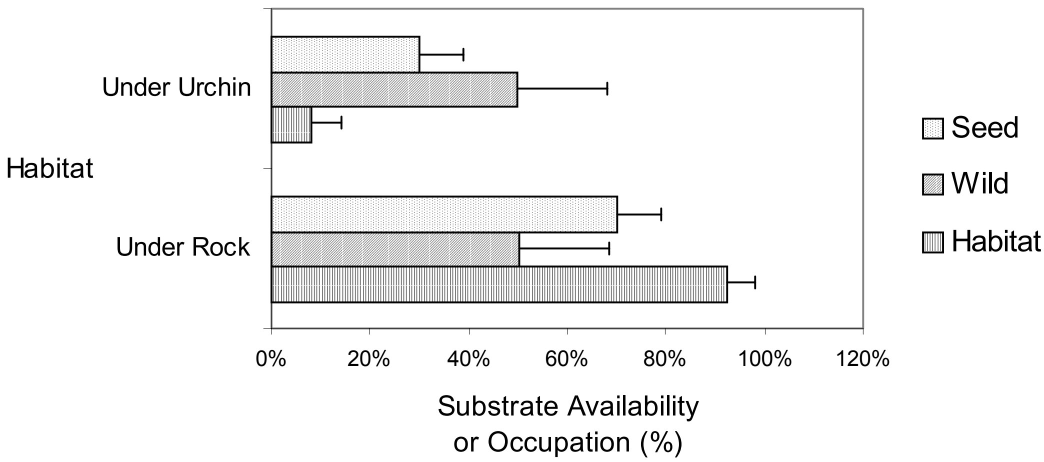

Figure 3.14 **Substrate availability and occupation rates of substrate by seeded and wild *H. midae*.**

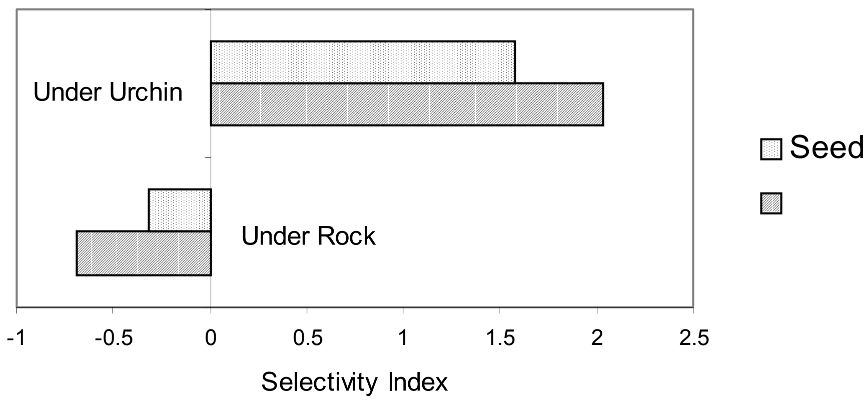

Figure 3.15 **Selectivity indices calculated for under sea urchin or under rock by seeded and wild *H. midae*.**

A plot of percentage cover of each habitat against the proportion of wild and seed abalone found in each habitat is shown in Figure 3.16 and Figure 3.17 respectively. Values falling on or close to the line would indicate that abalone distribution is random (Day 1998). Values above or below the line would indicate a positive or negative relationship respectively. The plots for the wild abalone distribution indicate that they appear to favour sea urchin cover as opposed to simply under-rock habitat. The plots for the seed abalone indicate a similar scenario although the association again appears less strong (closer to the line). Chi-square tests supported these findings with significant results being found for both wild and seed abalone indicating that they were not randomly distributed (Table 3.7).

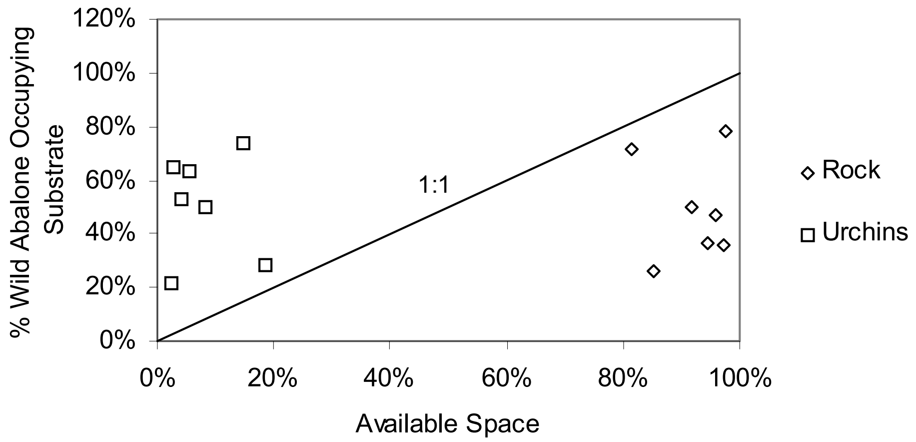

Figure 3.16 Plot of available substrate (under rock or under urchin) against proportion of wild *H. midae* occupying that substrate.

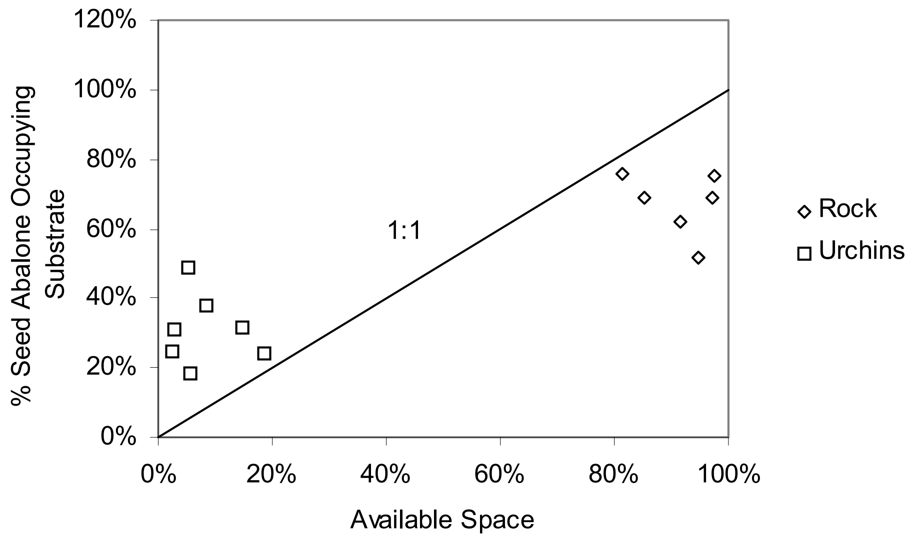

Figure 3.17 Plot of available substrate (under rock or under urchin) against proportion of seeded *H. midae* occupying that substrate.

Table 3.7 **Results of Chi-square analysis between expected and actual substrate occupation by wild and seed juvenile *H. midae*.**

Abalone Type	Chi Square	Degrees of Freedom	p
Wild	1377.15	6	<0.001*
Seed	1048.48	7	<0.001*

There was a strong size bias in the size distribution of the wild juvenile abalone found under the sea urchins. To ensure that the comparison was not biased by animals that could not fit under the sea urchins, all the wild abalone bigger than the largest that was found under an urchin were excluded (*i.e.* >35.5mm SL). A Mann-Whitney U test performed on the remaining abalone revealed that there was still a significant difference in the size distribution of the wild abalone found under the urchins as opposed to under rocks ($U=41077.50$, $Z=-9.5$, $p<0.001$). The average size was 11.3mm under urchins and 17.0mm under rocks.

Predation

Several potential predators were observed during the seeding process. One large octopus was removed from a plot during seeding on the first day of the experiment and a second one was removed the following day. This octopus was found in a hole that it seemed to have recently excavated for itself. No abalone shells were however found in its lair once it was removed. There were also very few shells found when the plots were destructively sampled. The number of collected shells varied between zero and four per plot, with some shell fragments also being collected. The average number of shells found per plot was 2.7% of the unaccounted for seeded abalone. Several species of African klipfish (Family: Clinidae) as well as some gobies (Family: Gobiidae) were observed attempting to consume the seed abalone (see Table 3.1), although only larger super klipfish, *Clinus superciliosus*, were able to consume the seed whole. A few juvenile individuals from the Sparid family were observed near the seeding plots while the abalone were being released. In most cases the research divers were able to scare these fish away until the seed had gained refuge.

TRIAL 3 – MEDIUM-TERM EFFECT OF HABITAT ON ABALONE SEED SURVIVAL AND GROWTH

Introduction

While it was postulated that the mortality of seed would be highest soon after introduction, a better understanding of the longer-term survival of the seed was required. A longer term (*ca.* 2½ months), simplified version of the previous experiment was thus undertaken to investigate the effects of habitat and seed size on survival.

Methods

Seeding Area and Experimental Design

This experiment was conducted in a similar way to that in Trial 2 and in the same area (see Figure 3.2). Care was taken to avoid previously used areas, although there was a small degree of overlap in some cases due to a limitation in suitable seeding substrate. An interval of 40 days separated the two experiments. Only four rectangular plots were used; three plots were 2 x 5m and one was reduced from 1 x 10m to 1 x 9m due to a shortfall of seed at the time of seeding (Figure 3.18).

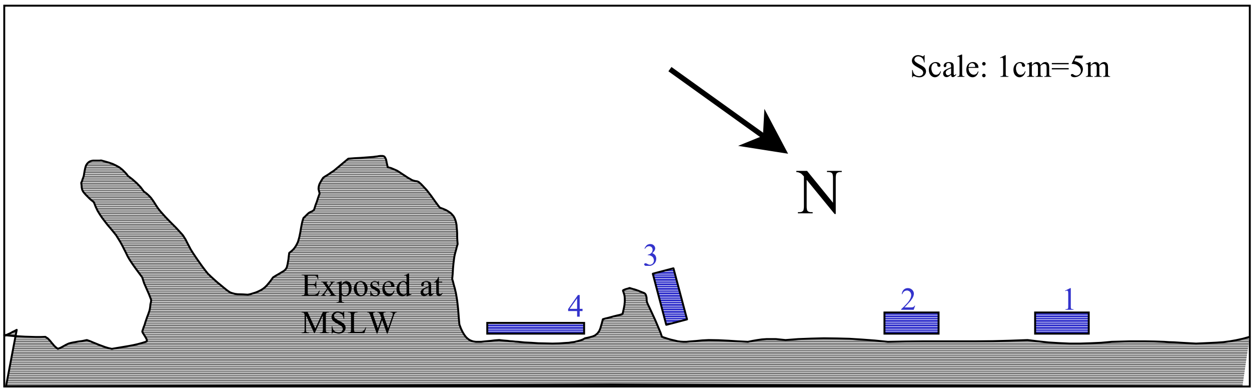

Figure 3.18 **Schematic illustration of experimental plot layout in rock pool for Trial 3.**

Seed

The seed abalone used in this experiment had been spawned 20 months previously and all came from the same grow-out basket. They had a mean shell length of 24.6mm (±2.7 SD).

Release Method

The seed were released in a similar manner to Trial 2 but previous observations had shown that the seed were quick to find their way into cryptic positions and therefore extra time was not spent placing them directly into cracks and crevices. The presence of divers usually meant fish predators would not approach too closely.

Sampling and Field Observations

One randomly chosen plot was sampled after approximately one month to obtain a spot survival estimate. No other data were collected from this plot. The remaining three plots were then destructively sampled after another month using similar methods to Trial 2. Habitat parameters were also collected but no comparisons with survival were attempted owing to the number of samples (n=3).

Growth

Growth was measured and analysed using the same procedures as described in Trial 1. The artificial food tended to cause a paler pigmentation to occur and the seed abalone used in this experiment were therefore all fed it for as long as possible, with the proviso that they were weaned back onto a mixture of natural algae for a period of 7–10 days prior to release.

Results

Survival

The survival figure of the plot sampled after one month was 57%. The three sites that were sampled after approximately 2 months had an average survival of 51.7% (±5.8 SD, Table 3.8). A Chi-square analysis using the average number of survivors as the expected value showed no significant differences between all four plots (Chi-square=5.063, df=3, $p<0.167$).

Table 3.8 **Stocking density and percentage survival of plots in Trial 3.**

Plot	Time at Large (Whole Days)	Density (m^{-2})	Survival (%)
1	31	40	57.0
2	74	40	52.0
3	72	40	45.8
4	66	40	57.4

Movement

The mean percentage of retrievals found outside of the plot was 25.4% (±7.2 SD). Most of the retrievals outside the plot were in the 1m fringe but were very close to the plot, although there was a greater proportion of seed found in the fringes compared to Trial 2 (Table 3.9).

Table 3.9 **Time at large and number of retrievals in fringe area of plots in Trial 3.**

Area	Plot	Time at Large (Days)	Retrievals in Fringe (% of Total)
Rock pool	1	31	6.6
Rock pool	4	66	27.9
Rock pool	3	72	31.1
Rock pool	2	74	17.3

Size Differential Survival

Size differential survival was assessed in the same way as in Trial 2. In this case, however, growth had occurred, so the release size was taken to be where the change in shell colour occurred (original shell length). A one-way ANOVA showed no significant differences between any of the retrieved groups' original shell length and the pre-release subsample (Figure 3.19).

Growth

New growth was measured directly from the change in shell colour that was described in Trial 1. Growth increments were all divided by the number of days at large to obtain a daily growth increment. The data for each plot were then tested against each other using a one-way ANOVA. A significant difference in growth rate was found (Table 3.10). The daily growth rate varied between 0.038 and 0.063mm.day^{-1} which equates to 1.14 and 1.89mm.30days^{-1} with a mean of 1.5mm.30days^{-1} (Figure 3.20, Table 3.11).

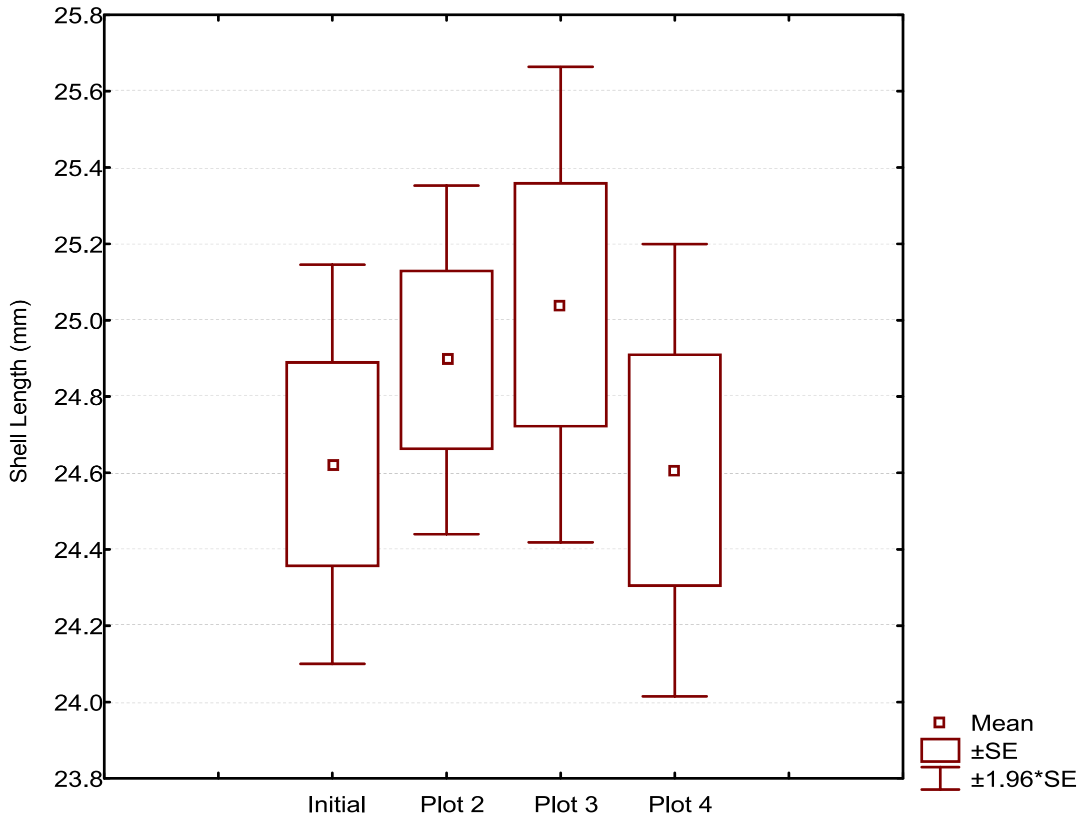

Figure 3.19 Shell lengths of released and retrieved seed (original size) in Trial 3.

Table 3.10 Results of one-way ANOVA comparing growth between plots in Trial 3.

Effect	Degrees of Freedom	F	p
Daily Growth	2	44.048	<0.001

Tukey tests: Plot 4 significantly different to Plots 2 and 3 (p<0.001 for both).

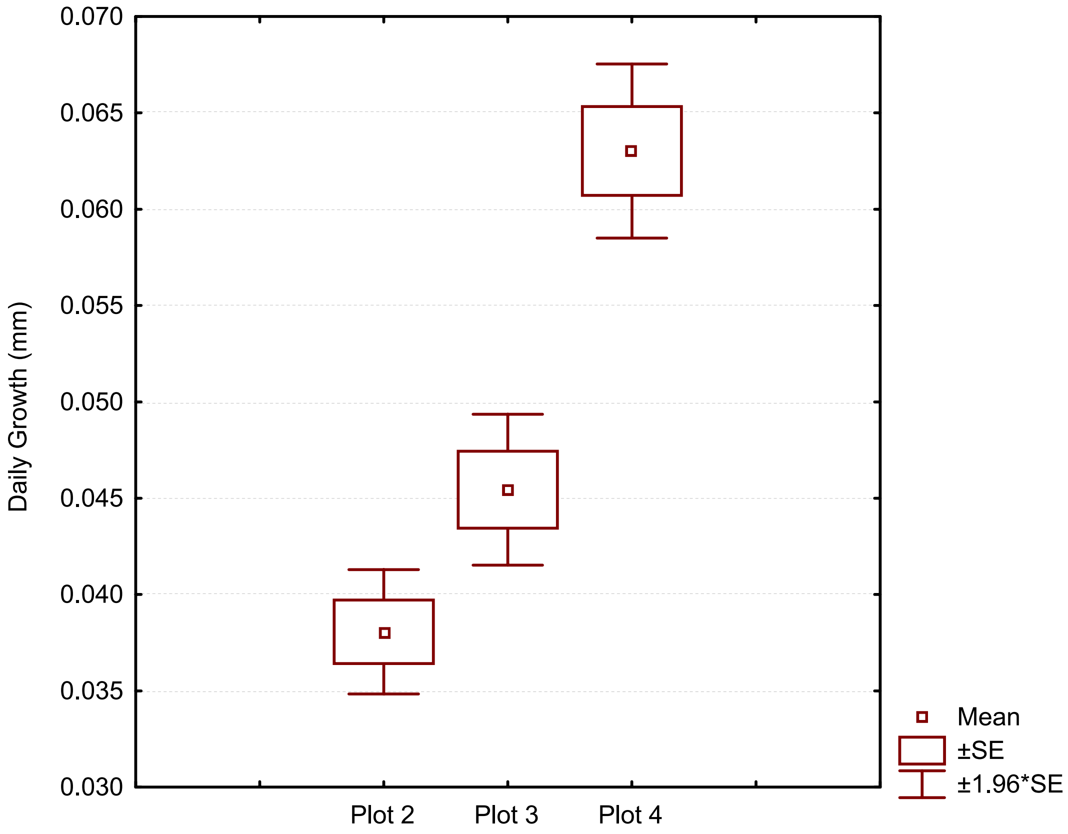

Figure 3.20 **Mean daily growth rate from sites in Trial 3.**

Table 3.11 **Summary of seed size at release, release period, and growth rates from Trial 3.**

Sample	Shell Length (mm)	Time (Days)	Growth ($mm.30days^{-1}$)
Initial	24.6	0	-
Plot 1	26.7	31	-
Plot 2	27.6	74	1.1
Plot 3	28.4	72	1.4
Plot 4	29.1	66	1.9

TRIAL 4 - SEEDING TRIAL IN MORE EXPOSED SHALLOW HABITAT

Introduction

We attempted similar experiments to those described above in a more exposed representative natural habitat that provided sufficiently sheltered water for effective diving and sampling.

Methods

Seeding Area and Experimental Design

An exposed area immediately south of the protected rock pool was identified as a suitable area for performing this trial (see Figure 3.2, Grid Area). The area was chosen as it provided a habitat that was more exposed, but still had a measure of protection from wave action. The substrate consisted partly of cobbles similar to those described in the rock pool area, which would enable relatively effective searching. Depth ranged between 0.2 and 0.5m at MSLW.

To allow multiple experimental plots to be set up in this area, as well as precise re-location of these plots, a mapping system was set up. This entailed the precise placement of concrete markers in two sets of parallel rows at right angles to each other (Figure 3.21). The markers in each row were 15m apart from each other. Whilst sites were being seeded or sampled, bamboo poles were placed in the markers to allow for visual triangulation of each seeding site. Only seven plots were successfully seeded and sampled owing to adverse sea conditions.

Seed

The seed used in these experiments were batched in baskets containing 250 individuals or less, depending on the intended seeding density. The size of seed and seeding density is summarized in Table 3.13.

Release Method

Releases were performed using a pie-shaped quadrat as described in Trial 2 and Trial 3.

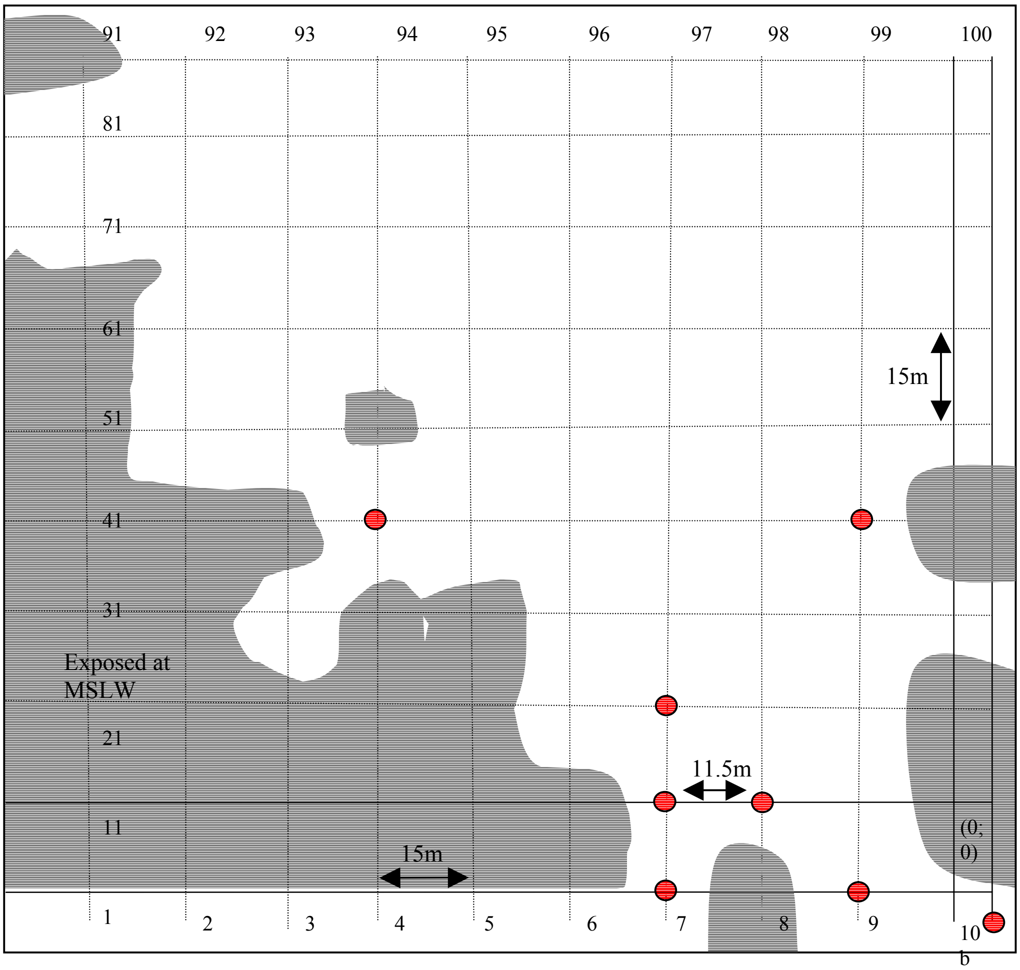

Figure 3.21 Schematic illustration of mapping grid used for location of seeding sites. Circles indicate sites that were seeded and sampled. Solid lines in the diagram had concrete markers placed at 15m intervals. The circular plots were separated from each other by a distance of 11.5m.

Sampling and Field Observations

The plots were sampled between 25 and 27 days after release, using a pie-shaped quadrat as described in Trial 2 and Trial 3. A 2m-boundary area (fringe) was also searched.

Growth

Owing to unfavourable sea conditions, the release of seed was delayed by a few weeks, and the animals were kept on mixed diet, which included natural algae, for more than the usual weaning period. As a result, accurate post-seeding growth data could not be determined for these abalone since the shell length at release could not be established with any certainty, owing to the premature formation of a darker shell band.

Results

Movement

Most of the seed were found within the release area. Table 3.12 shows the percentage of retrievals found beyond the plots boundaries.

Table 3.12 Time at large and percentage of retrievals in fringe area of plots in Trial 4.

Area	Plot	Time at Large (Days)	Retrievals in Fringe (% of Total)
Grid	9	25	0.0
Grid	10b	26	1.1
Grid	7	26	0.0
Grid	17	26	0.0
Grid	49	26	0.0
Grid	18	27	0.0

Survival

Seven sites were seeded and sampled, owing to poor sea conditions and a strong surge encountered in the study area. The survival figures from these experiments varied significantly (Table 3.13), with a mean survival of 32.1% (±23.2 SD). One of these plots (44) gave a very low survival figure (1.3%) and in hindsight the plot was seen as unsuitable for abalone (only one live wild abalone was found there). At low tide it was very shallow with no through-flow of water and a noticeably high water temperature at the time of sampling. When this site was excluded the variation was reduced and the average survival was 37.2%.

Table 3.13 Summary of seeding and habitat parameters of plots in Trial 4.

Plot No	Interval (Whole Days)	Mean Shell Length at Release (mm)	Seed Density (m^{-2})	Total Survival (%)	Survival-Plot (n)	Density-Wild *H. midae* (m^{-2})	Habitat Suitability Ranking	Comments
9	25	26.4	25	20.4	51	1.3	1	
49	26	20.1	25	18.4	46	2.4	2	
44	27	20.1	23.9	1.3	3	0.1	2	Pool with high water temperature.
7	26	26.4	25	33.6	84	2.2	2	
17	26	24.6	50	46.8	234	3.8	2	
10b	26	26.4	25	73.6	182	6.8	4	
18	27	24.6	50	30.4	152	1.2	2	

It was not possible to make any deductions concerning size differential mortality since the size at release could not be established with certainty and no attempt was made to compare the survival rates of the various plots.

Habitat

The ARCSINE transformed survival data was regressed against wild juvenile abalone density and the habitat index that was described in Trial 2. Significant correlations were obtained between survival and wild density, and survival and the habitat suitability index once the anomalous result from plot 44 was excluded (Table 3.14).

Table 3.14 Correlation coefficients (r) and significance levels (p) of wild abalone density and subjective indices compared to ARCSINE transformed survival data in Trial 4.

	Wild Density (n=6)	Habitat Suitability Ranking (n=6)
Survival	0.938 p=0.006	0.889 p=0.015

TRIAL 5 – SHORT-TERM EFFECT OF SIZE AND DENSITY ON ABALONE SEED SURVIVAL

Introduction

The results from Trial 2 did not conclusively answer whether density and seed size affect survival in the rock pool habitat. A more stringent experimental protocol was designed to test the effect of these two parameters while still measuring the influence of habitat on survival, in the same way as in Trials 2 and 3.

Methods

Seeding Area and Experimental Design

This experiment was performed in the rock pool that was described previously (see Figure 3.2). Eight months had elapsed since the previous work had been done in this area. It was felt that this was sufficient time for recovery from the disturbances. Twelve $4m^2$ plots were set out in the area.

Seed

Batches of either 40 or 160 abalone were made up two days prior to seeding. Two size groups of seed were used. The large size group had a mean size of 29.4mm (±4.6 SD) and the small group had a mean size of 17.6mm (±2.8 SD).

Release Method

The seed was once again released using $1m^2$ quadrats in a similar manner to that described in Trial 2 (see Figure 3.8).

Sampling and Field Observations

Destructive sampling of the plots was performed after a period of 7 or 8 whole days after release. A similar method to that described in Trial 2 was used.

Habitat

All wild abalone were collected to provide an index of habitat suitability. A subjective habitat suitability ranking was assigned to each plot as described in Trial 2.

Data Analysis

Survival

A two-way fixed effects ANOVA was employed to test for size and density effects. In this case no ARCSINE transformation was performed on the data since it is not necessary for ANOVAs unless samples sizes differ by more than five orders of magnitude (Zar 1999).

Habitat

Habitat parameters were regressed with ARCSINE transformed percentage survival data, as suggested by Zar (1999) for proportional or percentage distributions, to test for potential relationships. Assumptions of normality were assumed to hold for all the data.

Results

Movement

In this experiment, no distinction was made between the seed found inside the plots and those outside. During sampling, it was found that very few, if any, were retrieved beyond the boundaries of the plot, and in most cases these were very close to the edge.

Survival

The mean survival figure for this experiment was 72.1%, which was similar to the other short-term experiment (*i.e.* 68.2%, Trial 2). The mean survival for each group displayed some variation (Table 3.15), but when they were compared using a two-way ANOVA with density and size as factors, there were no significant differences between the various treatments (Table 3.16). Large seed appeared to survive slightly better than smaller seed (Figure 3.22). The large seed introduced at a higher density suffered higher mortalities relative to the lower density.

Table 3.15 **Summary of seeding and survival parameters for plots in Trial 5.**

Plot No.	Interval (Whole Days)	Density (m^{-2})	Size	Actual Seed Survival (%)	Group Mean % (±1 SE)
1	7	10	Large	87.5	
8	8	10	Large	65.0	81.7
9	8	10	Large	92.5	(±8.5)
3	7	40	Large	81.3	
6	7	40	Large	86.3	78.3
11	8	40	Large	53.8	(±10.1)
2	7	10	Small	70.0	
5	7	10	Small	35.0	64.2
10	8	10	Small	87.5	(±15.4)
4	7	40	Small	63.1	
7	8	40	Small	75.6	64.2
12	8	40	Small	67.5	(±3.7)
			Mean (±1 SE):	72.1±9.8	

Table 3.16 **Results of two-way ANOVA to test for differences in survival between stocking density and seed size (df=1).**

Effect	F	p
Density	0.0256	0.87682
Seed Size	1.1977	0.30564
Interaction	0.3636	0.56324

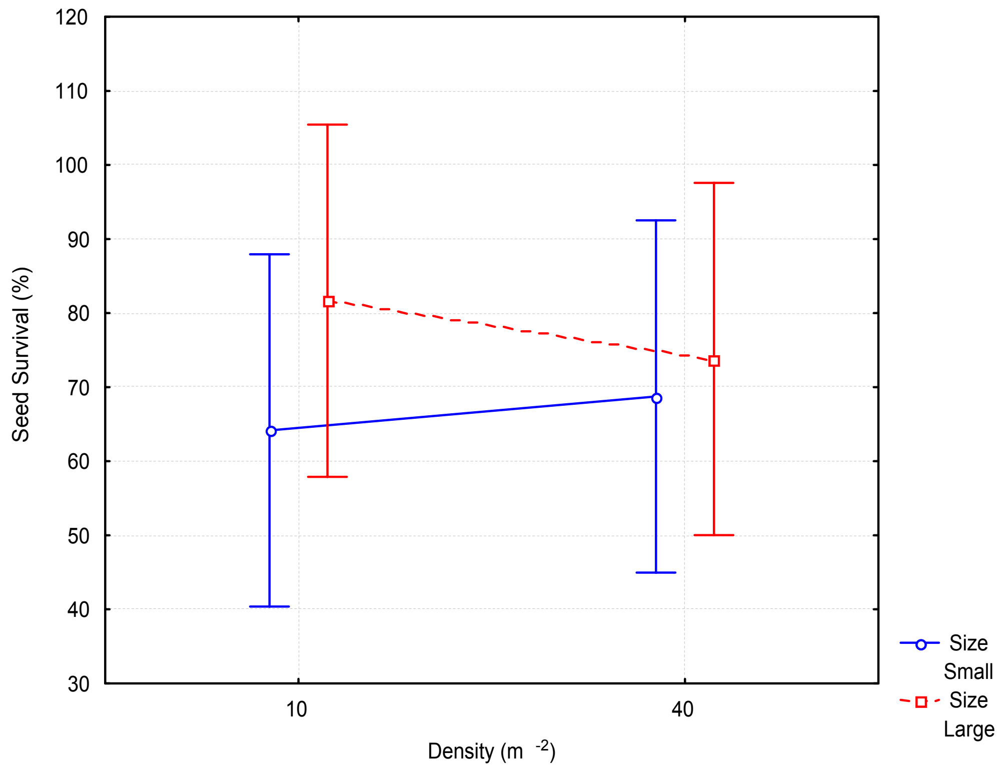

Figure 3.22 Plot of seed density and survival for small and large animals in Trial 5 (vertical bars denote 95% confidence intervals).

Size Differential Mortality

To test for size differential mortality using changes in size distribution, the two sets of seed used in this experiment had to be treated separately. Initially ANOVAs were used to test for differences between plots in the same treatments. These tests showed no significant differences and were therefore pooled to test for differences between density treatments using Student t-tests. These also failed to show any significant differences and as a result a comparison could be made between the released seed subsample and that of all the retrieved abalone from each size group.

At this point differences became apparent and tended to corroborate the results of the 2-way ANOVA. In both the small and large size classes, the mean size of retrieved abalone were larger than the mean size at release (Figure 3.23). The only significant difference was observed in the small size class treatments where the mean size at release was 17.6mm and that of all the retrieved abalone was 19.1mm (t=-5.552, df=533, P<0.001). No growth was assumed to have occurred over the release period due to the short duration of the trial.

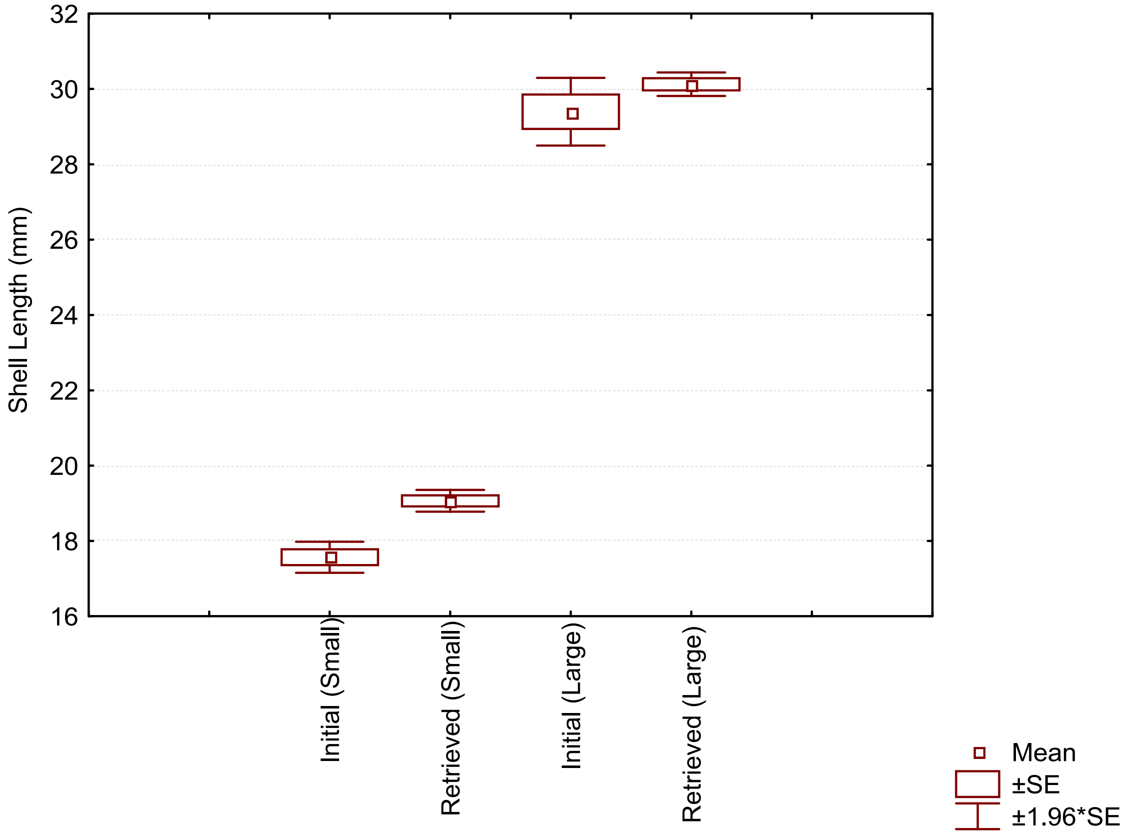

Figure 3.23 Shell lengths of released and retrieved seed in Trial 5.

Habitat and General

There were no significant correlations between seed survival and any of the habitat parameters that were measured, although the wild abalone density - seed survival correlation was marginally significant (p=0.051). Interestingly, two sites had no wild abalone in them but seed survived there (Table 3.17). The water in these two plots was extremely shallow at low tide (<15cm), and the substrate was characterized by a high degree of sedimentation. The low number of unaccounted for shells was once again noteworthy.

Table 3.17 **Summary of seeding and habitat parameters of plots in Trial 5.**

Plot No.	Seed Survival (%)	Wild No. (n)	Wild Density (m^{-2})	Habitat Suitability Ranking	No. of dead shells per plot (n)
1	87.5	71	17.8	3+	0
2	70.0	71	17.8	4	1
3	81.3	93	23.3	4	0
4	63.1	87	21.8	4-	0
5	35.0	20	5.0	4	0
6	86.3	50	12.5	4	0
7	75.6	27	6.8	4-	0
8	65.0	55	13.8	4-	0
9	92.5	92	23.0	3+	0
10	87.5	59	14.8	4+	0
11	53.8	0	0.0	3	1
12	67.5	0	0.0	3	0

TRIAL 6 – COMPARISON OF RELEASE METHODS

Introduction

While small-scale experiments can provide valuable insights into factors affecting seed survival, larger scale experiments need to be undertaken to evaluate the viability of abalone ranching. One of the most important issues for mass introductions is that of release method. The use of a release module while theoretically advantageous, presented practical problems and experience with hand seeding suggested large-scale releases would take too long (see discussion). It was postulated that a surface-scattering method might be used to seed fairly large areas of substrate (Cowx 1994). This hypothesis was tested by seeding two adjacent areas using the hand seeding and the surface-scattering methods.

The problems associated with assessing the suitably of seeding sites in the open-water environment also needed to be overcome. Lack of manpower and poor sea conditions had consistently prevented reasonable survival estimates in Trial 1. The method employed by Schiel (1993) to assess large-scale seeding sites was adopted as an alternative to obtaining an absolute estimate of survival. This entailed using randomly placed quadrats to assess post-trial seed density, which was expressed as a proportion of initial seeding density.

Methods

Seeding Area

The area chosen for seeding was within Habitat 1 situated to the east of Cape Recife (Figure 3.2, Area A). Two adjacent plots (1 and 2), of known area that had suitable reference points, were identified to carry out the experiment.

Hand Seeding

The first plot was rectangular and a weighted tape measure was used to orientate the seeding process. It was seeded in a similar manner to the rectangular rock pool plots, using a $1m^2$ quadrat. Two thousand seed were released at a density of $50m^{-2}$ and the exact layout of the quadrats is shown in Figure 3.24 (Plot 1). Since there was some water movement in this area, the seed sometimes had to be held in place to ensure that they were not washed away.

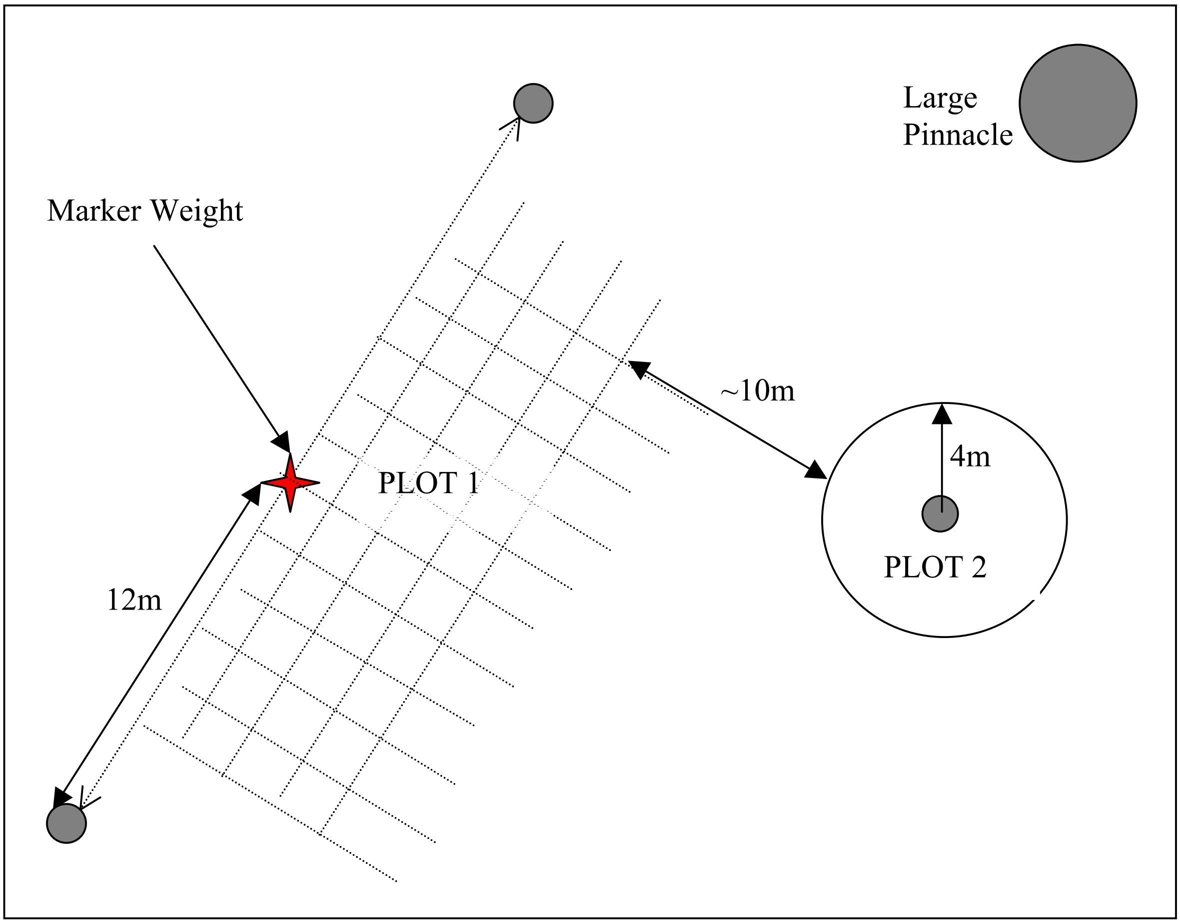

Figure 3.24 **Schematic diagram of seeding plots used for Trial 6.**

Scatter-Seeding

Before seeding using the scatter method, the area to be seeded needed to be calculated. By knowing the area beforehand, the number of seed that would be required to obtain the correct seeding density could be calculated. A prominent rock was used as a central marker and a circle with a radius of 4m was chosen as the target area, which equated to a seeding area of 50m^2 (Figure 3.24, Plot 2). This plot was seeded with approximately 2500 abalone at a density of 50m^{-2}. A field-worker stood in the centre of the plot and randomly scattered seed on the surface of the water making sure that they fell within the specified area.

Seed

Two different sized batches of seed abalone were used in this trial. The large size group had a mean size of 28.7mm SL (±2.6 SD) and the smaller group had a mean size of 20.0mm SL

(±2.4 SD). The two groups were mixed together prior to seeding with a ratio of 3:2, with the smaller seed being more numerous.

Field Observations and Sampling

Owing to the manner of seeding employed in Plot 1, the seed could be observed during, and for some time after, the animals were released. Subsequent to the scattering of seed in Plot 2, this area was observed to take note of seed behaviour and of the presence of any predators.

No attempt was made to recapture all the surviving seed in each plot, to obtain a minimum survival estimate. Three $1m^{-2}$ quadrats were randomly deployed within each treatment plot and all the seed and wild abalone were collected. Seed survival was calculated as a percentage of the sampled density over the initial seeding density (Schiel 1993). Although the treatment plots were only separated by approximately 10 metres, owing to the low movement noted in the previous trials, it was assumed that there was no migration between the plots.

Growth

Growth was measured and analysed using the same procedures as described in Trial 1.

Results

Field Observations

The time to seed the two respective areas differed markedly. Plot 1, where 2000 animals were seeded, took 2.5 hours to seed, whereas Plot 2, which had approximately 2500 animals placed in it, took half an hour to seed. The behaviour of the seed after seeding in Plot 1 was similar to the rock pool experiments in that they were quick to attach themselves and to seek refuge. The seed in both Plot 1 and 2 appeared to be impeded in their efforts to gain refuge by the higher degree of water movement encountered here. Immediate observations after seeding in Plot 2 showed that numerous fish were present. These were mainly shoals of blacktail *Diplodus sargus capensis*, and the Cape stumpnose *Rhabdosargus holubi* (see Table 3.1). No actual predatory events on the seed were seen however and most seed appeared to have established themselves on the substrate in relatively cryptic positions with the surge seemingly aiding them in this process by washing them into crevices.

Survival and Size Differential Mortality

Sampling was once again limited by prevailing sea conditions and only three 1m^2 quadrats could be sampled in each of the two seeding plots. The period between release and sampling was 41 days. Since there was no replication for the two seeding methods, the data from each individual plot were pooled. Mean survival for the hand seeding method was 44.0% (±13.9 SD) and that of the scattering method was lower at 38.7% with a higher variation (±28.0 SD, Figure 3.25). To compare differences in survival between treatments, the actual numbers of retrieved seed from each plot were compared to the mean of both treatments using a Chi-square analysis. There was no significant difference between the two treatments (Chi-square=0.516, df=1, p<0.472).

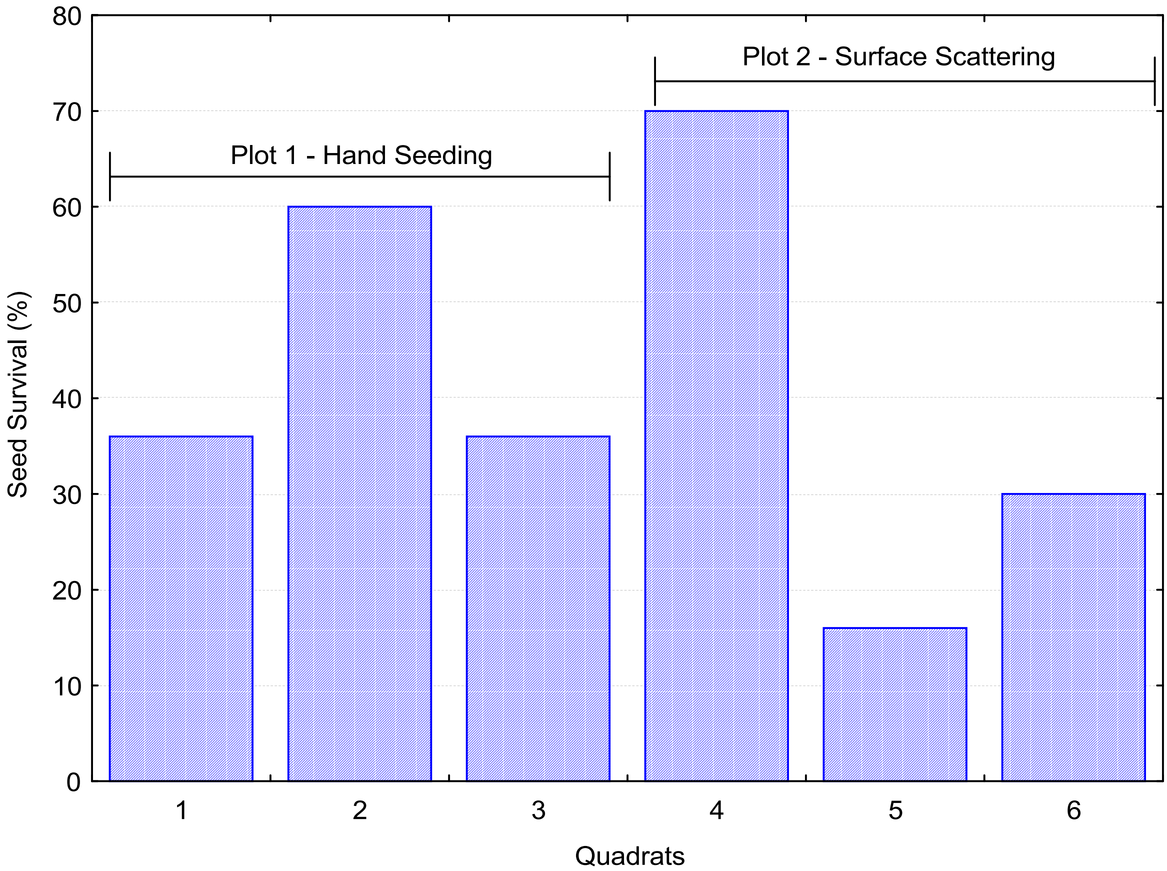

Figure 3.25 Estimation of percentage survival in two plots seeded using different seeding methods.

The effects of size differential mortality were investigated using a change-in-ratio analysis with no change in size ratio as the null hypothesis. The abalone were seeded at a ratio of 3:2 of small to large abalone size groups. Given that there was a small overlap between the two groups, the retrievals were separated using the median size difference between the smallest in the large group and the largest in the small group. Using this figure as a cut-off point the retrieved abalone were categorized into either being from the small or large size groups. A Chi-square analysis of the retrieved ratio versus the release ratio showed that there were significant differences in survival between the released abalone and the surviving abalone. In the hand-seeding method there was a significant difference in favour of small seed (Chi-square=4.848, df=1, $p<0.028$, n=65). With respect to the second seeding method there was a significant difference in favour of the larger seed (Chi-square=15.860, df=1, $p<0.000068$, n=56).

A further assessment corroborated these findings. A comparison was made between the mean size of released abalone (pre-seeding subsample, 24.4mm SL) and the shell length of the retrieved seed at release from each plot. In other words, the seed from each plot was collected (pooled) and two shell length measurements were taken from each animal; the actual shell length and the shell length of the animal when it was released using the shell-colour boundary. This second measurement was compared to the pre-seeding subsample. A Kruskal-Wallis test showed significant differences between the three samples ($H(2, n=320)=7.25$, $p=0.027$). *Post-hoc* Mann-Whitney U tests revealed that the only significant difference lay between the two retrieved samples release size ($U=1269.50$, $Z=2.75$, $p<0.01$). The hand seeding sample had a mean size of 23.1mm and the scatter sample had a mean size of 25.6mm (Figure 3.26).

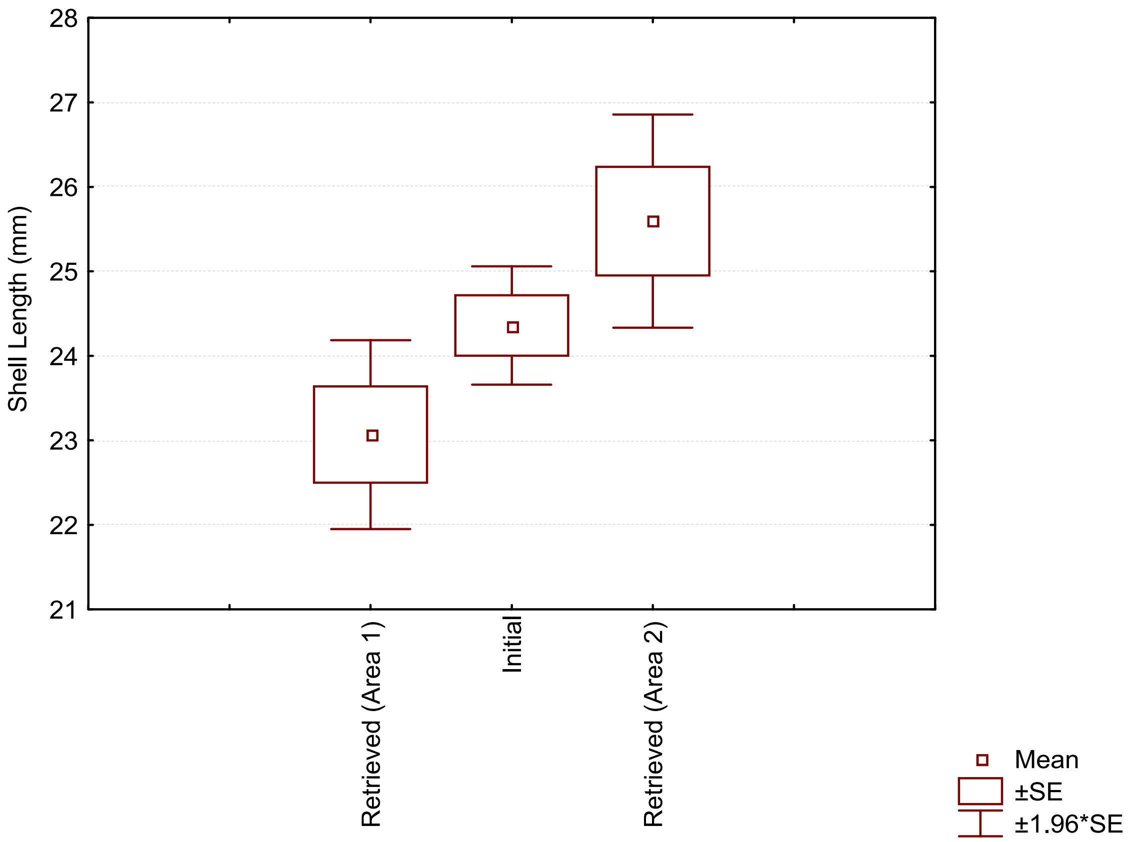

Figure 3.26 **Shell lengths of released and retrieved seed (original size) in Trial 6.**

Growth

A Students t-test comparing the daily growth increments of abalone between the two treatments showed no significant difference. They had a mean growth rate of 0.053mm.day^{-1} (0.052mm.day^{-1}, plot 1 and 0.057mm.day^{-1}, plot 2).

TRIAL 7 - MASS SURFACE-SEEDING

Introduction

The results from the comparative release method trial suggested that the surface-scattering method of seed release could be useful for large-scale releases of seed. This hypothesis was tested in a series of three large-scale releases.

Methods

Seeding Areas, Seed, Transport and Release Method

The high numbers of abalone required for these seeding trials necessitated their being packed at high densities. To this end, a process similar to that used for exporting live abalone was used. On the morning that seeding was to take place, a team of at least five people was needed to pack the seed in a sufficiently short time period to prevent excessive stress to the seed. The animals were removed from their grow-out baskets by hand, drained of excess moisture and placed in a large plastic bag that had been lined with a thin plastic sheet, a 1cm thick piece of moist foam rubber, and a set of plastic internal dividers. The base sheet, foam and dividers were sized to fit a large polystyrene cooler-box (70cm long x 35cm wide x 30cm high, external dimensions). Once the box contained sufficient abalone, a second piece of moist foam was placed on top of them, oxygen was pumped in to replace the air, and the plastic bag was closed. Two sets of cooler packs were then placed on top of the bag before the box was closed. Up to nine boxes were packed in this way during one seeding run.

These experiments were performed within Habitats 1 and 3 at Cape Recife, and three separate releases were performed (see Figure 3.2, Areas B-D). The animals were seeded using the surface-scattering method described in Trial 6. The first release was conducted in a 1350m^2 rectangular plot in the Area B (Figure 3.2). Approximately 39 000 abalone were seeded at a density of 29m^{-2}. Their shell lengths ranged between 14 and 64mm, but the majority of seed (>90%) were less than 35mm. The second release (Area C) comprised of approximately 54 000 animals with a mean size of 17.6mm (±0.2 SE), and were seeded at a density of 42.5m^{-2}. The last release (Area D), consisted of 36 000 seed, with a mean shell length of 29.4mm (±0.5 SE), and were seeded at a density 51m^{-2}.

Field Observations and Sampling

The seeded areas were checked immediately after seeding for seed behaviour and the presence of predators. Survival in these seeding sites was assessed in the same manner as that described in Trial 6 and once again sea conditions limited replication of quadrats.

Growth

Growth was measured and analysed using the same procedures as described in Trial 1.

Results

Survival and Size Differential Mortality

The estimated survival figures for the three mass seeding operations undertaken showed a large variation in survival, particularly when the results from each quadrat were compared (Table 3.18). This was not unexpected given the nature of the seeding and sampling methods as well as the heterogeneous substrate encountered in the seeding areas. In certain quadrats it was not possible to search the whole area since some solid substrate was encountered that had inaccessible crevices and under-boulder habitat.

Only three of the retrievals from Area D showed discernable differences between farm growth and new growth, possibly due to the diet of these animals not containing the necessary pigments to produce a noticeable colour change. This prevented assessments based on size from this site. Comparisons between the pre-release subsample and the measured release size (from shell colour change, as used in Trials 3 and 6), for sites B and C, showed an apparent bias towards the large size classes. Site Bs mean size at release was 20.6mm and the retrieved size was 23.8mm (Figure 3.27, B). A Mann Whitney-U test gave a highly significant p-value for difference in shell length ($U=53547.50$, $Z=-3.469$, $p<0.001$). Site Cs pre-release subsample had a mean size of 17.6mm and the retrieved size was 18.3mm (Figure 3.27, C). A t-test on normalized data (Log_{10} transformation) did not show a significant difference.

Table 3.18 Release period, stocking density and survival of seed in Trial 7.

Seeding Area	Time at Large (Days)	Seeding Density (m^{-2})	Retrievals per $1m^{-2}$ Quadrat (n)	Mean Survival (% ±1 SD)
Area B	114	29	33 (113.8%) 4 (13.8%) 5 (17.2%) 0 (0%) 3 (10.3%)	31.0 (±46.7)
Area C	83	42.5	25 (58.8%) 21 (49.4%) 24 (56.5%) 14 (32.9%)	42.9 (±11.7)
Area D	83	51	16 (31.4%) 10 (19.6%) 17 (33.3%) 7 (13.7%)	24.5(±9.4)

Growth

The growth rates in Sites B and C were 0.087 and 0.043mm.day^{-1} respectively (Figure 3.28). A t-test comparing growth rates between these two sites showed significant differences ($t=10.327$, $df=54$, $p<0.001$).

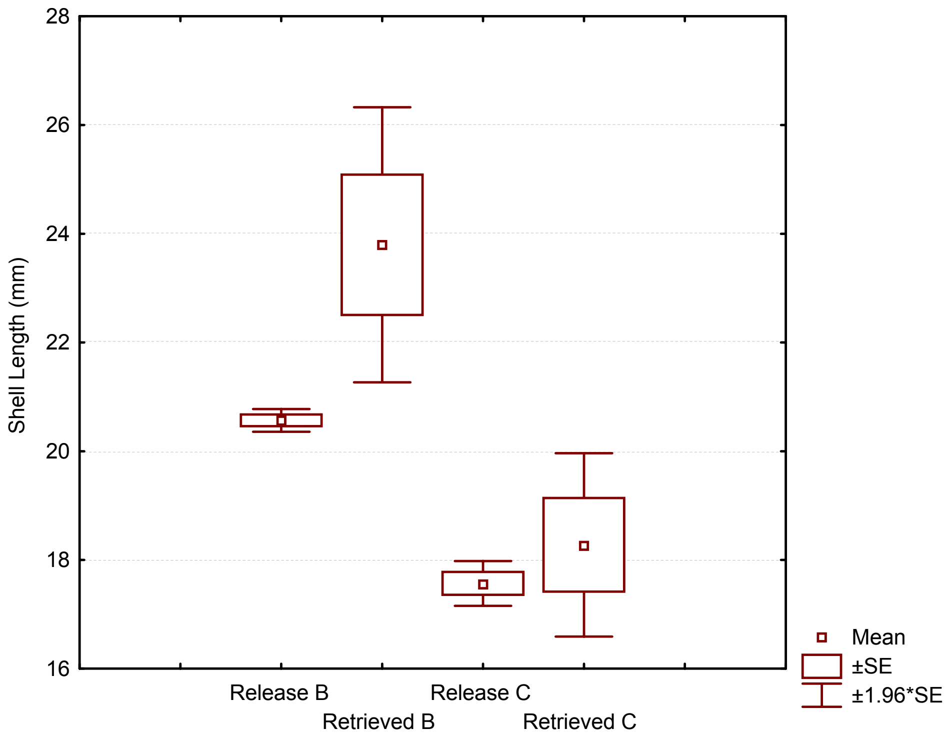

Figure 3.27 **Shell lengths of released and retrieved seed (original size) in Trial 7.**

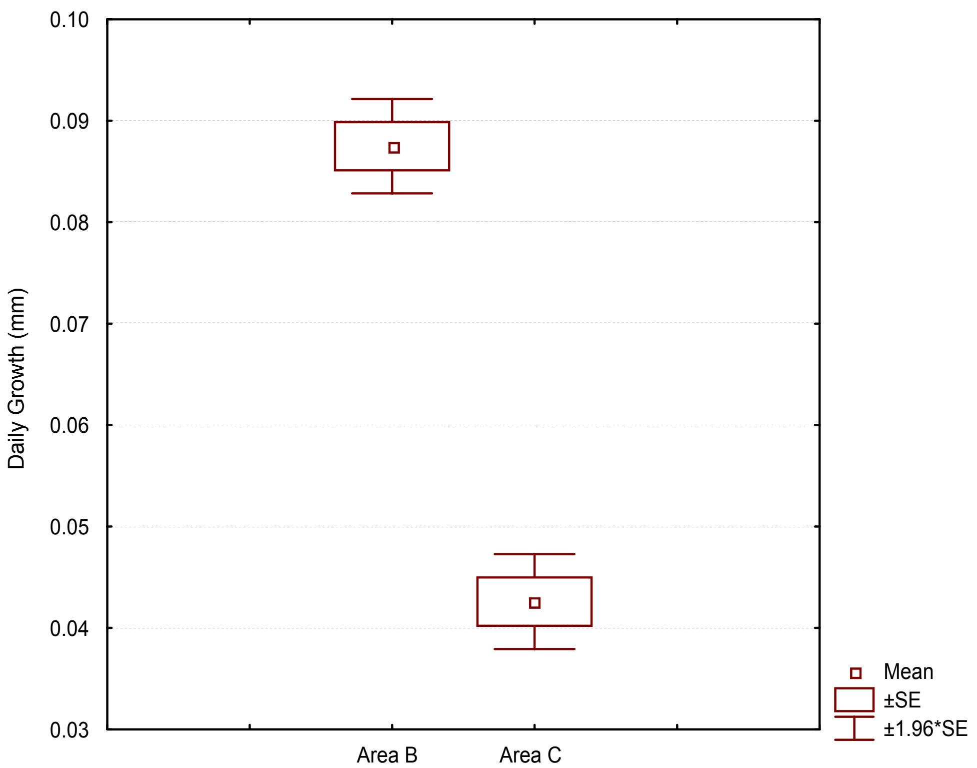

Figure 3.28 **Mean daily growth rate from sites B and C in Trial 7.**

DISCUSSION

The results of this chapter indicate that hatchery-bred, juvenile *H. midae* can be successfully introduced into their natural habitat in the Eastern Cape Province and that they display short to medium term survival rates that are encouraging for future ranching operations. Their growth rate while variable, compared favourably with wild conspecifics of a similar size. The study however failed to obtain robust survival estimates from appropriate habitats over time-scales that are necessary for fully evaluating commercial ranching. Valuable insights into various aspects of the seeding process were gained, which suggested future avenues for research.

Survival Estimation

Seed Identification

The unreliability of plastic tags that was demonstrated in the first seeding trial highlighted the need for methods to distinguish stocked animals from their wild counterparts. The ability to recognize seeded *H. midae* in these trials from their farm colouration, as demonstrated with other Haliotids, is important (Tegner and Butler 1985, Ebert 1989, Rogers-Bennett and Pearse 1998, Shepherd *et al.* 2000, Seki and Taniguchi 2000). For the purposes of the short and medium-term trials (up to three months) in this study, this colouration was highly effective for identifying and measuring growth of farmed seed and should be used in future short-term trials for these purposes. The gradual occlusion or fading of the shell colouration in Trial 1, however, militates against its usefulness in longer term assessments of enhancement and alternatives need to be considered.

The use of genetic tagging methods has attracted worthwhile attention as a substitute for physical marking methods. Genetic monitoring is able to fulfil a number of applications, including seed identification and the effects of interaction between seed and wild stock (Carvalho and Cross 1998). The reduced costs and relative ease of application make them particularly attractive (Shaklee and Bentzen 1998). An allozyme marker was used by Gaffney *et al.* (1996) to show an enhancement effect of seeded *H. rufescens*, but this result has been called into question by Tegner (2000). This criticism notwithstanding, and given the lack of an appropriate long-term physical tag for Haliotids, the use of genetic methodologies in general, and specifically the use of nuclear and mitochondrial DNA techniques to assess both the survival of stocked animals and their effect on natural populations remains the most promising avenue for the future (Sweijd 1999).

Survival

A wide range of survival estimates were obtained over short to medium time-scales (7 to 314 days) and represented a cross-section of habitat types found in the study area. The most reliable estimates of survival were obtained from the rock pool owing to high catchability. Minimum survival estimates averaged 70.4% (±3.4 SE) for the short-term experiments and 53.1% (±2.7 SE) for the medium-term experiment. These results were not necessarily representative for all the habitat types encountered at Cape Recife, since the rock pool was a unique area within the general study area. The survival estimates obtained from the mouth of the rock pool were probably similarly reliable but were noticeably more variable (18.4–73.6%). The more rigorous biophysical conditions encountered in this area probably caused this, but emigration and lower catchability may have depressed these estimates. Survival estimates averaged between 3.1% (±0.4 SE) for the release module experiments and 36.2% for the comparative and mass seeding trials. The precision of the survival estimates from Trial 1 can be questioned owing to the poor searching efficiency. Survival estimates from the sites where the change-in-density method was used (Trials 4, 6 and 7) were less robust because of low replication. Illegal fishing may also have played a significant role in decreasing recovery rates of seed at the open-water sites. Trials 1, 4, 6 and 7 were conducted within the favoured area for poaching and divers have been observed turning over cobbles in search of abalone in this area (Pers. Comm., G. Kant, MCM, 2001).

While the relatively short duration of some of these trials needs to be taken into account, the survival rates that were measured compared favourably with estimates obtained from other abalone seeding studies. Direct comparisons with other studies are made in the following paragraphs, where the various influences on survival are discussed.

Seed Performance

While the potential influence of hatchery conditions, and handling and transport were not directly quantified in this study, some observations are pertinent. Overall, the hatchery raised seed appeared to respond well to natural conditions and handling and transport did not appear to have significantly weakened them. In the trials where the seed were closely observed, none showed an inability to right themselves - they became mobile, and sought a cryptic position. Similarly, seed abalone in the open ocean were quick to respond after being placed back into water. An exception to these observations is worth consideration. The few abalone that were observed immediately after release, in the large-scale release (Trial 7), appeared to show a lower propensity for movement despite being able to reattach themselves. Whether this had to do with the longer time out of the water prior to release and the higher transport densities, or the existence of significant surge and the presence of prostrate foliar algae at the release sites is not known.

Although there was no conclusive evidence to suggest that hatchery seed were adversely affected by hatchery and handling conditions, they need to be considered in any seeding operation. Acclimation of seed prior to release, by exposing them to stimuli which they are likely to encounter in the natural environment, should be done if practically feasible (Cowx 1994) and intermediate holding facilities near the release site should be a minimum requirement if seed are to be transported at high densities and for long distances. The selection for particular traits that are favourable for artificial production must also be avoided, but this can be overcome by regular rotation of sufficient wild caught broodstock and the use of only first generation offspring (Busack and Currens 1995, Carvalho and Cross 1998, Cross 1999).

Release Method

The release module technique was the first and only release method that had been used in South Africa prior to this study and it was decided to use them because they offered a proven seeding method. While it was not possible to properly evaluate the success of the release modules in my experiment, given the poor sampling efficiency, it is worth considering their practical value to a large-scale seeding operation in relation to the other seeding methods that were employed.

The practical experience that was gained with release modules and other types of release methods, as well as from information provided by other workers in South Africa (Pers. Comm., S. De Waal, 2001), suggests that release modules of the type so far employed are of limited value for introducing large numbers of seed. De Waal (2002) used release modules in his seeding efforts on the north-west and southern coasts of South Africa but his experiments were limited to relatively low numbers of animals in each unit. Ebert and Ebert's (1988) work on *H. rufescens* using release modules also used relatively low numbers of seed. They found that discernable differences in seed survival were only apparent between hand-released seed and seed placed in a release module, for animals that were approximately 10mm SL. There was however a high proportion of unaccounted for seed in all of their treatments. Their release module was also a combination of the release module used in this study ("collector-transporter") and an additional protector, which excluded all predators that could not fit through a 5 x 4cm gap. Rogers-Bennett and Pearse (1998) used the same method and they reported extremely low recoveries from all their trials. In commercial scale releases conducted on the north-west coast of South Africa, release module trials had very high initial mortalities (Pers. Comm., Q. Snethlage, Port Nolloth Sea Farms, 2001). While release-modules can offer protection to seed while they are stressed this advantage may be outweighed by an increased vulnerability to predation once they leave the protection of the release module. The related issues of the number of seed in a release module, the dispersal rate of seed and the availability of cryptic refuges need to be taken into account. The first two factors will determine the density of seed at any given time and the third issue will determine whether the seed can find protection from predators. A release module is essentially a point in space which results in a theoretically infinite initial density and the density will only be reduced once seed moves away or dies. Clearly, if all the seed remains in the release module, they will obtain a degree of protection, but even a small number of seed dispersing within a small area (*e.g.* 250 into a circle of 1m radius), would still result in a density of approximately $80m^{-2}$, which is at the upper limit of what is typically found in juvenile Haliotids (Schiel 1993).

Whether these seed survive will depend on the amount of available refuge. It has been recognized for some time that juvenile abalone rely primarily on cryptic refuges for protection against predators (Shepherd and Breen 1992). Without sufficient provision of refuge it is reasonable to assume that exposed seed abalone will not survive. While Munro and Bell (1997) postulated that habitat (space) is unlikely to be a limiting factor for survival of (shell)fish, this observation is contradicted by Douros (1987) who observed density-dependent stacking behaviour in *Haliotis cracherodii*. An indication of possible competition for space was also noted in this study, when a wild juvenile abalone was observed occupying a non-cryptic position, with a seed abalone occupying the space under an adjacent sea urchin. Less persuasive but also applicable, is the persistent utilization of the release modules by seed abalone up to several weeks after release, which was also observed De Waal and Branch (2002). If refuge is indeed a limiting factor, large amounts of concentrated seed, unable to find shelter, would provide a bonanza for predators (Tegner and Butler 1989). In addition, it is likely that octopus, a voracious predator of juvenile abalone (Tegner and Butler 1985, Kojima 1988, Okei 1999), could extract seed from within release modules further exacerbating these concerns. The other seeding trials used in this study sought to distribute the seed relatively evenly throughout the seeding area and therefore would not suffer from the pronounced concentration effects outlined above.

The space limitation theory discussed above is contradicted to some degree by the findings in Trial 5, where density did not affect survival rates. The rock pool habitat supported significantly higher densities of wild juvenile *H. midae*, however (see Chapter 2), and it is possible that refuge limitation was not a factor in this area. Although this high density could be explained, at least in part, by other factors (*e.g.* higher settlement, less predation), the rock pool had a noticeably higher degree of under-rock habitat. This would clearly influence density-dependant survival.

Release modules may also be impractical from a logistical perspective. Large numbers of release modules would be required for large-scale releases and the deployment and retrieval of many release modules may be impractical. The number of release modules required would also increase if the number of seed in each release module were reduced to diminish the potential competition for space.

Comparisons between the various release techniques were difficult to make from a quantitative point of view, because of differences between trials. The only direct comparison was in Trial 6, which indicated that while hand-seeded animals had a better survival rate (44%), it was not significantly different to the survival rate of seed released using the surface-scatter method (39%). This comparison is tenuous however owing to no treatment replication and the non-robust estimates of survival. The time required to hand seed a similar amount of animals was significantly higher, however, and this method may not be practical for large-scale releases. This is especially true in areas where poor diving conditions are the norm. The results from the trials where surface-scattering was used to release seed, seem to suggest that this method may be viable, although further investigation is required, given the non-robust estimates of survival. The fact that seed did survive and endure after being seeded in this manner suggests that a rapid and cost effective alternative to hand seeding does exist (Shepherd *et al.* 2000). The use of a biodegradable, mini-release module (oyster shells for example), which could be abandoned and reduce the bonanza effect, could also help to increase survival of the scattered seed, by reducing handling stress and providing some interim shelter.

Seed Movement

Most of the seed retrieved in the release module trial were found close to the release point, at noticeably higher densities than further away; a result also observed by De Waal and Cook (2001). Comprehensive searches were not performed, so further speculation on dispersal rates is difficult. Retrievals from experimental plots, which were accurately demarcated, appeared to show very low dispersal rates, particularly in the case of Trial 4. Abalone movement has been shown to be influenced by a number of factors. Shepherd (1986) showed that *H. laevigata* movement was related to crevice abundance and De Waal (2002) postulated that the differing rates of dispersal that he observed resulted from increased exposure to wave action, which may explain the low rates of dispersal, particularly in the rock pool, where refuge availability was high and wave action low. Whereas the relatively lower survival estimates in the open-water sites may be partly explained by a combination of lower refuge availability and higher wave action. Handling stress or disturbance can also induce movement in abalone (Shepherd 1986, Tarr 1995), but the availability of refuge is likely to be the most important factor influencing dispersal (De Waal and Cook 2001). Wild *H. midae* have been shown to move quite large distances (Newman 1966), but adults in particular are known to exhibit high site fidelity (Tarr 1995). Tegner and Butler (1985) found evidence of seed dispersion well beyond the release area, while Werner *et al.* (1995) showed that Haliotids have the ability to move over a sandy substrate. The low dispersal observed in my accurately demarcated plots supports the view that movement is related to habitat availability and to a lesser extent, wave action, since cryptic refuges were abundant and water movement low in these sites, while there was a weak trend towards greater dispersal of seed in the open-water sites, where refuge availability appeared to be lower and wave action stronger.

Habitat

The importance of available suitable habitat for the survival of juvenile abalone is clear. What constitutes favourable habitat is open to interpretation, however, and there have been few attempts to quantify habitat suitability (Shepherd and Partington 1995). The difficulties encountered with reliably measuring survival and the failure to quantify habitat in the open-water in this study meant that the influence of habitat availability could only be meaningfully investigated in the rock pool and grid areas.

Since survey techniques were used to obtain the correlations between survival and habitat characteristics, cause and effect can only be inferred and relationships between variables must be treated with caution (Day and Branch 2000a). While there were some significant relationships obtained between seed survival and the indices of habitat suitability, they were at best illustrative, since trends were not consistent throughout these trials. As to be expected, wild abalone density was important but not an absolute indicator of seed survival, since there were no wild juveniles in some plots where seed survived. The success of seeding efforts using seed abalone beyond their natural range in South Africa (Sweijd *et al.* 1998, De Waal 2002), and in Japan (Saito 1979), supports this finding. Sea urchin density and the habitat suitability ranking also correlated with survival in one trial each, but not in two others.

The significant relationship between seed survival and the habitat suitability ranking, although not conclusive, suggests that this type of assessment will be useful for future seeding efforts. A similar regression between the survival estimates from all the seeding trials where a subjective index was allocated also gave a highly significant result ($p<0.01$, $n=31$). Although not explicitly stated in previous abalone seeding efforts, many researchers make subconscious or subjective decisions as to the suitability of a seeding site without having quantified it. This type of evaluation will be important in any future ranching projects for two reasons. Firstly, in planning any commercial ranching program, some knowledge of the total available habitat is required. Habitat can vary on several scales and from a planning point of view it is important to have a realistic knowledge of this variation on a scale of 10s to 100s of metres (Andrew and O'Neill 2000). The use of a qualitative habitat index will be required since it is not usually logistically feasible to assess the entire potential habitat. Secondly, on a smaller scale when the abalone are actually being seeded, irrespective of the method used, workers will be required to make a rapid on site evaluation of site suitability (*i.e.* refuge availability). The significant correlations observed in this study suggest that experienced abalone workers can make such an assessment.

The failure of the other habitat parameters to correlate significantly with seed survival can be interpreted either as an inability to correctly quantify the parameter or that the parameter is not important in all contexts. For example, the calculation of under-rock habitat availability was crude primarily because the under-rock surface could not be seen and therefore needed to be estimated. This inaccuracy would suggest that this technique will not be useful in future habitat suitability assessments even though an accurate ratio of under-rock to open area should be an important indicator of habitat suitability. In contrast, De Waal and Cook (2001) correlated survival with the number of small boulders (<30cm) in their seeding sites, which suggests that my rock-count index, while being relevant may not have been quantified correctly or another factor altered this effect .

The role of sea urchins in providing refuge and therefore ensuring survival of both seeded and wild *H. midae* is a complex one. The evidence presented in Trial 2 and that of Day and Branch (2000a), suggests that sea urchins are strongly favoured as a refuge by wild and seeded juveniles, but that the trend is not as strong with seeded abalone. The question as to whether sea urchins are a necessary requirement for juvenile abalone survival, as proposed by Tarr *et al.* (1996) and Day and Branch (2000a), is however, less clear. De Waal and Cook (2001) showed that the presence of sea urchins are not an absolute requirement for seed survival, and that seed survival was also correlated with the presence of boulders. Similarly, many seed (and wild juveniles) survived in my study that were not sheltering under urchins. Although not quantified, the abundance of sea urchins was also noticeably lower in the open-water environment, but seed and juvenile abalone still found refuge under rocks.

The attempts to quantify and compare habitat in terms of refuge availability in this study highlights the difficulties in assessing habitat requirements in general and in comparing widely separated sites (Andrew and O'Neill 2000). The importance of the interaction between the physical substrate (geological and geomorphological processes), and biological processes is a dynamic one. Site characteristics are likely to differ on scales ranging from metres to 100s of kilometres and biological factors (*e.g. s*eed size, predator type and predator density) will also vary. Refuge is of primary importance to juvenile abalone but it is likely that their requirements can be fulfilled by various substrates that can interact with each other. The favouring of one type of refuge does not mean that the seed or wild juvenile abalone depend on that type of refuge for survival (De Waal 2002). For example, a continuum of refuge suitability ranging from flat open rock to sea urchins to deep crevices and under-rock habitat with urchins as extra cover is more likely than an either or scenario (Tegner and Levin 1982). With this in mind, and the fact that this study found large numbers of wild juvenile urchins under rocks, other refuges should not be discounted as potential nursery or release areas.

Size of Seed

Although no clear picture emerged in this study as to the effect that seed size had on survival, there were indications that larger seed survived better in some cases. To illustrate, although no significant difference was found in the survival rates between hand-seeded and surface-scattered seed in Trial 6, smaller seed survived significantly better when hand-seeded but larger seed survived better when released using the scattering method, possibly caused by the smaller seed being more vulnerable while in the water column. This suggests that larger seed should be used if the surface-scattering method is employed especially as water depth increases. In contrast, there was no significant difference found in survival rates between two size classes (Mean SL: 17.6 and 29.4mm) of animals in Trial 5. The acceptance of the null-hypothesis in the 2-way ANOVA in Trial 5 needs to be treated with some caution however, since treatment replications were very low. To illustrate, there was a significant difference in size between pre-release and post-trial seed from the t-tests in the smaller size group from the same experiment. This suggests that the 2-way ANOVA may not be sufficiently powerful to detect the changes that were being tested. The results from the other trials where size differential mortality was measured were equivocal and no firm conclusions could be drawn on the effect of seed size on survival. This contrasts sharply with De Waal and Cook's (2001) findings using similar sized *H. midae*, where larger seed survived significantly better than small seed, although their trials were conducted in an area subjected to heavier wave action. As in some of the trials in this study, his trials introduced the different sized seed together, so predators would have been able to choose between different sized animals, perhaps preferring the smaller seed because they would be easier to consume. Similar contrasts have been observed in other abalone seeding studies (Saito 1984, Schiel and Weldon 1987, Zhao *et al.* 1991, Schiel 1992). The lack of consistent differences in survival between different size classes of animals in this study and the rejection of the hypothesis that larger seed survives better than smaller seed in Trial 5 may be a deficiency in the sample design used in these trials and suggests that further study is required on this issue using more appropriate experimental designs. Even if there is a no significant difference in survival between different size classes of animals the time to maturity or harvest will be less for the larger animals and this might outweigh the decreased cost of putting in smaller (cheaper) seed. These types of scenarios are best investigated with cost-benefit analyses (see the following chapter).

Predation

Predation is one of the main contributors to natural mortality of juvenile abalone and numerous species that can potentially prey on juvenile abalone were observed in this study. In addition several overt acts of predatory behaviour were observed on seed abalone. Most notable were shoals of blacktail and cape stumpnose that were present during many seeding operations and the attraction of at least one octopus to a seeding site during the placement of a release module, probably through olfactory stimulus (Tegner and Butler 1989). The low recovery of seed shells, which are relatively easy to find (Ebert and Ebert 1988), would suggest that many of the un-accounted for seed especially in the rock pool, were consumed by fish predators who are able to consume a small abalone whole. While dispersal, non-location or fishing could lead to unaccounted for seed, the large amount of missing shells, would suggest that many of the seed had been consumed in their entirety. The attraction of predators to seeding sites during or soon after seed introduction is counter-productive, since this is when seed is at its most vulnerable. Seeding should therefore be done at times when predator activity is at its lowest. Shepherd *et al.* (2000) has suggested that late afternoon is when fish predation is likely to be lowest and octopuses are also likely to less active at this time.

Growth

The growth of seed abalone in this study appeared to vary significantly over relatively small distances. This is typical for Haliotids in general and appears to be caused largely by variations in food type and availability (Day and Fleming 1992, McShane and Naylor 1995), but has also been ascribed to variations in the degree of exposure to wave action (Wood 1993), or temperature (Newman 1968). Owing to the lack of standardization for time, size of seed and non-quantification of algal abundance, comprehensive comparisons between sites and experiments is difficult. The growth rates measured for seeded animals, although measured for a fairly wide size range of animals, was similar to that measured for wild juveniles in this study and also for other studies of *H. midae* in South Africa (Table 3.19, Wood 1993, Tarr 1995). The variation in growth of wild juveniles measured in Chapter 2 may also be explained by the absence (mortality) of larger sized animals in the rock pool, which would have had the effect of decreasing the average size of larger cohorts. The variation in growth that has been measured in this study is important and needs to be taken into account when addressing the economic feasibility of commercial ranching operations (see the following chapter).

Table 3.19 Summary of growth rates from seeding trials (standardized to 30 days).

Experiment	Site (n)	Period (days)	Mean ($mm.30days^{-1}$)	Minimum ($mm.30days^{-1}$)	Maximum ($mm.30days^{-1}$)	Standard Error
Release Modules	Prelim (14)	174	0.5	0.1	1.2	0.09
	Boiler 1 (36)	176–373	1.5	0.7	2.3	0.07
	Habitat 1 (41)	212–413	2.4	1.2	3.1	0.07
Medium Term	Plots 2 & 3 (207)	72–74	1.2	0.1	2.8	0.04
	Plot 4 (96)	66	1.9	0.3	3.4	0.07
Comparative	All (119)	42	1.6	0.4	3.6	0.06
Mass Seeding	Site B (42)	115	2.6	1.6	3.8	0.07
	Site C (14)	84	1.3	0.9	1.8	0.07
Average (All)	**569**	**-**	**1.6**	**0.7**	**2.8**	**0.07**
Wild 1	Rock pool	110 (mid-summer to end autumn)	2.2	-	-	-
Wild 2	Rock pool	252 (start winter to mid-summer)	1.9	-	-	-
Average (All)	**Rock pool**	**1 Year**	**2.0**	**-**	**-**	**-**

General Enhancement Effects

Although it is beyond the scope of this study to look at the overall enhancement effects of seeding at Cape Recife, some comments are valid in light of observations made in this study.

Ratio of Wild to Seed Abalone

It was observed in the course of sampling for seed abalone that they appeared to outnumber the wild cryptic abalone at all the open-water seeding sites. No quantitative data was collected since there was an emphasis on maximizing search effort for seed, but this trend was consistent and the ratio was estimated at approximately 3:1. This result, while not of any use from a quantitative aspect, does illustrate that seed can make a meaningful contribution to the wild stock (Rogers-Bennett and Pearse 1998) and that natural juvenile production may be limited in some way. This means that even if seeding is not viable from an economic point of view, it could be used for rehabilitation purposes.

Similarly, several of the larger seed that were collected in Trial 1 had also begun to develop gonad material within approximately a year after release. The contribution of seeded animals to the spawner stock is one of the primary aims of stock enhancement and this result is in general agreement with the findings of Wood (1993) who investigated size-at-sexual maturity of wild *H. midae* in the Eastern Cape Province.

Displacement of Wild Juveniles

In contrast, the occurrence of a wild juvenile abalone in a non-cryptic position at one seeding site, suggests that seeding may not be beneficial to the wild stock. While no before and after surveys were done and therefore passive displacement (*i.e.* competition for limited refuges after nocturnal foraging) of wild by seeded juveniles can only be assumed, this example does illustrate the problem of only considering seed survival. Even if good survival is possible, this may be at the expense of wild conspecifics, and will detract from the overall enhancement effect (Cowx 1994).

Summary

This chapter delivered a diverse set of results on juvenile abalone seed survival. Short-term studies conducted in favourable habitat showed that seed survival rates can be high. The results from the mass seeding trials indicate that large-scale releases, using cost-effective release methods, are feasible and that reasonable survival rates are possible. Large-scale mass seeding trials are required to demonstrate whether commercial ranching will produce the survival required for economic viability.

CHAPTER 4

ECONOMIC ASSESSMENT OF AN ABALONE RANCHING OPERATION

INTRODUCTION

The declines in abalone abundance demonstrated at Cape Recife in Chapter 2 demonstrated the need for investigating restorative or remedial management actions and the results of the seeding trials in Chapter 3 suggested that ranching applied in conjunction with a territorial user right fishery (TURF) could be an appropriate management tool. Recent reviews of marine stock enhancement have emphasized the need for a thorough evaluation of experimental results prior to the implementation of large-scale releases (Blankenship and Leber 1995, Hilborn 1998) and that they must be evaluated in terms of their stated objectives (Welcomme 1998, Bartley 1999). A cornerstone of stock enhancement evaluation is considered to be a demonstration of economic feasibility, especially since money may be better spent on more traditional means of fisheries management, particularly if public funds are being used (Hilborn 1998).

While abalone stock enhancement measures have been investigated for several years, few studies have focussed on the economic sustainability of this practise. In Japan where the majority of research and commercial-scale releases have occurred, critical cost evaluations are almost non-existent (Kitada 1999), which seems to stem from the way that ranching is funded (McCormick *et al.* 1994, Imamura 1999) *e.g.* juveniles are typically sold for 25–50% of their production cost (McCormick and Hahn 1983). In New Zealand, Schiel (1993) demonstrated the potential economic viability of seeding *H. iris* juveniles, but found that the release of larvae would not be profitable (Schiel 1992).

In South Africa, Sweijd *et al.* (1998) used preliminary survival and growth rates from their seed releases to model profitability of ranching *H. midae* on the north-west coast. Although their model was relatively simple, and did not take into account several factors such as operating costs and the internal rate of return on the investment, they concluded that survival rates of about 20% would favour economic success. A more comprehensive analysis was performed by De Waal (2002) and he focussed on modelling the minimum initial survival and differential survival rates of seed that would be required to produce profitable returns from ranched animals. He found that initial survival after release played the most important role in determining final mortality and that releasing animals of at least 25mm SL would yield the most favourable returns on investment. An important feature of the coastline where these two previous studies were conducted is the very low human population density as well as large areas where access is restricted or limited by diamond mining activities. This restricted access would reduce the necessity for added security measures that can significantly increase the cost of managing a TURF.

If abalone ranching is to be used as a tool for managing abalone resources in the Eastern Cape Province, it needs to be evaluated in terms of stated management objectives. In light of current fisheries policy in SA, which is discussed in the general discussion (Chapter 5), the sustainable utilization of abalone resources is the primary aim of fisheries managers. If new or alternative regimes can be shown to be feasible they can be considered for implementation. It is beyond the scope of this project to consider all the management issues surrounding the abalone resource in the Eastern Cape Province, but an initial economic evaluation of a proposed ranching model and its allied fishery management regime will help managers and investors to make decisions for implementing future schemes.

One of the key elements for operating a successful ranching operation would be to ensure that no illegal fishing would occur, which would protect and aid the recovery of wild stocks, and ensure the sustainability of seeded and wild populations. This will obviously have cost implications for a business plan. While the burden of compliance monitoring should not necessarily fall exclusively on a private concession holder, in a TURF, the concession holder would be expected to cover the majority of security and other management costs.

AIM AND OBJECTIVES

The aim of this chapter was to investigate the economic feasibility of managing abalone stocks in the Eastern Cape Province using an area based management system (TURF) in conjunction with abalone ranching. This was performed using a simple spreadsheet model to investigate the internal rate of return (IRR) and the nett present value (NPV) of a proposed ranching business plan.

METHODS

Business Plan

The business plan was designed after consultation and input from a commercial abalone farmer (Pers. Comm., C. Muller, Marine Growers (Pty.) Ltd., 2000). Profitability analyses were performed by calculating the internal rate of return (IRR) and the nett present value (NPV) of various ranching operating scenarios. The NPV method is sometimes preferred over the IRR method owing to the difficulties encountered with calculating the correct profitability figure when the cash flow changes from negative to positive (Moksness and Støle 1997). The interest rate on invested money was set at 20% for all the analyses, since this is the approximate money-lending rate in SA (See Table 4.1 for a summary of parameters pertinent to the ranching model). The NPV and IRR were calculated using the following formula, where NPV was set at zero to calculate the IRR (Microsoft® Excel 2000 was used to perform the actual calculations):

$$NPV = - I + \frac{(T - O)_1}{(1 + i)^1} + ... + \frac{(T - O)_n}{(1 + i)^n}$$

Where the symbols stand for the following:

NPV	Nett present value
I	Size of investment year 0
T	Turnover per year
O	Operating costs per year
n	The amount of years of operation
U	The value of the business at the end of the period
i	Rate of interest / risk premium (IRR)

The term (T - O) is the nett cash flow per year and in this model I and O are set at zero and all the capital costs are incorporated into the annual nett cash flows (T). If the NPV is above zero the investment is profitable as long as the input figures are realistic (Moksness and Støle 1997). Annual inflation was not considered in the model.

An attempt has been made to be as realistic as possible in the design of the business plan. The various elements were broken down in the following manner. Two different harvest strategies were used to investigate the financial feasibility of the ranching plan and were based on the present minimum legal size limit (MLS) and the MLS recommended by Wood (1993) for *H. midae* in the Eastern Cape Province (Table 4.1). A growth rate of 1.6mm.month^{-1} over the whole period before harvest was used, which results in the seed taking 5 or 6 years to reach the two harvest sizes. The business plan was based on a monthly harvest of approximately 3 tons of abalone per month. No assumptions were made on the carrying capacity of the natural environment, and stocking densities and total area required was therefore not considered. Although seeded animals would be expected to contribute to the overall recruitment of the fishery once they had reached maturity, this component was not considered in the model.

Table 4.1 **Critical assumptions for profitability analyses of the *H. midae* ranching project.**

Model Parameters	**Harvest Size**	
	140mm SL	**121mm SL**
Mean Seed Size (SL mm)	25	25
Unit Cost of Seed	R 2.50	R 2.50
Seed (month^{-1})	26 000	36 000
Survival	27%	30%
Growth Rate (mm.month^{-1})	1.6	1.6
Years before Harvest (years)	6	5
Monthly Harvest (n)	6 909	10 629
Seed Harvest Mass (kg)	0.445	0.285
Harvest (kg.month^{-1})	3 076	3 028
Market Price ($)	37.50	37.50
Exchange Rate (R:$)	10.00	10.00
Interest Rate	20%	20%

A size of 25mm SL was chosen for the seed, and these were valued at R2.50 each. Seed survival was calculated using the combined components of seeding induced mortality and natural mortality (De Waal 2002). An initial seeding induced mortality of 50% was chosen and was based largely on the results from Trials 2, 3 and 5 in Chapter 3, which were conducted over periods from 1 week to 2 months, using similar sized animals. A subsequent natural mortality of 10% per year was then used to obtain the overall survival rate of seed. This is based on the figure of 11% used for the natural mortality of *H. midae* for all size classes used by MCM (De Waal and Cook 2001). Table 4.2 illustrates the annual final survival rates of 25mm seed as a combination of seeding mortality and natural mortality.

Table 4.2 Combination of initial seed survival and natural mortality for *H. midae* ranching model, and size at harvest.

Time	Survival Rate	Total Survival Rate	Shell Length (mm)
T_0	50%	50.0%	25
1st Year	90%	45.0%	44.2
2nd Year	90%	40.5%	63.4
3rd Year	90%	36.5%	82.6
4th Year	90%	32.8%	101.8
5th Year	**90%**	**29.5%**	**121**
6th Year	**90%**	**26.6%**	**140.2**
7th Year	90%	23.9%	159.4
8th Year	90%	21.5%	178.6

Personnel and Capital Expenditure

The business plan allowed for a total of 13 people to operate the ranching scheme. The security aspect of the project was fulfilled by having 24-hour surveillance, comprising of 3 eight-hour shifts of 2 people each and a standby team. A supervisor and four divers who would seed and harvest the abalone completed the personnel requirements. When the divers were not required for seeding or harvesting, they could also be used as extra security personnel.

Two four-wheel drive vehicles, a 4-wheel motorcycle and a small skiboat were provided for compliance monitoring and day-to-day running of the project. Communication equipment, insurance, running costs and general expenses were also allowed for in the budget (Table 4.3 and Table 4.4). Capital expenditure items (CAPEX) were paid off over 5 years.

Harvesting

Using the combined morphometric regression equations calculated for *H. midae* in the Eastern Cape Province by (Wood 1993) and a growth rate of 1.6mm.month^{-1} for seed (average growth of seed measured in Chapter 3), it was calculated that 25mm seed would reach 121mm SL after an interval of 5 years and 140mm SL after 6 years (Table 4.2). The whole mass equivalent of these animals was calculated as 285g and 445g respectively.

Selling Price

The selling price of live *H. midae* in the Far East markets fluctuates according to demand, the quality of the product and other less tangible factors. Premium prices of \$38.kg^{-1} have been obtained but prices as low as \$32kg^{-1} are also obtained (Pers. Comm., C. Muller, Marine Growers, 2000). For the purposes of this model the current price of US\$37.50kg^{-1} was used.

Exchange Rate

The South African Rand is subject to trading on the open market, and has tended to be volatile over the last 5–10 years, with a steady decline against the US dollar being the norm. A price of R10.00 to the US dollar is used in this model.

Cost of Sales

The export of live abalone incurs significant costs, comprised largely of packaging and freight expenses. Current freight charges are approximately 10% by weight of the product and a further 5% was added for packaging costs.

Interaction of Seed Survival, Seed Price and Market Price

The degree to which overall seed survival and seed price affects the profitability of the 140mm SL harvesting model was investigated by varying these two factors using the original basic spreadsheet model. Similarly, the interaction between seed survival and market price was also investigated. The 121mm SL harvesting model was not considered further since the recommendations of Wood (1993) have not been implemented by the management authorities in the Eastern Cape Province.

Interaction of Seed and Wild Harvest - Enhancement Effect

In areas where there are no natural stocks of abalone, the catch will depend on the amount of seeded animals that survive to harvest size (disregarding the possibility that the seeded animals may reproduce). In areas such as the Eastern Cape Province of SA, which supports natural *H. midae* stocks, it is feasible to fish these wild stocks while waiting for seeded animals to reach harvestable size. While no results were available for the degree to which *H. midae* seeding practices can increase overall production in endemic areas, by investigating the combined catch of wild and seed abalone, rehabilitation and enhancement effects can be investigated. During the "fallow" years before seed reaches a harvestable size, different catch rates of wild stock were modelled. Once the seed had reached a harvestable size, the wild catch is deemed to be zero, though in reality this would not be the case. An increase of seeded catch over wild catch can be considered as an enhancement effect.

RESULTS

Harvest at 140mm and 121mm Shell Length

Owing to the 5 or 6 year fallow period in the two basic ranching models, nett cash flow is negative for the first 5 and 6 years after seeding, for the 121mm and 140mm SL harvest regimes respectively (Table 4.3 and Table 4.4). As can be expected, this has serious implications for the profitability analyses of these two regimes (Table 4.5 and Table 4.6). IRR was not calculated for both regimes over the first 5 years and the NPVs were negative for both regimes. After a 10-year period, owing to the high market prices obtained for abalone, the trend of losses is reversed and a nett profit is shown for both ranching models. The 140mm harvesting regime, despite higher individual mass-at-harvest, has a lower IRR and NPV compared to the 121mm harvesting regime, owing to a lower overall survival rate of seed. The NPV is R3.1m (30.3% IRR) for the 140mm SL harvest regime and R5.8m (36.9% IRR) for the 121mm SL harvest regime.

Table 4.3 **Outline of 10-year business plan for *H. midae* ranching project with harvest at 140mm SL (all figures are in .SA Rands).**

Expenses		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Cost of Juveniles		780,000	780,000	780,000	780,000	780,000	780,000	780,000	780,000	780,000	780,000
Salaries and Wages											
	Supervisor (1)	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000
	Guards (8)	384,000	384,000	384,000	384,000	384,000	384,000	384,000	384,000	384,000	384,000
	Divers (4)	144,000	144,000	144,000	144,000	144,000	144,000	144,000	144,000	144,000	144,000
Vehicles											
	4x4 (2)	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000
	4 Wheelers (1)	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000
	Boat (1)	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000
Vehicle costs											
	Diesel	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000
	Maintenance	24,000	24,000	24,000	24,000	24,000	24,000	24,000	24,000	24,000	24,000
Insurance		36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000
Radios and telephones		48,000	48,000	48,000	48,000	48,000	48,000	48,000	48,000	48,000	48,000
General		60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000
Total expenses		1,692,000	1,692,000	1,692,000	1,692,000	1,692,000	1,692,000	1,692,000	1,692,000	1,692,000	1,692,000
Income											
Sales		0	0	0	0	0	0	13,841,203	13,841,203	13,841,203	13,841,203
Cost of Sales		0	0	0	0	0	0	2,076,180	2,076,180	2,076,180	2,076,180
Annual Total Income		0	0	0	0	0	0	11,765,023	11,765,023	11,765,023	11,765,023
TOTAL NETT INCOME		-1,692,000	-3,384,000	-5,076,000	-6,768,000	-8,460,000	-10,152,000	-78,977	9,994,045	20,067,068	30,140,090

Table 4.4 **Outline of 10-year business plan for *H. midae* ranching project with harvest at 121mm SL (all figures are in .SA Rands).**

Expenses		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Cost of Juveniles		1,080,000	1,080,000	1,080,000	1,080,000	1,080,000	1,080,000	1,080,000	1,080,000	1,080,000	1,080,000
Salaries and Wages											
	Supervisor (1)	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000
	Guards (8)	384,000	384,000	384,000	384,000	384,000	384,000	384,000	384,000	384,000	384,000
	Divers (4)	144,000	144,000	144,000	144,000	144,000	144,000	144,000	144,000	144,000	144,000
Vehicles											
	4x4 (2)	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000	72,000
	4 Wheelers (1)	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000
	Boat (1)	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000
Vehicle costs											
	Diesel	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000
	Maintenance	24,000	24,000	24,000	24,000	24,000	24,000	24,000	24,000	24,000	24,000
Insurance		36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000
Radios and telephones		48,000	48,000	48,000	48,000	48,000	48,000	48,000	48,000	48,000	48,000
General		60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000
Total expenses		1,992,000	1,992,000	1,992,000	1,992,000	1,992,000	1,992,000	1,992,000	1,992,000	1,992,000	1,992,000
Income											
Sales		0	0	0	0	0	13,627,833	13,627,833	13,627,833	13,627,833	13,627,833
Cost of Sales		0	0	0	0	0	2,044,175	2,044,175	2,044,175	2,044,175	2,044,175
Annual Total Income		0	0	0	0	0	11,583,658	11,583,658	11,583,658	11,583,658	11,583,658
TOTAL NETT INCOME		-1,992,000	-3,984,000	-5,976,000	-7,968,000	-9,960,000	-368,342	9,223,316	18,814,975	28,406,633	37,998,291

Table 4.5 **Nett profit, annual return on investment and nett present value (NPV) for *H. midae* ranching model with harvest at 140mm SL.**

	Expenditure	Sales	Nett Profit	IRR	NPV
5 years	R8,460,000	R0	**-100.0%**	**-**	**-R5,060,116**
10 Years	R25,224,722	R55,364,812	119.5%	30.3%	R3,106,164

Table 4.6 **Nett profit, annual return on investment and nett present value (NPV) for *H. midae* ranching model with harvest at 121mm SL.**

	Expenditure	Sales	Nett Profit	IRR	NPV
5 years	R9,960,000	R0	**-100.0%**	**-**	**-R5,957,299**
10 Years	R30,140,875	R68,139,166	126.1%	36.9%	R5,570,530

Survival Rate, Seed Price and Market Price

Manipulation of seed survival, seed price and market price did not affect the overall profitability of the 140mm harvest regime in the first five years and is therefore not presented. The results of the profitability analyses for the 10-year plan are shown in Table 4.7 and Table 4.8. The results showed that seed survival, seed price and market price can all have a notable influence on the profitability of the ranching scheme for the range of parameters that were chosen. For the range of seed and market prices that were tested, an overall survival rate of 20% was where the IRR became more than 20% (the minimum benchmark for investment in SA). The IRR ranged between 17.4 and 31.4% for the seed prices that were tested and between 15.9 and 24.1% for the range of market prices tested.

Enhancement Effect

By introducing a wild catch component to the 140mm SL business plan, the profitability of the investment is changed significantly (Table 4.9). With only a relatively small wild catch of 6 ton per year, the investment is profitable over both the 5 and 10-year periods and given the high value of the product, obviously becomes highly profitable with progressively larger wild catches. While the addition of seeded catches improves the revenues derived from the model by increasing total catch, the profitability (IRR) decreases as the seeded catch increases for a given wild catch. This stems from the increasing costs of seeding more abalone.

Table 4.7 **Internal rate of return for 10-year business plan for harvest at 140mm SL with overall seed survival and seed price as variables.**

Seed Price	Overall Seed Survival					
	5%	10%	20%	30%	40%	50%
R1.00	**-11.9%**	**11.6%**	31.4%	42.8%	51.1%	57.6%
R1.50	**-17.1%**	**7.9%**	28.0%	39.4%	47.6%	54.1%
R2.00	**-22.5%**	**4.6%**	25.0%	36.4%	44.5%	50.9%
R2.50	**-28.4%**	**1.5%**	22.3%	33.7%	41.8%	48.2%
R3.00	**-35.2%**	**-1.4%**	**19.7%**	31.2%	39.3%	45.6%
R3.50	**-44.1%**	**-4.2%**	**17.4%**	28.9%	37.0%	43.3%

Table 4.8 **Internal rate of return for 10-year business plan for harvest at 140mm SL with overall seed survival and market price as variables.**

Market Price	Overall Seed Survival				
	10%	20%	30%	40%	50%
$30	**-6.2%**	**15.9%**	27.4%	35.5%	41.8%
$35	**-0.8%**	20.3%	31.7%	39.8%	46.2%
$40	**3.6%**	24.1%	35.5%	43.6%	50.0%

Table 4.9 **Internal rate of return for 5 and 10-year business plan for harvest at 140mm SL.**

Wild Catch	Seeded Catch				
	0 ($t.yr^{-1}$)	6 ($t.yr^{-1}$)	12 ($t.yr^{-1}$)	18 ($t.yr^{-1}$)	36 ($t.yr^{-1}$)
0 ($t.yr^{-1}$)	-	-	-	-	-
	-	-	**10%**	**18.9%**	32.1%
6 ($t.yr^{-1}$)	188%	156%	130%	107%	53%
	188%	157%	133%	113%	81%
12 ($t.yr^{-1}$)	428%	371%	326%	287%	208%
	428%	371%	326%	288%	209%
24 ($t.yr^{-1}$)	884%	773%	687%	613%	464%
	884%	773%	687%	613%	465%
36 ($t.yr^{-1}$)	1335%	1169%	1040%	930%	711%
	1335%	1169%	1040%	930%	711%

DISCUSSION

Quality of Input

Before discussing the outcome of the economic assessment of operating a restricted access fishery in conjunction with *H. midae* ranching, it is worth considering the quality of the input parameters since several important assumptions are made. The quality of input will determine how relevant an economic assessment will be to the real situation (Moksness and Støle 1997).

Growth Rate

As discussed in Chapter 3, growth rate was measured for a variety of seed sizes and over different durations and time periods during the year. The average daily growth rate of 1.6mm.month^{-1} that was obtained in this study resulted in similar size-at-age to measured and calculated shell lengths of wild *H. midae* in the Eastern Cape Province (Table 4.10, Wood 1993), with a slight underestimate of seed growth being more likely. This growth rate is therefore considered to be a realistic if somewhat conservative estimate. Given the variability of growth rate that is exhibited by Haliotids in general, this is probably a prudent method to use.

Table 4.10 Length-at-age for abalone calculated for *H. midae* in the Eastern Cape Province by (Wood 1993) compared to the calculated length of seed (adjusted for comparative purposes).

Age (Years)	(Wood 1993) - Calculated SL (mm)	(Wood 1993) - Measured SL (mm)	This Study - Shell Length (mm)
1	20	22	20
2	54	48	39
3	80	82	58
4	101	101	78
5	117	118	97
6	130	134	116 (121)
7	140	139	135 (140)

Seed Cost, Market Price, Exchange Rate and Harvesting Costs

Seed and harvesting costs, market price and exchange rates all significantly affect the outcome of profitability analyses. The figures used in this study were all accurate at the time of writing but potential fluctuations must be considered by investors. The price of seed may be less if produced by the same company that is conducting the ranching operation and this would improve the financial feasibility of the ranching plan.

The operating costs used in this analysis were calculated for an existing abalone production and processing plant, so most of the infrastructure for producing seed and processing would not have to be provided for, thereby reducing capital expenditure significantly. If ranching were to be considered in areas further away from the seed supplier, holding facilities would need to be provided, thereby increasing costs. In contrast, while seed price discounting was not done in this instance, it is possible that seed costs could be reduced if the seed was produced by the ranching rights holder (as is the case). Alternatively, as more abalone farms become operational in SA, excess seed may become available at discounted prices. Many abalone farms “dump” slow growing abalone, which are usually the lower 30% of a farmed “cohort”. These animals are considered as a potential source of seed for the ranching program in Port Nolloth, but this type of practice has negative genetic implications for ranching in areas with endemic populations of *H. midae*.

Even though an attempt was made to be realistic in terms of planning security and operating protocol for the ranching scheme, it is possible, and one might argue likely that given the unknown nature of this endeavour, these costs could be higher. Given the high demand for *H. midae* and the current high levels of poaching, security may have to be given an even higher priority in areas such as the Eastern Cape Province.

The cost of borrowing money, market price of abalone and foreign exchange rates are all subject to fluctuations but a full discussion of these topics is beyond the scope of this study. The market price of $37.50kg^{-1} used in this study, is probably at the upper limit being obtained for live *H. midae*. If the abalone was not marketed live then the nett income from the abalone would be lowered. At present the price of abalone is related largely to the supply of, and demand for abalone in the Far East (Gordon and Cook 2001). As abalone aquaculture facilities proliferate worldwide, supply may start to exceed demand with a possible lowering of market prices in the future. The Rand - Dollar exchange rate was as low as R13.50 at the beginning of 2002 and if the long-term trend of a weaker Rand continues, the profitability of a ranching operation will improve.

Seed Survival

The most important factor that can affect the outcome of the profitability analysis is that of seed survival, since it plays the greatest role in determining the final returns on the total investment (De Waal 2002). At present the data concerning the long-term survival of seeded *H. midae* is sparse. Only two previous studies have provided seed survival estimates for *H. midae* and survival rates were only measured over periods of up to six months, necessitating speculation for longer term survival rates (Sweijd *et al.* 1998, De Waal and Cook 2001, De Waal 2002). The long-term survival rates used in the initial model in this study, are similarly speculative, and probably represent a scenario, which although not unrealistic, is probably towards the upper end of possible survival rates. De Waal and Cook (2001) has shown that profitability is dependant on both initial mortality associated with seeding and long-term age specific mortality, with initial mortality being the most important. Until more data is available for seed survival rates, economic modelling will remain relatively speculative, which increases the overall risk of the business venture. The large variances in seed survival rates obtained in Chapter 3, although partly caused by the limitations of the experimental designs, are indicative of the high variations that are likely for seeding operations This observation exposes the limitations in the deterministic approach used for the economic assessment in this study. Although various survival rates were used to generate different financial outcomes, this issue might have been better dealt with by building a stochastic element into the survival rates used for the basic model. This would have enabled a more realistic assessment to be made of the economic feasibility of *H. midae* ranching.

Outcome of Basic Business Plan

The viability of operating a territorial user right fishery based solely on the ranching of *H. midae* in the Eastern Cape Province has to be questioned in light of the financial analysis of the business plan. While an IRR of just over 30% is shown for the 140mm SL harvest regime after 10 years, this is probably insufficient to justify the risks of the investment given the uncertainties surrounding the input parameters, particularly the survival rate of seed. The long period before the business shows positive returns is also an important consideration for investors and would also detract from the financial feasibility of the scheme. While the adoption of a smaller harvest size does improve the financial outcome to a degree, it is unlikely that the increased returns are sufficient to justify the risks (*i.e.* uncertain survival rates) either. While long-term seed survival rate data remains unavailable, the investment required to operate such a ranching scheme is probably too risky unless far higher returns on investment were apparent. "Economics of scale" could improve the profitability by reducing unit costs for personnel and capital expenditure but a greater total investment of capital will be required. Manipulation of input parameters clearly has an important influence on the feasibility of the business plan, but there is no reason to suppose that these parameters will change to benefit the model as a whole. While it is possible that the most important parameter, that of seed survival, will increase as more scientific knowledge is gained, it is not appropriate to speculate on this given current knowledge.

The inclusion of a wild catch component into the TURF/ranching model has a significant influence on the economic feasibility of operating such a scheme. By adding a relatively small wild catch ($6t.year^{-1}$) and reducing the ranched catch to zero, it is possible to operate a TURF in a sustainable manner. Operating such a scheme will ultimately depend on the biological sustainability of the abalone resource. In that sense there is a problem since there has never been a large-scale fishery in the Eastern Cape Province, so there is very little information on long-term catch rates in relation to stock sustainability and no comprehensive stock abundance data available. However, given the amount of illegal catches being made in the Eastern Cape Province it seems reasonable to assume that there are sufficient wild abalone available for fishing. The most important question to resolve will be to determine how much catch should be allowed from a particular area and here a precautionary approach should be adopted.

The type of ranching program that is envisaged is not a "small-scale" operation and requires large sums of capital owing to the long pay-back period. It will therefore require sophisticated management to succeed and will be difficult to operate as a "stand-alone" venture but could complement existing abalone farms cost-effectiveness.

In conclusion, it has been demonstrated that a territorial user right fishery for *H. midae* using stock enhancement may be financially feasible under certain conditions. However, given the uncertainty over input parameters, particularly seed survival rate and the slow return on investment, the risk may be too high to justify investing in such a scheme. However, with the addition of a small wild catch component, the operation of a TURF appears to be economically feasible given ecological sustainability, and represents a viable alternative to the present fishery management scheme that appears to be failing to prevent large-scale illegal fishing.

CHAPTER 5

GENERAL DISCUSSION

INTRODUCTION

The underlying premise of this thesis was that cultured juvenile abalone introductions could be used as a management tool to rehabilitate and enhance natural populations of *H. midae* in the face of perceived over utilization by illegal fishing. The results from this study suggest that abalone stock enhancement has potential as a management tool in areas where *H. midae* occur naturally, and in particular, the Eastern Cape Province of South Africa.

Stock Appraisal

The results of Chapter 2 showed that the scale of illegal fishing had increased substantially over the study period, leading to declines in abundance of abalone in the study area. The use of records of illegal catches to measure increase in fishing effort and their effects was successful. Validation of this data source by fishery independent survey methods, as was done in this study, is recommended however. The failure to curb illegal fishing and the declines in abalone abundance catalogued at Cape Recife are indicative of the failure of overall current fisheries management structures and suggests that the objectives of the *Marine Living Resource Act 1998* (SA 1998) are not being met. It is probably reasonable to conclude that despite a failure to show decreases in settlement at Cape Recife, if the present management situation is not addressed and poaching continues unabated, then stock collapse at Cape Recife is imminent. Similarly, there is evidence to suggest that the illegal fishing pattern occurring at Cape Recife will be repeated throughout the Eastern Cape Province, which will have dire consequences for the sustainability of the *H. midae* stock in this region.

Seeding and Economic Evaluation

The results from the stocking trials in this study were encouraging in terms of the survival rate of seeded animals in the natural environment. Good estimates of survival were obtained in sheltered habitats, while problems were encountered with measuring survival in the open-ocean, which were overcome to a degree by using change-in-seed density ratios. This method is suggested as a rapid and cost-effective solution to the problems of evaluating short to medium-term seeding trials without destructive interference, but with the proviso that sufficient replication is performed to measure seed survival accurately. In general, seed survival and movement seemed to be influenced by the amount of cryptic habitat available to the seed, and the degree of exposure to wave action. The difficulties of estimating seed survival in the open-ocean notwithstanding, the survival rates obtained in this study were promising for future seeding projects. Consistent estimates of seed survival are required before thorough evaluations and firm predictions can be made. This applies particularly to cost-benefit analyses such as the one performed in Chapter 4 which showed that commercial abalone ranching may be feasible if consistent survival rates of between 20 and 30% are obtained. However, because of the long time before returns on investment are obtained, consistent seed survival of at least 30% are probably required to satisfy investors and, at present, the variability associated with estimates of seed survival mitigate against a ranching/TURF operation relying exclusively on seeded abalone. By introducing a small wild catch into the operation of an area-based fishery (TURF) however, the economic feasibility of the overall operation is altered significantly in favour of a positive outcome. Stock enhancement must be evaluated in terms of its stated goals (Bartley 1999) and this pilot-scale project succeeded in this sense. It demonstrated that reasonable seed survival is possible in endemic areas, that they display comparable growth to wild stock, that they can contribute to the overall abalone reproductive output and also probably to overall abalone abundance.

Fisheries Management and Philosophy

If, as has been indicated in this study, *H. midae* stock enhancement can be used as a management tool in endemic *H. midae* areas, the question of how these measures should be implemented needs to be posed. As previously mentioned, commercial scale ranching of abalone and the issue of stock ownership are inextricably linked (Munro and Bell 1997, Cowx 1998, Howell 1998). Stock ownership issues are critical to the effective management of stocked animals and in the case of relatively sedentary species such as abalone, stock ownership can be easily based on a defined area.

Current fisheries management philosophy in South Africa, which is encapsulated in the *Marine Living Resource Act 1998 (SA 1998)*, must be kept in mind when decisions on whether to allow the implementation of abalone ranching projects and complementary area-based fisheries are made. This law makes specific provisions for the optimal and sustainable use of living marine resources to achieve *economic growth and human resource development*, whilst conserving them using precautionary management principles. Emphasis is also placed on redressing historical imbalances in resource allocation to achieve equity in the fishing industry. The current management regime of *H. midae*, particularly in the Eastern Cape Province, where a "do nothing" approach has prevailed with respect to fishery development, is failing to fulfil these provisions. Optimal use is not being made of the resource in the Eastern Cape Province, where poaching activities indicate that there is sufficient scope for commercial scale utilization. Poaching is continuing to escalate with severe implications for the long-term economic and ecological sustainability of the resource in all areas. This will hinder much needed economic growth in the region and preclude participation of new entrants into the fishery. Although poaching can be considered a fishery, its illegal nature prevents benefits accruing to the state and country as a whole through legitimate taxation and foreign income benefits. In addition, the high levels of criminality associated with poaching activities and their association with organized crime, especially Chinese Triad gangs, impacts negatively on the social development of the country.

From a global perspective, there has been a growing realization that many of the present mechanisms to ensure fisheries sustainability have failed, and alternative schemes need to be evaluated (Jentoft 1989, Stephenson and Lane 1995, De Alessi 1995, Caddy 1999). It has been argued that open-access to valuable resources leads to disaster (De Alessi 1995) - the classic case of the "tragedy of the commons" (Hardin 1968). Inshore fisheries in the developing world are singled out as areas where fisheries management paradigms used in the developed world may not apply (Caddy 1999). As an alternative, it is argued that private or limited ownership of marine resources, using an area-based management system such as a territorial user right fishery (TURF), is more likely to ensure the sustainability of fisheries (Hilborn 1992, Prince *et al.* 1998). In particular, inshore fisheries that involve sedentary target species such as abalone, lend themselves to this practice (Caddy 1999). This type of management scheme has the added advantage of fitting in well with the provisions of the *Marine Living Resource Act 1998 (SA 1998)* regarding the devolution of management structures from national to local structures (Hilborn 1992).

If the sustainability of our fisheries resources is the aim of management, then we have to evaluate both the present management scheme as well as other alternatives. The collapse of the abalone stock in highly productive sectors in the commercial fishing area in the south-western Cape and the imminent collapse of abalone stocks in areas such as Cape Recife, are indicative of management failures. Without significant state intervention, mainly in terms of increased and comprehensive compliance efforts, a highly lucrative and beneficial fishery is likely to be lost. While not necessarily being mutually exclusive from increased compliance, area-based fisheries have benefits which can help to manage the abalone resource sustainably. The most important of these benefits is the development of a sense of ownership of the resource, that will create an incentive amongst rights holders to manage the stock in a sustainable manner, leading inevitably to non-state driven compliance efforts. The use of stock enhancement measures could further encourage owners to protect and manage “their” resource sustainably for maximum economic return.

If stock enhancement and TURFs are accepted as tools to manage the H. midae resource in the Eastern Cape Province, consideration needs to be given as to how these will be implemented. It is clear from the economic evaluation in Chapter 4 that this type of scheme is not presently feasible without a contribution from wild catches. The benefits of operating a TURF can be immediately accrued for any abalone population that can be sustainably fished, but effort limitation must be set with the precautionary principle in mind. A TURF rights holder needs to demonstrate the capacity, more than likely in conjunction with state compliance agencies given the present high rates of poaching, that they can effectively manage a local stock. This should also include the ability, probably in combination with independent research agencies (Hilborn 1999), to quantify stock abundance in relation to fishing effort. The success of a devolved (i.e. non-state driven), management system in the New Zealand southern scallop fishery is a good example of how such a system could work (Arbuckle 2000). Based on individual transferable quotas, this fishery has demonstrated that ownership can be the incentive for commercial enterprise to be responsible for implementing management policies that result in rehabilitating and sustaining a fishery. The danger in this success is that the state may be tempted to allow new entrants into a fishery once increased yields seem possible, thereby removing the incentive of the original quota holders for continuing their good management practices. In other words, quota holders need to be allowed to reap the benefits of their good management policies and investment, otherwise the incentive-driven system will break down.

Clearly, more information is required on the feasibility of ranching before it can be considered for widespread implementation in the Eastern Cape Province and South Africa. It is the opinion of this author, in light of the difficulties associated with assessing seed survival in this study, that the only meaningful way to evaluate commercial scale ranching is to conduct a large-scale seeding operation on an experimental commercial basis. Small-scale results, which are probably locale-specific, can elucidate factors which may be important to seed survival but they will not necessarily be applicable to ranching schemes conducted over a large area (Munro and Bell 1997, De Waal 2002). Large-scale trials can be evaluated on a before and after type basis (Underwood 1992, Underwood 1995), with the inclusion of appropriate controls to measure stock enhancement success or failure. Concerns over deleterious effects to the natural stock can also be addressed in this manner using both physical and genetic tagging techniques. If these types of trials are successful, they will result in a relatively rapid improvement of stock yield for the area under consideration. Care will, however, have to be taken by the management authority to ensure that if enhancement measures fail it does not result in overfishing of the wild stock *i.e.* the financial risk of stock enhancement must be borne by the private investor and not the wild stock.

Cape Recife is a special case since there is enough evidence to suggest that certain areas have been overfished already. There are, however, nearby adjacent areas where poaching has not had as significant effect, probably owing to inshore areas being less accessible through poor diving conditions. If the access right included these areas, a small annual TAC from these areas could be used to subsidize the TURF/stock enhancement operation until stocks had recovered sufficiently within the overfished areas. In addition, it is likely that in areas such as this, drastic measures, such as a blanket ban on diving may be required to bring illegal diving under control (Pers. Comm., G. Kant, MCM, 2000, Britz *et al.* 2002).

In conclusion, the implementation of area-based fisheries in conjunction with abalone stock enhancement measures should be seen as a practical and viable alternative to the present abalone management regime. If we are to fulfil the vision of the *Marine Living Resource Act 1998 (SA 1998)*, pragmatic and innovative solutions are required. Unless the state is willing to spend large amounts of money on continuous compliance, to ensure the significant limitation of illegal fishing in all areas, TURFs and in some cases stock enhancement offer more appropriate solutions to the current management system and may also be applicable to other inshore resources.

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